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College of Engineering



**Mechanical Engineering
Department**

Using Multi-Criteria Decision-Making (MCDM) to Assess the Sustainability of Educational Building Designs

A Thesis Submitted in Partial Fulfilment of the Requirements for the Doctor
of Philosophy Degree in Engineering Management

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Defense Committee's Approval

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- ☐ Without making any changes to the thesis.
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Abstract

Sustainability within the building sector has garnered significant attention due to its notable impact on the economy, environment, and society. Comprehensive sustainability encompasses environmental, social, and economic dimensions. Multi-Criteria Decision-Making (MCDM) methods have gained widespread utilization among researchers in the building industry to develop analytical Sustainability Building Assessment Tools (SBATs) for various building occupancy types worldwide. The design stage of any building is crucial to its sustainability throughout its life cycle; therefore, developing an SBAT to ensure design sustainability will significantly impact future building performance. The educational building sector in Bahrain is expanding due to the ongoing process of urbanization, population growth, and the need to replace outdated educational buildings, necessitating the integration of sustainability measures into New Educational Building Designs (NEBDs) and assessing their effectiveness using an SBAT. Consequently, this research aims to develop a comprehensive analytical SBAT using an MCDM method for NEBDs in Bahrain. Well-recognized Sustainability Building Rating Systems (SBRs) and the literature were examined, resulting in the identification of three key criteria and 21 indicators that are crucial for assessing the sustainability of NEBDs. An online survey was then conducted among practitioners and academics involved in the built environment in Bahrain to investigate the local importance of the indicators. The 364 valid responses received, with a 95% confidence level and a 5% margin of error, were analyzed using the Fuzzy Synthetic Evaluation (FSE) method. Finally, the SBAT was developed, encompassing three criteria: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials,” which accounted for 33.1%, 34.2%, and 32.7%, respectively, of the sustainability attainment in NEBDs. The findings can be generalized to other countries with similar regional characteristics to Bahrain, such as those of the Gulf Cooperation Council (GCC). The novel analytical SBAT developed is simple and easy to use individually. The design team can apply it to assess and improve the sustainability of an NEBD during the design phase. Additionally, it can be used by decision-makers to provide a snapshot of the level of sustainability attainment in an NEBD or to rank several NEBDs with regard to their level of sustainability attainment.

Publications

- Shams, D. S., & Alkhalifa, F. (2025). Sustainability assessment of new building designs: a review for a region and occupancy-specific accessible tool. *Architectural Engineering and Design Management*, 21(2), 191-210. <https://doi.org/10.1080/17452007.2024.2357610>.
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Dedication

I dedicate this work to my husband and my beloved children. I want to express my gratitude to them for being a source of strength, support, and motivation throughout this wonderful experience.

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List of Abbreviations

AHP	Analytic Hierarchy Process
BIM	Building Information Modeling
BQA	Education and Training Quality Authority
BRE	Building Research Establishment
BREEAM	Building Research Establishment's Environmental Assessment Methodology
BSE	Bahrain Society of Engineers
CALGreen	California Green Building Standards Code
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
CBA	Choosing by Advantages
COEPP	Committee of Organizing the Engineering Professional Practice
COPRAS	Complex Proportional Assessment
CRPEP	Council for Regulating the Practice of Engineering Professions
EDB	Economic Development Board
ELECTRE	Elimination and Choice Translating Reality
FSE	Fuzzy Synthetic Evaluation
GCC	Gulf Cooperation Council
GDP	Gross Domestic Product
GSAS	Global Sustainability Assessment System
HEC	Higher Education Council
HEIs	Higher Education Institutions

HSAT	Housing Sustainability Assessment Tool
IgCC	International Green Construction Code
ISO	International Organization for Standardization
LEED	Leadership in Energy and Environmental Design
MADM	Multiple Attribute Decision-Making
MCDM	Multi-Criteria Decision-Making
MF	Membership Function
MIVES	Spanish Integrated Value Model for Sustainability Assessment
MODM	Multiple Objective Decision-Making
MOE	Ministry of Education
MOH	Ministry of Housing
MOW	Ministry of Works
MS	Mean Score
MTT	Ministry of Transportation and Telecommunications
NEBDs	New Educational Building Designs
NEEAP	National Energy Efficiency Action Plan
NGFS	Network for Greening the Financial System
NREAP	National Renewable Energy Action Plan
PRS	Pearl Rating System
RESI	Real Estate Sustainability Index
SAHSB ^{PT}	Sustainability Assessment of High School Buildings in Portugal
SAM	Sustainability Assessment Model
SAW	Simple Additive Weighing

SBASs	Sustainability Building Assessment Systems
SBATs	Sustainability Building Assessment Tools
SBCs	Sustainability Building Codes/Standards
SBI	Sustainable Building Initiatives
SBRs	Sustainability Building Rating Systems
SBTool	Sustainable Building Tool
SCE	Supreme Council for Environment
SD	Standard Deviation
SDGs	Sustainable Development Goals
SEA	Sustainability Energy Authority
TOPSIS	Technique for Order Preference by Similarity to Ideal Solutions
UNCED	United Nations Conference on Environment and Development
UNFCCC	United Nations Framework Convention on Climate Change
USGBC	US Green Building Council
WASPAS	Weighted Aggregated Sum Product Assessment
WCED	World Commission on Environment and Development
WPM	Weighted Product Method
WSM	Weighted Sum Model

Research Terminology

Building Design: The provision of comprehensive information for building construction that fulfills the owner's requirements and also adheres to the standards of public health, welfare, and safety (Merritt & Ricketts, 2001).

Built Environment Engineers and Academics: Architects, civil engineers, mechanical engineers, electrical engineers, project and construction managers, and other engineers practicing in the built environment or working as academics in higher education institutions that offer engineering programs related to the built environment.

Choosing by Advantage (CBA): A particular type of Multi-Criteria Decision-Making (MCDM) method that distinguishes the alternatives by consolidating their advantages and then weighing the importance of the advantages to introduce a subjective decision (Arroyo, Tommelein, & Ballard, 2015; Arroyo, Mourgues, Flager, & Correa, 2018).

Comprehensive-ness: The approach for developing new types of Sustainability Building Assessment Tools (SBATs) should fully cover environmental, social, and economic sustainable building themes (Hacking & Guthrie, 2008).

Conceptual Sustainability Frameworks: A hierarchical tree approach comprising various levels that indicate the dimensions, criteria, sub-criteria, and indicators, providing comprehensive coverage of sustainability. They are helpful because they can facilitate interactions between performance measures, ecosystems, industry, society, and other relevant entities (Bhakar, Digalwar, & Sangwan, 2018).

Economic Sustainability: In the building context, this term refers to economic value, affordability, the effects on the local economy, and the enhancement of profitability through the optimization of resource utilization, encompassing water, energy, and material (Ahmad & Thaheem, 2018; Hussin, Abdul Rahman, & Memon, 2013).

Education Sector: This encompasses public and private institutions, including early education centers, schools, universities, colleges, higher education institutions, and special education centers.

Environmental Sustainability: In the building context, this term refers to the mitigation of greenhouse gas emissions, resource efficiency, energy efficiency, and water efficiency (Rahman & Khondaker, 2012).

Fuzzy Synthetic Evaluation (FSE): A fuzzy MCDM modeling technique that quantifies multi-attributes and multi-variants, suitable for aggregating indicators' scores to develop a sustainability index (Owusu, Chan, & Ameyaw, 2019).

Integrate-ness: The approach for developing new types of SBATs should align, connect, compare, and combine the environmental, social, and economic sustainable building themes (Hacking & Guthrie, 2008).

Membership Function (MF): The degree of an element's membership in a fuzzy set is known as the Membership Function (MF) (Xu, Chan, & Yeung, 2010). The FSE method expresses the extent of an element's belonging to or membership of a fuzzy set in terms of varying degrees of relation, considering any value within a closed range of 0 and 1 (Ameyaw, Chan, Owusu-Manu, & Coleman, 2015; Tah & Carr, 2000).

Multi-Criteria Decision-Making (MCDM): A discipline within the domain of operational research that aims to identify optimal outcomes in complex situations characterized by the presence of diverse indicators, conflicting criteria, and objectives (Kumar, Sah, Singh, Deng, Kumar, & Bansal, 2017).

Multiple Attribute Decision-Making (MADM): A category of MCDM that enables the evaluation and comparison of a predetermined discrete number of alternatives using discrete mathematics that can solve problems in discrete decision spaces (Allaoui, Guo, Choudhary, & Bloemhof, 2018; Zhao, Qin, Pan, & Wu, 2021).

Multiple Objective Decision-Making (MODM): A category of MCDM that does not involve decision alternatives. Instead, it applies programming methods to optimize objectives while involving other objectives in a constraint set (Allaoui et al., 2018; Zhao et al., 2021). Using continuous mathematical spaces, they postulate continuous solution spaces (Triantaphyllou, 2000).

Regional Conditions: Conditions such as climate, geographic factors, resources, etc., specific to a particular region (Ezennia & Hoskara, 2019).

Social Sustainability: In the building context, this term refers to enhancing living standards, encouraging social integration, reducing social inequality, and ensuring a secure and healthy environment for all individuals involved (Fatourehchi & Zarghami, 2020; Wong & Fan, 2013).

Strategic-ness: The approach for developing new types of SBATs should be broad and future-oriented (Hacking & Guthrie, 2008).

Sustainability Accounting: Determining the specific information and data, as well as the reason for which they are collected, by establishing and evaluating appropriate indicators, usually arranged in conceptual frameworks, used as conceptual SBATs (Zyznarska-Dworczak, 2020).

Sustainability Assessment: Utilizing analytical tools to lend meaning to the collected information and data, thereby employing numerical methods to aggregate and transform the qualitative and quantitative data into actionable insights (Lazar & Chithra, 2020).

Sustainability Building Assessment Systems (SBASs): These are developed by private and public organizations and state authorities around the world to assess and track the sustainability performance in buildings and collect information to aid the decision-making process of designers across their various phases (Mateus & Bragança, 2011).

Sustainability Building Assessment Tools (SBATs): These are flexible methodologies primarily designed for internal use to evaluate and enhance the sustainability of buildings. They might relate to specific components, such as energy efficiency and water usage, or encompass broader aspects of sustainability. They may use rating levels similar to those used in Sustainability Building Rating Systems (SBRs), but usually they are analytical (Ramani & García De Soto, 2021).

Sustainability Building Codes (SBCs): These are guidelines and standards that need to be implemented in the design or execution phases of a project, or that may guarantee compliance with local regulations (Ramani & García De Soto, 2021).

Sustainability Building Rating Systems (SBRs): These provide guidance and a systematic approach to facilitate the evaluation of sustainable performance in building projects. They employ either a credit or point system, wherein projects are assessed and assigned to specific rating levels based on predetermined categories (Ramani & García De Soto, 2021).

Sustainability Criteria: These refer to the criteria utilized to examine the positive and negative impacts associated with the three dimensions of sustainability (economic, environmental, and social) (Zink, 2005).

Sustainability Indicators: Indicators under each sustainability criterion are employed to appraise and assess the satisfaction and advancement of the sustainability criterion towards sustainability (National Research Council of the National Academies, 2010).

Sustainability Dimensions: In the building context, these refer to the various sustainability dimensions that are considered in relation to the building's occupancy and location. These could include environmental, social, economic, functional, governance, cultural, technical, and socio-cultural dimensions (Lazar & Chithra, 2020).

Sustainable Building Initiatives (SBIs): These are developed by private and public organizations, as well as state authorities worldwide, to incorporate and disseminate sustainable practices into building projects. They assess and track the sustainability performance of these projects, collecting information to aid the decision-making process of designers across various phases. They include SBRs, SBATs, and SBCs (Haapio & Viitaniemi, 2008; Mateus & Bragança, 2011).

Sustainable Building: A building intended to maximize favorable social and economic outcomes while mitigating adverse effects on the environment (Gibberd, 2002).

Sustainable Construction: A built environment development that will ensure the society's well-being by adhering to resource-efficient and ecology-driven principles (Kibert, 1994).

Sustainable Development: A development that meets the needs of current generations without compromising or limiting the needs of future generations (World Commission on Environment and Development, 1987).

Chapter One

Introduction to the Study

1.1. Overview

Sustainable development, particularly in the building sector, has garnered significant attention due to its notable impact on the economy, environment, and society. According to the United Nations Environment Programme (2021), buildings are responsible for 36% of the energy used worldwide and 37% of the energy-related carbon dioxide (CO₂) emissions.

Comprehensive sustainability of buildings is a synthesis of three dimensions: environmental, social, and economic, which are known as the “triple bottom line” (Dobrovolskienė, Pozniak, & Tvaronavičienė, 2021). A building cannot attain the highest results in all the sustainability aspects; it has to balance the three dimensions (Eklova, 2020).

Ensuring optimal sustainability in buildings requires the analysis and integration of sustainability measures to be initiated during the design stage (Azhar, Brown, & Sattineni, 2010; Basbagill, Flager, Lepech, & Fischer, 2013; Santos, Costa, Silvestre, & Pyl, 2019). The choices made during the design stage have a significant impact on the building’s performance throughout its various phases. Buildings follow general criteria for development in later stages, which primarily address cost, time, and quality. Nevertheless, these criteria alone are insufficient for establishing a cohesive foundation for an optimal, sustainable building. Therefore, it is necessary to adopt additional criteria and approaches specifically designed to enhance the building’s sustainability performance (Deru & Torcellini, 2004). Once the building is carefully planned, including sustainability criteria in its design stage, it will be able to reduce negative impacts more significantly and will be more economical than when adding them after construction (Shahda, 2018). To achieve a more sustainable building, defining project goals and integrating

new sustainability criteria must be considered in the design stage of any project.

Sustainability Building Assessment Tools (SBATs) are considered one of the most effective management tools to enhance a building's sustainability performance. Academicians and practitioners have developed and are still developing SBATs for different occupancy types of buildings worldwide (Lazar & Chithra, 2020). SBATs are easy to use, may help projects self-assess, and are tailored to fit the building's occupancy type and region (Ramani & García De Soto, 2021).

Conceptual SBATs are developed for accounting purposes. This is related to the determination of relevant information to gather for specific objectives by defining suitable indicators and measuring them, which requires strong conceptual frameworks, such as indicator sets (Gibberd, 2002; Lockwood, 2006). Analytical SBATs are developed to interpret the collected qualitative and quantitative data by means of analytical techniques (Büyükożkan & Karabulut, 2018).

According to the findings of Lazar and Chithra (2020), the predominant analytical methods employed for establishing analytical SBATs are the Multi-Criteria Decision-Making (MCDM) methods. MCDM is a subfield encompassed within the domain of operational research. Its purpose is to identify the most favorable outcomes in complex situations characterized by multiple indicators, conflicting criteria, and objectives (Kumar et al., 2017). These methods have gained significant popularity in composing indices due to their ability to incorporate several criteria, which may sometimes be conflicting (de Oliveira, Alencar, & Costa, 2015; Sarma, Karnitis, Zutters, & Karnitis, 2019). According to Si, Marjanovic-Halburd, Nasiri, and Bell

(2019), these methods facilitate the conversion of complex decision-making problems into clearly delineated steps, leading to the identification of the optimal solution.

The Gulf Cooperation Council (GCC) is a regional association in the Middle East, officially founded on 25 May 1981, in Riyadh, Saudi Arabia. It encompasses six countries: the United Arab Emirates, Qatar, Saudi Arabia, Kuwait, Oman, and Bahrain. The GCC member countries have witnessed high consumption rates of energy and greenhouse gas emissions per capita, making them among the highest consumers worldwide (Atallah & Tarlochan, 2021). This may be related to the extremely high-temperature climate during summer and poorly designed buildings, the high dependence on fossil fuels for producing energy, and the severe water scarcity, in addition to the rapid expansion of different types of buildings because of the increase in population, rapid urbanization, industrialization, and commercialization (Elnabawi, 2021; Wahl, 2017). Therefore, this region requires more attention.

In Bahrain, attention to educational buildings is essential for many reasons: Education is one of the major sectors in Bahrain's strategy towards economic development, the expanding urbanization and population growth, the increase in international education in Bahrain, and the need for new educational buildings to replace the old Ministry of Education (MOE) buildings (Economic Development Board, 2022; Ministry of Foreign Affairs, 2023; ZAWYA, 2019). This has led to an enormous expansion in the education sector's buildings, resulting in rapid growth in energy and resource demand and necessitating an urgent solution to address the problem.

1.2. Research Problem

The topic of sustainable development has become dominant among researchers nowadays, with a global emphasis on the practical assessment of building sustainability (Akhanova, Nadeem, Kim, & Azhar, 2019). Sustainability Building Initiatives (SBIs), which include Sustainability Building Rating Systems (SBRs), SBAs, and Sustainability Building Codes (SBCs), have been introduced by various organizations, academics, and practitioners to promote sustainable building practices. They are also continually improved and revised to consider new dimensions of sustainable design and adapt to evolving environmental, economic, and societal standards.

Both SBRs and SBAs are Sustainability Building Assessment Systems (SBASs) used to assess a building's sustainability. SBRs are output-driven, focusing on the assessment of the overall sustainability of a building to obtain a certification or rating (Markelj, Kuzman, Grošelj, & Zbašnik-Senegačnik, 2014). They consume time and money, are complex, and require a licensed assessor (Birgisdottir & Hansen, 2011). In contrast, SBAs are process-driven and help monitor and improve a building's sustainability throughout its life cycle. They are simple and easy to use, and are tailored to suit the occupancy type and region of a building, making their evaluation more accurate and relevant than that of SBRs (Ramani & García De Soto, 2021).

A conceptual SBA framework is helpful in founding the aspects that reflect sustainability performance, identifying relevant indicators, and establishing expectations for their measurement (Büyükožkan & Karabulut, 2018). Frameworks determine the specific data that should be collected and the corresponding purpose for which they are intended (Halla & Merino-

Saum, 2022). Developing a conceptual SBAT framework is necessary for accounting determinations; however, due to their assessment limitations, such conceptual frameworks frequently fail to capture the entirety of the sustainability assessment objectively and consistently (Boggia, Massei, Pace, Rocchi, Paolotti, & Attard, 2018). Therefore, researchers have developed analytical SBATs.

From the literature, it was found that MCDM methods were considered the most used to develop analytical SBATs that can assess sustainability objectively and consistently. It was also found that hundreds of SBATs have been developed and continue to be developed worldwide. In addition, most studies worldwide and in the GCC developed SBATs mainly for generic and residential buildings. Thus, there is still a gap when it comes to developing SBATs for other occupancy building types worldwide.

There is currently no SBAT specifically developed for assessing the three dimensions of sustainability in buildings within Bahrain. Hence, as a consequence of the ongoing processes of urbanization, the increase in population, and the imperative to replace outdated educational buildings, it is necessary to integrate sustainability measures during the design stage of these buildings to ensure the best final results and assess their effectiveness using conceptual and analytical SBATs that are:

1. Specific to Bahrain (country-specific).
2. Specific for education sector buildings (occupancy type-specific).
3. Comprehensive, including the three main sustainability dimensions related to Bahrain's education sector buildings.
4. Suitable for independent use during the design stage and at a low cost.

Thus, the problem in this research can be formulated as follows: The lack of comprehensive conceptual and analytical SBATs tailored for New Educational Building Designs (NEBDs) in Bahrain hinders the attainment of sustainability within these buildings.

1.3. Research Aim and Objectives

This study aims to develop comprehensive conceptual and analytical SBATs for NEBDs in Bahrain, utilizing MCDM methods.

The following objectives can support the aim:

1. Specify the sustainability assessment criteria and indicators and develop a comprehensive conceptual SBAT framework for NEBDs in Bahrain.
2. Investigate the opinions of specialists in the built environment in Bahrain to find the local importance of the identified criteria and indicators.
3. Use MCDM to develop an analytical SBAT (index or model) tailored to assess the sustainability of NEBDs in Bahrain.
4. Explore the tools' generalizability, transferability, and future development.

1.4. Research Questions

The main question in this research is how to develop comprehensive conceptual and analytical SBATs specific to NEBDs in Bahrain. The following questions are involved:

1. What sustainability assessment criteria and indicators are necessary to develop a conceptual SBAT that best suits NEBDs in Bahrain?
2. What are the opinions of local specialists about the importance of the specified criteria and indicators in Bahrain?
3. Which MCDM method is best suited for developing an analytical SBAT (index or model) to assess the sustainability of NEBDs in Bahrain?
4. To what extent can such tools be generalized and applied to other contexts? And how can they be updated in the future?

1.5. Research Hypothesis

The main hypothesis could be divided into two parts, each with its sub-components:

1. A conceptual SBAT can be developed by identifying sustainability assessment criteria and indicators that best suit NEBDs in Bahrain.
 - Sustainability assessment criteria and indicators can be identified by reviewing SBRs and the literature and selecting those relevant to NEBDs and Bahrain.
 - The integration of the selected criteria and indicators into a conceptual SBAT will result in a tool that is more effective and applicable for evaluating the sustainability of NEBDs in Bahrain than existing tools developed globally.
 - The conceptual SBAT will serve as a guiding framework to improve the sustainability performance in NEBDs in Bahrain.

2. An analytical SBAT for NEBDs in Bahrain can be developed using MCDM methods.
 - MCDM methods can effectively prioritize sustainability criteria and indicators based on experts' judgment.
 - The application of MCDM methods will yield justifiable weighting schemes for the criteria and indicators relevant to Bahrain.
 - The application of MCDM will improve the objectivity and analytical precision of the developed SBAT compared to tools based only on qualitative or subjective assessment.
 - The developed analytical SBAT using MCDM methods will serve as an assessment tool that provides an index to measure the sustainability attainment of an NEBD in Bahrain.

1.6. Research Significance

This research is essential as it has several benefits:

1. It develops a comprehensive conceptual SBAT for NEBDs in Bahrain.
2. It develops a comprehensive analytical SBAT (index or model) for NEBDs in Bahrain.
3. The design team can independently use the developed SBATs to ensure the sustainability of NEBDs in Bahrain.
4. Decision-makers can independently use the developed analytical SBAT to obtain a snapshot of the level of sustainability attainment in an NEBD or rank multiple NEBDs.

The developed tools will ensure the sustainability of NEBDs in Bahrain, creating many benefits such as significant cost savings, protection for the

environment, and increased learning outcomes for students (Alhilli & Burhan, 2021). In addition, the provision of an improved working environment promotes better health and comfort for the users (Hidayat, Rohman, & Utomo, 2020). Also, the students' understanding of the sustainable development concept, their acquisition of scientific knowledge, and the encouragement of low-carbon lifestyle adoption will all be enhanced (Saraiva, de Almeida, & Bragança, 2019).

1.7. Research Methodology

The methodology employed to achieve the objectives of this research consists of:

1. Literature review: To specify the sustainability assessment criteria and indicators critical for NEBDs in Bahrain. This included investigating the common criteria and indicators used by well-recognized SBRs and the literature, then selecting the critical and most representative criteria and indicators to assess the sustainability in NEBDs in Bahrain.
2. Online survey: To investigate the opinions of specialists in the built environment in Bahrain to find the local importance of the identified criteria and indicators using a five-point Likert scale. The reliability of the data collected was checked using the Cronbach's Alpha test, and the significance of the indicators was found using the Mean Score ranking (MS) method.
3. FSE method: To develop the analytical SBAT (model/index), which can be used to evaluate an NEBD and assign it a numerical score (index) indicating its level of attainment towards sustainability.

1.8. The Study's Setting

The GCC represents an institutionalized collaboration in the Middle East aimed at fostering a cohesive position among its member countries to achieve economic growth and regional stability while respecting their unique cultural and political identities (Zaidan, Al-Saidi, & Hammad, 2019).

The GCC countries are similar in many ways, including their Islamic identity, the common Arab cultural heritage, economies highly reliant on oil exports, and comparable political systems, primarily characterized by the monarchy (Al-Saidi, 2021). However, they differ in some respects, such as their level of economic diversification, political structures, and foreign policies (Asif, 2016). Nowadays, the region is confronting many sustainability challenges due to the rapid growth of populations, infrastructure, economies, and consumption (Elnabawi, 2021).

The education sector has witnessed substantial growth in student enrollment (Bystrov & Panigrahi, 2021). This has prompted all GCC countries to increase their financial investment in enhancing infrastructure and improving the quality of education as part of their long-term national objectives in the education sector (Erdoğan, Yıldırım, & Gedikli, 2020). Therefore, to overcome the sustainability challenges in the region, educational buildings require attention.

This study will focus on developing comprehensive conceptual and analytical SBATs to ensure the sustainability of NEBDs in Bahrain, one of the GCC countries. The following provides an overview of the Kingdom of Bahrain, its sustainability policies, and the country's education sector.

1.8.1. The Kingdom of Bahrain

I. Location, Population, and Area

The Kingdom of Bahrain is situated in the Arabian Gulf, in Western Asia (**Figure 1.1**). It is an island nation composed of a small archipelago consisting of 50 naturally formed and 33 artificially constructed islands (Alnuaimi, Fernandez, & Eid, 2021). It is located to the northeast of Saudi Arabia and is connected to it through the King Fahd Causeway (25 km) (Ministry of Information, 2023a). Its capital city is Manama. Bahrain has a population of 1.854 million, and its total area is 785 km² (World Bank, 2020; Worldometer, 2023).

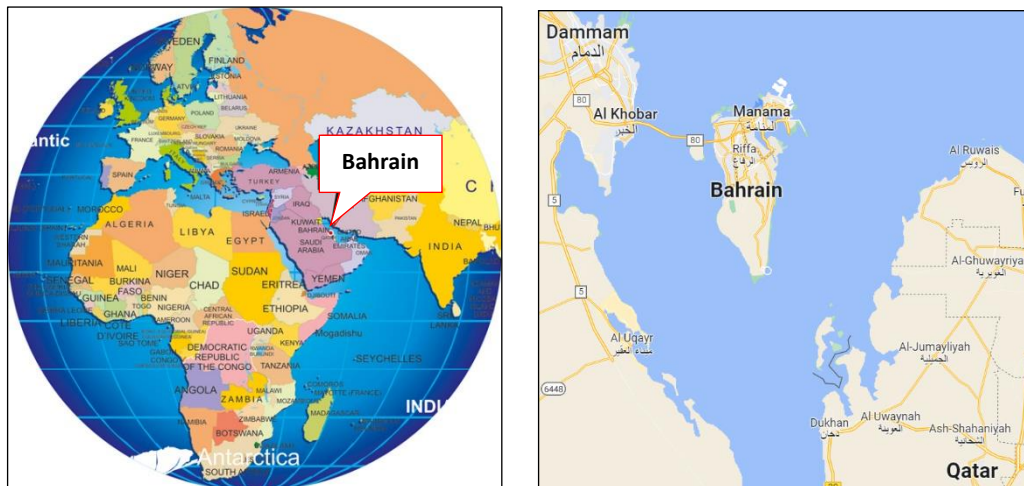


Figure 1.1: Map and Location of the Kingdom of Bahrain (Ministry of Information, 2023a)

II. Climate

Bahrain has an arid climate characterized by two distinct seasons: a hot summer and a comparatively mild winter. The summer season, spanning from April to October, is uncomfortable due to high humidity and temperatures averaging between 40°C and 46°C. Furthermore, throughout the summer, a hot, dry wind blowing from the southwest, known locally as the qaws, pushes

sand clouds across Bahrain. During the winter season, which spans from November to March, humidity levels often exceed 90%, and temperatures range from 10°C to 20°C. During the period from December to March, prevailing winds from the northwest, known as the shamal, push damp air across Bahrain (World Bank Group, 2021).

III. Political System and Built Environment Governmental Organizations

Since 2002, Bahrain has used a parliamentary and constitutional monarchy political system (IMUNA, 2022). The king appoints the country's government representatives, who the prime minister leads. The country is governed by a bicameral legislative parliament known as the Shura Council, which is administered by two councils. The first is the Consultative Council (upper), appointed by the king, and the second is the Council of Representatives (lower), selected through a public vote (Shura Council, 2021).

Several ministries in Bahrain collaborate to ensure the built environment's functionality, sustainability, and alignment with national development goals. Each focuses on different aspects of planning, development, and regulation. The Ministry of Works (MOW), the Ministry of Municipalities Affairs and Agriculture, and the Urban Planning and Development Authority heavily influence infrastructure, urban planning, and public works (Ministry of Works, 2025). The Ministry of Housing (MOH) has a primary responsibility for housing development and the provision of affordable housing (Ministry of Housing and Urban Planning, 2025). The Ministry of Interior, through the Civil Defense, is responsible for overseeing

building safety standards and permits (Civil Defense, 2025). The Ministry of Transportation and Telecommunications (MTT) is responsible for developing and maintaining transportation networks, including highways and public transit (Ministry of Transportation and Telecommunications, 2025). The Ministry of Sustainable Development and the Supreme Council for Environment (SCE) are responsible for overseeing the environmental impact and sustainability of construction practices (Supreme Council for Environment, 2023).

IV. Economy

Bahrain has been actively implementing sustainable and diversified economic growth strategies. It has pursued economic diversification outside oil-dependent sectors, including banking, services, logistics, tourism, and industry, since the 1960s (Nakibullah, 2018).

In 2000, the Economic Development Board (EDB) of Bahrain was established. Its mission was to assist existing and potential investors in their pursuits and improve Bahrain's investment environment. One of the important approaches employed in the development process involved prioritizing the private sector for the purpose of promoting entrepreneurship and innovation (Nakibullah, 2018).

In October 2008, the EDB introduced Bahrain's Economic Vision 2030, outlining the country's long-term development strategy. The document outlined a clear direction for the ongoing advancement of the Kingdom's economy with a shared goal of fostering an improved quality of life for all citizens of Bahrain. It focused on providing a clear procedure for the

development of the government, society, and economy, with a particular emphasis on three fundamental principles: sustainability, justice, and competitiveness (Economic Development Board, 2008).

1.8.2. Sustainability Policies in Bahrain

Bahrain's Economic Vision 2030 addresses the United Nations' Sustainable Development Goals (SDGs) as one of its guiding principles and has taken several steps to achieve them. It embodies a vision of transformation, whereby economic vitality, environmental responsibility, and social equality come together to forge a prosperous, dynamic Bahrain prepared to confront future challenges, aiming to cultivate a society in which every individual has an equal chance to realize their potential, contribute to national development, and experience a high quality of life in a secure, dynamic, and egalitarian Bahrain (Information & eGovernment Authority, 2022).

The government continually stresses sustainability by integrating it into its policies and structures. The Government Plan for 2023-2026, entitled "From Recovery to Sustainable Growth," emphasizes its robust connection with the SDGs across social, economic, and environmental domains (Government of Bahrain, 2023). The Economic Recovery Plan, initiated in 2021, promotes a robust, inclusive, and sustained recovery in the aftermath of the worldwide COVID-19 pandemic (Ministry of Finance and National Economy, 2025).

Bahrain has established the Ministry of Sustainable Development and the SCE to develop a comprehensive environmental and sustainable strategy that protects its natural and human environments and ensures the sustainability of its various components, preserving and enhancing its resources for the coming generation (Bahrain News Agency, 2023b; Supreme Council for Environment, 2023). Additionally, it has established the Sustainability Energy Authority (SEA), the first authority dedicated to sustainable energy. The SEA is responsible for advancing renewable technologies and formulating energy efficiency policies, which support Bahrain in its pursuit of sustainable environmental protection and long-term climate action objectives (Sustainable Energy Authority, 2021). Bahrain has launched the National Renewable Energy Action Plan (NREAP) and the National Energy Efficiency Action Plan (NEEAP) as part of an intensified effort to transition to a more efficient renewable energy system.

Bahrain has participated in the United Nations Framework Convention on Climate Change (UNFCCC) and ratified the Paris Agreement within this framework, announcing its goal to achieve net-zero emissions by 2060 (Bahrain News Agency, 2023a). Furthermore, in 2023, Bahrain participated in the SDGs summit held in New York and presented three national voluntary commitments aimed at accelerating the achievement of the SDGs: (1) Enhancing SDG data infrastructures and national statistics capabilities, (2) Utilizing creative financing from the financial sector to promote sustainable development and attain SDGs, and (3) Promoting climate initiatives for sustainable and inclusive economic growth (Government of Bahrain, 2025).

The country is a member of the Network for Greening the Financial System (NGFS), one of the most prominent international bodies focused on

the green economy. It is part of the Coalition of Finance Ministers for Climate Action, which brings together financial and economic policymakers from more than 75 countries to lead the global climate response and secure an equitable transition towards resilient, low-carbon development (Bahrain News Agency, 2023a).

To ensure the sustainability of the construction and building industry, Bahrain has implemented significant initiatives and legislative measures. The MOW, the Ministry of Municipalities Affairs and Agriculture, and the Urban Planning and Development Authority play a pivotal role in formulating policies that govern construction projects, aiming to achieve Bahrain's strategy of reducing carbon emissions, enhancing environmental quality, and ensuring long-term sustainable urban development. This includes the development of energy-efficient infrastructure and green spaces, as well as ensuring that urban development adheres to environmental sustainability objectives (Ministry of Municipalities Affairs and Agriculture, 2025; Ministry of Works, 2025; Urban Planning and Development Authority, 2025).

Additionally, Bahrain has established the Green Building Code and Labeling Program under the guidance of the SCE (Supreme Council for Environment, 2023). The Bahrain Green Building Code is a comprehensive document that targets new buildings and retrofit projects. It aims to integrate sustainability into construction, focusing on energy efficiency, water conservation, waste management, and the use of sustainable materials, thus promoting more eco-friendly buildings that contribute to Bahrain's long-term sustainability objectives. The Green Building Labelling Program serves as a mechanism to acknowledge buildings that achieve energy efficiencies,

meeting or exceeding the Green Building Code requirements, which has a significant influence on encouraging developers to adopt green practices.

1.8.3. The Education Sector in Bahrain

Education and Training constitute one of six sectors upon which Bahrain's economic development strategies are built (Economic Development Board, 2022). Formal education in Bahrain dates back to 1919 for males and 1928 for females (Ministry of Information Affairs, 2023).

In Bahrain, infants and children under the age of six are entitled to attend early education centers, including nurseries and kindergartens. Compulsory education spans nine years, comprising primary education, which includes elementary and intermediate levels, where all students of school age are required to be enrolled in either public or private educational institutions. This is followed by an additional three-year period of secondary education with its various tracks. The MOE offers tuition-free education to both Bahraini and non-Bahraini students enrolled in public schools. There are also private schools that provide the opportunity to pursue the International Baccalaureate (IB) Diploma Program or the United Kingdom's Advanced Level (A-Levels). Children with disabilities are actively engaged in special education centers.

The age distribution of the population in Bahrain reveals that 25.42% are 19 years old or younger, 43.64% are between the ages of 20 and 39, 25.2% are between 40 and 59, and 5.74% are 60 years old or older (Ministry of Information, 2023b). This indicates that a considerable proportion of the population consists of individuals enrolled in educational institutions.

According to the MOE statistics report for the academic year 2018/2019, there were 250 early education centers, 210 government schools, and 79 private schools in Bahrain, employing approximately 22,386 staff members. These institutions serve more than 253,000 students, including 39,000 in early education centers, 144,000 in public schools, and over 70,000 in private schools (Ministry of Education, 2025). Bahrain also has three public, one regional, and 15 private higher education institutions (Higher Education Council, 2023). All educational institutions are subject to regulation by various bodies, including the MOE and the Education and Training Quality Authority (BQA), among others.

Education in Bahrain is highly demanding, necessitating supplementary expenditures and resources to sustain its development. It is anticipated that the number of individuals under the age of 20 will experience an annual growth rate of approximately 1.7%, resulting in an estimated increase of 30,000 individuals each year (Economic Development Board, 2022). In addition, the high number of expats and the increased expenditures parents are eager to spend towards their children's education are both contributing to the growing popularity of international education in Bahrain. These factors mean that the field of education is an optimal setting for investment in Bahrain, requiring the construction of new educational buildings.

1.9. Research Structure

This research is organized into five chapters as presented in **Figure 1.2**. The specific chapter descriptions are as follows:

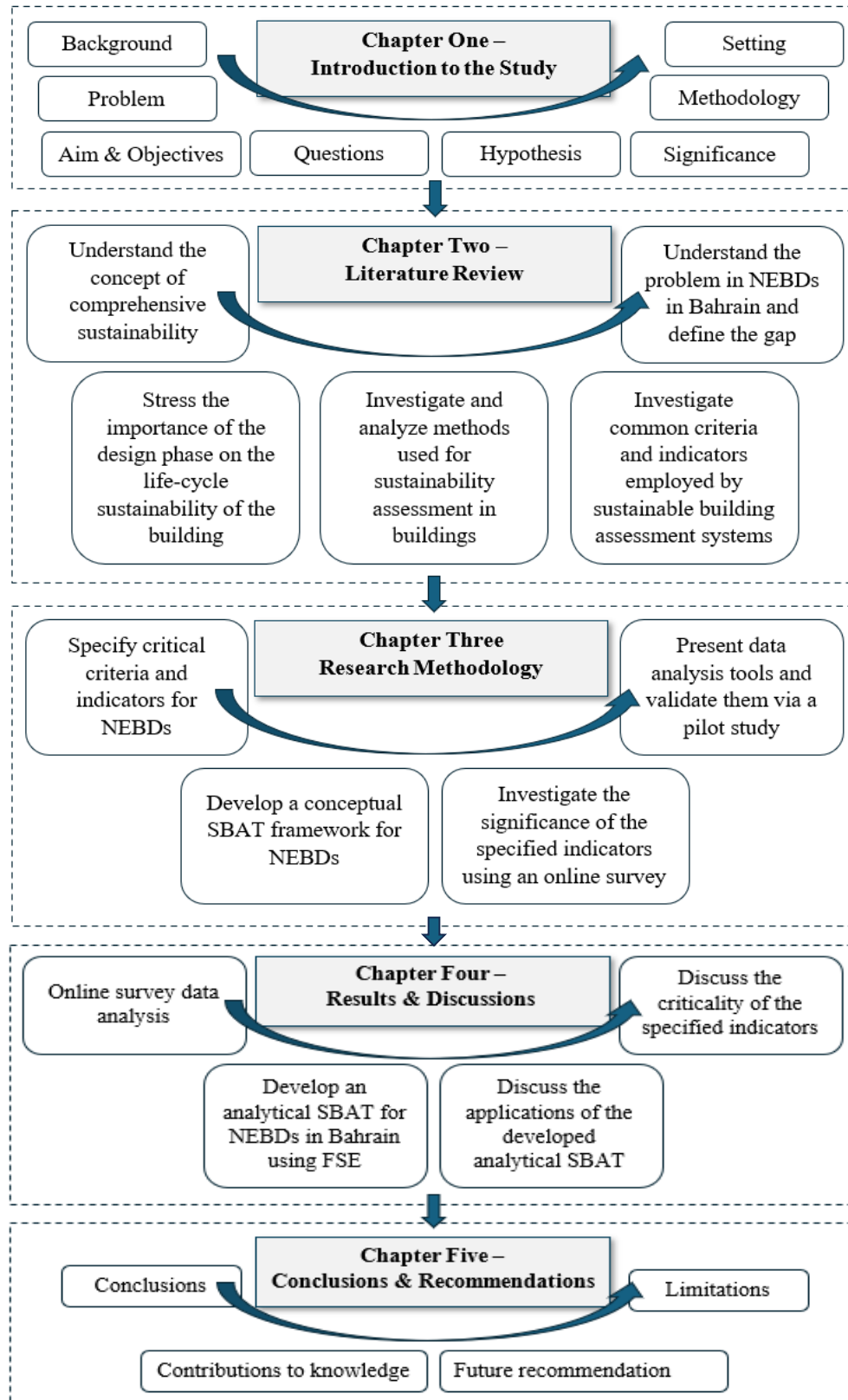


Figure 1.2: Research Structure

Chapter One

This chapter introduces the research background. It explains the importance of this research and identifies the existing problem and gap. The research aim and objectives, questions, hypothesis, methodology, and setting are all highlighted.

Chapter Two

This chapter builds a theoretical foundation for the research by reviewing the literature. It provides information on comprehensive sustainability in buildings and the importance of incorporating sustainability measures within the design stage of buildings. It gives an overview of the SBIs established worldwide and concentrates on the procedures for developing SBATs. It investigates the common criteria and indicators used to assess the sustainability of buildings. It reviews the frequently employed MCDM methods in the construction and building industry. Finally, it provides information on the GCC challenges towards sustainability and the expanding education sector buildings in Bahrain.

Chapter Three

This chapter details the methodology and methods employed to achieve the research objectives. It specifies criteria and indicators critical for the assessment of NEBDs and develops the conceptual SBAT for NEBDs in Bahrain. It explains the data collection method (online survey) and the data reliability and analysis methods (Cronbach's Alpha test, MS, and FSE) used to develop the analytical SBAT. It conducts a pilot study to check the feasibility and applicability of the survey and data analysis tools.

Chapter Four

This chapter presents the data reliability and analysis results and develops the analytical SBAT for NEBDs in Bahrain using the FSE method. It then discusses the MS results, the analytical SBAT applications, the criticality of the selected indicators, and compares the developed SBAT with the global SBATs.

Chapter Five

This chapter presents the research's conclusions and explains how the research has contributed to the knowledge. It explains the limitations of the research and suggests future perspectives, which are expected to be followed in future research projects.

1.10. Summary

To ensure the sustainability of a building, it is essential to analyze and integrate sustainability measures within the design stage process through the design team's utilization of a country-specific and occupancy-specific SBAT.

Conceptual SBAT frameworks are helpful in founding the aspects that reflect sustainability performance, identifying relevant indicators, and establishing expectations for their measurement, making them suitable for accounting determinations (Büyükoçkan & Karabulut, 2018). However, due to the assessment limitations of conceptual SBATs, analytical SBATs are developed to capture the total sustainability assessment objectively and consistently (Boggia et al., 2018).

MCDM methods are the most used analytical methods for developing analytical SBATs due to their ability to compose indices for decision-making scenarios that include many indicators, opposing criteria, and objectives (de Oliveira et al., 2015; Sarma et al., 2019).

In Bahrain, due to the need for new educational buildings, sustainability measures must be integrated and assessed during the design stage to ensure the efficiency of these buildings.

Most studies worldwide and in the GCC have developed SBATs mainly for generic and residential buildings. In Bahrain, studies on building sustainability have primarily focused on residential buildings and have not developed an SBAT. Therefore, in response to the need for new educational buildings in Bahrain, this research develops comprehensive conceptual and analytical SBATs for NEBDs in Bahrain using MCDM methods.

Chapter Two

Literature Review

2.1. Introduction

To understand the concept of sustainability in buildings and the methods employed by researchers to ensure it, the following questions were considered through a review of the existing literature:

1. What is the definition of a sustainable building?
2. Why is it essential to incorporate sustainability in new building designs? And how can sustainability in building designs be ensured?
3. What are the common sustainability assessment criteria and indicators used by leading SBRs and previous research that cover economic, environmental, and social sustainability in buildings?
4. Which MCDM methods are commonly used to assess building sustainability?
5. What are the sustainable building challenges in the GCC region? And is it necessary to ensure the sustainability of NEBDs in Bahrain?

Accordingly, the following sections of this chapter discuss the concept of sustainable development, with a focus on sustainable buildings. The chapter emphasizes that sustainable measures should be analyzed and integrated into the design stage of any building to achieve optimal results. It then gives an overview of the existing SBIs developed worldwide to promote building sustainability, with a focus on SBATs, one of the most effective methods for enhancing a building's sustainable performance. It also investigates the criteria and indicators employed by six globally and locally renowned leading SBRs, as well as those used by various researchers to assess building sustainability. The chapter also explains the importance of sustainability conceptual frameworks and their ability to provide comprehensive coverage of the sustainability problem. It then explains

MCDM and describes its most common methods employed within the construction and building industry, analyzing their advantages and disadvantages. Finally, it introduces sustainable educational buildings, provides an overview of the education sector and the sustainable building challenges in the GCC region, and subsequently focuses on the need for sustainable NEBDs in the Kingdom of Bahrain. The chapter ends with a summary that highlights the knowledge gap on which this research will focus.

Figure 2.1 illustrates the approach employed in this chapter.

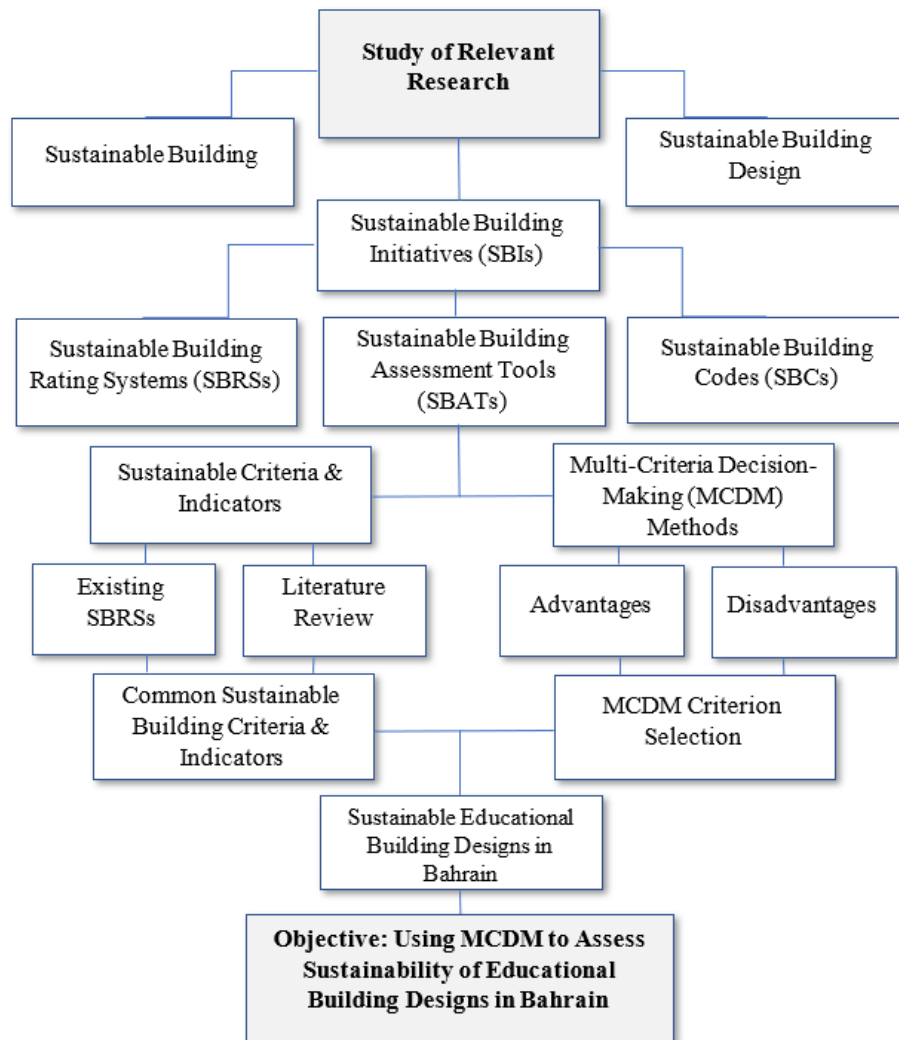


Figure 2.1: Literature Review Approach

2.2. Sustainable Building Design Considerations

2.2.1. Sustainable Development

The general paradigm of economic growth that emerged in the 1980s, with its detrimental societal and environmental consequences, gave rise to the concept of sustainable development. It emphasized that sustainable development needs to consider living and non-living resources and alternative actions' long-term and short-term advantages and disadvantages, incorporating economic, social, and environmental aspects (Akadiri, Olomolaiye, & Chinyio, 2013).

In 1987, the World Commission on Environment and Development (WCED) (1987) defined sustainable development in its report, “The Brundtland Report,” also known as “Our Common Future,” as a development that meets the needs of current generations without compromising or limiting the needs of future generations. The report led the concept of sustainable development to gain a broader appreciation and encouraged its implementation within the policies of many countries globally (Berggren, 1999). In addition, the WCED has proposed seven critical objectives and requirements aimed at altering unsustainable trends and enhancing the living quality for people worldwide:

Objectives of Sustainable Development

- Growth revival
- Growth quality change
- Assuring necessities, including food, water, energy, and sanitation
- Maintaining sustainable population levels
- Enhancing the resource base and conserving it

- Incorporating the environment and economics into decision-making
- Technology reorientation and risk management

Requirements for Sustainable Development

- A political system that guarantees the active involvement of citizens in decision-making
- An economic system that alleviates tensions caused by imbalanced development
- An administrative scheme that is adaptable and capable of self-correction
- A production system that adheres to the responsibility of protecting the ecosystem
- A technological system that promotes trade and finance patterns' sustainability
- An international system that facilitates trade and finance practices' sustainability

Following the publication of the Brundtland Report, numerous events and initiatives were undertaken that significantly contributed to the current comprehensive understanding and application of sustainable development. A significant event in 1992 in Rio de Janeiro was the United Nations Conference on Environment and Development (UNCED), also known as the “Earth Summit.” The leaders in attendance reached a consensus on a comprehensive international strategy known as Agenda 21, aimed at fostering sustainable development plans and suggesting the production of national policies within each country to ensure sustainable development (Akadiri et al., 2013). Thus, all these initiatives ensured that countries around the world need to develop their strategies to achieve sustainable development.

Another significant event was the 2015 United Nations General Assembly. It consisted of leaders representing 193 countries and resulted in the identification of 17 SDGs. These were established as a comprehensive action plan aimed at effecting the transformation of Earth into a sustainable planet by the year 2030 (**Figure 2.2**) (United Nations, 2023). The SDGs addressed a range of development concerns involving economic, environmental, and social aspects, including health and well-being, hunger, poverty, quality education, climate action, gender equality, water, sanitation, peace and social justice, and energy and environment (McArthur & Rasmussen, 2017). Today, countries worldwide are establishing new policies that aim to increase their resources and improve their technology and innovation to be able to face the challenge of achieving the SDGs (Bebbington & Unerman, 2017).



Figure 2.2: Sustainable Development Goals (SDGs) - UN 2030 Agenda
(United Nations, 2023)

Among the 17 SDGs, 7 are directly related to the built environment. These include G3: Good Health and Well-being, G6: Clean Water and Sanitation, G7: Affordable and Clean Energy, G9: Industry, Innovation, and Infrastructure, G11: Sustainable Cities and Communities, G12: Responsible Consumption and Production, and G13: Climate Action. Thus, ensuring the sustainability of the built environment is central to achieving the SDGs.

Over the past three decades, numerous events and activities have significantly influenced the prevailing understanding of sustainable development. This has also been compounded by ongoing debates about its definition, resulting in an overabundance of definitions (Silvestre & Țîrcă, 2019).

The concept of sustainable development has been adopted by various entities, including enterprises, national governments, and international organizations, each offering its own interpretation. Historical perspectives defined sustainable development as follows: According to Hill and Bowen (1997), it mitigates adverse environmental effects, including societal requirements. According to Postle (1998), it extends beyond its environmental dimension and encompasses various social and ethical elements, including culture, social welfare, employment, economy, and infrastructure, which means that achieving it necessitates considering all enduring societal benefits when making decisions. Ding (2005) supported the idea that it requires balancing economic, social, and environmental systems. Stigson (1999) and Rohrer (2001) discussed it as encompassing economic growth with social and environmental considerations, as pursuing economic growth is a primary goal for governments worldwide to ensure rising living standards and meet human needs.

While there are several opinions regarding the precise meaning of the “sustainable development” term and its interpretation, recent studies have shown that achieving it requires the integration of economic, environmental, and social dimensions, referred to as the “triple bottom line” or the “sustainability triangle” (Dobrovolskienė et al., 2021; Rodrigues, Delgado, Mendes, Lima, & Guimarães, 2023) (see **Figure 2.3**). The economic dimension emphasizes the promotion of economic growth, the maintenance of financial stability, and the generation of material welfare. The social dimension emphasizes objectives related to education, health, and social protection. The environmental dimension encompasses concerns regarding the preservation and maintenance of natural resources, as well as the recognition of nature’s capacity to withstand environmental pressures.

The different opinions about the term imply that sustainability encompasses such a wide range of concepts that a single definition is unable to fully encapsulate its many meanings (Omer & Noguchi, 2020). According to Klarin (2018), sustainable development may be seen as an ongoing and dynamic balancing process rather than a fixed target that must be achieved within a specific timeframe.

Thus, sustainable development requires the adoption of responsible, fair, effective, efficient, sensitive, and long-term actions that reflect the societal imperative in all decision-making processes. Additionally, sustainable development relies on striking a balance among economic, social, and environmental aspects.

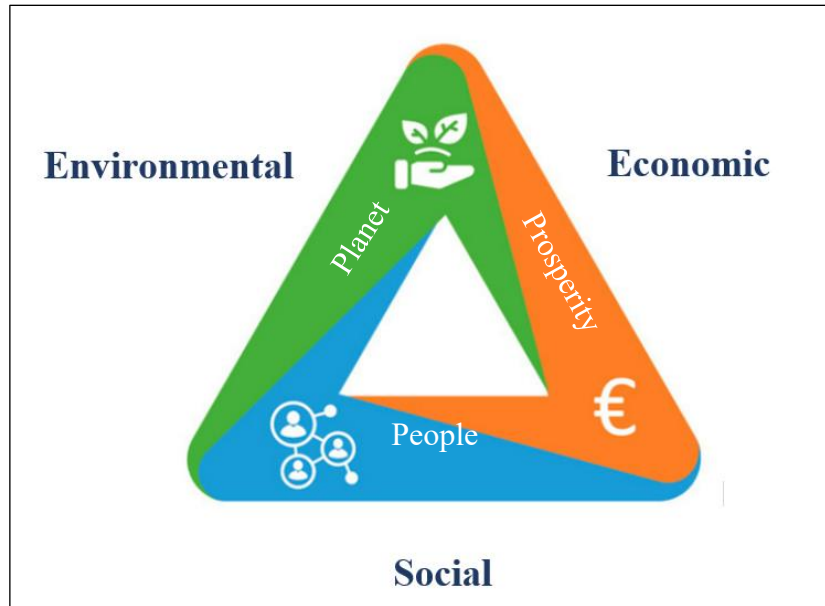


Figure 2.3: The Sustainability Triangle
(adapted from Rodrigues et al., 2023)

2.2.2. Sustainable Construction

Many governments worldwide have established sustainable policies in their construction industry (Rafindadi, Mikić, Kovačić, & Cekić, 2014), as this industry is of such paramount importance that most other industrial areas fade in comparison (Czarnecki & Kapron, 2010). The construction industry has been experiencing significant growth, with a substantial impact on the global economy, contributing approximately 13% to the global GDP, a figure expected to rise to 15% in the near future (Robinson, Leonard, & Whittington, 2021). It also contributes to the enhancement of quality of life through the provision of socio-economic infrastructure, including hospitals, roads, schools, and other essential amenities. Additionally, it offers employment prospects for approximately 7% of the world's working population, either directly or indirectly, through other sectors associated with the construction industry (Robinson et al., 2021).

However, it also has negative effects on the environment and society. Many projects have low energy efficiency, overlook environmental consequences, and fail to preserve natural resources due to traditional design approaches, resulting in noise, dust, water pollution, waste, traffic congestion, and the consumption of large quantities of natural and human resources, which negatively impact our ecological integrity. Statistics indicate that the construction industry consumes 40% of the energy worldwide, and is responsible for 50% of the climate change, 40% of the contaminated drinking water, 23% of the air pollution, and 50% of the landfills' waste (Woodhart, 2022). Therefore, “sustainable construction” should be implemented to balance the economic, social, and environmental dimensions (Shen, Tam, Tam, & Ji, 2010).

The term “sustainable construction” evolved as an indication of the improvements in construction industry practices towards achieving sustainability (Sjostrom & Bakens, 1999). In 1994, the first Sustainable Construction International Conference was held in Tampa, Florida, in the United States, marking the recognition of the new discipline of sustainable construction. Kibert (1994), the conference facilitator, defined sustainable construction as the process of developing a built environment that ensures society's well-being by adhering to resource-efficient and ecologically driven principles. This highlights the significance of implementing design and construction techniques that prioritize resource efficiency and do not compromise the environment's well-being or the health of society and future generations.

Traditionally, projects were managed based on time, cost, and quality objectives, but with the integration of sustainability within projects, they

became redirected towards a more comprehensive approach that emphasizes resource conservation, environment protection, and healthy built environment promotion (**Figure 2.4**) (Huovila, 2001; Rafindadi et al., 2014). The transition towards sustainability was seen as a novel paradigm at the beginning of the twenty-first century, where the new sustainable objectives were considered throughout the different phases of projects (Shen & Tam, 2002).

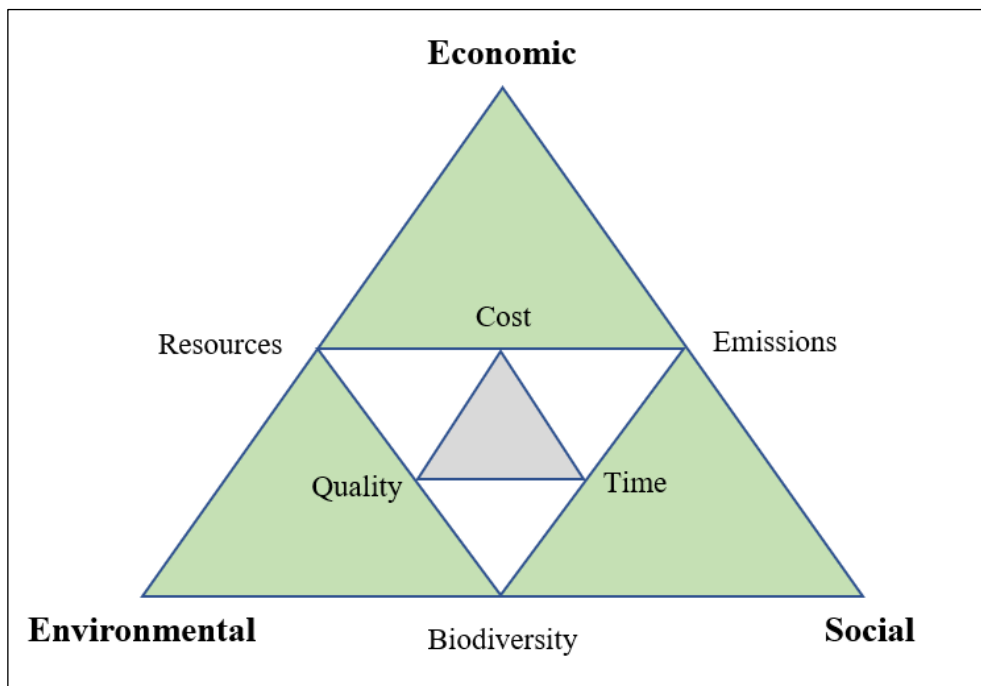


Figure 2.4: Sustainable Construction (adapted from Huovila, 2001)

Decision-makers within the construction industry need to be flexible and exhibit a willingness to adjust their ideas to cope with the dynamic nature of sustainability, which requires balancing and integrating the fundamental principles, namely economic, environmental, and social sustainability dimensions (Hussin et al., 2013):

Economic Aspect

- Consider life cycle expenses
- Internalize external expenses
- Promote sustainable consumption using suitable economic mechanisms
- Consider the economic influence on local structures
- Consider alternative financing mechanisms

Environmental Aspect

- Conserve non-renewable resources
- Consider how projects will affect air, soil, water, plants, and animals
- Reduce material intensity via substitute technology
- Increase the recyclability of materials
- Reduce the use and spread of harmful materials
- Reduce energy usage
- Maximize biological and renewable resource utilization
- Support international convention agreements

Social Aspect

- Involve stakeholders to enhance a participatory approach
- Encourage public engagement
- Consider the impact on the existing social structure
- Encourage the creation of adequate institutional frameworks
- Evaluate the effect on health and well-being

Thus, sustainable construction encompasses all phases of a project, from design to demolition, aiming to mitigate the project's adverse effects on society, the economy, and the environment.

2.2.3. Sustainable Buildings

Within the construction industry, buildings are considered an important output, as they largely determine the environmental and well-being influences of humans (Union Internationale des Architectes, 2020). Buildings have always been essential to human history, with multiple central roles in social advancement, economic expansion, and environmental preservation (Omer & Noguchi, 2020).

However, the environmental, societal, and economic effects of buildings have increased significantly throughout their life cycle (Hossaini, Hewage, & Sadiq, 2015). Building construction, renovation, refurbishment, and retrofitting are associated with noise generation, increased energy consumption, greenhouse gas emissions, the utilization of natural resources, and the release of various pollutants. Furthermore, the demolition of buildings involves a disposal process, which is similarly linked to energy use and waste generation. Statistics show that buildings are responsible for (United Nations Environment Programme, 2021):

- 37% of the utilized energy-related CO₂ emissions worldwide
- 36% of the energy utilized worldwide
- 12% of the freshwater withdrawal worldwide
- 30% of the raw materials used worldwide
- 20% of the water effluent generation worldwide
- 45-65% of the landfill waste worldwide

Therefore, recognizing building consequences that may affect the environment and society either positively or negatively, along with mitigating negative effects while enhancing and providing positive outcomes, the

concept of sustainable building has gained importance in countries worldwide (Allen, MacNaughton, Laurent, Flanigan, Eitland, & Spengler, 2015). The terms “sustainable building,” “green building,” and “high-performance building” are often used interchangeably by researchers and practitioners.

There are many definitions for the term “sustainable building”. Gibberd (2002) defined it as a building intended to maximize favorable social and economic outcomes while mitigating adverse environmental effects. Kibert (2016) defined it as a well-being facility that implements resource-efficient and ecological principles in its design and construction. Robichaud and Anantatmula (2011) defined it in terms of four aspects: reducing environmental impacts, improving occupants’ health conditions, generating economic benefits for the local community and investors, and considering all building phases throughout the planning and development processes. Thus, sustainable building approaches encompass environmental, social, and economic responsibility over the whole lifespan of a building.

In the building context, environmental sustainability refers to the mitigation of greenhouse gas emissions, resource efficiency, energy efficiency, and water efficiency (Rahman & Khondaker, 2012; Sadineni, Madala, & Boehm, 2011). Social sustainability refers to the enhancement of living standards, ensuring a secure and healthy environment for all individuals involved, such as construction workers, users, and operators (Wong & Fan, 2013). Social sustainability should extend beyond the scope of individual buildings and include the broader local community (Zuo, Jin, & Flynn, 2012). Economic sustainability refers to the economic value, affordability, and impact on the local economy.

It is also essential to know that, in different countries, consideration of the specific climatic conditions and the people's needs will have a great influence on the process of developing a sustainable building (Zuo & Zhao, 2014). Therefore, each country must establish its own standards and methods to ensure sustainability within its buildings.

Figure 2.5 illustrates the achievement of the SDGs through sustainable buildings (World Green Building Council, 2023).

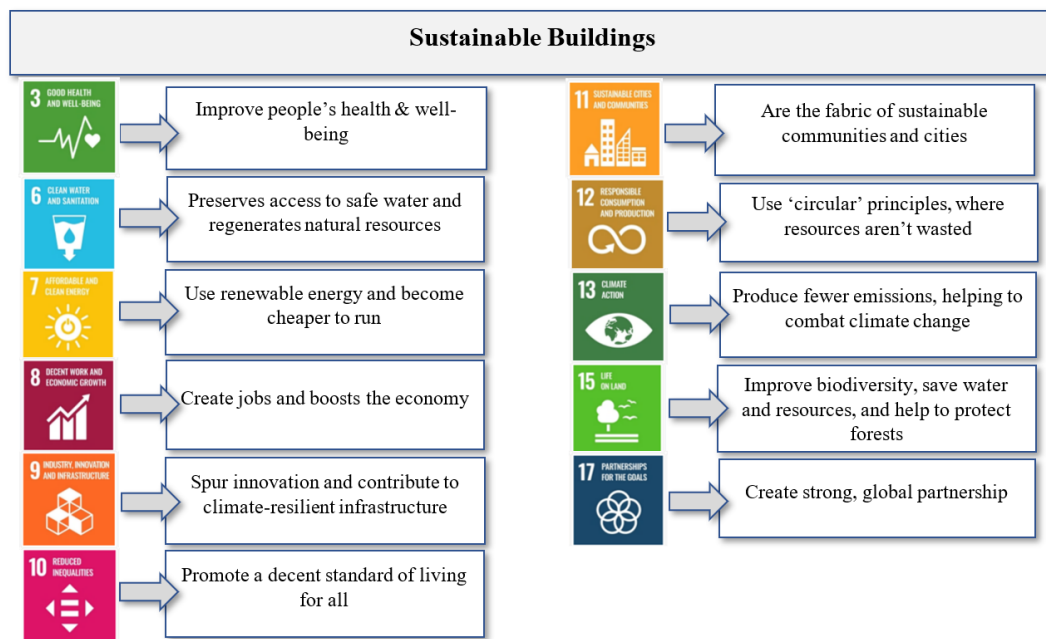


Figure 2.5: Achievement of SDGs Through Sustainable Buildings
(World Green Building Council, 2023)

2.2.4. Sustainable Building Designs

The design stage is crucial to achieving optimal, sustainable results throughout the building's life cycle. It is the first stage of any building project, which involves providing the required information to construct a building that satisfies the owner's needs and implements the building standards and regulations that ensure the health, welfare, and safety of society (Merritt &

Ricketts, 2001). It is based on the architectural, engineering, and technical applications to the design of the building and includes means of communication such as drawings, plans, specifications, and models used to create a building or resolve issues within a building.

According to many authors (Azhar et al., 2010; Basbagill et al., 2013; Santos et al., 2019), building life cycle impacts are mainly influenced by choices made at the design stage; therefore, sustainable measures need to be included and examined within this stage to ensure a building's sustainability. Postponing or changing such decisions during this stage significantly increases the building impacts (Schlueter & Thesseling, 2009).

The design of a building often adheres to general criteria. These criteria primarily address functional, economic, social, and time considerations. Nevertheless, these alone are insufficient in establishing a coherent foundation for the building's optimal sustainable outcomes. The enhancement of the building's sustainability performance can be done by adding new criteria and approaches that were previously unconsidered (Deru & Torcellini, 2004). Incorporating sustainable criteria within the design process enhances the potential of mitigating negative consequences more significantly and is more economical compared to addressing them post-construction (Shahda, 2018). Thus, enhancing a building's sustainability is directly correlated to how quickly the sustainability requirements are implemented.

Feria and Amado (2019) developed guidelines with the purpose of aiding design stage practitioners in the process of identifying optimal solutions and assessing their compatibility with sustainability objectives (**Figure 2.6**). These are explained below within the four phases of the design stage:

1. Program and Data Collection: This is the starting point where the design requirements are set. It requires the designer to evaluate the site's bioclimatic features in addition to best practices for energy and potable water conservation. Minimize impermeabilized zones and adapt them to user numbers and profiles, building functions, and space typologies to protect ecosystems and natural resources. Moreover, the future building's interior consumption and needs must be estimated, and other important factors related to social, cultural, and economic aspects need to be examined (Akadiri, Chinyio, & Olomolaiye, 2012; Gallo, 2015).
2. Feasibility Study: This phase determines how the building integrates with its surroundings to ensure optimal energy efficiency. It defines orientation and form, which will greatly affect the building's energy efficiency. For heating or cooling the building, passive design solutions, natural ventilation, and daylighting must be prioritized, along with design, landscaping, and mass to match climate and topography (Widera, 2015).
3. Preliminary Design: During this phase, the design team tests the area, internal layout, height, and building envelope features, including openings and shading systems, as these choices significantly impact building energy efficiency. Active solutions are explored to incorporate renewable heating and cooling systems into the building and employ prefabrication (Vieira, Amado, & Pinho, 2017).
4. Detail Design: In this phase, the interior layout and dimensions are finalized. Choices are made regarding materials, finishes, water fittings, electrical equipment, and artificial lighting. Sustainability is still important in this phase since these approaches affect the building's

water efficiency, sound comfort, durability, indoor air quality, and energy efficiency (Das, Moulick, & Bera, 2015).

Certain aspects, such as the required energy for the construction or operation phases, water consumption, and the amount of hazardous gas emissions, can be improved in the subsequent stages, but only to a limited extent.

Therefore, sustainability should be smoothly incorporated into the design process in order to preserve control over all factors related to sustainability in buildings and assess their impact on the end product (Schlueter & Thesseling, 2009). This can be ensured using SBIs.

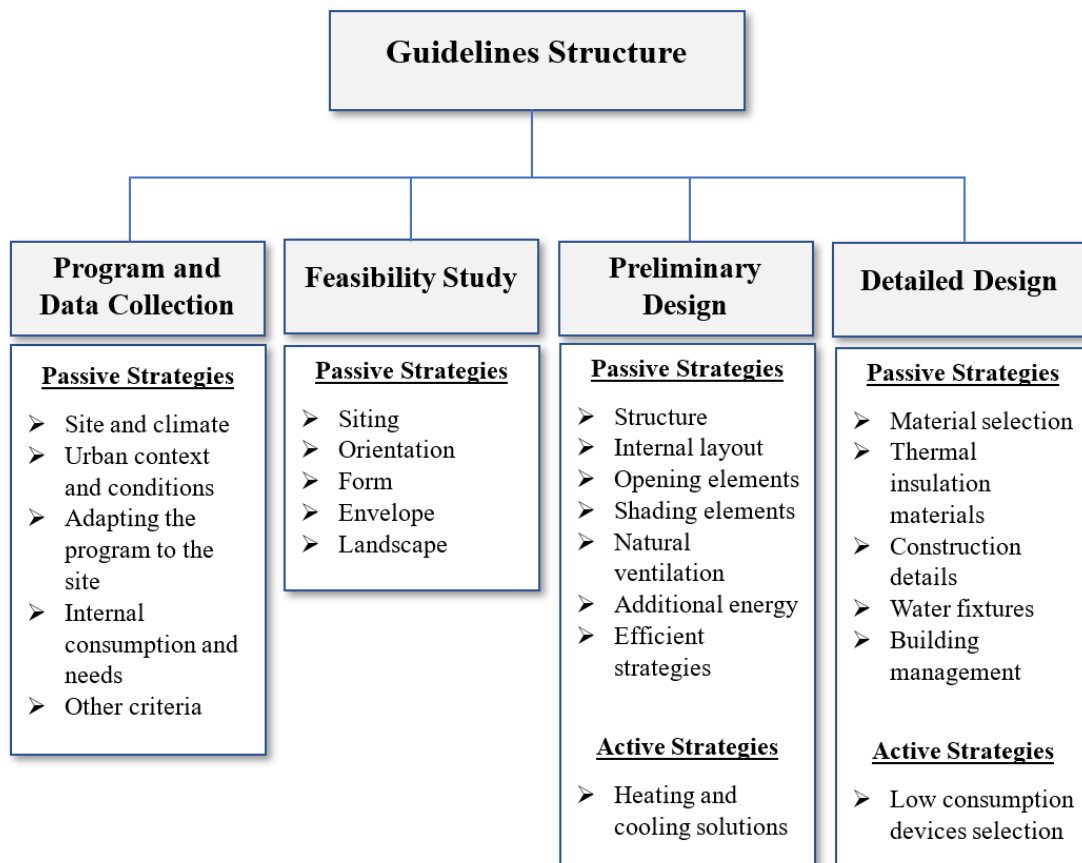


Figure 2.6: Guidelines Structure for Sustainable Building Design
(Adapted from Feria & Amado, 2019)

2.2.5. Sustainable Building Initiatives (SBIs)

Private and public organizations and state authorities around the world have established several SBIs in order to incorporate and disseminate sustainable practices into building projects, assess and track their sustainability performance, and collect information to aid the decision-making process of designers across their various phases (Haapio & Viitaniemi, 2008; Mateus & Bragança, 2011). Some SBI methods were developed for use worldwide, while others were tailored or modified to accommodate the unique environmental, economic, and socio-cultural characteristics of a specific region (Haapio & Viitaniemi, 2008; Kamaruzzaman, Salleh, Lou, Edwards, & Wong, 2016).

The literature review classifies three SBIs: SBRs, SBAs, and SBCs, as the current global SBIs designed to promote building sustainability (Ramani & García De Soto, 2021):

I. Sustainability Building Rating Systems (SBRs)

These provide guidance or a systematic approach to facilitate the sustainable performance evaluation process of a building project. They employ either a credit or point system, wherein projects are assessed and assigned to specific rating levels based on predetermined categories. **Table 2.1** shows some of the commonly used systems.

II. Sustainability Building Assessment Tools (SBAs)

These are flexible methodologies primarily used for internal evaluation and enhancement of the building's sustainability. They might relate to specific components, such as energy efficiency and water usage, or encompass broader

aspects of sustainability. They may use rating levels similar to those used in SBRs, but these are usually analytical. **Table 2.2** shows some examples of developed SBAs.

III. Sustainability Building Codes (SBCs)

These guidelines and standards must be implemented during the design or execution phases of a project to ensure compliance with local regulations. **Table 2.3** shows some examples of developed SBCs.

Table 2.1: Commonly Used SBRs (Ameen et al., 2014; Awadh, 2017; M. S. Ferwati et al., 2019; Larsson & Bragança, 2012; Yadegaridehkordi et al., 2020)

SBRs	Country of Origin	Year	Context	Developer
BREEAM - Building Research Establishment's Environmental Assessment Method	United Kingdom (UK)	1990	Global	Building Research Establishment (BRE)
SBTool - Sustainable Building Tool	Canada	1996	Global	International Initiative for a Sustainable Built Environment (iiSBE)
LEED - Leadership in Energy and Environmental Design	United States (US)	1998	Global	US Green Building Council (USGBC)
CASBEE - Comprehensive Assessment System for Building Environmental Efficiency	Japan	2001	Global	Ministry of Land, Infrastructure, Transport and Tourism of Japan
PRS - Pearl Rating System	Abu Dhabi	2008	Local	Abu Dhabi Urban Planning Council (AUPC)
GSAS - Global Sustainability Assessment System	Qatar	2009	Local	Gulf Organization for Research and Development (GORD)

Table 2.2: SBAT Examples

SBATs	Year	Purpose	Reference
SAHSB ^{PT} - Sustainability Assessment of High School Buildings in Portugal	2019	Evaluate and compare Portugal's high school buildings' sustainability.	Saraiva et al. (2019)
SAM - Sustainability Assessment Model	2020	Guide Ghanaian affordable housing construction and retrofitting to sustainability.	Adabre & Chan (2020)
RESI - Real Estate Sustainability Index	2021	Evaluate and compare real estate projects.	Dobrovolskienė et al. (2021)
HSAT - Housing Sustainability Assessment Tool	2021	Guide sustainable housing.	Adamec, Janoušková, & Hák (2021)
Optimal Model	2021	Evaluate and compare the sustainability and affordability of Saudi Arabian residential neighborhoods and detached villas.	Haidar & Bahammam (2021)

Table 2.3: SBC Examples

SBCs	Country of Origin	Year	Reference
IgCC - International Green Construction Code	The US	2010	International Code Council (2010)
CALGreen - California Green Building Standards Code	California (US)	2010	California Building Standards Commission (2010)
Green Building Regulations & Specifications	Dubai (United Arab Emirates - UAE)	2011	Dubai Municipality (2011)
ISO 15392-International Organization for Standardization	ISO Technical Committees Worldwide	2019	ISO 15392 (2019)
Green Building Manual	Bahrain	2019	Bahrain Municipalities Affairs & Urban Planning (2019)

2.2.6. A Comparison of the SBIs

SBRSS have been established throughout the world, each possessing its advantages and disadvantages. Some offer versions in terms of occupancy type, and others in terms of project stage (Shan & Hwang, 2018). Many studies have criticized them due to various deficiencies (Awadh, 2017; Mattoni, Guattari, Evangelisti, Bisegna, Gori, & Asdrubali, 2018; Zuo & Zhao, 2014).

Most SBRSS have a narrow perspective, primarily focusing on assessment criteria for environmental sustainability, with the absence or inadequate allocation of weightings for assessment criteria pertaining to social and economic sustainability, resulting in an assessment of the environmental impact of the building rather than its overall sustainability (Atanda, 2019; Awadh, 2017; Hamid, Zain, Hung, Noor, Roslan, Kilau, & Ali, 2014; Raouf & Al-Ghamdi, 2019).

Although international SBRSS have attempted to adopt their assessment systems to different global regions, there are arguments regarding their effectiveness and accuracy in evaluating the sustainability of building projects beyond their country of origin. This is due to the challenge of using the same system to measure the sustainability of diverse projects that possess distinct geographic, climatic, and technological attributes (Alyami & Rezgui, 2012; Banani, Vahdati, Shahrestani, & Clements-Croome, 2016; Bueno, Vassallo, & Cheung, 2015; Haapio & Viitaniemi, 2008).

The use of a fixed-point scoring system for sustainability assessment may yield misleading results if it fails to include the distinctive regional characteristics and seasonal variations associated with a particular project (Sharifi & Murayama, 2013). To ensure a dependable assessment, it is

necessary to modify these benchmarks to align with the project's unique limitations. The utilization of rating, score, or certification levels, such as "Good," "Very Good," and "Excellent," to present outcomes may potentially lead to misinterpretation or overshadow the assessment of underlying procedures (Haider, Hewage, Ruparathna, Chhipi-Shrestha, Culver, Holland, Kay, & Sadiq, 2018).

Additionally, the procedure for assessing and certifying buildings using these systems is lengthy and complex, as it requires a substantial amount of time and a variety of tools to thoroughly examine the extensive range of components and verify the results (Markelj et al., 2014). Also, a significant limitation of the existing methods is their lack of suitability for independent application, as they necessitate the involvement of a licensed assessor during the certification process, or they may have complicated criteria fulfillment requirements that demand the expertise of a specialized consultant, which results in these methods not being used more frequently (Birgisdottir & Hansen, 2011). Evaluating and certifying a building using these systems will require payment of a registration fee to the certification organization, as well as the engagement of several consultants and licensed inspectors, which will incur additional costs (Birgisdottir & Hansen, 2011; Markelj et al., 2014).

However, SBATs help in achieving a balance between the economic, environmental, and social dimensions of sustainability and improve practicality and resiliency (Awadh, 2017). They are able to exhibit variations globally, encompassing various factors such as culture, climate, geography, resources, technology, and policy perspectives. Thus, they are broader and more accurate than SBRs, allowing for even more sustainability dimensions to be considered. They may use a rating system, as in SBRs, but usually

develop an index or model that guides the project towards sustainability. Each region has established its SBAT through the process of detecting appropriate categories, defining evaluation criteria, and developing appropriate assessment procedures (Ramani & García De Soto, 2021). Finally, the SBCs are standards implemented by state authorities or organizations to ensure sustainability in buildings but are not used to assess or evaluate building sustainability.

In summary, SBRs and SBATs are considered SBASs, whereas SBCs are not. Most SBRs are environmental-oriented. They are considered a standardized approach for sustainability assessment, but may not be effective or accurate when implemented beyond their country of origin. They are typically employed by governmental entities that require a rating for new projects or by project developers who secure new clients contingent upon the attained rating. They entail numerous formalities and laborious procedures and are costly.

On the other hand, SBATs are simple and accessible for use. They may be used in conducting self-assessments for projects by developing assessment procedures that guide projects towards sustainability. They are broader, considering many sustainability dimensions tailored to suit the building's region and occupancy type. Therefore, for the aim of this thesis, SBATs are discussed further to aid researchers globally in developing country-specific and occupancy-specific SBATs that the design team can utilize to assess new building designs and improve them towards comprehensive sustainability. **Table 2.4** shows a comparison between SBRs and SBATs.

Table 2.4: A Comparison between SBRs and SBATs

SBRs	SBATs
Output-driven, focusing on the assessment of the overall sustainability of a building to obtain a certification or rating.	Process-driven, helping to monitor and improve a building's sustainability throughout its life cycle.
Environmental-oriented (assigning very low weighting to the other dimensions).	Broader, balancing the three sustainability dimensions (economic, environmental, and social), in addition to other relevant dimensions, such as culture, technology, and governance, as necessary.
A standardized approach not suitable for implementation beyond the country of origin.	A tailored approach to suit the building's occupancy type and region.
Formal, tedious, and costly.	Accessible and simple to use.
Credit or point outcome.	Credit, point, index, or model outcome.

2.3. Sustainability Building Assessment Tools (SBATs)

SBATs are widely recognized as very influential and efficient mechanisms for enhancing the sustainability performance of buildings (Lockwood, 2006). They are considered a management tool that provides an indicative guide to a building's sustainability performance across its entire life cycle by gathering and analyzing various performance indicators (Gibberd, 2002). Academicians and practitioners have developed numerous assessment tools and continue to develop new SBATs to address distinct requirements, including occupation-specific and region-specific systems (Lazar & Chithra, 2020).

Different versions of SBATs are developed to effectively identify and address the unique needs of diverse building types (Sev, 2011). Also, the applicability of available tools is limited across various countries due to multiple issues, including regional diversity, which includes factors such as

climatic situations, geographical attributes, the potential for renewable energy generation, resource utilization, construction practices and materials, building inventory, governmental policies and regulations, preservation of historical significance, population expansion, and public consciousness (Alyami & Rezgui, 2012).

Initially, the primary purpose of developing these tools was to evaluate a building's environmental impacts. However, they are too limited in scope and lack a strategic component, frequently being introduced into the development of a project in its late phases (Amezaga, Maltitz, & Boyes, 2010; Gibson, 2006).

Today, the evaluation of sustainability using SBATs has expanded to encompass social, environmental, and economic impacts within various management contexts, spanning different scopes such as individual projects, local contexts, or even state dimensions (Amezaga et al., 2010; Hacking & Guthrie, 2008). SBATs facilitate the integration of qualitative data into the evaluation process, as well as the inclusion of analytical data derived from scientific or technical investigations, which provides an opportunity to explore a broader range of information pertaining to sustainability, encompassing insights that extend beyond analytical and quantifiable measures (Pope & Grace, 2006). SBATs have the potential to facilitate the acknowledgment, examination, and resolution of conflicting interests across many levels of authority, providing clear and precise definitions of goals and fostering constructive conversations among stakeholders ranging from local to global decision-makers (Perruccio, 2015).

According to Gibberd (2002), 15 primary domains within buildings need to be assessed to ensure sustainability achievement. These domains fall under environmental, economic, and social categories:

Environmental: Site, Energy, Water, Waste, and Materials & Components.

Economic: Local Economy, Efficiency of Use, Adaptability & Flexibility, Capital Costs, and Ongoing Costs.

Social: Occupant Comfort, Inclusive Environments, Facility Access, Participation & Control, and Education, Health & Safety Local Contractors.

Hacking and Guthrie (2008) highlighted three factors that need to be considered throughout the approach for developing new types of SBATs in order to guarantee their efficiency:

Comprehensive-ness: The approach should fully cover environmental, social, and economic sustainable building themes.

Integrate-ness: The approach should align, connect, compare, and combine the themes.

Strategic-ness: The approach should be broad and future-oriented.

Following the expansion in the field of SBATs, many studies have proposed new dimensions in addition to the three basic dimensions: Technological, Cultural, Governance, Institutional, and others (Adamec et al., 2021; Dobrovolskienė et al., 2021; Lazar & Chithra, 2020).

Cole (2005) suggests that the best way to develop a novel assessment tool is to review, analyze, and compare the available tools. Generally, sustainability can be assessed sequentially through a process that includes sustainability accounting, assessment, and reporting (see **Figure 2.7**) (Büyüközkan & Karabulut, 2018). As this research concerns the sustainability assessment method, the focus will be on the sustainability accounting and assessment processes to develop an SBAT.

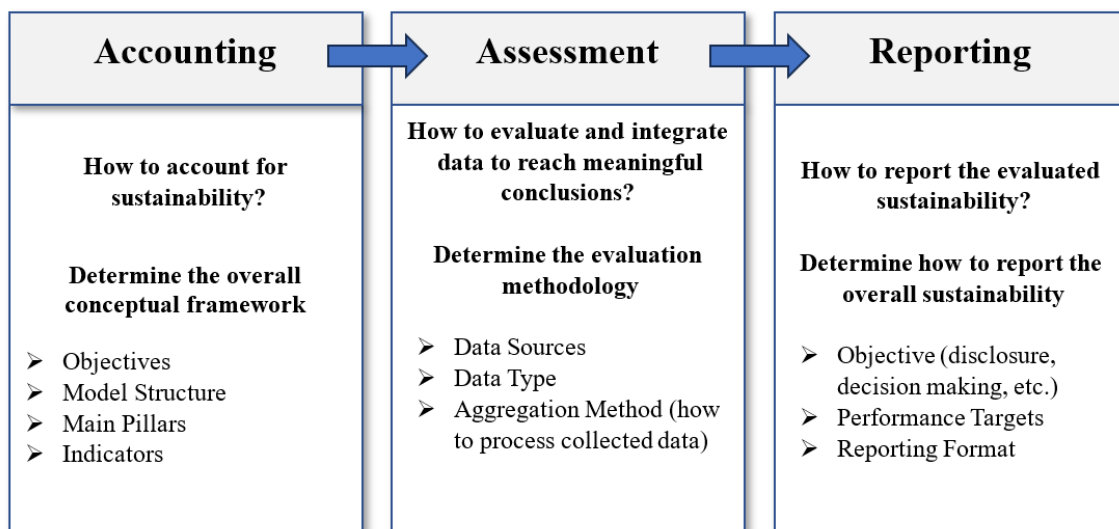


Figure 2.7: Sustainability Assessment Process (Adapted from Büyüközkan & Karabulut, 2018)

I. Sustainability Accounting

This process focuses on determining the specific information and data, as well as the reason for which they are collected, by establishing and evaluating appropriate indicators, usually arranged in conceptual frameworks, used as conceptual SBATs (Zyznarska-Dworczak, 2020).

II. Sustainability Assessment

This process utilizes analytical tools to give meaning to the collected information and data, employing numerical methods to aggregate and transform both qualitative and quantitative data into useful insights (Lazar & Chithra, 2020). Researchers in the field of sustainability have used different tools, such as Input-Output Analysis (Acquaye, Feng, Oppon, Salhi, Ibn-Mohammed, Genovese, & Hubacek, 2017), Descriptive Statistics (Maltz, Bi, & Bateman, 2018), Composite Index (Chardine-Baumann & Botta-Genoulaz, 2014), Scenario Analysis (Yao, Shen, Tan, & Hao, 2011), Numerical Analysis (Yakovleva, 2007), Data Envelopment Analysis (Lee & Farzipoor Saen, 2012), and Multi-Criteria Decision-Making (MCDM) (Boggia et al., 2018). The construction and building industry frequently utilizes MCDM analytical tools for the development of SBASs, as these tools aid in addressing the complex, multidimensional nature of sustainability (Cinelli, Coles, & Kirwan, 2014). Sustainability in construction encompasses a broad range of factors, including environmental impact, economic feasibility, and social implications. MCDM tools provide a structured framework for evaluating these various, often conflicting criteria, which is why they are highly valuable in decision-making processes (Cinelli et al., 2014; Lazar & Chithra, 2020; Medineckiene, Zavadskas, Björk, & Turskis, 2015).

III. Sustainability Reporting

Once sustainability is accounted for and assessed, comprehensive sustainability may be subsequently communicated as a strategic instrument for decision-makers (Seele, 2016).

The following is a review of the sustainable building criteria and indicators for developing a conceptual sustainability framework (sustainability accounting) and various MCDM analytical methods (sustainability assessment).

2.3.1. Sustainability Criteria and Indicators in Buildings

Developing an SBAT that balances environmental, economic, and social dimensions will first require the accumulation of a broad pool of sustainability criteria and indicators.

Sustainability criteria are requirements for a project's sustainable quality, which must be fulfilled to obtain a sustainability status or certification. According to Zink (2005), sustainability criteria refer to the criteria used to assess the positive and negative impacts associated with the three dimensions of sustainability (economic, environmental, and social). Ness, Urbel-Piirsalu, Anderberg, and Olsson (2007) highlighted that their utilization can facilitate the identification of unsustainable patterns and impacts, hence enabling the recognition of policy initiatives that are not sustainable. Graymore, Wallis and Richards (2009) emphasized that they could be quantitative or qualitative. Pavlovskaja (2014) stressed that sustainability criteria are not fixed and may need ongoing evaluation and adjustments. Therefore, it is essential to clearly define the purpose for which the sustainability criteria were developed to understand and interpret their content accurately.

To fulfill each criterion, indicators are usually used. According to the literature, an indicator is defined as a parameter that serves the purpose of

providing information and describing a particular phenomenon (Delzeit & Holm-Müller, 2009; Sahely, Kennedy, & Adams, 2005). Indicators are purpose-bound tools utilized to provide guidance, assistance, and monitoring for decision-making processes (Spangenberg, 2005). The formulation of an indicator should be unambiguous and relatively easy to use (Ness et al., 2007).

Indicators under each sustainability criterion are used to evaluate and assess the progress towards achieving sustainability within the respective criterion. They should emphasize the aims and objectives of sustainability and indicate the sustainability performance of the criteria. Indicators can pertain to human actions and their consequential effects on the surrounding environment using both quantitative measurement and qualitative evaluations (National Research Council of the National Academies, 2010).

Studies have shown that researchers use the concepts of “sustainability criteria” and “sustainability indicators” in different ways. Sometimes, the criteria have been expressed in quantifiable terms with no accompanying indicators. Several interpretations, methodologies, and approaches exist pertaining to the development and utilization of indicators; nonetheless, it is essential to include the following characteristics (National Research Council of the National Academies, 2010):

- Understandable and pertinent for users
- Accurate and present their function and process
- Adapt and alter with time and between various methods
- Rational in terms of time, cost, and degree of expertise needed

Indicators may be classified into two types: Core and supplementary. The difference between them is shown in **Figure 2.8**. It is essential to note

that core indicators are more general and can be applied to measure sustainability across various projects, whereas supplementary indicators are more specific to a project's location and type. Thus, core indicators are not regarded as more significant; rather, they are used at the initial stage of the indicator selection as they are more common (Veleva & Ellenbecker, 2001).

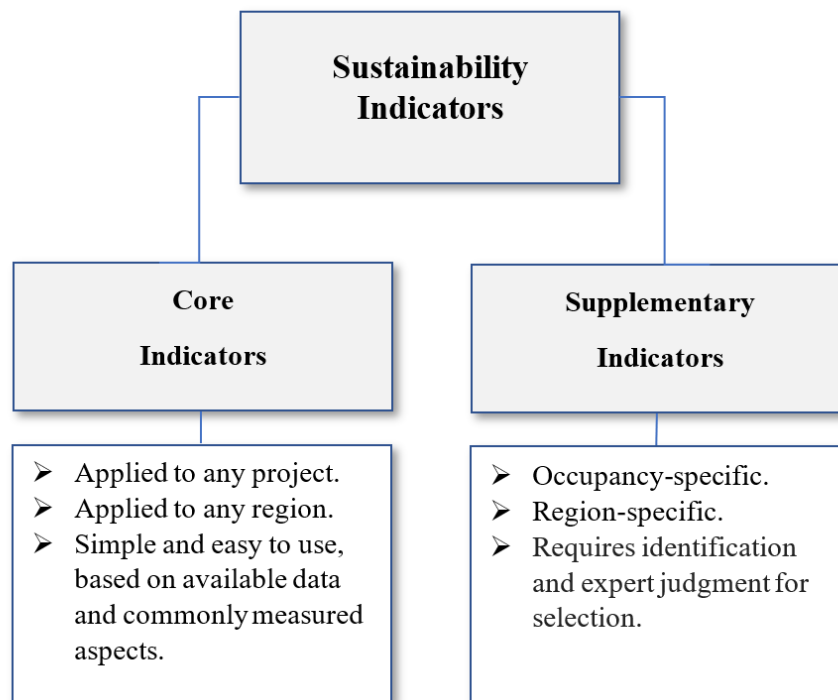


Figure 2.8: Difference Between Core and Supplementary Sustainability Indicators (adapted from Veleva & Ellenbecker, 2001)

The following two sections will review the SBRs available and the literature to define the economic, environmental, and social sustainable building criteria and indicators used by international and local sustainability systems, as well as previous research. The third section will summarize the common sustainability criteria and indicators reviewed.

I. Criteria and Indicators from Existing SBRs

Criteria and indicators used by BREEAM, LEED, CASBEE, SBTTool, Estidama (PRS), and GSAS were investigated (**Appendix 1**). The rationale for selecting these rating systems was based on considering them as globally and locally well-recognized leading systems (Al Khalifa, 2019; Alhilli & Burhan, 2021; Awadh, 2017; Mattoni et al., 2018; Ramani & García De Soto, 2021; Saraiva et al., 2019). For this research, concerned with sustainability in new building designs, the design and construction manuals for new buildings developed by the SBRs were reviewed.

BREEAM is the world's first SBR, established in 1990 in the UK by the Building Research Establishment (BRE) (Alyami & Rezgui, 2012; Chen, Yang, & Lu, 2015). The widespread utilization of BREEAM may be attributed to its flexible nature, allowing its application in international buildings (Marjaba & Chidiac, 2016). BREEAM facilitates the assessment by providing a range of manuals for all building phases, including design, construction, operation, and refurbishment. According to Doan *et al.* (2017), while BREEAM can assess all dimensions of sustainability, it is evident that the environmental dimension remains the most influential. The BREEAM International New Construction Manual includes 10 main criteria, under which a total of 55 indicators are defined (Building Research Establishment Environmental Assessment Methodology, 2016).

LEED was established in 1998 by the US Green Building Council (USGBC) as a voluntary standard (Ofori-Boadu, Owusu-Manu, Edwards, & Holt, 2012; Potbhare, Syal, Arif, Khalfan, & Egbu, 2009). Despite being introduced after BREEAM, it is acknowledged as the most extensively embraced (Kokame, 2017). Like BREEAM, LEED can be used to assess all

sustainability dimensions, but it predominantly evaluates environmental factors (Doan, Ghaffarianhoseini, Naismith, Zhang, Ghaffarianhoseini, & Tookey, 2017). LEED can be applied to all building types throughout their entire life cycle, utilizing a range of manuals tailored to the different phases (Al Khalifa, 2019; Doan et al., 2017). The LEED Building Design and Construction (New Construction & Major Renovation) Manual comprises seven main criteria, under which a total of 41 indicators are defined (US Green Building Council, 2019).

CASBEE was established through a collaborative effort, including academic institutions, industrial stakeholders, and local government bodies in Japan in 2001 (Haapio, 2012). Initially, it was limited to the Japanese context until 2015, when a pilot version was introduced, making it suitable to assess a broad context globally (Miyazaki, Kawakubo, Murakami, & Ikaga, 2019). The assessment of buildings using CASBEE involves various stages, from design to renovation, through a range of manuals (Doan et al., 2017). CASBEE for Building (New Construction) Manual includes six main criteria with 20 sub-criteria, under which a total of 41 indicators are defined (Institute for Building Environment and Energy Conservation, 2014).

SBTool was established in 1996 by the International Initiative for a Sustainable Built Environment (iiSBE) in Canada, as an international and generic sustainability assessment method for buildings (Larsson & Bragança, 2012; Ameen, Li, & Mourshed, 2014). The SBTool is a general assessment framework that third parties can use to create rating systems applicable to diverse local contexts and building typologies. Thus, it may be regarded as a toolkit for rating systems (Larsson & Bragança, 2012). The SBTool Building Design Manual comprises seven main criteria, 26 sub-criteria, and a total of

41 indicators (International Initiative for a Sustainable Built Environment, 2020).

Estidama was established in 2008 by the Abu Dhabi Urban Planning Council (AUPC) as the first environmental assessment method in the Arabian Gulf (Ferwati, Al Saeed, Shafaghat, & Keyvanfar, 2019). The PRS rating tool is utilized within Estidama to assess four sustainable building categories: environmental, cultural, economic, and social (Ferwati et al., 2019). The PRS Building Design and Construction Manual includes eight main criteria, under which a total of 86 indicators are defined (Abu Dhabi Urban Planning Council, 2010).

GSAS was founded in 2009 in Qatar by the Gulf Organization of Research and Development (GORD) (Awadh, 2017). It aimed to enhance the built environment's sustainability by mitigating its adverse environmental impacts and maintaining the values, customs, and identity of the region (Awadh, 2017). Best practices from the most well-recognized global SBRs, including BREEAM, LEED, SBTOOL, and CASBEE, served as the basis for the GSAS (Awadh, 2017). The GASA Building Design and Construction Manual includes eight main criteria, under which a total of 159 indicators are defined (Gulf Organization for Research & Development, 2019).

II. Criteria and Indicators from the Literature Review

Criteria and indicators from the literature review were also investigated. The search involved international peer-reviewed publications within the Web of Science and Scopus databases, focusing on papers that included criteria and indicators used to assess the three dimensions of sustainability

(environmental, economic, and social) in educational buildings and buildings in general to suit the purpose of this research. Only two recent papers on educational buildings and two on buildings in general were identified as suitable, focusing on criteria and indicators to assess building sustainability during design, construction, and operation (**Appendix 1**).

Educational Buildings

Alhilli and Burhan (2021) developed a decision-making system to implement sustainability ideas during the life cycle of school building projects in Iraq. The assessment of school buildings in this study was conducted using appropriate criteria and indicators derived from internationally recognized sustainability systems, including BREEAM, LEED, PRS, and the AlSa'fat (Dubai Green Building System) system, as well as previous research and expert opinion. The study encompassed six main criteria, under which 38 indicators were defined.

Saraiva et al. (2019) adapted an existing sustainability assessment tool, namely the Sustainable Building Tool for Portugal (SBTool^{PT}), to develop a new method tailored for the Sustainability Assessment of High School Buildings in Portugal (SAHSB^{PT}). This involved retaining certain indicators from the original tool, while also modifying and incorporating additional indicators. Criteria and indicators were drawn from other methodologies that encompass factors related to the school environment, including BREEAM Education 2008, SBTool for K-12 schools, and LEED BD+C Schools (LEED Building Design and Construction Schools). The study included 11 main criteria, under which a total of 24 indicators were defined.

Buildings in General

Akhanova et al. (2019) devised a comprehensive framework for policymakers in Kazakhstan to evaluate the sustainability of buildings. The categories of the framework were assessed for reliability through a comparative analysis of their performance sensitivity with four well-recognized SBRs: BREEAM, LEED, SBTool, and CASBEE. The study findings also indicated that the proposed framework has the potential to be applied in nations adjacent to Kazakhstan that share comparable climatic zones and circumstances. The study included nine main criteria, under which a total of 45 indicators were defined.

Reddy, Raj, and Kumar (2018) developed an SBAT using a comprehensive framework consisting of sustainable criteria and their corresponding indicators to assess the sustainability of buildings. The tool was designed to support decision-makers and stakeholders in developing nations, such as India, in improving the sustainability of buildings. The study included eight main criteria, under which 43 indicators were defined.

III. Summary of Criteria and Indicators

Throughout the review of the globally and locally well-recognized leading SBRs and previous research, common criteria and indicators covering economic, environmental, and social sustainability in buildings were identified.

From **Appendix 1**, all the criteria primarily used and reiterated by the SBRs and the literature review were verified. These included: “Site,” “Health & Well-being,” “Materials,” “Energy,” “Pollution,”

“Transportation,” “Quality of Service,” “Water Efficiency,” and “Waste.” Then, all the indicators under the verified criteria in all the SBRs and the literature review were listed, and the common, repeated indicators were selected. The common sustainable building criteria and indicators used by SBRs and the literature review are shown in **Table 2.5**.

Table 2.5: Common Sustainable Building Criteria and Indicators Used by SBRs and Previous Research (Abu Dhabi Urban Planning Council, 2010; Akhanova et al., 2019; Alhilli & Burhan, 2021; Building Research Establishment Environmental Assessment Methodology, 2016; Gulf Organization for Research & Development, 2019; Institute for Building Environment and Energy Conservation, 2014; International Initiative for a Sustainable Built Environment, 2020; Reddy et al., 2018; Saraiva et al., 2019; US Green Building Council, 2019)

Sustainable Building Economic, Environmental, and Social Criteria and Indicators	
Site	Health & Well-being
➤ Site selection ➤ Site protection ➤ Efficient land use ➤ Services availability ➤ Heat island reduction ➤ Open space ➤ Shading ➤ Vegetation ➤ Visual comfort ➤ Construction practices ➤ Light pollution reduction ➤ Drain & stormwater contamination ➤ Rainwater runoff ➤ Surrounding considerations (wind, noise, odor, vibration, sand damage & daylight barriers) ➤ Site ecology enhancement ➤ Biodiversity protection ➤ Orientation effect on passive solar potential & natural ventilation	➤ Visual comfort ➤ Glare ➤ Interior lighting ➤ Daylighting ➤ Indoor air quality ➤ Thermal comfort ➤ Insolation level ➤ Acoustic comfort ➤ Accessibility ➤ Hazards ➤ Humidity control ➤ Private space ➤ Mechanical ventilation ➤ Air pollution monitoring ➤ Natural ventilation ➤ Water pollution & quality ➤ Sanitation/Safety facilities
Materials	Energy
➤ Life cycle impact reduction ➤ Responsible sourcing ➤ Durable and resilient design	➤ Commissioning enhancement ➤ Energy efficiency enhancement ➤ Generation of renewable energy

➤ Material efficiency ➤ Low-energy material ➤ Environmentally friendly material ➤ Existing structure re-use ➤ Locally available material ➤ Recycled & re-used material ➤ Reflective material use ➤ Flexible & adaptable design ➤ Hazardous materials elimination ➤ Material reduction	➤ Balancing green energy & carbon ➤ Energy monitoring & reporting ➤ Energy-efficient heating & cooling ➤ Energy-efficient equipment ➤ Progressed energy metering ➤ Vertical mobility ➤ Peak demand mitigation ➤ Energy-efficient design ➤ Efficient management of refrigerant ➤ Outer surface heat load control
Pollution	Transportation
➤ Refrigerant impact ➤ NOx emissions ➤ Emissions of CO₂ ➤ Runoff of surface water ➤ Heat island effect ➤ Nocturnal light pollution mitigation ➤ Sound pollution mitigation ➤ Fire risk ➤ Natural disaster	➤ Accessibility ➤ Pedestrian & cyclist safety ➤ Travel plan ➤ Proximity to amenities ➤ Alternative transport ➤ Eco-parking ➤ Community/urban connectivity
Quality of Service	Water Efficiency
➤ Usability & functionality ➤ Adaptability & flexibility ➤ Reliability & durability ➤ Controllability of system ➤ Performance maintenance ➤ Safety & Security	➤ Water fixture & conservation strategy ➤ Reduction of potable water consumption ➤ Water monitoring & leak detection ➤ Water re-use & recycle ➤ Managing runoffs ➤ Innovative water-efficient equipment ➤ Effective landscape design ➤ Water metering
Waste	
➤ Efficient management of waste ➤ Recycled aggregates ➤ Ease of disassembly, re-use, or recycling ➤ Recyclable waste storage ➤ Waste treatment ➤ Recycling facilities	

2.3.2. Conceptual Sustainability Frameworks/SBATs

Sustainability is a complex problem that requires considering multiple dimensions, each with its corresponding criteria, sub-criteria, and indicators, to achieve comprehensive coverage. Due to this complexity, researchers address it using an approach with different levels, known as a hierarchical tree

or a conceptual sustainability framework, because it can accommodate intricate interrelationships among many components, such as performance measures, ecosystems, industry, society, and more (Bhakar et al., 2018).

In a conceptual sustainability framework approach, criteria are usually organized hierarchically, progressing from broad to specific levels of detail. For a framework to be comprehensive, the criteria at each level must possess the qualities of being mutually exclusive while still being encompassed within the higher-level criteria. Nevertheless, this poses a challenge because the interrelation of economic, social, and environmental criteria necessitates precise organization to avoid information overlap, which might result in duplicative analysis (Si, Marjanovic-Halburd, Nasiri, & Bell, 2016). The efficiency of an air-conditioning unit, for example, is based on cost, environmental criteria, and social criteria, as the efficiency of the unit has implications in terms of greenhouse gas emissions, which in turn affect the environment and human well-being, as well as fuel expenditure reduction. Therefore, it is essential to begin by accurately organizing the criteria and specifying their consequences to establish a clear hierarchy framework that exhibits well-defined relationships.

To develop an SBAT, a conceptual framework or a hierarchy tree must be established (Bai, Wang, Shi, Du, & Li, 2017). Conceptual frameworks have demonstrated notable advancements due to their ability to incorporate new criteria and indicators, their adaption to various industries and countries, and their application in specific instances (Büyüközkan & Karabulut, 2018). Conceptual frameworks are helpful in identifying the aspects that reflect sustainability performance, selecting relevant indicators, and setting expectations for their measurement. They aim to determine the specific data

that should be collected and the corresponding purpose for which the data are intended. Some can also be utilized for reporting (Büyüközkan & Karabulut, 2018).

In the literature, SBATs have adopted several framework levels. A four-level framework considered dimensions, criteria, sub-criteria, and indicators. Dimensions, criteria, and indicators, or criteria, sub-criteria, and indicators, were considered within a three-level framework. Dimensions and criteria, dimensions and indicators, or criteria and indicators, were considered within a two-level framework. Only indicators were considered in a single-level framework. It is essential to note that organizing indicators into a framework at an early stage facilitates the establishment of a comprehensive framework with distinct relationships (Si et al., 2016).

Figure 2.9 illustrates an example of a three-level framework for a sustainable building that is occupancy- and region-specific. The researcher specifies dimensions, criteria, and indicators (i.e., additional dimensions can be considered, and the number of criteria categorized, and indicators selected will depend on the building's occupancy type and region). The three sustainability dimensions are achieved by categorized criteria (illustrated by the arrows between the dimensions and the criteria). Under each criterion, indicators are selected to assess how well the sustainability criterion advances sustainability.

Adapting a conceptual sustainability framework is necessary to develop a conceptual SBAT, used for accounting determinations; however, due to the limitations of these frameworks in assessing sustainability, they frequently fail to capture the entirety of the sustainability assessment objectively and

consistently. Therefore, researchers have developed analytical SBATs (Büyüközkan & Karabulut, 2018).

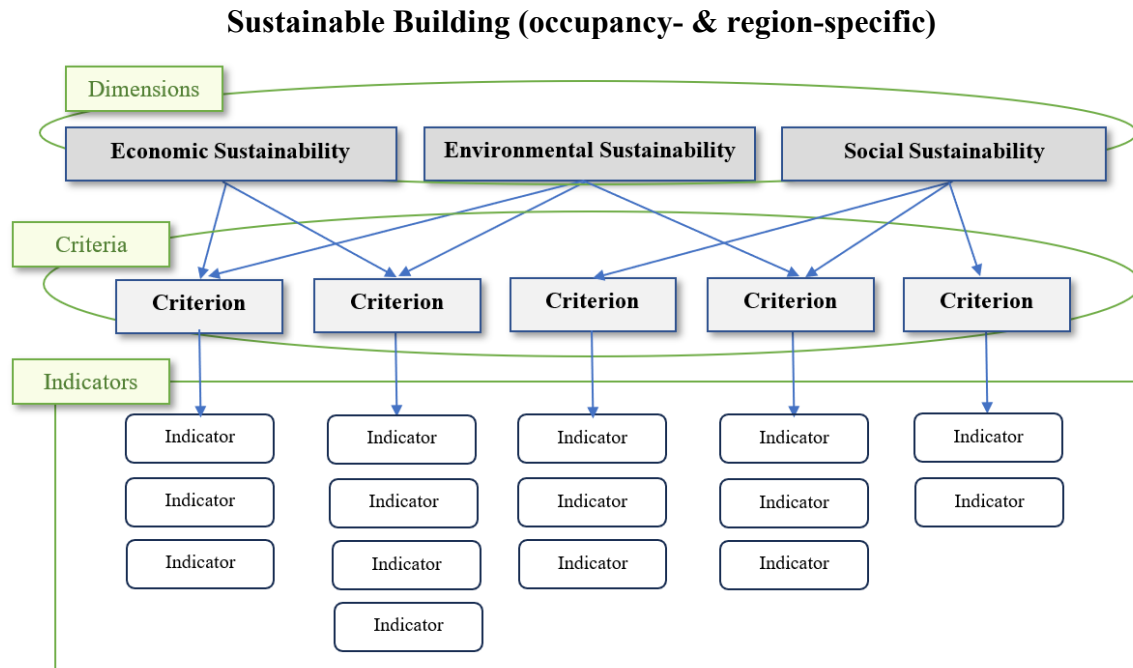


Figure 2.9: Conceptual Sustainability Framework Illustration

2.3.3. Multi-Criteria Decision-Making (MCDM)

MCDM is a discipline within the domain of operational research that aims to identify optimal outcomes in complex situations characterized by the presence of diverse indicators, conflicting criteria, and objectives (Kumar et al., 2017). Its application has experienced continuous growth in the sustainability field, which is attributed to the recognition of its benefits in facilitating sustainable decision-making problems. It is now gaining prominence in specific building types analysis and the field of sustainability management (Klumbytė, Bliūdžius, Medineckienė, & Fokaides, 2021)

MCDM methods have gained significant popularity in composing indices due to their capacity to incorporate several criteria, which may

sometimes be conflicting (de Oliveira et al., 2015; Sarma et al., 2019). They can convert intricate decision-making problems into clearly delineated steps, leading to the identification of the best possible solution (Si et al., 2019).

The illustration in **Figure 2.10** shows the two classifications of MCDM methods. Methods based on a problem-solving approach include outranking, value-based, or Choosing by Advantages (CBA). Methods based on mathematical characteristics include Multi-Attribute Decision-Making (MADM), Multi-Objective Decision-Making (MODM), or a hybrid of both (Kumar et al., 2017; Triantaphyllou, 2000).

In value-based methods, the decision depends on the remuneration, either partially or entirely, of the various components involved (Paz Arroyo, 2014). For example, in a situation where a high energy performance level is achieved with a low initial cost, these methods calculate numerical scores for each component or criterion. Subsequently, the weights of the criteria or components are obtained, and an aggregation model is developed to assist decision-makers in their judgments. On the other hand, outranking methods use individual criteria to compare different alternatives, followed by the aggregation of preferences, ultimately leading to the prioritization of one alternative over the other (Triantaphyllou, 2000).

The decision-making process in Choosing by Advantages (CBA) methods revolves around evaluating the advantages associated with different alternatives, rather than considering both advantages and disadvantages. This helps prevent the duplication of consideration for components. Upon the identification of the advantages associated with each alternative, these methods proceed to evaluate the significance of these advantages via conducting a comparative analysis (Kumar et al., 2017).

In MODM methods, decision alternatives are not provided, and programming techniques are employed to optimize objectives while connecting other objectives to a set of constraints (Allaoui et al., 2018; Zhao et al., 2021). These methods aim to determine the most favorable compromises and resolve the issue by formulating a mathematical programming model (Triantaphyllou, 2000). They are considered to have limited applicability for designers because most practical MCDM problems cannot be effectively addressed using mathematical programming (Kumar et al., 2017). However, MADM methods utilize discrete mathematics to find solutions for issues involving discrete decision spaces, allowing for the comparison of a predetermined, finite number of alternatives (Allaoui et al., 2018; Zhao et al., 2021).

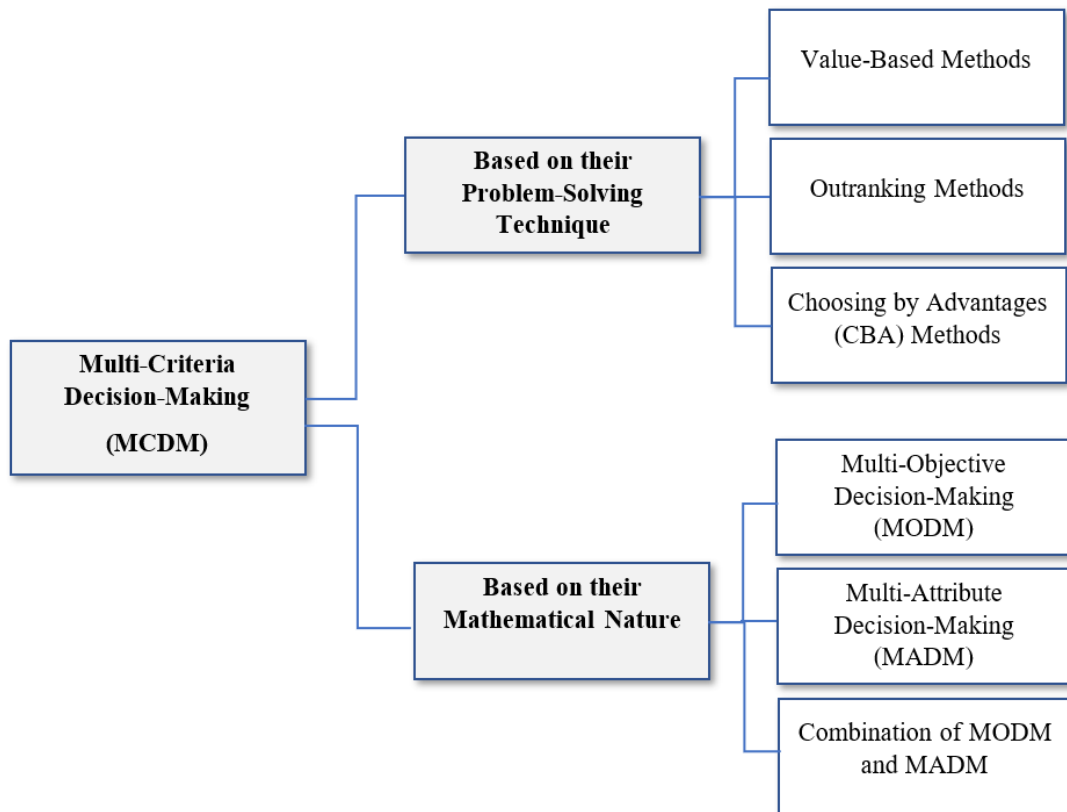


Figure 2.10: Most Common Categorization of MCDM Methods
(adapted from Triantaphyllou, 2000; Kumar et al., 2017)

MCDM has been extensively used in the development of SBASs, including SBRs and SBATs (Cinelli et al., 2014; Lazar & Chithra, 2020; Medineckiene et al., 2015). In their study, Lazar and Chithra (2020) revealed a concise overview of six main stages associated with using MCDM methods to develop SBASs:

1. Identification of criteria: A consolidated list of relevant criteria is derived from a broad pool of criteria.
2. Criteria selection and categorization: The full list of criteria acquired in the criteria identification stage is filtered, focusing on their relevance and significance.
3. Weighting and aggregation: Weighting relies on expert judgment. To determine the weights of each criterion, a group judgment is derived from aggregating the individual judgments of experts (Gan, Fernandez, Guo, Wilson, Zhao, Zhou, & Wu, 2017).
4. Concurrence between expert judgment: Assessing expert judgment agreement is crucial when making a decision based on a pool of experts (Raslanas, Kliukas, & Stasiukynas, 2016). This shows how well experts agree.
5. Performance values normalization: Establishing an index or model will require converting the distinct units expressed by the values of the criteria's performance to a single dimensionless unit (Iwaro, Mwasha, Williams, & Wilson, 2014).
6. Establishing an index or model: In the final stage, an index or model is established by aggregating the weights and performance values.

The following is a review of MCDM methods previously used by researchers.

I. Overview of Previously Used MCDM Methods

MCDM methods have recently experienced a widespread increase in their utilization, including both single and hybrid approaches. Nevertheless, researchers in the construction and building industry favor some of these methods over others. The following outlines the most frequently used MCDM methods for assessing sustainability within various building project categories, including municipal residential buildings, real estate projects, affordable housing, heritage buildings, building façades, and modular residential buildings.

Klumbytė et al. (2021) used three MCDM methods in their study. They proposed a model for assessing the sustainability of municipal residential buildings in Kaunas City Municipality, Lithuania. A framework was employed, including the environmental, social, and economic sustainability dimensions, and three criteria were categorized: Normative Requirements, State/Municipal Requirements, and Social Housing Residents Requirements, under which 30 indicators were defined. A questionnaire survey was conducted, consisting of the 30 indicators, and their significance was determined using the Analytic Hierarchy Process (AHP). Then, two additional methods, Weighted Aggregated Sum Product Assessment (WASPAS) and Complex Proportion Assessment (COPRAS), were used to develop normalized and weighted decision-making matrices, which were employed to rank investment alternatives related to building management.

Dobrovolskienė et al. (2021) proposed an MCDM Real Estate Sustainability Index (RESI) to evaluate and compare real estate projects, encouraging technological advancements and investments within these projects. Four sustainability dimensions were considered: economic,

environmental, social, and technological, with eighteen sustainability indicators being defined. A questionnaire survey was conducted consisting of the indicators, and the AHP was used to find their significance. An index was developed using Simple Additive Weighting (SAW), also known as the Weighted Sum Model (WSM) method.

Adabre and Chan (2020) utilized an MCDM method to develop an index for assessing the sustainability of affordable housing construction projects in Ghana. A framework was employed, including the environmental, social, and economic sustainability dimensions, with four criteria: Household Satisfaction, Quality-Related, Housing & Transportation, and Efficient Stakeholder Management, under which 16 sustainability indicators were defined. The indicators' weights were then investigated using a questionnaire survey, and the Fuzzy Synthetic Evaluation (FSE) method was employed to obtain the aggregated scores of the indicators and calculate a sustainability assessment index.

Al-Sakkaf (2020) designed a hybrid, multi-criteria sustainability rating model and scale for heritage buildings. The study employed three criteria, with nine sub-criteria: Environmental (Site & Ecology, Material & Waste Reduction, and Transportation), Physical (Energy Efficiency, Water Use, Heritage Value, and Structural Conditions), and Sustainable (Indoor Environmental Quality and Building Management). Under these criteria, 33 indicators were defined. The significance of the indicators was then investigated through a questionnaire survey targeting Canadian and Saudi Arabian experts. The Fuzzy Technique for Order Preference by Similarity to Ideal Solutions (Fuzzy TOPSIS) was employed to calculate the weights and determine the model's indices. Finally, two case studies were employed to

assess the model's sensitivity using MCDM methods, including Fuzzy TOPSIS, SAW, and the Weighted Product Model (WPM).

Gilani (2020) proposed a novel and comprehensive methodology that computes a sustainability index for façade systems in Barcelona, Spain. The study employed the three dimensions of sustainability, with eight criteria defined: economic (Cost), environmental (Consumption, Emissions, and Waste), and social (Safety, Labor Availability, Added Comfort, and Aesthetics), encompassing 13 sustainability indicators. A questionnaire survey was conducted, consisting of indicators, and then the weights and index were determined using the Integrated Value Model for Sustainable Assessment (MIVES), an MCDM method.

Kamali, Hewage, and Milani (2018) developed a comprehensive model to evaluate the sustainability of modular residential buildings. The research employed a questionnaire survey that incorporated 33 indicators to assess the three dimensions of sustainability. An outranking MCDM method, namely the Elimination and Choice Translating Reality (ELECTRE), was used for data analysis and model development. A case study was then employed in British Columbia, Canada, to check the model's sensitivity.

Olawumi and Chan (2020) employed the Building Sustainability Assessment Method (BSAM), a specific SBRS established to evaluate the sustainability of buildings in Sub-Saharan Africa, to categorize eight criteria covering the three sustainability dimensions, under which 32 indicators were identified. A questionnaire survey was conducted, and the Generalized Choquet Fuzzy Integral, an MCDM approach, was then employed to determine the significant weights of the criteria.

The following section will provide a detailed explanation of each method, highlighting both its positive and negative aspects.

II. Analyzing Previously Used MCDM Methods

Although many MCDM methods exist, researchers have not been able to define an optimum method among the methods adopted that can be used for all decision-making scenarios, which indicates that selecting a suitable MCDM method among the different methods available for a specific problem is actually a problem itself (Roy & Słowiński, 2013; Taherdoost & Madanchian, 2023).

The process of identifying and selecting a suitable MCDM method is thus a multifaceted undertaking that requires careful deliberation and evaluation of several factors (Banaitiene, Banaitis, Kaklauskas, & Zavadskas, 2008; Chang & Yeh, 2001; Zanakis, Solomon, Wishart, & Dublisch, 1998). Many authors have developed guidelines for choosing an appropriate MCDM method (Singh & Pant, 2021). Nevertheless, it has been recognized that multiple methods may hold prospective validity in a specific scenario involving decision-making; there is not invariably a compelling rationale for favoring one method over another (Hajkowicz & Higgins, 2008). An essential factor to consider when selecting an MCDM method is whether it aligns with the problem's objective (Gan et al., 2017).

The frequently employed MCDM methods within the construction and building industry are presented in **Appendix 2**. A short description of the methods and the advantages and disadvantages of adopting them is presented in **Table 2.6**. Each method has both advantages and disadvantages, resulting

in a lack of consensus on determining the most suitable method for solving a decision-making problem.

Table 2.6: Frequently Employed MCDM Methods in the Construction and Building Industry: Description, Advantages, and Disadvantages (adapted from Moghtadernejad, Chouinard & Mirza, 2018; Gilani, 2020)

Description	Advantages	Disadvantages	References
1. SAW/WSM			
Earliest and widely used by researchers. It establishes a model/index by adding the scores of each criterion multiplied by its weights.	Simple computation. Can balance between the criteria. Understandable. Easy for decision-makers to use.	The actual situation may differ from estimates. Multi-dimensional problems with distinct criterion units & numerical values several orders of magnitude apart are difficult. Illogical outcomes may occur.	Adabre & Chan (2020); Al-Sakkaf (2020); Dobrovolskienė et al. (2021); Triantaphyllou & Mann (1989)
2. WPM			
Differs from SAW in that alternatives are ranked based on a multiplicative measure instead of an addition. It was suggested to solve SAW's single-dimensionality issue.	Used for single- and multi-dimensional decision-making. Uses relative values instead of real ones. Dimensionless.	Deprioritizing or prioritizing the alternative, deviating significantly from the norm. Normalization only considers minimum (non-beneficial attributes) and maximum (beneficial attributes), excluding other performance values.	Al-Sakkaf (2020); Mulliner, Malys, & Maliene (2016)
3. ELECTRE			
An outranking approach that assesses preference between alternatives using pairwise comparison. Select alternatives with favorable performance in most criteria & no unsatisfactory performance in any of the other criteria.	Deals with both quantitative & qualitative criteria. Final results are validated with reasons. Deals with heterogeneous scales.	Complex & time-consuming. After four revisions, it still requires further development and occasionally struggles to find the best alternative. Eliminating less desirable alternatives is the only way to enhance the understanding of the available alternatives. Outranking obscures the strengths & weaknesses of alternatives.	Aruldoss, Lakshmi, & Venkatesan (2013); Hosseini, Pons, & de la Fuente (2019); Triantaphyllou (2000)

4. AHP			
Splits difficult MCDM problems into hierarchies.	Intuitive & verifiable for inconsistencies. Easy to use. Applicable for single or multi-faceted decision-making. Ranks irregularities. Ideal for determining criterion weights. Numerically easy.	It is subjective; hence, the decision may not be accurate. Possibility of rank reversals. Pertains to linear equations. Depends on probability & possibility. Difficulty in considering judgment uncertainties. Criteria & alternatives are interdependent, which might cause judgment & ranking criteria contradictions.	Hosseini et al. (2019); Pohekar & Ramachandran (2004)
5. TOPSIS			
An alternative method to ELECTRE. Operates depending on the alternative remoteness to the optimal decision.	Implements fundamental rankings & maximizes the utilization of allocated data. Simple to use. The quality of clarity. Mathematical simplicity.	Uses Euclidean Distance, which ignores attribute correlation. Hard to weigh & keep judgment consistent.	Al-Sakkaf (2020); Chen (2020); Stanujkic, Magdalinovic, & Jovanovic (2013); Triantaphyllou (2000)
6. COPRAS			
Alternatives are ranked according to their utility level & the corresponding criteria weights. The selection of the optimum alternative is done by comparing the best & worst solutions.	Simple calculation with less time. The values of maximizing & minimizing criteria are evaluated independently. Alternatives are ranked depending on their significance.	Variable data makes it less stable than other methods. The number & values of minimizing criteria determine COPRAS results.	Ayrim, Atalay, & Can (2018); Klumbyte et al. (2021); Podvezko (2011)
7. Choquet Integra			
A function of aggregation is specified in relation to fuzzy measures. It can show criterion interactions.	Considers criterion interactions. Handles the qualitative & quantitative nature of criteria. Mathematical simplicity. Used for single- and multi-dimensional decision-making.	Time-consuming. A panel of experts' subjective advice makes weighing difficult. As criteria multiply, weighting becomes nearly impossible.	Schuck & Blasch (2010)

8. MIVES			
This method can provide global sustainability indices through specialized & comprehensive sustainability assessment.	Allows assessment subjectivity reduction.	Time-consuming. Difficult to assign weights & complex, depending on inputs from an expert panel. Fails to consider criterion interactions.	Pons & Aguado (2012); Pons, de la Fuente & Aguado (2016)
9. WASPAS			
Combines the findings of two methods: SAW & WPM.	Easy to use. The combination of WPM & SAW improves precision. Provides a more generic equation for assessing the total relative importance of alternatives. Successfully applied in various areas.	Beneficial & non-beneficial criteria are treated equally. Normalization only considers minimum (non-beneficial attributes) & maximum (beneficial attributes), excluding other performance values.	Chakraborty & Zavadskas (2014); Klumbyte et al. (2021); Mulliner et al. (2016); Zavadskas, Antucheviciene, Šaparauskas, & Turskis (2013)
10. FSE			
A fuzzy MCDM modeling technique that quantifies multiple attributes & multiple variants. Suitable for aggregating indicators' scores to develop a sustainability index.	Handles data limitations, the linguistic scale of the indicators, and the subjectivity of responses. Delivers an objective & consistent assessment model/index for projects. Considers criterion interactions.	Complex & time-consuming. Mathematical complexity.	Adabre & Chan, (2020); Haider et al. (2018); Owusu et al. (2019)

Although MCDM methods exhibit many differences, they share common features. These encompass the presence of an alternative set, the consideration of numerous attributes, the existence of conflicting criteria, the utilization of incommensurable units, the incorporation of weighting functions, and the formation of matrices (Gilani, 2020).

2.4. Sustainable Educational Buildings

A key component of human capital is education. Education plays a crucial role in achieving the SDGs. Educational institutions bear a distinct social obligation to foster societal progress, specifically by imparting knowledge to prospective leaders and increasing the public's sustainability consciousness (Amaral, Martins, & Gouveia, 2015). Therefore, educational establishments must serve as role models, advocating for the adoption of development patterns that align with the principles of intergenerational equity and environmental protection. Additionally, increasing education expenditures helps political authorities enhance their economic growth performance (Erdoğan et al., 2020).

Developing sustainable educational buildings is a goal of education environment policies, as buildings play a crucial role in delivering quality education (Alhilli & Burhan, 2021). With the growing demand for education and the subsequent requirement to accommodate the growing student population, the sustainability of educational buildings has become a significant challenge in the current era (Al Shboul, 2018). Hence, to meet the future needs of the pedagogical process, it is imperative to scrutinize educational buildings and assess their sustainable growth and capacity.

The sustainability of educational buildings encompasses several concerns, including the efficient utilization of the facility and its educational amenities, which comprise classroom spaces, staff offices, halls, learning resources, labs, and cafeterias. In addition, the ongoing maintenance of the various educational building facilities, coupled with the subsequent measures taken to repair them, and sustain their quality, is essential to ensure their durability and provide all the necessary physical conditions, such as lighting,

heating, and cooling ventilation, thereby creating an environment that satisfies the users (Al Shboul, 2018).

According to Filho, Shiel and do Paço (2015), various educational institutions are realizing the impact of their activities on the environment and seeking to understand the effects of their operations. Sewilam, McCormack, Mader, and Abdel Raouf (2015), Rospi, Cardinale, Intini, and Negro (2017), and Antunes and Ghisi (2020) have emphasized that sustainability is important and that educational buildings need to enhance the sustainability of their settings.

2.4.1. The Education Sector in the GCC

In the Gulf region, a significant expansion of different types of buildings, including educational buildings, has been observed (Elnabawi, 2021). The GCC education industry has witnessed substantial growth in student enrolments and an expansion of related infrastructure. The demand for educational buildings in the GCC has increased due to the rising enrolment of students in public and private schools and higher education (Bystrov & Panigrahi, 2021). This has prompted all GCC countries to increase their financial investment in the education sector (Erdoğan et al., 2020).

The majority of enrolments have been in public schools for many years. However, with the growing number of expats (representing 51% of the total population), private schools are becoming increasingly popular as they cater to the curricula needs of expats (Almasri & Alshitawi, 2022). Additionally, there is an increase in locals choosing private education systems because it allows their children to have international exposure. Due to this expanding

demand, investment in the private education market has increased (Elnabawi, 2021).

The GCC countries have also seen exponential growth in their higher education sector, which comprises purely local institutions (funded by the government or investors), joint ventures, and satellite campuses of international universities, such as those from the United Kingdom, Australia, Canada, and the United States (Peddada & Alhuthaifi, 2021).

The GCC countries' dedication to enhancing infrastructure and improving the quality of education as part of their long-term national objectives further boosts the sector's investment potential. This will promote infrastructure development projects by both the public and private sectors (Gulf Finance House, 2020).

Therefore, for these development projects to be successful, integrating sustainability measures in the new educational buildings of the GCC countries is essential.

2.4.2. Sustainable Building Challenges in the GCC

The GCC nations face distinct environmental and energy challenges in the building sector. These can be summarized as follows:

- The extremely high summer temperatures and poorly designed buildings significantly increase air-conditioning energy utilization (Wahl, 2017).
- The construction and operation of buildings heavily rely on fossil fuels for energy (Elrahmani, Hannun, Eljack, & Kazi, 2021).

- The severe water scarcity and high consumption lead these countries to rely heavily on water desalination (Kumar, 2013).
- The rapid expansion in the building sector due to the population increase, economic growth, and modernization has negative effects on the energy and environmental situation (Elnabawi, 2021).

These factors led to the GCC countries consuming a yearly total of 6260 MWh of energy per capita, the highest globally (Elrahmani et al., 2021), contributing more than 3% of global CO₂ emissions (Mahmood, Asadov, Tanveer, Furqan, & Yu, 2022).

2.4.3. Sustainable NEBDs in Bahrain

To face the sustainable building challenges in the GCC, Bahrain incorporated sustainability into its Economic Vision 2030 as an essential principle to produce a prosperous and safe future for Bahraini citizens and residents (Information & eGovernment Authority, 2022).

Bahrain is carrying out many steps in order to fulfil the SDGs devised by the United Nations through developing the necessary legislative guarantees to enhance the efficiency of natural resource utilization, protect the environment, and encourage progress with minimal societal and environmental adverse effects (Supreme Council for Environment, 2023).

Bahrain has established the Ministry of Sustainable Development and the SCE to develop a comprehensive environmental and sustainable strategy that protects its natural and human environments and ensures the sustainability of its various components, preserving and enhancing its resources for the coming generation (Bahrain News Agency, 2023b; Supreme

Council for Environment, 2023). Additionally, it established the SEA, the first authority dedicated to sustainable energy, through a royal decree in 2019 (Sustainable Energy Authority, 2021). The SEA is responsible for advancing renewable technologies and formulating energy efficiency policies, which support Bahrain in its pursuit of sustainable environmental protection and long-term climate action objectives.

Bahrain has established the Green Building Code and Labeling Program under the guidance of the SCE (Supreme Council for Environment, 2023). The Green Building Code is a comprehensive document that supplements existing building energy efficiency codes, aiming to establish unambiguous principles that mandate energy efficiency by targeting new buildings and retrofit projects. The Green Building Labelling Program serves as a mechanism to acknowledge buildings that achieve energy efficiencies, meeting or exceeding the Green Building Code requirements.

Similar to other GCC countries, the educational building sector in Bahrain requires significant attention for several reasons. Education is considered crucial to achieving Bahrain's economic advancement strategy (Ministry of Foreign Affairs, 2023). Sustaining the growth of education in Bahrain requires additional investments and resources, given the projected annual increase of 1.7% (approximately 30,000) in the number of citizens under the age of 20. Moreover, the presence of a significant number of expatriates and the willingness of parents to allocate higher expenditures towards their children's schooling contribute to the popularity of international education in Bahrain. Consequently, this creates a favorable environment for investment in the country's education sector (Economic Development Board, 2022).

The Supreme Council for the Development of Education and Training, in collaboration with the MOE, has formulated a plan to address the growing need for new educational buildings in various governorates, driven by expanding urbanization and population growth. The MOE has also evacuated some outdated educational buildings and is designing alternative new buildings to accommodate the students (ZAWYA, 2019).

Therefore, with the need for new educational buildings, sustainability measures should be analyzed and integrated during the design phase, as a substantial proportion of the impacts caused by buildings throughout their life cycle are influenced by choices made at this stage. This will result in sustainable NEBDs that offer numerous advantages, including significant cost savings, environmental protection, improved academic performance, a more comfortable and healthier workplace for users, an expansion of students' understanding of sustainable development and pertinent scientific concepts, and the promotion of low-carbon lifestyles.

2.5. Summary and Gap in the Knowledge

Several countries have developed country-specific and occupancy-specific SBATs that enable sustainability assessments. This approach acknowledges the challenge of implementing a standardized worldwide sustainability assessment system for buildings, given the inherent variations in geographical and cultural factors among countries.

MCDM methods are widely used in developing SBATs. Researchers in the construction and building industry have frequently used several MCDM analytical approaches, including SAW, WPM, ELECTRE, AHP, TOPSIS,

COPRAS, Choquet Integra, MIVES, WASPAS, and FSE. Although numerous MCDM methods exist, researchers have not defined an optimal method among the adopted methods that can be applied to all decision-making scenarios (Roy & Słowiński, 2013; Taherdoost & Madanchian, 2023). An essential factor to consider when selecting an MCDM method is whether it aligns with the problem's objective (Gan et al., 2017).

In Bahrain, to achieve the Economic Vision 2030, and with the expansion and necessity of constructing new educational buildings, sustainability measures should be analyzed and integrated during the design stage of these buildings to ensure the best final results, using an SBAT (specific to educational buildings in Bahrain).

Thus, the rationale for conducting this research is rooted in the importance of incorporating the concept of sustainability into NEBDs. There is currently no SBAT specifically developed for assessing the three dimensions of sustainability in buildings within the Kingdom of Bahrain. Hence, as a consequence of the ongoing processes of urbanization, population growth, and the imperative to replace outdated educational buildings, it is necessary to integrate sustainability measures into NEBDs in Bahrain and assess their effectiveness through the utilization of an SBAT. Consequently, this research will fill the gap by providing comprehensive conceptual and analytical SBATs that consider the three sustainability dimensions to assess NEBDs in the Kingdom of Bahrain, which can also be generalized to other countries with similar regional characteristics, such as the GCC.

Chapter Three

Research Methodology

3.1. Introduction

The literature review (**Sections 2.3.2 and 2.3.3**) revealed that NEBDs in Bahrain can be assessed conceptually using sustainability frameworks (i.e., conceptual SBATs) and analytically using MCDM methods (i.e., analytical SBATs).

To develop the conceptual SBAT, the literature in Chapter Two (**Section 2.3.1**) investigated the common criteria and indicators specified for the design and construction of new buildings within leading SBRs and previous research. Accordingly, in this chapter, criteria and indicators relevant to NEBDs are categorized and selected, and a four-level conceptual SBAT for assessing the sustainability of NEBDs is proposed.

For the analytical SBAT, FSE, an MCDM method, is used to develop an index/model. This required employing an online survey using the Microsoft Forms platform. The survey used a five-point Likert scale to investigate built environment specialists' opinions regarding the local importance of the identified criteria and indicators in Bahrain. To check the statistical reliability of the collected data, the Cronbach's Alpha Test is employed, and the responses are analyzed using the Mean Score Ranking (MS) and the FSE methods.

This chapter explains and justifies in detail the methodology and methods used in this research to develop a conceptual and analytical SBAT for NEBDs in Bahrain. **Table 3.1** summarizes the methodology and methods used in relation to the four objectives of this research.

Table 3.1: Methodology and Methods to Achieve Research Objectives

Research Aim	Research Objectives	Methodology & Methods	Results
Develop a conceptual and analytical SBAT for NEBDs in Bahrain using MCDM methods	1. Specify the sustainability assessment criteria and indicators for NEBDs in Bahrain.	Literature Review	Comprehensive conceptual SBAT framework for NEBDs in Bahrain
	2. Investigate the opinions of specialists in the built environment in Bahrain to find the local importance of the identified criteria and indicators.	Online Survey (Microsoft Forms)	Sustainability significance of indicators selected
	3. Use MCDM to develop an analytical SBAT tailored to assess the sustainability of NEBDs in Bahrain.	FSE Method	Comprehensive analytical SBAT (index/model) for NEBDs in Bahrain
	4. Explore the tool's generalizability, transferability, and future development.	Results Analysis	Limitations and Recommendations

3.2. Specifying Criteria and Indicators for NEBDs

Specifying the criteria and indicators required for NEBDs' sustainability assessment was the first objective of this research, which was achieved through three steps, as follows:

Step 1: Investigate the criteria and indicators used by BREEAM, LEED, CASBEE, SBTool, Estidama (PRS), and GSAS. The rationale for selecting these rating systems was based on considering them as globally and locally well-recognized leading systems (Alhilli & Burhan, 2021; Awadh, 2017; Mattoni et al., 2018; Ramani & García De Soto, 2021; Saraiva et al., 2019). As this research was concerned with sustainability assessment in NEBDs, from the SBRs, the manuals that were used were those relating to the design and construction of new buildings.

In addition, criteria and indicators from the literature review were also investigated. The search involved international peer-reviewed publications within the Web of Science and Scopus databases, focusing on papers that included criteria and indicators used to assess the three dimensions of sustainability (environmental, economic, and social) in educational buildings and buildings in general, to suit the purpose of this research. Only two recent papers on educational buildings and two on buildings in general were found suitable and focused on criteria and indicators to assess building sustainability during design, construction, and operation.

The collected criteria and indicators from the SBRs and the literature review guaranteed a comprehensive collection (economic, environmental, and social) of criteria and indicators (**Appendix 1**).

Step 2: Identify the commonly reviewed sustainability criteria and indicators. From **Appendix 1**, all the criteria that were mainly used and repeated by the SBRs and the literature review were verified. These included: “Site,” “Health & Well-being,” “Materials,” “Energy,” “Pollution,” “Transportation,” “Quality of Service,” “Water Efficiency,” and “Waste.” Then, all the indicators under the verified criteria in all the SBRs and the literature review were listed, and the common, repeated indicators were selected. The common sustainable building criteria and indicators used by SBRs and the literature review are shown in **Table 2.5**.

Step 3: Select all the criteria and indicators that were relevant and critical for the sustainability assessment procedure of NEBDs from **Table 2.5**. This was done by considering the selection of criteria and indicators related to the design stage and educational buildings. In addition, to avoid overlapping of the indicators, the least and most important indicators were selected. This is

necessary to develop a clear and accurate conceptual and analytical SBAT (Chan & Adabre, 2019).

For the criteria categorization, all the common criteria in **Table 2.5** were considered, except the “Waste” and “Pollution” criteria, which were eliminated because they included indicators related more to the construction and operation phases. In addition, ensuring building sustainability in the design phase will consequently reduce waste and pollution. The remaining criteria in **Table 2.5**, which were related to each other, were then combined, for the purpose of minimizing their number, resulting in the categorization of three criteria in this research. The two criteria, “Site” and “Transportation” were categorized as “Site & Transportation;” the two criteria “Health & Well-being” and “Quality of Services” were categorized as “Health & Well-being;” and the three criteria “Material,” “Energy,” and “Water,” were categorized as “Resources & Materials.”

In the case of indicator selection, indicators under all the criteria in **Table 2.5** (except indicators under “Pollution” and “Waste” as they were eliminated) were listed under the three categorized criteria (combining the indicators of the combined criteria), and the indicators that were considered critical for the assessment of NEBDs were then selected. In addition, to avoid overlapping of the indicators, it was necessary to minimize their number; therefore, similar indicators with the same influence were also combined; for instance, the four indicators “mechanical ventilation,” “indoor air quality,” “natural ventilation,” and “thermal comfort” were combined into one indicator labeled “indoor air & thermal quality.” This was also performed on some other indicators that were found to be similar. **Table 3.2**, **Table 3.3**, and **Table 3.4** below describe the selected indicators.

The three steps above resulted in the categorization of three criteria: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials,” and the selection of seven indicators under each criterion (21 indicators in total) that are independent of each other and that are considered to be the most representative for assessing the sustainability of NEBDs.

3.2.1. Description of Criteria and Indicators for NEBDs

The categorized criteria and selected indicators to assess NEBDs’ sustainability in this research are briefly explained below (C: Criteria and I: Indicator):

C1: Site & Transportation

This criterion concerns the site’s selection and design, directly impacting both the site itself and any neighboring site. The selection of a site location is an important issue to ensure a building’s sustainability. Selecting sites that are easily accessible and that are within existing infrastructure contexts will enhance the use of more sustainable transportation methods, such as walking, cycling, and the use of public transportation. In addition, the availability of close amenities to the site will reduce car trips, which will, as a result, reduce congestion and CO₂ emissions throughout a building’s life cycle (Building Research Establishment Environmental Assessment Methodology, 2016).

Moreover, integrating sustainability criteria and indicators in the site landscaping and design will greatly enhance the site’s quality and reduce its effects on the adjacent areas, which will have a great influence on promoting the sustainability of a building. This will reduce fossil fuel usage, water consumption, climate change, water and air pollution, and use and

contamination of land, and ensure human health and comfort (Gulf Organization for Research & Development, 2019).

Seven indicators were selected for this criterion: “community/urban connectivity,” “accessibility,” “surrounding environment consideration,” “land use efficiency,” “site ecology enhancement,” “pedestrian & cyclist safety,” and “eco-parking.” **Table 3.2** describes each indicator.

C2: Health & Well-being

The internal spaces and their quality greatly affect the occupants’ productivity and well-being in any building type. Therefore, in assessing the sustainability of educational buildings, accounting for health and comfort indicators is necessary to ensure better concentration and learning outcomes for students and a comfortable working environment for staff, who spend considerable amounts of time in these buildings (Saraiva, de Almeida, Bragança, & Barbosa, 2018).

Seven indicators were selected for this criterion: “visual comfort,” “indoor air & thermal quality,” “acoustic comfort,” “design flexibility & scalability,” “design functionality & usability,” “security & safety,” and “use of entries & mobility.” **Table 3.3** describes each indicator.

C3: Resources & Materials

The management of energy, water, and material use is very important to ensure a building’s life cycle sustainability. The design and specification need to consider energy-efficient and water-efficient use through implementing innovative solutions, systems, and equipment. It is also necessary to consider methods that will enhance the efficiency of material use and reduce their impacts on the environment (US Green Building Council, 2019).

Seven indicators were selected for this criterion: “efficient energy consumption,” “renewable energy production,” “efficient water consumption,” “water treatment & recycling,” “material efficiency & durability,” “material available regionally,” and “recycled & re-used material.” **Table 3.4** describes each indicator.

Table 3.2: Site & Transportation Indicators’ Descriptions

Code	Indicators	Description	References
I1	Community/ Urban connectivity	Select sites within existing infrastructure to reduce distance traveled by vehicles and promote transport efficiency and physical activities through walking and cycling, which will improve public health.	Alhilli & Burhan (2021)
I2	Accessibility	Select sites close to public transport networks to allow for different transportation options (buses, private vehicles, bicycles, or walking), which will reduce traffic congestion, air pollution, and commuting costs.	Building Research Establishment Environmental Assessment Methodology (2016)
I3	Surrounding environment consideration	Consider any constraints around the site, such as odor, sand, traffic, noise, vibration, wind, and daylight barriers.	Reddy et al. (2018)
I4	Land use efficiency	Preserve the environment through efficient and reduced construction land size and proper landscaping.	Saraiva et al. (2019)
I5	Site ecology enhancement	Improve the site’s ecological value through heat island reduction, vegetation, shading, flood management, and open spaces. In addition, consider the existing natural features, such as soil, plants, trees, topography, ground cover, wildlife habitats, and water features.	Building Research Establishment Environmental Assessment Methodology (2016); Gulf Organization for Research & Development (2019)
I6	Pedestrian & cyclist safety	Provide safe, separate cyclist and pedestrian pathways, buffer zones between pathways and roads, crosswalks with appropriate signage, speed bumps, bicycle parking, and adequate lighting.	Moussa, Mostafa, & Abou Elwafa (2017); International Initiative for a Sustainable Built Environment (2020)
I7	Eco-parking	Provide maximum sustainable parking areas that are distant from classrooms and gardens, and that include permeable pavement, vegetation, solar panels, electric vehicle charging stations, and bicycle parking.	Gulf Organization for Research & Development (2019); Tönük & Kayihan (2013)

Table 3.3: Health & Well-Being Indicators' Descriptions

Code	Indicators	Description	References
I18	Visual comfort	Ensure sufficient visual comfort and optimum visual performance through efficient design and specification for daylight, artificial light, and occupant controls.	Building Research Establishment Environmental Assessment Methodology (2016)
I19	Indoor air & thermal quality	Ensure healthy internal spaces and adequate thermal comfort through efficient design and specification of equipment, techniques, and finishes for mechanical and natural ventilation.	Abu Dhabi Urban Planning Council, (2010); Saraiva et al. (2019)
I10	Acoustic comfort	Ensure sufficient acoustic comfort by implementing solutions that reduce sound disturbance between classrooms or different spaces and provide echo-free sounds within large spaces (e.g., theaters and sports halls), such as sound-insulating doors and windows, acoustic panels and ceilings, proper room design and layout, specific furniture and fixtures, and advanced acoustic systems.	Milo (2020); Okechukwu, Okafor, & Okeke (2020); Saraiva et al. (2019)
I11	Design flexibility & scalability	Provide flexible design layouts that can adapt to future changes in the number and size of classrooms, changes in the layout, or changes in the use of some spaces.	Institute for Building Environment and Energy Conservation (2014)
I12	Design functionality & usability	Provide designs that ensure comfortable and adequate physical performance of the spaces in terms of areas and heights to suit the occupants' different functions and activities, including access, parking, spatial capacity, utilities, communications, circulation, and equipment.	Institute for Building Environment and Energy Conservation (2014)
I13	Security & safety	Use safe equipment and provide fire protection to preserve occupants' highest safety and security measures by considering hallways, stairways, classrooms, fencing, lighting at night, fire exits, gathering areas, fire protection, use of safe equipment, access control systems, and surveillance cameras.	Saraiva et al. (2019)
I14	Use of entries & mobility	Consider effective measures and standards to ensure the safety and security of disabled users, such as ramps, automatic doors, toilets, corridors, elevators, and furniture.	Alhilli & Burhan (2021)

Table 3.4: Resources & Materials Indicators' Descriptions

Code	Indicators	Description	References
I15	Efficient energy consumption	Conserve energy using passive solutions (orientation, form, shading, thermal insulation, natural ventilation, daylighting, and green roof) and efficient equipment.	Reddy et al. (2018)
I16	Renewable energy production	Reduce adverse effects on the economy and ecosystem caused by non-renewable energy using renewable energy (solar energy, wind energy, geothermal energy, and energy storage).	US Green Building Council (2019)
I17	Efficient water consumption	Conserve water using efficient systems and materials, such as low-flow plumbing fixtures, water-efficient urinals, efficient irrigation, and proper landscape design.	Akhanova et al. (2019); Sheth (2017)
I18	Water treatment & recycling	Promote water conservation through the use of recycling strategies and the re-use of rainwater, groundwater, or greywater.	Saraiva et al. (2019); Sheth (2017)
I19	Material efficiency & durability	Enhance material efficiency and resilience to reduce use and waste without affecting the stability, durability, or service life of the building structure.	Building Research Establishment Environmental Assessment Methodology (2016)
I20	Material available regionally	Promote the use of materials that foster regional economy and have fewer adverse transport effects.	Abu Dhabi Urban Planning Council (2010)
I21	Recycled & re-used material	Reduce the production of waste and conserve natural resources by using materials that have been previously used, recycled, or salvaged.	Gulf Organization for Research & Development (2019)

3.2.2. A Conceptual SBAT Framework for NEBDs

Accordingly, the categorized criteria and selected indicators were then used to propose a four-level SBAT framework for assessing the sustainability of NEBDs conceptually (as shown in **Figure 3.1**). The main scheme, “Sustainable NEBDs,” was the highest level of the framework, followed by the second level representing the goals, which are the “Economic,” “Environmental,” and “Social” sustainability dimensions. Then, the three categorized criteria, “Site & Transportation,” “Health & Well-being,” and

“Resources & Materials,” were specified in the third level. Finally, the fourth level contained the 21 selected indicators, seven under each criterion category.

The illustration of the conceptual SBAT framework (**Figure 3.1**) indicates that the three categorized criteria and their relevant indicators cover the three sustainability dimensions: economic, environmental, and social, as explained below:

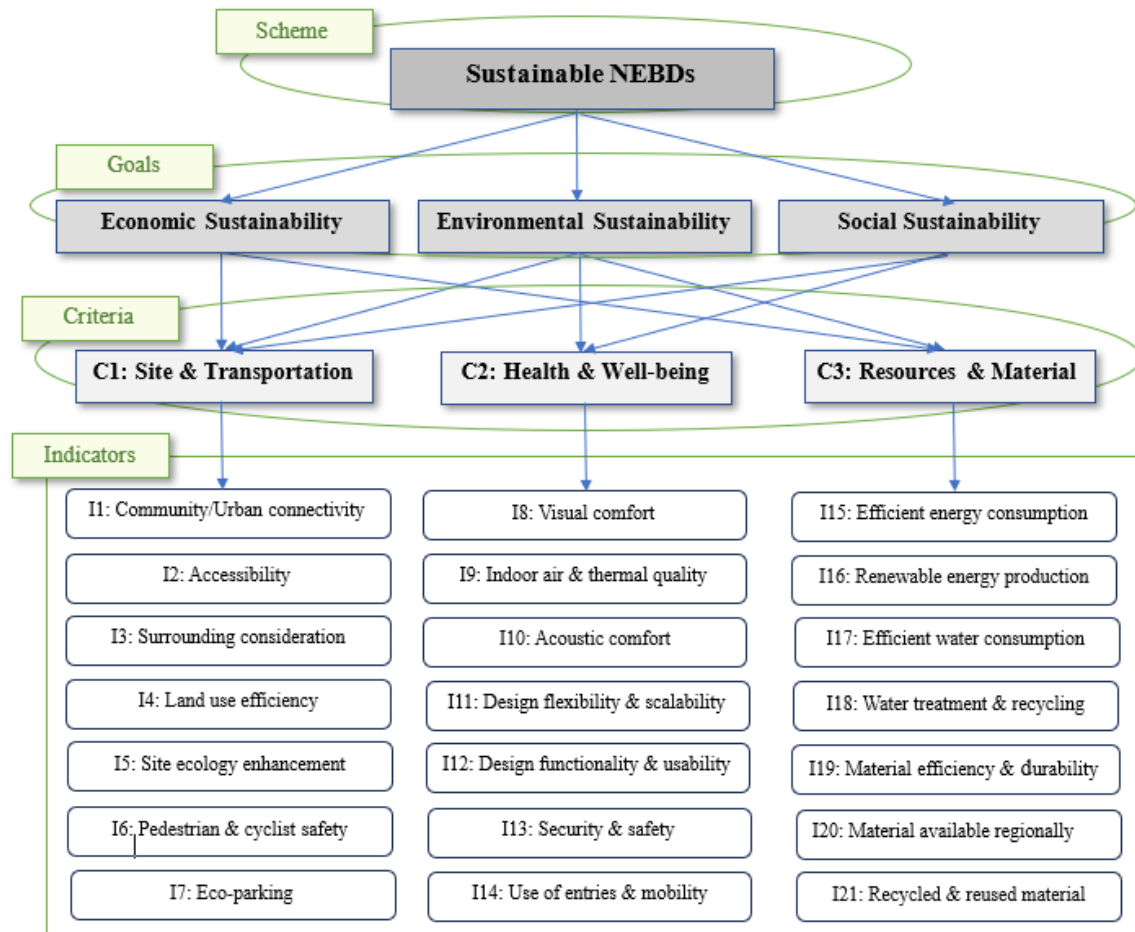


Figure 3.1: Conceptual SBAT Framework for NEBDs

The economic dimension is achieved through two criteria, “Site & Transportation” and “Resources & Materials”. In “Site & Transportation”, this is recognized through reduced commuting costs and fossil fuel depletion when selecting accessible sites with existing infrastructure, which will encourage pedestrian and cyclist movement. In “Resources & Materials”, this is recognized through the reduced costs of operating and maintaining the project, which is due to efficient energy and water conservation strategies and optimal material selection.

The environmental dimension is achieved through all three criteria, “Site & Transportation”, “Health & Well-being”, and “Resources & Materials”. In “Site & Transportation”, this is recognized through the reduction of greenhouse gas emissions as a result of less vehicle movement due to accessibility and the improvement of site ecology. In “Health & Well-being”, this is recognized through providing efficient active and passive solutions for ventilation and illumination, which will improve the internal environment of the building. In “Resources & Materials”, this is recognized through greenhouse gas and non-renewable energy reduction by using energy and water conservation strategies and the efficient selection and use of materials.

The social dimension is achieved through two criteria: “Site & Transportation” and “Health & Well-being.” In “Site & Transportation,” this is recognized through improved social cohesion by encouraging pedestrian and cyclist movement and by providing gathering areas, vegetation, seating, and shading when designing the site. In “Health & Well-being,” this is recognized through providing comfortable, safe, and secure internal spaces.

The conceptual SBAT framework for NEBDs proposed in this research can be applied when conducting conceptual assessments for any NEBD globally (**Table 3.1**- research objective 4) because the criteria and indicators implemented in it were categorized and selected for the design phase of educational buildings based on well-known global and local SBRs and previous research.

3.3. Data Collection

The second objective of this research was to investigate the opinions of specialists in the built environment regarding the local significance of the identified criteria and indicators to be able to estimate their weights and develop an analytical SBAT for NEBDs, specific for Bahrain (**Table 3.1**). This was achieved through an online survey circulated among professionals involved in the built environment (i.e. architects, civil engineers, mechanical engineers, electrical engineers, project/construction managers, and other engineers practicing in the built environment, or working as academics in higher education institutions offering engineering programs related to the built environment) in Bahrain.

3.3.1. Online Survey

Online surveys provide valid, reliable data and save time and money (Hoxley, 2008). They allow participants to respond freely and carefully due to the absence of researchers' interference (Osei-Kyei & Chan, 2017). They assure participants' privacy and protect their identification data (Owusu et al.,

2019). In addition, they allow many questions to be addressed and encourage participation (Osei-Kyei & Chan, 2017).

Data collection was achieved using Microsoft Forms' online survey platform. The research aim was clarified at the start of the survey form to ensure competent participation, and instructions were given to facilitate the response process.

The online survey consisted of three sections (**Appendix 3**). The first section included questions to help understand the participants' profiles. Participants were required to indicate their institution type, institution name, profession, and years of experience. This was necessary to ensure the participants' suitability for the research's purpose (i.e., they should be practicing in the built environment in Bahrain).

The second section was necessary to investigate the opinions of specialists in the built environment and find the local importance of the identified criteria and indicators that are needed for the FSE method to develop the analytical SBAT for NEBDs in Bahrain. Participants were required to rate the significance of the 21 selected indicators using a five-point Likert scale (1 = not important, 2 = less important, 3 = neutral, 4 = important, and 5 = very important).

Finally, the third section was provided for the participants to indicate any critical indicators not captured in the survey. This helped in checking the completeness of the indicators and provided insights for future research recommendations. The analysis of the online survey questions is shown in **Figure 3.2**.

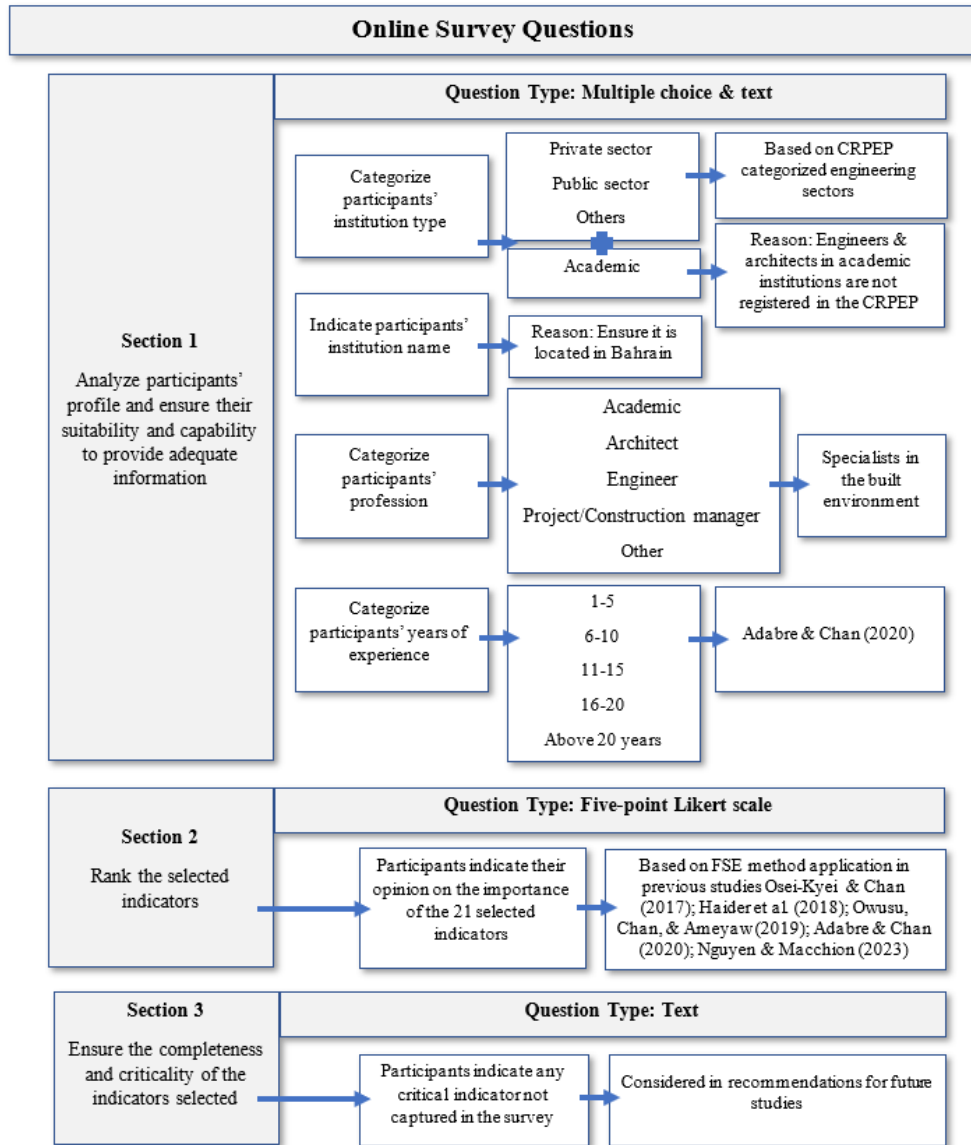


Figure 3.2: Analysis of the Online Survey Questions

Bennett (2001) suggests that researchers must manage the issue of missing data in surveys from the beginning, since it can profoundly impact the research outcomes. Consequently, this study implemented control measures from the outset via Microsoft Forms settings, mandating responses to all questions for form submission, with the exception of the final question (question 8), which was designated as optional for participants, as it does not influence the data analysis of the current study.

Online surveys have some disadvantages. Most importantly, the absence of an interviewer in open-ended questions precludes immediate follow-up questions by the researcher, and participants are unable to request clarification of unclear or new terms (Ball, 2019). In addition, online surveys may include the collection of non-representative or biased responses when participants are unfamiliar with or uninterested in the topic, or when they favor certain results (Andrews, Nonnecke, & Preece, 2003; Bernard, 2017). Likewise, this may occur if the sample validation is disregarded (Duda & Nobile, 2010). Moreover, question validation is usually overlooked in online surveys; therefore, it is important to ensure that the questions capture the anticipated data required for the research (Ball, 2019).

To overcome those challenges, this research did not use open-ended questions, as the purpose of the survey was to investigate the opinions of specialists in the built environment regarding the local significance of the identified criteria and indicators, which required employing a five-point Likert scale, except for question 8, which was optional for the participants to indicate any critical indicators not captured in the survey. Also, the indicator descriptions were added to the online survey to ensure the participants clearly understood them (**Appendix 8**). To ensure the reliability of the data collected, Cronbach's Alpha Test was used to measure the internal consistency within the responses. To ensure sample validation, the targeted participants were clearly mentioned in the introduction of the online survey (**Appendix 3**), invitations to participate were limited to only professionals and academics involved in the built environment in Bahrain, and any participant that was found to be not involved in the built environment or practicing out of Bahrain was excluded (identified by questions 2 and 3 in the survey). In addition, to

ensure the validity of the online survey questions, a pilot study was conducted to identify any needed modifications to the survey questions and test their feasibility and applicability to capture the data required. These are elaborated on in **Sections 3.3.2, 3.4.1, and 3.6** below.

3.3.2. Survey Participants

The sample frame of participants in the survey for this research included professionals and academics involved in the built environment in Bahrain. The sample size of the participants was identified through two governmental authorities:

The Council for Regulating the Practice of Engineering Professions (CRPEP), which was established as the Committee of Organizing Engineering Professional Practice (COEPP) in 1982, then retitled as CRPEP in 2014, is responsible for issuing licenses for all engineering offices and engineers in Bahrain, to ensure the participation of only qualified and competent engineers in the profession (Council for Regulating the Practice of Engineering Professions, 2023). They were contacted to identify the total population of engineers practicing in both the private and public sectors in Bahrain (**Appendix 4**). This was found to be 5868, excluding engineers not involved in the built environment discipline, i.e., chemical engineers, computer engineers, electronics engineers, petroleum & national gas engineers, and process & instrumentation engineers. Academics were also excluded, as they are not registered under the CRPEP.

The Higher Education Council (HEC), was established in 2006 for the purpose of regulating, promoting, and monitoring the higher education sector in Bahrain (Higher Education Council, 2024). They were contacted to identify

the total population of built environment academics in public and private Higher Education Institutions (HEIs). Academics in eight HEIs that provide engineering programs related to the built environment were considered for the research, namely, the University of Bahrain, Bahrain Polytechnic, American University of Bahrain, Kingdom University, Royal University for Women, Applied Science University, British University of Bahrain, and Gulf University (**Appendix 5**). The population was found to be 231.

Accordingly, the total population of engineers (5868) and academics (231) involved in the built environment in Bahrain was found to be 6099. Thus, the sample size estimated for this research was 362 participants, considering a 95% confidence level and a 5% margin of error.

To ensure an unbiased population representative of the sample, a higher quality of findings, and generalized results, probability sampling, namely simple random sampling, was used (Acharya, Prakash, Saxena, & Nigam, 2013). Any engineer or academic involved in the built environment in Bahrain was given a random equal chance to participate in the survey. Participants were also asked to help distribute the questionnaire by circulating it among their acquaintances. Thus, by snowball sampling, additional prospective participants were identified and approached.

To disseminate the survey among academic participants, it was necessary to first request an approval letter from the HEC (**Appendix 6**). This letter was then used to approach the eight HEIs mentioned above. These were visited to introduce the research topic and circulate the survey through the secretary or head of the related department. In addition, email addresses found on the HEIs' websites were also used to send the survey directly to academics. For the private sector engineering offices, the annual report of the CRPEP was

used as all contacts and emails for licensed engineering offices were listed (Council for Regulating the Practice of Engineering Professions, 2022). In addition, managers' and key contact persons' email addresses were obtained directly from the CRPEP. These were contacted either by email, telephone calls, WhatsApp, or a visit to explain the research topic and circulate the survey.

In addition, departments in the public sector, namely, the MOW, the MOH, and the Ministry of Municipalities Affairs and Agriculture, were contacted by emails and social contacts to circulate the survey through the human resource or public relations departments. Finally, the Bahrain Society of Engineers (BSE) was also contacted, and the survey was circulated among their members and networks (**Appendix 7**).

After nearly five months (15 January 2024 to 24 June 2024), 376 responses had been received. The first section (questions 1-4) of the survey helped in analyzing the participants' profiles and checking their suitability for the survey. Twelve responses were excluded due to their unsuitability regarding the scope of the study, of which eight participants were found to be practicing in institutions out of Bahrain (identified by Q2 in the survey: please write your institution's name); these were one from Jordan, three from India, one from the Philippines, two from Egypt, and one from Syria. In addition, four participants' professions were found not to be related to the scope of the study (identified by Q3 in the survey: please indicate your profession); these were two IT specialists, one accountant, and one computer specialist. Therefore, 364 valid responses, corresponding to a 95% confidence level and a 5% margin of error, were used in this study. **Table 3.5** and **Figure 3.3** show

the participants' profiles according to their institution type, profession, and years of experience.

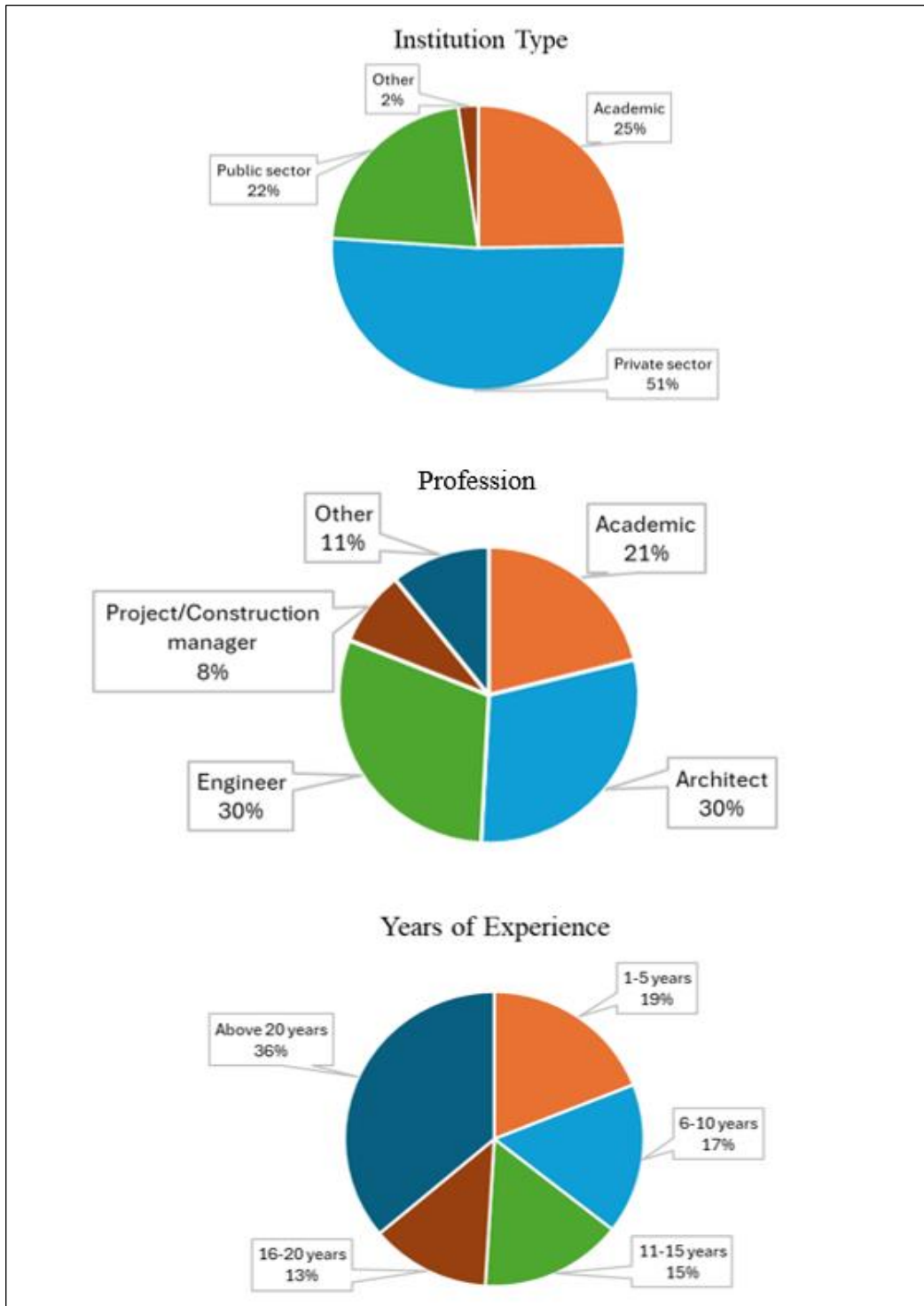


Figure 3.3: Participants' Profiles

Table 3.5: Participants' Profiles

Category	Characteristics	No. of responses	Percentage
Institution type	Academic	90	25
	Private sector	187	51
	Public sector	79	22
	Other	8	2
Profession	Academic	77	21
	Architect	108	30
	Engineer	110	30
	Project/Construction manager	30	8
	Other	39	11
Years of experience	1-5 years	69	19
	6-10 years	61	17
	11-15 years	56	15
	16-20 years	47	13
	Above 20 years	131	36

In terms of the participants' institution type, 90 participants (25%) were from academic institutions, 187 participants (51%) were from the private sector, 79 participants (22%) were from the public sector, and eight participants (2%) indicated "other" in their response. The participants who selected "other" were checked, and their responses either showed public/private partnership institutions or indicated that they had retired or were working as part-timers in the academic, public, or private sectors, which was accepted. The majority of responses were from the private sector (51%), which was expected as it has the highest population of engineers compared to the other sectors in Bahrain. Responses from the academic (25%) and public (22%) sectors were nearly equal, which indicated a balanced data collection

in terms of the different institution types that involve built environment engineers in Bahrain.

With regard to the participants' profession, 77 participants (21%) were academics, 108 participants (30%) were architects, 110 participants (30%) were engineers, 30 participants (8%) were project/construction managers, and 39 participants (11%) indicated "other" in their response. The participants who selected "other" were checked, and their responses either showed interior designer, urban planner, civil engineer, architectural engineer, quantity surveyor, dean of the college, office owner, engineer and project manager, electrical engineer, director of the architectural section, or landscape architect, which were all accepted as being within the scope of the study. The fewest responses were from project/construction managers (8%); this was also expected, as few practice as project/construction managers compared to architects and engineers in Bahrain. Responses from academics (21%), architects (30%), and engineers (30%) were nearly equal, which again indicated a balanced data collection in terms of the different professions that participated in the survey.

With regard to the participants' years of experience, 69 participants (19%) had 1-5 years of experience, 61 participants (17%) had 6-10 years of experience, 56 participants (15%) had 11-15 years of experience, 47 participants (13%) had 16-20 years of experience, and 131 participants (36%) had above 20 years of experience. The majority of participants had above 20 years of experience (36%), which indicated that the data collected was dependable. The other years of experience groups (1-5, 6-10, 11-15, 16-20) were nearly equal (19%, 17%, 15, and 13%, respectively), which indicated a balanced data collection with regard to the participants' years of experience.

Thus, based on the participants' profiles, it can be concluded that the data collected from the survey were acceptable.

3.4. Data Reliability and Analysis Tools

Microsoft Office Excel, Minitab Statistical Software version 21, and MATLAB R2022b were used to check the statistical reliability of the collected data and conduct statistical analysis to facilitate the development of the analytical SBAT for NEBDs in Bahrain using the FSE method, which was the third objective of this research (**Table 3.1**). This included three different tools:

3.4.1. Cronbach's Alpha Test

To check the statistical reliability of the collected data and ensure that further investigation was not required, Cronbach's Alpha Test was employed in this research to examine the weighted correlation and internal consistency within the responses. Alpha values range between 0 and 1. The closer the value of Alpha is to 0, the less reliable the data are, and the closer the value is to 1, the higher their reliability. It is widely accepted that an Alpha value ≥ 0.7 is considered acceptable for the reliability of any data set (Nunnally, 1978).

3.4.2. Mean Score Ranking (MS)

Many research studies conducted in the construction industry have used the MS method to investigate the relative significance among a number of indicators (Chan & Adabre, 2019; Osei-Kyei & Chan, 2017).

Correspondingly, this research has used it to rate the importance of the 21 selected indicators and estimate their sustainability significance with respect to NEBDs in Bahrain.

As the Likert scale used in this research ranged from 1 to 5, the mean values for each indicator (M_i) had the same range. An M_i closer to 5 indicated that the indicator had a higher rank, and an M_i closer to 1 indicated that the indicator had a lower rank; in the case where two or more indicators had the same M_i value, the values of their standard deviation (SD) were checked to establish their ranks. A lower SD indicated a more consistent rating among respondents and vice versa (Adabre & Chan, 2020). Thus, the lower an indicator's SD, the higher it was ranked, and the higher the SD, the lower it was ranked.

3.4.3. Fuzzy Synthetic Evaluation (FSE)

From the literature review related to the different MCDM methods discussed in Chapter Two, it was clear that researchers had not been able to define an optimum method among the adopted methods that can be used for all decision-making scenarios (Guitouni & Martel, 1998; Roy & Słowiński, 2013). It was also clear that selecting from among the MCDM methods is mainly dependent on their suitability to the objective of a problem (Gan et al., 2017).

Assessing the sustainability of projects is often a challenge for decision-makers and practitioners (Haider et al., 2018). Researchers have always faced difficulties in assessing qualitative indicators when establishing an analytical SBAT for a project. This is because using benchmarks, such as “not

important,” “less important,” “neutral,” “important,” and “very important”, for assessing qualitative indicators is considered subjective and of vague non-mathematical claims leading to uncertainties (Shan, Chan, Le, & Hu, 2015). Thus, decision-making situations that include various decision-makers involved in a problem with qualitative data and numerous indicators are usually difficult to manage and may include uncertainties.

Zadeh (1965) introduced the fuzzy set theory to deal with imprecise data. Fuzzy logic is a very effective approach for handling uncertainties associated with ambiguous human understanding and imprecise data (Haider, Sadiq, & Tesfamariam, 2016; Sadiq & Rodriguez, 2004). Human understanding or expert opinion is more accurately described using degrees of certainty, known as fuzzy logic, rather than absolute certitude, as in classical logic (Ross, 2010).

The FSE method is based on the concept of fuzzy logic. FSE is mainly used in the assessment of objects that are associated with different criteria through the use of a fuzzy decision environment (Mu, Cheng, Chohr, & Peng, 2014). It can handle data limitations, the linguistic scale of the indicators, and the subjectivity of responses (Adabre & Chan, 2020). It is a modeling technique that can convert problems, including multi-attributes and multi-variants, into measurable quantities (i.e., through the aggregation of indicators’ scores, it develops a sustainability index) (Osei-Kyei & Chan, 2017; Owusu et al., 2019).

Many research disciplines have used the FSE method, including the construction and building industry. Osei-Kyei and Chan (2017) used it to develop an index that evaluates the degree of success in public-private partnerships. Haider et al. (2018) used it to develop a model that assesses the sustainability of small urban neighborhoods. Adabre and Chan (2020) used it

to develop a model that guides the sustainability of affordable housing projects. Owusu et al. (2019) used it to develop a model that evaluates the susceptibility to corruption within the procurement process. And Nguyen and Macchion (2023) used it to develop a model that assesses risk in green buildings.

Thus, to develop an analytical SBAT for NEBDs, the use of the FSE method in this research was found the most suitable among the different MCDM methods discussed earlier, in Chapter Two (see **Table 2.6** and **Appendix 2**). This is due to the following reasons: 1. Comprehensive sustainability in buildings encompasses three dimensions, economic, environmental, and social, each comprising several criteria and indicators. FSE facilitates flexible hierarchical assessment and may integrate multiple criteria with disparate units, significance levels, and qualitative characterizations. 2. Sustainability indicators are often qualitative and are ranked using a linguistic scale (e.g., “high,” “moderate,” “low”) by various experts. FSE employs fuzzy logic to transform subjective respondents’ opinions into a mathematical index or model. 3. Sustainability entails ambiguous or incomplete information (e.g., prospective energy efficiency, social value, etc.). FSE employs fuzzy logic to model imprecise or vague judgements, rendering it more realistic than strictly numerical methods such as SAW and TOPSIS.

The following six steps show the method adopted to develop the analytical SBAT for NEBDs in Bahrain using the FSE technique (Adabre & Chan, 2020; Haider et al., 2018; Nguyen & Macchion, 2023; Osei-Kyei & Chan, 2017; Owusu et al., 2019):

Step 1: Develop the selected indicators' set.

$I = \{I_1, I_2, I_3 \dots I_m\}$; where m is the number of selected indicators.

Step 2: Label the grade alternatives' set.

$L = \{L_1, L_2, L_3 \dots L_n\}$; which is the five-point Likert scale (L_1 = not important, L_2 = less important, L_3 = neutral, L_4 = important, and L_5 = very important).

Step 3: Calculate each indicator's weight.

The indicator weight (W) was found by applying the survey data collected in **Equation (3.1)**:

$$W_i = \frac{M_i}{\sum_{i=1}^k M_i} \text{ and } \sum_{i=1}^k W_i = 1 \quad (3.1)$$

Where W_i is the weight of an indicator ranging from 0 to 1; M_i is its mean score; k is a criterion's indicator number; the $\sum W_i$ is the weightings' sum.

Step 4: Establish a fuzzy evaluation matrix for every criterion. $R_i = (r_{ij})_{m \times n}$ was used to express the matrix, where r_{ij} is the degree to which the alternative L_j satisfies the criterion C_j .

Step 5: Find the FSE matrices for evaluation.

The FSE results were reached by considering the weighting vector and the matrix of the fuzzy evaluation as stated in **Equation (3.2)**:

$$D = W_i^o R_i \quad (3.2)$$

Where D is the final FSE matrix, and “ ^{o} ” is the fuzzy composition operator.

Step 6: Normalize the FSE matrix using **Equation (3.3)**, to establish the sustainability assessment index (SAI):

$$SAI = \sum_{i=1}^5 DL \quad (3.3)$$

The normalized sustainability assessment indices for each criterion are then used as the coefficients to develop a linear additive analytical SBAT index/model (Hu, Chan, Le, Xu, & Shan, 2016; Osei-Kyei & Chan, 2017).

3.5. Assessing Sustainability Attainment in NEBDs

To assess the sustainability attainment of NEBD in Bahrain, using the developed analytical SBAT, the design fulfillment score for each criterion is first calculated. The assessment team will rate the seven indicators in each criterion separately on a five-point Likert scale (1= not fulfilled, 2 = less fulfilled, 3 = neutral, 4 = fulfilled, and 5 = very fulfilled) for the NEBD. The design fulfillment score for each criterion is then calculated by adding up all assessment team Likert-scale scores of the seven indicators for each criterion. Then, the total score obtained is divided by the maximum possible total score (i.e., all indicators rated as 5), and the result is multiplied by 100 to obtain a percentage design fulfillment score (Ogu, 2002). The design fulfillment score (in percentage) for a criterion can be calculated using **Equation (3.4)**:

$$DFS_c = \frac{\sum_{i=1}^N y^i}{\sum_{i=1}^N Y^i} \times 100 \quad (3.4)$$

Where DFS_c is the design fulfillment score (in percentage) for a criterion, N is the number of indicators being assessed, y^i is the actual score given by a designer on the i th indicator, Y^i is the maximum possible score that i could have on the scale used (Addo, 2016; Mohit, Ibrahim, & Rashid, 2010).

The calculated design fulfillment score and the coefficient of each criterion in the developed analytical SBAT model are then used to find the sustainability attainment for each criterion of the NEBD using **Equation (3.5)**:

$$Sustainability\ attainment_c = Coefficient_c \times DFS_c\% \quad (3.5)$$

3.6. Pilot Study

Conducting a pilot study is an important step for any research. A pilot study is a small trial version of the main study that tests the feasibility of the methods and procedures used in that study (Porta, 2008). Usually, 10-20% of the research's sample size is considered a reasonable number to conduct a pilot study (Hazzi & Maaldaon, 2015).

A pilot study was conducted to improve the quality and efficiency of the survey in this research and increase its likelihood of success. This helped in making decisions regarding the participants' responses before continuing with the full sample and in identifying any modifications needed to the survey. It also helped in testing the feasibility and applicability of the data analysis tools used in this research.

3.6.1. Pilot Study Participants' Profiles

Fifty-nine participants, corresponding to 16.3% of the sample size, were considered for the pilot study. **Table 3.6** shows their profiles, which indicates that the pilot sample included all types of professionals involved in the built environment in Bahrain with different years of experience, indicating an acceptable sample for the pilot study.

Table 3.6: Pilot Study Participants' Profiles

Category	Characteristics	No. of responses	Percentage
Institution type	Academic	20	33.9
	Private sector	26	44.1
	Public sector	13	22
	Other	0	0
Profession	Academic	14	23.7
	Architect	22	37.3
	Engineer	15	25.4
	Project/Construction manager	8	13.6
	Other	0	0
Years of experience	1-5 years	10	16.9
	6-10 years	11	18.6
	11-15 years	8	13.6
	16-20 years	9	15.3
	Above 20 years	21	35.6

3.6.2. Pilot Study Data Reliability and Analysis

The data collected from the survey, representing the opinions of specialists in the built environment regarding the 21 sustainability indicators (questions 5-7), were then checked for reliability and used to develop the analytical SBAT for NEBDs in Bahrain.

I. Cronbach's Alpha Test

Using Minitab Statistical Software version 21, the Cronbach's Alpha Test was found to be 0.89, thus greater than 0.7, indicating reliable data collected from the pilot sample.

II. Mean Score Ranking (MS)

MS and SD were calculated to rank the 21 sustainability indicators (Table 3.7). Where two or more indicators have the same MS, their ranking is based on the SD, with a higher rank allocated to the indicator with a lower SD.

Table 3.7: Pilot Study Mean Score Ranking of the Indicators

Code	Indicators (I)	Mean (M_i)	SD	Rank
I9	Indoor air & thermal quality	4.797	0.45	1
I12	Design functionality & usability	4.627	0.58	2
I13	Security & safety	4.610	0.64	3
I2	Accessibility	4.593	0.59	4
I15	Efficient energy consumption	4.441	0.82	5
I10	Acoustic comfort	4.424	0.77	6
I19	Material efficiency & durability	4.373	0.83	7
I6	Pedestrian & cyclist safety	4.288	0.89	8
I17	Efficient water consumption	4.288	0.98	9
I11	Design flexibility & scalability	4.254	0.82	10
I1	Community/Urban connectivity	4.254	0.84	11
I14	Use of entries & mobility	4.203	0.66	12
I3	Surrounding environment consideration	4.203	0.78	13
I8	Visual comfort	4.186	0.84	14
I4	Land use efficiency	4.136	0.92	15
I7	Eco-parking	4.136	0.96	16
I20	Material available regionally	4.085	0.86	17
I16	Renewable energy production	4.034	0.83	18
I5	Site ecology enhancement	3.932	0.94	19
I18	Water treatment and recycling	3.864	1.07	20
I21	Recycled and re-used material	3.746	1.08	21

III. Fuzzy Synthetic Evaluation (FSE)

FSE steps (explained earlier in 3.4.3) were used to develop the analytical SBAT through the conversion of the subjective respondents' opinions into a mathematical index or model.

Before using the FSE method, two levels were established based on the categorization of the various indicators shown in **Figure 3.1**. The three criteria, namely, "Site & Transportation," "Health & Well-being," and "Resources & Materials," were defined as the first-level constructs and were represented as C1, C2, and C3. The indicators under each criterion were termed second-level constructs (Osei-Kyei & Chan, 2017; Owusu et al., 2019). The two levels could be conveyed as follows:

$$C1 = \{I1, I2, I3, I4, I5, I6, I7\}$$

$$C2 = \{I8, I9, I10, I11, I12, I13, I14\}$$

$$C3 = \{I15, I16, I17, I18, I19, I20, I21\}$$

The second-level constructs' variables are the input variables for the fuzzy synthetic analysis. For example, I1 is an input variable that represents the indicator "Community/Urban connectivity." It is under the criterion "Site & Transportation," which is expressed as C1.

The following steps were then performed:

➤ Calculate each indicator's weight

Each indicator weight was calculated as shown in **Table 3.8**, where M_C represents the total mean of each criterion, which was found by summing the mean scores for all indicators in a criterion, and W_i represents the weight of each indicator calculated using **Equation (3.1)**.

The following is an example of the calculation done for C1:

$$M_{C1} = 4.254 + 4.593 + 4.203 + 4.136 + 3.932 + 4.288 + 4.136 = 29.542$$

$$W_{I1} = 4.254 / 29.542 = 0.144$$

Table 3.8: Pilot Study Calculated Weightings of Indicators

Criteria and their underlying indicators	Code	Mean (M_i)	Weightings of indicator (W_i)
C1: Site & Transportation			
Community/Urban connectivity	I 1	4.254	0.144
Accessibility	I 2	4.593	0.155
Surrounding environment consideration	I 3	4.203	0.142
Land use efficiency	I 4	4.136	0.140
Site ecology enhancement	I 5	3.932	0.133
Pedestrian & cyclist safety	I 6	4.288	0.145
Eco-parking	I 7	4.136	0.140
Total mean of each criterion (M_{C1})		29.542	
C2: Health & Well-being			
Visual comfort	I 8	4.186	0.135
Indoor air & thermal quality	I 9	4.797	0.154
Acoustic comfort	I 10	4.424	0.142
Design flexibility & scalability	I 11	4.254	0.137
Design functionality & usability	I 12	4.627	0.149
Security & safety	I 13	4.610	0.148
Use of entries & mobility	I 14	4.203	0.135
Total mean of each criterion (M_{C2})		31.101	
C3: Resources & Materials			
Efficient energy consumption	I 15	4.441	0.154
Renewable energy production	I 16	4.034	0.140
Efficient water consumption	I 17	4.288	0.149
Water treatment and recycling	I 18	3.864	0.134
Material efficiency & durability	I 19	4.373	0.152
Material available regionally	I 20	4.085	0.142
Recycled and re-used material	I 21	3.746	0.130
Total mean of each criterion (M_{C3})		28.831	

➤ Determine the membership functions of the indicators

The degree of an element's membership in a fuzzy set is known as the membership function (MF) (Xu et al., 2010). The FSE method expresses the extent of an element's belonging to or membership of a fuzzy set in terms of

varying degrees of relation considering any value within a closed range of 0 and 1 (Ameyaw et al., 2015; Tah & Carr, 2000). MFs use quantitative methods to represent uncertainty in indicator benchmarks and inputs determined by experts' confidence levels (Haider et al., 2018). They are obtained from the second level to the first level (Ameyaw & Chan, 2016). Thus, the MFs of the indicators are calculated first, followed by the MFs of each criterion.

MFs of the indicators are determined based on the ratings given by survey respondents using the five-point Likert scale (L_1 to L_5) (Osei-Kyei & Chan, 2017). For example, for the indicator “community/urban connectivity”, represented by I_1 , 3.4% of the respondents rated it as less important, 15.2% as neutral, 33.9% as important, and 47.5% as very important.

$$MF_{I_1} = \frac{0.00}{L_1} + \frac{0.03}{L_2} + \frac{0.15}{L_3} + \frac{0.34}{L_4} + \frac{0.48}{L_5}$$

The “+” in the FSE does not indicate an addition but a notation (Ameyaw & Chan, 2016). Thus, the MF_{I_1} can be written as (0.00, 0.03, 0.15, 0.34, 0.48). Similarly, the MFs of the remaining indicators were calculated and are shown in **Table 3.9**.

➤ Determine the membership functions of the criteria

After finding the MFs for level 2, the MFs for level 1 (each criterion) can be calculated using **Equation (3.2)**. Where D in the equation is the MF matrix for level 1.

For example, the fuzzy evaluation matrix for C_1 can be expressed as:

$$R_{C1} = \begin{bmatrix} 0.00 & 0.03 & 0.15 & 0.34 & 0.48 \\ 0.00 & 0.00 & 0.05 & 0.31 & 0.64 \\ 0.00 & 0.01 & 0.17 & 0.41 & 0.41 \\ 0.02 & 0.03 & 0.15 & 0.39 & 0.41 \\ 0.00 & 0.07 & 0.27 & 0.32 & 0.34 \\ 0.02 & 0.02 & 0.13 & 0.32 & 0.51 \\ 0.03 & 0.03 & 0.09 & 0.46 & 0.39 \end{bmatrix}$$

And MF for level 1 can be calculated for C1 as follows:

$$MF_{C1} = (0.144, 0.155, 0.142, 0.140, 0.133, 0.145, 0.140)$$

$$\times \begin{bmatrix} 0.00 & 0.03 & 0.15 & 0.34 & 0.48 \\ 0.00 & 0.00 & 0.05 & 0.31 & 0.64 \\ 0.00 & 0.01 & 0.17 & 0.41 & 0.41 \\ 0.02 & 0.03 & 0.15 & 0.39 & 0.41 \\ 0.00 & 0.07 & 0.27 & 0.32 & 0.34 \\ 0.02 & 0.02 & 0.13 & 0.32 & 0.51 \\ 0.03 & 0.03 & 0.09 & 0.46 & 0.39 \end{bmatrix} = (0.01, 0.03, 0.14, 0.36, 0.46)$$

Similarly, the MFs of the remaining criteria were calculated and are shown in **Table 3.9**.

Table 3.9: Pilot Study MFs for Indicators and Criteria

Criteria	Code	W_i	MF for level 2	MF for level 1
C1: Site & Transportation	I 1	0.144	0.00,0.03,0.15,0.34,0.48	0.01,0.03,0.14,0.36,0.46
	I 2	0.155	0.00,0.00,0.05,0.31,0.64	
	I 3	0.142	0.00,0.01,0.17,0.41,0.41	
	I 4	0.140	0.02,0.03,0.15,0.39,0.41	
	I 5	0.133	0.00,0.07,0.27,0.32,0.34	
	I 6	0.145	0.02,0.02,0.13,0.32,0.51	
	I 7	0.140	0.03,0.03,0.09,0.46,0.39	
C2: Health & Well-being	I 8	0.135	0.00,0.05,0.12,0.42,0.41	0.00,0.02,0.08,0.34,0.56
	I 9	0.154	0.00,0.00,0.02,0.17,0.81	
	I 10	0.142	0.00,0.02,0.05,0.42,0.51	
	I 11	0.137	0.00,0.03,0.14,0.37,0.46	
	I 12	0.149	0.00,0.00,0.05,0.27,0.68	
	I 13	0.148	0.00,0.00,0.08,0.22,0.70	
	I 14	0.135	0.00,0.02,0.08,0.58,0.32	
C3: Resources & Materials	I 15	0.154	0.00,0.02,0.15,0.20,0.63	0.02,0.04,0.14,0.38,0.42
	I 16	0.140	0.00,0.06,0.12,0.53,0.29	
	I 17	0.149	0.02,0.05,0.12,0.25,0.56	
	I 18	0.134	0.07,0.03,0.14,0.49,0.27	
	I 19	0.152	0.02,0.02,0.06,0.37,0.53	
	I 20	0.142	0.00,0.05,0.17,0.42,0.36	
	I 21	0.130	0.05,0.07,0.22,0.41,0.25	

➤ Determine a sustainability assessment index for each criterion

The sustainability assessment index (*SAI*) for each criterion is then calculated using **Equation (3.3)**.

$$SAI = D_n \times L_n = (D_1, D_2, D_3, D_4, D_5) \times (L_1, L_2, L_3, L_4, L_5)$$

Where D_n is the fuzzy evaluation matrix or MF for level 1 and L_n is the grade alternative. Thus, the SAI for each criterion is calculated as follows:

$$SAI_{C1} = (0.01, 0.03, 0.14, 0.36, 0.46) \times (1, 2, 3, 4, 5) = 4.23$$

$$SAI_{C2} = (0.00, 0.02, 0.08, 0.34, 0.56) \times (1, 2, 3, 4, 5) = 4.44$$

$$SAI_{C3} = (0.02, 0.04, 0.14, 0.38, 0.42) \times (1, 2, 3, 4, 5) = 4.14$$

➤ Develop the analytical SBAT for NEBDs

To develop the analytical SBAT, a linear additive approach combining the criteria to assess NEBDs in Bahrain was used. This enabled the calculation of a composite index that shows the level of sustainability within NEBDs with regard to “Site & Transportation,” “Health & Well-being,” and “Resources & Materials.” A linear and additive approach was used in previous studies (Hu et al., 2016; Osei-Kyei & Chan, 2017).

To develop the SBAT, all criteria sustainability assessment indices were normalized, summing up to 1 (as shown in **Table 3.10**). These were then used as the coefficients in the model. Normalizing the indices is important to provide a better reflection of the relative criticality of each criterion in the model for the assessment of NEBDs. Thus, the analytical SBAT for NEBDs in Bahrain can be expressed as follows:

$$SBAT \text{ for NEBDs} = 0.33C1 + 0.347C2 + 0.323C3$$

Table 3.10: Pilot Study Assessment Index for the Criteria

No	Criteria	SAI	Coefficient
C1	Site & Transportation	4.23	0.330
C2	Health & Well-being	4.44	0.347
C3	Resources & Materials	4.14	0.323
Total		12.81	1.000
Note: Coefficient = Criterion Index / Sum of Indices of all Criteria			

3.6.3. Pilot Study Recommendations

The data collected from the survey questions and the methods used to check the reliability of the data and develop the analytical SBAT for NEBDs in Bahrain were found feasible for this research.

The following two recommendations from the pilot study were observed:

1. Responses from participants not practicing in Bahrain and those not involved in the built environment had to be excluded. Therefore, it was necessary to maximize the data collection to ensure the collection of the required sample size.
2. The responses to question 8 (requesting participants to indicate any critical indicator for NEBDs in Bahrain that were not captured in the survey) were mostly similar to the indicators already in the survey but either elaborated upon or written with different terminology. Therefore, the indicators' descriptions (shown in **Table 3.2**, **Table 3.3**, and **Table 3.4**) were added to the second section of the survey, questions 5-7, to ensure they were clearly understood by all participants (**Appendix 8**).

3.7. Research Ethics

Ethical considerations concerning participants' rights and well-being were addressed by clearly outlining the research objectives and the voluntary nature of their participation before starting the survey. Furthermore, participants were given the option to withdraw at any time, and their privacy was protected through the use of anonymous responses in the survey settings.

To distribute the survey among private sector engineering offices, managers and key contacts were approached for approval to share the survey with their employees. In the public sector, the human resources or public relations departments evaluated the survey's suitability before sending it to their employees.

To disseminate the survey among academic participants in HEIs, it was necessary first to request an approval letter from the HEC (**Appendix 6**). The HEC checked the suitability of the survey for circulation and requested compliance with the following ethical guidelines:

1. Adherence to the implementation of the sanctioned research survey.
2. Avoidance of any detriment to the educational process and students' performance through prior coordination with the administration.
3. Maintenance of confidentiality about the acquired data, utilizing it solely for scientific research objectives.
4. The researcher is to be solely responsible for all processes and actions required to utilize scientific research instruments.

To ensure an unbiased population representation of the sample, a higher quality of findings, and generalized results, probability sampling, namely simple random sampling, was used (Acharya et al., 2013). Any engineer or

academic involved in the built environment in Bahrain was given a random equal chance to participate in the survey.

Academic integrity was considered. Twelve responses were excluded due to their unsuitability to the scope of the study (eight practicing out of Bahrain and four professions not related to the built environment). Furthermore, the data from the 364 valid responses were all checked for reliability and considered for the analysis, and the findings were presented honestly without misrepresentation.

3.8. Summary

This chapter explained and justified in three steps the categorization and selection of the criteria and indicators essential to assess NEBDs. Three criteria were categorized: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials.” Under each criterion, seven indicators were selected (21 indicators in total), encompassing the three sustainability dimensions and being the most suitable, representative, and independent for assessing sustainability in NEBDs, achieving the first objective of the research. The criteria and indicators were then arranged in a conceptual sustainability framework to develop an SBAT intended to assess NEBDs conceptually in Bahrain.

The second objective was then achieved using an online survey via the Microsoft Forms online survey platform to investigate the local significance of the identified criteria and indicators. The survey consisted of three sections. The first section included questions to understand the participants’ profile, the second section required the participants to rate the significance of the 21

selected indicators using a five-point Likert scale, and the third section was provided for the participants to indicate any critical indicators not captured in the survey.

The sample frame of participants in the survey included professionals and academics involved in the built environment in Bahrain. These were identified through two governmental authorities: the CRPEP and the HEC. Accordingly, the total population of engineers (5868) and academics (231) involved in the built environment in Bahrain was found to be 6099. Thus, the sample size estimated for this research was 362 participants, considering a 95% confidence level and a 5% margin of error.

The data reliability was checked using Cronbach's Alpha Test. The MS was employed to determine the indicators' significance and the FSE to develop the analytical SBAT (index/model) for NEBDs in Bahrain, as it can solve decision-making problems, which are prone to uncertainties and involve several criteria and indicators.

A pilot study on 59 responses (16.3% of the sample size) was conducted, which revealed that the data collected from the survey questions and the methods used to check the reliability of the data and develop the analytical SBAT for NEBDs in Bahrain were found to be feasible for this research. The pilot study recommendations included excluding participants not practicing in Bahrain or not involved in the built environment. Moreover, to ensure a clear understanding of the indicators, the form was edited by adding the indicators' descriptions to the second section of the survey, questions 5-7.

It is worth mentioning that this research has proposed an SBAT framework for conceptually assessing NEBDs that can be applied globally. It

can also be considered as the basis for developing future analytical SBATs in other countries for NEBDs. This is because the criteria and indicators implemented in it were categorized and selected for the design phase of educational buildings based on well-known global and local SBRs and previous research. It is also important to know that the analytical SBAT proposed in this research is specific to Bahrain and may be applicable to countries that share similar “regional characteristics,” such as the GCC region.

Chapter Four

Results and Discussions

4.1. Introduction

The previous chapter specified the sustainability assessment criteria and indicators and developed a conceptual SBAT framework for NEBDs in Bahrain (objective# 1, **Table 3.1**) that can be used for sustainability accounting determinations. The next step is to develop the analytical SBAT (index/model) for NEBDs in Bahrain to obtain a quantifiable, consistent assessment.

In this research, FSE, an MCDM method, is employed to develop the analytical SBAT (index/model) for NEBDs in Bahrain, as it can solve decision-making problems, which are prone to uncertainties and involve several criteria and indicators. This required employing an online survey, which took nearly five months to collect 364 valid responses. These are then used to find the sustainability significance of the 21 selected indicators and develop the analytical SBAT (objectives# 2 & 3, **Table 3.1**).

This chapter elaborates on the outcomes of the study survey data comprehensively. It presents the reliability of the data collected using Cronbach's Alpha test, ranks the selected 21 sustainability indicators using the MS and SD values, and develops the analytical SBAT for NEBDs in Bahrain using the FSE method. Finally, it discusses the results, the applications of the developed SBAT, the criticality of its indicators, and compares it with SBATs developed globally.

4.2. Data Reliability and Analysis Results

4.2.1. Cronbach's Alpha Test Result

The Cronbach's Alpha for this study is 0.9462, which indicates very strong reliability of the participants' responses (Izah, Sylva, & Hait, 2024; Metinal & Gumusburun Ayalp, 2024; Naji, Gunduz, & Salat, 2021; Olanrewaju, Kineber, Chileshe, & Edwards, 2022).

4.2.2. MS Results

The MS and SD are calculated and subsequently used to rank the 21 selected indicators and estimate their sustainability significance with respect to NEBDs in Bahrain, as shown in **Table 4.1** and **Figure 4.1**. The SD in this study is used to decide the rank between the two indicators, I2 and I12, which have equal MS, allocating a higher rank to I12 due to its lower SD, as explained in Chapter Three, **Section 3.4.2**.

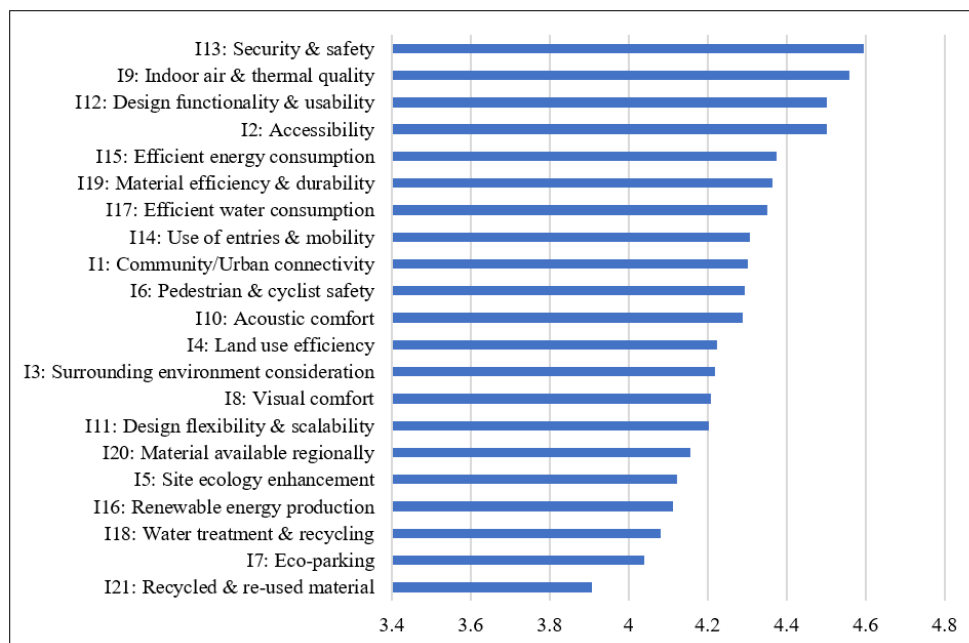


Figure 4.1: MS of the Indicators as Evaluated by Respondents

Table 4.1: MS Ranking of the Indicators

Code	Indicators (I)	Sustainability Dimension	Mean (M_i)	SD	Rank
I13	Security & safety	Social	4.596	0.785	1
I9	Indoor air & thermal quality	Environmental	4.56	0.778	2
I12	Design functionality & usability	Social	4.503	0.773	3
I2	Accessibility	Economic/Environmental	4.503	0.794	4
I15	Efficient energy consumption	Economic/Environmental	4.374	0.893	5
I19	Material efficiency & durability	Economic/Environmental	4.365	0.86	6
I17	Efficient water consumption	Economic/Environmental	4.352	0.886	7
I14	Use of entries & mobility	Social	4.308	0.819	8
I1	Community/Urban connectivity	Economic/Environmental/Social	4.302	0.889	9
I6	Pedestrian & cyclist safety	Social	4.294	0.964	10
I10	Acoustic comfort	Environmental	4.288	0.867	11
I4	Land use efficiency	Economic/Environmental	4.225	0.884	12
I3	Surrounding environment consideration	Environmental	4.22	0.885	13
I8	Visual comfort	Environmental	4.209	0.924	14
I11	Design flexibility & scalability	Social	4.203	0.867	15
I20	Material available regionally	Economic/Environmental	4.157	0.921	16
I5	Site ecology enhancement	Environmental/Social	4.124	0.905	17
I16	Renewable energy production	Economic/Environmental	4.113	0.919	18
I18	Water treatment & recycling	Economic/Environmental	4.082	1.023	19
I7	Eco-parking	Economic/Environmental	4.041	1.034	20
I21	Recycled & re-used material	Economic/Environmental	3.907	1.027	21

4.2.3. FSE Results

The FSE is the main MCDM method used for developing the analytical SBAT of NEBDs in Bahrain using the steps explained in detail earlier, in Chapter Three in the pilot study data analysis (Section 3.6.2).

The following are the steps and results for the full data collected:

- Each indicator weight is calculated as shown in Table 4.2.

Table 4.2: Calculated Weightings of Indicators

Criteria and their underlying indicators	Code	Mean (M_i)	Weightings of indicator (W_i)
C1: Site & Transportation			
Community/Urban connectivity	I 1	4.302	0.145
Accessibility	I 2	4.503	0.152
Surrounding environment consideration	I 3	4.220	0.142
Land use efficiency	I 4	4.225	0.142
Site ecology enhancement	I 5	4.124	0.139
Pedestrian & cyclist safety	I 6	4.294	0.145
Eco-parking	I 7	4.041	0.136
Total mean of each criterion (M_{C1})		29.709	
C2: Health & Well-being			
Visual comfort	I 8	4.209	0.137
Indoor air & thermal quality	I 9	4.560	0.149
Acoustic comfort	I 10	4.288	0.140
Design flexibility & scalability	I 11	4.203	0.137
Design functionality & usability	I 12	4.503	0.147
Security & safety	I 13	4.596	0.150
Use of entries & mobility	I 14	4.308	0.140
Total mean of each criterion (M_{C2})		30.667	
C3: Resources & Materials			
Efficient energy consumption	I 15	4.374	0.149
Renewable energy production	I 16	4.113	0.140
Efficient water consumption	I 17	4.352	0.148
Water treatment & recycling	I 18	4.082	0.139
Material efficiency & durability	I 19	4.365	0.149
Material available regionally	I 20	4.157	0.142
Recycled & re-used material	I 21	3.907	0.133
Total mean of each criterion (M_{C3})		29.35	

- The MFs of the indicators (level 2) are determined based on the ratings given by survey respondents using the five-point Likert scale (L_1 to L_5) (Osei-Kyei & Chan, 2017). These are found from the analysis of the Microsoft Forms shown in **Figure 4.2**. The MFs of the indicators are then calculated, as shown in Error! Reference source not found..
- The MFs of the criteria are calculated as shown in **Table 4.3**.

Table 4.3: Membership Function of Indicators and Criteria

Criteria	Code	W_i	MF for level 2	MF for level 1
C1: Site & Transportation	I 1	0.145	0.03,0.02,0.08,0.38,0.50	0.02,0.03,0.12,0.35,0.49
	I 2	0.152	0.01,0.02,0.06,0.28,0.64	
	I 3	0.142	0.02,0.02,0.13,0.38,0.45	
	I 4	0.142	0.01,0.02,0.15,0.35,0.46	
	I 5	0.139	0.02,0.03,0.17,0.38,0.40	
	I 6	0.145	0.03,0.03,0.10,0.30,0.54	
	I 7	0.136	0.04,0.05,0.16,0.36,0.40	
C2: Health & Well-being	I 8	0.137	0.03,0.02,0.13,0.37,0.46	0.02,0.02,0.09,0.32,0.56
	I 9	0.149	0.01,0.02,0.05,0.24,0.68	
	I 10	0.140	0.02,0.02,0.10,0.38,0.48	
	I 11	0.137	0.02,0.02,0.13,0.41,0.43	
	I 12	0.147	0.01,0.01,0.07,0.28,0.63	
	I 13	0.150	0.02,0.01,0.05,0.20,0.72	
	I 14	0.140	0.01,0.02,0.10,0.38,0.48	
C3: Resources & Materials	I 15	0.149	0.03,0.02,0.07,0.34,0.56	0.03,0.04,0.11,0.37,0.45
	I 16	0.140	0.01,0.06,0.12,0.42,0.39	
	I 17	0.148	0.01,0.04,0.09,0.31,0.55	
	I 18	0.139	0.04,0.03,0.12,0.40,0.40	
	I 19	0.149	0.02,0.02,0.06,0.36,0.53	
	I 20	0.142	0.03,0.03,0.14,0.40,0.41	
	I 21	0.133	0.04,0.05,0.20,0.40,0.32	

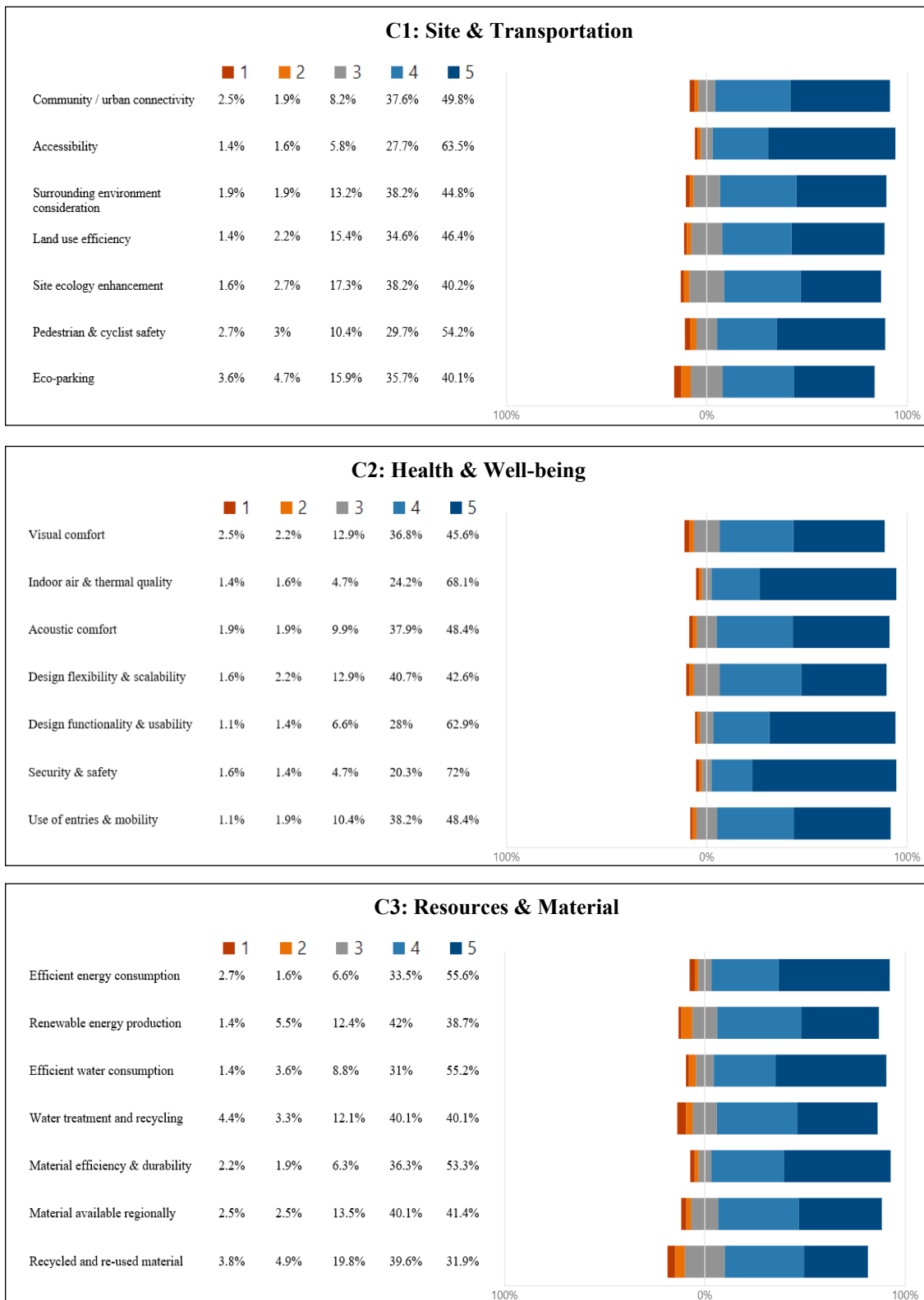


Figure 4.2: Likert-Scale Chart and Percentage of Indicators Rating

- The sustainability assessment index (SAI) for each criterion is then calculated, as shown in **Table 4.4**.
- To develop the SBAT, all criteria sustainability assessment indices are normalized, summing up to 1 (shown in **Table 4.4**). These are then used as the coefficients in the model. Thus, the analytical SBAT for NEBDs in Bahrain (research objective #3-**Table 3.1**) can be expressed as follows:

$$SBAT \text{ for NEBDs} = 0.331C1 + 0.342C2 + 0.327C3$$

Table 4.4: Assessment Index for the Criteria

No	Criteria	SAI	Coefficient
C1	Site & Transportation	4.261	0.331
C2	Health & Well-being	4.391	0.342
C3	Resources & Materials	4.206	0.327
Total		12.857	1.000
Note: Coefficient = Criterion Index / Sum of Indices of all Criteria			

Figure 4.3 illustrates the analytical SBAT for NEBDs in Bahrain, indicating its assessment criteria, the sustainability attainment percentage accounted for by each criterion, and the assessment indicators with their weights and ranks.

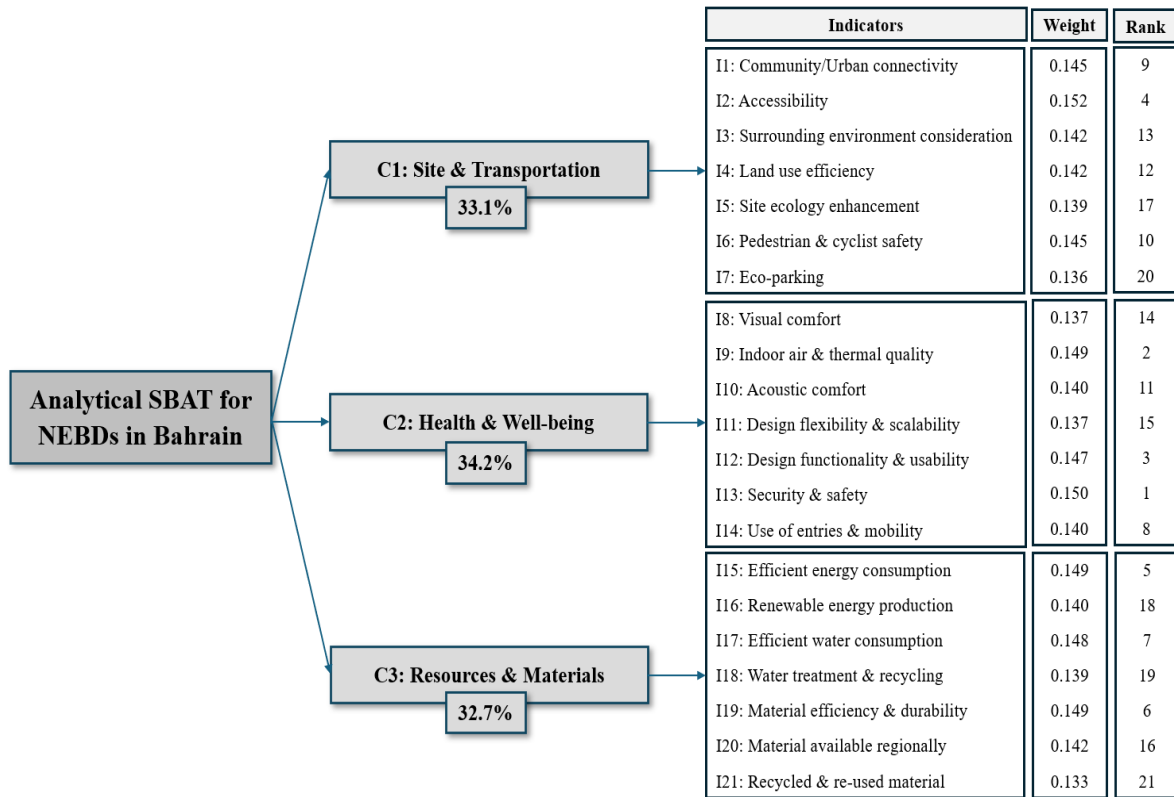


Figure 4.3: The Analytical SBAT for NEBDs in Bahrain

4.3. Results Discussion

4.3.1. MS Discussion

From **Table 4.1**, the environmental, social, and economic indicators are all ranked high (MS for all the indicators > 3.9), showing the importance of the three sustainability dimensions in assessing the sustainability of NEBDs in Bahrain. In addition, the first and third highest ranks are given to the “security & safety” and “design functionality & usability” indicators, which are social sustainability indicators. This is not the case in most SBRs, which primarily focus on environmental sustainability and allocate inadequate weightings for assessment criteria pertaining to social and economic sustainability (Atanda, 2019; Awadh, 2017; Hamid et al., 2014; Raouf & Al-Ghamdi, 2019). Therefore, researchers around the world developed SBATs to

overcome the shortages in SBRs (Table 2.4), as the priority of environmental, social, and economic sustainability indicators in SBATs varies depending on the building's occupancy and location, which makes SBATs more accurate and efficient for assessment (Adabre & Chan, 2020; Adamec et al., 2021; Dobrovolskienė et al., 2021; Haidar & Bahammam, 2021; Janjua, Sarker, & Biswas, 2020; Klumbytė et al., 2021; Saraiva et al., 2019; Zavadskas, Turskis, Šliogerienė, & Vilotienė, 2021).

The three highest-ranked indicators, “security & safety,” “indoor air & thermal quality,” and “design functionality & usability,” all belong to the “Health & Well-being” criterion. This indicates that the participants consider that accounting for the health and comfort of the occupants in NEBDs in Bahrain is the most important to attain sustainability. This is necessary to ensure better concentration and learning outcomes for students, and a comfortable working environment for staff, who spend considerable time in these buildings (Saraiva et al., 2018).

“Security & safety” was ranked highest by the participants. The security and safety of the occupants in educational buildings is a high priority (Al-Hemoud & Al-Asfoor, 2006; Wang, Almassy, Wei, & Shohet, 2022). This includes implementing all preventive measures to ensure the well-being of users and facility-designated use. Effective teaching and learning can only be delivered in educational buildings that provide a safe and secure environment where the users will be safe from injury and violence. This safe and secure environment involves the classrooms, the school campus, learners, educators, parents, and the community (Xaba, 2006). Therefore, these buildings require the designer to take serious measures to ensure the highest safety and security by giving great attention to the hallways, stairways, classrooms, fencing,

lighting at night, fire exits, gathering areas, fire protection, and the use of safe equipment to prevent hazardous events.

The second-ranked indicator is “indoor air & thermal quality,” which is an environmental sustainability-related indicator. Children, young adults, and educators spend more time in educational buildings than in any other indoor environment except their homes, which requires these buildings to provide a comfortable and healthy environment that improves their productivity, performance, and well-being (McLeod, Mathew, Salman, & Thomas, 022). Therefore, educational building designers need to pay considerable attention to the efficient design and specification of equipment, techniques and finishes for mechanical and natural ventilation to ensure healthy internal spaces and adequate thermal comfort (Abu Dhabi Urban Planning Council, 2010; Saraiva et al., 2019).

The third-ranked indicator is “design functionality & usability,” which is related to social sustainability. A functional and usable educational building will have a great influence on the performance and academic attainment of its users, reduce distractions, and create a sense of community and belonging. The functionality and usability of an educational building are related to the spatial requirements, system performance, and durability of the building components (Okechukwu et al., 2020). The designer should consider functional elements that directly facilitate the educational building’s specific requirements for users and their activities, paying attention to the performance of various functional building elements, including access, parking, spatial capacity, utilities, communications, circulation, and equipment.

“Water treatment & recycling,” “eco-parking,” and “recycled & re-used material” were ranked low by the participants. “Water treatment & recycling”

and “recycled & re-used material” indicators belong to the “Resources & Materials” criterion, whereas the “eco-parking” indicator belongs to the “Site & Transportation” criterion. “Water treatment & recycling” might be rated low by participants in Bahrain due to groundwater depletion, and the substantial costs and energy consumption associated with its implementation (Qureshi, 2020). “Eco-parking” might be rated low due to the high initial and maintenance costs associated with its construction, as well as spatial constraints in Bahrain. “Recycled & re-used material” might be rated low due to several challenges, such as the high cost of importing recycled material or processing local waste into recycled or re-used material, technical challenges, and the hot, humid weather that may affect the performance of these materials (Abbas, Kirwan, & Lu, 2020).

Although “water treatment & recycling,” “eco-parking,” and “recycled & re-used material” were ranked low by the participants, they were still considered important, as can be seen by their high MS values (> 3.9).

The nineteenth-ranked indicator was “water treatment & recycling,” which is an economic and environmental sustainability-related indicator. Educational buildings are considered high-water consumption buildings. Paying attention to water treatment and recycling strategies during the design stage rather than after it can conserve water usage and provide an educational opportunity for students and staff (Brkovic & Milosevic, 2012). Therefore, the designer is required to promote water conservation through recycling strategies and the re-use of rainwater, groundwater, or greywater (Saraiva et al., 2019; Sheth, 2017).

The twentieth-ranked indicator was “eco-parking,” which is an environmental and economic sustainability-related indicator. Eco-parking at

educational buildings is important due to the large number of vehicles that visit these buildings daily. This requires the designer to provide maximum sustainable solutions for the parking areas, such as the use of permeable pavement, vegetation, solar panels, electric vehicle charging stations, and bicycle parking (Gulf Organization for Research & Development, 2019). In addition, the designer will need to locate the parking area out of the gardens and at a distance from the classroom (Tönük & Kayihan, 2013). All these considerations will ensure a healthier environment for the students, reinforce their environmental education, and reduce future operating expenses.

The lowest-ranked indicator in this study was the “recycled & re-used material,” which is an economic and environmental sustainability-related indicator. This requires the designer to reduce the production of waste and conserve natural resources by using materials that have been previously used, recycled, or salvaged (Gulf Organization for Research & Development, 2019).

4.3.2. The Developed Analytical SBAT Discussion

The following sections discuss how the analytical SBAT developed in this research can be used by the design team during the design stage for the assessment of each criterion and its indicators to ensure full sustainability attainment within their NEBD in Bahrain.

I. Site & Transportation

This criterion has an index of 4.261 and a coefficient of 0.331 (shown in **Table 4.4**). The “Site & Transportation” criterion consists of seven main indicators: “community/urban connectivity,” “accessibility,” “surrounding environment consideration,” “land use efficiency,” “site ecology

enhancement,” “pedestrian & cyclist safety,” and “eco-parking.” These indicators account for 33.1% of the sustainability attainment in NEBDs. This can be used to identify suitable site locations for educational buildings and assess site designs, leading to more sustainable NEBDs such as environmental sustainability (i.e., energy conservation and pollution reduction), economic sustainability (i.e., transportation costs reduction), and social sustainability (i.e., access to improved economic opportunities and a reduction in accident risks) (Building Research Establishment Environmental Assessment Methodology, 2016; Gulf Organization for Research & Development, 2019).

To achieve this criterion, the design team needs to consider the seven indicators, as described in **Table 3.2**. However, as shown in **Table 4.4**, this criterion accounts for only 33.1% of the sustainability attainment in NEBDs. Thus, the full sustainability development of NEBDs will not be accomplished if the designer focuses only on the “Site & Transportation” criterion and neglects the other criteria.

The developed analytical SBAT for NEBDs can be used to determine the level of sustainability attainment with regard to the “Site & Transportation” criterion as follows: The design team will rate the seven indicators of this criterion on a five-point Likert scale (1= not fulfilled, 2 = less fulfilled, 3 = neutral, 4 = fulfilled, and 5 = very fulfilled) for their NEBD, to assess the level of execution of the considerations for each indicator as described **Table 3.2**. The design fulfillment score can then be calculated using **Equation (3.4)** by adding up all design team Likert-scale scores of the seven indicators. Then, the total score obtained is divided by the maximum possible total score (i.e., all indicators rated as 5), and the result is multiplied by 100 to obtain a percentage design fulfillment score with regard to the “Site & Transportation”

criterion (Ogu, 2002). Then, the level of sustainability attainment in the NEBD with regard to this criterion is found using **Equation (3.5)** by multiplying the coefficient of the criterion by the calculated percentage design fulfillment score (i.e., $0.331 \times DFS_{S\&T}\%$).

An example is given below to explain how the design team can individually use the developed analytical SBAT to assess the sustainability attainment of the “Site & Transportation” criterion in their NEBD:

First, the design team will rate the level of design fulfillment with regard to the “Site & Transportation” criterion for their design on a five-point Likert scale. Then, the total actual score given by the design team (y^i) and the maximum possible score (Y) of the indicators are calculated, as illustrated in **Table 4.5**.

Then, $DFS_{S\&T}$ is calculated using **Equation (3.4)**, as follows:

$$DFS_{S\&T} = \frac{65}{105} \times 100 = 61.9\%$$

Finally, the sustainability attainment level of the NEBD with regard to this criterion is found using **Equation (3.5)**:

$$Sustainability\ Attainment_{S\&T} = 0.331 \times 61.9\% = 20.49\%$$

Thus, the NEBD’s sustainability attainment with regard to the “Site & Transportation” criterion is 20.49%, whereas the seven indicators in this criterion account for 33.1%. This indicates that full sustainability attainment for this criterion is not achieved in the design. The design team will need to either select another site, improve the site design, or both. They will need to go through the seven indicators and check which indicators were rated low to improve their design’s sustainability level.

Table 4.5: Rating of the “Site & Transportation” Criterion’s Indicators by the Design Team (an Example)

Site & Transportation	Design team rating			
	Designer 1	Designer 2	Designer 3	Total
Community/Urban connectivity	5	4	4	13
Accessibility	3	4	3	10
Surrounding environment consideration	2	3	1	6
Land use efficiency	4	4	5	13
Site ecology enhancement	3	3	2	8
Pedestrian & cyclist safety	4	3	3	10
Eco-parking	2	2	1	5
Total actual score by designers (y^i)				65
Maximum possible score (Y^i)	35	35	35	105

II. Health & Well-being

This criterion has the highest index of 4.391 and a coefficient of 0.342 (shown in **Table 4.4**). Seven main indicators were used to determine the weight of the “Health & Well-being” criterion: “visual comfort,” “indoor air & thermal quality,” “acoustic comfort,” “design flexibility & scalability,” “design functionality & usability,” “security & safety,” and “use of entries & mobility.” Attaining these indicators will account for 34.2%. This will require some considerations to be implemented in the design, as described in **Table 3.3**, to ensure the suitability and quality of the internal spaces, which have a great influence on the concentration, learning process, and working environment of the students and staff. In addition, it will lead to a more sustainable NEBD, such as environmental sustainability (i.e., efficient ventilation, illumination, and acoustic provision) and social sustainability (i.e., comfortable, safe, and secure internal space provision). However, as shown in **Table 4.4**, this criterion accounts for only 34.2% of the sustainability

attainment in NEBDs. Thus, other criteria should also be considered to achieve full sustainability development of the NEBD.

The developed analytical SBAT for NEBDs can be used to determine the level of sustainability attainment with regard to the “Health & Well-being” criterion, using a similar approach as explained earlier in the example in **Section I**, where the design team will rate the seven indicators of this criterion on a five-point Likert scale for their NEBD to assess the level of execution of the considerations for each indicator as described in **Table 3.3**. Suppose the sustainability attainment calculated is less than 34.2%. In that case, this will indicate that the NEBD’s sustainability is not fully achieved, and the design team is required to revisit the design to improve its sustainability with regard to the “Health & Well-being” criterion considerations.

III. Resources & Materials

This criterion has the lowest index of 4.206 and a coefficient of 0.327 (shown in **Table 4.4**). The scores of the seven main indicators: “efficient energy consumption,” “renewable energy production,” “efficient water consumption,” “water treatment & recycling,” “material efficiency & durability,” “material available regionally,” and “recycled & re-used materials,” were used to estimate an index of 4.206 for the “Resources & Materials” criterion. It accounts for 32.7% of the sustainability attainment in NEBDs, which can be used to assess the efficiency and adequacy of implementing energy, water, and material use solutions, systems, and equipment in NEBDs, as they have a great effect on the building’s life cycle sustainability. In addition, it will lead to a more sustainable NEBD, such as environmental sustainability (i.e., greenhouse gas and non-renewable energy

reduction) and economic sustainability (i.e., operation and maintenance cost reduction). However, as shown in **Table 4.4**, this criterion accounts for only 32.7% of the sustainability attainment in NEBDs. Thus, considering it alone will not fulfill the requirements of fully sustainable attained NEBDs.

The developed analytical SBAT for NEBDs can be used to determine the level of sustainability attainment with regard to the “Resources & Materials” criterion, using a similar approach as explained earlier in the example in **Section I**, where the design team will rate the seven indicators of this criterion on a five-point Likert scale for their NEBD to assess the level of execution of the considerations for each indicator as described in **Table 3.4**. Suppose the sustainability attainment calculated is less than 32.7%. In that case, this will indicate that the NEBD’s sustainability is not fully achieved, and the design team is required to revisit the design to improve its sustainability with regard to the “Resources & Materials” criterion considerations.

4.3.3. The Developed Analytical SBAT Applications

This research established a comprehensive analytical SBAT for assessing the economic, environmental, and social sustainability of NEBDs in Bahrain. The tool may also be applicable to other GCC countries, as they share similar “regional characteristics,” with regard to the three sustainability dimensions considered in this research. These include:

- Similar climatic and environmental challenges, such as hot-arid and hot-humid weather, water scarcity, dust availability, and high solar exposure, necessitate considerations regarding energy efficiency, water conservation, material selection, and thermal comfort in buildings.

- Similar social and economic expectations with regard to educational environments, education systems, government ownership of public educational institutions, and student population growth. In addition to their similar aspirations that align with Vision 2030 strategies.
- Similar national sustainability goals that mainly align with LEED and the local rating systems, such as PRS in the United Arab Emirates and GSAS in Qatar.

Due to these similarities and as the developed SBAT for NEBDs considered LEED, PRS, and GSAS, which are mainly applied in the GCC countries, the developed SBAT in this research can be considered suitable for implementation in the GCC countries. **Figure 4.4** below shows the analytical SBAT applications.

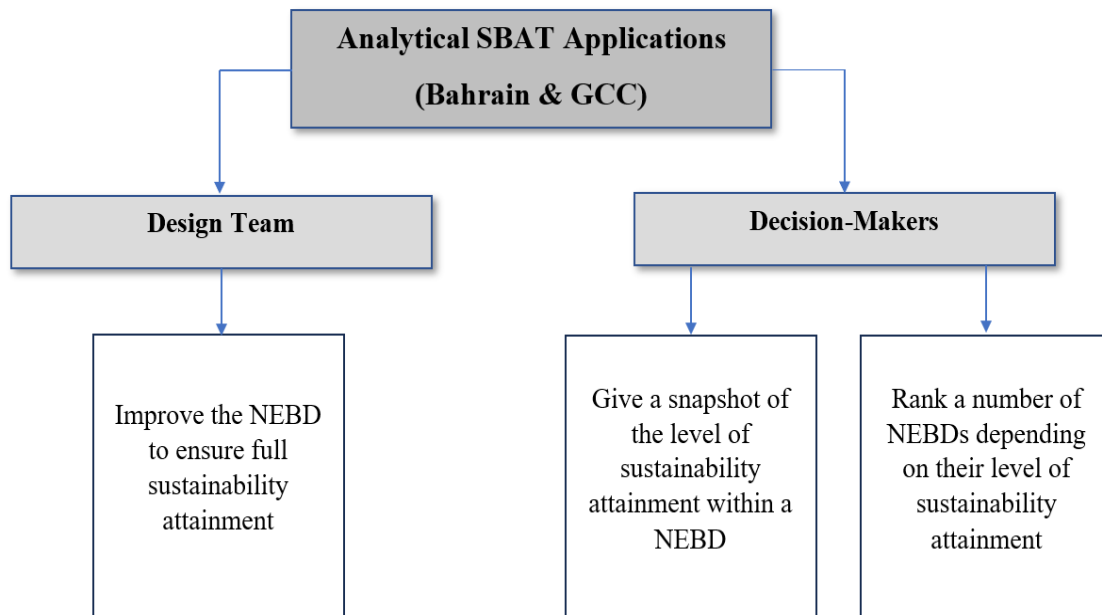


Figure 4.4: The Developed Analytical SBAT Applications

The design team can apply the analytical SBAT during the design phase to assist them in producing a sustainable NEBD. This can be done by using the estimated indices of the various criteria in the SBAT to assess the NEBD's sustainability attainment with regard to the three main criteria, "Site & Transportation," "Health & Well-being," and "Resources and Materials," as explained in **Sections II, II, and III** earlier, which will help the design team to answer the following questions regarding the sustainability attainment of their NEBD: Is full sustainability attainment achieved in the NEBD? Which criteria in the NEBD did not achieve full sustainability attainment? How far is each criterion from achieving full sustainability attainment? Which indicators can be improved to increase sustainability attainment? **Figure 4.5** below illustrates the process of assessment by the design team for NEBDs during the design phase to ensure full sustainability attainment.

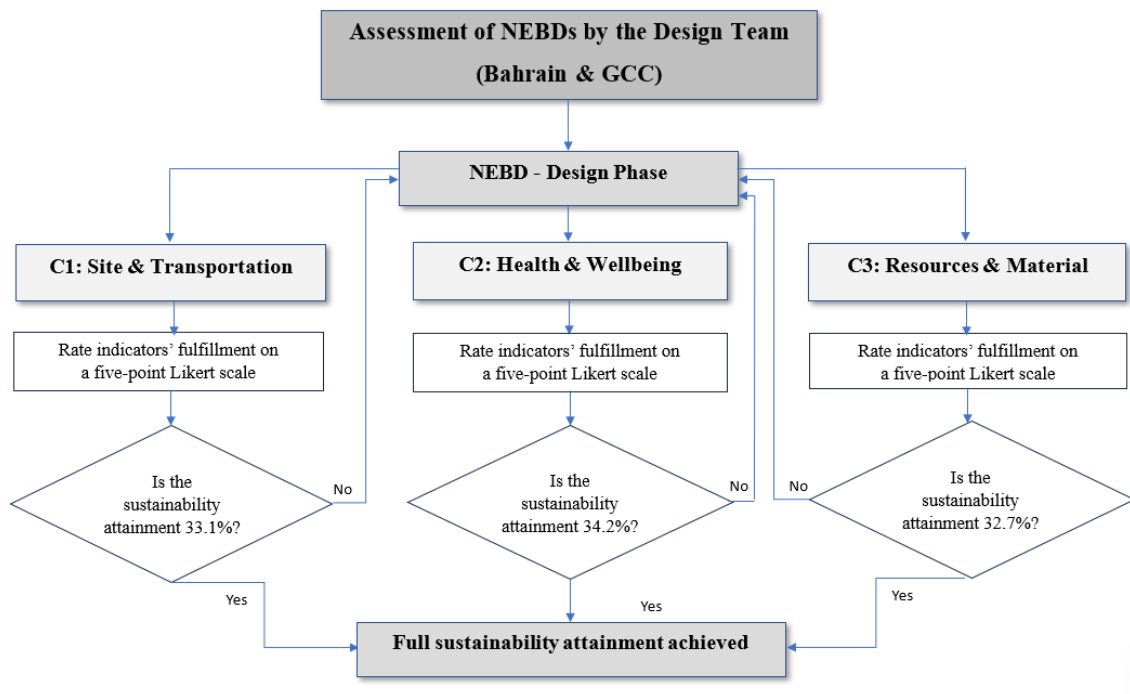


Figure 4.5: Assessment of NEBDs by the Design Team

In addition, the analytical SBAT can also be applied to provide a snapshot of the level of sustainability attainment in an NEBD or rank a number of NEBDs with regard to their level of sustainability attainment by developers, MOE, decision-makers, and the different authorities in Bahrain interested in the sustainability of NEBDs. This is illustrated in the following example:

- For the level of sustainability attainment in an NEBD, as explained in **Sections I, II, and III** earlier, the sustainability attainment for each criterion is calculated:

$$\text{Sustainability attainment of } NEBD_{S\&T} = 20.49\%$$

$$\text{Sustainability attainment of } NEBD_{H\&W} = 25.32\%$$

$$\text{Sustainability attainment of } NEBD_{R\&M} = 31.10\%$$

Thus,

The NEBD's sustainability attainment is $20.49\% + 25.32\% + 30.1\% = 75.91\%$.

- For ranking a number of NEBDs, the sustainability attainment for each NEBD is calculated as shown in the above bullet point; then, the designs are ranked. For example, the sustainability attainment for $NEBD_1 = 75.91\%$, $NEBD_2 = 82.34\%$, and $NEBD_3 = 65.2\%$. Thus, $NEBD_2$ is found to have the highest rank and could be selected for execution.

To aid assessors in using the developed analytical SBAT for NEBDs, a manual and an Excel sheet are provided (**Appendix 9**). The manual helps the assessors check the fulfillment of the design with regard to the design

considerations under each indicator. The Excel sheet facilitates the use of the developed analytical SBAT by the assessment panel. Assessors are required to rate each indicator on a five-point Likert scale (1= not fulfilled, 2 = less fulfilled, 3 = neutral, 4 = fulfilled, and 5 = very fulfilled). Columns need to be adjusted depending on the number of assessors involved in the assessment panel (ranging from 1 assessor to more than 1). The maximum possible score (Y_i) is always 35; this should be added in each assessor's column. The sheet will automatically calculate the sustainability attainment of the building with regard to the three criteria separately: "Site & Transportation," "Health & Well-being," and "Resources & Materials," and the total sustainability attainment of the NEBD considering all the criteria collectively. The manual and the Excel sheet can be accessed from the following link: https://drive.google.com/drive/folders/1F3HC_zoZAAG-qEO_TWjSULQ6IkzP1ncX?usp=sharing. This can be developed into a program or be part of a Building Information Modeling (BIM) tool.

4.3.4. Criticality of the Developed SBAT Indicators

As illustrated in **Table 4.1**, the MS for all the indicators is high (> 3.9); this is also clear in **Figure 4.2**, which shows that the majority of the participants rated all indicators as 4 and 5 on the five-point Likert scale. This confirms that the participants consider all the indicators identified in this study significant for assessing the sustainability of NEBDs in Bahrain.

In addition, out of the collected 364 valid responses in this research, 184 (50.55%) participants did not answer the third section (question 8) in the survey, which asked them to indicate any critical indicator that was not captured in the survey and that they consider important in the design stage of

new educational buildings in Bahrain. Thus, those participants considered the provided indicators sufficient to evaluate the sustainability of NEBDs.

The responses of the 180 (49.45%) participants who answered question 8 were further investigated to capture any indicator that needs to be considered in future studies. Responses included: esthetic façade design, class supporting equipment, material selection, geotechnical information, site levels, outdoor activity and learning spaces, outdoor thermal comfort, psychological well-being, building orientation, passive design solutions, none, the questionnaire includes most of the points, spaces that are conducive to learning and collaboration, functional, daylight, natural ventilation, spaces connectivity and proper circulation, consider future changes in size and activities, green technology and innovations, sport facilities, sewage systems, flexibility, accessibility, safety and security, ergonomics, technology integration (high-speed internet connectivity, smart classrooms, audio-visual systems, and IT infrastructure), flexible and collaborative spaces, outdoor sports facilities, outdoor green spaces, community connectivity, durable material selection, life cycle cost assessment, noise control, building scale and finishes type and color, underground parking, shading, esthetic design, student opinions, preserve natural ecology, local archaeological features, green roofs, vertical gardens, efficient equipment, compliance with relevant laws and regulations, Bahraini or traditional design, Islamic design, construction waste reduction, durability, cost-effectiveness, carbon footprint, recycled and re-used material, budget, considerations for disabled users, water recycling, life cycle assessment, flood management, educating occupants about sustainability, use of solar and wind energy, biophilic design, and biodiversity and green spaces.

Responses to question 8 were very similar to the indicators and their descriptions shown in **Table 3.2**, **Table 3.3**, and **Table 3.4**, except for three responses, which were the use of technology and innovation, cost-effectiveness, and considering student opinions.

Technology and innovation were embedded in indicator I7 when designing eco-parking, and also in indicators I8, I9, I10, and I11 when designing spaces that provide visual, acoustic, and thermal comfort and that are flexible. In addition to I15, I16, I17, I18, I19, and I21, innovation and technology are required for efficient consumption of energy and water, and the re-use and recycling of materials and water.

Regarding cost-effectiveness, as explained earlier, the economic dimension of sustainability is accounted for in this research, but the cost was not considered as the research is prioritizing the design of sustainable educational buildings. Designing a sustainable building may have a high initial cost but will often lead to long-term savings due to reduced maintenance and reduced energy, water, and material consumption.

Finally, regarding considering student opinions, in this research, it was not possible as it is challenging for students to understand the full technical and design aspects of the indicators used. Therefore, it is recommended that future studies consider educational building users, but will also need to consider providing guidance, explanation, and simplified indicators.

4.3.5. Comparison of the Developed SBAT with Global SBATs

Researchers have developed occupancy- and region-specific conceptual and analytical SBATs worldwide (Adabre & Chan, 2020; Adamec et al.,

2021; Haidar & Bahammam, 2021; Reddy et al., 2018). Most of these tools were developed for generic and residential buildings, emphasizing the need for other building types to be considered worldwide (Lazar & Chithra, 2020). This research filled the gap, by developing an SBAT tailored for educational buildings, a category that researchers have only explored to a lesser extent. Further, this SBAT is for Bahrain, where no prior SBAT has been established for any building type.

Recent studies have shown that achieving comprehensive sustainability in buildings requires the integration of economic, environmental, and social dimensions, referred to as the “triple bottom line” or the “sustainability triangle” (Dobrovolskienė et al., 2021; Rodrigues et al., 2023). Most developed SBATs focused on the basic three sustainability dimensions, while others incorporated additional factors such as culture, affordability, technology, governance, and others, depending on the objectives of the study. This research, similar to most research studies, focused on the three sustainability dimensions for the objective of identifying sustainability criteria and indicators for NEBDs commonly employed by leading SBRs and the literature, which mainly examined the positive and negative impacts associated with the three dimensions.

Globally, the development of analytical SBATs (index/model) using MCDM methods has been similar. This included specifying criteria and indicators that are suitable for the type and location of the building. This was followed by determining the weights of the indicators, which depend on expert judgment, by aggregating the individual judgments of experts to obtain a group judgment, ensuring experts' concurrence. Then, the criteria's

performance values were normalized. Finally, an index/model was established by aggregating the weights and performance values.

Criteria and indicators were usually determined from the literature review and/or from well-recognized SBRs. Different methods have been employed to determine the indicators' significance and to establish an index/model. Researchers selected these based on their suitability for the particular study's objectives.

Numerous MCDM approaches have been created or enhanced by various authors during the last decades (Taherdoost & Madanchian, 2023). The primary distinctions among these methods are the complexity of algorithms, the weighting techniques for criteria, the representation of preference evaluation criteria, the potential for ambiguous data, and the type of data aggregation employed (Bączkiewicz, Wątróbski, Kizielewicz, & Sałabun, 2021). Most common MCDM methods employed to assess sustainability in the construction and building industry were used either to compare alternative projects or to guide a project towards sustainability by developing an index/model.

The AHP method was the most-used MCDM method for determining the indicators' weights (Taherdoost & Madanchian, 2023). It is based on a pairwise comparison of the indicators by experts using Saaty's scale. A deficiency in this method is the consistency in the expert's judgment as the number of indicators increases, because humans are not capable of keeping consistent pairwise judgments when the number of elements increases (Asadabadi, Chang, & Saberi, 2019; Piengang, Beauregard, & Kenné, 2019). It requires repetition to adjust the experts' judgment and improve consistency

(Asadabadi et al., 2019). Thus, it is complex and involves a small number of selected experts who need to be familiar with the method.

As the sample size estimated for this research is 362 participants, and the number of indicators is 21, the AHP was not applied due to its limitations. The research employed the MS method to find the indicators' weight. The MS is simple for experts, allowing more participation (Adabre & Chan, 2020).

Among the MCDM methods commonly employed in the construction and building industry (**Table 2.6**), the SAW, WPM, Choquet Integra, MIVES, and the FSE were employed by researchers to develop an index/model (the aim of this research). Other methods were used for outranking alternatives. All the methods for developing an index/model could have been employed in this research, but, based on their description, advantages, disadvantages, application through the literature, and the objectives of this research, the FSE method was selected for the reasons discussed earlier, in **Section 3.4.3**.

The FSE method has been used by many researchers in the construction and building industry to address the complexity and subjectivity involved in sustainability assessments. For example, FSE was used to develop an index to assess the sustainability of small urban neighborhoods, the sustainability of affordable housing projects, and risk in green buildings. (Adabre & Chan, 2020; Haider et al., 2018; Nguyen & Macchion, 2023). These tools were generic or tailored for residential buildings. This research utilized the FSE method to develop an SBAT that is tailored for educational buildings, focusing on their unique spatial, functional, and environmental requirements. The research is the first to develop an FSE-based SBAT (index) tailored to the environmental, social, and economic context of Bahrain and the neighboring GCC countries that share similar regional characteristics. The data were

collected from experts in Bahrain, ensuring that the weighing reflects practical priorities rather than abstract standards. Further, this research enhances educational buildings' sustainability by providing a tool that corresponds with national education development goals and the Vision 2030 objectives.

4.4. Conclusion

This chapter analyzed and discussed the results of the data collected from 364 valid responses. The Cronbach's Alpha test for the collected data is 0.9462, which indicates very strong reliability of the participants' responses. The MS and SD are calculated to rank the 21 selected indicators and estimate their sustainability significance with respect to NEBDs in Bahrain.

Although most SBRs primarily focus on environmental sustainability rather than social and economic dimensions, in this study, the first and third highest ranks are given to the "security & safety" and "design functionality & usability" indicators, which are social sustainability indicators. Thus, the priority of sustainability indicators varies depending on the building's occupancy and location.

The three highest-ranked indicators, "security & safety," "indoor air & thermal quality," and "design functionality & usability," all belong to the "Health & Well-being" criterion. This indicates that the participants consider that accounting for the health and comfort of the occupants in NEBD in Bahrain is the most important to attain sustainability.

As illustrated in **Table 4.1**, the MS for all the indicators is high (> 3.9); this is also clear in **Figure 4.2**, which shows that the majority of the participants rated all indicators as 4 and 5 on the five-point Likert scale. This

confirms that the participants consider all the indicators identified in this study significant for assessing the sustainability of NEBDs in Bahrain.

The indicators were used to develop a comprehensive analytical SBAT that accounts for the economic, social, and environmental sustainability assessment of NEBDs in Bahrain using the FSE method. The SBAT consists of three main criteria: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials.” These criteria account for 33.1%, 34.2%, and 32.7%, respectively, of the sustainability attainment in NEBDs in Bahrain. Among these criteria, “Health & Well-being” accounts for the highest contribution to sustainability attainment. The three main criteria’s coefficients were combined in a linear and additive SBAT (model/index) to provide the total sustainability attainment in NEBDs in Bahrain:

$$\textbf{\textit{SBAT for NEBDs}} = \mathbf{0.331C1} + \mathbf{0.342C2} + \mathbf{0.327C3}$$

The SBAT developed may also be applicable to other GCC countries, as they share similar “regional characteristics.” The design team can apply the analytical SBAT to assess the sustainability of an NEBD during the design phase. In addition, the SBAT can also be used to provide a snapshot of the level of sustainability attainment in an NEBD or rank a number of NEBDs with regard to their level of sustainability attainment by developers, MOE, decision-makers, and the different authorities in Bahrain interested in the sustainability of NEBDs.

Chapter Five

Conclusions and Recommendations

5.1. Introduction

Sustainability in the building sector has garnered significant attention worldwide. This research emphasizes the importance of integrating comprehensive sustainability criteria and indicators into the design phase of new buildings and develops an SBAT for NEBDs in Bahrain.

As the educational building sector in Bahrain is expanding and outdated MOE buildings are being replaced, many new educational building designs are being produced. Ensuring the implementation of sustainability criteria and indicators within these designs will ensure the life cycle sustainability of these buildings. No assessment method has been developed for any building in Bahrain. Therefore, this research fills the gap by developing an SBAT that ensures the sustainability of NEBDs in Bahrain.

This chapter presents and discusses the novelty of this research, focusing on its conclusions and contributions to knowledge. The chapter further indicates the research limitations and proposes several uncovered topics as recommendations for future studies.

5.2. Research Conclusions

This research mainly developed a conceptual and analytical SBAT for comprehensively assessing the sustainability attainment of NEBDs in Bahrain.

The conceptual SBAT (**Figure 3.1**) was developed through an extensive literature review and an investigation of the design and construction of new building manuals using analysis of BREEAM, LEED, CASBEE, SBTool,

Estidama (PRS), and GSAS to find critical sustainability criteria and indicators necessary for the sustainability assessment of NEBDs. Three criteria were categorized: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials,” and seven indicators under each criterion were identified (21 indicators in total) that covered the three sustainability dimensions: economic, environmental, and social.

The conceptual SBAT for NEBDs proposed in this research can be applied in conducting conceptual assessments for any NEBD globally because the criteria and indicators implemented in it were categorized and selected for the design phase of educational buildings based on well-known global and local SBRs and previous research.

The analytical SBAT (model/index) was developed using FSE, an MCDM method. FSE can handle data limitations, the linguistic scale of the indicators, and the subjectivity of responses (Adabre & Chan, 2020). It is a modeling technique that can convert problems, including multi-attributes and multi-variants, into measurable quantities (Osei-Kyei & Chan, 2017; Owusu et al., 2019). The method required the conduction of an online survey among public and private sector practitioners and HEI academics involved in the built environment in Bahrain, to investigate the local importance of the indicators and integrate the criteria into a model representing the analytical SBAT.

The novel analytical SBAT (model/index) developed in this research included the three criteria: “Site & Transportation,” “Health & Well-being,” and “Resources & Materials,” accounting for 33.1%, 34.2%, and 32.7%, respectively, of the sustainability attainment in NEBDs in Bahrain. It is simple and easy for individual use. The design team can apply it to assess and improve the sustainability of an NEBD during the design phase, which was

the main purpose of implementing this research. In addition to its main purpose, it can also be used to provide a snapshot of the level of sustainability attainment in an NEBD or rank a number of NEBDs with regard to their level of sustainability attainment by decision-makers. In addition, the analytical SBAT can be generalized to other countries with similar attributes and regional characteristics to Bahrain, such as those of the GCC.

5.3. Research Contributions to Knowledge

The main contribution of this research is the development of comprehensive conceptual and analytical SBATs to assess the sustainability of NEBDs in Bahrain. Although different SBATs exist worldwide, the value of this work lies in its comprehensiveness, covering the three sustainability dimensions and its novelty in being specific to NEBDs in Bahrain, as no assessment tools have previously been developed for buildings in Bahrain. Research contributions can be categorized as follows:

Comparative and investigative studies

These were necessary to identify the most suitable methods for assessing the sustainability of NEBDs in Bahrain, as well as for selecting the critical sustainability criteria and indicators for this assessment.

- The study compared SBRs and SBATs (**Table 2.4**) and showed that SBATs are broader and balance the three sustainability dimensions, simple and easy to use, and tailored to suit a building's occupancy type and region.
- It investigated the frequently employed MCDM methods in the construction and building industry that researchers have employed to

develop analytical SBATs. These were the SAW, WPM, ELECTRE, AHP, TOPSIS, COPRAS, Choquet Integra, MIVES, WASPAS, and FSE (**Table 2.6** and **Appendix 2**). And it concluded that selecting among them depends on their alignment with the objective of the problem.

- It investigated the literature and the well-recognized global and local SBRs' new buildings' design and construction manuals (**Appendix 1**), namely, BREEAM, LEED, CASBEE, SBTool, Estidama (PRS), GSAS, and identified the common criteria and indicators between them (**Table 2.5**). Then it specified three criteria, "Site & Transportation," "Health & Well-being," and "Resources & Materials," and 21 indicators (seven indicators under each criterion) critical for assessing NEBDs.
- It investigated the opinions of specialists in the built environment in Bahrain using an online survey to find the local importance of the identified criteria and indicators.
- It proved the criticality and completeness of the identified criteria and indicators for assessing NEBDs in Bahrain using the online survey.

The comparative and investigative studies concluded that SBATs are more accurate to use than SBRs when assessing occupancy- and region-specific buildings. The studies also provided a detailed overview of existing MCDM methods used to develop SBATs in the construction and building sector. Additionally, they specified critical criteria and indicators for assessing NEBDs and found their significance according to the opinions of built environment experts in Bahrain. Thus, these studies serve as a reference for

different researchers looking to design SBATs for other building types worldwide.

Novel conceptual and analytical SBATs for NEBDs

The comparative and investigative studies guided the research to achieve its main aim:

- The study developed a novel SBAT framework for conceptually assessing the sustainability of NEBDs (**Figure 3.1**) that can be used globally.
- It developed an analytical SBAT for assessing NEBDs in Bahrain and the GCC that can convert the assessors' assessment of the linguistic indicators into measurable quantities, thus calculating the sustainability attainment as a percentage in an NEBD.
- It proved the suitability of the FSE method in developing analytical SBAT for problems that include multi-attributes and multi-variants.

Automation

To provide a smooth experience for the analytical SBAT users:

- A manual and an Excel sheet have been created to aid assessors in using the developed analytical SBAT for NEBDs (**Section 4.3.2**). Assessors are only required to rate each indicator on a five-point Likert scale, and the sheet automatically calculates the sustainability attainment of the NEBD, eliminating manual work.

5.4. Research Limitations

This research has some limitations. These do not diminish the significance of the developed analytical SBAT; rather, they reflect time and resource constraints, decisions regarding the scope of the research, and areas for improvement and future research.

Methodological limitations

Selecting a suitable MCDM method among the different methods available for a specific problem is complex, as there is no clear process to compare and check the suitability of applying a certain method among the other methods (Roy & Słowiński, 2013; Taherdoost & Madanchian, 2023). In this research, investigative and comparative studies were conducted on the MCDM methods commonly employed in the construction and building industry (**Table 2.6**) to develop an index/model. The FSE method was selected due to its alignment with the research's objectives, as explained in **Section 3.4.3**, its use in the literature within comparable research, and its applicability verified through the pilot study (**Section 3.6**). However, the lack of a framework for MCDM method selection introduces subjectivity. Future studies may establish more methodological comparison frameworks to aid in decisions regarding MCDM methods selection.

In addition, the development of the analytical SBAT was enhanced by the substantial input of 364 built-environment experts' opinions regarding the local importance of the indicators through an online survey. But due to delays in data collection, some unexpected research obstacles, and the researcher's interest in publishing papers based on this research, it was not possible to conduct case studies for NEBDs in Bahrain to test the validity of the

developed analytical SBAT (index/model), which limits the tool's empirical grounding. Future studies may consider NEBD case studies in Bahrain to check the validity of the tool and case studies in the GCC to check its generalizability across the GCC countries.

Contextual limitations

Responses for the data were collected from experts practicing only in Bahrain. Therefore, the analytical SBAT developed in this research could be suitable for the GCC countries in the same region, but is unlikely to be comprehensive for educational buildings in different regions. Other regions can use the conceptual SBAT framework developed in this research or modify it and perform a similar approach as in this research to investigate the opinions of specialists in the built environment in that region, find indicators' weights, and develop an analytical SBAT specifically for NEBDs in that region.

Analytical and technical limitations

The developed analytical SBAT considers each criterion's index but neglects the weights of indicators obtained from the survey participants. Improving a criterion's sustainability attainment requires improving the indicators' considerations within that criterion regardless of the weight of each indicator, i.e., in the "Site & Transportation" criterion, improving the sustainability attainment for this criterion is achieved by improving the considerations of any indicator, although different indicators have different weights (e.g., "accessibility" is ranked forth and has a higher weight than "eco-parking," which is ranked twentieth by participants). In this research, this limitation can be ignored as all indicators are ranked high and have nearly equal weight. Future studies that may observe great differences in the

indicators' weights will need to explore other approaches to overcome this issue, such as employing sub-indicators and investigating their scores to obtain a score for each indicator.

Additionally, this research aims to develop an SBAT specifically for NEBDs; thus, long-term sustainability outcomes cannot be assessed because the tool excludes post-occupancy performance, operational aspects, and overall life-cycle impacts. Future studies may develop other tools for subsequent phases of educational building projects.

Moreover, the SBAT includes economic indicators but does not incorporate Life Cycle Costing (LCC). This is because the tool's scope is to guide the design stage in achieving sustainability considerations rather than to perform quantitative analysis. Since cost justification is important, especially in NEBDs of public projects, the strategic decision-making ability of the tool may be enhanced by integrating simplified LCC components that align with the design stage.

Furthermore, a manual and an Excel sheet have been created to enhance user accessibility and simplicity. However, the lack of integration of the tool with digital design environments, such as Building Information Modeling (BIM) and other architectural platforms, presents a technical limitation that hinders the tool's automation, digital collaboration, and visualization capabilities during the design process. To enhance the usability, scalability, and industry adoption of the developed SBAT, future studies may integrate it with digital design tools.

5.5. Recommendations for Future Studies

The following recommendations for future studies are categorized into short-term and long-term based on their level of advancement, technical complexity, and required development resources. These suggestions aim to guide subsequent research to enhance the accuracy and applicability of the developed SBAT.

Short-term recommendations

- Future research may utilize NEBD case studies in Bahrain to validate the practical application and efficiency of the developed analytical SBAT index/model. Case studies in the GCC may be utilized to evaluate the tools' validity and generalizability across the GCC countries
- Future research may investigate educational building users' opinions on the significance of sustainability indicators, considering the need to provide guidance, explanations, and simplified indicators. This can enhance the tool and ensure it aligns with users' priorities.
- Future research may focus on expanding the developed SBAT by identifying sub-indicators and examining their scores. This will enhance assessment specificity and improve the tool's sensitivity to sustainability aspects in NEBDs.
- Future studies may utilize an alternative MCDM method or hybrid methods to develop the analytical SBAT for NEBDs in Bahrain. This will evaluate the tool's sensitivity and resilience across various MCDM methods.

Long-term recommendations

- Future studies may develop conceptual and analytical SBATs tailored for different building phases across various regions/countries and types of building occupancy, using this research as a reference.
- Future studies may investigate and compare additional SBRS criteria and indicators related to NEBDs to propose a standard conceptual framework for NEBDs that can be applied globally.
- Future studies may integrate simplified LCC components into the tool, aligning them with inputs from the design stage to enhance the tool's strategic decision-making capacity, particularly in NEBDs of public projects where cost justification is crucial.
- Future studies may incorporate digital design tools such as BIM into the developed SBAT. This will improve the tool's efficiency in collaborative design environments and ensure that it is consistent with industry trends.
- Future studies may introduce a systematic framework to guide and reduce subjectivity in selecting MCDM methods for sustainability assessments in the building sector. This framework may encompass variables such as problem type, stakeholder engagement, data availability, and preferred output format.
- Future studies may conduct post-occupancy evaluations on educational buildings designed using the developed SBAT in Bahrain to validate the tool's outcomes. This will allow for a comparison between the predicted sustainability performance during the design stage and the actual performance during building operation, which will enhance the practical validity and credibility of the tool.

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Appendices

Appendix 1: Sustainability Criteria and Indicators in Buildings

From Existing SBRs – LEED, BREEAM, CASBEE, SBTTool, PRS & GSAS

Criteria/Sub-Criteria	Indicators
BREEAM - UK Building Design and Construction (International New Construction Manual) (10 Criteria & 55 Indicators) Reference: Building Research Establishment Environmental Assessment Methodology (2016)	
Management	➤ Project brief and design ➤ Life cycle cost and service life planning ➤ Responsible construction practices ➤ Commissioning and handover ➤ Aftercare
Health & Well-being	➤ Visual comfort ➤ Indoor air quality ➤ Safe containment in laboratories ➤ Thermal comfort ➤ Acoustic performance ➤ Accessibility ➤ Hazards ➤ Private space ➤ Water quality
Energy	➤ Reduction of energy use and carbon emissions ➤ Energy monitoring ➤ External lighting ➤ Low carbon design ➤ Energy-efficient cold storage ➤ Energy-efficient transport systems ➤ Energy-efficient laboratory systems ➤ Energy-efficient equipment ➤ Drying space
Transport	➤ Public transport accessibility ➤ Proximity to amenities ➤ Alternative modes of transport ➤ Maximum car parking capacity ➤ Travel plan
Water	➤ Water consumption ➤ Water monitoring ➤ Water leak detection ➤ Water efficient equipment

Materials	➤ Life cycle impacts ➤ Hard landscaping and boundary protection ➤ Responsible sourcing of materials ➤ Insulation ➤ Designing for durability and resilience ➤ Material efficiency
Waste	➤ Construction waste management ➤ Recycled aggregates ➤ Operational waste ➤ Speculative floor and ceiling finishes ➤ Adaptation to climate change ➤ Functional adaptability
Land Use & Ecology	➤ Site selection ➤ Ecological value of site and protection of ecological features ➤ Minimizing impact on existing site ecology ➤ Enhancing site ecology ➤ Long-term impact on biodiversity
Pollution	➤ Impact of refrigerants ➤ Nox emissions ➤ Surface water run-off ➤ Reduction of night-time light pollution ➤ Reduction of noise pollution
Innovation	➤ Innovation

Criteria/Sub-Criteria	Indicators
LEED – US Building Design and Construction (New Construction & Major Renovation Manual) (7 Criteria & 41 Indicators) Reference: US Green Building Council (2019)	
Location & Transportation	➤ Sensitive land protection ➤ High-priority site ➤ Surrounding density and diverse uses ➤ Access to quality transit ➤ Bicycle facilities ➤ Reduced parking footprint ➤ Green vehicles
Sustainable Sites	➤ Site assessment ➤ Site development - protect or restore habitat ➤ Open space ➤ Rainwater management ➤ Heat island reduction ➤ Light pollution reduction
Water Efficiency	➤ Outdoor water use reduction ➤ Indoor water use reduction ➤ Cooling tower water use ➤ Water metering
Energy & Atmosphere	➤ Enhanced commissioning ➤ Optimize energy performance ➤ Advanced energy metering ➤ Demand response ➤ Renewable energy production ➤ Enhanced refrigerant management ➤ Green power and carbon offsets
Materials & Resources	➤ Building life cycle impact reduction ➤ Building product disclosure and optimization - environmental product ➤ Declarations ➤ Building product disclosure and optimization - sourcing of raw materials ➤ Building product disclosure and optimization - material ingredients ➤ Construction and demolition waste management
Indoor Environmental Quality	➤ Enhanced indoor air quality strategies ➤ Low-emitting materials ➤ Construction indoor air quality management plan ➤ Indoor air quality assessment ➤ Thermal comfort ➤ Interior lighting ➤ Daylight ➤ Quality views ➤ Acoustic performance
Innovation	➤ Innovation ➤ LEED Accredited Professional

Criteria/Sub-Criteria		Indicators
CASBEE – Japan Building Design & Construction (New Construction Manual) (6 Criteria, 20 Sub-Criteria & 41 Indicators) Reference: Institute for Building Environment and Energy Conservation (2014)		
Indoor Environment	Sound Environment	➤ Noise ➤ Sound insulation ➤ Sound absorption
	Thermal Comfort	➤ Room temperature control ➤ Humidity control ➤ Type of air-conditioning system
	Lighting & Illumination	➤ Daylight ➤ Anti-glare measures ➤ Illuminance level ➤ Lighting controllability
	Air Quality	➤ Source control ➤ Ventilation ➤ Operation plan
Quality of Service	Serviceability	➤ Functionality & usability ➤ Amenity ➤ Maintenance
	Durability & Reliability	➤ Earthquake resistance ➤ Service life of components ➤ Reliability
	Flexibility & Adaptability	➤ Spatial margin ➤ Floor load margin ➤ System renewability
Outdoor Environment (On-site)	Preservation & Creation of Biotope	
	Townscape & Landscape	
	Local Characteristics & Outdoor Amenity	➤ Attention to local character & improvement of comfort ➤ Improvement of the thermal environment on site
Energy	Control of Heat Load on the Outer Surface of Buildings	
	Efficiency in Building Service System	
	Natural Energy Utilization	
	Efficient Operation	➤ Monitoring ➤ Operation & Management System
Resources & Materials	Water Resources	➤ Water saving ➤ Rainwater & grey water

	Reducing Use of Non-Renewable Resources	➤ Reducing the use of materials ➤ Continuing use of existing structure frame ➤ Use of recycled materials as structural materials ➤ Use of recycled materials as non-structural materials ➤ Timber from sustainable forestry ➤ Efforts to enhance the reusability of components and materials
	Avoiding the Use of Materials with Pollutant Content	➤ Use of materials without harmful substances ➤ Elimination of CFCs & halons
	Consideration of Global Warming	
	Consideration of Local Environment	➤ Air pollution ➤ Heat island effect ➤ Load on local infrastructure
Off-site Environment	Consideration of Surrounding Environment	➤ Noise, vibration & odor ➤ Wind, sand damage, & daylight obstruction

Criteria/Sub-Criteria		Indicators
SBTool - Canada Building Design Manual (7 Criteria, 26 Sub-Criteria & 159 Indicators) Reference: International Initiative for a Sustainable Built Environment (2020)		
Site Regeneration & Development, Urban Design & Infrastructure	Site Regeneration & Development	➤ Protection and restoration of wetlands ➤ Reforestation for carbon sequestration, soil stability, and biodiversity ➤ Development or maintenance of wildlife corridors ➤ Remediation of contaminated soil, groundwater, or surface water ➤ Shading of building(s) by deciduous trees ➤ Use of vegetation to provide ambient outdoor cooling ➤ Use of native plant types ➤ Provision of public open space(s) ➤ Provision and quality of children's play area(s) ➤ Facilities for small-scale food production for residential occupants ➤ Provision and quality of bicycle pathways and parking ➤ Provision and quality of walkways for pedestrian use
	Urban Design	➤ Maximizing efficiency of land use through development density ➤ Reducing need for commuting transport through provision of mixed-uses ➤ Impact of orientation on the passive solar potential of building(s) ➤ Building morphology, aggregate measure ➤ Impact of site and building orientation on natural ventilation of building(s) during warm season(s) ➤ Impact of site and building orientation on natural ventilation of building(s) during cold season(s)
	Project Infrastructure & Services	➤ Supply, storage, and distribution of surplus thermal energy amongst groups of buildings ➤ Supply, storage, and distribution of surplus photovoltaic energy amongst groups of buildings ➤ Supply, storage and distribution of surplus hot water amongst groups of buildings ➤ Supply, storage and distribution of surplus rainwater and greywater amongst groups of buildings ➤ Provision of facility to produce energy from solid waste ➤ Provision of solid waste collection and sorting services ➤ Composting and re-use of organic sludge ➤ Provision of split grey/potable water services

Energy & Resource Consumption	Total Life Cycle Non-Renewable Energy	➤ Provision of surface water management system
		➤ On-site treatment of rainwater, stormwater, and greywater
		➤ On-site treatment of liquid sanitary waste
		➤ Provision of on-site communal transportation system(s)
		➤ Provision of on-site parking facilities for private vehicles
		➤ Connectivity of roadways
		➤ Provision of access roads and facilities for freight or delivery
		➤ Provision and quality of exterior lighting
	Electrical Peak Demand	➤ Embodied non-renewable energy in original construction materials
		➤ Embodied non-renewable energy in construction materials for maintenance or replacement(s)
Environmental Loadings	Use of Materials	➤ Consumption of non-renewable energy for all building operations
		➤ Consumption of renewable energy for all building operations
		➤ Consumption of non-renewable energy for project-related transport
		➤ Consumption of non-renewable energy for demolition or dismantling process
		➤ Electrical peak demand for building operations
		➤ Scheduling of building operations to reduce peak loads on generating facilities
	Use of Potable Water, Stormwater & Greywater	➤ Degree of re-use of suitable existing structure(s) where available
		➤ Protection of materials during construction phase
		➤ Material efficiency of structural and building envelope components
		➤ Use of virgin, non-renewable materials
		➤ Efficient use of finishing materials
Environmental Loadings	Greenhouse Gas Emissions	➤ Ease of disassembly, re-use, or recycling
		➤ Embodied water in original construction materials
		➤ Use of water for occupant needs during operations
		➤ Use of water for irrigation purposes
		➤ Use of water for building systems
Environmental Loadings	Greenhouse Gas Emissions	➤ GHG emissions from energy embodied in original construction materials
		➤ GHG emissions from energy embodied in construction materials used for maintenance or replacement(s)
		➤ GHG emissions from primary energy used for all purposes in facility operations
		➤ GHG emissions from primary energy used for project-related transport

	Other Atmospheric Emissions	➤ Emissions of ozone-depleting substances during facility operations ➤ Emissions of acidifying emissions during facility operations ➤ Emissions leading to photo-oxidants during facility operations
	Solid & Liquid Wastes	➤ Solid waste from the construction and demolition process retained on the site ➤ Solid non-hazardous waste from facility operations sent off the site ➤ Risk of non-radioactive hazardous waste resulting from facility operations ➤ Radioactive waste resulting from facility operations ➤ Liquid effluents from building operations that are sent off the site
	Impacts on Project Site	➤ Impact of construction process on natural features of the site ➤ Impact of construction process or landscaping on soil stability or erosion ➤ Recharge of groundwater through permeable paving or landscaping ➤ Changes in biodiversity on the site ➤ Adverse wind conditions at grade around tall buildings
	Other Local & Regional Impacts	➤ Impact on access to daylight or solar energy potential of adjacent property ➤ Impact of construction process on local residents and commercial facility users ➤ Impact of building user population on peak load capacity of public transport system ➤ Impact of private vehicles used by building population on peak load capacity of local road system ➤ Potential for project operations to contaminate nearby bodies of water ➤ Cumulative (annual) thermal changes to lake water or sub-surface aquifers ➤ Contribution to Heat Island Effect from roofing, landscaping, and paved areas ➤ Degree of atmospheric light pollution caused by project exterior lighting systems
Indoor Environment Quality	Indoor Air Quality & Ventilation	➤ Pollutant migration between occupancies ➤ Pollutants generated by facility maintenance ➤ Mold concentration in indoor air ➤ Volatile organic compounds' concentration in indoor air ➤ CO2 concentrations in indoor air ➤ Effectiveness of ventilation in naturally ventilated occupancies during cooling seasons

		➤ Effectiveness of ventilation in naturally ventilated occupancies during intermediate seasons ➤ Effectiveness of ventilation in naturally ventilated occupancies during heating seasons ➤ Air movement in mechanically ventilated occupancies ➤ Effectiveness of ventilation in mechanically ventilated occupancies
	Air Temperature & Relative Humidity	➤ Appropriate air temperature and relative humidity in mechanically cooled occupancies ➤ Appropriate air temperature in naturally ventilated occupancies
	Daylighting & Illumination	➤ Appropriate daylighting in primary occupancy areas ➤ Control of glare from daylighting ➤ Appropriate illumination levels and quality of lighting in non-residential occupancies
	Noise & Acoustics	➤ Noise attenuation through the exterior envelope ➤ Transmission of facility equipment noise to primary occupancies ➤ Noise attenuation between primary occupancy areas ➤ Appropriate acoustic performance within primary occupancy areas
	Control of Electromagnetic Emissions	➤ Electromagnetic emissions
Service Quality	Safety & Security	➤ Construction safety ➤ Risk to occupants and facilities from fire ➤ Risk to occupants and facilities from flooding ➤ Risk to occupants and facilities from windstorms ➤ Risk to occupants and facilities from earthquake ➤ Risk to occupants and facilities from use of explosive device ➤ Risk to occupants from incidents involving biological or chemical substances ➤ Occupant egress from tall buildings under emergency conditions ➤ Maintenance of core building functions during power outages ➤ Personal security for building users during normal operations
	Functionality & Efficiency	➤ Appropriateness of types of facilities provided for tenant or occupant needs ➤ Functionality of layout(s) for required functions ➤ Appropriateness of space provided for required functions ➤ Appropriateness of fixed equipment for required functions

Social, Cultural & Perceptual Aspects		➤ Provision of exterior access and unloading facilities for freight or delivery
		➤ Efficiency of vertical or horizontal transportation systems in building
		➤ Spatial efficiency
		➤ Volumetric efficiency
	Controllability	➤ Effectiveness of facility management control system
		➤ Capability for partial operation of facility technical systems
		➤ Degree of local control of lighting systems
		➤ Degree of personal control of technical systems by occupants
	Flexibility & Adaptability	➤ Ability for building operator or tenant to modify facility technical systems
		➤ Potential for horizontal or vertical extension of structure
		➤ Adaptability constraints imposed by structure or floor-to-floor heights
		➤ Adaptability constraints imposed by building envelope and technical systems
		➤ Adaptability to future changes in type of energy supply
	Optimization & Maintenance of Operating Performance	➤ Operating functionality and efficiency of key facility systems
		➤ Adequacy of the building envelope for maintenance of long-term performance
		➤ Durability of key materials
➤ Existence and implementation of a maintenance management plan		
➤ On-going monitoring and verification of performance		
➤ Retention of as-built documentation		
➤ Provision and maintenance of a building log		
➤ Provision of performance incentives in leases or sales agreements		
Social Aspects	➤ Level of skills and knowledge of operating staff	
	➤ Universal access on site and within the building	
	➤ Access to direct sunlight from living areas of dwelling units	
	➤ Visual privacy in principal areas of dwelling units	
	➤ Access to private open space from dwelling units	
	➤ Involvement of residents in project management	
Culture & Heritage	➤ Compatibility of urban design with local cultural values	
	➤ Provision of public open space compatible with local cultural values	
	➤ Impact of the design on existing streetscapes	
	➤ Use of traditional local materials and techniques	

		➤ Maintenance of the heritage value of the exterior of an existing facility ➤ Maintenance of the heritage value of the interior of an existing facility
	Perceptual	➤ Impact of tall structure(s) on existing view corridors ➤ Quality of views from tall structures ➤ Sway of tall buildings in high wind conditions ➤ Perceptual quality of site development ➤ Aesthetic quality of facility exterior ➤ Aesthetic quality of facility interior ➤ Access to exterior views from interior
Cost & Economic Aspects	Cost & Economics	➤ Construction cost ➤ Operating and maintenance cost ➤ Life cycle cost ➤ Investment risk ➤ Affordability of residential rental or cost levels ➤ Impact of project on land values of adjacent properties ➤ Impact of construction and operations on the local economy ➤ Economic viability of commercial occupancies

Criteria/Sub-Criteria	Indicators
PRS for Estidama - Abu Dhabi, United Arab Emirates Building Design and Construction Manual (8 Criteria & 86 Indicators) Reference: Abu Dhabi Urban Planning Council (2010)	
Integrated Development Process	➤ Integrated development strategy ➤ Tenant fit-out design & construction guide ➤ Basic commissioning ➤ Life cycle costing ➤ Guest worker accommodation ➤ Construction environmental management ➤ Building envelope verification ➤ Re-commissioning ➤ Sustainability communication
Natural Systems	➤ Natural systems assessment ➤ Natural systems protection ➤ Natural systems design & management strategy ➤ Re-use of land ➤ Remediation of contaminated land ➤ Ecological enhancement ➤ Habitat creation & restoration
Livable Buildings: Outdoors	➤ Plan 2030 ➤ Urban systems assessment ➤ Outdoor thermal comfort strategy ➤ Improved outdoor thermal comfort ➤ Pearl-rated communities ➤ Accessible community facilities ➤ Active urban environments ➤ Private outdoor space ➤ Public transport ➤ Bicycle facilities ➤ Preferred car parking spaces ➤ Travel plan ➤ Light pollution reduction
Livable Buildings: Indoors	➤ Healthy ventilation delivery ➤ Smoking control ➤ Legionella prevention ➤ Ventilation quality ➤ Material emissions: adhesives & sealants ➤ Material emissions: paints & coatings ➤ Material emissions: carpet & hard flooring ➤ Material emissions: ceiling systems ➤ Material emissions: formaldehyde reduction ➤ Construction indoor air quality management ➤ Car park air quality management ➤ Thermal comfort & controls: thermal zoning ➤ Thermal comfort & controls: occupant control ➤ Thermal comfort & controls: thermal comfort modeling

	➤ High-frequency lighting ➤ Daylight & glare ➤ Views ➤ Indoor noise pollution ➤ Safe & secure environment
Precious Water	➤ Minimum interior water use ➤ Exterior water monitoring ➤ Improved interior water use reduction ➤ Exterior water use reduction: landscaping ➤ Exterior water use reduction: heat rejection ➤ Exterior water use reduction: water features ➤ Water monitoring & leak detection ➤ Stormwater
Resourceful Energy	➤ Minimum energy performance ➤ Energy monitoring & reporting ➤ Ozone impacts of refrigerants & fire suppression systems ➤ Improved energy performance ➤ Cool building strategies ➤ Energy-efficient appliances ➤ Vertical transportation ➤ Peak load reduction ➤ Renewable energy ➤ Global warming impacts of refrigerants & fire suppression systems
Stewarding Materials	➤ Hazardous materials elimination ➤ Basic construction waste management ➤ Basic operational waste management ➤ Non-polluting materials ➤ Design for materials reduction ➤ Design for flexibility & adaptability ➤ Design for disassembly ➤ Modular flooring systems ➤ Design for durability ➤ Building re-use ➤ Material re-use ➤ Regional materials ➤ Recycled materials ➤ Rapidly renewable materials ➤ Re-used or certified timber ➤ Improved construction waste management ➤ Improved operational waste management ➤ Organic waste management
Innovating Practice	➤ Innovative cultural & regional practices ➤ Innovating practice

Criteria/Sub-Criteria	Indicators
GSAS - Qatar Building Design and Construction Manual (8 Criteria & 54 Indicators) Reference: Gulf Organization for Research & Development (2019)	
Urban Connectivity	➤ Proximity to infrastructure ➤ Proximity to amenities ➤ Load on local traffic conditions ➤ Public transportation ➤ Green transportation ➤ Neighborhood acoustics
Site	➤ Land preservation ➤ Waterbody preservation ➤ Biodiversity preservation ➤ Vegetation ➤ Drain & stormwater contamination ➤ Rainwater runoff ➤ Heat island effect ➤ Shading ➤ Accessibility ➤ External lighting ➤ Light pollution ➤ Noise pollution ➤ Eco-parking ➤ Construction practices
Energy	➤ Thermal energy demand performance ➤ Energy use performance ➤ Primary energy performance ➤ CO₂ emissions ➤ Energy sub-metering ➤ Renewable energy
Water	➤ Water demand performance ➤ Water re-use performance ➤ Water sub-metering
Materials	➤ Locally sourced materials ➤ Materials eco-labeling ➤ Recycled content of materials ➤ Materials re-use ➤ Existing structure re-use ➤ Design for disassembly ➤ Responsible sourcing of materials
Indoor Environment	➤ Thermal comfort ➤ Natural ventilation ➤ Mechanical ventilation ➤ Lighting ➤ Daylight ➤ Glare ➤ Views ➤ Acoustics

	➤ Low-VOC materials
	➤ Airborne contaminants
Cultural & Economic Value	➤ Heritage & cultural identity
	➤ Support of national economy
Management & Operations	➤ Systems commissioning
	➤ Waste management
	➤ Facility management
	➤ Leak detection systems
	➤ Automated control system
	➤ Transportation systems in building

From the Literature Review – Educational Buildings

Criteria	Indicators
School Buildings - Iraq Design, Construction & Operation (6 Criteria & 38 Indicators) Reference: Alhilli & Burhan (2021)	
Environmental Design	➤ Use natural ventilation ➤ Use of natural daylight ➤ Use a ratio of green areas to solid areas ➤ Use of integrated design (interior design consistency with lighting, air conditioning, and finishes) ➤ Use of windows and glass: to balance the light and the thermal effect of the sun ➤ Use thermal insulators ➤ Use of the indirect solar system (as a source of heating, ventilation, and lighting) ➤ Use of climate comfort around the building: high centrifugal devices for heat and use of colors in the interfaces ➤ Use of design flexibility and scalability: Increase the number of classrooms in the future ➤ Use of entries and mobility: for people with special needs
Sustainable Site Selection	➤ Selection of non-green land when constructing the building ➤ Location near population density ➤ Availability of services ➤ Transportation (use of a site that is suitable for the use of environmentally friendly transportation such as bicycles) ➤ Construction in pre-invested areas ➤ Redevelopment: Selection of previously exploited sites such as industrial land ➤ Use of previously constructed buildings and sites (rehabilitation) ➤ Location selection: High above sea level
Materials & Resources Management	➤ Use of demolition and construction waste ➤ Use of waste management system ➤ Use of recyclable materials ➤ Reduce the use of new construction material ➤ Use of reflective materials for heat ➤ Use of environmentally friendly materials ➤ Use the old building casing of the structure, windows, and doors in the new building ➤ Flooring (use of easy-to-clean, maintenance, recyclable and low-emission organic matter)
Energy Management	➤ Use of power generators (without emissions) ➤ Use of LED lighting and sensors for daytime lighting ➤ Energy conservation in outer spaces ➤ Using intelligent monitoring technology ➤ Use advanced cooling and heating systems

	➤ Use refrigerant management systems to protect the ozone layer
	➤ Use (soundproof design - furniture - insulators) to control the noise
Management of the Internal Environment	➤ Use of ventilation and control of smoking
	➤ Use of paints, carpets, furniture, and cleaning materials free of volatile organic matter in the building
	➤ Use of absorbent materials for moisture
Management of Water & Treated Water	➤ Use of mechanisms to reduce water consumption

Criteria/Sub-Criteria	Indicators
High School Buildings - Portugal Design, Construction & Operation (11 Criteria & 24 Indicators) Reference: Saraiva et al. (2019)	
Climate Change & Outdoor Air Quality	➤ Life cycle environmental impacts (use materials and construction solutions that have low environmental impact) ➤ Heat island effect (use of outdoor green areas and high reflectance material)
Biodiversity & Land Use	➤ Land use efficiency (optimizing land occupation) ➤ Certificated materials (use of organic products with environmental certification)
Energy	➤ Energy consumption (reduction through the use of passive solutions and efficient equipment) ➤ Renewable energy (use passive solutions and efficient equipment) ➤ Commissioning (appropriate management of mechanical systems throughout the building life cycle)
Materials, Solid Residues & Resources Management	➤ Re-use and recycling of materials (use of re-used materials and materials with recycled content) ➤ Environmental management plan (appropriate management of resources during the use phase of the building) ➤ Flexibility and adaptability (construction solutions and processes to facilitate the changing uses of the building)
Water	➤ Water consumption (using efficient systems) ➤ Water treatment and recycling (using recycling devices and reusing rainwater, groundwater, or greywater) ➤ Collection and re-use of rainwater
User Health & Comfort	➤ Indoor air quality ➤ Thermal comfort ➤ Visual comfort (illumination levels provided by natural lighting and artificial lighting) ➤ Acoustic comfort ➤ Ergonomic comfort
Accessibility	➤ Mobility plan
Security & Safety	➤ Occupants' security and safety
Education for Sustainability Awareness	➤ Sustainability awareness
Sustainability of the Area	➤ Accessibility to public transport
Life Cycle Costs	➤ Life cycle costs (maximize initial costs and reduce life cycle costs)

From the Literature Review – Buildings in General

Criteria	Indicators
General Buildings - Kazakhstan Design, Construction & Operation (9 Criteria & 45 Indicators) Reference: Akhanova et al. (2019)	
Construction Site Selection & Infrastructure	➤ Land use ➤ Low-impact site construction ➤ Access to social, domestic, and socio-economic facilities ➤ Access to public and ecological transport ➤ Greenspace ➤ Landscape irrigation ➤ Visual comfort
Building Architectural & Planning Solutions Quality	➤ Building architectural appearance quality ➤ Building form and orientation ➤ Greening the building ➤ Useful floor space ➤ Parking capacity ➤ Safety and inclusiveness of opportunities
Indoor Environmental Quality & Comfort	➤ Thermal comfort ➤ Daylighting ➤ Insolation level ➤ Acoustic comfort ➤ Noise protection ➤ Air pollution monitoring ➤ Natural ventilation
Water Efficiency	➤ Building water conservation ➤ Application of innovative water-efficient equipment ➤ Leak detection ➤ Water-efficient landscaping ➤ Water recycling and re-use
Energy Efficiency	➤ Building commissioning ➤ Renewable energy sources use ➤ Greenhouse gases emission ➤ Energy-efficient heating and cooling ➤ Energy-efficient equipment ➤ Energy-saving - Reduction of electricity consumption ➤ Energy-saving - Natural gas efficiency
Green Building Materials Waste	➤ Local/regional building materials ➤ Recycled materials ➤ Secondary use of recycled materials ➤ Construction waste management ➤ Building operation and disposal impact
Economy	➤ Building total life cycle costs ➤ Annual operating costs ➤ Affordability

Management	➤ Environmental management certificate ➤ Green building accredited expert ➤ Designer's green building experience ➤ Contractor's green building experience ➤ Education and awareness
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Criteria/Sub-Criteria	Indicators
General Buildings - India Design, Construction & Operation (8 Criteria & 43 Indicators) Reference: Reddy et al. (2018)	
Water Efficiency	➤ Water monitoring and leak detection ➤ Building water use reduction ➤ Minimize portable water use ➤ Recycling and re-use of water ➤ Rainwater management ➤ Efficient landscaping
Materials & Waste Management	➤ Low-energy materials ➤ Regionally available materials ➤ Recycled and re-use materials ➤ Responsible sourcing ➤ Efficient waste management ➤ Recycled aggregates
Health & Well-being	➤ Visual and thermal comfort ➤ Water quality & water pollution ➤ Reduce air pollution ➤ Outdoor & indoor noise levels ➤ Sanitation/Safety facilities & accessibility ➤ Minimize ozone depletion
Energy Efficiency	➤ Renewable energy production ➤ Energy-efficient design ➤ Energy monitoring ➤ Refrigerant and green power management ➤ Optimize energy performance ➤ Vertical transportation
Sustainable Sites	➤ Site selection ➤ Protect or restore habitat ➤ Heat island reduction ➤ Open space ➤ Joint use of facilities ➤ Site improvement plan
Social Welfare	➤ Sustainable or environmental education ➤ Responsible construction practices ➤ Design for durability ➤ Health, well-being, and accommodation ➤ Employment opportunities ➤ Innovation
Transportation	➤ Green vehicles/Alternative modes of transport ➤ Bicycle facilities ➤ Proximity to amenities ➤ Public transport accessibility ➤ Home office ➤ Reduced parking footprint
Management	➤ Project brief and design ➤ Site management

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- Life cycle costing
 - Audit and validation
 - Commissioning and handover
 - Aftercare
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Appendix 2: Frequently Employed MCDM Methods in the Construction and Building Industry (adapted from Moghtadernejad et al., 2018; Gilani, 2020)

Steps	Area of application	References
1. SAW or WSM		
$A_{WSM} = \sum_{j=1}^n a_{ij}w_j$ Where A_{SAW} is the SAW score of each alternative, with n decision criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion.	Sustainability assessment of real estate, heritage buildings, affordable housing, and cladding product selection.	Adabre & Chan (2020); Dobrovolskienė et al. (2021); Friedrich & Luible (2016); Mulliner et al. (2016)
2. WPM		
$P(A_i) = \prod_{j=1}^n (a_{ij})^{w_j}$ Where $P(A_i)$ is the WPM score of each alternative, with n decision criteria, a_{ij} is the actual value of the i^{th} alternative in terms of the j^{th} criterion, and w_j is the weight of importance of the j^{th} criterion.	Sustainability assessment of heritage buildings, and assessment of façade alternatives.	Al-Sakkaf (2020); Zavadskas et al. (2013)
3. ELECTRE		
Associating appropriate weights to the matrix, determination of the concordance and discordance sets and construction of the related matrices, determination of the concordance and discordance dominance matrices and the aggregate dominance matrix, and finally elimination of the less favorable alternatives. If alternative A_l is preferred to A_k: $C_{lk} = \sum_{j=1}^n w_j c_j(A_l A_k) / \sum_{j=1}^n w_j$ Where w_j is the weight associated with j^{th} criterion.	Sustainable building material selection, and sustainability assessment of modular residential buildings.	Chen, Martínez, Chang, Wang, Xionge, & Chin (2019); Kamali et al. (2018)
4. AHP		
$A_{AHP-Score} = \sum_{j=1}^n a_{ij}w_j$ Where a_{ij} are elements of the matrix A, and w_j is the weight assigned to the j^{th} criterion, using pairwise comparisons, and calculating the priority vector (normalized principal Eigen vector).	Weighing sustainability indicators of municipal residential buildings, real estate projects, buildings in general, renewable energy development, and green technologies.	Dobrovolskienė et al. (2021); Klumbytė et al. (2021); Kumar et al. (2017); Medineckiene et al. (2015); Si et al. (2019)

5. TOPSIS

$$S_i^* = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^*)^2} \text{ and}$$

$$S_i^- = \sqrt{\sum_{j=1}^n (v_{ij} - v_j^-)^2}, \quad C_i^* = \frac{S_i^-}{S_i^- + S_i^*}$$

Where S_i^* and S_i^- , are ideal and negative-ideal solutions respectively, and v_{ij} is the weighted normalized value of i^{th} alternative. v_j^* and v_j^- are respectively the best and the worst scores of j^{th} criterion among alternatives. C_i^* corresponds to the relative closeness to the ideal solution which is the basis for ranking the alternatives.

Sustainability assessment in heritage buildings, and assessment of sustainable building components.

Al-Sakkaf (2020); Fazeli, Jalaei, Khanzadi, & Banihashemi (2022)

6. COPRAS

$$N_j = \frac{Q_j}{Q_{max}} \cdot 100\%$$

$$Q_j = S_{+j} + \frac{S_{-min} \cdot \sum_{j=1}^n S_{-j}}{S_{-j} \cdot \sum_{j=1}^n \frac{S_{-min}}{S_{-j}}}$$

$$j = \overline{1, n}$$

Where N_j is the utility degree of j^{th} alternative, Q_j is the relative significance of j^{th} alternative, Q_{max} is the most efficient alternative from the set of alternatives, S_{+j} is the sum of “pluses” of each j^{th} alternative, S_{-j} is the sum of “minuses” of each j^{th} alternative, S_{-min} is the minimum of S_{-j} and n is the number of alternatives.

Sustainability assessment in municipal residential buildings, and assessment of external wall alternatives.

Klumbytė et al. (2021); Zavadskas, Kaklauskas, Turskis, & Tamošaitienė (2008)

7. Choquet Integra

$$C_{\mu}^k(x_1, \dots, x_n) = \sum_{i=1}^n (x_{(i)} - x_{(i-1)}) \mu(A_i)$$

Where μ denotes the fuzzy measures, (i) is the permuted rank of a criteria such that $0 \leq x_{(1)} \leq x_{(2)} \leq \dots \leq x_{(n)}$, $x_{(0)} = 0$ and $A_{(i)} = \{x_{(i)}, \dots, x_{(n)}\}$

Sustainability assessment of buildings, and façade alternatives.

Olawumi & Chan (2020); Moghtadernejad et al. (2018)

8. MIVES

$$SI = V(P_x) = \sum_{i=1}^{i=N} \alpha_i \cdot \beta_i \cdot \gamma_i \cdot V_i(P_{i,x})$$

$V(P_x)$ measures the degree of sustainability of the alternative x evaluated with respect to various criteria. α_i are the weights of each requirement, β_i are the weights of each criterion and γ_i are the weights of the different indicators.

Sustainability assessment of façade systems, architecture and civil engineering, and technologies used to build schools.

Gilani (2020); Pons et al. (2016); Pons & Aguado (2012)

9. WASPAS

$$Q_i = \lambda \sum_{j=1}^n \bar{x}_{ij} w_j + (1 - \lambda) \prod_{j=1}^n (\bar{x}_{ij})^{w_j}$$

$$\lambda = 0, \dots, 1$$

Q_i is relative importance of alternative i , x_{ij} stands for the performance value of alternative i when it is evaluated in terms of criterion j and w_j is relative significance (weight) of the criterion j .

Sustainability assessment of municipal residential buildings, and façade alternatives.

Klumbytė et al. (2021); Zavadskas et al. (2013)

10. FSE

$$I = \{I_1, I_2, I_3, \dots, I_n\}$$

I is the set of indicators, and n is their number

$$L = \{L_1, L_2, L_3, \dots, L_n\}$$

L is the set of grade alternatives, and n is their number

$$W_i = \frac{M_i}{\sum_{i=1}^k M_i} \quad 0 < W_i < 1$$

$$\sum_{i=1}^k W_i = 1$$

W_i is the weight of an indicator ranging from 0 to 1, M_i is its mean score, k is the number of indicators in a criterion, and $\sum W_i$ is the weightings' sum

$$D = W_i^o R_i$$

D is the final FSE matrix, “ $\circ$ ” is the fuzzy composition operator, and $R_i = (r_{ij})_{m \times n}$, where r_{ij} is the degree to which alternative L_j satisfies the criterion C_j

$$AI = \sum_{i=1}^n DL$$

AI is the assessment index

Sustainability assessment of affordable housing, small-sized urban neighborhoods, and evaluating the proneness of the procurement process of construction projects to corruption.

Adabre & Chan (2020); Haider et al. (2018); Owusu et al. (2019)

Appendix 3: Microsoft Forms Online Survey

Sustainable New Educational Building Designs

This survey investigates the opinions of specialists in the built environment regarding the local importance of twenty-one indicators (economic, social, and environmental) used to assess the sustainability of new educational building designs in Bahrain.

Your participation is appreciated and is of great value to enhance the development of sustainable educational building designs. It is also voluntary, and you can request withdrawal at any time.

The survey is part of a Ph.D. study in Engineering Management at the University of Bahrain conducted by Dalia Shams (contact for any inquiry: dshamshuldin@uob.edu.bh).

Please help in circulating this survey among architects, engineers, project/construction managers, and academics involved in the built environment in Bahrain.

Please take a few minutes to complete this survey.

* Required

Section 1:

General Participants Information

1. Please indicate your institution type *

- ☐ Academic
- ☐ Private Sector
- ☐ Public Sector
- ☐ Other

2. Please write your institution's name *

3. Please indicate your profession *

- ☐ Academic
- ☐ Architect
- ☐ Engineer
- ☐ Project / Construction Manager
- ☐ Other

4. Please indicate your years of experience *

- ☐ 1-5
- ☐ 6-10
- ☐ 11-15
- ☐ 16-20
- ☐ Above 20

Section 2:

Investigating Local Importance of Sustainability Indicators

Questions 5, 6, and 7 will include twenty-one indicators that need to be considered during the design stage of new educational buildings in Bahrain to enhance their whole lifecycle sustainability economically, environmentally, and socially. Please indicate your opinion on their importance below:

- 1 = Not Important
- 2 = Less Important
- 3 = Neutral
- 4 = Important
- 5 = Very Important

5. Site Selection & Design Indicators

These are concerned with the site's selection and design, directly impacting both the site itself and any neighboring site *

	1	2	3	4	5
Community / urban connectivity	☐	☐	☐	☐	☐
Accessibility	☐	☐	☐	☐	☐
Surrounding constraints consideration	☐	☐	☐	☐	☐
Land use efficiency	☐	☐	☐	☐	☐
Site ecology enhancement	☐	☐	☐	☐	☐
Pedestrian & cyclist safety	☐	☐	☐	☐	☐
Eco-parking	☐	☐	☐	☐	☐

6. Health & Wellbeing Indicators

These are concerned with the internal spaces and their quality *

	1	2	3	4	5
Visual comfort	☐	☐	☐	☐	☐
Indoor air & thermal quality	☐	☐	☐	☐	☐
Acoustic comfort	☐	☐	☐	☐	☐
Design flexibility & scalability	☐	☐	☐	☐	☐
Design functionality & usability	☐	☐	☐	☐	☐
Security & safety	☐	☐	☐	☐	☐
Use of entries & mobility	☐	☐	☐	☐	☐

7. Resources & Material Indicators

These are concerned with the management of energy, water, and material use *

	1	2	3	4	5
Efficient energy consumption	☐	☐	☐	☐	☐
Renewable energy production	☐	☐	☐	☐	☐
Efficient water consumption	☐	☐	☐	☐	☐
Water treatment and recycling	☐	☐	☐	☐	☐
Material efficiency & durability	☐	☐	☐	☐	☐
Material available regionally	☐	☐	☐	☐	☐
Recycled and re-used material	☐	☐	☐	☐	☐

Section 3:

Additional Critical Sustainability Indicators

8. Please indicate any critical indicator that was not captured in the survey and that you consider important in the design stage of new educational buildings in Bahrain.

Appendix 4: Number of Licensed Engineers by Discipline in Public and Private Sectors

(The Council for Regulating the Practice of Engineering Professions)

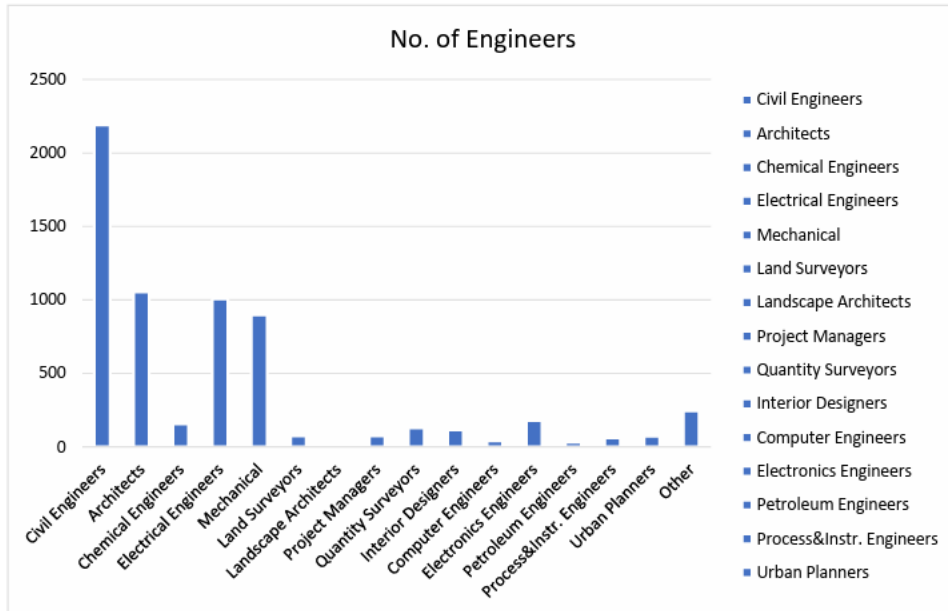
مجلس تنظيم مزاولة المهن الهندسية
The Council for Regulating the
Practice of Engineering Professions



Number of Licensed Engineers by Discipline

Discipline	No. of Licenses Engineers	Ratio
Civil Engineers	2190	35 %
Architects	1055	17 %
~~Chemical Engineers~~	~~156~~	~~2 %~~
Electrical Engineers	1007	16 %
Mechanical	898	14 %
Land Surveyors	76	1 %
Landscape Architects	6	0 %
Project Managers	75	1 %
Quantity Surveyors	129	2 %
Interior Designers	115	2 %
~~Computer Engineers~~	~~40~~	~~1 %~~
~~Electronics Engineers~~	~~180~~	~~3 %~~
~~Petroleum Engineers and National Gas~~	~~32~~	~~0 %~~
~~Process & Instrumentation~~	~~62~~	~~1 %~~
Urban Planners	72	1 %
Other	245	4 %
Total	6338	100%

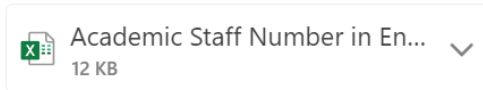
Number of Licensed Engineers by Discipline



Appendix 5: Number of Academic Staff in Public and Private Higher Education Institutions Offering Engineering Programs

(The Higher Education Council)

MY Maram Mahmood Yousif <maram.m.yousif@moe.gov.bh>  ...
To: Dalia Shamshuldin Tue 3/12/2024 1:04 PM



الفاضلة الأستاذة داليا شمس الدين المحترمة

السلام عليكم ورحمة الله وبركاته،،،

بالإشارة إلى طلبكم الوارد عبر النظام الالكتروني لخدمة "تسهيل مهمة باحث" لتطبيق أدوات البحث المعنون "استخدام المعايير المتعددة لصنع القرار لتقييم الاستدامة في تصميم المباني التعليمية"؛ تجدون مرفقاً الاحصائيات المطلوبة بحسب أحدث بيان معتمد.

ملاحظة: يرجى الاخذ بعين الاعتبار، المحافظة على المعلومات التي يتم جمعها، وعدم استخدامها إلا لأغراض البحث العلمي.

مع تمنياتنا لكم بالتوفيق، وتفضلوا بقبول خالص التحية والاحترام.



مرام لنكاوي

Maram Langawi

أخصائي إدارة جودة

Quality Management Specialist

 Maram.m.yousif@moe.gov.bh  (+973) 17896727

No.	HEI Name	Academic Staff Number in Engineering Departments											Total
		Civil Engineering	Civil & Architectural Engineering	Architectural Engineering	Mechanical Engineering	Mechanical & Motor Vehicle	Electrical & Mechanical Engineering	Electrical & Electronics Engineering	Interior Design Engineering	Industrial Engineering	Quantity Surveying	School of Engineering	
1	Bahrain Polytechnic (BP)											36	36
2	Bahrain Training Institute (BTI)	5				10		5					20
3	Royal University for Women (RUW)			6					4	4	4		18
4	Applied Science University (ASU)		10				3						13
5	The Kingdom University (KU)	3		4					7	7	7		28
6	Gulf University (GU)				3		2		6				11
7	British University - Bahrain (BUB)	4		2							1		7
8	American University - Bahrain (AUBH)	1			2					1	1		5
9	University of Bahrain (UOB)	22		28	12			18	13				93
Total Number of Academic Staff in HEIs													231

Note: Bahrain Polytechnic recently acquired Bahrain Training Institute

Appendix 6: Approval Letter Provided by the HEC to Circulate the Survey Among HEIs

KINGDOM OF BAHRAIN
Higher Education Council



مجلس التعليم العالي
مملكة البحرين

الرقم: ٢٠٢٤ / ٠٤ / ٠٤ ت م ب / ٢٠٢٤

التاريخ: ٢٧ مايو ٢٠٢٤

الفاضلة السيدة داليا شمس الدين محمد المحزومة

السلام عليكم ورحمة الله وبركاته،،،

الموضوع: الموافقة على تطبيق أدوات البحث

بالإشارة إلى طلبكم الوارد عبر النظام الالكتروني لخدمة "تسهيل مهمة باحث" لتطبيق أدوات البحث المعنون "استخدام المعايير المتعددة لصنع القرار لتقييم الاستدامة في تصميم المباني التعليمية" نحيطكم علماً بعدم الممانعة على تطبيق أدوات البحث في مؤسسات التعليم العالي الخاصة.

على أن تتم مراعاة الآتي:

١. الالتزام عند التطبيق بأداة / أدوات البحث التي تمت الموافقة عليها.
٢. عدم الإضرار بسير العملية التعليمية وتحصيل الطلبة، من خلال التنسيق المسبق مع الإدارة في جهة التطبيق.
٣. المحافظة على المعلومات التي يتم جمعها، وعدم استخدامها إلا لأغراض البحث العلمي.
٤. جميع الإجراءات والخطوات اللازمة لتطبيق أدوات الدراسة تقع على عاتق الباحث نفسه.

مع تمنياتنا لكم بالتوفيق، وتفضلوا بقبول خالص التحية والاحترام.

الدكتورة فرزانة عبدالله المراغي

الأمين العام المساعد لمجلس التعليم العالي

Appendix 7: Survey Circulation Evidence Documents - Public Sector

(Ministry of Works, Ministry of Municipalities Affairs and Agriculture,
Ministry of Housing, and Bahrain Society of Engineers)

Ministry of Works



وزارة الأشغال

الرقم: HRD/TDS/051/2024

التاريخ: 15 فبراير 2024م

سعادة الدكتورة الفاضلة هيفاء بنت إبراهيم آل خليفة المحترمة
عميد كلية الهندسة بجامعة البحرين

السلام عليكم ورحمة الله وبركاته وبعد،

الموضوع: تسهيل جمع البيانات اللازمة للطلالبة داليا شمس الدين شمس

بالإشارة الى خطابكم المؤرخ في 6 فبراير 2024م بشأن الموضوع المذكور أعلاه حول جمع البيانات اللازمة
لبرنامج الدكتوراه تحت عنوان "استخدام المعايير المتعددة لصنع القرار لتقييم الاستدامة في تصميم
المباني التعليمية". نود الإفادة بأنه لا مانع من جمع البيانات اللازمة من أجل استكمال رسالة الدكتوراه في
حدود المعلومات القابلة للنشر ومتطلبات جامعة البحرين.

للتسيق، يرجى التكرم بالإيعاز للطلالبة للتواصل مع السيدة / إيمان عمر سعيد - أخصائي
موارد بشرية أول بقسم التدريب والتطوير على هاتف رقم 17545918.

وتفضلوا بقبول وافر التحية والتقدير،،،

محمد صالح عاشر
مدير إدارة الموارد البشرية



Sent from [Outlook for iOS](#)

شكرا جزيلا علي المعلومات .

→ Forward

Researcher: Dalia Shams

MR

Mohammed A. Rashdan <Mohammed.rashdan@housing.gov.bh>



...

To: Dalia Shamshuldin

Mon 2/12/2024 11:27 AM

Dear Eng.Dalia,

Thank you for contacting me , in support of all kind of studies, Thea team and myself would be our pleasure to take part of your research.

Thanks and Regards,



Mohamed Abdulaziz Rashdan

DIRECTOR

Project Follow-Up and Management Directorate

Tel.: +973 17528230

Fax: +973 17514102

P.O. Box:5802, Kingdom of Bahrain

Email: mohammed.rashdan@housing.gov.bh



Please consider the environment before printing this email.

استبانة رسالة دكتوراة في الإدارة الهندسية

الأعضاء الأعزاء ..

نرجو التكرم بالإجابة على الاستبانة الخاصة بأحد متطلبات رسالة دكتوراة للباحثة:

داليا شمس الدين شمس

محاضر - قسم العمارة والتصميم الداخلي
كلية الهندسة - جامعة البحرين

للتفضل بالدخول والإجابة على أسئلة الاستبانة يرجى الضغط على الرابط أو الرمز (أو تصويره).

رابط الاستبانة: <https://forms.office.com/r/LYuuKG11xM>



امسح أو اضغط
للدخول للاستبانة



bsmohandis (+973) 32215274 www.bse.bh

Appendix 8: Edited Section of the Microsoft Forms Online Survey

(Pilot study recommendation- section 2: questions 5-7)

5. Site Selection & Design Indicators

These are concerned with the site's selection and design, directly impacting both the site itself and any neighboring site *

Community/ urban connectivity	Accessibility	Surrounding constraints consideration	Land use efficiency	Site ecology enhancement	Pedestrian & cyclist safety	Eco-parking
Encourage the selection of sites within existing infrastructure to reduce the distance traveled by vehicles, promote transport efficiency, and promote physical activities through walking and cycling	Encourage the selection of sites close to public transport networks to reduce congestion and transportation pollution	Consider any constraints around the site, such as odor, sand, traffic, noise, vibration, wind, and daylight barriers	Preserve the environment through efficient and reduced construction land size and proper landscaping	Improve the site's ecological value through heat island reduction, vegetation, shading, open spaces, and considering the existing natural features, such as soil, plants, trees, wildlife, topography, ground cover, habitats, and water features	Provide safe bicycle pathways and pedestrian walkways	Provide maximum sustainable parking areas

	1	2	3	4	5
Community / urban connectivity	☐	☐	☐	☐	☐
Accessibility	☐	☐	☐	☐	☐
Surrounding constraints consideration	☐	☐	☐	☐	☐
Land use efficiency	☐	☐	☐	☐	☐
Site ecology enhancement	☐	☐	☐	☐	☐
Pedestrian & cyclist safety	☐	☐	☐	☐	☐
Eco-parking	☐	☐	☐	☐	☐

6. Health & Wellbeing Indicators

These are concerned with the internal spaces and their quality *

Visual comfort	Indoor air & thermal quality	Acoustic comfort	Design flexibility & scalability	Design functionality & usability	Security & safety	Use of entries & mobility
Ensure sufficient visual comfort and optimum visual performance through efficient design and specification for daylight, artificial light, and occupant controls	Ensure healthy internal spaces and adequate thermal comfort through efficient design and specification of equipment, techniques and finishes for mechanical and natural ventilation.	Ensure sufficient acoustic comfort by implementing solutions that reduce sound disturbance between classrooms or different spaces and provide echo-clear sounds within large spaces, such as theaters and sports halls	Provide flexible design layout with respect to adaptability in the number and size of classrooms in the future, change in the layout or change in the use of some spaces	Provide designs that ensure comfortable and adequate physical performance of the spaces in terms of areas and heights to suit the occupants' different functions and activities	Preserve occupants' highest safety and security measures through the use of safe equipment and the provision of fire protection	Consider effective measures and standards to ensure the safety and security of disabled users

	1	2	3	4	5
Visual comfort	☐	☐	☐	☐	☐
Indoor air & thermal quality	☐	☐	☐	☐	☐
Acoustic comfort	☐	☐	☐	☐	☐
Design flexibility & scalability	☐	☐	☐	☐	☐
Design functionality & usability	☐	☐	☐	☐	☐
Security & safety	☐	☐	☐	☐	☐
Use of entries & mobility	☐	☐	☐	☐	☐

7. Resources & Material Indicators

These are concerned with the management of energy, water, and material use *

Efficient energy consumption	Renewable energy production	Efficient water consumption	Water treatment and recycling	Material efficiency & durability	Material available regionally	Recycled and re-used material
Conserve energy using passive solutions and efficient equipment	Reduce adverse effects on the economy and ecosystem caused by non-renewable energy using renewable energy	Conserve water using efficient systems	Promote water conservation through the use of recycling strategies and the reuse of rainwater, groundwater, or greywater	Enhance material efficiency and resilience to reduce its use and waste without affecting the stability of the building structure, its durability, or its service life	Promote the use of materials that foster regional economy and have less transport adverse effects	Reduce the production of waste and conserve natural resources through using materials that have been previously used, recycled, or salvaged

	1	2	3	4	5
Efficient energy consumption	☐	☐	☐	☐	☐
Renewable energy production	☐	☐	☐	☐	☐
Efficient water consumption	☐	☐	☐	☐	☐
Water treatment and recycling	☐	☐	☐	☐	☐
Material efficiency & durability	☐	☐	☐	☐	☐
Material available regionally	☐	☐	☐	☐	☐
Recycled and re-used material	☐	☐	☐	☐	☐

Appendix 9: Analytical SBAT for NEBDs in Bahrain

(Analytical SBAT – Manual)

Analytical SBAT for NEBDs in Bahrain

(Manual Applicable for NEBDs)

Abbreviations:

SBAT: Sustainability Building Assessment Tool

NEBDs: New Educational Building Designs:

Note: This manual is used to assist the assessors in rating the twenty-one indicators in the Excel sheet titled (Analytical SBAT for NEBDs in Bahrain) to assess the sustainability attainment in an NEBD. Assessors check the fulfillment of the NEBD with regard to the design considerations under each indicator (sub-indicators)

Criteria, indicators, and sub-indicators for assessing the sustainability of NEBDs in Bahrain

Criteria	Indicator	Sub-indicator / issues to be considered under each indicator
Site & Transportation	Community / urban connectivity	Within existing infrastructure
	Accessibility	Different transportation options, including buses, private vehicles, bicycles, or walking
	Surrounding environment consideration	Odor; sand; traffic; noise; vibration; wind; daylight barrier
	Land use efficiency	Efficient and reduced construction land size; proper landscaping
	Site ecology enhancement	Heat island reduction; vegetation; shading; open spaces; embracing the existing natural features, such as soil, plants, trees, topography, ground cover, wildlife habitats, and water features
	Pedestrian & cyclist safety	Separate pedestrian and cyclist pathways; buffer zone between pathways and roads; crosswalks with appropriate signage; speed bumps; bicycle parking; adequate lighting
	Eco-parking	Permeable pavement; vegetation; solar panels; electric vehicle charging stations; bicycle parking; parking area out of building gardens and distant from classroom
	Visual comfort	Daylight; artificial light; occupant controls

Health & Wellbeing	Indoor air & thermal quality	Equipment, techniques and finishes for mechanical and natural ventilation
	Acoustic comfort	Sound-insulating doors and windows; acoustic panels and ceilings; proper room design and layout; specific furniture and fixtures; advanced acoustic systems
	Design flexibility & scalability	Number and size of classrooms; changes in the layout; changes in the use of some spaces
	Design functionality & usability	Access; parking; spatial capacity; utilities; communications; circulation; equipment
	Security & safety	Hallways; stairways; classrooms; fencing; lighting at night; fire exits; gathering areas; fire protection; use of safe equipment
	Use of entries & mobility	Ramps; automatic doors; toilets; corridors; elevators; furniture
Resources & Material	Efficient energy consumption	Passive solutions (orientation, form, shading, thermal insulation, natural ventilation, daylighting, green roof); efficient equipment
	Renewable energy production	Solar energy; wind energy; geothermal energy; energy storage
	Efficient water consumption	Efficient systems and materials, such as low-flow plumbing fixtures, water-efficient urinals, efficient irrigation, and proper landscape design
	Water treatment and recycling	Recycling and reuse strategies of rainwater, groundwater, or greywater
	Material efficiency & durability	Efficient and resilient materials
	Material available regionally	Regional materials
	Recycled and re-used material	Materials that have been previously used, recycled, or salvaged

Analytical SBAT for NEBDs in Bahrain

Note: Sheet can be downloaded and only assessor columns need to be adjusted depending on the number of assessors involved in the assessment panel (ranging from 1 assessor or more). Maximum possible score (Yi) is always 35, this should be added in each assessor's column

Site & Transportation (S&T)		Assessment Panel														
		Assess or 1	Assess or 2	Assess or 3	Assess or 4	Assess or 5	-	-	-	-	Total					
1	Community / urban connectivity										0	DFS(S&T)=	0 %			
2	Accessibility										0					
3	Surrounding environment considerations										0					
4	Land use efficiency										0					
5	Site ecology enhancement										0					
6	Pedestrian & cyclist safety										0					
7	Eco-parking										0					
Total actual score by designers (μ')											0					
Maximum possible score (μ)											35			35		

Health & Wellbeing (H&W)		Assessment Panel														
		Assess or 1	Assess or 2	Assess or 3	Assess or 4	Assess or 5	-	-	-	-	Total					
1	Visual comfort										0	DFS(H&W)=	0 %			
2	Indoor air & thermal quality										0					
3	Acoustic comfort										0					
4	Design flexibility & scalability										0					
5	Design functionality & usability										0					
6	Security & safety										0					
7	Use of entries & mobility										0					
Total actual score by designers (μ')											0					
Maximum possible score (μ)											35			35		

Resources & Material (R&M)		Assessment Panel														
		Assess or 1	Assess or 2	Assess or 3	Assess or 4	Assess or 5	-	-	-	-	Total					
1	Efficient energy consumption										0	DFS(R&M)=	0 %			
2	Renewable energy production										0					
3	Efficient water consumption										0					
4	Water treatment and recycling										0					
5	Material efficiency & durability										0					
6	Material available regionally										0					
7	Recycled and re-used material										0					
Total actual score by designers (μ')											0					
Maximum possible score (μ)											35			35		

Total sustainability attainment of the NERD=												0 %
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Abstract (Arabic)

لقد حظيت الاستدامة في قطاع البناء باهتمام كبير، نظرًا لتأثيرها الكبير على الاقتصاد والبيئة والمجتمع. والاستدامة الشاملة تمتد لتشمل الأبعاد البيئية والاجتماعية والاقتصادية. وقد حظيت طرق اتخاذ القرار متعدد المعايير (MCDM) باعتماد واسع بين الباحثين في قطاع البناء، بهدف تطوير أدوات تحليلية لتقييم استدامة المباني (SBATs) لمختلف أنواع المباني حول العالم. تُعدّ مرحلة التصميم لأي مبنى مرحلة محورية في ضمان استدامته طوال دورة حياته، لذا فإن تطوير أداة تقييم مخصصة لاستدامة التصميم يمكن أن يسهم بشكل كبير في تحسين أداء المبنى في المستقبل. وفي مملكة البحرين يشهد قطاع المباني التعليمية توسعًا متزايدًا، نتيجة للتحضر المستمر، والنمو السكاني، والحاجة إلى استبدال المباني التعليمية القديمة، مما يستدعي دمج معايير الاستدامة في تصاميم المباني التعليمية الجديدة (NEBDs)، وتقييم مدى فاعلية هذه المعايير من خلال أداة تحليلية متخصصة. بناءً على ذلك، يهدف هذا البحث إلى تطوير أداة تحليلية شاملة لتقييم استدامة المباني التعليمية الجديدة في البحرين، بالاعتماد على منهجية اتخاذ القرار متعدد المعايير (MCDM). وقد تم تحليل أنظمة تصنيف استدامة المباني المعترف بها عالميًا، إلى جانب مراجعة الأدبيات ذات الصلة، مما أسفر عن تحديد ثلاثة معايير رئيسية و21 مؤشرًا تُعد ضرورية لتقييم استدامة هذه المباني. وللتحقق من مدى ملاءمة هذه المؤشرات للبيئة المحلية، أُجري استبيان إلكتروني استهدف الممارسين والأكاديميين العاملين في قطاع البيئة المبنية في البحرين، لاستقصاء مدى أهمية المؤشرات من منظور محلي، وتم تحليل 364 استجابة صالحة، ضمن مستوى ثقة يبلغ 95% وهامش خطأ 5%، باستخدام منهجية التقييم الاصطناعي الضبابي (FSE). وفي نهاية المطاف تم تطوير أداة تقييم استدامة شاملة تضمنت ثلاثة معايير رئيسية: الموقع والنقل (33.1%)، والصحة والرفاهية (34.2%)، والموارد والمواد (32.7%). وهي التي شكلت الأبعاد الأساسية لتحقيق الاستدامة في تصاميم المباني التعليمية الجديدة في البحرين. ويمكن تعميم نتائج هذه الدراسة على دول أخرى تتشابه في خصائصها الإقليمية مع البحرين، مثل دول مجلس التعاون الخليجي. وتتميز الأداة التحليلية الجديدة ببساطتها، وسهولة استخدامها بشكل فردي، إذ يمكن لفريق التصميم تطبيقها لتقييم وتحسين استدامة المباني التعليمية الجديدة خلال مرحلة التصميم، كما يمكن لصنّاع القرار استخدامها للحصول على تصور عام حول مدى تحقيق الاستدامة في تصميم معين، أو لمقارنة عدة تصاميم وفقًا لمستوى استدامتها.

جامعة البحرين

قسم الهندسة الميكانيكية



كلية الهندسة

استخدام طرق اتخاذ القرار المتعدد المعايير (MCDM) لتقييم الاستدامة في تصميم المباني التعليمية

أطروحة مقدمة كجزء من متطلبات الحصول على درجة دكتوراة الفلسفة في الإدارة الهندسية

اعداد

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الدكتورة في عبد الله آل خليفة

أستاذ مشارك

مملكة البحرين

مايو 2025