

Review

An Overview of Weighting Schemes in Building Sustainability Assessment Systems: Current Situation and Prospects

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Abstract

This literature review examines weighting schemes within Building Sustainability Assessment Systems (BSAs). Given the widespread adoption of BSAs and their direct link to significant economic benefits for investors and owners, weighting schemes serve as critical tools for policymaking in the sustainable building sector. The review synthesizes findings from 102 articles, covering multiple building types, subsystems, design parameters, lifecycle phases, locations, and sustainability dimensions. The identified schemes are categorized as subjective, objective, hybrid, or equal, based on established definitions. First, the weighting schemes of Leadership in Energy and Environmental Design (LEED) and Building Research Establishment Environmental Assessment Method (BREEAM)—the two most frequently referenced BSAs—are analyzed within this framework. Second, a systematic analysis of novel weighting schemes proposed in the literature is conducted. Among these methodologies, 75% employed subjective weighting schemes, while objective, hybrid, and equal weighting schemes accounted for 12%, 6%, and 3%, respectively. No discernible temporal trend was observed in these proportions over the last 25 years. The geographical analysis further underscores the global dominance of subjective schemes. Notably, nearly 71% of the studies focus on developing countries in Asia and Africa, where the proportion of subjective schemes reaches 75% and 85%, respectively. Consequently, the results indicate the pivotal role of experts in shaping BSAs priorities. Finally, the discussion evaluates the advantages and limitations of these weighting approaches regarding their capacity to guide the building sector toward sustainability goals.

Keywords: weighting schemes; building sustainability assessment; subjectivity; objectivity; experts; data-driven weighting; equal weights; green building rating systems



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1. Introduction

1.1. Building Sector Panorama

It is estimated that the global building sector accounts for 32% of global energy demand and 34% of human-generated CO₂ emissions, with these proportions being even higher in developed economies [1]. Moreover, buildings worldwide, over their entire lifecycle, generate roughly 100 billion tons of waste, of which approximately 35% ends up in landfills [2]. This places them among the significant consumers of natural resources [3].

In fact, following the recovery from COVID-19, the building sector in most affluent countries entered a new development phase, which slowed down in 2022 due to the new global economic situation [4]. As a result, despite the ambitious goals of the Paris Agreement and the significant role of the building sector in achieving them, in 2022,

building operational energy demand and CO₂ emissions both exceeded the levels of 2021 [5].

Given the global geopolitical instability, economic recovery and further growth face numerous threats [3]. Simultaneously, the energy transition, which is crucial for the decarbonization of the building sector [6], has transformed into an energy crisis in many countries worldwide [7–9].

This situation is accompanied by the now tangible effects of climate change and urban overheating. Consequently, the current building stock, especially in poor regions, is not only economically and environmentally inefficient, but also unable to provide modern living and working conditions [10,11].

1.2. Approaching the Concept of Building Sustainability

The most widely accepted definition of sustainability was formally articulated by the United Nations (UN) World Commission on Environment and Development in 1987. According to that definition, sustainability is a “Development that meets the needs of the present without comprising the ability of the future generations to meet their own needs.” [12]. In this light, the concept of sustainability indicates a new economic growth model that addresses societal and environmental imperatives. Therefore, the three main pillars of sustainability encompass the economy, society, and the environment [13,14].

One perspective asserts that sustainable development signifies an elevated form of economic growth, considering the environment’s capacity and the holistic requirements of society. Essentially, it safeguards humanity’s ability to maintain progress and attain enhanced living standards for all. Conversely, another viewpoint suggests that sustainability entails a trade-off, as objectives for economic growth may clash with those of environmental preservation and societal welfare. This perspective inherently introduces the notion of equilibrium among the three pillars of sustainability.

In 2015, the UN introduced 17 Sustainable Development Goals (SDGs), with some specifically targeting the building sector and the built environment [15]. Building sustainability is particularly linked to goals such as promoting good health and well-being (SDG 3), ensuring access to affordable and clean energy (SDG 7), fostering decent work and economic growth (SDG 8), advancing industry, innovation, and infrastructure (SDG 9), reducing inequalities (SDG 10), creating sustainable cities and communities (SDG 11), and encouraging responsible consumption and production (SDG 12) [16]. Given the projection that the urban population is expected to comprise 68% of humanity by 2050 [17], coupled with the fact that a significant portion of individuals spend approximately 90% of their lifetime inside various types of buildings [12], it becomes apparent that both buildings and the building industry will wield significant influence in realizing the SDGs by 2030.

Examining the definition of sustainability and the SDGs, it becomes obvious that buildings must be examined throughout their entire lifecycle, considering their economic, environmental, and societal impacts. Bearing this approach, the concept of sustainability appears to encompass nearly every aspect related to buildings, such as energy efficiency, zero global warming potential, resources circularity, economic efficiency, health and comfort indoor environment for all, contribution to other aspects of urban sustainability (e.g., mobility, land use), and resilience to natural and human-made hazards.

1.3. Building Sustainability Assessment Systems

In the early 1970s, the approach of “green building” came to light aiming to create a framework to support the conservation of resources and the preservation of the environment. Therefore, the initial rating systems developed during the 1990s were designed to fulfill this objective, primarily focusing on assessing the environmental footprint of

buildings [18]. In addition to addressing climate change mitigation and achieving fossil fuel independence, it has become evident that the lifecycle footprint of buildings and the built environment encompass critical economic and societal aspects as well [19,20].

Ade and Rehm [21] described the property industry's view of the "green building" approach as a method of protecting natural capital and remediating the environmental impacts of building by seeking to merge the priorities of economic prosperity, environmental quality and social equity, lighting the three dimensions of sustainability [22]. As a result, over time there is a trend in moving from the concept of "green" to the concept of "sustainable", in fact considering all the three pillars of sustainability [12,23].

However, economic and societal aspects pose challenges in quantification, while also adding factors whose relative importance must be determined. This inherent complexity clouds the directions of sustainability efforts and renders the evaluation of actions to implement it a formidable task. Consequently, over the last 30 years, multiple approaches have been proposed to assess building sustainability and translate it into meaningful, comparable outcomes.

As of 2021, there were 74 recorded Green Building Rating Systems (GBRSs) in use in no less than 184 countries worldwide [4]. Moreover, several national or international indicators or decision-making methodologies have been proposed and used in the fields of sustainable renovation [24], sustainable waste management [25], occupant well-being assessment [26], and sustainable building materials selection [27], among others. Specifically, in the European Union, there are 37 international and 54 national GBRSs in use, along with more than 500 sustainability indicators [28].

In this study, sustainability is treated as a superset that encompasses all aspects of building assessment. Additionally, building sustainability assessment may either succeed in rating and certification or remain at a stage without specific tangible results. Moreover, studying some specific aspects of building sustainability, such as building materials, is a necessary part of studying whole building sustainability. Therefore, to address the well-known variation in terminology within this scientific field [13,29], this study adopts the universal term "Building Sustainability Assessment Systems (BSASs)" to describe approaches proposed to assess building sustainability.

1.4. Objectives and Structure

Undoubtedly, weighting schemes significantly influence the outcomes and mirror the directions set in building sustainability assessment [9,30]. Considering that the sustainability rating directly affects the commercial value of buildings, investors and owners often tailor their decisions to better align with the most heavily weighted criteria, with the objective of maximizing the final building rating [21,31–33]. In the same vein, the UN 2024 Global Status Report for Buildings and Construction suggested leveraging "building certification schemes" as tools to access funding and investment schemes [5]. Therefore, with the increasingly widespread adoption of BSASs and their direct link to significant economic benefits for investors and owners, weighting schemes can be regarded as important tools for policymaking within the sustainability of the building sector [34].

Regarding the direct impact of weighting schemes on crucial sustainability goals, such as carbon neutrality and energy efficiency, the literature indicates that energy-oriented BSASs (e.g., LEED) often lead to suboptimal results in terms of embodied energy [31]. In fact, adopting weights that primarily focus on achieving high energy efficiency has a direct adverse effect on the embodied energy of the building envelope, thereby hindering progress toward carbon neutrality [35]. It is also worth noting that this disproportionate focus on energy efficiency has indirect negative implications for other aspects of building

sustainability, such as initial investment costs, Indoor Environmental Quality (IEQ), and thermal comfort [36,37].

Given the profound importance of BSASs' weighting schemes, this study aims to conduct a systematic review of the weighting schemes used in both well-known BSASs and novel building sustainability assessment methodologies. Rather than presenting and comparing the weights assigned by different systems to various sustainability aspects, this study emphasizes the prioritization mechanisms behind these weights. The analysis is grounded in the fundamental concepts of subjectivity and objectivity, particularly within the context of the building sector, which has not been systematically explored in existing literature. By examining the weighting mechanisms from this perspective, this literature review seeks to answer the following research questions:

1. What is subjective and objective, and when is a BSAS weighting scheme characterized as subjective, objective, or hybrid?
2. What weighting schemes are used by LEED and BREEAM, the two leading BSASs worldwide, and how are they classified?
3. What weighting schemes are adopted by novel sustainability assessment methodologies, and how are they classified?
4. What are the advantages and disadvantages of the identified weighting schemes, and which schemes are dominant worldwide?

Therefore, this study's novelty lies in systematically addressing these significant questions for the first time. Filling this research gap will enrich the existing literature and provide valuable insights for researchers and stakeholders in the building sector regarding the reliability and long-term effectiveness of weighting schemes in BSASs.

The structure of the article follows the process of addressing the research questions. First, Section 2 covers the literature review methodology, with Section 2.1 detailing the process of identifying the studies included in this review, and Section 2.2 describing the analysis framework applied to these studies. With the analysis framework established and the first research question addressed, Section 3 presents the analysis results.

Specifically, Section 3.1 analyzes the weighting schemes of LEED and BREEAM in relation to the second research question, while also summarizing the literature on the weaknesses and limitations of widely adopted BSASs that have paved the way for novel sustainability assessment methodologies. Therefore, Section 3.2 presents the findings on novel sustainability assessment methodologies, covering the third research question.

Next, Section 4 provides a discussion of the results from the literature review, focusing on answering the fourth research question. Finally, Section 5 concludes the review, summarizing its key findings and suggesting directions for future research.

2. Methodology

2.1. Identification of Relevant Literature

The literature review was conducted using two widely accepted online databases, Scopus and Web of Science (WoS), ensuring access to peer-reviewed literature. The search queries in both databases included the terms "building sustainability assessment systems," "weights," "weighting," and "weighting schemes," as follows:

(ALL(building sustainability assessment systems))
AND (ALL(weights) OR ALL(weighting) OR ALL(weighting schemes)).

The selection "ALL" was chosen to search across all searchable fields or field codes in one query string. This selection includes searching within authors, editors, keywords, abstracts, main texts, publications, references, subject categories, and other special fields

provided by the two databases. This deliberate selection ensured that no relevant studies were excluded, although it also yielded many studies that were often outside the scope of the current literature review.

Following the initial results, filters were applied based on document type, language, research area, and publication year. This process resulted in the selection of articles and review articles in English, covering all areas related to the building sector from 2000 to 2025. Notably, no articles published before 2009 were identified.

Applying the filters resulted in approximately 2800 articles in Scopus and 2700 articles in WoS. The titles and abstracts of the identified articles were then examined for their relevance to the scope of the literature review. After excluding duplicates, 102 unique articles were identified, forming the basis of the current literature review (Figure 1).

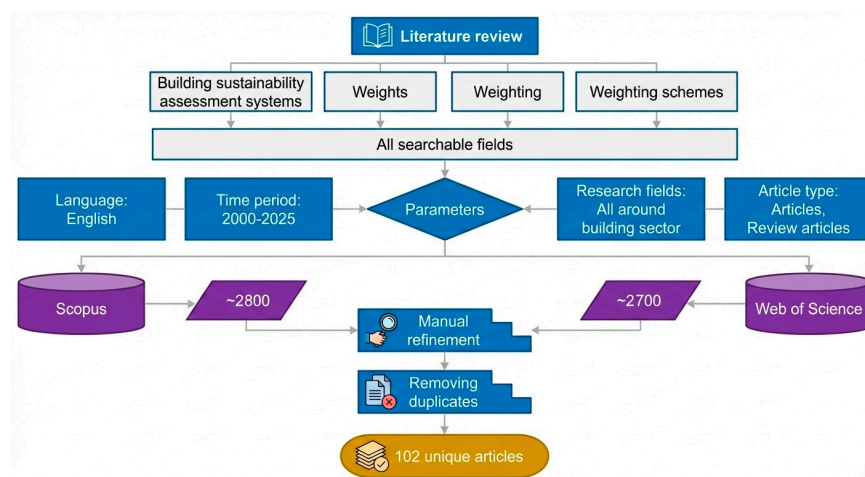


Figure 1. Schematic representation of the research methodology, detailing data collection, filtering parameters, and article selection process employed in this review.

2.2. Analysis Framework

The necessity for weights arises from the presence of multiple factors in determining an outcome, such as the value of a composite indicator, a score, or a rank. As noted by Greco et al. [38], weights are coefficients attached to criteria, indicating their relative importance during an aggregation process. In fact, weights represent a specific situation where finite resources must be effectively allocated to achieve multiple goals.

One way to classify weighting schemes is based on whether they are subjective or objective. According to Sharp [39], subjectivity asserts that perception is influenced by an individual's viewpoint. This concept is often juxtaposed with objectivity, where knowledge is considered to be unaffected by the person who creates it [39]. In a sense, every human-made process can be characterized as subjective since it inevitably reflects personal knowledge, motivation, desire, attitude towards risk, and a unique point of view. Adherence to the scientific process ensures the objectivity of conclusions, positions, and results, as their correctness is proven independently of any subject.

As noted earlier, sustainability is not a physical quantity. Therefore, the proof of sustainability approaches may only emerge indirectly and over time [40]. All approaches contain various forms of subjectivity, which may be why no weighting scheme is beyond criticism [38,41]. Since BSAs borrow weighting methodologies from other scientific fields such as economics and management, they incorporate their unique features, including weaknesses and limitations.

A weighting scheme is classified as subjective when the initial input of the weighting process is derived from human judgment. Participatory approaches are based on experts' opinions and are thus often labeled as subjective [42]. Approaches such as Analytic

Hierarchy Process (AHP), Conjoint Analysis, Budget Allocation Method (BAM), Swing, and Stepwise Weight Assessment Ratio Analysis (SWARA) often consider the perspectives of various stakeholders, including construction experts, consultants, academics, policymakers, and occupants in the case of the building sector. The aim is to make subjectivity as transparent as possible, thereby reducing biases, errors of judgment, and the lack of consistency between participating stakeholders [38,42].

On the other hand, a weighting scheme is classified as objective when the initial input of the weighting process is derived from data. Therefore, approaches such as Principal Component Analysis (PCA), Data Envelopment Analysis, Multiple Linear Regression Analysis, and unsupervised machine learning techniques are often referred to as objective [38,42,43].

While these approaches are free from subjectivity drawbacks, their significant differences lead to variations in weights determination [42]. Moreover, perhaps the most crucial aspect of objective methods is that the weights are derived from existing data. Consequently, the weights reflect the distribution of importance among the assessment criteria that exists. While this information is valuable for strategy-making, it may not inherently dictate future strategy or, in other words, pave the road we should follow [38].

Additionally, a weighting scheme is classified as hybrid when it integrates at least two distinct weighting approaches (i.e., subjective, objective, or equal). Hybrid approaches combine different weighting schemes, aiming to overcome their respective limitations and drawbacks [42]. Of course, the decision on which methods to combine and how is ultimately up to the system developer. Given that every method has its own advantages and disadvantages, developers must choose those that best fulfill the assessment requirements. Thus, even this initial decision contains an element of subjectivity [38].

The most widely adopted weighting approach in the literature on composite indicators is known as equal weights [44]. Under the ‘no weights’ or ‘equal weights’ approach, all contributing indicators are assigned equal importance in determining the outcome. Although there is no consensus on whether equal weighting is subjective or objective [38,42], it is classified as subjective when applied due to a lack of theoretical structure justifying a differential weighting scheme, or when based on developers’ judgment [38]. Conversely, it is considered objective when there is evidence supporting the equal importance of contributing indicators.

Within this framework, the identified weighting schemes are analyzed in terms of their weighting processes and input data, whether derived from participants’ judgments, simulations, time series, or other sources. The final characterization of these schemes as subjective, objective, hybrid, or equal is based on this analysis. This methodology can uncover unclear assumptions regarding the subjectivity and objectivity of weighting schemes in BSAs, highlighting their unique advantages and limitations. It can also shed light on advancements in research efforts toward developing more reliable and efficient weighting schemes.

3. Results

3.1. Existing BSAs with National and International Scope

3.1.1. LEED and BREEAM

LEED and BREEAM are by far the two most frequently referenced BSAs in the literature reviewed (see Figure 2). They are internationally applied systems that have been extensively studied with respect to the outcomes of their implementation worldwide. Moreover, they have been widely used as the basis for the development of new BSAs at both national and international levels.

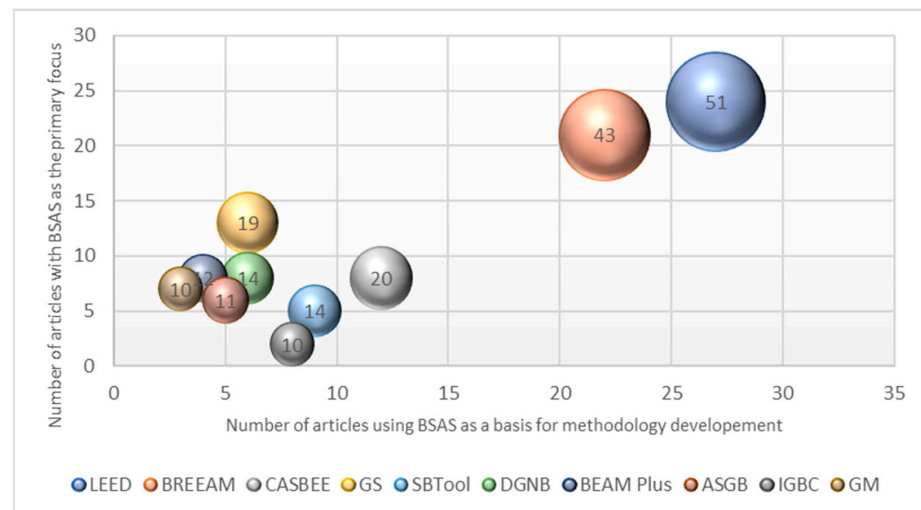


Figure 2. Bubble chart of the ten most frequently referenced BSASs in the literature. The x-axis represents the number of articles using each BSAS as a foundation for developing novel methodologies, while the y-axis shows articles where each BSAS is the main topic. Bubble size indicates the total number of references per BSAS.

In 2016, BREEAM published a briefing paper that presents the newly developed methodology for deriving consensus-based category weightings for use in BREEAM schemes operated by BRE Global consisting of two stages: Establish ratings and Apply Scoring [45]. The first stage establishes linguistic ratings for the importance of each BREEAM scheme category concerning “seriousness”, “relevance”, and “potential” related to the three dimensions of sustainability. In the second stage, the linguistic ratings for “seriousness”, “relevance”, and “potential” are converted to numerical equivalents. For each sustainability dimension within each category, the scores for seriousness, relevance, and potential are multiplied. Subsequently, for each category, the scores for the three sustainability dimensions are summed to generate the category score. Finally, this score is normalized to generate the category weightings (see Figure 3) [45].

The required ratings for the UK context were obtained through rounds of stakeholder consultation activities. A second round involved an online survey, where respondents were asked to verify the general consensus category ratings obtained from the first round [45]. Concerning the BREEAM International New Construction version, the weightings of the ten technical categories, both “Fixed” and “Variable”, are adapted for local conditions based on forwarded from local experts [46]. The weightings are planned to be reviewed at least every five years according to the proposed methodology [45].

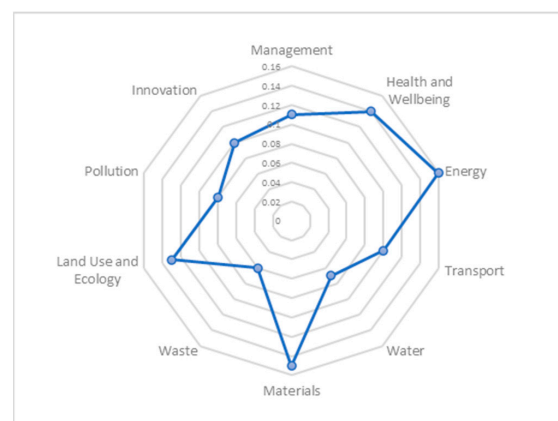


Figure 3. The weighting coefficients assigned to the assessment categories in BREEAM UK v.6 for new constructions [47].

Furthermore, LEED v4.1 for new constructions comprises 9 assessment categories and 57 criteria, with 12 of them being prerequisites [48]. A total of 110 points is available, distributed among the nine categories, and the final score is the unweighted sum of the scores in all categories [48]. Therefore, LEED adopts the equal weights approach for the weighting coefficients assigned to the assessment categories (see Figure 4a), with the maximum scoring points for each category predefined, thus shaping the final importance distribution between them (see Figure 4b).

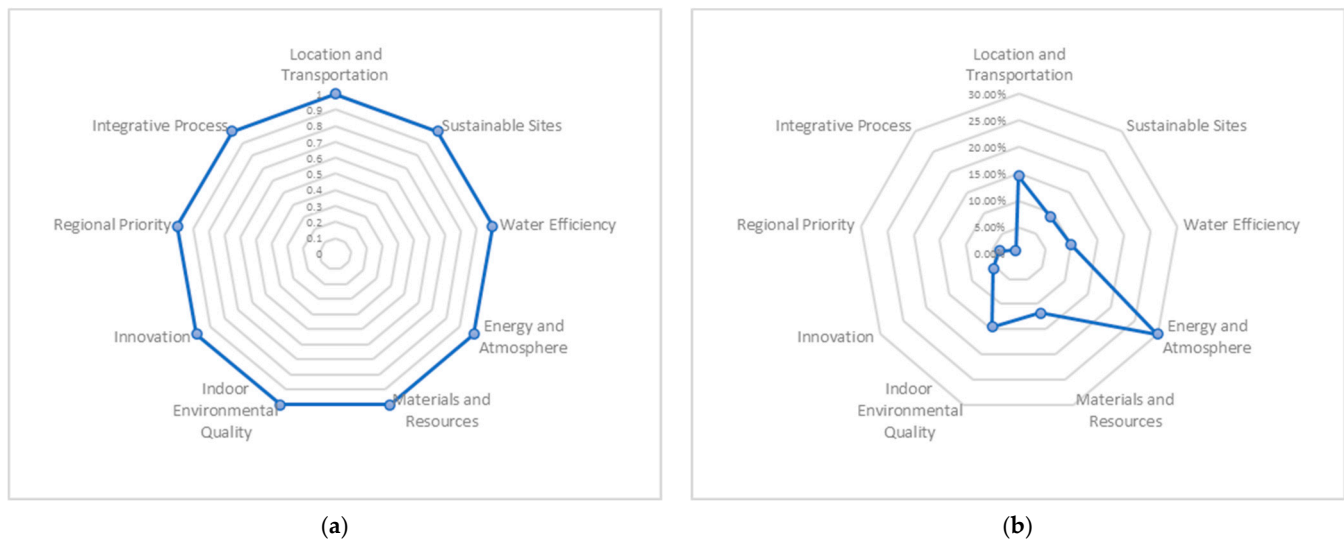


Figure 4. (a) The weighting coefficients assigned to the assessment categories in LEED v4.1 for new constructions. [48]. (b) The distribution of weight percentages among the assessment categories in LEED v4.1 for new constructions [48].

Therefore, BREEAM adopts a multi-participant judgment-based weighting approach, indicating a subjective weighting scheme. However, details about the weighting process, e.g., Potentially All Pairwise Rankings of all possible Alternatives (PAPRIKA), the participants involved at each stage and the consistency of their judgments remain unclear.

On the other hand, LEED applies equal weights to the assessment categories, with predefined maximum scoring points for each. Although there is no consensus on whether the equal weights approach is subjective or objective, there is also no information on how these equal weights were derived. Similarly, it remains unclear how the maximum scoring points for each category were determined. Characteristically, Seinre et al. [49] mentioned that even with 700-page documentation, LEED somewhat remains a “black box” for users.

3.1.2. Weaknesses and Limitations of Widely Adopted BSASs

Widely adopted BSASs, such as LEED and BREEAM, face significant criticism from researchers worldwide, particularly regarding their weighting schemes, among other factors.

It has been established that they differ significantly across many aspects, including the relative importance assigned to the three pillars of sustainability [50–52] and to the lifecycle stages considered in environmental assessments [53,54]. Further differences have been identified in passive design [55], architectural design [31], water management [56], health and well-being [18], indoor thermal comfort [35], waste management [20,57], and in the sustainability assessment of special building types [58,59]. The literature indicates that variations in weighting complicate the comparison of results across different systems.

Moreover, BSASs with international scope and widespread global adoption, such as LEED, BREEAM, Deutsche Gesellschaft für Nachhaltiges Bauen (DGNB), Comprehensive Assessment System for Building Environmental Efficiency (CASBEE), and Green Star (GS), often fall short in terms of local adaptation [60–62]. In fact, their weights do not adequately

account for local conditions, including climate [63], the availability of natural resources [56], and regional agendas [33]. Consequently, systems with a national or regional focus, such as Protocollo Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale (ITACA), Pearl Rating System for Estidama (Estidama), and Global Sustainability Assessment System (GSAS), are better able to reflect local sustainability priorities through their assigned weights [56,64].

3.2. Novel Methodologies

Although at least 74 BSASs are documented across no fewer than 184 countries, the literature review highlights a growing interest in developing new systems.

Mattinzioli et al. [13] argued for the necessity of a new globally applicable framework for sustainable building evaluation. Mattoni et al. [64] underlined the non-applicability of the weights of well-known BSASs in each specific country across the world as they may not be suitable for all of them. In the same vein, Sallam and Abdelaal [65] noted that no single tool can reliably rate environmental performance and water efficiency worldwide.

In a globalized world, there is a need for comparing building sustainability among different countries according to worldwide shared sustainability strategies and targets, while respecting local priorities and special characteristics [64,66]. Due to various reasons, including challenges in weight determination, achieving a globally applicable framework may be far from the near future. However, researchers from around the world have been working on developing novel methodologies for more effectively assessing building sustainability (see Table 1).

The following review of novel methodologies for assessing building sustainability focuses on identifying the weighting schemes adopted and classifying them according to the defined analysis framework.

3.2.1. Subjective Schemes

AHP is a widely used decision-making methodology employing a hierarchical approach to evaluate and prioritize alternatives based on criteria and sub-criteria [67]. Notably, nearly 42% of the studies introducing novel sustainability assessment methodologies have utilized the AHP method (see Figure 5). Steps include creating a hierarchical structure, pairwise comparisons of criteria and alternatives [68], and consistency verification using Saaty's methodology [67]. In the standard form of AHP, experts or participants use the Saaty scale (along with other scales mentioned in the literature) to express varying levels of preference and populate the pairwise comparison matrix.

Hazem et al. [19] developed a new BSAS for existing buildings in Egypt using the AHP method with local experts. Zheng et al. [69] proposed a Multi-Criteria Decision Making (MCDM) approach for selecting building energy efficiency retrofitting measures, utilizing an enhanced AHP model. This method integrates subjective expert judgments while reducing the dimensions of the pairwise comparison matrix to streamline the decision-making process.

Additionally, several studies have involved multiple stakeholder groups in the weighting process using AHP. Ardda et al. [22] developed a methodology to prioritize the social aspects of sustainability for new residential buildings in Palestine. In this study, designers and occupants ranked the three sustainability dimensions and specific social categories via questionnaires. Relative weights were derived using AHP based on the aggregated judgments of both groups, revealing significant disparities in their perceptions of social sustainability. Similarly, Too et al. [70] engaged expert groups from the UK and Australia in a framework designed to guide decision-making for zero-carbon building design. Using Voting AHP, they found that both groups placed a strong priority on initial capital expenditure.

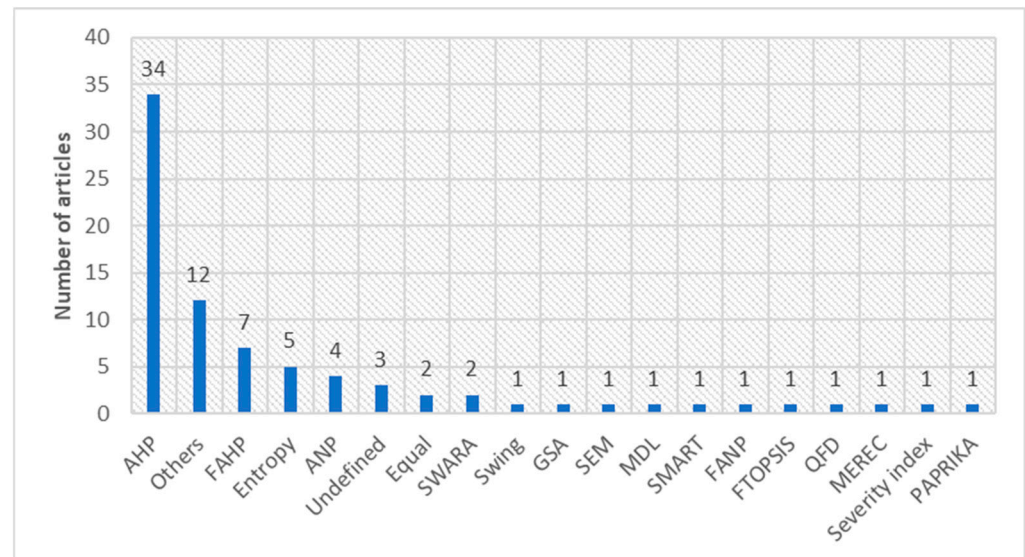


Figure 5. Distribution of articles categorized by weighting method.

Alternatively, Arafat et al. [62] developed a customized weighting system based on the Green Pyramid Rating System (GPRS) to assess the sustainability of university buildings using the AHP. The methodology comprised two phases: the first engaged all stakeholders and experts to construct a pairwise comparison matrix for the primary GPRS categories, while the second involved stakeholders and external experts in assessing the criteria within each category.

The AHP, which inherently relies on participant judgments, has also been integrated with the equal weights approach. Raslanas et al. [71] developed a sustainability model for recreational buildings, classifying criteria into social, economic, and environmental categories. Using AHP with input from local experts, they determined the relative weights for these main categories, while assigning equal weights to the sub-criteria within each group. Similarly, Cuadrado et al. [72] investigated the applicability of the MIVES method to industrial buildings through three Spanish case studies. In this approach, local experts determined criteria weights via AHP, but equal importance was assigned to all sustainability dimensions.

On the other hand, Marzouk et al. [73] proposed an MCDM framework to evaluate building system alternatives based on energy performance. In this case, the analysis included four weighting scenarios derived from expert-determined initial weights using the AHP, including equal and random weights. By conducting a sensitivity analysis of the criteria weights, they observed that the most heavily weighted criteria are not necessarily the most critical in determining the ranking of alternatives.

Furthermore, researchers have utilized the Fuzzy Analytic Hierarchy Process (FAHP), Analytic Network Process (ANP), and Fuzzy Analytic Network Process (FANP) methods, which are derived from the traditional AHP. Specifically, FAHP is an extension of AHP that incorporates the concept of fuzzy logic [74]. Unlike the traditional numerical or crisp pairwise scale of AHP, FAHP involves input fuzzification, which converts values into linguistic variables that align more with how humans describe the values [74]. The implementation of fuzzy logic aims to represent uncertainty in the decision-making process.

Vyas and Jha [75] compiled a list of sustainability attributes for new residential buildings in India. Local professionals evaluated the inclusion of these attributes in a BSASs using a 5-point Likert scale and PCA, while an expert panel employed the FAHP method to determine the attribute weights. In another study focusing on India, Bhyan et al. [76] devised a methodology for assessing sustainability in new group housing constructions.

Using the FAHP, they interviewed local experts to determine the relative importance of building lifecycle phases, categories, and criteria.

Sadeghi et al. [77] created a framework to adapt LEED for existing buildings in Iran. Using k-means clustering, they divided Iran into four climatic zones. A survey with local experts determined the weights of LEED categories and criteria for each zone using the FAHP method. In another Iranian study, Fatourehchi and Zarghami [78] proposed a social sustainability assessment framework for residential buildings. Local experts prioritized the assessment criteria using the FAHP method. It is noteworthy that the authors suggested that a fuzzy weight hierarchy could fill the gap in sustainability design.

Galvani et al. [79] established operational assessment criteria for green government buildings in Indonesia. Through a case study, they conducted a comparative analysis of weighting outcomes using crisp AHP and FAHP with triangular fuzzy numbers. Drawing on responses from staff at the Public Works and People's Housing Agency and building occupants, the study revealed divergences between the methods, demonstrating that the priority weights were significantly influenced by the subjective nature of the questionnaire responses.

While similar to AHP, the ANP accounts for criteria correlations, making it better suited for complex systems characterized by interdependent criteria and alternatives [80]. Conventional ANP typically involves three key steps: developing a network structure (rather than a strict hierarchy), constructing judgment matrices based on expert opinions, and forming a supermatrix to determine final priorities [80]. Furthermore, ANP has been integrated with fuzzy logic to address uncertainty, leading to the development of the FANP method.

Hu et al. [81] proposed an environmental and energy performance assessment method for various building types using scenario modeling. Relative weights were determined via the FANP, accounting for the interrelationships between criteria as estimated by experts. The authors acknowledged weight variations stemming from subjective interpretations of performance indicators but suggested that these could be calibrated over time. In a different approach, Xie et al. [80] integrated ANP and the entropy method into a sustainability assessment framework for prefabricated buildings in China, grounded in Importance-Performance Analysis. Both methods engaged experts from Guangzhou, albeit through distinct participant groups. The final weights were calculated as the arithmetic mean of the values derived from the two methods.

Table 1. Summary of subjective, objective, and hybrid weighting schemes identified in the review, highlighting their main characteristics and key differentiating factors.

Methodology	Type	Main Characteristics	Key Factors and Differences	Representative Studies
SWARA + MEREC	Hybrid	Integration: Combines SWARA (subjective expert ranking) with MEREC (objective removal effects) within an Intuitionistic Fuzzy Set context. Final weights are the arithmetic mean of both methods.	Key: MEREC leverages causality: criteria gain weight if their removal significantly changes the aggregate performance. Diff: Balances expert subjectivity with the objective impact of criteria on the decision matrix.	[82]
Literature averages + Entropy	Hybrid	Combines Literature averages (Subjective) with Entropy weights (Objective from simulation data).	Pros: Uses heuristic algorithms to merge domain knowledge with building performance data.	[69]

Table 1. Cont.

Methodology	Type	Main Characteristics	Key Factors and Differences	Representative Studies
Impact-based Shares (with fixed constraint)	Hybrid	Assigns a fixed weight (e.g., 50%) to a priority category. Remaining weights are calculated based on the percentage share of impacts (e.g., CO ₂ emissions) across groups.	Key: Relative importance is significantly influenced by external factors like energy source carbon intensity. Diff: Requires a common metric (CO ₂ , Energy) for all categories to be comparable.	[49]
PCA + Clustering with manual labeling	Hybrid	Uses unsupervised learning (PCA, Hierarchical Clustering) to group buildings and extract dominant features. “Green labels” are then assigned manually (e.g., via Skytrax ratings) to cluster medoids to derive assessment rules.	Key: Derives “Green Rules” from large datasets. Diff: Unlike pure machine learning, it strictly requires human intervention to assign value/ranking to the data-driven clusters.	[83]
GSA	Objective	Quantifies the impact of input parameter uncertainties on model output variation. Weights are derived by transforming sensitivity indices (from regression, screening, or variance-based methods) across various design scenarios.	Key: Directly links weights to the model’s physical behavior and uncertainty. Diff: Utilizes diverse mathematical approaches (e.g., Sobol, Morris, Multi-Linear Regression) to determine importance based on simulation outputs.	[84]
Monetary valuation	Objective	Expresses impacts in monetary units (LCC, Willingness-to-pay). Weights impacts by their probability of occurrence.	Pros: Unified unit (money) for all pillars. Key: Incorporates extreme events/resilience.	[85]
Probabilistic Risk Assessment	Objective	Combines sustainability (normal conditions) and resilience (exceptional events) into a global assessment.	Diff: Requires expressing all criteria in a common unit (normalization or monetary) to combine probabilistic impacts.	[34]
Predefined Weighting Functions	Objective	Utilizes independent functions to map various variable types (numerical, categorical) to normalized scores (e.g., 0–10).	Key: The importance range is determined by the function’s structure and value fields. Diff: Weights are embedded in the scoring function itself rather than derived from external comparisons.	[24]
Entropy (data)	Objective	Statistical approach measuring data dispersion. Greater dispersion implies higher information value and results in higher weights.	Key: Effective in uncertain/variable environments; purely data-driven. Diff: Weights change based on dataset variance (e.g., shifting priorities in future climate scenarios) rather than expert preference.	[86,87]
AHP/FAHP	Subjective	Decomposes problems into hierarchy; uses pairwise comparisons (crisp or fuzzy).	Pros: Consistency validation. Cons: Complexity with many criteria.	[19–22,62,70,75–79]
ANP/FANP	Subjective	Generalization of AHP for interdependent criteria (network structure).	Pros: Handles dependencies. Cons: Complex supermatrices.	[81]
SWARA	Subjective	Step-wise ranking and relative significance weighting.	Diff: Simpler than AHP; focuses on relative steps.	[88]
SMART + PAPRIKA	Subjective	Direct rating (SMART), or trade-off scenarios (PAPRIKA).	Diff: Focus on trade-offs and sensitivity intervals rather than matrices.	[89]
Swing	Subjective	Worst-to-best transitions.	Diff: Focus on trade-offs and sensitivity intervals rather than matrices.	[90]
MDL	Subjective	Modified Digital Logic using nonlinear scaling.	Pros: Avoids extreme values bias.	[91]

Table 1. Cont.

Methodology	Type	Main Characteristics	Key Factors and Differences	Representative Studies
AHP + Equal Weights (no justification)	Subjective	Uses AHP for one hierarchical level (e.g., criteria groups) and assigns equal weights to the other level (e.g., sub-criteria), or vice versa.	Pros: Reduces the number of pairwise comparisons while keeping expert structure. Key: Both methods engaged experts, but used distinct participant groups for each method.	[71–73]
ANP + Entropy	Subjective	Calculates weights separately using ANP (expert) and Entropy (expert), then aggregates them.	Diff: Balances subjective network priorities with data dispersion derived from a different group of experts.	[80]
QFD + IBULI + FSI	Subjective	QFD combined with IBULI (linguistic approach) and FS).	Pros: Models high uncertainty and varying stakeholder power better than standard methods.	[86]
Multi-Source Fuzzy Average	Subjective	Fuzzy weighted average of three data sources: User survey + Expert analysis + Direct building survey.	Pros: Improves precision by triangulating data from different actor groups.	[92]
Severity index + Monte Carlo	Subjective	Integration: Prioritizes criteria from professional surveys using the Severity Index (nonparametric classification) and refines decisions via Monte Carlo simulations (numerical predictions through repeated random sampling of input distributions).	Key: Weighs criteria based on severity; leverages statistical distribution. Diff: Refines subjective survey data using statistical classification and probabilistic sampling rather than simple aggregation.	[93]

Four purely subjective weighting methods identified in the literature are SWARA, Swing, Simple Multi-Attribute Rating Technique (SMART), and PAPRIKA. SWARA is an approach where experts rank criteria from most to least significant [88]. Each criterion is then compared to the one immediately preceding it to determine its relative significance [82]. In contrast, the Swing method utilizes a reference state where all criteria are initially assumed to be at their worst levels. Participants assign points based on the relative importance of moving each criterion, one at a time, to its best state [90]. Conversely, in SMART, participants assign the highest score to the most important criterion (serving as a benchmark) and subsequently score the remaining criteria relative to it [89].

Finally, PAPRIKA elicits preferences through hypothetical scenarios. In each case, two criteria vary while the others remain constant, requiring participants to evaluate trade-offs and select a preferred scenario [89]. Based on these choices, the method iteratively calculates and adjusts points until final weights are derived [89].

Mirzaee et al. [89] evaluated SMART and PAPRIKA methods for resilient and sustainable building design. Two surveys were conducted with the same group of experts, uncovering notable preference differences between the two approaches. The authors concluded that decision-makers' valuations vary not only based on the survey method but also inconsistently across criteria and groups, aligning with the findings of Galvani et al. [79].

Focusing on masonry buildings, Seddiki et al. [90] proposed a multi-criteria decision-making framework for thermal renovations. The Swing method was employed to determine criteria importance based on input elicited from local experts. Subsequently, a sensitivity analysis revealed stable weight intervals, demonstrating the robustness of the rankings against minor variations in the decision-makers' preferences.

Zolfani et al. [88] employed SWARA within an MCDM framework to evaluate hotel construction projects in Iran. Specifically, SWARA was used to determine criteria weights,

while Complex proportional assessment was applied to rank the alternatives. However, the authors acknowledged that methodologies such as AHP and ANP might be more appropriate for weighting sustainable criteria in highly complex scenarios.

Two additional participatory weighting methods identified in the literature are Modified Digital Logic (MDL) and Quality Function Deployment (QFD). MDL builds upon the Weighted Properties Method by incorporating digital logic principles [94]. It employs a nonlinear scaling approach combined with a modified three-state digital logic, which ensures more balanced results by mitigating the influence of extreme high or low values [94]. Conversely, QFD—originally a quality management tool—begins with the creation of a ‘stakeholders’ fields of conflicts’ decision matrix. Experts subsequently determine the impact of these conflicts on the assessment criteria to form the conflict-assessment criteria matrix. The final weights are derived through matrix multiplication, yielding the stakeholders-assessment criteria matrix [27].

Gamalath et al. [91] suggested a framework for evaluating the energy systems of multi-unit residential buildings, integrating asset and operational rating concepts. Through a case study, they determined relative weights using survey responses from four stakeholder groups via the MDL method, with final weights calculated as unweighted averages. Additionally, they explored two alternative weighting scenarios—neutral and eco-centric—deriving weights from literature and expert consultation. The authors observed variations in assessment ratings across different weighting scenarios, attributed to differences in criteria allocation.

Furthermore, Chen et al. [27] presented a decision-making framework for sustainable building material selection. Assessment criteria weights were derived using a QFD-based method. With the Improved Basic Uncertain Linguistic Information (IBULI) and Factor of Stakeholder Influence (FSI) method, seven expert groups with varying opinion weights determined criteria weights. The Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) method was applied for optimal material selection. The authors concluded that the IBULI, as an enhanced linguistic approach, effectively models and processes information under high uncertainty, resembling human cognitive levels.

Barreca and Cardinali [92] introduced a method for assessing agri-food building performance in Italy using a fuzzy weighted average across three levels: user survey, expert analysis, and direct survey of building characteristics. They illustrated a case study of a bakery goods factory, evaluating criteria in various building areas. The authors emphasized that combining these measurement techniques with the fuzzy weighted average improved precision and mitigated inherent limits and subjectivity.

Cabral and Blanchet [93] identified criteria for selecting structural and envelope materials in wooden prefabricated buildings. They conducted a pilot survey in Canada and the US to prioritize these criteria based on professional opinions. To refine decision-making and classification, they used Monte Carlo simulations with various iterations and a severity index, leveraging data from the initial survey.

The severity index is a nonparametric statistical procedure used for data classification [93]. This method allows criteria to be prioritized and subsequently weighed based on their severity [93]. On the other hand, Monte Carlo simulations provide numerical predictions by performing repeated random sampling based on the statistical distribution of the input data [93,95].

3.2.2. Objective Schemes

Purely objective weighting schemes have also been identified in the literature. Bocchini et al. [34] proposed a unified framework for resilience and sustainability in civil infrastructure systems, including buildings, using risk assessment. The authors argued

that infrastructure impact on society should be assessed through sustainability analysis under normal conditions and resilience analysis after exceptional events. These impacts should be weighted by their probabilities and combined in a global impact assessment. As this approach is probabilistic, it can incorporate extreme events that may occur during the building's lifecycle and impact its sustainability, thus incorporating the concept of building resilience. To achieve this, it is necessary to express all the assessment criteria in a common unit through normalization or by using monetary units [34].

Expressing environmental and social impacts in monetary units, in the form of environmental and social external costs, is an approach called monetary valuation [85]. Monetary valuation permits a direct comparison of the environmental, economic, and social impacts throughout each stage of a building's lifecycle or its entire lifecycle [85]. Allacker et al. [85] employed monetary valuation to optimize 16 representative residential buildings in Belgium. They applied the Lifecycle Assessment (LCA) method to assess lifecycle environmental impacts, expressed as environmental external costs via the willingness-to-pay approach, and the LCC method for economic impacts. Their analysis of Pareto optima revealed differing priorities between environmental and financial considerations.

Serrano-Jiménez et al. [24] suggested a multi-criteria whole sustainability decision support method for selecting housing renovation strategies in Sweden. They conducted two case studies involving 700 post-war apartments, outlining four main renovation strategies based on budget. Impact factors for each strategy were weighted by assigning normalized scores between 0 and 10 per variable, utilizing predefined weighting functions.

This approach utilizes independent predefined weighting functions for each assessment criterion [24], spanning numerical, categorical, or other variable types. These functions participate in numerical or logical operations but must yield numerical output for aggregation. While each criterion may have its own function [24], their independence and structure, including value fields, determine the importance range of each criterion.

Global Sensitivity Analysis (GSA) quantifies the impact of input parameter uncertainties on model output variation [38]. Common GSA methodologies include regression-based (e.g., Multi-Linear Regression), screening-based (e.g., Morris method), and variance-based approaches (e.g., Sobol, Fourier Amplitude Sensitivity Test) [38,84]. In this context, weighting coefficients are derived from the sensitivity quantification of building performance across various design scenarios. Chen et al. [84] employed these three approaches to determine weighting coefficients, transforming the resulting sensitivity indices into weights and integrating them with performance scales to formulate their assessment framework.

The entropy method is a statistical approach particularly effective in uncertain or variable environments, as it quantifies data dispersion. Greater dispersion indicates a higher information value and, consequently, a greater impact on the evaluation, resulting in higher weights for the specific criterion [80]. Applying this concept, Chen and An [86] proposed a green residential building design optimization framework in China using the orthogonal experiment method. In a case study of Nanjing villa, they utilized simulation results to construct the decision matrix for entropy weighting, while the optimal alternative was determined via the TOPSIS method. In the same vein, Shi and Chen [87] developed an optimization method for hospital building energy renovation. They applied the entropy method to a dataset derived from simulation samples, further observing that weight priorities shifted when considering future climate scenarios.

3.2.3. Hybrid Schemes

Zeng et al. [96] employed the entropy method within a hybrid weighting scheme to evaluate IEQ in office buildings. This approach synthesized subjective weights, derived from literature averages, with objective weights determined via the entropy method using

building performance simulation data. The final weight values were calculated “through a case-driven method and heuristic algorithm,” thereby balancing theoretical benchmarks with case-specific data.

Seinre et al. [49] assessed the environmental and economic impacts of design options for office buildings in Estonia. A fixed weight of 50% was assigned to the indoor climate quality category. The remaining weights were derived by averaging the percentage shares of categories across three impact groups and scaling them to the remaining 50%. This methodology presumes the use of a common metric—such as monetary values, energy, or CO₂ emissions. In this case, CO₂ emissions were utilized as the common unit. The authors emphasized that the specific carbon intensity of different energy sources significantly influences the relative importance of the assessment categories.

Additionally, Ramakrishnan et al. [83] analyzed environmental and sustainability reports from 312 airports, compiling a dataset of 17 input features to determine the most critical environmental factors and their relative weights. The authors applied PCA for dimensionality reduction and used Agglomerative and Divisive Hierarchical Clustering to group the airports. Skytrax ratings were employed for green labeling of the medoids within the clusters. Ultimately, 12 green rules were derived for assessing the green performance of airport buildings. This approach integrates unsupervised and supervised learning techniques. While clustering and extracting dominant features rely on the dataset, assigning green performance labels is performed manually, highlighting the necessity of human intervention. Correspondingly, the green performance assessment of unseen buildings is guided by green rules, with priority features and thresholds established through unsupervised data analysis, while the assignment of green labels is based on comparisons with reference buildings ranked by human evaluators.

Mishra et al. [82] employed SWARA within a hybrid MCDM framework developed for industrial building sustainability assessment. To balance subjectivity and objectivity, they combined SWARA with a method based on the Removal Effects of Criteria (MEREC). Data was collected via an 11-point Likert questionnaire involving local participants and processed within an intuitionistic fuzzy set context to handle uncertainty. The final weights were derived by calculating the arithmetic mean of the values obtained from the two methods.

Regarding MEREC, this method derives criterion importance from their removal effects in the decision matrix [97], leveraging causality. Criteria gain weight if their removal significantly impacts alternatives' aggregate performances, aiding in exclusion decisions [97]. Overall alternative performance is determined using a score matrix and an aggregate performance function. Performance is then reassessed by removing each criterion individually [82,97].

4. Discussion

As demonstrated in the literature review (see Table 1), there remains a lack of consensus regarding the construction of weighting schemes [84]. Notably, Villalba et al. [98] emphasized that the weighting of criteria is often the most subjective step.

Novel BSAS methodologies seek to address the weaknesses and limitations of well-known and widely adopted systems, particularly with respect to local adaptation and specific aspects of building sustainability. To this end, they propose frameworks with new assessment criteria, mainly derived from the literature and existing BSASs, along with new weighting coefficients based on defined weighting schemes.

When focusing on local adaptation, the literature reveals that the weights recommended by international BSASs differ significantly from those proposed by studies that focus on a single country or a group of countries [77]. However, this difference should

not be interpreted as evidence of the superiority of novel methodologies in ensuring sustainability; rather, it indicates significant variations in weighting schemes. At this point, it is worth noting that novel methodologies such as the Jordanian SABA [68], the Saudi Arabian Saudi Environmental Assessment Method (SEAM) [63], the Nigerian Building Sustainability Assessment Method (BSAM) [30], and the Ethiopian Ethio-SBAT [99] have been subsequently studied in the literature as new BSAs (see Table A1).

As outlined in Section 3, 75% of novel methodologies employed subjective weighting schemes, while objective schemes accounted for 12%, and hybrid schemes made up 6% (see Figure 6). Additionally, 3% used equal weights without justification. Therefore, 78% of the studies relied exclusively on subjective judgments for determining weights (see Table A2).

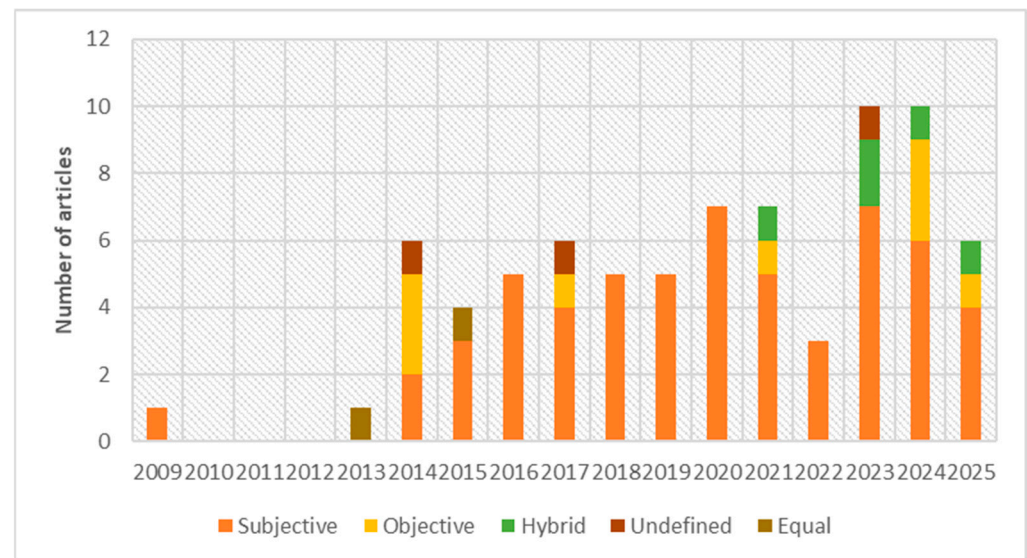


Figure 6. Annual distribution of weighting schemes in novel methodologies from 2009 to 2025. The overall percentage share for each category across the entire period is: subjective (75%), objective (12%), hybrid (6%), undefined (4%), and equal (3%).

Furthermore, no clear trend was observed in the fluctuation of these proportions over the period studied (see Figure 6). The analysis of geographical distribution, combined with the classification of the adopted schemes, further highlights the dominance of subjective schemes (see Figure 7). Only in studies related to European countries is a more balanced distribution observed, with the objective schemes accounting for 25%.

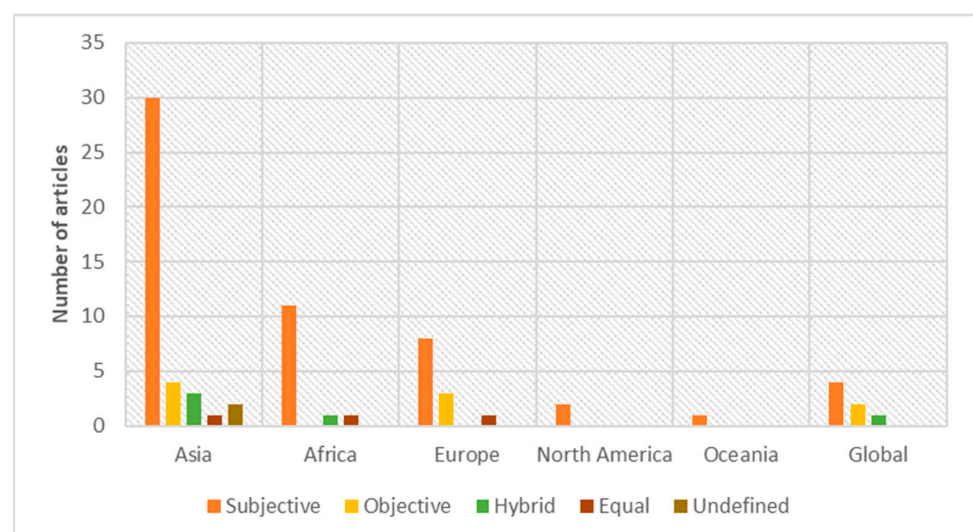


Figure 7. Geographical distribution of articles categorized by weighting scheme type.

A significant finding of this review emerges from the synthesis of Figures 2, 7 and 8. While LEED and BREEAM—originating in North America and Europe, respectively—remain the most adopted and influential BSASs worldwide, 53% of the methodologies proposing new BSASs focus on Asian countries. Additionally, 75% of these studies adopt subjective weighting schemes.

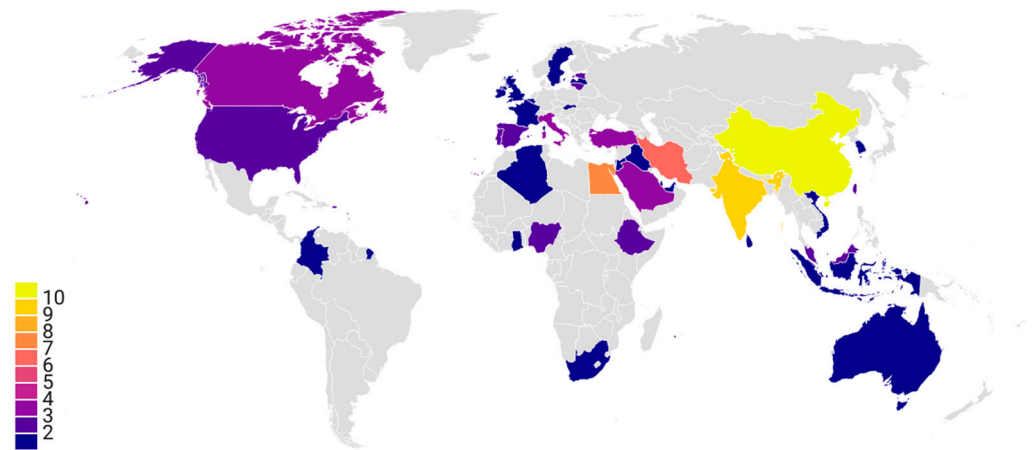


Figure 8. Global distribution of articles by country. Each country is shaded based on the number of articles focused on it. Twenty-four articles are indicated to have an international scope.

Consequently, developed countries in North America and Europe established the first BSASs in the 1990s, dominating the global construction market. In contrast, developing Asian countries began formulating their own BSASs in the mid-2010s. Since then, the research landscape has been led by novel methodologies from Asian countries, proposing primarily subjective schemes based on local expert judgment.

AHP is the most applied weighting method in the literature, utilized in approximately 44% of the studies, followed by other frequently used methods such as FAHP and ANP (see Figure 6). Notably, the entropy method has been used in subjective [80], objective [87], and hybrid schemes [96]. This observation emphasizes that the characterization of a weighting scheme should not rely solely on the method used, such as AHP, but should also consider the source of the input data.

The number of participants in subjective and hybrid schemes varies significantly across studies. On average, there were approximately 67 participants, with a standard deviation of about 132. Although the appropriate number of participants is not defined in the literature, this wide variation is noteworthy, especially since a similar pattern is observed in studies employing the same method, such as AHP. Moreover, researchers have underlined variations in judgments between different participant groups, as well as across various survey methods, assessment criteria, and categories [22,89].

Focusing on the identified objective schemes, it is important to note that estimating environmental and social external costs across the entire building lifecycle can be highly challenging. Moreover, these estimations often involve the subjectivity of the methods used, such as those based on willingness-to-pay approaches [100]. Although expressing diverse and sometimes difficult-to-quantify concepts in a common unit ensures an objective comparison of solutions or strategies within the sustainability framework, as LCA does, there are significant concerns about the assumptions made along the way. These include the consideration of crucial parameters, such as nonlinearity effects, given that the weighting results will ultimately be applied to hundreds of thousands of buildings [101,102].

That is, examining one or several case studies to determine how different impact categories affect the sustainability of these buildings, and calculating the weighting factors for a building category across an entire country based on these quantitative analyses,

may be contentious. This approach relies on a broad generalization based on a specific spatiotemporal snapshot, which may not provide a fully reliable basis for guiding the future of the building sector.

The basic argument supporting subjective schemes lies in the participants' opportunity to infuse their human knowledge, experience, and foresight into their choices, thereby influencing the weights of assessment systems. This aspect is unattainable through data analysis alone. Conversely, proponents of data-driven studies advocate for the objectivity of the proposed weighting processes, which are founded on transparent analysis methodologies with specific assumptions rather than relying on individual opinions. Data-driven approaches offer the advantage of producing testable and comparable results, allowing different methods to be employed while utilizing the same data.

Hybrid approaches emerge as a promising option, combining both subjective and objective methods to leverage their unique advantages. One significant advantage of assessing criteria weights using two different methods is the opportunity to compare them and ensure consistency in scale. On the other hand, hybrid schemes require substantial effort, as they involve both data analysis and participatory processes.

Subjective, objective, or hybrid, weighting schemes require a sufficient number of diverse experts in the building sector or substantial amounts of reliable data, respectively. In a fast-changing world, BSASs should be dynamic to better respond to new and challenging situations and goals, effectively guiding the building sector. Dynamic BSASs imply dynamic weights, which, in turn, necessitate new participatory processes and up-to-date data. While this task may pose challenges in developed economies, it could be a significant obstacle in developing and undeveloped economies.

Future research should focus on evaluating the effectiveness of BSAS weighting schemes using real-world data from a sufficiently large number of buildings that have applied them [103]. However, meaningful comparison among BSASs requires that they share common sustainability goals, which are inherently reflected in their weighting structures.

As the SDGs are globally recognized as the primary framework for humanity's transition to sustainable development, both international and locally focused BSASs should align with these priorities. The first step in this alignment is the proper integration of building-sustainability-related SDGs into the assessment criteria. This step is crucial for comparing different BSASs with a similar scope. The second step concerns weighting schemes, as weights drive the transformation of the construction market through sustainability certification. To ensure this intended transformation, there is a need for integrated tools capable of forecasting how various weighting combinations influence the local or international construction market and contribute to meeting the SDGs.

The third step is the evaluation of the alignment process. Using real-world data from a sufficiently large number of buildings, the effectiveness of the assigned weights—and consequently the weighting schemes—will be validated, allowing for the refinement of the forecasting tools. A fundamental prerequisite is transparency throughout all stages of the weighting process.

5. Conclusions

The effort to establish a globally applicable building sustainability assessment approach faces serious difficulties, primarily because of significant variations in local conditions worldwide. Climatic and geomorphologic conditions, availability of natural resources, political and socioeconomic situations, and cultural factors all play substantial roles in shaping national or regional priorities, thereby influencing the interpretation of building sustainability [19,104].

Therefore, while international BSASs such as LEED and BREEAM have made significant contributions to paving the road for a sustainable building sector since the 1990s, the literature indicates that their applicability and efficiency are limited. Novel methodologies are continually being proposed to overcome the existing weaknesses and limitations of existing widely adopted BSASs and to address new aspects of building sustainability. However, their superiority can only be established through the comparison of a sufficient amount of real-world data, while sharing common long-term goals for the building sector.

LEED and BREEAM, the two leading BSASs worldwide, use subjective and equal-weight approaches. BREEAM employs a multi-participant, judgment-based weighting method, reflecting a [19,104] subjective weighting scheme. In contrast, LEED applies equal weights to its assessment categories, with predefined maximum scoring points for each. However, there is no information on how these equal weights were determined or how the maximum scoring points for each category were established.

In novel methodologies, subjective schemes dominate, with no clear temporal or geographical trend indicating a shift toward objective or hybrid schemes. As a result, most researchers opt to base the prioritization of assessment criteria on subjective judgments, leveraging human knowledge, experience, and foresight in their BSASs. Specifically, AHP is identified as the most widely used weighting method in the literature, although the appropriate number of participants remain unresolved issues.

Weighting schemes, having the potential to transform the construction market through sustainability certification, must align with SDGs at regional and local levels. This ensures contextual adaptation while maintaining consistency with global sustainable development efforts. To achieve this alignment, greater research focus is required to understand the impact of BSASs weights on the dynamics of regional or local construction markets. A critical step in this process is the evaluation of these weights using real-world evidence regarding the achievement of SDGs. Although this endeavor is resource-intensive and challenging, it is indispensable for understanding how BSASs can contribute to fostering a more sustainable built environment.

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Abbreviations

The following abbreviations are used in this manuscript:

AHP	Analytic Hierarchy Process
ANP	Analytic Network Process
ASGB	Assessment Standard for Green Building
BAM	Budget Allocation Method
BEAM Plus	Building Environmental Assessment Method Plus
BREEAM	Building Research Establishment Environmental Assessment Method
BSAM	Building Sustainability Assessment Method
BSASs	Building Sustainability Assessment Systems

BWM	Best Worst Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
DGNB	Deutsche Gesellschaft für Nachhaltiges Bauen
Estidama	Pearl Rating System for Estidama
FAHP	Fuzzy Analytic Hierarchy Process
FANP	Fuzzy Analytic Network Process
FTOPSIS	Fuzzy Technique for Order of Preference by Similarity to Ideal Solution
GBI	Green Building Index
GBRSs	Green Building Rating Systems
GG	Green Globes
GM	Green Mark
GPRS	Green Pyramid Rating System
GRIHA	Green Rating for Integrated Habitat Assessment
GS	Green Star
GSA	Global Sensitivity Analysis
GSAS	Global Sustainability Assessment System
G-SEED	Green Standard for Energy and Environmental Design
HQE	Haute Qualité Environnementale
IBULI	Improved Basic Uncertain Linguistic Information
IEQ	Indoor Environmental Quality
IGBC	Indian Green Building Council Rating System
ITACA	Istituto per l'Innovazione e Trasparenza degli Appalti e la Compatibilità Ambientale
LBC	Living Building Challenge
LCA	Lifecycle Assessment
LEED	Leadership in Energy and Environmental Design
MCDM	Multi-Criteria Decision Making
MDL	Modified Digital Logic
MEREC	Method based on the Removal Effects of Criteria
PAPRIKA	Potentially All Pairwise RanKings of all possible Alternatives
PCA	Principal Component Analysis
QFD	Quality Function Deployment
SBTool	Sustainable Building Tool
SDGs	Sustainable Development Goals
SEAM	Saudi Environmental Assessment Method
SEM	Structural Equation Modeling
SMART	Simple Multi-Attribute Rating Technique
SPeAR	Sustainable Project Assessment Routine
SWARA	Stepwise Weight Assessment Ratio Analysis
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
FSI	Factor of Stakeholder Influence

Appendix A

Table A1. Overview of the existing BSASs-related literature.

No.	Country/Region	Year	Authors	Topic	Building Type	BSASs
1	Global	2015	Chen et al. [55]	Passive design	Buildings generally	BREEAM, LEED, BEAM Plus, ASGB
2	Canada, Turkey, China, Egypt	2015	Suzer [61]	Environmental comparison	Buildings generally	LEED, BREEAM, SBTool, CASBEE, GS
3	Global	2016	Andrade and Bragança [50]	Sustainability	Residential buildings	BREEAM, LEED, SBTool, CASBEE, DGNB
4	UAE, Qatar	2017	Awadh [33]	Sustainability	Buildings generally	LEED, BREEAM, Estidama, GSAS
5	Global	2018	He et al. [35]	Green design	Buildings generally	GS, LEED, ASGB
6	Global	2018	Ismaeel [54]	LCA	Buildings generally	LEED, BREEAM, GS, GM, GG, HQE, SBTool
7	Global	2018	Mattoni et al. [64]	Critical review	Buildings generally	CASBEE, GS, BREEAM, LEED, Protocollo ITACA
8	Saudi Arabia	2019	Al-Qawasmi et al. [56]	Water-related aspects	Buildings generally	LEED, BREEAM, DGNB, CASBEE, GS, GM, BEAM Plus, G-SEED, GSAS, Estidama, SBTool
9	Saudi Arabia	2019	Alyami [63]	Energy efficiency assessment	Buildings generally	BREEAM, LEED, Estidama, GSAS, SEAM
10	Global	2019	Brambilla and Capolongo [18]	Building healthiness and sustainability	Hospital buildings	BREEAM, LEED, CASBEE, GS, WELL, DQI
11	Global	2019	Ismaeel [60]	Operating mechanisms	Buildings generally	LEED, BREEAM, GG, GS, HQE, GM, BEAM Plus, SBTool
12	Global	2020	Ade and Rehm [21]	Review	Buildings generally	BREEAM, LEED, GS
13	Hong Kong	2020	Jaillon et al. [20]	Construction waste	Residential buildings	BEAM Plus
14	Global	2020	Wen et al. [51]	Sustainability	Buildings generally	LEED, BREEAM, GM, BEAM Plus, ASGB, CASBEE, DGNB, HQE, EEW, GS
15	Global	2021	Liang et al. [52]	Sustainability	Buildings generally	LEED, BREEAM, DGNB, GS, GBI
16	USA	2021	Luo et al. [103]	Water-related aspects	Office, school, residential buildings	LEED
17	Global	2021	Mattinzioli et al. [13]	Review	Residential, commercial buildings	BREEAM, HQE, LEED, Passivhaus, BEAM Plus, CASBEE, GG, GS, Estidama, DGNB
18	Global	2022	He et al. [31]	Indoor thermal comfort environments design	Buildings generally	LEED, BREEAM, GS, GM, ASGB, BEAM Plus
19	Global	2022	Lazar and Chithra [53]	Sustainability and LCA	Buildings generally	BREEAM, LEED, IGBC, GRIHA
20	China	2023	Cai and Gou [59]	Sustainability	Data centers	ASGB, BEAM Plus, BREEAM, GBI, GM, IGBC, LEED
21	Global	2023	Ferreira et al. [58]	Sustainability	Retail buildings	LEED, BREEAM, DGNB
22	Colombia	2023	Jorge-Ortiz et al. [57]	Waste management	Buildings generally	LEED, BREEAM, CASBEE, GS, GG, Level(s), DGNB, Verde, CASA
23	Global	2023	Song et al. [105]	Architectural design	Buildings generally	LEED, ASGB, GM, WELL, ASHB, LBC
24	Portugal	2024	Feijão et al. [23]	BSAS selection	Buildings generally	BREEAM, LEED, WELL, LiderA
25	Global	2024	Rebelatto et al. [40]	Energy efficiency assessment	Office buildings	LEED, BREEAM, DGNB

Table A2. Overview of novel methodologies-related literature.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
1	Jordan	2009	Ali and Al Nsairat [68]	Green building performance assessment	Residential buildings	7	42	157	LEED, CASBEE, BREEAM, SBTool	AHP with local experts and non-experts	60
2	India	2013	Sabapathy and Maithel [106]	Building walling systems performance assessment	Buildings generally	8	36	-	Not clearly stated	Equal weights	-
3	Belgium	2014	Allacker et al. [85]	Building environmental and economic sustainability assessment	Residential buildings	2	11	-	Not clearly stated	Pareto optimization by expressing LC environmental and economic impacts to monetary values	-
4	Global	2014	Bocchini et al. [34]	Resilience and sustainability	Civil infrastructures	-	-	-	Not clearly stated	Normal and exceptional events probabilities as weights	-
5	Turkey	2014	Cetiner and Edis [107]	Building environmental and economic sustainability assessment	Residential buildings	2	-	-	Not clearly stated	Undefined weights	-
6	Iran	2014	Namini et al. [108]	Building sustainability assessment	Residential buildings	3	5	50	Not clearly stated	AHP with local experts	118
7	Estonia	2014	Seinre et al. [49]	Building sustainability assessment	Office buildings	5	5	-	BREEAM, LEED, DGNB, SBTool	Average percentage shares of categories across the assessment indicators	-
8	Slovakia	2014	Vilcekova and Burdova [109]	Building energy efficiency assessment	Office buildings	1	3	10	Not clearly stated	AHP and authors judgment	Not clearly stated
9	Hong Kong	2015	Chen and Pan [110]	Low-carbon building performance assessment	Commercial buildings	3	5	-	Not clearly stated	Interviews with local experts	10
10	South Korea	2015	Kang [111]	Building sustainability assessment	Buildings generally	3	9	-	Not clearly stated	Equal weights	-
11	Malaysia	2015	Nilashi et al. [74]	Green building performance assessment	Buildings generally	3	9	44	Not clearly stated	FAHP with local experts	12
12	China	2015	Yu et al. [112]	Green building performance assessment	Store buildings	7	23	-	BREEAM, LEED, CASBEE, ASGB	Group AHP method with local experts	31
13	Spain	2016	Cuadrado et al. [72]	Building sustainability assessment	Industrial buildings	6	31	-	Not clearly stated	AHP with local experts	11

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
14	Lithuania	2016	Raslanas et al. [71]	Building sustainability assessment	Recreational buildings	3	19	-	BREEAM	AHP with local experts	8
15	Egypt	2016	Sallam and Abdelaal [65]	Building water efficiency assessment	Buildings generally	-	-	-	LEED, GPRS, BREEAM, Estidama, GG, GS	Authors judgment	-
16	Algeria	2016	Seddiki et al. [90]	Building thermal renovation assessment	Masonry buildings	3	4	-	Not clearly stated	Swing with local experts	4
17	India	2016	Vyas and Jha [75]	Green building performance assessment	Residential buildings	9	34	68	BREEAM, LEED, CASBEE, SBTool, IGBC, GRIHA	FAHP with local experts	Not clearly stated
18	Egypt	2017	AbdelAzim et al. [113]	Building energy efficiency assessment	Buildings generally	9	-	-	GG, LEED, BREEAM, Estidama, GPRS, IGBC	AHP with local experts	61
19	Ghana	2017	Addy et al. [114]	Building energy efficiency assessment	Office buildings	7	21	-	Not clearly stated	AHP with local experts	17
20	Hong Kong	2017	Chen et al. [84]	Building passive design assessment	Residential buildings	1	5	-	BEAM Plus	GSA methodologies	-
21	Global	2017	Mahmoud and Zayed [115]	Building sustainability assessment	Buildings generally	7	29	-	BREEAM, LEED, CASBEE	Fuzzy-based model with experts	Not clearly stated
22	South Africa	2017	Michael et al. [116]	Building renovation assessment	Buildings generally	5	-	-	LEED	Undefined weights	-
23	Estonia, Latvia, Lithuania	2017	Tupenaite et al. [117]	Building sustainability assessment	Residential buildings	3	9	53	BREEAM, LEED, CASBEE	AHP with local experts	9
24	Palestine	2018	Ardda et al. [22]	Building social sustainability assessment	Residential buildings	6	21	-	LEED, SBTool	AHP with local experts and occupants	148
25	Indonesia	2018	Galvani et al. [79]	Green building performance assessment	Government buildings	4	23	-	Not clearly stated	AHP and FAHP with local experts and occupants	20
26	Canada	2018	Gamalath et al. [91]	Building energy efficiency assessment	Residential buildings	4	28	-	Not clearly stated	MDL with various stakeholder groups and equal weights	Not clearly stated

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
27	Nigeria	2018	Nimlyat [118]	Building indoor environmental quality performance assessment	Healthcare buildings	4	12	-	Not clearly stated	SEM with building occupants	875
28	Iran	2018	Zolfani et al. [88]	Building environmental sustainability assessment	Hotel buildings	4	13	-	Not clearly stated	SWARA with local experts	8
29	Ireland	2019	Hu et al. [81]	Building environmental and energy performance assessment	Buildings generally	3	8	-	BREEAM	FANP with local experts	Not clearly stated
30	Global	2019	Mirzaee et al. [89]	Resilience and sustainability	Buildings generally	4	10	-	Not clearly stated	SMART and PAPRIKA with local experts	59
31	India	2019	Vyas et al. [119]	Green building performance assessment	Residential buildings	9	34	68	BREEAM, LEED, CASBEE, SBTool, IGBC, GRIHA	AHP and fuzzy integrals with local experts	42
32	China	2019	Wu et al. [120]	Green building interior decoration assessment	Buildings generally	8	138	-	LEED, BREEAM, GG, GS, CASBEE, GM, BEAM Plus	AHP with local experts	27
33	China	2019	Zheng et al. [69]	Building energy efficiency assessment	Buildings generally	4	9	19	Not clearly stated	AHP with local experts	52
34	Egypt	2020	Elkhatay et al. [121]	Building glazing systems sustainability assessment	Office buildings	4	16	-	LEED	AHP with LEED weights	-
35	Iran	2020	Fatourehchi and Zarghami [78]	Building social sustainability assessment	Residential buildings	5	15	-	Not clearly stated	FAHP with local experts	65
36	Egypt	2020	Hazem et al. [19]	Green building performance assessment	Buildings generally	7	40	-	LEED, GPRS	AHP with experts	Not clearly stated
37	Taiwan	2020	Liu et al. [122]	Green building performance assessment	Buildings generally	4	12	-	LEED, BREEAM, GS, BEAM Plus, ASGB, EEWI, GM, GBI	BWM-based ANP with local experts	9
38	Iran	2020	Madad et al. [123]	Building water efficiency assessment	Buildings generally	4	-	-	Not clearly stated	AHP with local experts	Not clearly stated

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
39	Nigeria	2020	Olawumi et al. [30]	Building sustainability assessment	Buildings generally	8	32	-	LEED, BREEAM, BEAM Plus, IGBC, GM, GS	Consultation of local experts	189
40	China	2020	Xie et al. [80]	Prefabricated building sustainability assessment	Buildings generally	3	13	-	Not clearly stated	ANP and Entropy method with local experts	70, 45
41	Iraq	2021	Alhilli and Burhan [124]	Building sustainability assessment	School buildings	6	37	-	BREEAM, LEED, Estidama	Statistical analysis of questionnaire responses with local experts	32
42	Italy	2021	Barreca and Cardinali [92]	Building performance assessment	Agri-food buildings	8	5	-	Not clearly stated	Fuzzy weighted average with multiple participants	39
43	Global	2021	Chen et al. [27]	Building materials performance assessment	Buildings generally	3	9	-	Not clearly stated	QFD method with experts	20
44	India	2021	Lazar and Chithra [125]	Building sustainability assessment	Residential buildings	11	84	-	LEED, BREEAM, CASBEE, DGNB, SBTool, GBI, LOTUS, BERDE, GRIHA, IGBC	FTOPSIS with local experts	120
45	Saudi Arabia	2021	Marzouk et al. [73]	Building energy performance assessment	Buildings generally	4	-	-	Not clearly stated	AHP with local experts, equal weights, random weights under conditions	Not clearly stated
46	India	2021	Reddy et al. [126]	Building sustainability assessment	Buildings generally	8	38	-	BREEAM, LEED, IGBC, GRIHA	FAHP with local experts	58
47	Sweden	2021	Serrano-Jiménez et al. [24]	Building sustainability assessment	Residential buildings	10	17	-	Not clearly stated	Independent predefined weighting function	-
48	Ethiopia	2022	Anshebo et al. [99]	Green building performance assessment	Buildings generally	8	67	-	LEED, BREEAM, CASBEE, DGNB, SBTool	AHP with local experts	93
49	Global	2022	Elshafei et al. [74]	AHP in green building optimization	Buildings generally				Not clearly stated	AHP	-
50	Malaysia	2022	Mansor and Sheau-Ting [26]	Building occupant well-being assessment	Office buildings	4	15	-	Not clearly stated	AHP with local experts	65

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
51	Iran	2022	Sadeghi et al. [77]	Climate customization of green building performance assessment	Buildings generally	6	24	-	LEED	FAHP with local experts	56
52	France, Portugal, Spain	2023	Abascal et al. [9]	Building energy renovation performance assessment	Residential buildings	3	11	-	Level(s)	Undefined weights	-
53	Egypt	2023	Arafat et al. [62]	Building sustainability assessment	University buildings	7	32	-	GPRS	AHP with local experts and non-experts	102, 73
54	India	2023	Bhyan et al. [76]	Building sustainability assessment	Residential buildings	5	16	57	BREEAM, GS, DGNB, GRIHA, IGBC	FAHP with local experts	20
55	Iran	2023	Delavar et al. [127]	Building sustainability assessment	Buildings generally	3	14	-	Not clearly stated	ANP with local experts	45
56	Ethiopia	2023	Gashaw et al. [128]	Green building performance assessment	Public buildings	6	29	-	LEED, GS	AHP with local experts	10
57	India	2023	Kumar et al. [129]	Building sustainability assessment	Buildings generally	11	35	-	LEED, BREEAM, CASBEE, GRIHA, DGNB, LBC, SBTool, SPeAR	AHP with local experts	19
58	China	2023	Li et al. [130]	Green building performance assessment	Residential buildings	6	20	20	Not clearly stated	AHP with local experts	14
59	India	2023	Mishra et al. [82]	Building sustainability assessment	Industrial buildings	3	27	-	Not clearly stated	MEREC and SWARA with local experts	25
60	Taiwan	2023	Shao et al. [131]	Building healthiness assessment	Buildings generally	7	17	65	EEWH, LEED, BREEAM, CASBEE, SBTool, ASGB	AHP with local experts	7
61	China	2023	Zeng et al. [96]	Building indoor environment quality performance assessment	Office buildings	4	-	-	LEED, BREEAM, CASBEE, DGNB, ASGB	Literature average and entropy method with simulation results	-
62	Italy	2024	[132]	Building heating systems assessment	Industrial buildings	5	15	-	No	AHP with experts and literature data	Not clearly stated

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
63	Canada, US	2024	Cabral and Blanchet [93]	Building materials performance assessment	Buildings generally	7	25	-	Not clearly stated	Severity index with local experts and Monte Carlo simulations	25
64	China	2024	Chen and An [86]	Green building design optimization	Residential buildings	3	-	-	ASGB	Entropy method with simulation results	-
65	Italy	2024	D’Agostino et al. [133]	Building thermal insulation materials performance assessment	Buildings generally	3	3	-	No	AHP with authors judgment	-
66	Hong Kong	2024	Feng et al. [134]	Building IEQ performance assessment	University buildings	3	11	23	No	AHP with building occupants	288
67	Egypt	2024	Gaber et al. [135]	Building fixed shading systems assessment	Buildings generally	2	5	12	No	AHP with experts and entropy method with simulation results	8
68	India	2024	Khanapure and Shastri [41]	Building sustainability assessment	Residential buildings	3	11	44	GRIHA, IGBC, LEED	AHP with local experts	9
69	Hong Kong, Sri Lanka	2024	Peiris [104]	Building smart retrofitting assessment	Office buildings	5	20	-	No	ANP with local experts	24
70	Global	2024	Ramakrishnan et al. [83]	Green building performance assessment	Airport buildings	17	-	-	No	PCA with AHC and DHC models	-
71	China	2024	Shi and Chen [87]	Building renovation assessment	Hospital buildings	3	-	-	No	Entropy method with simulation results	-
72	Global	2025	Er-retby et al. [136]	Building energy efficiency assessment	Buildings generally	5	26	-	Not clearly stated	Fuzzy DAMATEL with early career practitioners and mid-expert practitioners	34. 15
73	Vietnam	2025	Ngo et al. [137]	Building sustainability assessment	Airport buildings	3	6	-	Not clearly stated	AHP with local experts	9
74	China	2025	Wang et al. [138]	Building thermo-economic efficiency assessment	Residential buildings	4	-	-	No	Entropy method with survey data	-
75	Turkey	2025	Cenani and Can [139]	Building sustainability assessment	Hospital buildings	3	8	-	LEED	AHP with local experts	10

Table A2. Cont.

No.	Country/Region	Year	Authors	Topic	Building Type	Categories	Criteria/Indicators	Parameters	References	Weighting Scheme	Participants
76	UK, Australia	2025	Too et al. [70]	Zero carbon buildings assessment	Buildings generally	7	35	-	No	AHP with local experts	27, 29
77	Global	2025	Xu et al. [140]	Building energy efficiency assessment	Data centers	4	-	-	No	AHP with experts and entropy method with simulation results	Not clearly stated

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