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Research Review of Green Building Rating System under the Background of Carbon Peak and Carbon Neutrality

Jin Mao [1], Hao Yuan [2], Lun Xiong [1] and Bo Huang [2,*]

[1] China Construction Science and Industry Corporation Ltd., Shenzhen 518052, China; maojin@cscec.com (J.M.); xionglun@cscec.com (L.X.)

[2] State Key Laboratory of Mountain Bridge and Tunnel Engineering, Chongqing Jiaotong University, Chongqing 400074, China; 622230970085@mails.cqjtu.edu.cn

* Correspondence: bohuang@cqjtu.edu.cn

Abstract: In order to foster a more sustainable and eco-friendly trajectory for the construction industry, while concurrently mitigating environmental pollution and energy inefficiency, it is imperative to cultivate an environmentally conscious building and urban environment. Under the background of Carbon Peak and Carbon Neutrality, the green building rating system has become a research hotspot in the field of green building. This paper systematically summarizes the research progress of the GBRS in weight setting, indicator setting, and the evaluation process, and creatively proposes the following three directions for future research: (1) Weight determination methods based on machine learning or deep learning models, and reasonable weight allocation by mixing multiple evaluation methods. (2) Setting dynamic evaluation indicators, strengthening interdisciplinary research and regional consideration, and introducing a life cycle assessment to solve the problem of setting indicators in the existing evaluation system. (3) Combine building information modeling with GBRS to realize the automation and intelligence of evaluation and improve the comprehensiveness and accuracy of evaluation.

Keywords: green building; rating system; weight setting; indicators setting; automation

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1. Introduction

The green building rating system came into being in the context of increasing awareness of sustainable development and environmental protection. The global building industry is currently one of the most serious energy consumption and carbon emission industries, accounting for about 40% of the total [1]. Therefore, reducing the negative impact of buildings on the environment and improving the sustainability of the construction industry has become a common concern and an urgent problem for governments, enterprises, and the public around the world. To guide and support the sustainable development of the construction industry, many green building evaluation standards and evaluation systems have emerged. These evaluation systems evaluate and certify the sustainability and environmental friendliness of buildings through specific environmental, social, and economic indicators, and promote the development and application of green buildings [2]. In addition, in some regions, the government has also adopted specific policies and measures to promote the development of green buildings. In Europe, for example, more than 30 countries have adopted green building assessment standards. In the United States, green buildings have become one of the standards for governments and enterprises to select construction projects. Leadership in Energy and Environmental Design-certified buildings are considered to have excellent environmental performance and low energy consumption, and to be less affected by the economic recession [3]. In some Asian countries, governments have adopted green building certification to regulate and encourage the development of green buildings. Carbon Neutrality refers to the strategy of offsetting one's own carbon emissions to achieve a net zero emission level, stemming from the imperative to address climate change. Carbon Peak, on the other hand, signifies the target of gradually reducing emissions after reaching the peak of carbon emissions for a specific entity. These concepts are increasingly prominent in the global discourse on climate change, representing pivotal measures undertaken by the international community and business sector to combat climate challenges, aiming to realize emission reduction goals and advance sustainability. In order to achieve the requirements of Carbon Peak and Carbon Neutrality, it is essential that the criteria and weighting of popular GBRS such as LEED and BREEAM are more precise and comprehensive. Metrics related to energy efficiency, material selection, carbon emissions, and other aspects of these systems will become crucial indicators. Additionally, the weighting of evaluation criteria needs to be adjusted based on the importance of carbon emissions reduction to better reflect the goals of Carbon Peak and Carbon Neutrality. By leveraging intelligent technology, real-time monitoring and analysis of building energy consumption, material selection, and other data, the enhancement of evaluation efficiency and accuracy can be achieved. This will better align with the objectives of Carbon Peak and Carbon Neutrality. Based on the above research background, the green building evaluation system has become a research hotspot. To improve the sustainability of the construction industry and steer it towards a more environmentally friendly, energy efficient, and health-conscious direction, it is necessary to assess the environmental aspects of buildings through scientific standards and summarize the current status and future directions of green building rating systems. This will mitigate the adverse environmental impact caused by buildings while promoting resource efficiency and reducing operational costs [4,5].

2. Bibliometric Analysis

The analyzed article data are sourced from the Web of Science core dataset and retrieved using the keyword "TS = green building rating OR TS = green building assessment". The time range for searching articles is from 2010 to 2024, with review and journal articles retained. After manually removing highly irrelevant articles, a total of 2428 valid articles remain.

2.1. Number of Publications

As can be seen from Figure 1, from 2010 to 2024, the annual number of documents gradually increases with the growth of the number of years and reaches its peak in 2023. The proposed index trend line shows that the annual cumulative number of documents issued even shows an exponential growth from 2010 to 2023. This fully shows that with the passage of time, the research and attention in the field of green building assessment are increasing. As an important part of sustainable building, green building assessment plays an important role in reducing environmental impact and improving resource utilization efficiency. This trend reflects that people pay more attention to the evaluation of green buildings. In addition, this phenomenon also shows that the academic interest in green building assessment is gradually increasing, and researchers are increasingly committed to in-depth discussion of green building assessment related issues and publishing related papers. The field of green building assessment is becoming more and more important in academic, practical, and public attention, and its research and development prospects are broad, which needs more in-depth research and attention.

2.2. A Timeline of Research Trends on Green Building Assessment

Figure 2 depicts the timeline of research trends in green building assessment. At the top of the chart, the pink font represents a timeline. The size of the circle indicates the frequency of the study, with a larger circle indicating a higher frequency of research. It can be observed from the figure that the term "green building" appeared around 2010, reflecting the attention paid to green building research in that year. The term "sustainability" appeared around 2015, indicating a new phase in sustainable development research during that year. The term "rating system" emerged around 2019, suggesting that evaluation systems became a research hotspot around that time. In the evaluation system, indicators and weight settings are the two most important parts. The future green building assessment system should incorporate considerations of carbon emissions, human health, and environmental impacts in the development of indicators. Additionally, the integration of evaluation systems with BIM is expected to emerge as a prominent research area.

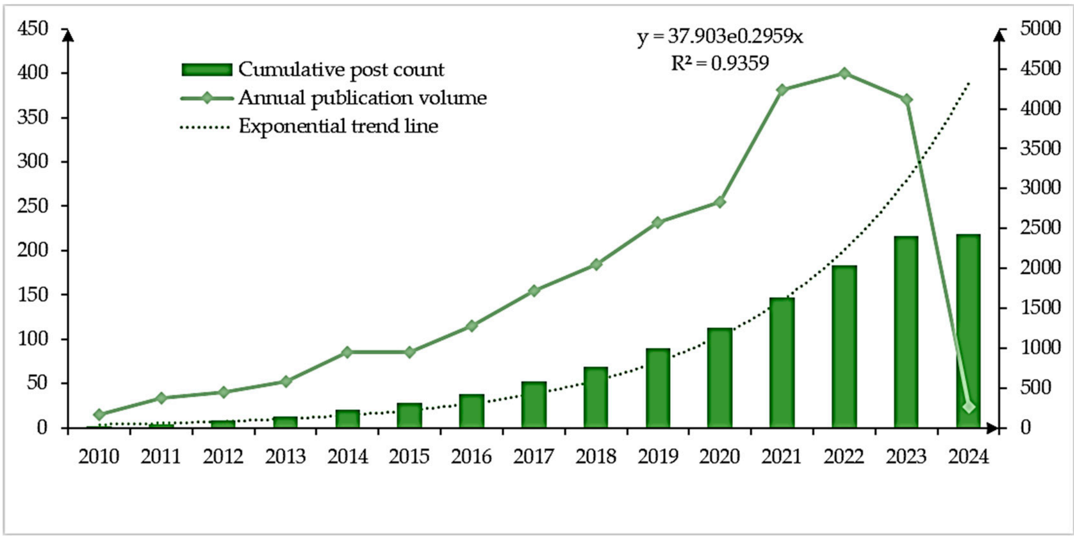

Figure 1. Annual and cumulative publications on green buildings in the past 15 years.

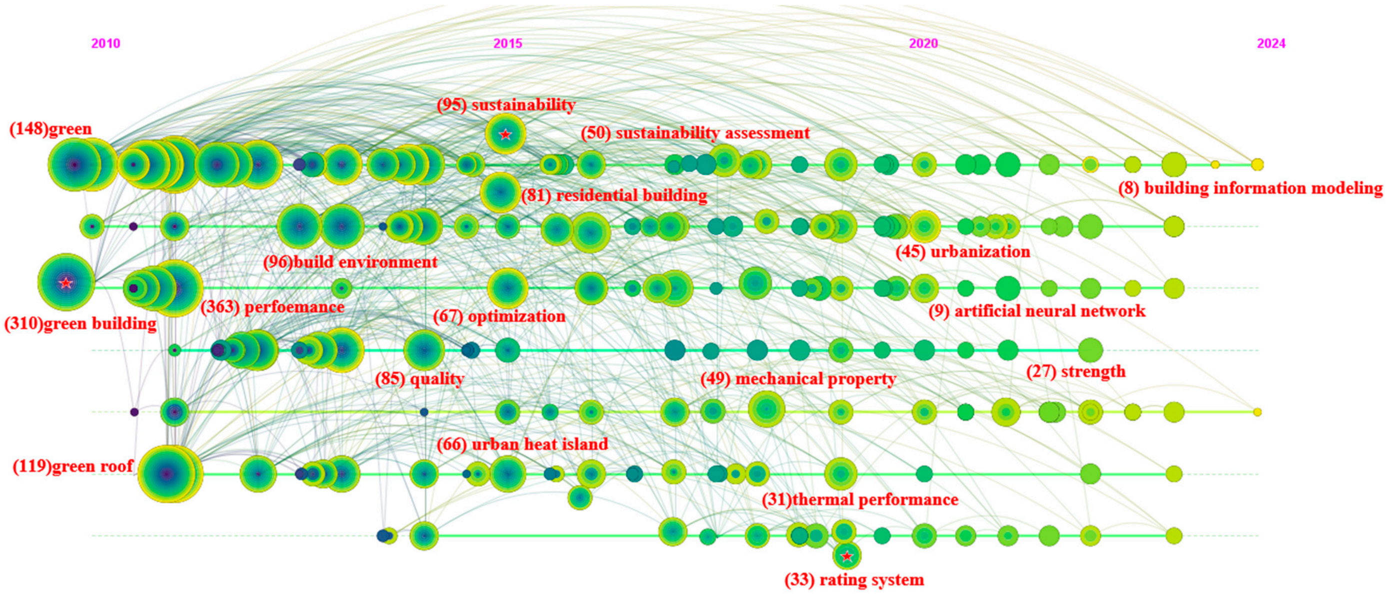

Figure 2. Timeline of research trends on green building assessment.

2.3. Keywords Co-Occurrence Graph

The nodes in the key co-occurrence graph represent keywords. Generally, larger and darker nodes represent important keywords or higher co-occurrence frequency. The line represents the co-occurrence relationship between keywords. Observe the thickness and length of the line. Generally, thicker lines represent higher co-occurrence times, and longer lines represent more distant associations. If a group of keywords with similar topics are clustered together in the graph, it indicates that this is a research hotspot or field. As can be seen from Figure 3, the main research hotspots in the field of green building assessment are building performance, assessment system, life cycle assessment, building design, impact on the surrounding environment, etc.

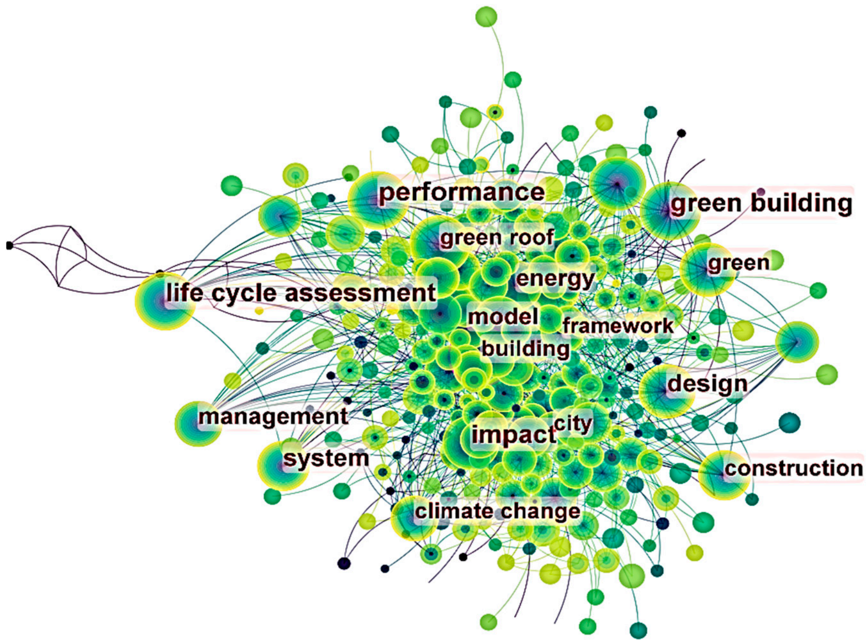

Figure 3. Keywords co-occurrence map of green building evaluation.

2.4. Organization Co-Occurrence Map

Figure 4 shows that the Chinese Academy of Sciences, Hong Kong Polytechnic University, Chongqing University, National University of Singapore, and Tsinghua University rank among the top five institutions that use CiteSpace to obtain green building evaluation. These institutions cooperate closely with other institutions. The aforementioned statement demonstrates China's prominent position in this particular field. Furthermore, The collaboration among CSIR NAT Resources and Env, Australian Museum, Arizona State University, Taipei Medical University, Stanford University, University of Maryland, and University of Queensland is exceptionally close and frequent.

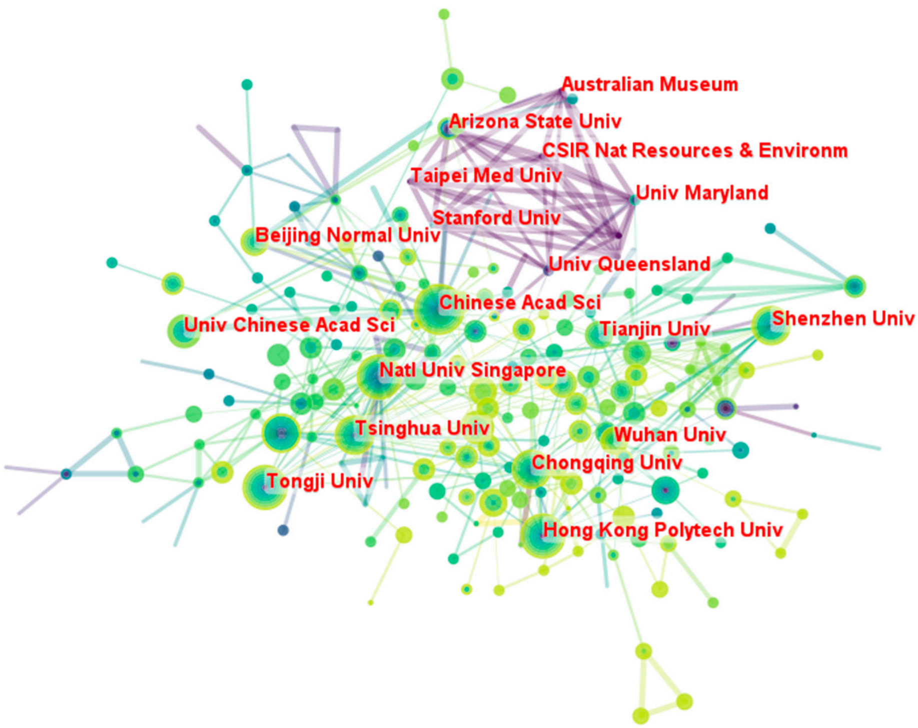

Figure 4. Institutional co-occurrence map of green building assessment.

3. Major GBRS

3.1. LEED

The LEED green building rating system is the world's most successful and widely used green building rating system launched by the US [6]. The scope of the LEED assessment covers sustainable land use planning, water management, energy and air quality, materials and resources, indoor environmental quality, indoor environmental quality, innovation and design processes, and regional priorities. It is one of the most comprehensive systems of assessment standards [7]. A building's rating is determined based on its score in various aspects, as well as the overall percentage of the rating. The specific classifications are as follows. Certified: a building that meets the minimum requirements of all evaluation criteria and receives more than 40% of the overall rating. Silver: a building that performs well in all evaluation criteria and receives more than 50% of the overall rating. Gold: a building that achieves a high level in all evaluation criteria and receives more than 60% of the overall rating. Platinum: a building that achieves excellence in all assessment criteria and receives more than 80% of the overall rating [8]. Since the first version was released in 1998, LEED has evolved and been revised. LEED, developed by the US Green Building Council, stands as the most globally embraced credit-based green building rating program to date [9]. The LEED 2.0 standard was released in 2000 to mark the establishment of the LEED assessment system, and since then it has been continuously refined and developed. As LEED has been updated and iterated, the scope of its assessment criteria has also been expanded and refined. Released in 2005, the LEED 2.2 version focuses on energy optimization and aligns with Canadian and European building standards [10]. LEED for Existing Buildings was launched in 2007 and focuses on improving the energy efficiency and indoor air quality of existing buildings. LEED3.0 was released in 2009 and became one of the most widely used international green building standards in the world at the time, emphasizing requirements for materials, water use, and energy consumption [11]. The LEED 4.0 version, launched in 2013, further strengthened the overall consideration of sustainability [12]. The latest LEED 4.1 version, which was launched in 2019, focuses on optimization and innovation in terms of cost and waste reduction. The weight and indicator settings for each version are shown in Table 1. Compared with the GBRS of other countries, LEED can encourage construction companies to adopt more energy-efficient designs. Son, P.V.H.'s [13] study uses the LEED v4.1 standard as a design goal and optimizes the lighting effect of buildings by using the integrated sunlight facade design method, providing a more comprehensive framework for optimizing building performance. The research by Obata, S.H. [14] suggests that although LEED has some limitations in promoting the development of buildings towards higher sustainability, it may lead projects to focus more on achieving minimum standard scores rather than truly pursuing higher levels of sustainability. However, further improvements can ensure that it becomes an important tool for promoting sustainable development. At the same time, the LEED certification can also increase the market value of buildings and promote the development of green buildings. However, the disadvantages of LEED include higher application costs, economic pressure on the project, certain restrictions, and may not be suitable for special or non-conventional construction projects, as well as its evaluation system. It is relatively complex and requires the support of professional knowledge and skills.

Table 1. LEED version features of weight and indicator settings.

Version	Year	Weight and Indicator Settings	Source
LEED 2.0	2000	Preliminary indicators such as energy efficiency and water resource protection have been established. These indicators have relatively balanced weights, but there is no strict priority ranking.	The official website of the USGBC. LEED v2.0 page.
LEED 2.2	2005	More detailed material requirements indicators have been introduced, and the weights of indicators such as energy efficiency and indoor environmental quality have been adjusted.	The official website of the USGBC. LEED v2.2 page.

Table 1. *Cont.*

Version	Year	Weight and Indicator Settings	Source
LEED 3.0	2009	Adjust and increase the evaluation standards and weights for energy utilization, building material sustainability, water resource utilization, and building operation stages.	The official website of the USGBC. LEED v3.0 page.
LEED 4.0	2013	Balanced allocation of weights to different evaluation indicators to ensure full consideration of sustainability in all aspects, not only focusing on energy efficiency, but also on evaluation indicators such as material sustainability, water resource management, ecosystem protection, and indoor environmental quality.	The official website of the USGBC. LEED v4.0 page.
LEED 4.1	2019	New indicators including principles of circular economy, social justice and health, and adaptation to climate change have been introduced, and the weight of standards such as building energy efficiency and material sustainability has been further increased.	The official website of the USGBC. LEED v4.1 page.

3.2. Building Research Establishment Environmental Assessment Method

BREEAM is a green building assessment method launched by the British architectural research institution. It was first introduced in 1990 and became the world's first green building assessment system [15]. Over time, the version history of BREEAM has included multiple revisions and upgrades, each aimed at continuously improving the adaptability and effectiveness of its evaluation criteria to cope with changing environments and technical requirements. Especially in terms of setting evaluation indicators, the 1990 version of BREEAM mainly focused on energy utilization, water resource management, and indoor environmental quality of buildings [16]. On the basis of the 1990 version, the 2000 version of BREEAM underwent a series of revisions and upgrades, including expanding the scope of evaluation, adding considerations for land use and ecology, and making evaluation standards more comprehensive. On the basis of the 2000 version, the 2008 version of BREEAM underwent further revisions and upgrades, including optimizing evaluation methods and indicator systems, adding key assessments on renewable energy utilization and carbon emission reduction, to reflect the latest developments in sustainable development concepts at that time [17]. The 2011 version of BREEAM further strengthened the environmental performance assessment of buildings, particularly through in-depth research and adjustments in energy utilization and carbon emission reduction to adapt to the global trend of sustainable development at that time [18]. The latest version of BREEAM was released in 2018, mainly adding dimensions for assessing the environmental impact of buildings, including considerations of social responsibility and health and well-being [19]. In addition, this version also strengthens the requirements for renewable energy utilization and carbon emission reduction, reflecting the higher demands of today's society for sustainable development. As the world's first green building rating system, BREEAM enjoys a good reputation and recognition in the international construction field and has become the preferred standard for green buildings in many countries and regions [20]. In addition, BREEAM can comprehensively evaluate the energy efficiency, indoor environment, material use, health, and comfort of buildings. By using quantitative indicators and scientific evaluation standards, the evaluation results are made more objective and reliable, which helps to improve the sustainability level of buildings. However, BREEAM also has some drawbacks. Firstly, the evaluation process is relatively complex and cumbersome, which may require more time and resources to complete. This increases the development cost of the project and may affect the active participation of some projects. Secondly, the evaluation criteria of BREEAM have certain limitations on building design and material selection and may not be applicable to certain special types of building projects or special environments. In some countries and regions, the impact of BREEAM is relatively small and it has not yet been widely used and recognized [21].

3.3. *Comprehensive Assessment System for Building Environmental Efficiency*

CASBEE was developed in 2001 by the Building and Urban Research Institute (BRI) in Japan and was first released in 2003 [22]. According to the CASBEE official website, CASBEE continues to increase and improve evaluation indicators in different versions to more comprehensively evaluate the environmental performance of buildings. The first generation CASBEE (2001) mainly focused on energy-saving performance, indoor environment, and building materials. The second generation CASBEE (2004) added assessments of land use and water resource utilization and introduced environmental management considerations. The third generation CASBEE (2007) considered the impact of architecture on society and economy, as well as the utilization of circular and renewable resources. The fourth generation CASBEE (2012) further considered the impact of architecture on ecosystem services and the health and well-being of residents. The fifth generation CASBEE (2017) focused on evaluating intelligence and innovation. The release of each generation of CASBEE reflects the continuous improvement and changing demand of society for building environmental performance evaluation, promoting the continuous expansion and improvement of CASBEE evaluation indicators. Over time, CASBEE has evolved and improved, drawing on the experience and lessons of other building appraisal systems at home and abroad. At present, CASBEE has become one of the most commonly used GBRS in Japan. CASBEE's assessment methodology is based on the environmental performance and resource use aspects of the building [23]. It uses the following assessment methodology, which includes four aspects:

1. Basic Assessment: evaluates the performance of the building in terms of energy consumption, water resources, indoor environmental quality, material use, etc.
2. Construction method assessment: evaluates the environmental impact of the construction method used in the construction process of the building, including the efficiency of use, management of waste, etc.
3. Management Assessment: evaluates the level of operation and management of the building, including energy management, water management, indoor environmental maintenance, etc.
4. Regional Assessment: assesses the impact of environmental characteristics and resource use in the area where a building is located on its rating.

The assessment scale is expressed in alphabetic grades (S, A, B, C, D), with S being the highest and D being the lowest [24,25]. The specific level divisions are listed in the following Figure 5.

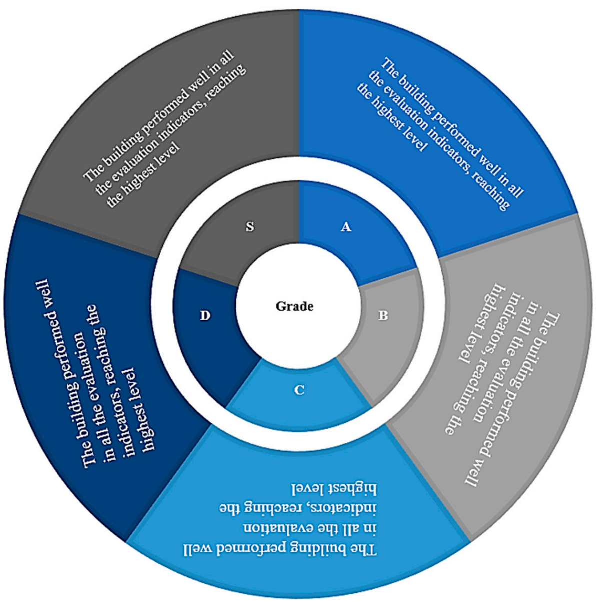

Figure 5. The specific level divisions of CASBEE.

The advantage of CASBEE is that it provides a comprehensive assessment result by taking into account multiple aspects of the building, including energy, water resources, indoor environmental quality, etc. [26]. In addition, factors such as climate, culture, and laws and regulations in Japan are taken into account to make the assessment method more appropriate and practical. CASBEE also provides specific evaluation metrics and recommendations to help architects and owners implement sustainability measures during the design and use phases. However, because CASBEE's assessment methodology is different from other international GBRS, it is difficult to directly compare the rating results of CASBEE with those of other systems [27]. CASBEE's assessment criteria are updated slowly, failing to keep up with the progress of green building technologies and practices in a timely manner [28]. The CASBEE system, despite its limitations, enjoys a high level of recognition and widespread adoption within the Japanese construction industry, thereby playing a pivotal role in promoting sustainable development practices.

3.4. Assessment Standard for Green Buildings

As an important standard for the promotion of green buildings in China, the development process of ASGB can be summarized into three stages. The first version was released in 2006, with the main goal of establishing a basic framework for evaluating the sustainability of buildings. However, the content is relatively simple and lacks detailed evaluation indicators, especially in the selection of building materials and ecological protection. The second edition, from 2014, expanded and refined on this basis, introducing more evaluation indicators and considerations, including requirements for energy utilization efficiency, water resource management, indoor environmental quality, etc., while also providing more detailed regulations on building materials and ecological protection. The latest and third edition, released in 2019, further improved and updated the standards, making corresponding adjustments to the application of new technologies and materials, as well as changes in the social environment, and strengthening the evaluation of the construction operation stage [29]. The advantage of this standard is that it is in line with international standards, in line with the needs of China's national conditions, and promotes the development of green buildings. However, there are some shortcomings, such as the lack of process standards and controversy over the calculation method of energy consumption indicators, as well as the high cost of implementation [30]. Therefore, in the process of promoting the development of green buildings, it is necessary to further improve and optimize this standard to better promote the sustainable development of green buildings in China.

3.5. Analysis of the above GBRS

During the development of evaluation systems such as LEED, BREEAM, CASBEE, and ASGB, a high degree of attention has been paid to indicator setting. Over time, more new indicators may be proposed. During the version revision process, there was relatively low attention paid to weight settings, and the methods were not uniform and scientific. Firstly, the weight setting of these evaluation systems often relies on expert consultation and related research, but the subjective opinions and research preferences of experts may lead to weight bias, resulting in certain evaluation indicators being assigned to too-high or too-low weights. Secondly, insufficient data and quality issues are also challenges. The data of certain evaluation indicators are difficult to obtain or there is uncertainty, which may lead to inaccuracies in weight setting. Meanwhile, information asymmetry may also affect the fairness and objectivity of weight setting, and the voices of certain stakeholders may be ignored or amplified, leading to an imbalance in the weight of evaluation indicators. In addition, regional differences and applicability issues are also important considerations. Due to differences in culture, regulations, climate, and socio-economic conditions in different regions, the importance and weight of evaluation indicators may need to be adjusted, but this may lead to incompatibility of evaluation results. In order to improve the accuracy and credibility of weight setting, these evaluation systems need to determine the weights of evaluation indicators more transparently, impartially, and scientifically, especially in terms of weight setting methods. It is not possible to use a single method or use subjective methods to determine the weights in order to ensure the accuracy and comparability of evaluation results.

4. Weights and Indicators Settings of Green Building Evaluation System

4.1. Setting of Weight

GBRS aims to evaluate the performance of buildings in terms of environmental friendliness and sustainability, in order to promote the development of the construction industry towards a more environmentally friendly and sustainable direction. In this evaluation process, weight allocation becomes a key issue, which determines the importance and impact of different indicators in the evaluation system. GBRS involves multiple indicators, usually subdivided into small indicators from three dimensions: environmental, social, and economic. The small indicators include energy efficiency, water management, material selection, indoor environmental quality, waste management, biodiversity, and social impact. However, the weights of these indicators are not fixed. Wen, B.H. [31] selected 10 global GBRSs, applied specific screening principles, and proposed a unified standard framework to fairly compare these GBRSs. They analyzed the changes in GBRS from three levels: categories, subcategories, and standards. The results revealed a trend over the past 30 years: the weight of environmental categories has continued to decline, the weight of social categories has significantly increased, and the weight of economic categories has slightly increased. Behind this trend of change may be factors such as technological progress, increased social awareness, and changes in policies and regulations. Over time, new technologies and materials may emerge that provide more effective solutions to reduce factors such as energy consumption, water use, and waste generation. The emergence of these new technologies may change the original weighting indicators, thereby bringing greater importance to specific environmental aspects. Different GBRS indicators have different weights. Awadh [32] conducted a critical analysis of LEED and BREEAM, and pointed out that energy and water use are two of the most important indicators. In addition, as people's understanding of environmental and climate change issues continues to increase, the demand and attention given to green buildings are also constantly changing. The level of public attention given to a specific issue may affect the weight indicators being evaluated; for example, the level of concern about carbon emissions may increase over time. The policies and regulations of the government and relevant institutions will also have an impact on the weight indicators of green building evaluation. Policy changes may put forward different requirements for energy efficiency, environmental friendliness, and sustainability, thereby affecting the changes in weight indicators.

4.1.1. Analytic Hierarchy Process

Green building rating involves the allocation of weights to various dimensions and indicators. Common methods in current research include the Delphi method and AHP. AHP was first proposed by the American mathematician and operations researcher Thomas L. Saaty in 1970. The steps used in AHP to calculate the weights are shown in Figure 6. Thomas L. Saaty is a pioneer in multidisciplinary research who has made important contributions to decision theory and operations research. The analytic hierarchy process is a qualitative and quantitative method of analysis that he proposed for evaluation and decision-making problems, particularly to address multicriteria decision-making problems. It includes steps such as determining the indicator system, constructing a judgment, calculating the weight vector, conducting consistency checks, hierarchy total sorting, and adjusting the judgment matrix. First, we identify the criteria relevant to the research question and construct a hierarchy based on the hierarchical relationships between them, as shown in Figure 7. Then, each criterion is compared pairwise to assess their relative importance, forming a table as shown in Table 2. Based on the comparison results, we construct a judgment matrix as shown in Figure 8. We normalize the matrix, then calculate the eigenvectors of each criterion and the Consistency Ratio value through the eigenvectors, which is used in the process of calculating the CR value. The values of random consistency are given in Table 3. Then, consistency testing is conducted to evaluate the degree of consistency of the comparisons made. Finally, we calculate the weight of each criterion based on the weight of the feature vectors and add them up to obtain the final weight.

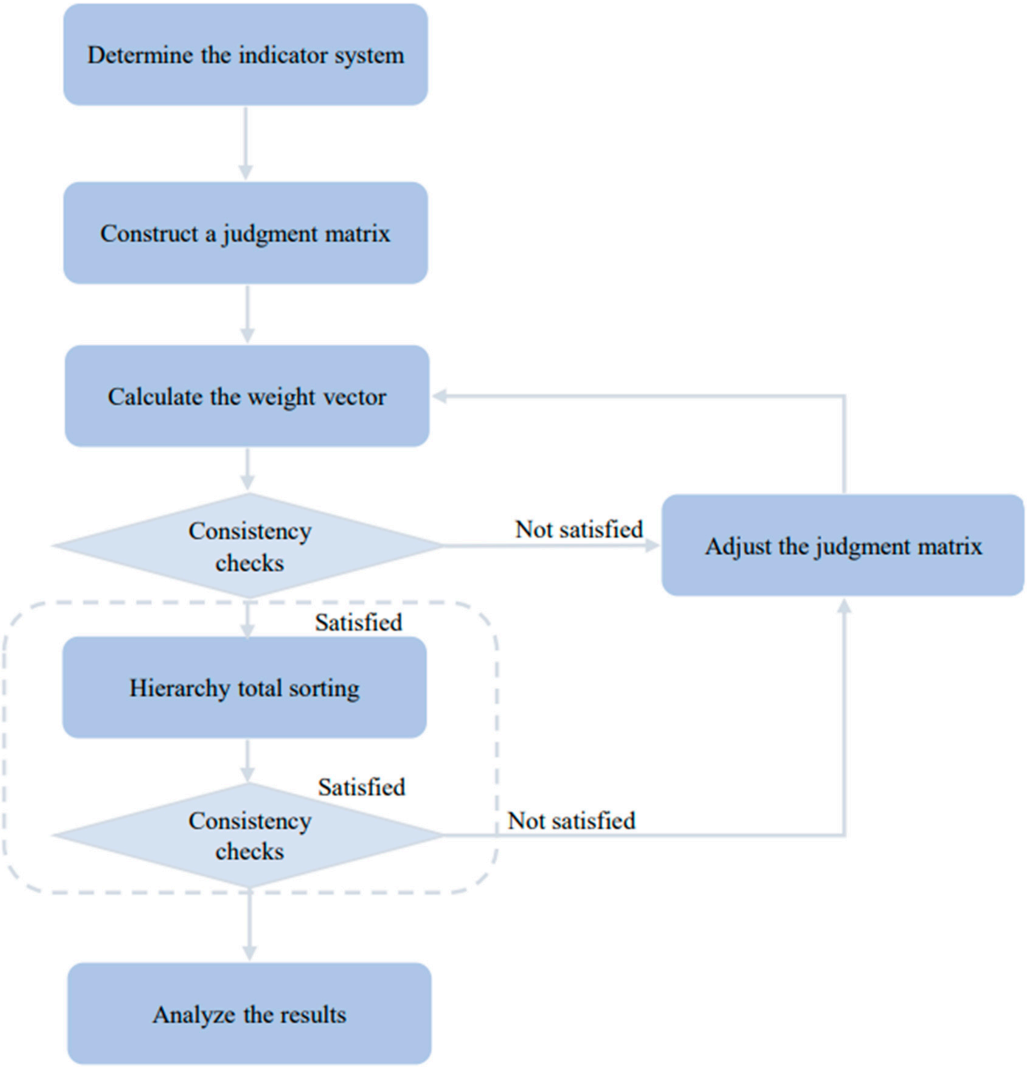

Figure 6. A multi-level analytical structural model.

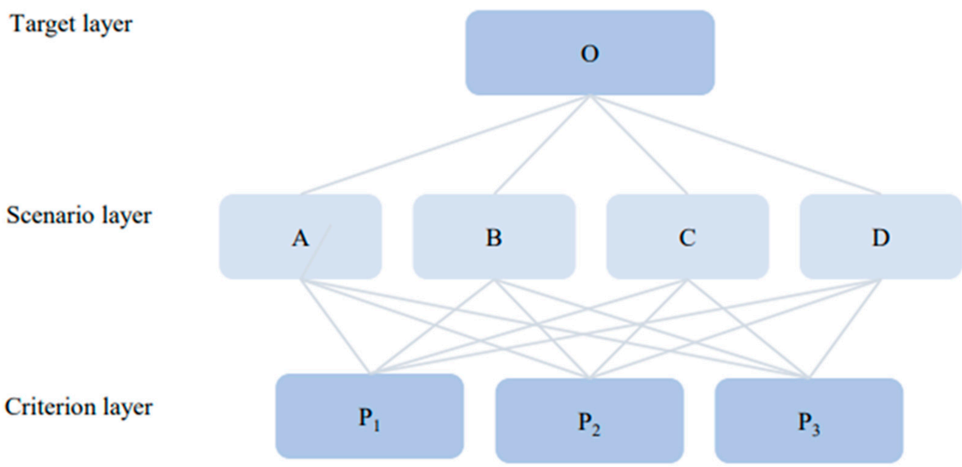

Figure 7. Schematic diagram of specific division of target structure hierarchy.

Table 2. Importance level.

Scale	Meaning
1	Consistently important
3	Slightly important
5	Obviously important
7	Strongly important
9	Extremely important
2, 4, 6, 8	The median value of the above two adjacent judgments
Reciprocal	If the scale of A and B is 5, then the scale of B and A is 1/5

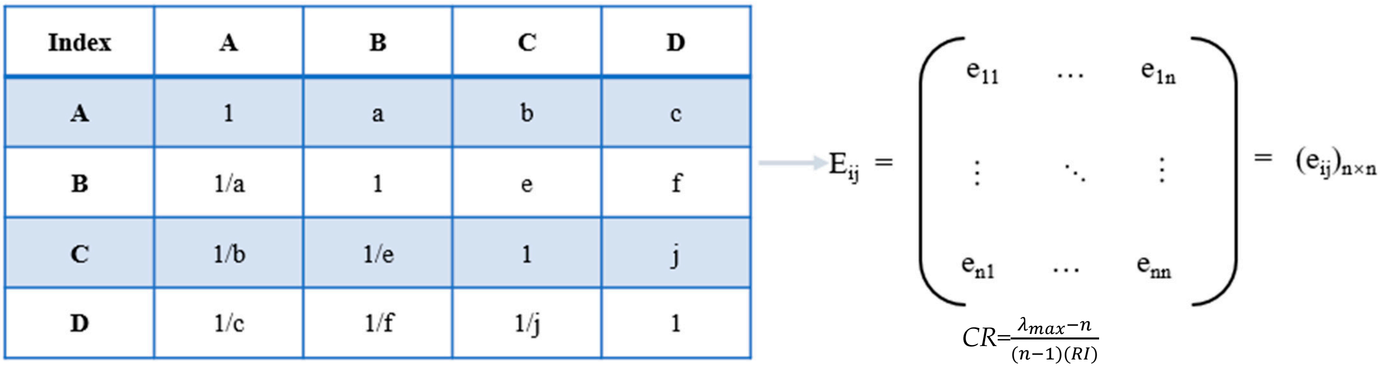

Figure 8. Judgment on the construction of matrices.

Table 3. Table of values for random consistency indicators.

Matrix Order	3	4	5	6	7	8	9	10	11	12	13
Value	0.58	0.90	1.12	1.24	1.32	1.41	1.45	1.49	1.51	1.54	1.56

This approach is widely used in engineering, economics, management, and other fields of decision analysis. Abdelazim, A.I. [33] discussed the use of a multicriteria decision-making technique AHP to develop the weights of the criteria for the proposed rating system and reviewed the development of a building energy rating system using AHP in general. While the AHP standard weighting method is applied in other countries, this study uniquely applies it to the development of a proposed rating system for existing buildings in Egypt. Mayhoub, M.M.G. [34] uses AHP to assign the weighted importance of the proposed criteria based on the average of the four rating systems. After that, a sensitivity analysis is performed to determine the impact of each criterion. Yu, W. [35] used AHP to develop a weighting system for green commercial buildings centered on indoor environmental quality, energy efficiency, and operation management in store buildings. At the same time, these studies have exposed the shortcomings of AHP, including subjectivity, complexity, uncertainty, incomplete information, and applicability limitations. These shortcomings can lead to inconsistencies, biases, or unreliability in the assessment results. However, the AHP method is still used as the basis of weighting method in current research. It can be combined with the Delphi method, fuzzy evaluation method, entropy weight method, and others, to improve its role in weight distribution.

4.1.2. Delphi Method

The Delphi method was first proposed in the 1950s by American political scientist Olaf Helmer and business consultant Norman Dalkey. The steps used in the Delphi method to calculate the weights are shown in Figure 9. This approach was originally developed for the US Air Force Research Institute to solve complex military and political decision-making problems. The Delphi method is a method of statistical analysis and integration of expert opinions through anonymous expert surveys and feedback loops to obtain consensus and predict future scenarios. This iterative process of collecting and analyzing expert opinions can overcome political issues and personal biases within the organization and provide a relatively objective and reliable decision support tool. Due to its wide application and multi-field applicability, the Delphi method is widely used, in academia and practice, in the fields of policy making, technology forecasting, demand forecasting, etc. The Delphi method is generally not used alone for the allocation of weights, and studies have shown that its combination with analytic hierarchy process produces better results. Li, Z.L. [36] proposed a fuzzy-analytic hierarchy process that uses a scientific procedure to perform a pairwise comparative analysis of the selected criteria and aspects to determine the weighting factors and scores in each case. This allows planners to rank municipal districts according to their potential to provide green buildings, and accordingly set allocations for the corresponding targets. Yan, J. [37] shows that the combination of the AHP method and Delphi method can effectively reduce the subjectivity of the weighting system determination process in theory. Qin, Y.G. [38] used the AHP method and Delphi to study the indicators system, weight system and adaptability of green building assessment. The subjectivity and uncertainty of the AHP method are alleviated by the introduction of the Delphi method, which allows experts to submit their opinions anonymously and engage in a feedback loop system. However, the approach also needs to take into account the transparency of the problem, the authority of the assessment experts, and the incompleteness of the information.

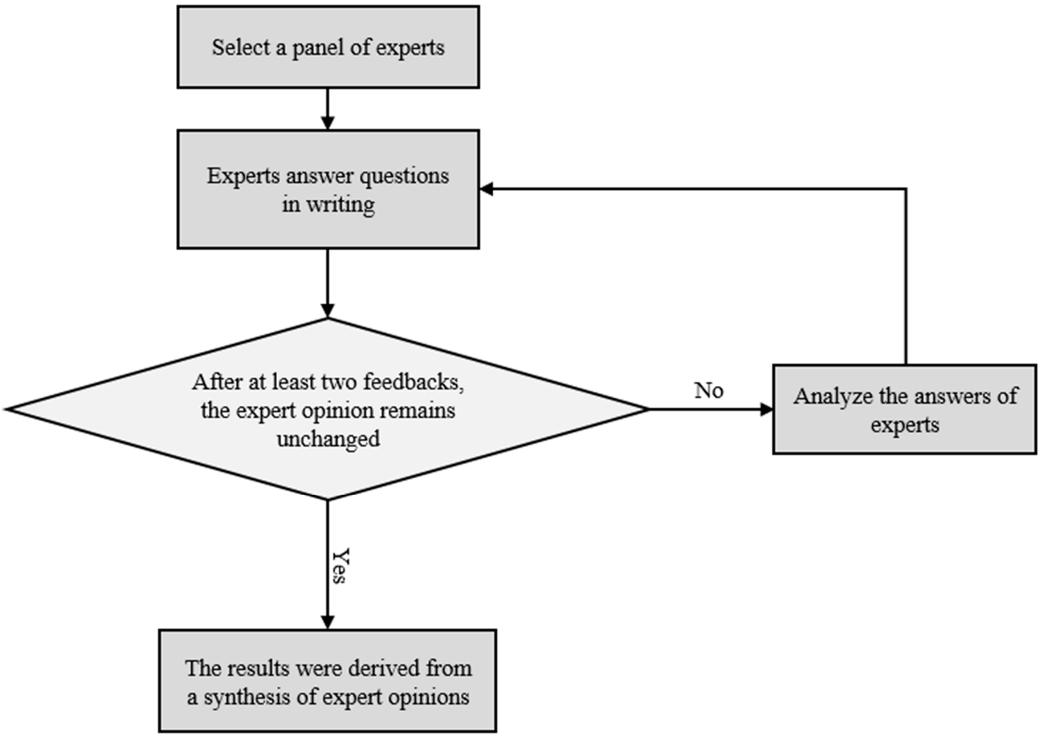

Figure 9. Operational flow chart of Delphi method.

4.1.3. Fuzzy Evaluation Method

The fuzzy evaluation method is a mathematical method to deal with uncertain information, and it is a tool for qualitative and quantitative analysis of problems under different levels of ambiguity and uncertainty. In the fuzzy evaluation method, the steps to find weights are relatively simple, as shown in Figure 10. Fuzzy evaluation is widely used in decision-making in many fields, such as engineering, finance, medicine, and environment. This method is suitable for those situations where the problem requires both qualitative and quantitative analysis to define the importance and relationship of each factor, but it is difficult to clearly state the weight or relationship of each factor due to uncertainty or ambiguity. The fuzzy evaluation method can solve these problems by directly allowing experts to convert qualitative information into numerical values while retaining the uncertainty and ambiguity of the information. In previous studies, there are few studies on the use of the fuzzy evaluation method alone, and the weight allocation is generally carried out by combining the fuzzy evaluation method and the analytic hierarchy process. Huang, Q.Y. [39] constructed a fuzzy evaluation model based on analytic hierarchy process to evaluate green buildings. The model first uses the analytic hierarchy process to determine the weight of each indicator in the green building evaluation indicators system, and then uses the fuzzy evaluation model to comprehensively evaluate the green building indicators system. Nilashi. [40] combines the fuzzy evaluation and analytic hierarchy processes to evaluate the performance level of green buildings from three dimensions: environmental, social, and economic. Combined with the advantages of the fuzzy evaluation method to deal with uncertainty and ambiguity in green building assessment, and the advantages of the analytic hierarchy process to analyze the relationship between complex factors and provide weight reference, the quality of green buildings can be evaluated more comprehensively and accurately. However, the high cost of data acquisition and computation, as well as the impact of subjectivity, on the evaluation results. Therefore, it is necessary to further study the measures to simplify the calculation method, improve the data quality, and reduce the influence of subjective factors, so as to continuously improve and expand the application of this method in green building assessment.

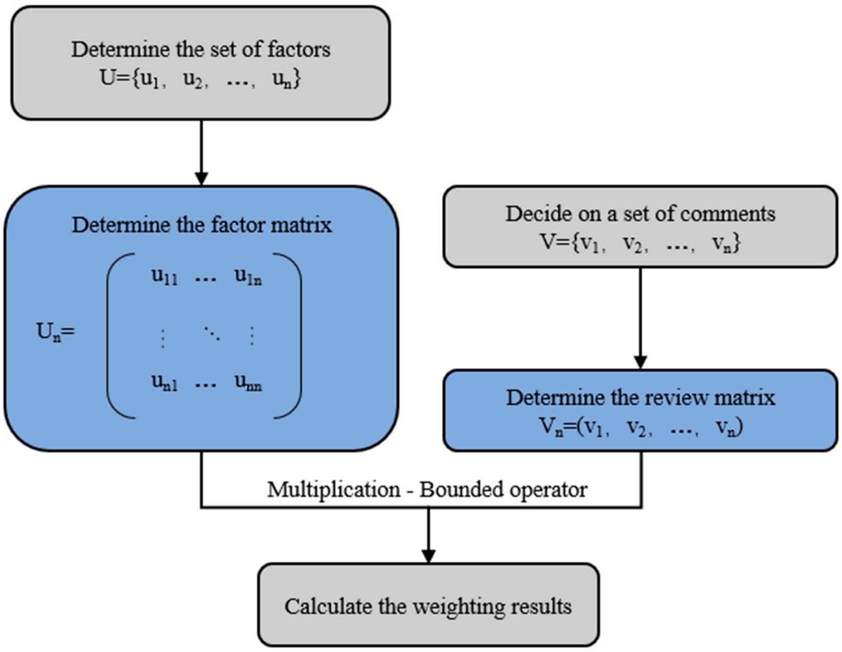

Figure 10. Operational flow chart of fuzzy evaluation method.

4.1.4. Entropy Weight Method

The entropy weight method is a method used for weight allocation, which allocates weights by calculating the information entropy between indicators to determine the importance of indicators. Figure 11 shows the specific steps for solving weights for the entropy weight method. In the green building assessment, the evaluation indicators should be determined, and the data should be normalized first, and then the weight of each indicator should be determined according to the calculated information entropy and normalized to ensure that the sum of the weights is one. The entropy weight method is a scientific and objective method for weight allocation in green building assessment, which can provide a basis for evaluation, but it needs to be combined with the analytic hierarchy process to complement and verify each other to obtain better evaluation results. Li, K.W. [41,42] applied the AHP–entropy weight method and used Yaahp software (version number: 10.1.5610.1378) to correctly specify the weights of each indicator.

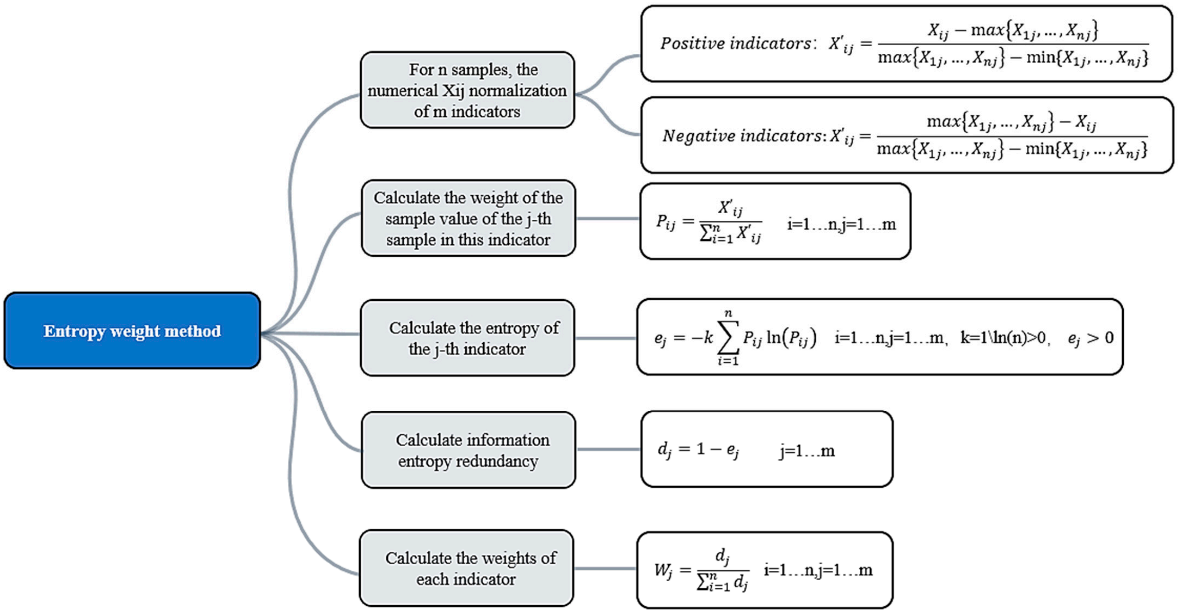

Figure 11. Operational flow chart of the entropy weight method.

4.1.5. Some Innovative Methods

In addition, some innovative methods are constantly being developed with the deepening of research. It is of key significance for Olawumi, T.O. [43] to use the generalized Choquet Fuzzy Integral Method to determine the importance weights of sustainability assessment criteria. The specific content is shown in Figure 12. By developing the fundamental inputs for assessing the impact of diverse sustainability standards based on regional disparities, utilizing data gathered from industry experts, it becomes possible to establish objective and accurate building sustainability metrics and grading systems. This approach facilitates a comprehensive understanding of the individual contributions made by different factors towards sustainability, thereby offering valuable guidance to the construction industry in promoting sustainable practices and decision-making.

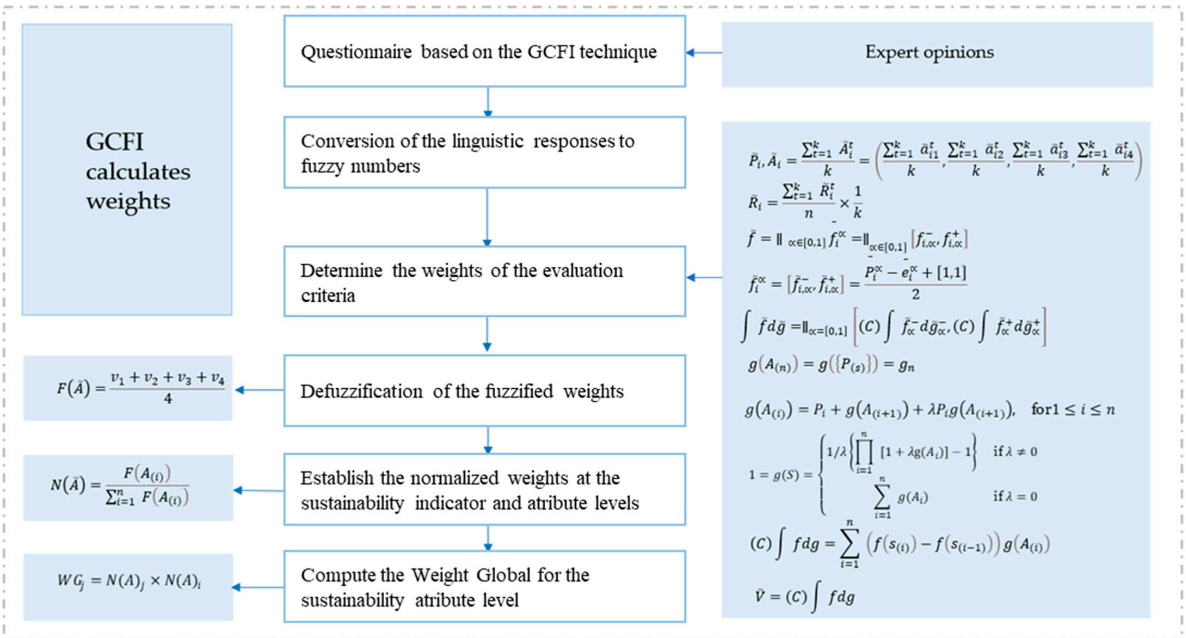

Figure 12. Operational flow chart of the generalized Choquet Fuzzy Integral Method. (Olawumi, T.O. [44]).

At the same time, it can also be optimized in combination with questionnaires, expert opinions, etc., so that the weights can more accurately reflect the importance of all aspects. Zhang, Z.J. [44] combined the questionnaire survey method and analytic hierarchy process to optimize the weights of various indicators in the framework of the model structure and constructed the evaluation model structure of the optimized green building evaluation system. Liu, P.C.Y. [45] used an Analytical Network Process model based on the Best Worst Method to determine the weight allocation of each criterion.

4.1.6. Problems and Development Direction of Weight Setting

According to the above analysis, although the AHP method can reduce subjectivity, the introduction of the Delphi method will increase transparency, but it also needs to consider the authority of evaluation experts and the incompleteness of information. Secondly, when using the fuzzy evaluation method, qualitative information needs to be converted into numerical value, and the uncertainty and fuzziness of information need to be considered. When using the entropy weight method, it is necessary to ensure data normalization, and combine the analytic hierarchy process for weight distribution to obtain better evaluation results. For the purpose of improving the objectivity, accuracy, and comprehensiveness of the evaluation system, model-based weight determination methods have gradually emerged. Although the current research is limited to the ANP model, the future direction may be based on machine learning or deep learning models, as well as a hybrid model combining multiple evaluation methods to reasonably allocate weights.

4.2. Setting of Indicators

The development of the green building rating system stems from the concern for environmental protection and sustainable development. To give full play to the scientific nature of its evaluation, GBRS should provide guidance standards for the construction industry and promote the sustainable development of buildings through scientific and systematic evaluation. Based on current research, the setting of indicators generally tends to be multipolar, diversified, and localized. The green building assessment system needs to comprehensively consider many aspects such as land saving, energy saving, water saving, material saving, and indoor environmental quality. Various regions have put forward their own green building evaluation system indicators. The indicators of the current mature evaluation system are summarized, as shown in the chart. The metrics of these GBRS have been implemented and improved over a long period of time, taking into account the energy efficiency, indoor environment, health and well-being, sustainable siting, material efficiency, water efficiency, and innovation aspects of the building as comprehensively as possible [46]. Through the comparative analysis of various systems, Xu, L.Y. [47] formulated the basic evaluation indicators system of green buildings, including 4 first-level indicators and 17 s-level indicators of the target layer. For each secondary indicator, the corresponding evaluation points are provided in the planning and design, construction, and operation management stages.

4.2.1. Setting of Waste Management Indicators

Based on the principles of land saving, energy saving, water saving, material saving, environmental protection, and pollution reduction, Guo, X.J. [48] constructed a green building evaluation indicators system, including six categories of indicators: land saving and outdoor environment, energy conservation and energy utilization, water conservation and water resource utilization, material saving and material resource utilization, indoor environmental quality, and operation management. According to the qualitative indicators in the evaluation system, a quantitative study was carried out, and the method of group expert decision-making was used to evaluate and judge the relative importance of each energy-saving evaluation indicator in the form of questionnaires. The above studies have given qualitative and quantitative consideration to the setting of indicators; however, for green buildings, they have not considered the setting of indicators in the demolition stage. Lu, W.'s [49] comparative study of LEED, Green Building Evaluation Label, and Building Environmental Assessment Method PLUS found that although the indicators of construction waste management were set, the weight of the three was too small, and the importance of waste management was not demonstrated. Jorge-Ortiz, A. [50] studied the waste management indicators set by the top 10 GBRS in the world, and the number of indicators, the proportion of waste, the life cycle stage of the building, and the waste grade all differed. Based on the current research, the setting of waste indicators is the first. First, attention should be paid to the classification and management of construction waste, so as to promote the reasonable classification and separation of waste in construction projects and achieve effective recycling, reuse, and safe treatment. Secondly, the assessment system should encourage the use of renewable, recyclable, and environmentally friendly building materials, thereby reducing the generation of construction waste and reducing the impact on the environment. In addition, the assessment system can require construction projects to develop a waste management plan, clarify waste treatment targets, and plan waste separation and recycling facilities to achieve waste reduction and recycling. At the same time, the assessment system should also encourage the reuse and recycling of waste in construction projects, and effectively reduce the consumption of natural resources through measures such as establishing recycling facilities, sorting waste, and cleaning processing. Finally, the assessment system should provide guidance and training to help industry practitioners understand the importance of waste management and promote the implementation and improvement of waste management measures. By taking these factors into account, the green building rating system can promote the sustainable development of the construction industry and reduce the negative impact on the environment.

4.2.2. Constantly Changing Indicators

At the same time, these indicators are constantly updated and improved, adjusted and optimized according to environmental, social, health, and economic factors to adapt to the development and the changing needs of green building-related technologies. Some researchers have shown their research on setting new indicators in Table 4.

Table 4. Some research on setting new indicators.

Year	Source of the Literature	Index Inclusion
2013	Kim, M.J. [51]	User experience
2013	Hedge, A. [52]	Ergonomic design
2015	Miller, D. [53]	Hide energy
2017	Illankoon, I. [54]	Economic sustainability
2017	Vyas, G.S. [55]	Disaster prevention and mitigation capacity
2019	Zhou, W.W. [56]	Water resource utilization efficiency

4.2.3. Problems and Development Direction of Indicator Setting

From the above analysis, it can be seen that the existing research has made some progress in setting GBRS indicators, but there are still some significant shortcomings. Among them, the main issues include a lack of comprehensive evaluation, subjective evaluation of user experience, inability to adapt to rapid technological and strategic changes, and neglect of regional and cultural differences. To address these shortcomings, future research can take a series of measures, such as developing dynamic evaluation indicators, strengthening interdisciplinary research, enhancing regional considerations, introducing lifecycle assessment, and utilizing technologies such as big data and artificial intelligence. Through the implementation of these measures, the performance and sustainability of green buildings can be evaluated more comprehensively and objectively, providing more effective guidance and support for their design and construction.

5. Combination of GBRS and BIM with Reasonable Setting of Weights and Indicators

With the development of technology and the change of market demand, the green building assessment system has gradually been innovated and modernized. The rise of emerging technologies and smart building systems has brought new sustainability opportunities to the construction industry. The assessment systems of various countries have begun to pay attention to the intelligence and automation of assessment, and the guiding role of green building design. In terms of automation and intelligence of evaluation, it is mainly reflected in the combination with BIM. The research of Seghier, T.E. [57] developed a method that integrates BIM with materials and resources to automatically generate green building assessment reports. By combining the amount of material extracted from BIM and templates and scripts developed using Green Building Information, a prototype system was developed based on Autodesk Revit and Dynamo extensions to automate the generation of evaluation results. Nizam, R.S. [58] proposes a collaborative framework for green construction management to facilitate performance-based decision-making through automated and semi-automated simulations. The framework uses the Green Pyramid Rating System as a third-party certified assessment provider, leveraging Dynamo code in Autodesk Revit and add-on modules using the API to extract information and parameters from BIM models. These data are used to carry out quantitative calculations and comprehensive analyses to help decision-makers investigate, analyze, improve, and evaluate aspects of the sustainability of the project. Zhang, D.X. [59] proposes an Intelligent Green Building Rating framework based on BIM semantic and social approaches to enable real-time rating in building design.

In terms of the guiding role of green building design, He, Y.E. [60] found that in LEED, BREEAM, Green Star, Green Mark, ASGB, and BEAM PLUS, the indicator setting and rating methodology affect the green design and indirectly affect the indoor thermal comfort. Suman, N. [61] has developed a framework for GBRS combined with cost-benefit analysis to achieve the best renovation of buildings based on green design, sustainability and economic benefits. Liu, K. [62] compared the evaluation mechanisms (range weights, inductive and measurement characteristics) of LEED, BREEAM, ASGB, and proposed a carbon emission control indicators framework for the low-carbon design path of building-integrated photovoltaic buildings.

6. Conclusions

In conclusion, the following three conclusions can be drawn: (1) On the weight setting of GBRS, several evaluation methods are summarized, including the AHP method, fuzzy evaluation method, and entropy weight method. Although these methods can reduce subjectivity and improve transparency to a certain extent, they also have some limitations, such as the consideration of expert authority and incomplete information. Future development directions may include weight determination methods based on machine learning or deep learning models, as well as mixing multiple evaluation methods to reasonably allocate weights. (2). In terms of the index setting of GBRS, the existing GBRS evaluation system has obvious shortcomings in some aspects, such as the lack of comprehensive evaluation, subjective evaluation of user experience, inability to adapt to rapid technological and strategic changes, and neglect of regional and cultural differences. Future research can take a series of measures to solve these problems, such as developing dynamic assessment indicators, strengthening interdisciplinary research, enhancing regional consideration, introducing life cycle assessment, etc. (3). In terms of GBRS assessment's intellectualization and automation, with the development of technology and the change of market demand, the green building assessment system has gradually innovated and modernized. The rise of emerging technologies and intelligent building systems has brought new opportunities for sustainable development to the construction industry. The assessment systems of various countries have begun to pay attention to the intelligence and automation of assessment and have increasingly attached importance to the guiding role of green building design. The future development direction may include combining BIM with other technologies to realize the automation and intelligence of evaluation and improving the comprehensiveness and accuracy of evaluation through cooperation with other evaluation agencies.

This study's main limitation is the use of a database that may not encompass all relevant sources, potentially leading to a less representative dataset. For future research on GBRS, it is suggested to employ neural networks to automate the weight determination process, either by leveraging existing deep learning architectures or developing new models tailored to specific needs. Additionally, creating a specialized decision support system that merges expert opinions with machine learning outcomes could enhance the scientific validity and reliability of weight assignment. To improve indicator selection, future studies should concentrate on dynamic indicators and incorporate expertise from diverse fields like environmental science, economics, and sociology to ensure a comprehensive evaluation framework. To enhance the evaluation process, it is recommended to explore advanced algorithms and technologies that integrate GBRS with cutting-edge tools such as BIM, artificial intelligence, and the Internet of Things to boost the automation and intelligence of the evaluation process.

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Abbreviations

Abbreviations	Specific meaning
CP	Carbon Peak (Refers to the point at which annual greenhouse gas emissions in a particular region or industry reach their historical peak.)
CN	Carbon Neutrality (Refers to a state where the total amount of carbon dioxide emissions from human activities in a certain area is offset by the total amount of carbon dioxide absorbed through activities such as afforestation, reforestation, and industrial carbon capture within a certain period.)
GBRS	Green Building Rating System
LEED	Leadership in Energy and Environmental Design
BIM	Building Information Modeling
USGBC	US Green Building Council
BREEAM	Building Research Establishment Environmental Assessment Method
CASBEE	Comprehensive Assessment System for Building Environmental Efficiency
ASGB	Assessment Standard for Green Buildings
AHP	Analytic Hierarchy Process
CR	Consistency Ratio
ANP	Analytical Network Process
BEAM	Building Environmental Assessment Method
MR	Materials and Resources

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