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Research Review of GBRS under the Background of Carbon Neutralization

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Article

Research Review of GBRS under the Background of Carbon Neutralization

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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, green building evaluation system (GBRS) has become a research hotspot in the field of green building. This paper systematically summarizes the current research progress based on GBRS, focuses on the current weight and indicators setting, analyzes it with Cite Space software, and puts forward its future development direction. The results show that the weight setting method of green building evaluation system is determined by multi-dimensional and multi-method. From the perspective of environment, society and economy, the scope of indicators setting is expanding. The green building evaluation system will play a guiding role in green building design, and the evaluation process will continue to be optimized and developed in the direction of intelligence and automation.

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, how to reduce the negative impact of buildings on the environment and improve the sustainability of the construction industry has become a common concern and 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 criteria for governments and enterprises to select construction projects [3]. In some Asian countries, governments have adopted green building certification to regulate and encourage the development of green buildings. Based on the above research background, the green building evaluation system has become a research hotspot. To improve the sustainability and environmental friendliness of the construction industry, it is necessary to evaluate the environmental aspects of buildings through scientific guidelines and standards and summarize the development status and future development direction of GBRS. It can facilitate the adoption of sustainable practices throughout the entire life cycle of buildings, guiding the construction industry towards a more environmentally friendly, energy-efficient, and health-conscious direction. 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 is 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 is sued gradually increases with the growth of the number of years and reaches the 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.

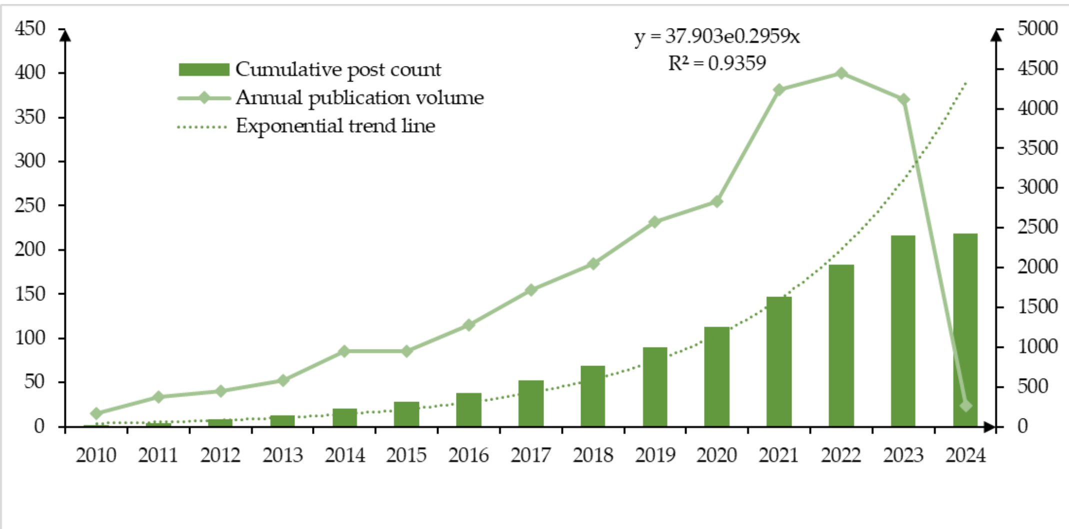

Figure 1. Annual and cumulative publications on green buildings in the past 15 years.

2.2. A Timeline of Research Trends on Green Building Assessment

Figure 2 is a timeline of research trends on green building assessment. On the right is the keyword clustering conducted by CiteSpace according to the retrieved articles, which has eight categories. The main content reflected in the figure is that green building became the focus of research in 2010, and the research on sustainable development entered a new stage in 2015. Since 2019, the evaluation system has become a research hotspot, paving the way for the green building certification in the future. In the evaluation system, indicators setting, and weight setting 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 Building Information Modeling (BIM) is expected to emerge as a prominent research area.

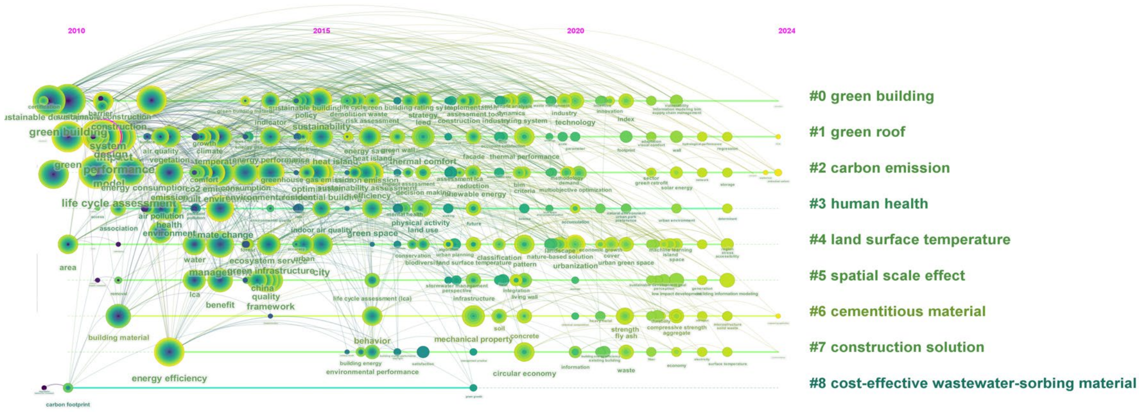

Figure 2. Timeline of research trends on green building assessment.

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.

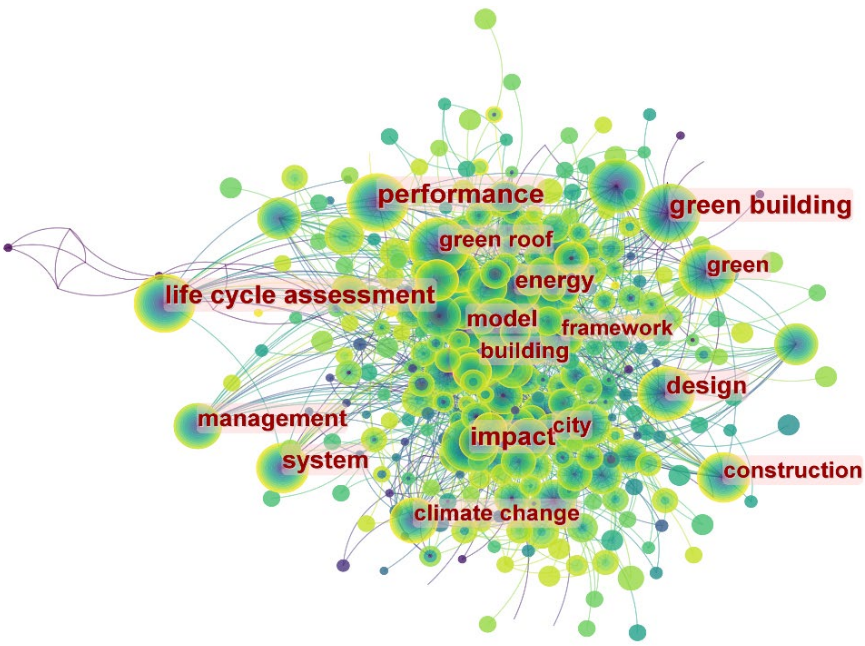

Figure 3. Key words co-occurrence map of green building evaluation.

2.4. Organization Co-Occurrence Map

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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 the seven institutions, with a focus on CSIR NAT Resources & Env, namely Arizona State University, Taipei Medical University, Australian Museum, Stanford University and University of Queensland, is characterized by its exceptional closeness and frequency.

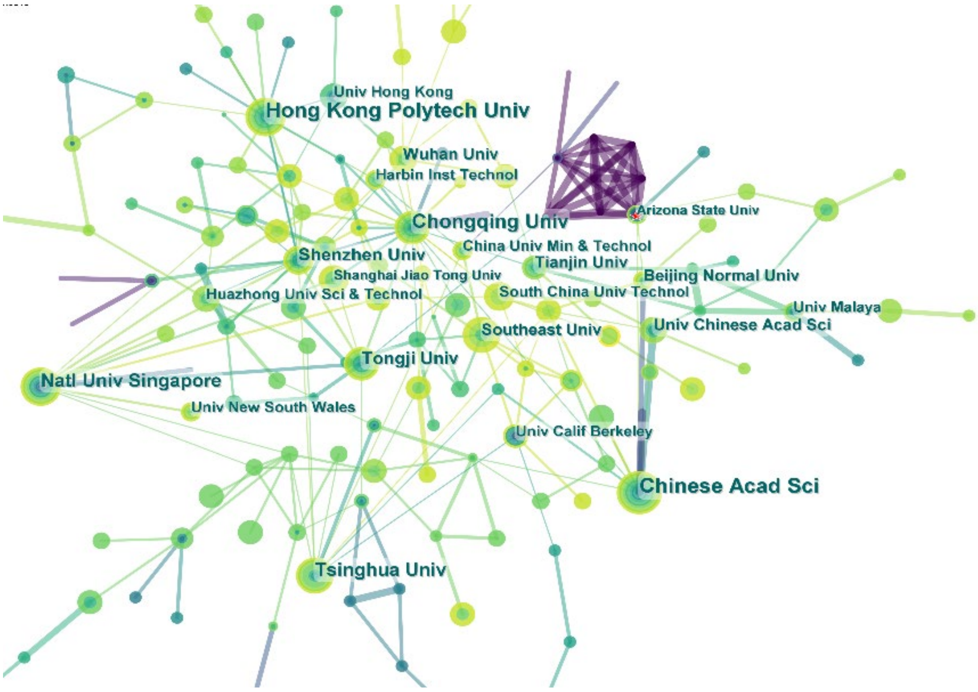

Figure 4. Institutional co-occurrence map of green building assessment.

3. Major Green Building Evaluation Systems

3.1. LEED (Leadership in Energy and Environmental Design)

The LEED green building rating system is the world's most successful and widely used green building rating system launched by the US [6]. Green Building Council (USGBC). 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 [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 [8]. Silver: The building performed well in all evaluation criteria and received more than 50% of the overall rating. Gold: The building achieves a high level in all evaluation criteria and receives more than 60% of the overall rating. Platinum: The building achieves excellence in all assessment criteria and receives more than 80% of the overall rating. Since the first version was released in 1998, LEED has evolved and been revised. LEED began in 1993 with the establishment of the USGBC to promote and raise awareness of green buildings [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 main features of each version are shown in the Table 1. Compared with the GBRS of other countries, LEED has the advantage of being globally recognized and widely adopted. Comprehensively evaluate all aspects of green building performance, with a comprehensive reflection of sustainability, scientific and measurable evaluation criteria [13,14]. At the same time, 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.

Version	Year	Key features
LEED 2.0	2000	The first LEED version includes criteria for the design, construction, and operation of green buildings.
LEED 2.2	2005	Revised based on LEED 2.0 with the addition of new credits and the optimization of certain credit requirements.
LEED 3.0	2009	A graded evaluation system (Platinum, Gold, Silver, Certified) was introduced, the assessment of the energy and atmospheric environment was increased, and stricter requirements were introduced.
LEED 4.0	2013	A more integrated scoring methodology has been introduced, focusing on material selection and sustainability over the life cycle of the building.
LEED 4.1	2019	Optimized for the Building Design and Construction sector, including residential, commercial, school, healthcare, and retail types.

3.2. BREEAM (Building Research Establishment Environmental Assessment Method)

BREEAM is a set of green building assessment methods launched by the Building Research Establishment in the United Kingdom, which was first launched in 1990 and became the world's first green building assessment system [15]. Over time, BREEAM has undergone several revisions and upgrades to adapt to evolving environmental and sustainability requirements. In 1990, BREEAM was launched in the United Kingdom as the world's first green building rating system [16]. In 1998, BREEAM 97 was released, an important revision and upgrade of the assessment system. In 2008, the BREEAM 2008 version was released, introducing higher environmental and sustainability requirements [17]. In 2011, the BREEAM International version was released, expanding to the international market for construction projects worldwide. In 2014, the BREEAM New Construction version was released to evaluate new buildings [18]. In 2018, the BREEAM 2018 version was released, further raising the requirements for energy, water, health, and well-being. One of the advantages of BREEAM compared to the assessment systems of other countries is its high international recognition and wide adoption [19]. As the world's first green building rating system, BREEAM has 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 is a broad and comprehensive assessment that comprehensively assesses a building's energy efficiency, indoor environment, substance use, health and comfort, and more. Through quantitative indicators and scientific evaluation criteria, BREEAM assessment results are more objective and reliable, which helps to improve the sustainability level of buildings [21]. However, BREEAM also has some drawbacks. First, the assessment process is relatively complex and cumbersome, and may require more time and resources to complete the assessment. This increases the development cost of the project and may affect the active participation of some projects. Secondly, BREEAM's evaluation

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criteria have certain restrictions on architectural design and material selection, which may not be applicable to some special types of building projects or special environments. In some countries and regions, the influence of BREEAM is relatively small and has not been widely used and recognized [22].

3.3. CASBEE (Comprehensive Assessment System for Building Environmental Efficiency)

CASBEE is a system developed in Japan to comprehensively evaluate the environmental performance of buildings. CASBEE was developed in 2001 by the Building and Urban Research Institute (BRI) in Japan and was first released in 2003 [23]. 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 [24]. It uses the following assessment methodology, which includes four aspects:

1. Basic Assessment: Evaluate the performance of the building in terms of energy consumption, water resources, indoor environmental quality, material use, etc.

2. Construction method assessment: Evaluate 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: Evaluate 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 [25,26]. The specific level divisions are listed in the following Figure 5.

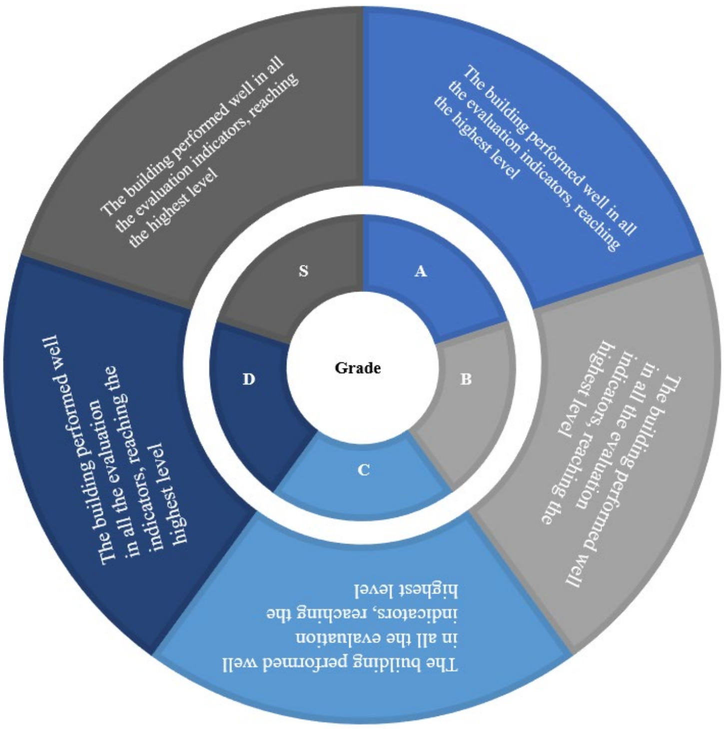

Figure 5. Rating scale.

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. [27]. 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

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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 [28]. Its assessment criteria are updated slowly, and CASBEE's assessment criteria are updated slowly, failing to keep up with the progress of green building technologies and practices in a timely manner [29]. 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. ASGB (Assessment Standard for Green Buildings)

As an important standard for the promotion of green buildings in China, the development process of "Green Building Evaluation Standards" can be summarized into three stages. The first edition was released in 2006, the second in 2014, and the third in 2019, successively improving and refining the problems and shortcomings of the previous edition [30]. 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 [31]. 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.

4. Weights and Indicators Settings of Green Building Evaluation System

4.1. Setting of Weight

GBRS are designed to assess a building's performance in terms of environmental friendliness and sustainability to help drive the construction industry towards a more environmentally friendly and sustainable direction. Weight allocation is a key issue when conducting green building evaluation, which determines the importance and influence of different indicators in the evaluation system. GBRS involves indicators in many aspects, which are generally subdivided into small indicators from the three dimensions of environment, society, and economy, such as energy efficiency, water management, material selection, indoor environmental quality, waste management, biodiversity, and social impact. However, the weighting of these indicators is not set in stone. Wen, B. H. [32] selected 10 global GBRS, using specific screening principles and proposed a unified standard framework to fairly compare these selected GBRS. The changes in GBRS were analyzed from three levels: categories, subcategories, and criteria. The results reveal a trend in the past 30 years: the weight of the environmental category has continued to decline, the weight of the social category has increased significantly, and the weight of the economic category has increased slightly. Over time, new technologies and materials may emerge that can provide more effective solutions to reduce factors such as energy consumption, water use, and waste generation. These new technologies may change the original weighting metrics to bring greater importance to specific environmental aspects. Different GBRS indicators have different weights. Awadh [6] made a critical analysis on LEED, BREEAM, GSAS, and Estidama, and made a quantitative discussion on their credit weights, indicating that the use of energy and water is the most important. In addition, as people's understanding of environmental and climate change issues continues to grow, the demand and concern for green buildings is also changing. The level of public attention to a particular issue can influence the weighting indicators assessed, for example, the level of concern about carbon emissions may increase over time. The policies and regulations of the government and relevant agencies can also have an impact on the weighting indicators of green building assessments. Changes in policy may create different requirements for energy efficiency, environmental friendliness, and sustainability, which will affect changes in the weighting indicators.

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4.1.1. Analytic Hierarchy Process

Green building rating involves the weight allocation of various dimensions and indicators, and the common methods in the current research include Delphi method, Analytic Hierarchy Process (AHP). AHP was first proposed by American mathematician and operations researcher Thomas L. Saaty in 1970. The steps for 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. Analytic hierarchy process is a qualitative and quantitative method of analysis that he proposed for evaluation and decision-making problems to deal with multi-criteria decision-making problems. It includes steps such as determining the indicator system, constructing a judgment, calculating the weight vector, consistency checks, hierarchy total sorting, and adjusting the judgement matrix. First, we identify the criteria that are 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 in pairs to assess their relative importance to form a table as shown in Table 2. Based on the comparison results, construct a judgment matrix as shown in Figure 8. Normalize the matrix, then calculate the eigenvectors of each criterion, and calculate the CR value through the eigenvectors, which is used in the process of calculating the CR value. The RI values are given in Table 3. Then, conduct consistency testing to evaluate the degree of consistency of the comparison made. Finally, calculate the weight of each criterion based on the weight of the feature vectors, and add them up to obtain the final weight.

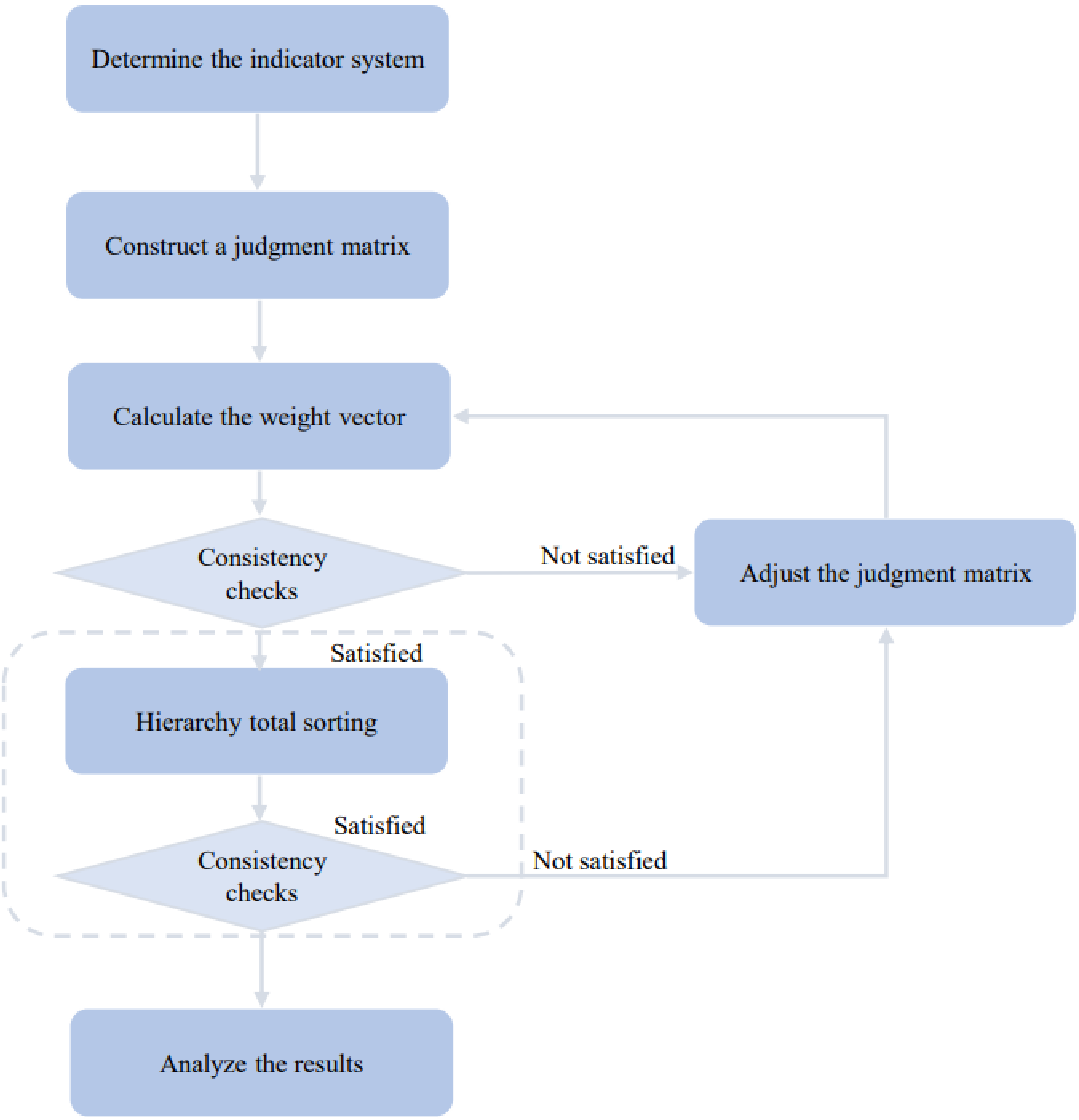

Figure 6. A multi-level analytical structural model.

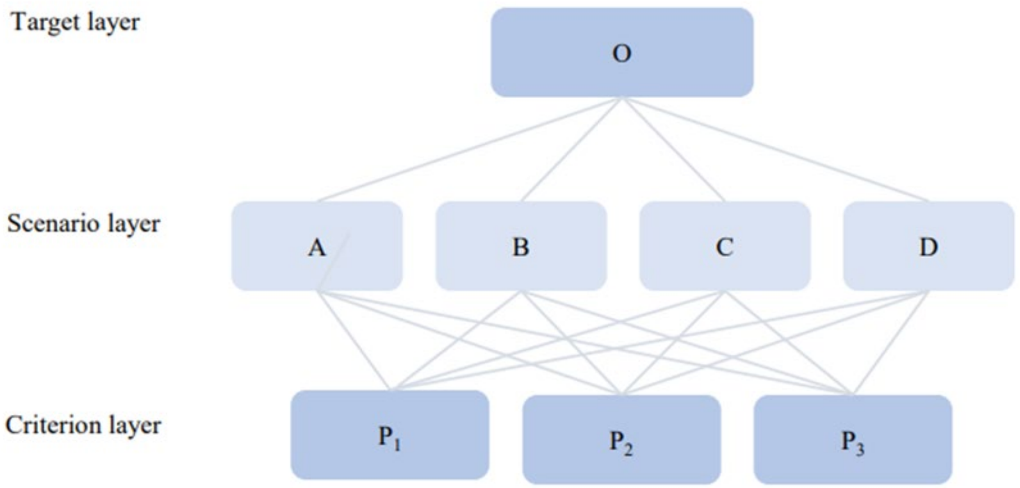

Figure 7. Target structure hierarchy.

Index	A	B	C	D
A	1	a	b	c
B	1/a	1	e	f
C	1/b	1/e	1	j
D	1/c	1/f	1/j	1

$$E_{ij} = \begin{pmatrix} e_{11} & \cdots & e_{1n} \\ \vdots & \ddots & \vdots \\ e_{n1} & \cdots & e_{nn} \end{pmatrix} = (e_{ij})_{n\times n}$$

$$CR=\frac{\lambda_{max}-n}{(n-1)(RI)}$$

Figure 8. Judgment on the construction of matrices.

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

Table 3. RI value.

Matrix order	3	4	5	6	7	8	9	10	11	12	13
RI	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 multi-criteria 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 building. 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, AHP method is still the basis of weighting method in current research. It can be combined with Delphi Method, Fuzzy Evaluation Method, Entropy Weight Method, and other methods to better play 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 for the Delphi method to calculate the weights are shown in Figure 9. This approach was originally developed for the U.S. 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 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 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.

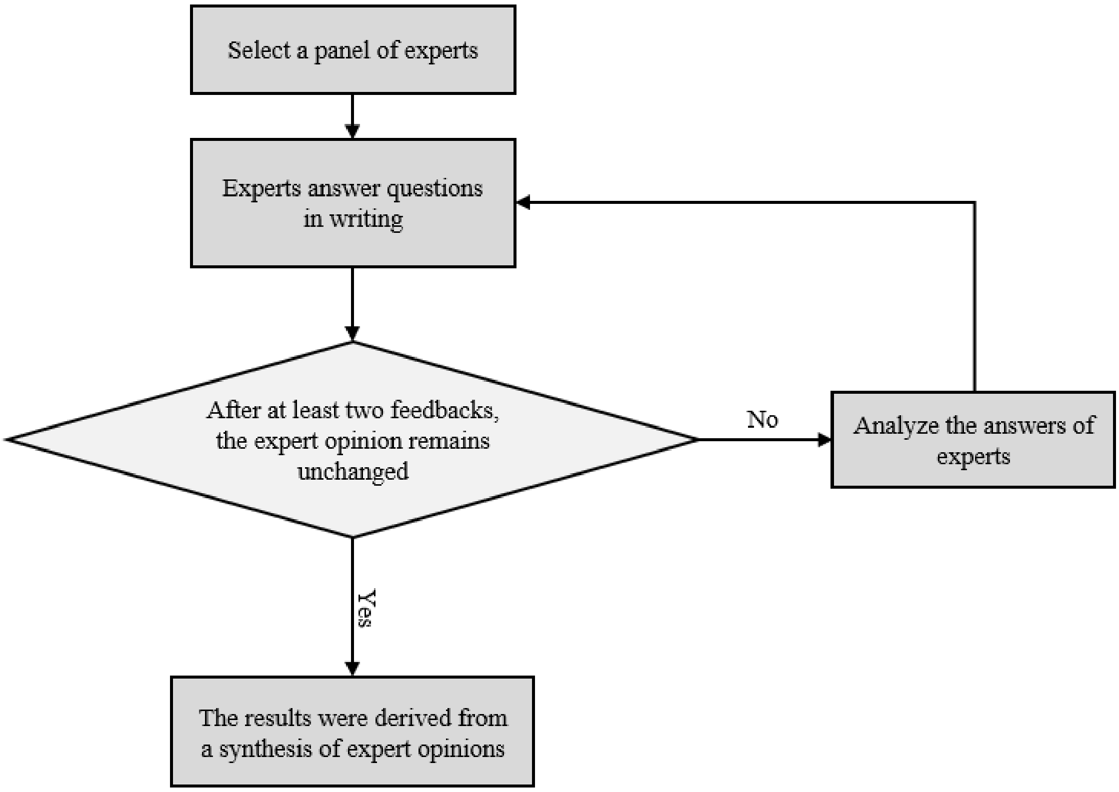

Figure 9. Operational flow chart of Delphi Method.

4.1.3. Fuzzy Evaluation Method

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 ambiguity and uncertainty. 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 the 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 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 indicators 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 fuzzy evaluation and analytic hierarchy process to evaluate the performance level of green buildings from three dimensions: environmental, social, and economic. Combined with the advantages of Fuzzy Evaluation Method to deal with uncertainty and ambiguity in green building assessment, and the advantages of 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.

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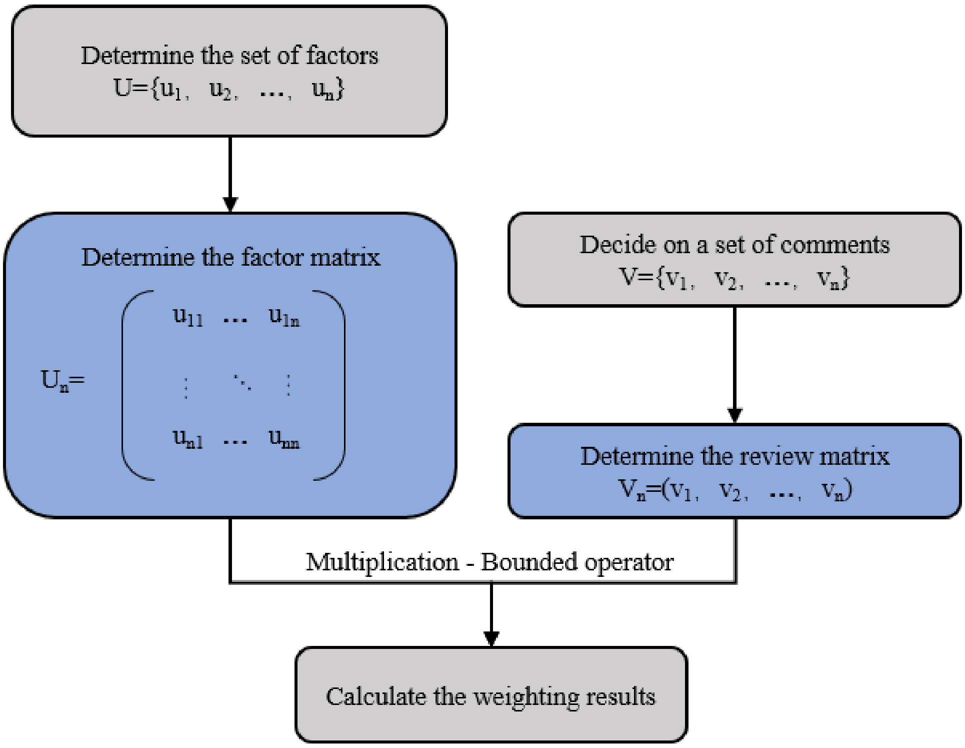

Figure 10. Operational flow chart of Fuzzy Evaluation Method.

4.1.4. The 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 indicators should be determined according to the calculated information entropy and normalized to ensure that the sum of the weights is 1. 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 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 to correctly specify the weights of each indicators.

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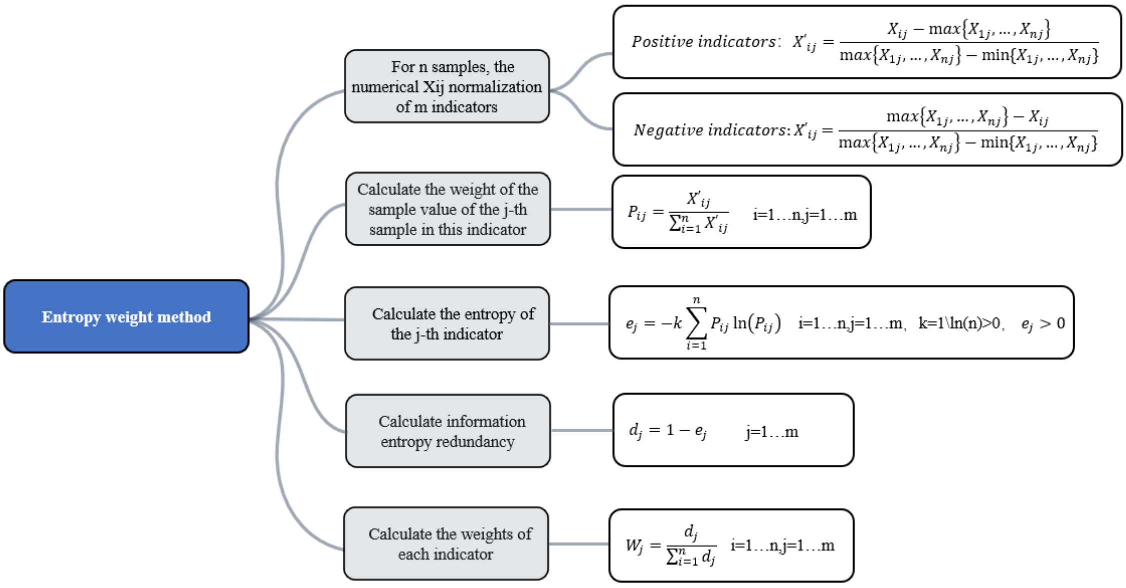

Figure 11. Operational flow chart of The Entropy Weight Method.

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 comprehension 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.

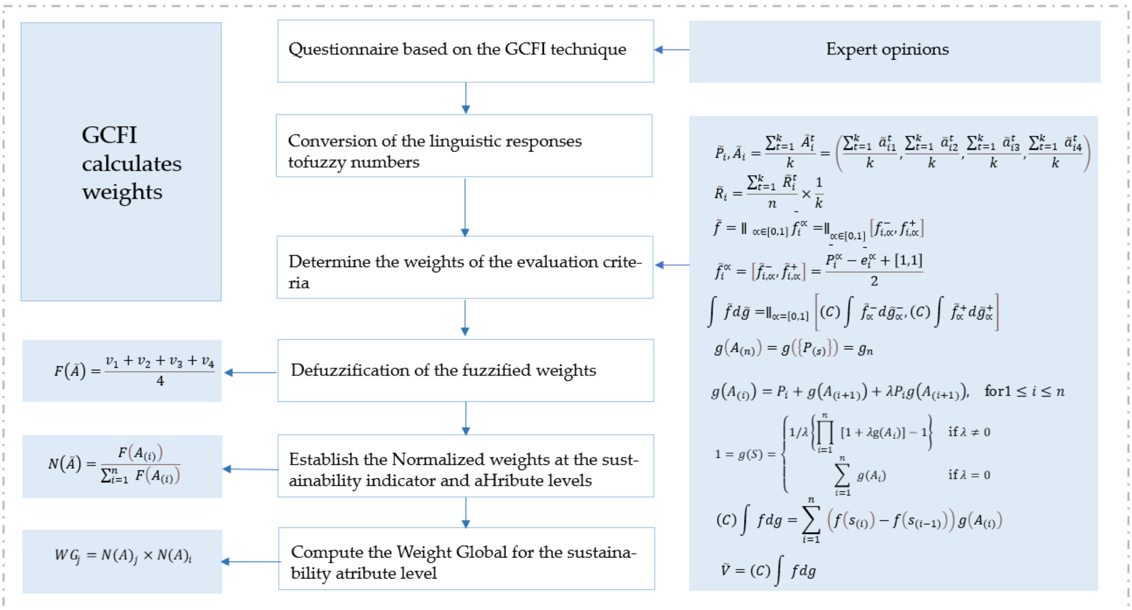

Figure 12. Operational flow chart of the generalized Choquet Fuzzy Integral Method. (Olawumi, T.O. [43]).

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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 (ANP) model based on the Best Worst Method (BWM) to determine the weight allocation of each criterion.

All in all, no matter what method is used, the ultimate goal is to build a more objective, accurate and comprehensive green building evaluation system to help promote the sustainable development of the construction industry.

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 second-level indicators of the target layer. For each secondary indicators, 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 indicators 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. [49] comparative study of LEED, GBEL, and BEAM 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 to 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

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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 changing needs of green building-related technologies. To prevent developers from blindly promoting inapplicable energy-efficient technologies for certification, some rating systems score technologies based solely on their use. However, this practice can lead to the failure to meet energy goals for green buildings. To solve this problem, a pre-evaluation system is proposed, which uses the improved TOPSIS method, the SA algorithm, and the theory-based data analysis method. The system sets evaluation indicators from many aspects such as technical performance, economy, and human satisfaction, and uses the measured database to evaluate the energy-saving technology of the target green building in a quantifiable and multi-dimensional manner with the help of the prior information and technology of the building in the design stage. The study by Kim, M.J. [51]. added user experience to the evaluation indicators. At present, most of the existing studies use quantitative methods to evaluate the performance of green buildings, but there is a lack of qualitative evaluation of users' interaction with green buildings. To fill this gap, a comprehensive approach to the evaluation of green building performance has been developed, which includes a qualitative evaluation of the user experience. Through the introduction of qualitative evaluation indicators, it is possible to understand the interaction between users and green buildings more comprehensively, and evaluate their impact on sustainability, which will help to provide more accurate building evaluation and improvement strategies, and promote the development and promotion of green buildings. Miller, D. [52] found that hidden energy contributes an average of 28.4% to the life cycle consumption of a building structure, and suggested that hidden energy should be considered in the evaluation criteria. lllankoon, I. [53] found that environmental sustainability is widely considered in green building rating tools, while economic sustainability is rarely used as an assessment criterion. The evaluation system of green buildings in various countries around the world has been developed for many years, but there is a lack of evaluation of the disaster prevention and mitigation (DPM) capacity of green buildings in many indicators. To solve this problem, combined with the complex natural disasters that occur in China and related regulations, Vyas, G.S. [54] proposes DPM indicators based on four main aspects: structural safety, DPM design, facility setting, and resource utilization. Subsequently, with the help of Fuzzy Analytic Hierarchy Process (FAHP), a green building DPM indicators evaluation system was established to evaluate the DPM capability of green buildings and quantify the impact of each indicators on their DPM capabilities. The role of Hedge, A. [55] ergonomics in green buildings and the U.S. LEED rating system was discussed. After the practitioners' summary, some ergonomic design issues in the LEED Platinum energy-efficient and sustainable buildings studied were identified. The results highlight the importance of ergonomic design as an integral part of the U.S. LEED rating system and its inclusion in green building evaluation indicators. In addition to complementing the current indicators, in-depth comparative studies of some of the existing indicators are lacking. For example, research on water use efficiency lacks some comparative considerations. Zhou, W.W. [56] focused on comparing the water efficiency of the LEED in the United States and the ASGB in China. To present the results of the comparison more thoroughly and comprehensively, the specific terms in six aspects, including macro water use, building water use, landscape water use, water use for cooling systems, use of non-traditional water sources, and water monitoring systems, were compared. Contribute to a more complete understanding of water efficiency standards.

Based on the current research, it is necessary to comprehensively consider the key issues of globalization and integration, climate change, life cycle, social sustainability, innovation, and technological development in the setting of indicators for future green building assessment systems. The evaluation system should consider the variations in regions and cultural backgrounds, while fostering global collaboration and advancement in sustainable construction. At the same time, it is necessary to pay attention to the climate adaptability and mitigation measures of buildings, and pay attention to key elements such as life cycle assessment of building materials, efficiency of energy and resource use, and indoor environmental quality. In addition, social sustainability needs to receive more attention in the assessment system, including the integration of buildings with communities, the impact on human health and comfort, and support for social equity and inclusion.

5. Development of GBRS

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 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 MR (materials and resources) to automatically generate green building assessment reports. As shown in Figure 13. By combining the amount of material extracted from BIM and templates and scripts developed using GBI, 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 (GPRS) 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. This data is 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 (IGBR) framework based on BIM semantic and social approaches to enable real-time rating in building design.

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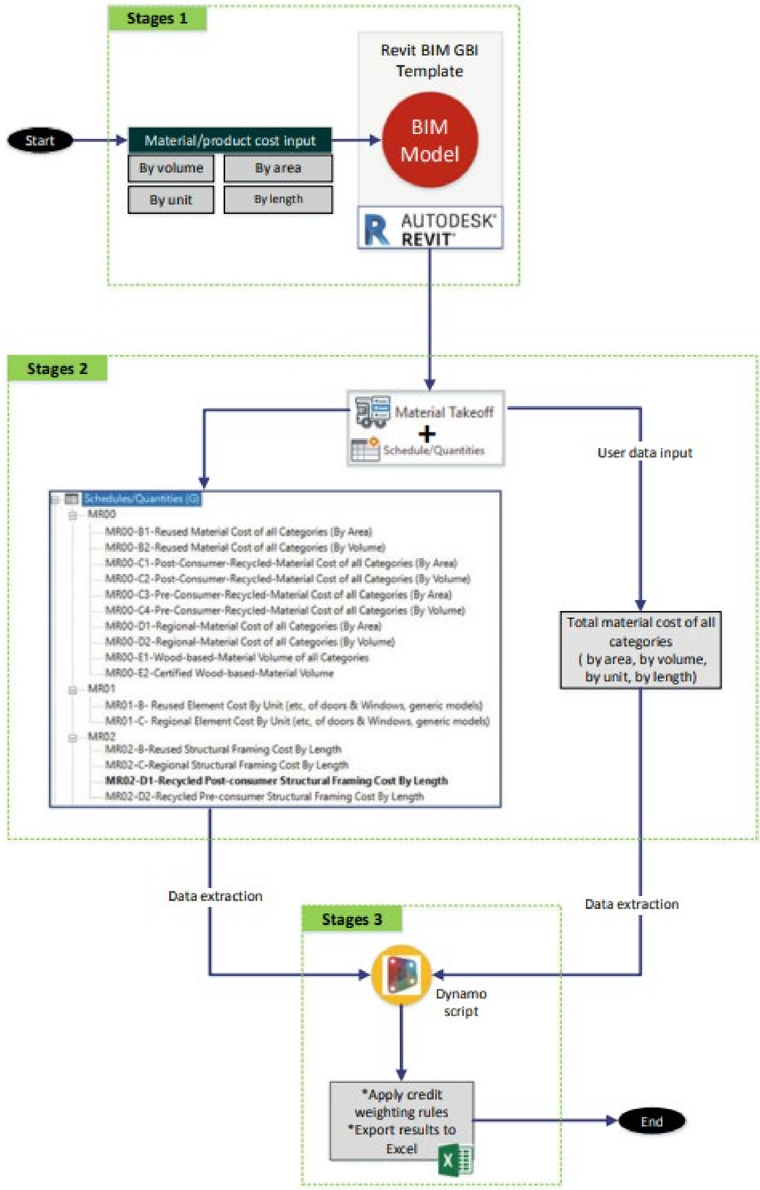

Figure 13. Workflow of the BIM-MR integration system (Seghier, T.E. [57]).

In terms of the guiding role of green building design, He, Y.E. [60] found: 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.

In the future, the possible development of GBRS may be in terms of innovation in building materials and technologies, dynamic assessment, and monitoring, or more consideration of ecosystem and community factors. Focus on the development of new building materials and technologies to reduce environmental impact. More renewable energy and energy-efficient materials will be included in the evaluation system. With the rapid development of smart buildings and the Internet of Things, green building assessment systems may collect real-time data to dynamically assess and monitor the environmental performance of buildings, which will help building managers better understand the energy usage and environmental impact of buildings, and take corresponding measures to optimize them. Future GBRS are likely to focus more on assessing the impact of buildings on surrounding ecosystems and communities. For example, consider factors such as the building's use of water, the way waste is disposed of, and the conservation of surrounding biodiversity.

6. Conclusions

With the increasing global requirements for green buildings, the weighting method of GBRS is constantly being updated and upgraded. Focusing on multi-dimensional and multi-method weighting settings, the scope of indicators setting is expanded, not only focusing on architectural design, but also focusing on building operation, environmental and social impact around the building, etc., which can better reflect the sustainability of the building in an all-round way.

At the same time, with the continuous progress of science and technology, the evaluation process of GBRS is also developing in the direction of intelligence and automation. For example, through artificial intelligence, big data, and other technical means, GBRS can more accurately assess the environmental, social, and economic performance of buildings, and provide more accurate guidance for green building design. Based on the intelligent and automated evaluation process, the GBRS evaluation system will continue to optimize and develop to promote the development and popularization of green buildings. In short, the continuous update and development of GBRS will provide more comprehensive, scientific, and effective support for the design and practice of green buildings.

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