

## Article

# A Comprehensive Framework for Evaluating Sustainable Green Building Indicators under an Uncertain Environment

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**Abstract:** The development of sustainable green buildings (GBs) is a major contribution to the preservation of the environment. Sustainable thinking in GB construction is not a supplementary element, but rather necessary to achieve the building's functional, economic, and environmental efficiency in order to preserve resources and meet current and future needs. In particular, developing countries can apply the idea of sustainability in GBs by following international policies and standards, combined with their local characteristics, to construct GBs that are aligned with the environment and are in line with the available local capabilities and resources. The paper focuses on the dimensions and indicators of sustainable design for GBs in developing countries to achieve the positive dimensions of building sustainability, such as preserving energy and natural resources, water management, adaptation to the surrounding environment, and respecting the needs of its users. We assess and prioritize the dimensions and indicators of GBs through the use of a multi-criteria decision-making (MCDM) method under a neutrosophic environment. Initially, the Delphi method is employed to capture preference and to determine the dimensions and their indicators in addition to provide preference among sub-indicators. The relative importance of the selected dimensions and indicators is assessed through the analytical hierarchy method (AHP) method. The results indicate that the water efficiency dimension is the most significant, with a weight of 0.330, while the energy efficiency dimension is the least significant for GBs in developing countries, with a weight of 0.100. The paper concludes with a set of administrative implications for applying sustainable development strategies in GBs.

**Keywords:** multi-criteria decision-making; green building; uncertainty; sustainability; AHP; Delphi



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## 1. Introduction

Although the twentieth century has made great advances in scientific, technical, and industrial development [1], there is increasing recognition of the need for a new concept of development, a development that proposes a balanced vision between preserving both the environment and continued economic growth. The construction and urbanization sector receives great attention in the framework of sustainable and comprehensive development, because the practices of this sector in design, implementation, maintenance, operation and even demolition have a great impact on people and the environment [2]. The construction sector alone accounts for 40% of the total energy consumption in the world, some 30% of raw materials are consumed in building and urban activity, and 16% of total water consumption is used for building and construction [3,4]. Developing countries produce about 30% of greenhouse gases [4,5] and are therefore a significant component of plans to reduce greenhouse gases. The International Panel on Climate Change (2007) indicated that there could be a reduction in energy consumption and a reduction in greenhouse emissions of 6 gigatons in the next decade if practices were changed to be sustainable [6].

The World Health Organization (WHO) also indicates that some new buildings in the world that are not suitable for human habitation [7], with poor internal environments as a result of the dangerous pollutants and plankton. There is a consequent economic cost as a result of the diseases contracted in such buildings, whether a direct cost for the diseases that may afflict a person as a result of the unsustainability of his home and its quality assurance, or an indirect cost such as low productivity of individuals due to their disease.

The concept of GBs has arisen as a framework for a set of solutions that enable the construction and urbanization sector to respond with a higher degree of interaction to environmental issues and health concerns. Accordingly, the trend has been to design GBs, to control the behavior of the buildings, and to develop strategies that preserve human health and reduce carbon emissions and energy consumption. In recent decades, interest is evident from all stakeholders in the GB concept, including governments, researchers, environmentalists, and stakeholders in both developing and developed countries [8,9].

Energy saving in buildings is the first priority in the concept of GBs, given that the construction sector consumes such a large proportion of total energy usage. There are many decisions taken in GBs to reduce energy consumption, such as the use of passive or natural systems for cooling, heating, ventilation, and even lighting; the optimal use of insulation in walls and roofs; and careful consideration of the best solutions to design the shape of the building and its location and direction. GBs also pay great attention to renewable energy sources, as this energy is constantly available and its production and use is not accompanied by significant environmental impact. Even the use of local materials and recycled materials is, in fact, saving energy.

Li et al. defined a GB as a building that reduces pollution and conserves natural resources throughout its life cycle [10]. GBs conform to the language of nature and are concerned with human comfort and safety avoiding materials that have not been tested for harmfulness to humans [11]. Xiaohong Zhang et al. indicated that building construction results in high energy consumption in addition to dangerous environmental impacts [12]. Developed and developing countries still have not reached the state of environmental efficiency in building construction [6], as the process of construction and then operation and maintenance may be accompanied by significant waste and emissions polluting the environment. There are many studies indicating that about 30% of solid waste is construction waste, and some of this waste is a major source of pollution [6]. For instance, in developed countries, the construction sector consumes about 35% of natural resources [6]. In China, the construction sector uses about 20% of the total energy consumption, and only about 2% of the buildings are considered to be non-energy consuming [6]. In America, annual building maintenance consumes from 35% to 60% of the energy budget [6]. Europe also allocates a large part of the energy to housing services compared to other sectors [6].

In order to address these issues, a number of countries have put in place long-term GB policies out to 2035 [13]. Wu et al. indicated that the construction sector establishes environmental policies to manage the use of natural resources and maintain an environment of high-quality buildings [14].

Although GBs have attracted researchers in various respects, the application of GB strategies still requires many improvements [15]. In developing countries, in particular, stakeholders rely on economic strategies related to the “take-make-consume-dispose” economy criterion in the construction sector without considering other factors to achieve environmental efficiency [16]. Furthermore, efforts directed towards implementing environmental efficiency in building construction have not been sufficient to achieve sustainability in construction projects, especially in developing countries [16]. In fact, there are some Green Building Rating Systems (GBRSs) already in place in a number of countries to contribute to the expansion of GBs: “LEED” in the USA, “BREEAM” in the UK, “SBTool” in Canada, “CASBEE” in Japan, and the Green Building Index (GBI) in Malaysia [6,17,18]. However, there are limited studies on the existence of a theoretical reference framework within which to determine the evaluation tools and factors for GB construction in developing countries and to rank the importance of the relative sustainability indicators [6].

Furthermore, little of the research on GBs and the evaluation of sustainability indicators has been carried out under the fuzzy environment [6].

A previous study by [6] assessed GB construction using the GBI rating system in Malaysia, although the authors only took into account the conditions of that single country so that the conclusions are limited to Malaysia or to countries that have the similar conditions. A further limitation of this study is that it was conducted under a fuzzy environment, which did not adequately address ambiguity and uncertainty. Smarandache presented neutrosophic theory to deal with ambiguities in human perceptions and uncertain phenomena [19]. Neutrosophic theory can fully deal with indeterminacy, while fuzzy theory [20] cannot deal at all with indeterminacy, and intuitionistic fuzzy theory [21] only partially deals with indeterminacy. Indeterminacy is an independent element only in the neutrosophic environment, while in the fuzzy environment and the intuitionistic fuzzy environment, indeterminacy is dependent, or does not exist [22]. Additionally, neutrosophic sets can deal with vague and inaccurate information from the real world and are more efficient in dealing with inevitably vague or not totally reasonable judgments [22].

To the best of our knowledge, no study has yet applied the advantages of the Delphi-AHP methods in this context to reduce uncertainties. Additionally, this research considered uncertainties in all phases, which has been neglected in the previous study [6]. The uncertainty commonly occurs in the data itself, in data aggregation, and in the analysis technique(s) and conclusions. In this study, uncertainty was reduced in data collection by circulating questions and answers among the researchers and experts and by applying the qualitative and quantitative techniques, specifically the Delphi technique [23]. Neutrosophic numbers were also applied to reduce data uncertainty [24]. Additionally, the AHP technique was applied to control uncertainties related to the evaluation method.

This paper addresses the previous problems by identifying a theoretical reference framework for GB construction tools and processes in developing countries and ranking the sustainability indicators based on the opinions of experts and some indicators used in the GBRs currently in place. In this regard, the dimensions and indicators of sustainability for the construction of GBs according to their priorities are assessed using the Delphi-AHP method under the neutrosophic environment. This approach yields a neutrosophic exactness to improve group decision-making, utilizes a literature-based list of evaluation criteria for application of the methodology in GB construction, and benefits from both qualitative and quantitative approaches.

The assessment of sustainable integrated green technologies for construction and prioritization of different dimensions and indicators is an MCDM process that consists of environmental and social dimensions, and others [4,25]. AHP is a very common technique used in a wide range of MCDM problems [26]. The strengths of this technique are to expound complex problems into simple sub-problems and to efficiently deal with both quantitative and qualitative data [27,28]. However, traditional AHP cannot deal with uncertainty, thus, applying AHP in a neutrosophic environment solves this drawback and improves decisions by considering uncertainty. Based on the data collected through the questionnaires, the AHP method was used to evaluate the dimensions and their indicators, and determine their priorities and the level of importance between them in the fields of GBs. In recent years, neutrosophic theory has attracted the interest of scholars and has been employed in many studies in various fields [29].

The main contributions of this paper are:

- A theoretical reference has been introduced which provides a useful archive of dimensions and their indicators for future scholars, architects, and stakeholders to use in GBs in developing countries.
- We suggested a neutrosophic MCDM approach based on AHP to help stakeholders to determine the most priority dimensions and indicators.
- For the first time, the dimensions and indicators of GB construction are being evaluated under a neutrosophic environment.

The remaining sections of this research are organized as follows. Section 2 presents a literature review concerned with GB construction. Section 3 discusses the GB dimensions and their indicators in developing countries. The steps of the research methodology are presented in Section 4 and the application of the research methodology is verified in Section 5. Section 6 provides some of the managerial implications for this research and Section 7 concludes.

## 2. Literature Review

Industrial companies are facing difficulties and exposes to great pressure to provide high-quality products and reduce environmental impacts under a greener environment and free of pollution [30]. Maruthi and Rashmi referred to the incorporation of key sustainability factors into the manufacturing system which includes environmental, economic and social factors [31]. In this regard, in light of green manufacturing, companies strive to assess energy consumption, reduce environmental impacts, and accurately regulate material consumption at every step in their products' life cycles to achieve the sustainability principle of the three main aspects of sustainability. Tian et al. outlined a case study on auto recycling in order to analyze basic operating patterns using the MCDM method to save energy, protect the environment from emissions, and reduce the cost of recycling [32]. Their MCDM model combined two methods, AHP, which was used for determining weights of influence criteria, and Technique for Order Performance by Similarity to Ideal Solution (TOPSIS), which applied for evaluating automotive components remanufacturing (ACR) production operation patterns. Their studies were conducted in a fuzzy environment that did not consider uncertainty well. Hanim et al. indicated that the social, economic, and environmental aspects are affected by green manufacturing based on data collected from previous studies [33]. Diaz-Elsayed et al. presented a study that targeted the automotive sector in terms of integrating green and lean strategies into the production process [34]. Their model aims to simulate the impact of implementing a combination of lean and green practices in a manufacturing facility. A green manufacturing model was introduced with the aim of achieving greener and more efficient manufacturing, based on various planning processes and processing activities [11]. Despite research that has dealt with various aspects of green practices in the manufacturing process and the life cycle of production, research related to the construction of GBs is still rare. Therefore, this paper aims to categorize the dimensions and indicators of sustainable GB construction in developing countries.

A multi-criteria analysis methodology has been proposed that helps stakeholders to understand the aspects of GB construction, such as clarifying the priority of criteria in importance, order, coherence between them, and structuring preferences. It should be noted that before the advent of multi-criteria methods, decision-making problems were often based on a single criterion, so it was more appropriate to resort to methods that include several aspects and several limitations, which are multi-criteria methods. These methods include both quantitative and qualitative criteria, and they are not often of equal importance in decision-making. MCDM deals with many difficult problems, such as engineering problems, through methodological approaches [35]. Zarghami et al. indicated that the MCDM method is widely used in GB research to categorize factors based on sustainability concerns, which rely mainly on a fuzzy process [18]. In the context of environmental sciences, the use of this technique is still growing [36]. Zarghami et al. developed the Iran sustainability design tool, which consists of six levels of certification, to assess the sustainability of buildings. They used the sustainability indicators in some of the existing systems, such as LEED, BREEAM, and SBTool CASBEE, to design an environmentally friendly building sustainability system in Iran [18]. They also assessed the indicators using the fuzzy AHP method to identify indicators of highest priority and importance in improving building sustainability while taking into account environmental, economic, and social conditions. Yadegaridehkordi et al. presented a study for identifying and ranking the sustainability indicators for assessing GB construction in Malaysia by considering GBI [6]. They applied the DEMATEL method to reveal the importance level and

relationships among sustainability indicators in GBs under neutrosophic environment [6]. The results showed that “Energy Efficiency” and “Indoor Environmental Quality” are the most important, while “Water Efficiency” and “Innovation” are the least important criteria in assessing GB construction in Malaysia. Haider et al. introduced an approach for evaluating small-sized urban systems under sustainability [37]. This methodology has been developed to include key aspects of sustainability, in addition to helping planners submit new proposals based on their practical experience in the field of sustainable construction. Mardani et al. applied fuzzy MCDM approaches for assessing energy saving technologies and solutions (ESTS) in five-star hotels based on AHP [38]. They used four ESTS in the evaluation process from the literature survey.

From this review of previous studies, it is evident that various MCDM methods and assessment tools have been used to assess GB dimensions and indicators and AHP is a commonly used approach in dealing with green practices in construction. Although there are studies in the field of GBs in some countries such as China, Europe, Iran and Malaysia, there is a lack of studies related to assessing sustainability indicators for GBs and determining the priorities of the indicators. Moreover, the researches in sustainable buildings or GBs were conducted only under a fuzzy environment. Therefore, in this paper, we identified several dimensions and indicators of GBs sustainability in developing countries in addition to evaluating the dimensions and indicators according to their importance and priorities according to the appropriate environmental, economic, and social conditions for developing countries using AHP. In addition, the study was conducted in a neutrosophic environment, which is an efficient way to treat uncertainty and deal with indeterminacy compared to fuzzy [20] and intuitionistic fuzzy [21].

### 3. Green Building Indicators

In this section, a set of GBs indicators (GBI) was developed to assess the design and environmental performance of GBs in developing countries. As shown in Figure 1, GBIs are divided into five dimensions: energy efficiency dimension, indoor environmental quality dimension, sustainable site planning and management dimension, materials and resources dimension, and water efficiency dimension. The development of GBIs depended on the opinions of consultants, experts, and architects, in addition to some GBRs such as LEED in the US, BREEAM in the UK, SBTool in Canada, CASBEE in Japan [17,18], and GBI in Malaysia [6]—see Figure 2 for examples of GBRs. Therefore, when developing a proposal for GBIs indicators for developing countries, all these systems were taken into consideration based on the opinion of experts in a single system that fits the environmental conditions, as well as cultural and social needs in developing societies. The dimensions and indicators of GBs are discussed in detail as follows.

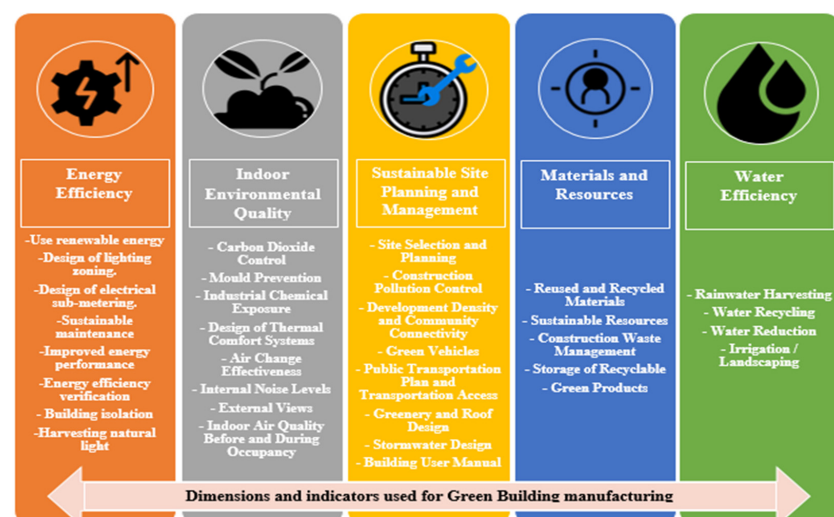
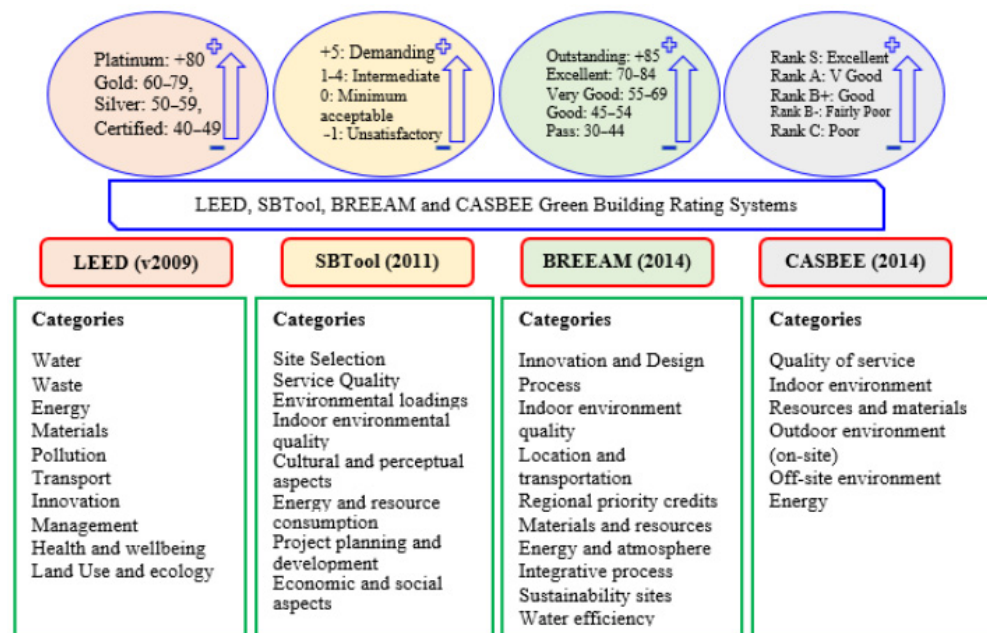


Figure 1. Dimensions and indicators used for GBs.



**Figure 2.** Some of GBRs in the world.

### 3.1. Energy Efficiency Dimension EED ( $D_1$ )

The energy efficiency criterion expresses special aspects of using renewable energy and improving energy performance. This criterion includes the following eight indicators [18].

#### 3.1.1. Use Renewable Energy URE ( $D_{1-1}$ )

This indicator shows the extent to which renewable energy is used in the construction of GBs and the types of renewable energies that are used. It clarifies whether renewable energy technologies are almost limited to the use of local resources only or from external sources, which helps protect the construction of buildings from unexpected shocks in terms of energy security [2].

#### 3.1.2. Design of Lighting Zoning DLZ ( $D_{1-2}$ )

This indicator refers to the visual considerations, lighting principles, and methods used in the design of GBs (i.e., artificial or natural lighting, day and night). It also indicates the extent to which the correct laws and mathematical equations are used for lighting.

#### 3.1.3. Design of Electrical Sub-metering DES ( $D_{1-3}$ )

This indicator refers to the existence of the electricity utility for GB. Sub-metering refers to the installation of meters in the direction of the main electricity supply, the measurement of consumption of individual units, and allowing equitable distribution of costs on the basis of consumption, with residents responsible for their own consumption [28].

#### 3.1.4. Sustainable Maintenance SM ( $D_{1-4}$ )

This indicator refers to some measures related to the maintenance and operation of GBs. No matter how sustainable a building is in design and construction, it can only remain so if it is operated responsibly and properly maintained.

#### 3.1.5. Improved Energy Performance IEP ( $D_{1-5}$ )

This indicator refers to the extent to which energy efficiency and cost savings are improved by replacing energy systems in buildings with others that are more efficient to reduce energy consumption, because this method gives quick results and has limited costs. Some cases can be satisfied with replacing energy systems; however, others are more prone to issues related to costs, or lack of experience [14,28].

### 3.1.6. Energy Efficiency Verification EEV ( $D_{1-6}$ )

This indicator refers to monitoring energy use during operation and making an assessment of energy use during the first months of the building's operating period to ensure optimal efficiency [28] and maintenance practices every five years. The EEV indicator also considers the availability of energy efficiency display screens in the building to enable building occupants to monitor and take the necessary measurements.

### 3.1.7. Building Isolation BI ( $D_{1-7}$ )

This indicator refers to the extent to which the insulation of external walls and surfaces is improved, adding external protection films on windows, improving window orientation, calculating the ratio of openings to the entire wall, and using double glazing.

### 3.1.8. Harvesting Natural Light HNL ( $D_{1-8}$ )

This indicator refers to the use of natural lighting in buildings as a strategic goal on which modern architecture depends to reach sustainable and green architecture that is appropriate for future cities [39]. GBs using daylight harvesting have automatic lighting control systems that measure the amount of natural light in each space and adjust electric lights accordingly.

## 3.2. Indoor Environmental Quality Dimension IEQD ( $D_2$ )

The urgent need for sustainable design, which establishes an internal environment that meets the requirements of comfort and safety, emerged as a strategy for minimizing building pollutants and maximizing the efficiency of positive exchange between the building and the natural environment around it [6]. Now that sustainable designs are available at all aesthetic and functional levels, awareness of the importance of sustainable design and its positive impact on human health must be raised. Although high-cost designs at the beginning, the aesthetics and functionality of the designs and the sustainable materials used are recyclable and remain for future generations and do not harm the environment. Hence, the problem of the determinants of sustainable interior design and its impact on the quality of the internal environment for interior design is addressed. This dimension includes the following eight indicators. [7].

### 3.2.1. Dioxide Control CDC ( $D_{2-1}$ )

This indicator refers to the concentration of carbon dioxide in the indoor environment or closed places, and it is an indication of whether ventilation is sufficient or not [18]. The quality of indoor air is also affected by the outdoor air pollution, as well as the internal sources of pollution (e.g., the building characteristics or the inhabitants' habits such as smoking [7]). For this, carbon dioxide monitors can be placed and the airflow can automatically increase if the carbon dioxide concentration increases beyond a specified level.

### 3.2.2. Mold Prevention MP ( $D_{2-2}$ )

This indicator refers to how to control the appearance of mold in GBs. Factors to be taken into consideration when designing GBs with no mold in the future are limiting the absence of direct sunlight inside the building, the high humidity in the air, wallpaper, glue and untreated wood, and even dust [2]. Hence, all these factors must be taken into consideration when designing GBs so that mold does not appear.

### 3.2.3. Industrial Chemical Exposure ICE ( $D_{2-3}$ )

This indicator refers to the amount of chemicals that residents are exposed to in buildings (e.g., sources, modes of transportation, and effects of chemicals on human health and the environment) [18]. This indicator is considered one of the most important indicators that must be taken into account.

#### 3.2.4. Design of Thermal Comfort Systems DTCS (D<sub>2-4</sub>)

This indicator refers to the design of GBs such that it works efficiently in both heating and cooling the buildings through adjusting the thermal gain and loss [14].

#### 3.2.5. Air Change Effectiveness ACE (D<sub>2-5</sub>)

This indicator refers to the location of the outdoor air intakes has a great impact on the effectiveness of changing the indoor air. Assuming that the outside air surrounding the building does not contain impurities or dirt, obtaining good quality of indoor air is possible through proper ventilation and the correct distribution of air inside the building, which must be taken into account in the design of GBs [7].

#### 3.2.6. Internal Noise Levels INL (D<sub>2-6</sub>)

This indicator refers to efficient acoustic design and noise avoidance for GBs. The efficiency of a wall in preventing the transmission of noise depends on its mass [39], so it is preferable to use sound-absorbing floors.

#### 3.2.7. External Views EV (D<sub>2-7</sub>)

This indicator refers to creating an outdoor environment that brings comfort in vision and environmental benefits such as shading in the summer with trees. The exploitation of environmental diversity confirms that the designs require a high technical approach with compatibility with aesthetic aspects [40].

#### 3.2.8. Indoor Air Quality before and during Occupancy IAQO (D<sub>2-8</sub>)

This indicator relates to indoor air quality monitoring before and during work inside GBs. It was found that the concentration of pollutants in the closed indoor places is much higher than in the external environment [7].

### 3.3. Sustainable Site Planning and Management Dimension SSPMD (D<sub>3</sub>)

The SSPM criterion is one of the most important in the sustainable GB industry. The basis of any project is the design stage, as it has the greatest ability to impact cost and sustainable performance [6,18]. The primary goal of sustainable GB projects is to reduce the overall environmental impact associated with all stages of the construction project life cycle. However, construction is not a simple industrial process. Buildings are complex products, consisting of many components that each constitute different design variants. The difference in each design variable may affect the environment during all relevant life cycle stages of the building. The SSPM dimension includes the following eight indicators [14].

#### 3.3.1. Site Selection and Planning SSP (D<sub>3-1</sub>)

This indicator shows that site selection and planning for GBs requires the integration of environmental, social, and economic factors. In addition, the successful implementation of GB sustainability requires a comprehensive and detailed planning process and real-need analysis that takes into account the environment from the start of the design process [5]. A suitable site must be chosen with the availability of raw materials, proximity to transportation, power grids, and the presence of the appropriate work force.

#### 3.3.2. Construction Pollution Control CPC (D<sub>3-2</sub>)

This indicator refers to the extent to which construction pollution is controlled (e.g., organic and inorganic gases that result from combustion, whether they are from moving vehicles or industrial or electrical facilities near the site). Therefore, in the planning stage of the construction process, the possible and potential sites for construction should be evaluated in terms of levels of environmental pollution, including organic compounds, analysis of nearby or adjacent sources of pollution, information on the climate, and the movement of the prevailing winds [14,40].



### 3.3.3. Development Density and Community Connectivity DDCC (D<sub>3-3</sub>)

This indicator refers to the development measures in GB industrialization areas with existing infrastructure, protection of green fields, and consideration of natural resources. In addition, it includes meeting community connectivity standards such as proximity to basic services.

### 3.3.4. Green Vehicles GV (D<sub>3-4</sub>)

This indicator refers to the measures taken towards the transition to green vehicles that meet the needs of the new development societies based on achieving the principle of sustainability [39]. Examples of low-impact transport methods (i.e., green transportation) are non-mechanical transportation, walking, cycling, green vehicles, car sharing, and using environmentally friendly energy [5,40].

### 3.3.5. Public Transportation Plan and Transportation Access PTPTA (D<sub>3-5</sub>)

This indicator refers to the measures taken and the recourse of urban planning experts who can efficiently connect public transportation—that is, transportation systems that are used to transport the public and suitable parking.

### 3.3.6. Greenery and Roof Design GRD (D<sub>3-6</sub>)

This indicator refers to designing green spaces and roofs to suit the conditions of the environment and the architectural structure of GBs [39], as well as compensating for the lack of green spaces at the general level by increasing the per capita green spaces. A green roof can easily reduce heat through the roof and reduce energy for heating or cooling, which easily leads to large cost savings.

### 3.3.7. Storm Design SD (D<sub>3-7</sub>)

This indicator refers to how to use and deal with rainwater, either by storing or disposing of excess water in an effective manner without affecting GBs. Plants on green roofs use rain and often excess water is stored so that it can be used later without any problem. In addition, the roofs are designed so that the roof plants do not easily retain rainwater, so there is no chance of surface runoff which does not cause local flooding of rainwater.

### 3.3.8. Building User Manual BUM (D<sub>3-8</sub>)

This indicator shows that the user manual should be written for the public—those who will be using the GB services. The user manual is coordinated by experts and consultants for each service.

## 3.4. *Materials and Resources Dimension MRD (D<sub>4</sub>)*

This dimension indicates that GBs are built from natural, non-toxic, and recycled materials that do not cost much. Building materials include rapidly regenerating plant materials such as bamboo and straw, recycled metals or environmentally friendly concrete, wood from forests that have been certified as an outboard forest standard, and other non-toxic and reusable products [6,39]. The materials and resources dimension includes the following five indicators.

### 3.4.1. Reused and Recycled Materials RRM (D<sub>4-1</sub>)

This indicator refers to the extent to which recycled materials are relied on in GB construction. Recycling is the process of converting waste or used materials into new products. The recycling process reduces energy use, waste of potentially useful materials, water pollution, air pollution, and greenhouse gas emissions.

#### 3.4.2. Sustainable Resources SR (D<sub>4-2</sub>)

This indicator refers to the use of sustainable materials and products in the construction process of GBs such as sustainable wood, as well as if local non-imported materials are relied on. It is imperative to choose materials that produce little gas emissions during or after installation. In addition, it includes the necessity to use products with recycled components and to recycle construction waste, provided that these materials are recyclable and achieve the principles of sustainability.

#### 3.4.3. Construction Waste Management CWM (D<sub>4-3</sub>)

This indicator refers to how to deal with the harmful environmental impacts resulting from improper disposal of construction and demolition waste by developing integrated and sustainable plans and solutions for waste management to preserve natural resources, such as minerals and ores [17]. Implementing integrated management programs for construction and demolition waste for construction projects must be in accordance with energy and environmental standards and designs.

#### 3.4.4. Storage of Recyclable SR (D<sub>4-4</sub>)

This indicator refers to dealing with recyclable materials and how to store them and use them when needed. The isolation of the storage area away from buildings and other facilities is important. In addition, the storage area should be in a cool, dry, and well-ventilated area, and the storage buildings must be constructed of fireproof materials.

#### 3.4.5. Green Products GP (D<sub>4-5</sub>)

This indicator refers to the extent to which green products are being relied on in the construction of GBs. A green product should satisfy a basic human need without polluting the earth's resources [5,40].

### 3.5. Water Efficiency Dimension WED (D<sub>5</sub>)

The main goal of GBs is to reduce consumption and raise the efficiency of the resources used, such as raising water efficiency. In this regard, GBs are designed to recycle and reuse various kinds of water, such as rainwater and gray water. Water efficiency criterion includes the following four indicators.

#### 3.5.1. Rainwater Harvesting RH (D<sub>5-1</sub>)

This indicator refers to the interest in collecting rainwater in GBs areas. The water usually runs through the roofs of buildings and collects in rainwater tanks for later use. Rainwater harvesting, directly or indirectly, greatly reduces reliance on groundwater sources. The collected rainwater can also be a source of regeneration of aquifers that have been depleted as a result of the increase in population.

#### 3.5.2. Water Recycling WR (D<sub>5-2</sub>)

This indicator refers to the recycling of rainwater that has been collected in special rainwater tanks for the purpose of treatment and later use. This recycled water replenishes groundwater sources and is used in street cleaning and watering of playgrounds and landscapes. A challenge when treating recycled water is community acceptance, because a large proportion of the population does not accept the use of recycled water [18].

#### 3.5.3. Water Reduction WD (D<sub>5-3</sub>)

This indicator refers to the extent of concern for the efficiency of water resources and work to reduce consumption through techniques such as the use of smart faucets that reduce the flow of water. This also includes the need to adjust and calibrate the water network pressure to reduce the flow of water from the taps and work on maintaining water lines, updating measurement systems, and detecting leaks.

### 3.5.4. Irrigation/Landscaping IL (D<sub>5-4</sub>)

This indicator refers to the use of highly efficient irrigation systems and the cultivation of plants with low irrigation needs. Landscaping is based on a set of practices adapted to environmental issues, including design, implementation, and garden management [18].

## 4. Research Methodology

In this section, we present the research methodology for this paper as shown in Figure 3. A survey of previous studies and the majority of the publications and various building systems related to the manufacture of GBs was conducted to determine the most important indicators to take into account when constructing GBs. In addition, qualitative and quantitative measures and neutrosophic theory were merged to assess the dimensions and indicators of GBs in developing countries. Thirty-three indicators, divided into five main dimensions, were collected for use in GBs in developing countries, based on two questionnaires that were conducted in succession.

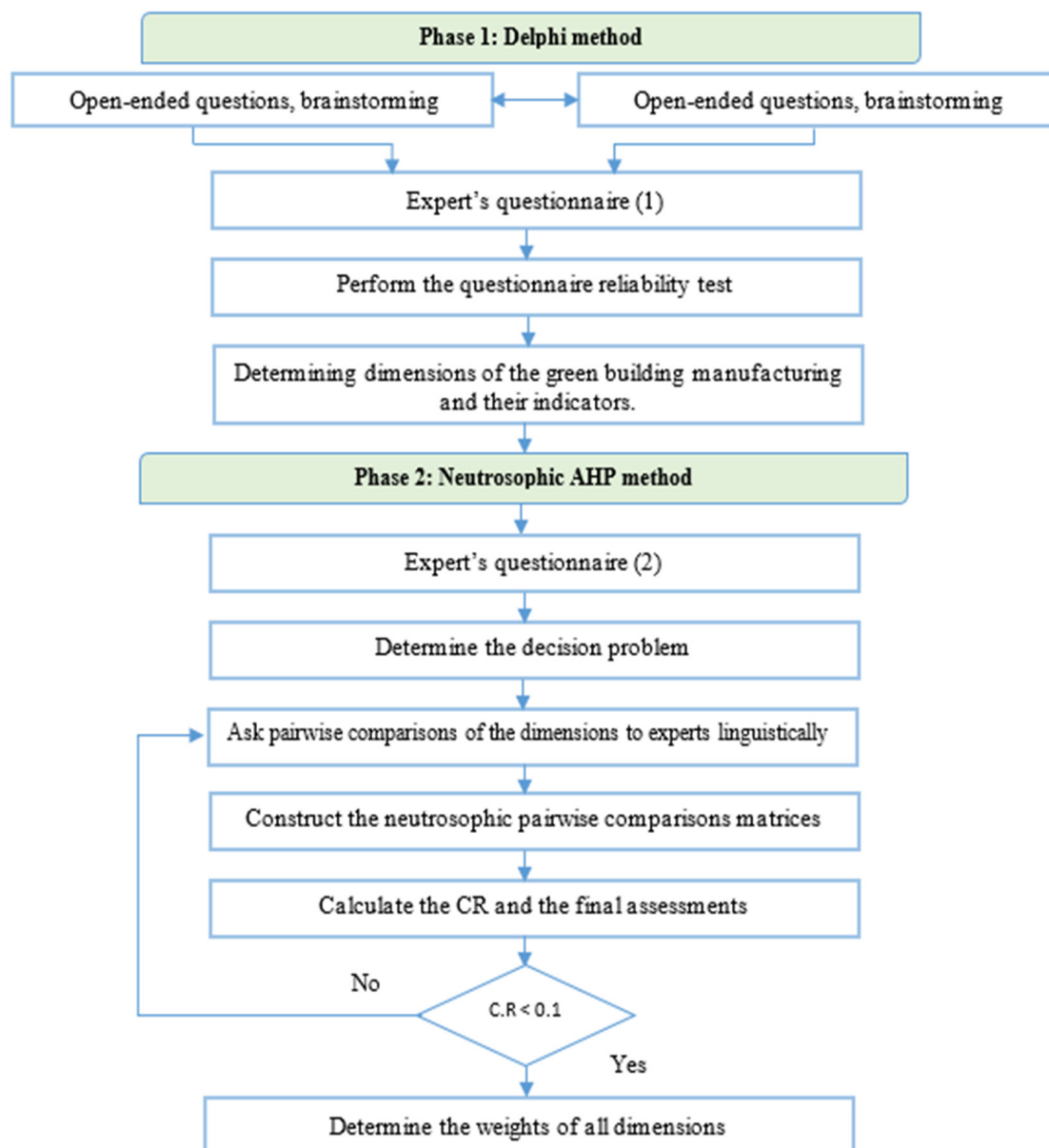


Figure 3. Summary of the research methodology.

The first questionnaire was used to determine the most important indicators and dimensions that are used in developing countries in the manufacture of GBs. The second questionnaire was conducted and distributed to the same experts involved in the field of green construction to express their opinions and assessments of these indicators and dimensions. The data required for a Delphi survey was collected using expert questionnaires, a very useful tool. It is preferable for the number of participating experts to be from 5 to 20 because the efficiency of the collective decision is affected by the size of the participating group. In this regard, Gumus showed that the size of the group participating in the questionnaire should be no less than five and no more than 50 individuals [41].

#### 4.1. Experts Selection

In this subsection, the experts participating in the questionnaires related to GB construction are identified as presented in Table 1. The participating experts were identified based on two conditions. First, they must have significant work experience in the field of green construction, and secondly, they must be aware of the new changes in the field of green construction and have a comprehensive knowledge of information system studies in the construction field. Forty experts were contacted to collect information, with 60% being experts in the field of GBs, and 40% being academics in the field of GBs, energy-saving, and consumption issues. All participating experts have experience of no less than seven years, whether in the field of GBs or academically.

**Table 1.** Characteristics of the participating experts.

Experts	Number of Experts	Education	Positional Titles	Employment Position	Working Year
Group <sub>1</sub>	3	Master's degree	Engineer	Project manager	>7
Group <sub>2</sub>	5	Master's degree	Engineer	Architect	>10
Group <sub>3</sub>	6	Master's degree	Engineer	General manager	>14
Group <sub>4</sub>	5	Master's degree	Senior engineer	Engineering technologists	>16
Group <sub>5</sub>	4	Master's degree	Senior engineer	Director of engineering	>14
Group <sub>6</sub>	4	Ph.D. Degree	Senior engineer	Sustainability program	>20
Group <sub>7</sub>	4	Ph.D. Degree	Senior engineer	Building environmental and environmental engineering	>18
Group <sub>8</sub>	4	Ph.D. Degree	Senior engineer	Energy assessments	>20
Group <sub>9</sub>	5	Ph.D. Degree	Senior engineer	Architect	>20

Finally, after completing the first questionnaire related to determining the indicators and dimensions on which to assess the construction of GBs, 40 questionnaires from the participating experts were collected and validated, and the data were converted into neutrosophic numbers based on the measures in Table 2.

**Table 2.** Linguistic and neutrosophic scales used for weighting dimensions and indicators.

Linguistic Terms	Abbreviation	Triangular Neutrosophic Number ( $(l, m, u); \alpha, \beta, \theta$ )
Highly Low Significance	(HLS)	$\langle (0.10, 0.29, 0.34); 0.10, 0.21, 0.16 \rangle$
Low Significance	(LS)	$\langle (0.26, 0.25, 0.25); 0.30, 0.15, 0.10 \rangle$
Simple Significance	(SS)	$\langle (0.39, 0.34, 0.49); 0.59, 0.11, 0.19 \rangle$
Intermediate Significance	(IS)	$\langle (0.50, 0.50, 0.50); 0.80, 0.10, 0.10 \rangle$
Primary Significance	(PS)	$\langle (0.65, 0.75, 0.80); 0.85, 0.25, 0.10 \rangle$
Highly Robust Significance	(HRS)	$\langle (0.80, 0.75, 0.80); 0.90, 0.20, 0.20 \rangle$
Extremely prioritized	(EP)	$\langle (0.95, 0.90, 0.95); 0.90, 0.10, 0.10 \rangle$

#### 4.2. Neutrosophic Delphi Method

We summarize steps of Delphi method:

Step 1: Determine the main dimensions related to the manufacture of GBs, which are divided into five dimensions: energy efficiency, indoor environmental quality, and sustainable site planning and management, materials and resources, and water efficiency.

Step 2: Defining and conducting questionnaires to identify indicators to be used in the construction of GBs in developing countries.

### 4.3. Neutrosophic AHP Method

The steps for the AHP method are summarized as follows:

Step 3: Construct the linguistic variables and the neutrosophic scales as in Table 2 based on triangular numbers which are used to evaluate dimensions and indicators of constructing GBs and determine their priorities.

Step 4: Construct the evaluation matrix  $A$  based on the data collected from questionnaires between dimensions of constructing GB by using the linguistic scale according to Equation (1) then, by neutrosophic scales as in Equation (2).

$$A = \begin{matrix} & D_1 & D_2 & \dots & D_i \\ \begin{matrix} D_1 \\ D_2 \\ \vdots \\ D_j \end{matrix} & \begin{bmatrix} - & a_{12} & \dots & a_{1i} \\ 1/a_{21} & - & \dots & a_{2i} \\ \dots & \dots & - & \dots \\ 1/a_{j1} & 1/a_{j2} & \dots & - \end{bmatrix} \end{matrix} \tag{1}$$

where  $a_{ij}$  is the performance rating of the element of the  $i^{th}$  criterion  $D_1, D_2, \dots, D_i$  regarding the  $j^{th}$  criterion  $D_1, D_2, \dots, D_j$ . Reciprocal values  $a_{ij}$  are applied at the upper diagonal in the comparison matrix. The lower diagonal is filled by  $1/a_{ij}$ . The element value related to the diagonal of the matrix is equal to 0.5 such that  $a_{ij} = 0.5$ .

$$A = \begin{bmatrix} - & \langle(l, m, u); \alpha, \theta, \beta_{12}\rangle & \dots & \langle(l, m, u); \alpha, \theta, \beta_{1i}\rangle \\ 1/\langle(l, m, u); \alpha, \theta, \beta_{21}\rangle & - & \dots & \langle(l, m, u); \alpha, \theta, \beta_{2i}\rangle \\ \dots & \dots & - & \dots \\ 1/\langle(l, m, u); \alpha, \theta, \beta_{j1}\rangle & 1/\langle(l, m, u); \alpha, \theta, \beta_{j2}\rangle & \dots & - \end{bmatrix} \tag{2}$$

where  $\langle(l, m, u); \alpha, \theta, \beta\rangle$  denote lower, median, and upper values of the scale neutrosophic numbers, respectively, and  $\alpha, \theta, \beta$  are the truth membership, indeterminacy membership, and falsity membership functions, respectively, of the triangular neutrosophic numbers.

Step 5: De-neutrosophication of the triangular neutrosophic numbers to real values according to Equation (3).

$$S(a) = 1/8 \times (l + m + u) \times (2 + \alpha - \theta - \beta) \tag{3}$$

Step 6: Based on the neutrosophic scale, the decision matrix is conducted, then the consistency ratio (CR) is calculated as in Equation (4) to evaluate the consistency of comparison.

$$CR = \frac{CI}{RI} \tag{4}$$

where  $CI = \frac{\lambda_{max} - n}{n - 1}$ ,  $\lambda_{max}$  is the mean of the weighted sum vector divided by the corresponding criterion, and  $n$  is the number of dimensions. RI is a random index assigned with the number of suggested dimensions being considered [26]. If CR has a maximum value of 0.1, then the level of consistency is adequate; otherwise, the comparison is inconsistent and decision maker is recommended to modify the comparison components to recognize superior consistency [42].

Step 7: Finally, determine the weights of all dimensions; likewise, indicators weights will be determined for each dimension of GB construction.

## 5. Calculation of Neutrosophic AHP Model

### 5.1. Application of the Suggested Framework

Step 1: Questionnaires on determining the dimensions and indicators of GB construction were conducted by 40 experts as in Table 1. Five main dimensions were identified: EED

(D<sub>1</sub>), IEQD (D<sub>2</sub>), SSPMD (D<sub>3</sub>), MRD (D<sub>4</sub>), and WED (D<sub>5</sub>). Eight indicators were identified for the EED: URE (D<sub>1-1</sub>), DLZ (D<sub>1-2</sub>), DES (D<sub>1-3</sub>), SM (D<sub>1-4</sub>), IEP (D<sub>1-5</sub>), EEV (D<sub>1-6</sub>), BI (D<sub>1-7</sub>), and HNL (D<sub>1-8</sub>). In addition, eight indicators were identified for the IEQD namely, CDC (D<sub>2-1</sub>), MP (D<sub>2-2</sub>), ICE (D<sub>2-3</sub>), DTCS (D<sub>2-4</sub>), ACE (D<sub>2-5</sub>), INL (D<sub>2-6</sub>), EV (D<sub>2-7</sub>), and IAQO (D<sub>2-8</sub>). In addition, eight indicators were identified for the SSPM: SSP (D<sub>3-1</sub>), CPC (D<sub>3-2</sub>), DDCC (D<sub>3-3</sub>), GV (D<sub>3-4</sub>), PTPTA (D<sub>3-5</sub>), GRD (D<sub>3-6</sub>), SD (D<sub>3-7</sub>), and BUM (D<sub>3-8</sub>). Five indicators were identified for the MRD: RRM (D<sub>4-1</sub>), SR (D<sub>4-2</sub>), CWM (D<sub>4-3</sub>), SR (D<sub>4-4</sub>), and GP (D<sub>4-5</sub>). Finally, four indicators were identified for the WED: RH (D<sub>5-1</sub>), WR (D<sub>5-2</sub>), WD (D<sub>5-3</sub>), and IL (D<sub>5-4</sub>).

Step 2: The linguistic scales and the triangular neutrosophic numbers were created to convert the data collected from experts using questionnaires into comparison matrixes between the dimensions and their indicators, as presented in Table 2.

Step 3: Construct the evaluation matrix using linguistic terms by applying Equation (1) as in Table 3. Then, convert to neutrosophic scales by applying Equation (2) as in Table 4.

Step 4: De-neutrosophication of the triangular neutrosophic numbers to real values by applying Equation (3).

Step 5: Calculate the CR according to Equation (4). Then, determine the weights of GBs dimensions as in Table 4 as shown in Figure 4.

Step 6: Similarly, indicators' weights are determined for each dimension of GB construction as in Table 5. EED indicators are weighed using linguistic terms as in Table A1 and by neutrosophic scales as in Table A2. Figure 5 presents the weights for the EED indicators. IEQD indicators are weighted using linguistic terms as in Table A3 and by neutrosophic scales as in Table A4. Figure 6 presents the weights for the IEQD indicators. SSPMD indicators are weighted using linguistic terms as in Table A5 and by neutrosophic scales as in Table A6. Figure 7 presents the weights for the SSPMD indicators. MRD indicators are weighted using linguistic terms as in Table A7 and by neutrosophic scales as in Table A8. Figure 8 presents the weights for the MRD indicators. Finally, WED indicators are weighted using linguistic terms as in Table A9 and by neutrosophic scales as in Table A10. Figure 9 presents the weights for the MRD indicators.

**Table 3.** Evaluation of main dimensions for GB construction using the linguistic scales.

Dimensions	EED (D <sub>1</sub> )	IEQD (D <sub>2</sub> )	SSPMD (D <sub>3</sub> )	MRD (D <sub>4</sub> )	WED (D <sub>5</sub> )
EED (D <sub>1</sub> )	-	HRS	PS	IS	HLS
IEQD (D <sub>2</sub> )	1/HRS	-	EP	LS	SS
SSPMD (D <sub>3</sub> )	1/PS	1/EP	-	IS	PS
MRD (D <sub>4</sub> )	1/IS	1/LS	1/IS	-	HRS
WED (D <sub>5</sub> )	1/HLS	1/SS	1/PS	1/HRS	-

**Table 4.** Evaluation of main dimensions for GB construction using neutrosophic scales.

Dimensions	EED (D <sub>1</sub> )	IEQD (D <sub>2</sub> )	SSPMD (D <sub>3</sub> )	MRD (D <sub>4</sub> )	WED (D <sub>5</sub> )
EED (D <sub>1</sub> )	-	$\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$	$\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	$\langle(0.10, 0.29, 0.34); 0.10, 0.21, 0.16\rangle$
IEQD (D <sub>2</sub> )	$1/\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$	-	$\langle(0.95, 0.90, 0.95); 0.90, 0.10, 0.10\rangle$	$\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$
SSPMD (D <sub>3</sub> )	$1/\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$1/\langle(0.95, 0.90, 0.95); 0.90, 0.10, 0.10\rangle$	-	$\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	$\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$
MRD (D <sub>4</sub> )	$1/\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	$1/\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$1/\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	-	$\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$
WED (D <sub>5</sub> )	$1/\langle(0.10, 0.29, 0.34); 0.10, 0.21, 0.16\rangle$	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$1/\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$1/\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$	-
Weights	0.10	0.12	0.15	0.30	0.33

**Table 5.** Final local and global weights of GB construction indicators.

Dimensions	EED (D <sub>1</sub> )								IEQD (D <sub>2</sub> )								
Weight	0.10								0.12								
Indicators	D <sub>1-1</sub>	D <sub>1-2</sub>	D <sub>1-3</sub>	D <sub>1-4</sub>	D <sub>1-5</sub>	D <sub>1-6</sub>	D <sub>1-7</sub>	D <sub>1-8</sub>	D <sub>2-1</sub>	D <sub>2-2</sub>	D <sub>2-3</sub>	D <sub>2-4</sub>	D <sub>2-5</sub>	D <sub>2-6</sub>	D <sub>2-7</sub>	D <sub>2-8</sub>	
Local weights	0.037	0.082	0.084	0.122	0.179	0.178	0.114	0.204	0.045	0.065	0.089	0.134	0.184	0.155	0.128	0.200	
Global weights	0.003	0.008	0.008	0.012	0.017	0.017	0.011	0.020	0.005	0.007	0.010	0.016	0.022	0.018	0.015	0.024	
Rank	33	29	28	23	19	20	26	15	31	30	27	21	14	18	21	11	
Dimensions	SSPMD (D <sub>3</sub> )								MRD (D <sub>4</sub> )				WED (D <sub>5</sub> )				
Weight	0.15								0.30				0.33				
Indicators	D <sub>3-1</sub>	D <sub>3-2</sub>	D <sub>3-3</sub>	D <sub>3-4</sub>	D <sub>3-5</sub>	D <sub>3-6</sub>	D <sub>3-7</sub>	D <sub>3-8</sub>	D <sub>4-1</sub>	D <sub>4-2</sub>	D <sub>4-3</sub>	D <sub>4-4</sub>	D <sub>4-5</sub>	D <sub>5-1</sub>	D <sub>5-2</sub>	D <sub>5-3</sub>	D <sub>5-4</sub>
Local weights	0.038	0.082	0.080	0.129	0.156	0.178	0.139	0.198	0.069	0.149	0.228	0.194	0.360	0.086	0.092	0.351	0.471
Global weights	0.005	0.012	0.012	0.019	0.023	0.026	0.021	0.030	0.020	0.044	0.068	0.058	0.108	0.028	0.030	0.115	0.155
Rank	32	24	25	17	13	10	12	7	16	6	4	5	3	9	8	2	1

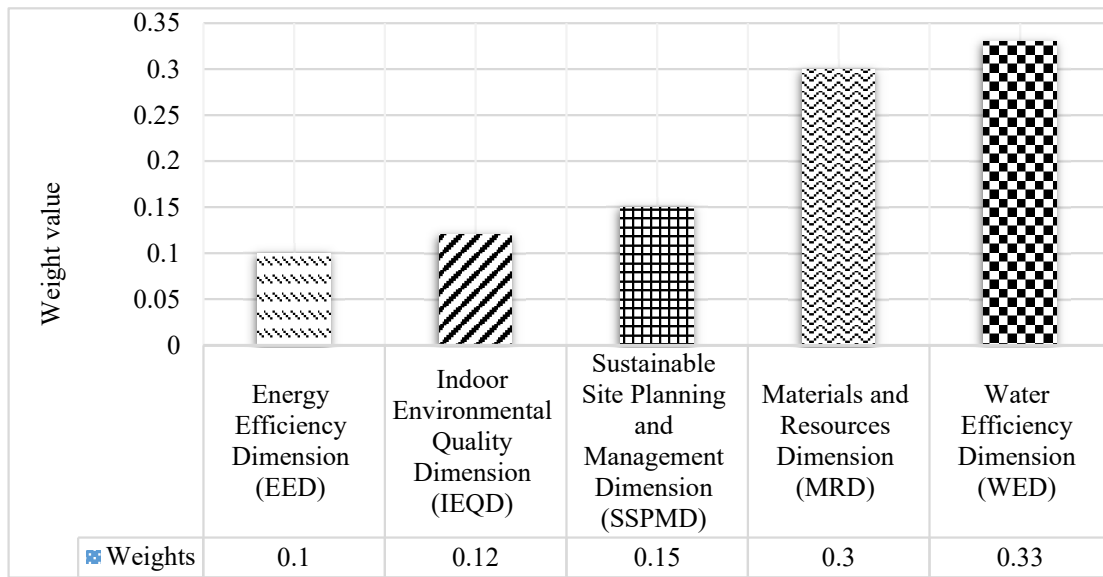


Figure 4. Weights of GB dimensions.

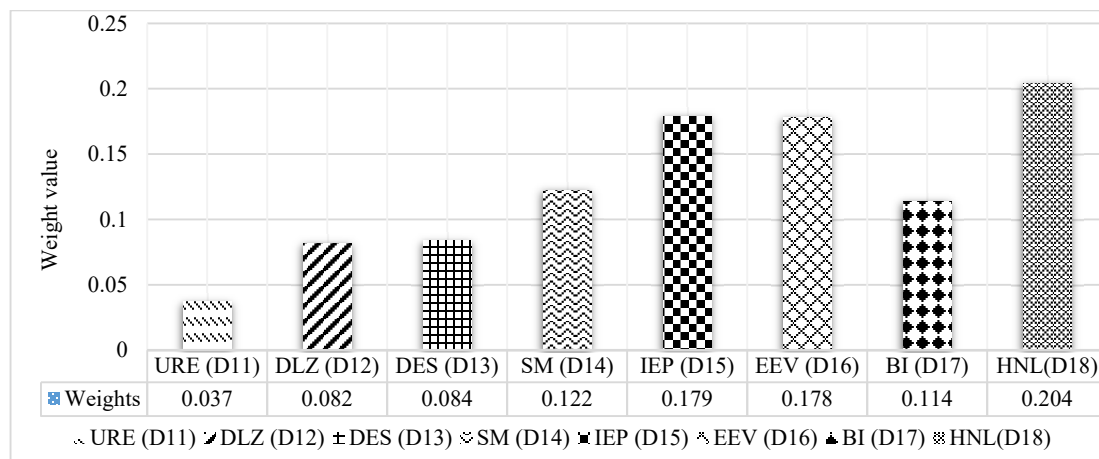


Figure 5. Final weights of EED indicators.

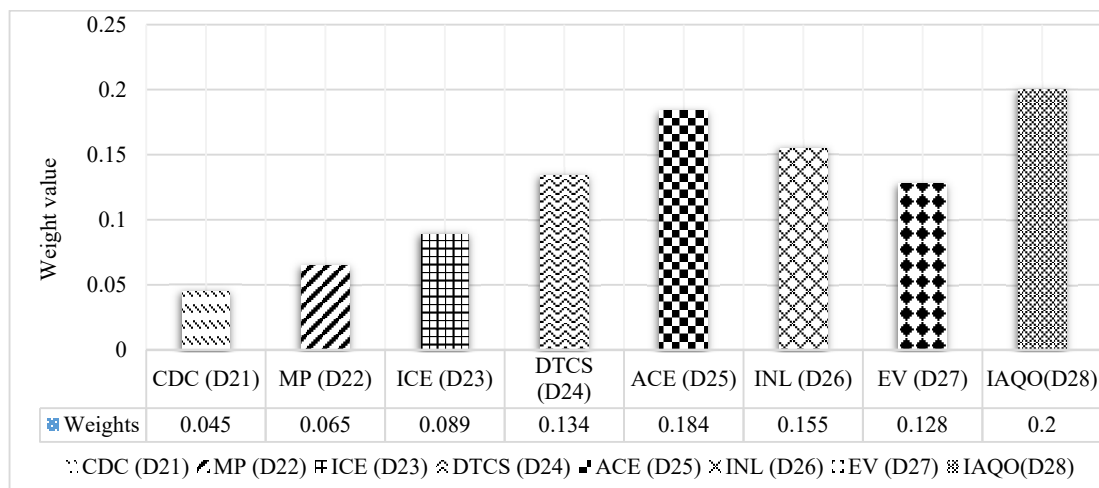


Figure 6. Final weights of IEQD indicators.



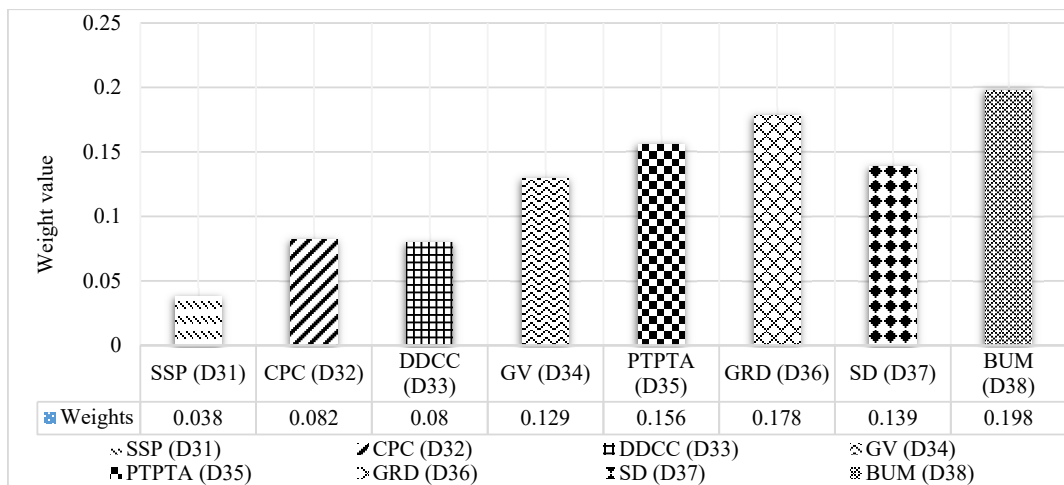


Figure 7. Final weights of SSPMD indicators.

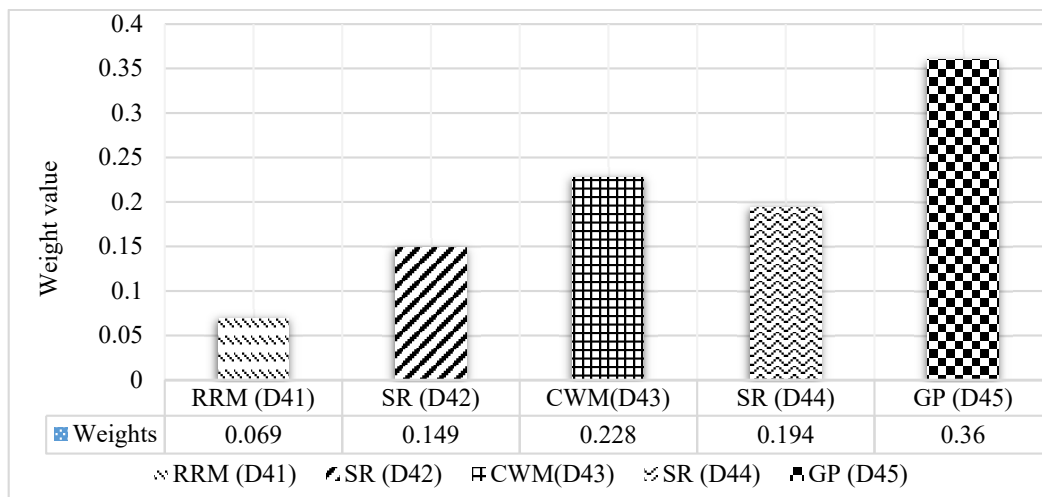


Figure 8. Final weights of MRD indicators.

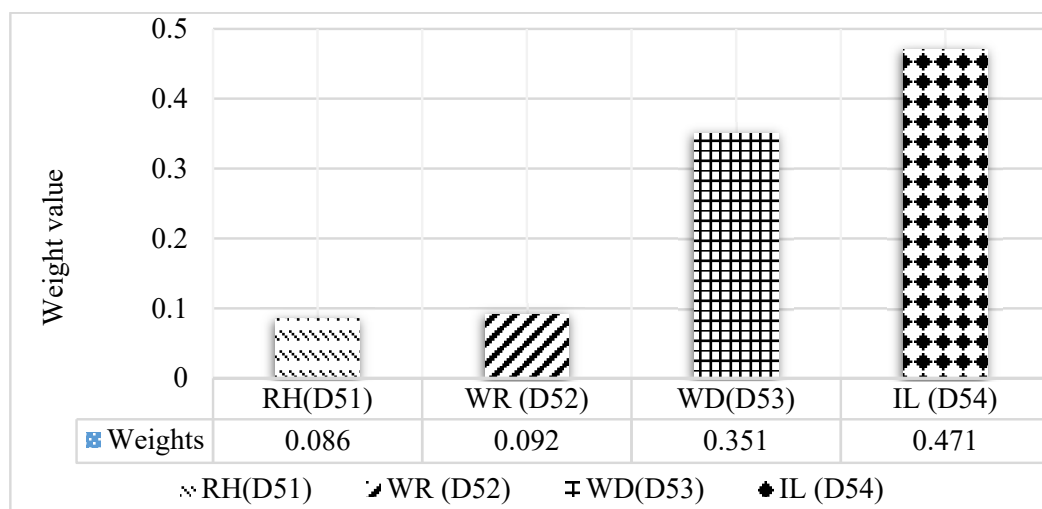


Figure 9. Final weights of WED indicators.

## 5.2. Results Analysis

In this section, we explain the results obtained from the proposed model to assess the dimensions and indicators of GB construction and to determine the weights of indicators for each dimension using the AHP method.

The weights of the five main dimensions are determined as Table 4 and Figure 4. WED has the highest importance in the GB construction in developing countries with weight 0.33, followed by MRD with a weight of 0.30. On the other hand, EED is the least important with weight 0.10, followed by the IEQD with weight 0.12.

Table A2 shows the weights of the EED indicators. The HNL ( $D_{1-8}$ ) indicator has the highest rating, followed by the IEP ( $D_{1-5}$ ) indicator. The URE ( $D_{1-1}$ ) indicator is the lowest ranked, followed by the DLZ ( $D_{1-2}$ ) indicator.

Table A4 shows the weights of the IEQD indicators. The IAQO ( $D_{2-8}$ ) indicator has the highest rank, followed by the ACE ( $D_{2-5}$ ) indicator. The CDC ( $D_{2-1}$ ) indicator is the lowest ranked, followed by the MP ( $D_{2-2}$ ) indicator.

Table A6 presents the weights of the SSPMD indicators. The BUM ( $D_{3-8}$ ) indicator has the highest importance, followed by the GRD ( $D_{3-6}$ ) indicator. The SSP ( $D_{3-1}$ ) indicator has the lowest importance, followed by the DDCC ( $D_{3-3}$ ) indicator.

In addition, Table A8 indicates the weights of the IEQD indicators. The GP ( $D_{4-5}$ ) indicator has the top rank, followed by the SR ( $D_{4-4}$ ) indicator. The RRM ( $D_{4-1}$ ) indicator has the lowest performance, followed by the SR ( $D_{4-2}$ ) indicator.

Finally, Table A10 shows the weights of the WED indicators. The IL ( $D_{5-4}$ ) indicator has the highest importance, followed by the WD ( $D_{5-3}$ ) indicator. The RH ( $D_{5-1}$ ) indicator has the lowest importance, followed by the WR ( $D_{5-2}$ ) indicator.

## 6. Managerial Implications

The concept of GBs raised several challenges that place pressure on many of current practices in the design and implementation of buildings and urban projects. A fundamental cultural change is required for architects and engineers to embrace the principles on which the concept of sustainable urban development is based. We list some administrative impacts to assess the dimensions and indicators of GB construction as follows:

- The proposed neutrosophic–AHP approach is applied based on the information gathered using the Delphi method to analyze the dimensions and indicators of GB construction that benefit architects, engineers, environmentalists, and stakeholders.
- The developed framework helps stakeholders and specialists to study the concepts of sustainable development related to GBs and to become acquainted with the points of view, mechanisms and pillars, methodological dimensions, principles, and goals and indicators of sustainable development before starting the work of the various designs.
- The approach helps identify the concepts of global sustainability in architecture while linking it with the concepts of local architecture, in order to produce an architecture that originates from the environment in which it is built and is not alien to it, aiding user acceptance.
- The proposed approach deals with identifying the main dimensions of GB construction in developing countries and their indicators through questionnaires that were conducted with 40 experts in various fields related to the field of sustainable GB construction. Five main dimensions and 33 indicators have been identified, covering all aspects of GB construction.
- The proposed approach tackled the problem of individual decisions by using collective decisions and collecting the necessary data through questionnaires that were divided into two parts, the first part is to define the indicators and dimensions for GB construction, and the second part is to collect the opinions of experts and their evaluations of the indicators and dimensions to classify and arrange them according to importance.
- The proposed approach provides the possibility of reflecting on the ambiguity in expert views and the linguistic imprecision of the problem of GB construction in

- developing countries under the neutrosophic environment, as well as describing a high degree of uncertainty in the process of generating evaluations and opinions.
- Defining the most important dimensions and indicators that must be taken into account when constructing GBs to achieve the main goal that the whole world is striving for, which is to achieve sustainable development with a balance between environmental, social, and economic development.

## 7. Summary and Conclusions

In this study, we determine the dimensions and indicators of GB construction for sustainable buildings in developing countries based on existing GBRs including LEED, BREEAM, SBTool, and CASBEE. In addition, the opinions and suggestions of 40 experts in the field of sustainable building were collected and organized through questionnaires conducted by the Delphi method. Consequently, five main dimensions and 33 sub-indicators were chosen for GB sustainability in developing countries. A MCDM model based on the AHP method has been proposed under the neutrosophic environment to classify and evaluate dimensions and indicators of GB construction in developing countries. The WED is shown to be the most important dimension, while the EED is the least important dimension in developing countries. In this regard, the EED includes eight sub-indicators where HNL has the highest rating, followed by the IEP indicator while the DLZ is the lowest ranked. Moreover, the IEQD includes eight sub-indicators where the IAQO indicator has the highest rank while the CDC indicator has the lowest rank. In addition, the SSPMD includes eight sub-indicators where the BUM indicator has the highest importance while the SSP indicator has the lowest importance. The MRD includes five sub-indicators where the GP indicator has the top rank while the PRM has the lowest rank. Finally, the WED includes four sub-indicators where the IL indicator has the highest importance, while the RH has the lowest importance.

In the future, similar studies can be applied based on various types of industries such as automotive and electronics. Moreover, this study can be extended by considering a larger number of dimensions and indicators and statistically validating the results.

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**Conflicts of Interest:** The authors declare that there is no conflict of interest about the research.

## Appendix A

The detailed tables for the AHP method for calculating weights of GB manufacturing indicators.

**Table A1.** Evaluation of EED indicators for GB manufacturing using neutrosophic scales.

Indicators	URE (D <sub>1-1</sub> )	DLZ (D <sub>1-2</sub> )	DES (D <sub>1-3</sub> )	SM (D <sub>1-4</sub> )	IEP (D <sub>1-5</sub> )	EEV (D <sub>1-6</sub> )	BI (D <sub>1-7</sub> )	HNL (D <sub>1-8</sub> )
URE (D <sub>1-1</sub> )	-	LS	HLS	SS	LS	PS	IS	LS
DLZ (D <sub>1-2</sub> )	1/LS	-	IS	PS	HLS	LS	HRS	EP
DES (D <sub>1-3</sub> )	1/HLS	1/IS	-	HLS	SS	LS	PS	IS
SM (D <sub>1-4</sub> )	1/SS	1/PS	1/HLS	-	IS	SS	HRS	HRS
IEP (D <sub>1-5</sub> )	1/LS	1/HLS	1/SS	1/IS	-	HRS	EP	EP
EEV (D <sub>1-6</sub> )	1/PS	1/LS	1/LS	1/SS	1/HRS	-	EP	HLS
BI (D <sub>1-7</sub> )	1/IS	1/HRS	1/PS	1/HRS	1/EP	1/EP	-	PS
HNL (D <sub>1-8</sub> )	1/LS	1/EP	1/IS	1/HRS	1/EP	1/HLS	1/PS	-

**Table A2.** Evaluation of EED indicators for GB manufacturing using neutrosophic scales.

Indicators	URE (D <sub>1-1</sub> )	DLZ (D <sub>1-2</sub> )	DES (D <sub>1-3</sub> )	SM (D <sub>1-4</sub> )
URE (D <sub>1-1</sub> )	-	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$
DLZ (D <sub>1-2</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	-	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$
DES (D <sub>1-3</sub> )	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	-	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$
SM (D <sub>1-4</sub> )	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	-
IEP (D <sub>1-5</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$
EEV (D <sub>1-6</sub> )	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$
BI (D <sub>1-7</sub> )	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$
HNL (D <sub>1-8</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$
Weights	0.037	0.082	0.084	0.122

Indicators	IEP (D <sub>1-5</sub> )	EEV (D <sub>1-6</sub> )	BI (D <sub>1-7</sub> )	HNL (D <sub>1-8</sub> )
URE (D <sub>1-1</sub> )	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$
DLZ (D <sub>1-2</sub> )	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$
DES (D <sub>1-3</sub> )	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10\rangle$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$
SM (D <sub>1-4</sub> )	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10\rangle$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19\rangle$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$
IEP (D <sub>1-5</sub> )	-	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$
EEV (D <sub>1-6</sub> )	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20\rangle$	-	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$
BI (D <sub>1-7</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	-	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$
HNL (D <sub>1-8</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10\rangle$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16\rangle$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10\rangle$	-
Weights	0.179	0.178	0.114	0.204

**Table A3.** Evaluation of IEQD indicators for GB manufacturing using neutrosophic scales.

Indicators	CDC (D <sub>2-1</sub> )	MP (D <sub>2-2</sub> )	ICE (D <sub>2-3</sub> )	DTCS (D <sub>2-4</sub> )	ACE (D <sub>2-5</sub> )	INL (D <sub>2-6</sub> )	EV (D <sub>2-7</sub> )	IAQO (D <sub>2-8</sub> )
CDC (D <sub>2-1</sub> )	-	IS	HLS	SS	LS	PS	IS	LS
MP (D <sub>2-2</sub> )	1/IS	-	IS	IS	HLS	LS	HRS	HRS
ICE (D <sub>2-3</sub> )	1/HLS	1/IS	-	HLS	SS	HRS	SS	IS
DTCS (D <sub>2-4</sub> )	1/SS	1/IS	1/HLS	-	IS	SS	HRS	HRS
ACE (D <sub>2-5</sub> )	1/LS	1/HLS	1/SS	1/IS	-	HRS	EP	EP
INL (D <sub>2-6</sub> )	1/PS	1/LS	1/HRS	1/SS	1/HRS	-	EP	LS
EV (D <sub>2-7</sub> )	1/IS	1/HRS	1/SS	1/HRS	1/EP	1/EP	-	PS
IAQO (D <sub>2-8</sub> )	1/LS	1/HRS	1/IS	1/HRS	1/EP	1/LS	1/PS	-

**Table A4.** Evaluation of IEQD indicators for GB manufacturing using neutrosophic scales.

Indicators	CDC (D <sub>2-1</sub> )	MP (D <sub>2-2</sub> )	ICE (D <sub>2-3</sub> )	DTCS (D <sub>2-4</sub> )
CDC (D <sub>2-1</sub> )	-	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$
MP (D <sub>2-2</sub> )	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	-	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$
ICE (D <sub>2-3</sub> )	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	-	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
DTCS (D <sub>2-4</sub> )	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	-
ACE (D <sub>2-5</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$
INL (D <sub>2-6</sub> )	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$
EV (D <sub>2-7</sub> )	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
IAQO (D <sub>2-8</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
Weights	0.045	0.065	0.089	0.134

Indicators	ACE (D <sub>2-5</sub> )	INL (D <sub>2-6</sub> )	EV (D <sub>2-7</sub> )	IAQO (D <sub>2-8</sub> )
CDC (D <sub>2-1</sub> )	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$
MP (D <sub>2-2</sub> )	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
ICE (D <sub>2-3</sub> )	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$
DTCS (D <sub>2-4</sub> )	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
ACE (D <sub>2-5</sub> )	-	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$
INL (D <sub>2-6</sub> )	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	-	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$
EV (D <sub>2-7</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	-	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$
IAQO (D <sub>2-8</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	-
Weights	0.184	0.155	0.128	0.200

**Table A5.** Evaluation of SSPMD indicators for GB manufacturing using neutrosophic scales.

Indicators	SSP (D <sub>3-1</sub> )	CPC (D <sub>3-2</sub> )	DDCC (D <sub>3-3</sub> )	GV (D <sub>3-4</sub> )	PTPTA (D <sub>3-5</sub> )	GRD (D <sub>3-6</sub> )	SD (D <sub>3-7</sub> )	BUM (D <sub>3-8</sub> )
SSP (D <sub>3-1</sub> )	-	HLS	HLS	SS	LS	PS	IS	HLS
CPC (D <sub>3-2</sub> )	1/HLS	-	IS	HLS	HLS	LS	HRS	EP
DDCC (D <sub>3-3</sub> )	1/HLS	1/IS	-	HLS	SS	LS	PS	IS
GV (D <sub>3-4</sub> )	1/SS	1/HLS	1/HLS	-	IS	HLS	HLS	HRS
PTPTA (D <sub>3-5</sub> )	1/LS	1/HLS	1/SS	1/IS	-	HRS	EP	EP
GRD (D <sub>3-6</sub> )	1/PS	1/LS	1/LS	1/HLS	1/HRS	-	EP	HLS
SD (D <sub>3-7</sub> )	1/IS	1/HRS	1/PS	1/HLS	1/EP	1/EP	-	PS
BUM (D <sub>3-8</sub> )	1/HLS	1/EP	1/IS	1/HRS	1/EP	1/HLS	1/PS	-

**Table A6.** Evaluation of SSPMD indicators for GB manufacturing using neutrosophic scales.

Indicators	SSP (D <sub>3-1</sub> )	CPC (D <sub>3-2</sub> )	DDCC (D <sub>3-3</sub> )	GV (D <sub>3-4</sub> )
SSP (D <sub>3-1</sub> )	-	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$
CPC (D <sub>3-2</sub> )	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	-	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
DDCC (D <sub>3-3</sub> )	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	-	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
GV (D <sub>3-4</sub> )	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	-
PTPTA (D <sub>3-5</sub> )	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$
GRD (D <sub>3-6</sub> )	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
SD (D <sub>3-7</sub> )	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
BUM (D <sub>3-8</sub> )	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$1/\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
Weights	0.038	0.082	0.080	0.129
Indicators	PTPTA (D <sub>3-5</sub> )	GRD (D <sub>3-6</sub> )	SD (D <sub>3-7</sub> )	BUM (D <sub>3-8</sub> )
SSP (D <sub>3-1</sub> )	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
CPC (D <sub>3-2</sub> )	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$
DDCC (D <sub>3-3</sub> )	$\langle\langle 0.39, 0.34, 0.49 \rangle\rangle; 0.59, 0.11, 0.19$	$\langle\langle 0.26, 0.25, 0.25 \rangle\rangle; 0.30, 0.15, 0.10$	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$
GV (D <sub>3-4</sub> )	$\langle\langle 0.50, 0.50, 0.50 \rangle\rangle; 0.80, 0.10, 0.10$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$
PTPTA (D <sub>3-5</sub> )	-	$\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$
GRD (D <sub>3-6</sub> )	$1/\langle\langle 0.80, 0.75, 0.80 \rangle\rangle; 0.90, 0.20, 0.20$	-	$\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$
SD (D <sub>3-7</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	-	$\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$
BUM (D <sub>3-8</sub> )	$1/\langle\langle 0.95, 0.90, 0.95 \rangle\rangle; 0.90, 0.10, 0.10$	$1/\langle\langle 0.10, 0.29, 0.34 \rangle\rangle; 0.10, 0.21, 0.16$	$1/\langle\langle 0.65, 0.75, 0.80 \rangle\rangle; 0.85, 0.25, 0.10$	-
Weights	0.156	0.178	0.139	0.198

**Table A7.** Evaluation of MRD indicators for GB manufacturing using neutrosophic scales.

Indicators	RRM (D <sub>4-1</sub> )	SR (D <sub>4-2</sub> )	CWM (D <sub>4-3</sub> )	SR (D <sub>4-4</sub> )	GP (D <sub>4-5</sub> )
RRM (D <sub>4-1</sub> )	-	PS	LS	SS	LS
SR (D <sub>4-2</sub> )	1/PS	-	IS	PS	HRS
CWM (D <sub>4-3</sub> )	1/LS	1/IS	-	EP	SS
SR (D <sub>4-4</sub> )	1/SS	1/PS	1/EP	-	IS
GP (D <sub>4-5</sub> )	1/LS	1/HRS	1/SS	1/IS	-

**Table A8.** Evaluation of MRD indicators for GB manufacturing using neutrosophic scales.

Indicators	RRM (D <sub>4-1</sub> )	SR (D <sub>4-2</sub> )	CWM (D <sub>4-3</sub> )	SR (D <sub>4-4</sub> )	GP (D <sub>4-5</sub> )
RRM (D <sub>4-1</sub> )	-	$\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$
SR (D <sub>4-2</sub> )	$1/\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	-	$\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	$\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$
CWM (D <sub>4-3</sub> )	$1/\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$1/\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	-	$\langle(0.95, 0.90, 0.95); 0.90, 0.10, 0.10\rangle$	$\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$
SR (D <sub>4-4</sub> )	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$1/\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$1/\langle(0.95, 0.90, 0.95); 0.90, 0.10, 0.10\rangle$	-	$\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$
GP (D <sub>4-5</sub> )	$1/\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$1/\langle(0.80, 0.75, 0.80); 0.90, 0.20, 0.20\rangle$	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$1/\langle(0.50, 0.50, 0.50); 0.80, 0.10, 0.10\rangle$	-
Weights	0.069	0.149	0.228	0.194	0.360

**Table A9.** Evaluation of WED indicators for GB manufacturing using neutrosophic scales.

Indicators	RH (D <sub>5-1</sub> )	WR (D <sub>5-2</sub> )	WD (D <sub>5-3</sub> )	IL (D <sub>5-4</sub> )
RH (D <sub>5-1</sub> )	-	PS	LS	SS
WR (D <sub>5-2</sub> )	1/PS	-	SS	HLS
WD (D <sub>5-3</sub> )	1/LS	1/SS	-	EP
IL (D <sub>5-4</sub> )	1/SS	1/HLS	1/SS	-

**Table A10.** Evaluation of WED indicators for GB manufacturing using neutrosophic scales.

Indicators	RH (D <sub>5-1</sub> )	WR (D <sub>5-2</sub> )	WD (D <sub>5-3</sub> )	IL (D <sub>5-4</sub> )
RH (D <sub>5-1</sub> )	-	$\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	$\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$
WR (D <sub>5-2</sub> )	$1/\langle(0.65, 0.75, 0.80); 0.85, 0.25, 0.10\rangle$	-	$\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$\langle(0.10, 0.29, 0.34); 0.10, 0.21, 0.16\rangle$
WD (D <sub>5-3</sub> )	$1/\langle(0.26, 0.25, 0.25); 0.30, 0.15, 0.10\rangle$	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	-	$\langle(0.95, 0.90, 0.95); 0.90, 0.10, 0.10\rangle$
IL (D <sub>5-4</sub> )	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	$1/\langle(0.10, 0.29, 0.34); 0.10, 0.21, 0.16\rangle$	$1/\langle(0.39, 0.34, 0.49); 0.59, 0.11, 0.19\rangle$	-
Weights	0.086	0.092	0.351	0.471

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