A Knowledge-based System to Estimate the Level of Efficiency of Green Buildings

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Abstract:

Sustainability has become an important initiative and has been discussed not only by green buildings but also by public buildings that are residential, office, commercial, as well as a hospital. Construction can withstand the design, construction, execution, maintenance, and removal of buildings in ways that conserve natural resources and reduce pollution. Ranking systems provide an efficient framework for assessing the environmental performance of a building and measure the tolerability of a building by applying a set of criteria organized in different classifications. A good green building rating system (GBRS) should cover key indicators that reflect building characteristics and keep their performance in balance. This paper presents a knowledge-based expert system as a tool to assess the performance level of a green building based on the evaluation factors of green building rating systems. Analytic hierarchical processing (AHP) and fuzzy logic have been adopted to develop a knowledge-based expert system. Data for this study were collected from experts in this field through Likert-based questionnaires in pairs. Using AHP, the most important parameters of ranking systems are selected according to their weights, to participate in the fuzzy inference system (FIS) of the fuzzy logic model. Fuzzy rules (knowledge) have been discovered from data collected for the FIS, to assess the level of performance of green buildings from the environmental, social, and economic aspects shown as SE2. The output of this study is a performance appraisal tool that analyzes the effect of factors on the development of a sustainable building.

Keywords: AHP; fuzzy inference system; fuzzy law; green building; ranking system

1. Introduction

Sustainability initiatives are considered in the construction of new buildings, the implementation, and reconstruction of existing buildings, and today it is clear that they have an important impact on the construction industry. As one of the key outputs of the construction industry, buildings extensively reflect their resources and the effects of their wastage over their life cycle. Construction activities are generally recognized as resource consumers, and the effects of natural resource consumption and pollution are reflected [1-3].

In general, sustainability is the ability of a system to continue on an uncertain basis that creates economic, social, and environmental problems [4]. The concept emphasizes the integration of humans into nature and requires that human activity remains within boundaries to avoid affecting ecological systems [36]. Achieving a low carbon economy through building consumption is essential because it is responsible for approximately 40% of CO2 (carbon dioxide) radiation in the UK and across Europe (EU), so Policies to overcome energy consumption through design and development are a priority [5-9].

Awareness and importance of maintaining and maintaining sustainable developments within the planning and engineering sector have led to the consideration of new innovative methods to include sustainability in their designs [10, 11]. The term "green" building defines the environmentally friendly techniques and technologies used in the design and construction of the construction environment [12-16]. The green building revolution has spread not only in the United States but in most parts of the world. This revolution is further driven by the knowledge that the world has little time to respond to the growing dangers of climate change, particularly global warming, and that buildings play a very large role in carbon dioxide emissions. Which changes the global climate, play, has grown [17]. To be responsive to sustainable development, green building technology must be applied not only to private buildings, but also to public buildings, including residential, commercial, office, and hospital buildings. Become the flagship of sustainable development in this century. Its purpose is to take responsibility for balancing long-term economic, environmental, and social health [18,19].

Evaluating the efficiency of green buildings is a vital task because different ranking systems emphasize different aspects of building efficiency and have become an interesting topic these days [20-25]. Due to the fact that human beings strive to increase financial comfort and dependence, the economic effects and quality of life are disrupted. At the same time, there are neutral health effects that must be protected from damage due to the increasing number of environmental disasters caused by climate change [26]. Once the indoor environment, in the principle of utility benefits, is related to the provision of high-quality indoor environments, durable building design will become a more common practice [24]. For example, research on the environmentally friendly design and management of systems is done on the life cycle of buildings [27-30]. In addition, there are various methods for evaluating the performance of buildings. Many of these methods emphasize the effect of buildings on the global environment and personal hygiene and focus on energy consumption, indoor climatic conditions, and other environmental issues [18].

MCDM or MCDA are well-known abbreviations for multi-criteria decision making and multi-criteria decision analysis. MCDM focuses on structuring and solving decision-making and planning problems by involving several criteria [40]. It is useful for solving many real-world problems [30-35,64,60,28]. Zadeh [74] introduced the concept of fuzzy sets to enable a precise analysis to examine implicit and subjective concepts and to examine linguistic variables in the various evaluation and decision-making programs. Fuzzy MCDM (FMCDM) problems [26,65,41,39,12,10], among which the ratings and weights of the criteria are evaluated on uncertainty, ambiguity, and ambiguity, are usually expressed by language And then set to fuzzy numbers.

A study by Lu et al. [39] that integrates complex human activities and social contexts into a new product development process (NDP) to adapt its design to different competitive markets. FMCDM) is shown in the context-based product evaluation. Their method combines MCDM with group decision-making (GDM) methods and provides hierarchical operators to combine data from human and machine evaluators.

We also considered the advantages of MCDM and the fuzzy set theory and developed an evaluation tool for the performance of green buildings. In our proposed method, the Analytic Hierarchy Process (AHP) is used for group decision making and ranking of performance evaluation criteria, and the fuzzy inference system is used to evaluate the final performance of green buildings. Hence, compared to the research efforts found in the articles, our work has the following differences. In this study:

1. Using AHP, performance evaluation criteria for green buildings are ranked and weighted in terms of SE2.

2. Using fuzzy set theory, an expert system based on new knowledge is presented to evaluate the level of efficiency of green buildings from environmental, social, and economic aspects.

1.1. Benefits of green buildings

The implementation and use of green buildings achieve three advantages, which are the benefits of SE2 [70]. Environmental benefits include increased biodiversity and ecosystems; Improving air and water quality, Reduce current loss; Preservation and restoration of natural resources; And minimize global warming.

While the second, economic benefits, in reducing implementation and maintenance costs; Creating green products and services, expanding them and shaping markets; Improving the utility and interest of the resident; To cover the absence of a resident of the house; Life cycle efficiency optimization; Improving the building facade; And reduce the cost of urban infrastructure.

On the other hand, social benefits, reduction in implementation and maintenance costs; Creating green products and services, expanding them and shaping markets; Improving the utility and interest of the resident; Minimize absenteeism; Life cycle economic efficiency optimization; Improving the building facade; And offer a reduction in urban infrastructure costs.

In a green building, energy efficiency is used to describe the fulfillment of several criteria to be met. This includes the use of energy-efficient equipment, and the durability of the case in different weather conditions, and the services and adaptations provided must complement the consumption of the building, and the building must consume less energy than similar buildings. Besides, another important aspect to consider is the energy involved in building construction and demolition [47]. Many countries have been introduced to reduce construction energy to improve energy efficiency in the construction sector.

Since sustainable development with social, environmental, and economic (SE2) principles has been strengthened to respond to carbon footprint measurements, many ranking systems have been developed to assess the "greenness" of green buildings. And many are thinking about measuring their true efficiency, that is, "the efficiency of the buildings we consider green." For example, many countries have developed their ranking systems, either by setting their parameters or by changing the ranking tools developed in other countries. Green building rating systems (GBRS) are one such system that measures the durability of a building by using a set of criteria organized in different categories [11]. In this GBRS, metrics perform various functions in measuring sustainable development responsiveness. GBRS can support the decision-making process and increase the efficiency of operations by simplifying, clarifying, and gathering available information.

1.2. Problem statement

Assessing the performance of green buildings in the post-residential phase is the most effective way to ensure that a building has achieved success in its design. Whereas a green building approach must consider three main criteria, which are social, economic, and environmental (SE2) criteria; Evaluation tools for measuring performance must necessarily consider these criteria [11]. Throughout the phases of the building life cycle, environmentally friendly (environmentally friendly) construction environments must be associated with safety, security, health, convenience, reasonable cost, and long-term adaptability. Meeting these criteria achieves the optimal combination of SE2 values for hard drives [14,15,32,66]. A wide range of criteria has been developed to evaluate building performance; However, there is a lack of general agreement on which factors have the most advantages in this area.

GBRS helps assess the performance of building metrics that affect the community, such as energy, waste generation, and indoor air quality, to improve efficiency. It is used as a tool to track performance and provide guidance to building owners and developers to help make a building more durable. Based on information obtained from the Intergovernmental Panel on Climate Change (IPCC), significant environmental and economic reactions will occur if the construction-implementation approach remains the status quo [6,11]. GBRS provides a way to continuously update functions and processes to ensure continuous improvement and initiative [6,11].

GBRS measures the durability of a building using a set of metrics, organized into different categories, and categorized factors, to perform factor-aware performance assessments of buildings. Existing models developed in previous studies [46] adopt fewer methods for ranking systems because there is a lack of quantitative evaluation of user interaction with green buildings. In general, research on green building rating systems can be divided into two main areas: (1) identifying criteria for the development of rating systems, and (2) research area concerns about the evaluation and validation of rating systems. Green Building. Such studies place more emphasis on energy efficiency in buildings and generally adopt quantitative methods. This is why there is a lack of quantitative evaluation methods in terms of discovering one's experience of buildings.

For a GBRS to be widely organized, it is essential that the system understands and reflects the needs of end-users [13,2,30]. In contrast, in this study, a fuzzy inference system that applies fuzzy decision rules is used to model the qualitative aspects of human knowledge and rationalize the process without the use of precise quantitative analysis.

The questions that arise for this study are: (a) Which factors are important to evaluate the performance of a green building on the three main criteria of SE2 aspects? (b) How are fuzzy logic and AHP methods used to evaluate the performance of green buildings?

Hence, this paper discusses an efficient expert system, which is developed and evaluated as fuzzy-AHP to evaluate the performance of a green building system by adopting a hierarchical process of analysis (AHP) and fuzzy logic. Using these approaches, the system is built on the three main dimensions of assessment in green buildings that are social, economic, and environmental and are represented by SE2. These three dimensions are widely used in most existing ranking systems. The main objectives of this research are divided into two parts:

1. Evaluation and weighting of criteria for green buildings from SE2 aspects.

2. Development of a new knowledge-based expert system to assess the level of efficiency of green buildings from SE2 aspects.

Besides, the main contribution of the paper is an integrated fuzzy-AHP logic approach to assess the level of performance of green buildings from SE2 aspects. Besides, the use of fuzzy logic, fuzzy and nonlinear SE2 factors on performance have been well investigated. As far as the authors know, there are few practical studies to evaluate the performance of green buildings using fuzzy set theory, and most previous research is based on methods based on several fuzzy criteria such as fuzzy-AHP. For the first time, however, this research, AHP, and fuzzy inferred systems (FIS), which process the formulation of mapping from a given input to an output using fuzzy logic, in a completely different and completely new way to Green building rating systems are employed.

The rest of this article is organized as follows: In Section 2, related work on green building rating systems is presented. In Section 3, the methodology used for expert systems is presented, and fuzzy-AHP is introduced. Section 4 provides an empirical study. Finally, the conclusion and future work are presented in Section 5.

2. Literature review

Green building rating systems measure a building's durability by using a set of criteria organized into different categories, including "location selection," "energy," "water," "resources," " Materials and components are "environmental," "loading," "transport," "radiation," and "wasted." For each criterion, a certain number of points are assigned. The overall scale (score) defines the type of certificate a building receives.

Durable labeling or credit incentive programs are often easy to understand and make it possible to achieve certain levels of "sustainability" or "greenness." Sustainability credit incentive programs provide examples, tools, and performance metrics for performing and detecting sustainable operations. Credit schemes are effective on two levels: they provide specific criteria for achieving different credits and thus provide a clear orientation for the implementation of sustainable operations; And they provide credibility recognition, thus providing incentives for sustainable operations.

When designing a green/durable building, it is important not only to ensure that the criteria are met but also to ensure that the building will perform as intended. That is, the methods used to gain credibility must lead to the right progress toward achieving a balance between economics, ecology, efficiency, functionality, and accountability to society.

Many related research studies on the development of an appropriate set of green building criteria in the last decade have provided the basis for the necessary additional studies. Reviewing articles provides a brief overview of new technologies and knowledge of what criteria a green building rating system should consider measuring the durability of a building properly. Various political and volunteer organizations, the Industry and University Alliance, individual scientists, and groups of scientists have researched this area.

In general, two types of assessment tools have been developed by the construction sector, the first of which are tools that incorporate benchmarks into the system to measure greenness. However, in the second group, the life cycle assessment (LCA) methodology is considered. Besides, LCA-based assessment systems are designed for use in building material selection, building design, and local applications such as transportation, waste management, and energy supply during the design phase [6].

The instrument components in this category, which include the LCA component, are -KCL (Finland), KCL Eco (2005), DBRI (Denmark) Beat (2005), OAE (USA) Bees (2004) and EcoQuantum (Netherlands). In contrast to LCA-based evaluation models, in criterion-based approaches, a specific scale range is considered for each criterion, for example, "low" and "high" environmental effects, in which these values represent the points of a selected number of parameters. Evaluate. Benchmarking systems are used as comprehensive environmental assessment tools around the world. The following are some GBRS [21,6,11].

2.1. GBTool (Canada)

In 1996, the Green Building Challenge (GBC) in Canada developed GBTool (Greenman Sustainable Buildings Green Building, Consulting, Education (Awareness) and Sales in Canada and the United States). It is a customizable building rating system, which evaluates environmental performance and durability. The system is designed as a general toolbox, which can be customized according to the performance requirements of the regional and local building and related needs. GBTool uses a scoring system (scaling) of 1- (deficient), 0 (minimum acceptance), 3+ (good performance), and 5+ (best performance).

2.2. CASBEE

CASBEE is a Japanese example of a green building licensing process and has been under development since 2001. The website states that under the Kyoto Protocol, an international protocol has been promoted in the United Nations Framework Convention on Climate Change as a means of reducing radiation. For each CASBEE website, there are two categories of assessments for CASBEE, the environmental quality of the building, and the efficiency and reduction of the building's environmental load. The CASBEE system achieves a measure of a formula model that results from a form filled out by customers for their buildings. Scales are rated from poor (C) to high (S) and buildings are assigned one of 5 different classification letters, namely C, -B, B +, A and S. Uniquely, the system ranks all levels of building performance from best to worst rather than simply praising the good. CASBEE has four rating categories: (i) pre-design, (ii) new construction, (iii) existing buildings, and (iv) renovation, each of which is evaluated based on five criteria; (a) efficiency Energy; (b) location selection; (c) indoor quality; (d) resources and materials, and (e) water storage (water conservation).

2.3. BREEAM

BREEAM is a top-rated British program of building education in the UK, and the world has finally become familiar with BREEAM International. Construction project managers have been working with a BREEAM evaluation organization since the beginning of the planning phases. As shown by their website [7], the method evaluates buildings against a set of criteria and provides an overall scale (score) that falls within the range where the ranking is passed. Provides good, very good, excellent, or outstanding.

USGBC Similar to BREAM, USGBC has a green building rating process called LEED, which is one of the industry standards in the US and abroad. According to the USGBC website, the LEED licensing and rating program has been in place since 1999. Projects require a LEED accreditation by professionals (AP), which is very similar to the BREEAM project in order to register a project and achieve each of the four ranking levels. The LEED rating system includes four levels of licensing: licensing to meet prerequisites and achieve a score of 32-26; Silver to reach the next level of points, i.e., 38-33; Gold to achieve a higher level of points: 51-39; And white gold (platinum) to meet or exceed all criteria for a license: Puan 60-52. A site or project to one of these different licensing levels by achieving the points listed for different credits under these six categories: sustainable, water-efficient, energy and atmospheric locations, materials and resources, indoor quality (IEQ), and The process of initiative and design is achieved.

2.4. DGNB

The German durable building permit states that durable building means intelligent construction [23]. "The focus is on the concept of total quality, which serves the building and the real estate sector, as well as the community as a whole. Durable features are useful for the environment, conserve resources, are easy to use, and They are healthy (safe) and adapt optimally to their socio-cultural environment "[17]. The German Durability Rating System was developed through a partnership with the German Durable Building Association (DGNB), and the Federal Ministry of Transport, Construction, and Urban Affairs (BMVBS), and was published in 2008. It was created to respond to changes in the German real estate market climate and to keep the market competitive and attractive to potential investors [17]. It is an optional system that covers six categories of assessment: ecology, economics, functional and socio-cultural issues, segregation, processes, and situation. Based on the number of points obtained in each category, the buildings are then ranked in bronze, silver, or gold. Buildings achieve a pre-permit rating based on the construction and design of their building.

2.5. BEAM

In 2002, the Business Environment Association (BEC) and the HK-Beam community developed BEAM in the HK BEAM community in Hong Kong. It assesses the environmental performance of buildings in Hong Kong. The assessment is based on five building performance criteria: health, wellness, comfort, and compatibility, land use, side effect, and transportation, material use, recycling, and waste management, water quality, conservation of natural resources, and Energy recovery, efficiency, resource conservation, and management.

2.6. Green Global

Green Global from the Green Building Institute (GBI) can offer certain advantages in terms of cost-effectiveness and user-friendliness, and it can offer it for smaller, more financially limited projects that want quality construction and execution. Determine the green, make it suitable [22].

2.7. Green Star

Green Star is a voluntary environmental rating system for existing buildings in Australia. It was started in 2003 by the Green Building Association of Australia. Nine categories are evaluated with Green Star tools: management, indoor quality, transportation, climate, materials, ecology and land use, initiative, and radiation (reflections and emissions) [50].

2.8. LEED

According to Yanarella et al. [69], LEED and other green rating systems are considered "transferable viability," although they are still moving towards achieving true durability. Ranking systems offer this position on a scale for two reasons. The first is the risk associated with trying to place the idea of sustainability in a building without taking a holistic approach. The second reason is the fact that changes in government (government) can derail any progress in the field of sustainability [69].

From the above description of rating systems, it can be seen that each rating system attributes signs or scales to different aspects of functionality. If these aspects are grouped into domains and the maximum possible scores for the aspects are collected, we can achieve the maximum scores for each domain and hence the appropriate weight for each domain by Assign a ranking system. A comparison of such related weights in the Pacific Northwest is made by Fowler and Rauch [19] and summarized in Table 1.

Table 1. Comparison of ranking systems using WBDG principles

	Weight						
System	Site(%)	Energy(%)	Water(%)	Material(%)	quality(%)	Maintanance(%)	Others(%)
BREEM	15	25	05	10	15	15	15
CASBEE	15	20	02	13	20	15	15
Green Globes	11	36	10	10	20	-	13
LEED	20	25	07	19	22	-	07

According to Sahamir and Zakaria [58], the Green Building Index (GBI) [20] presented in Table 2 is Malaysia's first comprehensive green ranking system for buildings and cities, which promotes sustainability in building environments and enhances awareness of environmental issues was created among developers, architects, engineers, planners, designers, contractors as well as the general public. GBI has been developed specifically for Malaysian tropical conditions, development-dependent and environmental conditions, and social and cultural needs. GBI is based on existing ranking tools such as Singapore's Green Mark system and Australia's Green Star, which have been extensively modified for the Malaysian program [56]. There are ten versions of GBI rating systems; 1. New Residential Construction (RNC), 2. New Non-Residential Construction (NRNC), 3. Existing Non-Residential Building (NREB), 4. NRNC Data Center, 5. NREB Data Center, 6. Construction New Industrial (INC), 7. Existing Industrial Building (IEB), 8. NRNC Retail, 9. NREB Retail, and 10. City Residents. With a comprehensive review of the articles, a comparison between ranking systems was performed by [58], which is presented in Table 2. The purpose of their study was to examine the criteria for green evaluation for the development of a public hospital building in Malaysia. It interprets the essential criteria of existing green rating systems for healthcare buildings around the world and provides the difference between each criterion compared to Malaysia's existing green rating system. The results of the analysis show the importance of the evaluation criteria of the Green General Hospital building corresponding to Malaysia.

Table 2. Distribution of points for each green ranking criterion [58]

Green element	**Weight**				
	GBI-NRNC	GBI-NRNB	BREEAM	LEED	GSTAR
Energy performance	35	38	17	35	17
Indoor quality	21	21	14	16	19
Sustainable site	16	10	11	16	10
Planning and management	-	-	-	-	-
material	11	9	11	15	20
Water performance	10	12	5	8	8
Innovation	7	10	9	5	3
Transport	-	-	7	-	7
Land-use	-	-	9	-	5
Pollution	-	-	9	-	12
Waste	-	-	7	-	-
Priority	-	-	-	4	-

In many studies, in the development of ranking systems, three dimensions of SE2 assessments have been considered for green buildings.

Ali and Al Nsairat [4] studied the international green building assessment tools and then defined new assessment items related to Jordan's local conditions. They have analyzed the characteristics of the principle of several building environmental performance assessment systems in different countries and studied the context and local situation. In their ranking system, the researchers defined seven important categories for evaluation: location, energy efficiency, water efficiency, materials, indoor quality, waste and pollution, and cost and economy.

Berardi [9] has designed a ranking system using these dimensions and several markers and categories (global markers) and markers. The designed system includes a total of nine durability categories that summarize building performance at some key aspects of durability and 25 indicators of durability within the three dimensions of durability obtained from the study by Mateus and Braganca [45]. Have. Assessment categories include climate change and outdoor air quality, land use and biodiversity, energy efficiency, waste and materials management, water efficiency, resident health and comfort, access, education, and sustainability awareness, and life cycle costs. One or more markers identify each evaluation category.

A survey was conducted by [11] among building construction professionals in a given national context, looking for relative weights for different slopes and aspects for a ranking system in Sri Lanka. They used direct ranking methods and the Analytic Hierarchy Process (AHP) to evaluate the components of the ranking system. They consider six domains of location, energy efficiency, water efficiency, materials, indoor quality, and waste and pollution for the ranking system. The overall range weights were compared with the weights associated with the other eight ranking systems, which were from eight different countries.

Comparing the most commonly used green building valuation methods, [72] has developed an evaluation method for green store buildings in China. The method refers to the rating requirements set by the China Green Building Evaluation Standard and the weighted credits for each category. The AHP method of expert group decision has been used to develop a weighing system for green store buildings. The standard store building performance indicator system includes seven categories: landscape, energy efficiency, water efficiency, materials and resources, interior environment, construction management, and operations management. Weight distributions demonstrate the importance of indoor quality, energy efficiency, and operations management in storage buildings.

Using a Delphi technique, Alyami et al. [5] found that outstanding international viability assessment models, such as BREEAM and LEED, did not apply to the Saudi position and context. Accordingly, they have developed a new ranking system with more categories and criteria for assessing the construction environment in Saudi Arabia. The categories of durability and building environment assessment include indoor quality, energy efficiency, water efficiency, water management, site quality, materials, pollution, service quality, economic aspects, cultural aspects, and management, and initiative. Each of the above categories includes a list of related criteria, which creates a 92-item list of criteria for evaluating durable residential buildings in Saudi Arabia.

Kabak et al. [28] developed a "fuzzy multi-criteria decision making (MCDM)" approach to analyzing the National Building Energy Efficiency Calculation Methodology (BEP-TR). Their approach was used to classify alternative buildings according to their overall energy efficiency. They discuss the results of their study in terms of developing a practical and new building rating system.

et al. [44] developed a ranking system for green bridges and followed the Simas process to obtain benchmark weights. In their research, a key list of metrics was collected, retrieved from articles, and discussed with bridge builders through unstructured calculations. To select the most important criterion that affects the durability of bridge construction projects, they developed a questionnaire interview, and finally, twenty-one is chosen criteria that were considered by experts using a questionnaire review.

Based on the analysis of formal (conventional) building energy certifications, Koo et al. [31] have developed a new energy efficiency rating system for existing residential buildings in two ways: (i) establishing reasonable and fair criteria for the rating system. Building energy efficiency, and (ii) creating comparable incentives for all residents (residents of homes) and a penalty program to encourage the voluntary participation of all residents in the energy storage campaign. In their study, the complexity of multi-family housing was selected as a representation of residential buildings in South Korea.

3. Methodology

The results of the review showed that no study uses AHP and fuzzy logic to evaluate the performance of green buildings and the effect of SE2 factors on overall performance. This study was then conducted using a combination of the AHP approach and fuzzy logic as fuzzy-AHP to evaluate the performance of green buildings.

Our research aims to develop a method for evaluating green efficiency, which is based on human knowledge and experience. The knowledge-based expert system uses human knowledge to solve problems that naturally require human intelligence [77,76]. In addition, the purpose of this paper is to demonstrate a fuzzy logic application for evaluating the performance of green buildings. Accordingly, the fuzzy logic performance evaluation model reveals some of the hidden relationships between the components of green building evaluation methods from SE2 as well as their markers and the level of performance of green buildings. It should be noted that the human experience of a green building plays an important role in building the proposed system. Also, the accuracy of the fuzzy rules presented in fuzzy logic for the FIS system depends more on human knowledge and experience. We conducted a case study in which we used Malaysian green buildings and discovered knowledge (fuzzy rules) in the fuzzy logic system from the collected data. An overview of the methodology of this study is provided in Figure 1.

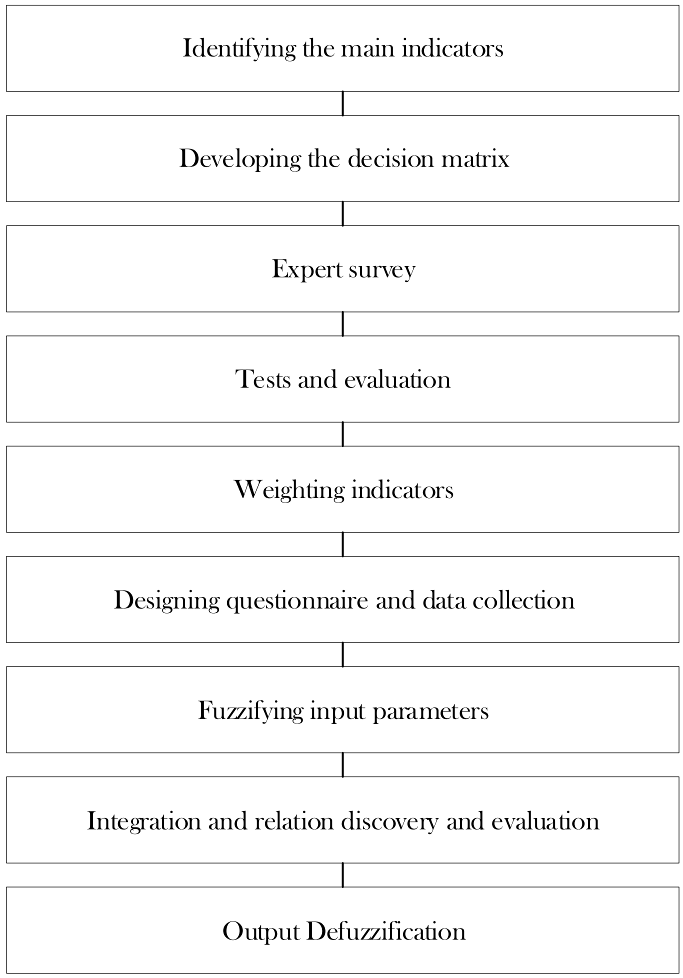

Figure 1. Research Methodology Framework

3.1. Analytic Hierarchy Process (AHP)

AHP is a systematic process for examining decision issues with multiple alternatives. AHP is based on a hierarchical structuring of decision elements using pairwise comparisons. This technique is very simple and practical and can be performed using the steps shown in Figure 2 [52,27,52,3,2]. In AHP, in order to be fair and arbitrary in comparisons between alternative pairs at each level of the hierarchy, a scale of 1-9 (1- equal preference; 5- highly preferred; 9- strongly preferred (See Table 3).

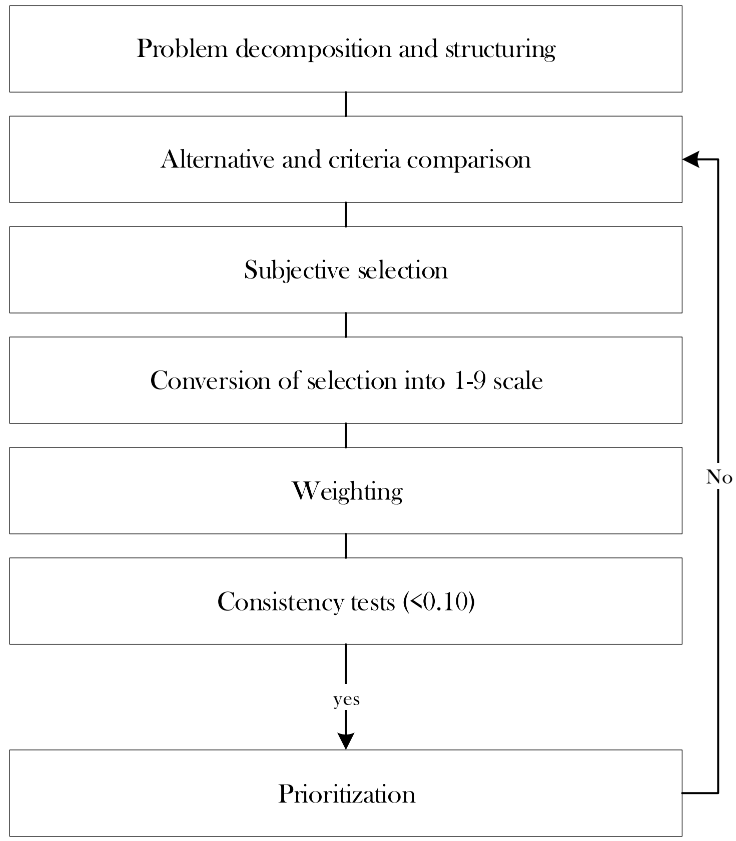

Figure 2. Analytic Hierarchy Process (AHP) Methodology Framework

Table 3. Preference scale for pairwise comparisons

Description	Scale
Equally preferred	1
Equally to moderately preferred	2
Moderately preferred	3
Moderately to strong preferred	4
Strongly preferred	5
Strongly to very strongly preferred	6
Very strongly preferred	7
Very strongly to extremely preferred	8
Extremely preferred	9

3.2. Fuzzy logic

Fuzzy logic has grown from the goal of teaching computer systems to human expertise. Fuzzy set theory has been developed for modeling complex systems under uncertain and uncertain environments [55,8]. It is widely used in decision making and problem solving [68,33,28,75,54,59,1]. It is difficult to turn an expert's knowledge into an equation that a computer can process when processing involves a number of variables and conditions. By encoding human experience in sets of decision rules, fuzzy logic can produce a smooth output surface for all input compounds without an explicit model of the corresponding process (51) [51].

Fuzzy inference is the process of formulating a map from a given input to an output using fuzzy logic. Mapping then provides the basis for decisions that can be made, or patterns identified. There are many types of fuzzy inference systems. The two most popular types of FIS are the Mamdani type [42] and the Sugeno type [62].

The main process of fuzzy inference and its pattern diagram is shown in Figure 3. The 'database' contains a number of fuzzy decisions and fuzzy rules, and the 'database' defines the MFs of the fuzzy sets used in the fuzzy rules [49]. Usually, the law database and the database are collectively referred to as the 'knowledge base.' The 'decision unit' executes the inference operation on the rules, and the two interfaces perform the fuzzy operation and the fuzzy operation, respectively.

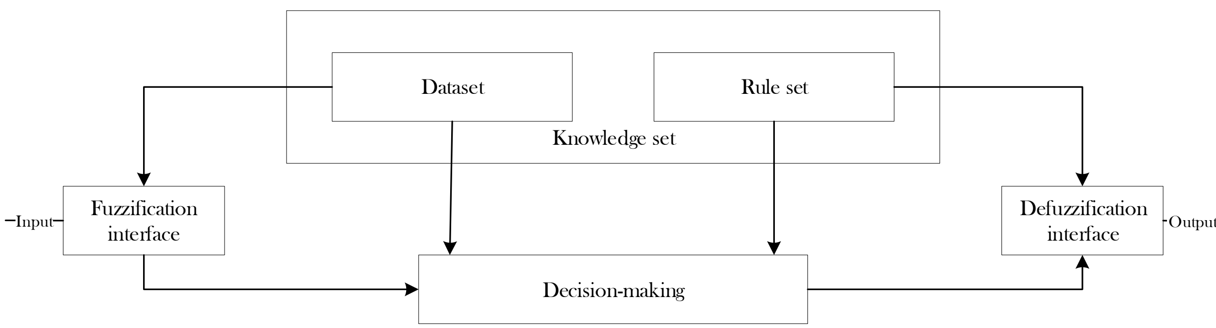

Figure 3. Steps in a fuzzy inference system

Input fuzzy involves converting numerical input values (called normal values) into linguistic variables. Linguistic variables are labels such as 'low' or 'high,' which are mostly related to the way a person would describe that value. Each input has its own set of MFs that define how input values are mapped to language variables. Unlike traditional sets, fuzzy sets allow data points to be members of a specific subset or to be members of more than one subset. The degree to which an input value belongs to a particular subset is called the degree of assignment and taking a value anywhere from zero (no allocation) to one (full allocation). Once the inputs to the language variables are fuzzy, they can be used to evaluate rules without explicitly referring to implicit numeric values. The basic structure of a rule provides a decision expression. The goal of the non-fuzzy process is to combine the outputs of the rule into a single normal output value for the entire network. If the outputs of the rules are membership functions, then the rule is used to calculate the incomplete domain under the membership function. The amplitudes of each rule are then combined, and the center of gravity is taken as the output. For faster processing, the calculation center can be changed from a correct center of gravity calculation to simpler approximations.

4. Results and discussion

4.1. AHP

As mentioned earlier, in this study, we used fuzzy logic and AHP in developing a model to evaluate the performance of a green building. AHP is a multi-criteria decision-making technique used to evaluate and weigh the components of a model. Therefore, in the first step, we provide a list of dimensions, markers, and parameters in which all the related markers and parameters from the articles reviewed in Section 2 were identified. Since the purpose of this study was to develop a new ranking system for evaluating green building performance, use an in-depth interview with construction professionals along with conducting a questionnaire interview as a convenient way to collect data to enable the study. It was necessary to get a clear picture of what is the main phenomenon in the real situation. Therefore, we contacted each specialist individually for an interview and obtained a complete questionnaire. A questionnaire was developed for each specialist, which included comparative matrices as well as descriptions of the components. All 12 professionals who participated in the survey and interview have at least five years of experience in construction, and more than ten years of professional experience. They were selected according to their roles and their impact on sustainable development practices. The interviewed experts made their judgments based on their professional experience and the information provided about the characteristics of the green building. Assume that if m has a complete questionnaire (m = 12) and n markers weighted by AHP, specialist e can provide a two-by-two comparison matrix such as the following:

$$A_e = \begin{pmatrix} a_{11}^e & a_{12}^e & \cdots & a_n^e \\ a_{21}^e & a_{22}^e & \cdots & a_{2n}^2 \\ \vdots & \vdots & & \\ a_{n1}^e & a_{n2}^e & \cdots & a_{nn}^e \end{pmatrix} \quad (1)$$

Where A_e is the pairwise matrix completed by the specialist e (e = 1,…, m), and a_{ij}^e is the relative importance between the marker i (i = 1,2,…, n), and the marker j (j = 1,2,…, n) based on expert judgment e and shows a comparative value of $a_{ji}^e = \frac{1}{a_{ij}^e}$.

The pairwise comparison matrices were developed by experts using the scale presented in Table 3, which is the preferred scale for pairwise comparisons proposed by Saaty. For example, designing a location and transportation under site selection using the question "How important is location design when compared to transportation?" The comparison and answer provided by the expert was "equal preference," rather than using a numerical value. We then substituted the corresponding numerical value in the appropriate cell from the comparison matrices (A_e). Following this process, the judgment matrix of each expert was created, and the weight of each parameter was calculated.

As can be seen, the list of parameters and indicators in each dimension is presented in Table 4. In order to calculate the rank of parameters in the AHP method, after collecting pair comparison questionnaires, Expert choice 2000 software was used. Based on the threshold chosen by the experts, the most important parameters in each dimension were selected. Table 5 shows the weights of the parameters in three dimensions. To achieve the general judgment, the geometric mean method was used to collect individual judgments. The geometric mean method for n elements $x_1, x_2, \dots, x_n$ is presented in equation. (1)

$$GM = \sqrt[n]{\prod_{i=1}^{\wedge} x_i} \quad (2)$$

From the weights in Table 5, the most important parameters are selected with a threshold value of 0.15. Therefore, location design, landform, on-site energy sources, and transportation were selected with weights of 0.30, 0.15, 0.15, and 0.18, respectively, for the location selection indicator. For pollution and waste, all parameters were selected because they weighed more than the threshold. For energy efficiency, except for mechanical systems and greenhouse gas emissions and machines/equipment with weights of 0.08, 0.11, and 0.09, all other parameters were selected. For this indicator, renewable energy was the most important parameter with a weight of 0.21. For the material marker, local/regional materials were excluded from participating in the next evaluation concerning other parameters in this group. This case had the lowest weight (0.06), according to experts. In the economic dimension and for cost and economic indicators, waste management, water efficiency, location, and energy efficiency with weights of 0.22, 0.18, 0.26, and 0.23 were the most important parameters. In the social dimension, all parameters were selected for accessibility and alienation indicators; however, for indoor quality, comfort indicators related to noise pollution and temperature comfort (heat) reached 0.05 and 0.07, which are not based on the threshold value. It can be considered. Finally, for the residents' satisfaction indicator, access to view (view), privacy, and internal qualities were selected with weights of 0.29, 0.36, and 0.23, respectively. In Table 6, the most important parameters for SE2 are presented by the AHP method.

Table 4. Dimensions of evaluation of indicators and parameters for the proposed model

Section	Indicator	Variable
Environmental	Site	Site design
		Land-use
		Landform
		Microclimate
		Energy resources
		Transportation
	Waste and pollution	Water conservation
		Water management
		Innovative technologies
		Water use
		Water efficiency
	Energy efficiency	Envelope performance
		Renewable energy
		Natural lighting
		Efficient cooling and heating
		Mechanical system
		Emissions
		Appliances

	Material	Regional materials
		Renewable material
		Recycle material
		Resource reuse
		Environmental impact
Economic	Cost	Material
		Waste management
		site
		Energy efficiency
		Water efficiency
Social	Accessibilities	urban amenities
		public transportation
	Externalities	Available Services
		Social Cost-Benefit Analysis
		Local Employment Opportunities
	Indoor environment	Natural ventilation efficiency
		Acoustic comfort
		Lighting comfort
		Thermal comfort
		Acoustic and noise control
		Indoor air quality performance
		Occupant health and safety
	Occupants satisfaction	Access to View
		Privacy
		Human Interactions
		Interior Qualities

Table 5. SE2 indicators, parameters, and their weights

Section	Indicator	Variable	Weight(%)
Environmental	Site	Site design	30
		Land-use	12
		Landform	15
		Microclimate	15
		Energy resources	10
		Transportation	15
	Waste and pollution	Water conservation	18
		Water management	16
		Innovative technologies	39
		Water use	18
		Water efficiency	27

	Energy efficiency	Envelope performance	18
		Renewable energy	21
		Natural lighting	17
		Efficient cooling and heating	16
		Mechanical system	08
		Emissions	11
		Appliances	09
	Material	Regional materials	06
		Renewable material	19
		Recycle material	25
		Resource reuse	16
		Environmental impact	25
Economic	Cost	Material	34
		Waste management	11
		site	22
		Energy efficiency	18
		Water efficiency	26
Social	Accessibilities	urban amenities	23
		public	44
		transportation	56
	Externalities	Available Services	25
		Social Cost-Benefit Analysis	34
		Local Employment Opportunities	41
	Indoor environment	Natural ventilation efficiency	16
		Acoustic comfort	05
		Lighting comfort	17
		Thermal comfort	07
		Acoustic and noise control	16
		Indoor air quality performance	18
		Occupant health and safety	21
	Occupants satisfaction	Access to View	29
		Privacy	36
		Human Interactions	12
		Interior Qualities	23

Table 6. The most important parameters for SE2 selected by the AHP method

Section	Indicator	Variable	Collative(%)
Environmental	Site	Site design	30
		Landform	15
		Energy resources	15
		Transportation	18
	Waste and pollution	Water conservation	16
		Innovative technologies	39
		Water use	18
		Water efficiency	27
	Energy efficiency	Envelope performance	18
		Renewable energy	21
		Natural lighting	17
		Efficient cooling and heating	16
	Material	Renewable material	19
		Recycle material	16
		Resource reuse	25
		Environmental impact	34
Economic	Cost	Waste management	22
		site	26
		Energy efficiency	23
		Water efficiency	18
Social	Accessibilities	urban amenities	44
		Public transportation	56
	Externalities	Available Services	25
		Social Cost-Benefit Analysis	34
		Local Employment Opportunities	41
	Indoor environment	Natural ventilation efficiency	16
		Lighting comfort	17
		Acoustic and noise control	16
		Indoor air quality performance	18
		Occupant health and safety	21
	Occupants satisfaction	Access to View	29
		Privacy	36
		Interior Qualities	23

4.2. Fuzzy logic-based model

This study is based on the argument that the actual efficiency level of a green building is based on three factors: what is the social efficiency level (S) of a green building, the environmental efficiency level (E) of a green building, and the economic efficiency level (C) What is a green building? Therefore, we propose a fuzzy logic evaluation model to identify the performance of a green building according to the following equation:

$$L_{performance}(Green\ Buildings) = f(S.E.C) \qquad (3)$$

From the relations, we can define that the performance level of a green building is a function of SE2.

Since a total of 32 parameters and nine markers were considered to construct the fuzzy logic evaluation model, the Likert-based questionnaire based on these parameters and markers was used to collect data from the second group (120 responses in total). Donor) Responders are designed. The data collected from this group is used to form fuzzy rules (knowledge discovery) in order to be used in FIS from the evaluation model based on fuzzy logic.

The fuzzy model is based on the Mamdani algorithm and runs on the fuzzy logic toolbox of the MATLAB software package. The proposed system consists of two main levels. In the first layer, the system evaluates the SE2 levels of a green building. Then, in the second layer, the performance level is evaluated based on the levels obtained from SE2. To enable the development of a performance evaluation model based on fuzzy logic, appropriate MFs must be defined for the model inputs and outputs (fuzzy variables) in the fuzzy inference system (FIS). In this study, all input variables in the FIS model use low, medium, and high language vocabulary, and their MFs are considered as Gaussian MFs. In addition, for model outputs, triangular (triple) MFs are considered as mentioned in the model. They are defined by the harmful variables Vlow (very low), low, medium, high, and Vhigh (very high). The structure of fuzzy models for evaluating the performance of green buildings is shown in table 4. Tables 7 and 8 show the membership functions for the input variables (markers) and the output variables, respectively.

Table 7. Membership functions for input variables (markers)

	Number of		Description of fuzzy system scale		
Main factor	Indicator	Parameters	Low	Moderate	High
1	1	4	1.3480	1.3484	1.3488
-	2	4	1.3480	1.3484	1.3488
-	3	4	1.3480	1.3484	1.3488
-	4	4	1.3480	1.3484	1.3488
2	1	4	1.3480	1.3484	1.3488
3	1	2	0.66830	0.66832	0.66834
-	2	3	-1.6020	1.0190	1.0200
-	3	5	1.6980	1.6985	1.6989
-	4	3	-1.6020	1.0190	1.0200

Table 8. Membership functions for output variables

Output	Description of fuzzy system scale				
	Vlow	Low	Moderate	High	Vhigh
Environment	0.0-0.2	0.2-0.4	0.3-0.5-0.7	0.6-0.8	0.8-1.2
Social	0.0-0.2	0.2-0.4	0.3-0.5-0.7	0.6-0.8	0.8-1.2
Economical	0.0-0.2	0.2-0.4	0.3-0.5-0.7	0.6-0.8	0.8-1.2
Performance	0.0-0.2	0.2-0.4	0.3-0.5-0.7	0.6-0.8	0.8-1.2

Based on the MFs for inputs and outputs, the language variables for inputs and outputs are considered at three and five levels, respectively. Using defined MFs, the fuzzy model can generate the actual level of efficiency of the green building based on the fuzzy rules discovered in the FIS system. It should be noted that the selection of MF types and their spectra for inputs and outputs plays an important role in evaluating performance. Therefore, based on the experiences and data collected from experts, the Gaussian type of MFs is selected for the inputs because it is more natural at all points [43], smooth and non-zero [67].

After the non-fuzzy process of input and output variables, in the next step, the IF-THEN (if-then) fuzzy rules are executed. The detected fuzzy rules show the fuzzy relationships between the input and output variables. Based on the knowledge of experts, the fuzzy model law base is constructed. In this study, the fuzzy rules used to evaluate performance are discovered from the knowledge of experts, and different fuzzy rules are identified for each layer. Table 9 shows the number of fuzzy rules. Table 9 shows that because the model in the first layer has four inputs for environmental variables, one input for economic variables, and four inputs for social variables, there are 165 fuzzy rules in FIS. In addition, in the second layer, since the model has three inputs, so 27 fuzzy rules participate in FIS. Therefore, a total of 192 fuzzy rules are considered to evaluate the efficiency of green buildings in FIS. It should be noted that the number of fuzzy rules can be controlled by increasing or decreasing the number of MFs. Accordingly, a formulation of fuzzy rules for performance evaluation is provided in Table 10 for the three main inputs (SE2) and one output (efficiency).

Table 9. Number of fuzzy rules for the FIS model of evaluation

Output	Input	Rules
Environmental	Site	3^4=81
	Waste and pollution	
	Energy efficiency	
	Material	
Economic	Cost	3
	Accessibilities	3^4=81
	Externalities	
	Indoor environment	
	Occupants satisfaction	
Performance	Environmental	3^3=27
	Economical	
	Social	
Total		192

Table 10. Creating fuzzy rules to evaluate the performance

Rule	Description							
	If	Environmental	And	Social	And	Economical	The	Performance
1		High		Low		Low		Moderate
2		High		Moderate		High		Very high
3		Low		Moderate		High		Low
4		Low		Low		High		Very low
…	…	…	…	…	…	…	…	…
24		Low		Low		Low		Very low
25		Low		High		Moderate		Moderate
26		High		High		Moderate		Very high
27		High		Moderate		Low		Moderate

The fuzzy model runs in the fuzzy logic toolbox of the MATLAB bundle. This system depends on the fuzzy model for the inference mechanism to maximize the method of addition (summation) between the rules to combine the fuzzy output set, so the fuzzy method here is the maximum-minimum, and the non-fuzzy method is the center of gravity. To simulate the model, the GUI tool library of the fuzzy logic toolbox is embedded in Simulink. The Fuzzy Logic Toolbox Library, which includes fuzzy logic controllers and fuzzy logic controllers with rule-monitoring blocks, uses a performance appraisal system to apply FIS models (including 192 rules). Simulink block diagrams include four fuzzy logic controllers with rule-watching blocks, nine fixed blocks, three multiplexer blocks, and a display window for output.

By combining input MFs and output MFs with the rules presented in Table 10, 2D curves and 3D plots can be obtained to provide instantaneous relationships between inputs and outputs. Demonstrating the interdependence between inputs and outputs is useful for revealing the level of efficiency of a green building. The model shows the interdependence of efficiency and the three main dimensions through the curves and control levels obtained from fuzzy rules and data collected from experts. The level of efficiency can be represented as a continuous function of input parameters as environmental, economic, and social. Curves and control levels show performance differences based on identified rules. Control levels also indicate the interdependence of performance on "environmental-economic," "environmental-social," and "socio-economic" items.

These surface models show the exact level of performance on both dimensions of the green building back. They also show that dimension can be important for the performance level. It should be noted that from the surface models and according to the discovered fuzzy laws, the level of efficiency depends more on the environmental dimension. The maximum performance level is around 0.911. However, for the other two dimensions, economic and social, the efficiency levels have reached around 0.513 and 0.603, respectively. This shows that the social dimension is more important for the level of efficiency than the economic factor. Here we can state that the performance evaluation of a green building can be modeled with FIS based on the knowledge of the experts who have formed the fuzzy rules.

To build fuzzy relationships, the maximum-minimum method is used, which is the most popular technique [55]. The area center of gravity (COA) method is the most widely used non-fuzzy method [25]. It is necessarily the weighted average of the fuzzy output set.

Using the COA, the FIS law monitor module provides an overview of the entire fuzzy inference process concerning the performance of a green building. The fuzzy law observer of the model created to show the efficiency of the green building under changes in the values of the three inputs is shown. From the above fuzzy law observer, for example, we can see that when the environmental input parameters are at 6.04, economic at 2, and social at 3.48, an output efficiency level of 0.861 is obtained.

It should be noted that the heart of the performance evaluation model proposed using FIS is the knowledge base that forms the inference engine. In this case, the expert human expertise is translated into the decision rules used in the inference engine. It can be argued that the level of expertise of a human specialist in the green buildings may differ from one another, and these form different fuzzy rules, but as long as they are fixed in the search engine, the FIS outputs always remain constant. In the model, it can be seen that FIS works by converting the quality indicators of green building performance evaluation into numerical values that allow determining the level of performance. Apart from this, it is also possible to store these numerical values in a database for new evaluations.

5. Conclusion

In this research, an attempt has been made to develop an expert system to evaluate the level of efficiency of green buildings using AHP and fuzzy logic approaches. Evaluation criteria are selected from the articles based on three main dimensions, namely the social, environmental, and economic dimensions, which are shown in this work as SE2. Data for this study were collected from experts in the field through Likert-based questionnaires in pairs. To select the most important factor, an efficient performance evaluation system based on fuzzy logic with its FIS has been developed to evaluate the level of performance. All input variables in the FIS model use language words modeled as triangular MFs. By defining these MFs for all fuzzy system inputs and outputs, 192 fuzzy rules were discovered for use in FIS. The results of the presented expert system show the ability of fuzzy logic to evaluate the level of efficiency of a green building. In addition, the evaluation results show that the environmental dimension is the most important for the level of efficiency concerning the social and economic dimensions based on the knowledge of experts.

In this study, there are some concepts and limitations that need to be focused on and explored in further studies. First, there were few specialists to complete the review for this study. Since the accepted analysis results in a large sample size of respondents, there is a great need for a more robust study to evaluate the evaluation of green buildings by a large number of respondents; This also leads to the generalization of the findings of the forthcoming study. Hence, from this limitation, we feel that data collection from multiple sources can improve the generalizability range of the proposed fuzzy model. Second, in this study, FIS output is limited by the design and number of MFs and knowledge base rules in the inference engine. In this particular scheme, triple and Gaussian MFs are used to represent linguistic vocabulary to assess performance levels. Therefore, different MFs like a trapezoid or S like may produce different outputs and therefore need to be investigated, and we will work on this aspect in the future.

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