Fuzzy-Based Decision Support Model for Assessing Green Building Performance

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***Abstract*—Global warming is currently a major environmental issue that is capable of causing unpredictable climate changes. The phenomenon is due to the accumulation of gases and carbon dioxide in the earth's atmosphere, partly attributed to building operation and construction. The Green Building Rating System (GBRS) is developed to assess and measure the level of green building practices to address this problem. The assessments have typically been conducted using conventional methods that require parameters to meet specific criteria. However, certain parameter values cannot be calculated using objective methods, such as bias, time series, and distance values. The existence of these challenges leads to the development and integration of the Decision Support Model (DSM) into the GBRS in the research. The DSM uses a mathematical model, Tsukamoto Fuzzy Inference System (FIS), and conventional methods to handle the parameter values. Moreover, data related to the parameters are collected and analyzed quantitatively. As a result, the DSM-GBRS model is successfully implemented with two findings. First, there are 83 parameters, related to policy, retrofit, construction, and utilization aspects based on Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 21 Tahun 2021. Second, the model provides precise decision values by splitting the treatment into four types: conventional, Fuzzy logic, slope, and Euclidean distance to ensure a comprehensive assessment of green building performance.**

***Index Terms*—Decision Support Model, Fuzzy Logic, Green Building**

I. Introduction

GLOBAL warming caused by the accumulation of gases and carbon dioxide in the earth's atmosphere has been an issue of major concern in recent decades. This phenomenon has significant implications for climate change, as observed in increasingly unpredictable patterns. Several studies have been conducted to explore the sources of global warming, including the contribution from the building sector. Human influence was found in a related research to be the primary cause of climate system changes from 1951 to 2010, accounting for approximately 95% [1]. Previous research has shown the importance of considering the construction and operation of buildings in efforts to mitigate the impacts of global warming. Moreover, some of the human activities identified are specifically the built environment, which is responsible for approximately a 40% increase in CO_2 emissions [2].

The lifecycle of buildings, from planning and construction to utilization, has both advantages and significant impacts related to the economic, political, and environmental aspects. The building sector is known to consume 31% of global energy, 54% of global electricity demand, account for 23% of global energy-related CO2 emissions, use 40% of the raw materials of the world economy, generate over 35% of waste, and consume 17% of global freshwater [3].

In recent years, several studies have focused on assessing the performance of buildings. The concept initially embraced widely is sustainable development. The intention is to pursue development that fulfills present needs while safeguarding the ability of future generations to meet their needs [4]. Later studies show that a high percentage of buildings in the United States has the potential to reduce energy consumption and improve building performance. It is achieved through retrofitting and the development of decision support systems [5]. Therefore, subsequent studies focus on building revitalization using cost-benefit analysis [6].

The previous research centers on assessing the construction aspect, but the model does not consider Fuzzy values [7]. Moreover, the importance of determining and weighing indicators is proposed based on the Analytical Hierarchy Process (AHP) [8]. Some studies apply Decision-Making Trial and Evaluation Laboratory and Analytical Network Process methods to understand the relationships between the elements in a complex evaluation system [9]. The rigidity in indicator values is also addressed through the Fuzzy

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TABLE I
GREEN BUILDING RATING SYSTEM (GBRS) ACROSS THE WORLD.

Name	Country
Leadership in Energy & Environmental Design (LEED)	US
Building Research Establishment Environmental Assessment Method (BREEAM)	UK
Green Star	Australia
Comprehensive Assessment System for Building Environmental Efficiency (CASBEE)	Japan
PUPR-GBRS	Indonesia

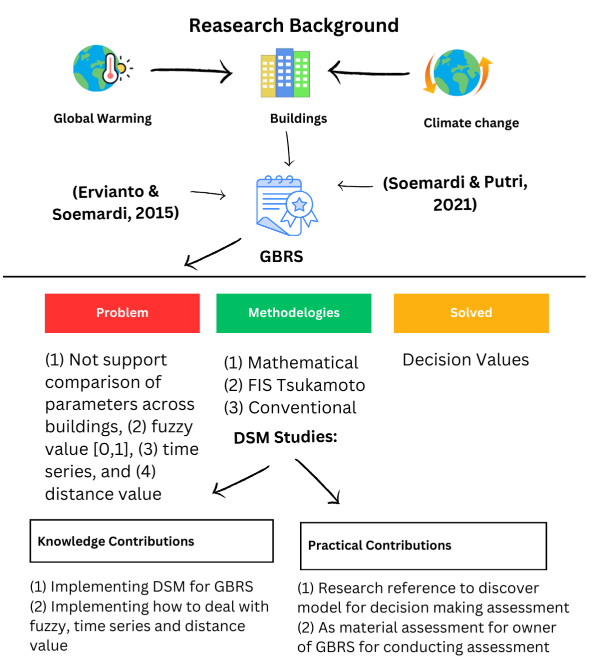

Fig. 1. Research framework.

Logic (FL) method to provide more accurate assessments [10, 11]. Furthermore, Fuzzy AHP produced through the application of FL to AHP has been used in a similar study [12].

The Green Building Rating System (GBRS) has been developed to measure the level of sustainability in building design, construction, and operation, with due consideration for the environmental, social, and economic aspects. The different types of GBRS available throughout the world are presented in Table I. However, the implementation is not easy due to the need to tailor the system to the geographical conditions of the building through a conventional method [3, 13, 14]. The process motivates the Indonesian government to establish regulations for green buildings through the Peraturan Menteri Pekerjaan Umum dan Perumahan Rakyat Nomor 21 Tahun 2021 (PUPR-GBRS).

Previous studies have identified the limitations in the application of conventional methods to calculate parameters. Moreover, the assessment method used shows that a full value can only be allocated to an indicator when the predetermined criteria have been fulfilled. It shows the method’s inability to compare parameter values across different buildings effectively and the failure to account for biased, time-series, and distance values. Therefore, the primary questions formulated to be addressed in the research are as follows:

1) What are the key parameters to be considered in the assessment of green building performance?
2) How can the Decision Support Model (DSM) be developed into the GBRS to enhance the evaluation of green building performance?

The first question focuses on identifying the important parameters to be considered when assessing the performance of green buildings. Meanwhile, the second question emphasizes the application of a DSM to solve complex problems by combining human and computer analyses to support efficient and effective decision-making processes. In the research, the DSM is used to generate objective decisions using narratives, flowcharts, as well as cause-and-effect structure diagrams to solve complex problems.

By addressing these questions, the research aims to provide valuable insights and recommendations for assessing and improving green building practices to support the development of more sustainable and environmentally friendly buildings. The novelty is the application of the DSM to GBRS, known as the DSM-GBRS, to overcome the problem of rigid, time-series, and distance values. It also focuses on providing performance values for each building and generating building rankings with objective calculations tailored to the geographical conditions of Indonesia. Figure 1 shows the research framework.

II. RESEARCH METHOD

Figure 2 shows that the research is conducted through three parts: methods, stages, and outputs, as required in the DSM Wheel [15]. The first stage is the analysis of cases using the Desk Research (DR) method. The stage is initiated by reviewing articles searched on Google Scholar through the keywords ‘Green Building Assessment’, ’Green Building Scoring’, ’Green Building Rating System’, ’Fuzzy Logic Green Building’, and ’Decision Support Model for Green Building’. The articles are subjected to in-depth screening followed by a summary and the output to understand the case.

The second stage is the analysis of the alternative decisions using the DR method. It is done through

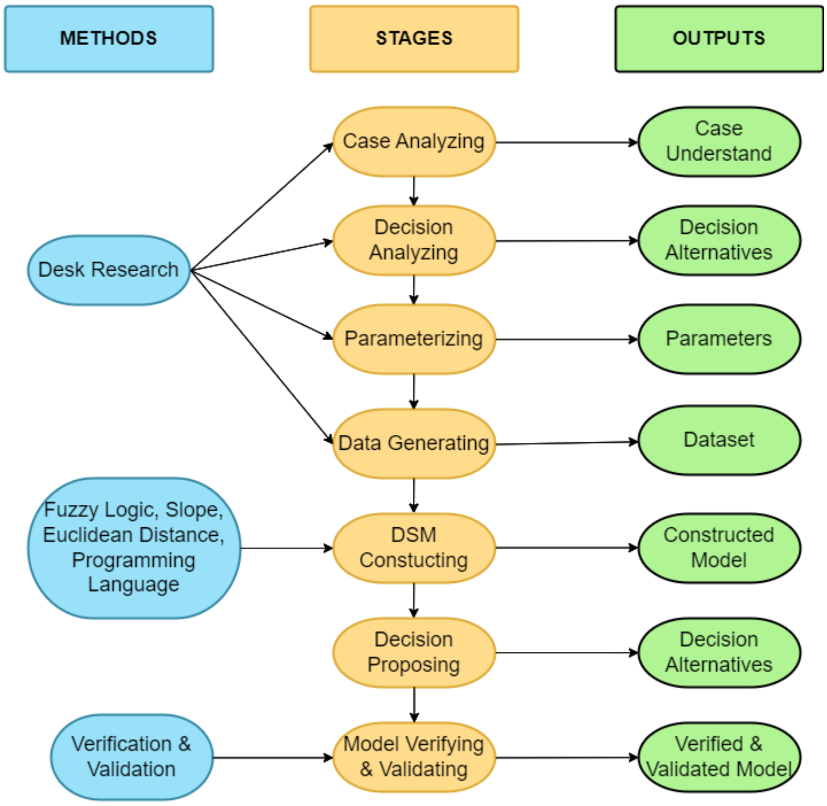

Fig. 2. Decision Support Model-Green Building Rating System (DSM-GBRS) as proposed methods.

online observations and literature studies to determine the types of alternative decisions available. The output is to understand and produce the alternative decisions suggested by the DSM-GBRS model.

The third stage is to analyze the parameters to understand the different criteria, parameters, and variables used. It is initiated through online observations and analysis of practical parameters from the PUPR-GBRS. The process is followed by the determination of the meaning or definition and data type of each parameter.

The fourth stage is for data generation, and it is achieved synthetically after parameters are set in DSM using a simulation method. Four types of parameter values, including Boolean, integer, float, and time series, are generated based on literature studies. Subsequently, the time series values are simulated using linear regression and analyzed by showing the data in a line graph to observe trends. However, Boolean, integer, and float values are simulated randomly and analyzed by checking the range of parameter values. The simulation classifies buildings into four definitions, including high, medium, and low performance.

The fifth stage focuses on explaining the activities needed for DSM construction. Therefore, the cases are visualized using the Unified Modeling Language (UML) to develop the class, influence, and Activity Diagrams (AD). These modeling diagrams are designed using the Visual Paradigm tool. Moreover, the programming language in Python is applied to build models using the FL method. It shows that the output of the stage is the constructed model.

After the development of the model, the sixth stage is to propose alternative decisions. The output is to produce green building level to be viewed and applied by decision-makers. Moreover, follow-up actions are provided to the authorities based on the results of the alternative decision model. The last stage is to verify and validate the model to determine the degree of correctness. The verification assesses the truthfulness of the model against the theory used, while the validation focuses on the accuracy in reflecting real-world data values.

Figure 3 shows the central image of the input-process-output model. The dataset is collected from buildings served as the input for the DSM construction through three processes. The first is Tsukamoto FIS, a computational framework to handle crisp parameter values for decision-making [16]. The second is a

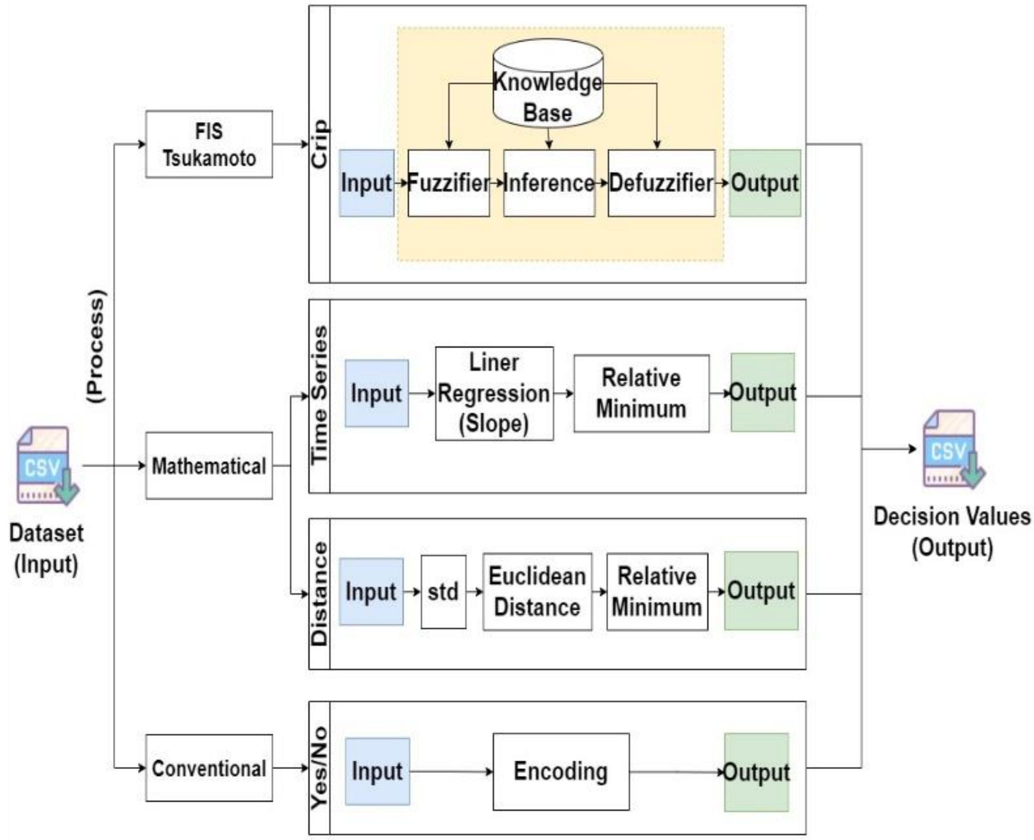

Fig. 3. The Detail of Decision Support Model (DSM) Constructing Stage.

mathematical process to manage time series and distance values. Meanwhile, the third is the conventional process of dealing with string conversion values. The detailed formulas for each process are explained in the algorithm model results section. Moreover, the output of the DSM construction stage is decision values.

III. Results and Discussion

A. Case Understanding

This section presents the results of the first stage, which focuses on using the DR method to analyze cases related to the performance of green buildings. The purpose is to understand important concepts such as global warming, climate change, GBRS, and issues related to the studied topic. The details have been explained comprehensively in the introduction section.

B. Decision Alternatives

The results of the decision analysis stage are described with a focus on the analysis of decision alternatives for all buildings within the study area using the DR method. The purpose is to implement further actions, such as the identification of the best or worst buildings in the list based on the established criteria. The process has been described in the methods with decision-making observed to have been used to rate the alternatives based on performance. The output is to understand decisions to be suggested by the DSM model based on the ratings of the alternatives, such as gold, silver, and bronze.

C. Parameters

The next stage collects the parameters needed to assess the performance of green buildings. It is done by conducting online observations to identify the PUPR-GBRS in Indonesia as a reference for parameter study. There is a high probability of obtaining the values required, leading to the determination of 83 parameters, which are subsequently divided into four categories, including policy, retrofit, construction, and utilization, as presented in Tables A1–A4 in Appendix, respectively. The meaning of each parameter is described in its name.

Table II presents the number of points assigned to each aspect based on the PUPR-GBRS and the

TABLE II
THE TOTAL POINT AND WEIGHT.

Aspect	Point	Weight
Policy	30	0.232558140
Retrofit	27	0.209302326
Construction	26	0.201550388
Utilization	46	0.356589147
Total	129	1.000000000

TABLE III
PARAMETER GROUPING.

Code	Parameters
ax	P01, P02, P03, P04, P05, P06, P07, P08, P09, P10, P11, P12, P13, P14, P15, P16, P17, P18, P19, P20, P21, P22, P23, P24, P25, P26, P27, P28, P29, P30, P31, P32, P35, P36, P37, P38, P39, P40, P41, P42, P43, P44, P45, P46, P47, P48, P49, P50, P52, P53, P54, P55, P56, P57, P58, P59, P60, P62, P64, P65, P66, P70, P74, P75, P76, P77, P78, P80, P81, P82, P83
bx	P33, P34, P63, P69, P71, P72, P73
cx	P51, P61, P68, P79
dx	P67

Note: conventional group (ax), crisp group (bx), time series group (cx), and distance group (dx).

maximum for green building performance, which is 129. The points are used in the weighting calculation by normalizing the values to be within the range of 0 to 1. The results show that utilization has the highest number of points, accounting for 36% of the total, followed by policy with 23%, retrofit with 21%, and construction with 20%.

In Table III, the parameters are grouped into four categories to serve as an overview. The first is the conventional group (ax) with 71 parameters, including P01, P02, P03, up to P83, and the raw data is the Boolean type. The second is the crisp group (bx) consisting of seven parameters, including P33, P34, P63, P69, P71, P72, and P73, characterized by integer or float data type. The third is the time series group (cx) consisting of P61, P51, P68, and P79. Meanwhile, the last is the distance group (dx) with only one parameter, P67.

D. Dataset

The determination of the parameters is followed by the generation of four synthetic data for each using the DR method. Moreover, the dataset is developed by selecting values that closely resemble the real case with a focus on the raw values of four buildings, representing good, fair, and poor conditions.

E. Constructed Model

First, the overview of the relationships between the entities in the model [17] is presented through the class diagram in Fig. A1 in Appendix. It is observed that the building entity has several classes, including policy, retrofit, construction, and utilization. Moreover, the polymorphic association showing the similarities between attributes is also presented as observed by the consumption class operating as the parent for three types of consumption, including water, energy, and waste.

Second, the influence diagram presented in Fig. A2 in Appendix represents the DSM process. It determines the independent and dependent variables, grouping parameters, as well as the outputs of the model [18]. It is necessary because several parameters require independent variables, such as the actual and reference products for P67. Moreover, a set of parameters is grouped into categories, as observed from the two oval lines. The outputs of the model are represented in green rectangle at the final level of the diagram.

Third, AD provides a stepwise model workflow from the beginning to the end of the DSM-GBRS assessment process [19], as shown in Fig. A3 in Appendix. The algorithm is initiated by reading a set of data followed by grouping the parameters into four categories, including ax, bx, cx, and dx. Furthermore, the encoding process is applied to a parameter classified as ax to convert the input values in string format to numerical values. For example, the "Yes" or "No" response in the parameters is converted to "0" and "1".

The parameters in the bx group experience the FL process, which is initiated by reading MF and LV, fuzzifying using Eqs. (1)–(3), inferencing by reading the rule base using Eqs. (4)–(6), as well as defuzzifying using Eq. (7) [20]. In these equations, certain variables need to be explained. For μMF_{Low}, μMF_{Mid}, and μMF_{Up}, they represent the degree of truth of a precise value (x) within the LVs such as low, mid, and up. Within each LV, there are variables a, b, c, and d that refer to domain range of LV.

$$\mu MF_{Low}(x) = \begin{cases} 0, x \geq c \\ \frac{c-x}{c-b}, b \leq x \leq c \\ 1, x \leq b \end{cases}, \quad (1)$$

$$\mu MF_{Mid}(x) = \begin{cases} 0, x \leq 0 \text{ or } x \geq d \\ \frac{x-a}{b-a}, a \leq x \leq b \\ 1, b \leq x \leq c \\ \frac{d-x}{d-c}, c \leq x \leq d \end{cases}, \quad (2)$$

$$\mu MF_{Up}(x) = \begin{cases} 0, x \leq a \\ \frac{x-a}{b-a}, a \leq x \leq b \\ 1, x \geq b \end{cases}. \quad (3)$$

In Eq. (4), α_pred_i is used to combine the membership values from several fuzzy sets. Equations (5) and (6) contains the variable Z_i, which represents the output value of rule based i, along with $zmin$ (the minimum output LV's range

TABLE IV
THE RESULTS OF ENCODING FOR AX GROUP.

No.	P01	P02	...	P82	P83
1	1	1	...	1	1
2	1	1	...	1	1
3	0	1	...	1	1
4	0	0	...	1	1

TABLE V
THE FINAL RESULTS FOR THE CONVENTIONAL METHOD.

No.	P01			...	$\sum$ax
	P	W	V		
1	1	0.0155	0.0155	...	0.8140
2	1	0.0155	0.0155	...	0.5969
3	0	0.0155	0.0000	...	0.5271
4	0	0.0155	0.0000	...	0.2791

Note: Point (P), Weights (W), and Value (V).

domain) and $zmax$ (the maximum output LV's range domain). Finally, Z^* variable is the new crip output, typically calculated based on the weighted average.

$$\alpha\_pred_i = \mu MF_{low}(x) \cup \mu MF_{up}(x), \quad (4)$$

$$Z_i = zmax - \alpha\_pred_i(zmax - zmin), \quad (5)$$

$$Z_i = zmin - \alpha\_pred_i(zmin - zmax), \quad (6)$$

$$Z^* = \frac{\sum_1^n \alpha\_pred_i * Z_i}{\sum_1^n \alpha\_pred_i}. \quad (7)$$

Slope calculation is applied to determine the time series data of the parameters in the cx category [21]. The results obtained are compared to the values from other buildings using Relative Minimum (RM) calculation. The method is used to divide the building slope by the smallest value. The last category is dx, which contains parameters with two independent variables: reference and reality. In the reference variable, reality can have a value of 0 with further influence on the Euclidean Distance (ED) calculation error. A standard deviation of 0.05 is needed for each reference value to overcome this issue. The determination of new reference values is followed by the ED calculation [22]. Moreover, the RM of the parameters is calculated for all the categories before the values are combined to determine the most suitable decision on the green level of the building.

Fourth, the conventional calculation starts by encoding the ax group from “Y” or “N” into 1 or 0. The results are saved in the point (P) column and fully presented in Table IV. The next stage is the multiplication of the ax group by the respective weights (W) for each parameter using Eq. (8). The results from the calculation of P and W are presented in the value (V) column. Meanwhile, the final results of $\sum$ax are listed in Table V.

$$\sum ax = (p01 * WP01) + \ldots + (P83 * WP83). \quad (8)$$

Fifth, in Tsukamoto FIS calculation, it is initiated by setting a Membership Function (MF) that maps a range of values to a Linguistic Variable (LV). It is necessary to represent the degree of truth for the parameter values between 0 and 1 [23]. The nine MFs used are Ozone Depletion Potential (ODP), Global

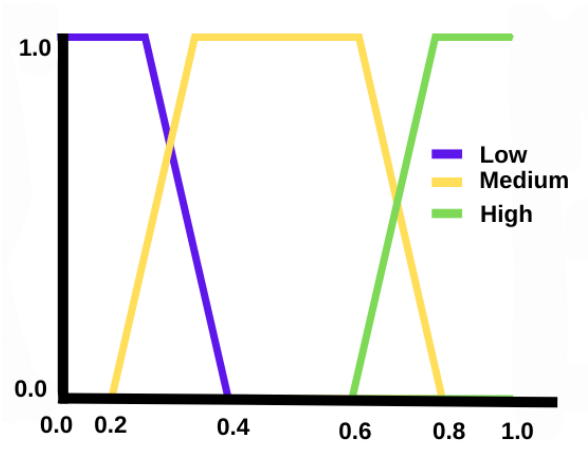

Fig. 4. Ozone Depletion Potential (ODP) Membership Function (MF) (P33).

Warming Potential (GWP), average energy increase, average water increase, maximum water lab month, temperature, humidity, decision value 1, and decision value 2. The type of MF used is trapezoidal, considering the range of the domain edge [24].

Figure 4 shows the ODP MF consisting of three trapezoidal MFs with a universe of [0, 1] as well as LOW, MEDIUM, and HIGH LVs at [0.0, 0.4], [0.2, 0.8], and [0.6, 1.0] domains, respectively. Moreover, Fig. 5 shows that the GWP MF also has three similar LVs with a universe of [0, 3500] as well as [0, 1400], [700, 2800], and [2100, 3500] domains, respectively.

Figures 6 and 7 show the average increase in energy and water MFs, respectively. It is also observed that both figures have three types of MFs marked with blue, yellow, and green colors. The blue color represents a linear down which is GOOD with a domain of [0.0, 0.2], a trapezoid considered MEDIUM with [0.1, 0.4], and a linear up designated as BAD with [0.3, 0.5].

Figure 8 shows the mapping of MFs on the maximum water lab month domain. A total of three LVs is identified, including NEW, MODERATE, and LONG, with [0, 12], [6, 24], and [18, 30] domains, respectively. The check conducted 30 months ago categorizes the last lab as LONG LV.

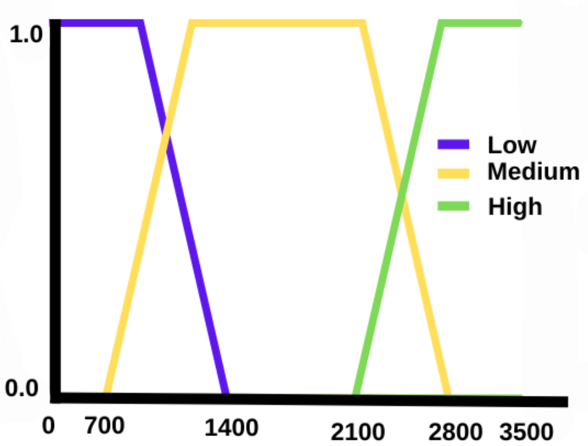

Fig. 5. Global Warming Potential (GWP) Membership Function (MF) (P34).

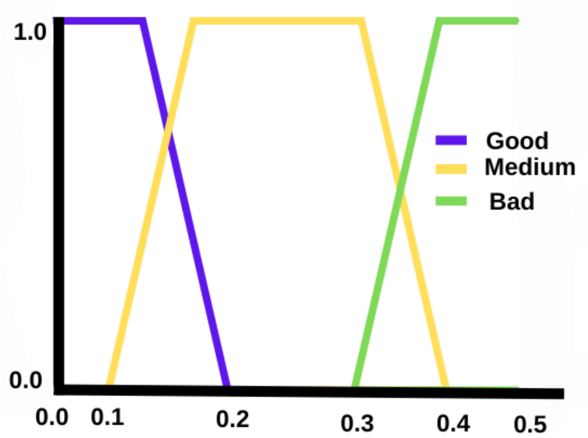

Fig. 6. Average Energy Increase Membership Function (MF) (P63).

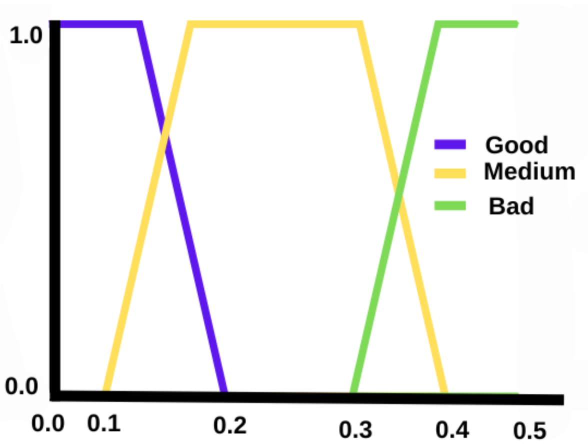

Fig. 7. Average Water Increase Membership Function (MF) (P69).

The parameters used in assessing the air quality of

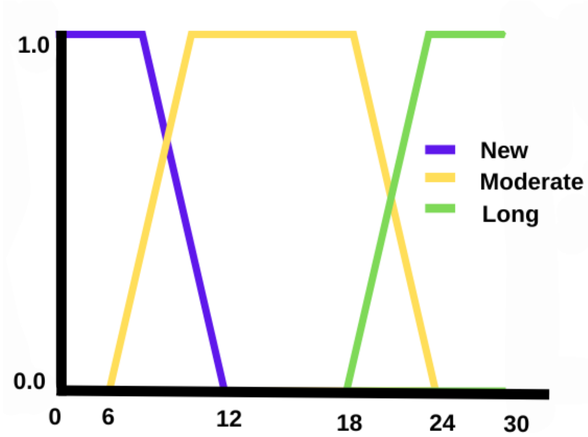

Fig. 8. Maximum Water Lab Month Membership Function (MF) (P71).

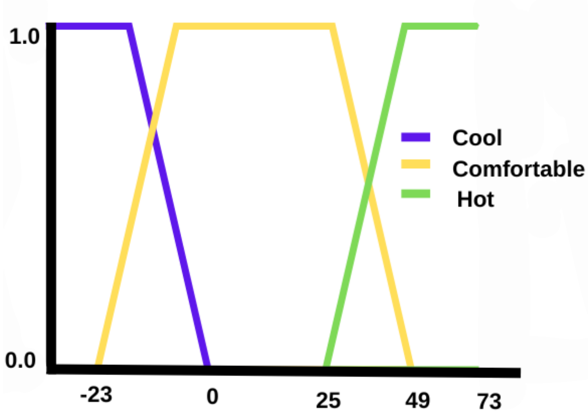

Fig. 9. Temperature Membership Function (MF) (P72).

building areas are temperature and humidity MFs. They are observed to have received maximum value when the parameters are under the COMFORTABLE LV, unlike the other MFs. When a crisp value is under the DRY or OVERCAST LV, the maximum value is not recorded.

Figure 9 shows that temperature has a universe of [-47, 73]. Moreover, the MF has three LVs, including GOOD, MEDIUM, and BAD, with [-47, 0], [-23, 49], and [25, 73] domains, respectively. The information presented in Fig. 10 shows that the humidity MF of a room is divided into three parts, including DRY with a domain of [-90, -10], COMFORTABLE [-40, 110], and OVERCAST [60, 160]. Furthermore, the membership universe of the MF is recorded to be [-90, 160].

Figures 11 and 12 show the Decision Value (DV) of MFs, represented by DV1 and DV2, with both having a universe of [0.0, 1.0]. It is observed that DV1 has three LVs, including BRONZE with a domain of [0.0, 0.4],

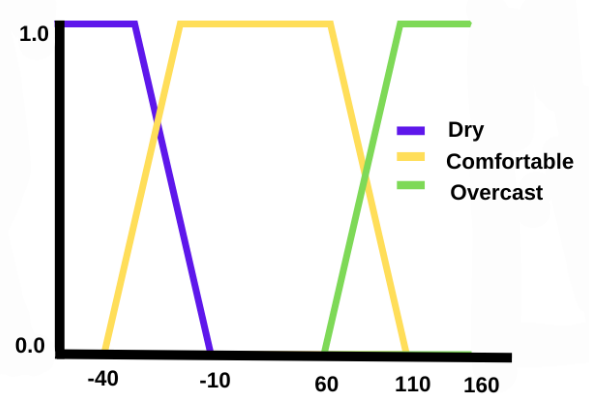

Fig. 10. Humidity Membership Function (MF) (P73).

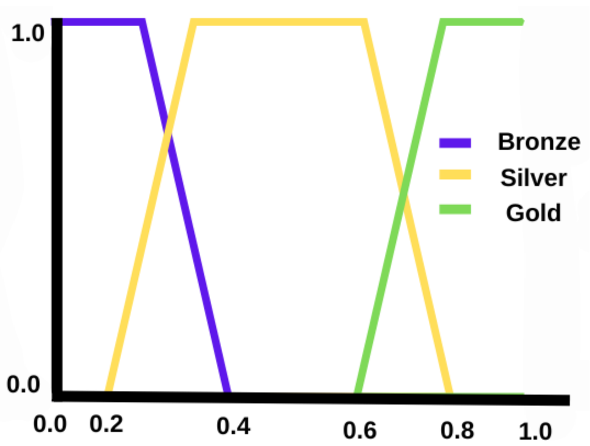

Fig. 11. Decision Value 1 Membership Function (MF) (DV1).

SILVER [0.2, 0.4], and GOLD [0.6, 1.0]. Meanwhile, DV2 has two LVs which are GOOD [0.0, 0.8] and BAD [0.2, 1.0]. The DV MFs are used to determine the output variable level based on the input.

The 19 fuzzy rules to determine DVs for each building are shown in Table VI. A total of 15 are used to determine the status of DV1 as GOLD, SILVER, and BRONZE, while the remaining 4 are applied to evaluate DV2 as GOOD and BAD. Each parameter has a set of rules. For example, P33 is observed to have 3 conditions, and P72 has 2.

The dataset for the bx group to be processed using the FL method is presented in Table VII. Meanwhile, the results of the calculation conducted are shown in the P column of Table VIII. Moreover, P is multiplied by W and stored in V as the final value of P33. The next stage is to determine the final value for the overall

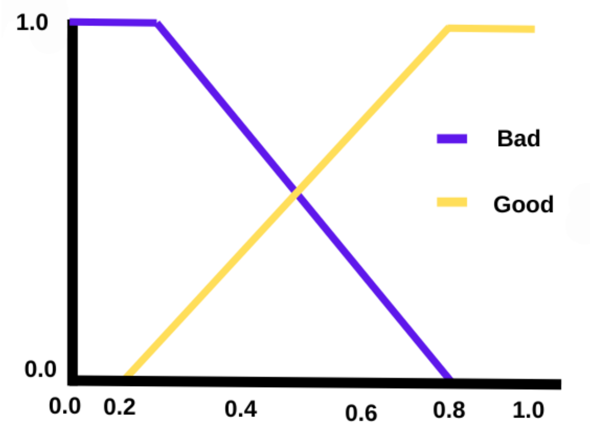

Fig. 12. Decision Value Membership Function (MF) (DV2).

TABLE VI
FUZZY RULES.

Parameter	Condition
P33	IF P33 is LOW, THEN decision value P33 is GOLD
P33	IF P33 is MEDIUM, THEN decision value P33 is SILVER
P33	IF P33 is HIGH, THEN decision value P33 is BRONZE
...	...
P73	IF P73 is DRY or P73 is OVERCAST, THEN decision value P73 is BAD
P73	IF P73 is COMFORTABLE, THEN decision value P73 is GOOD

TABLE VII
DATASET FOR BX GROUP.

No.	P33	...	P73
1	0.00	...	10
2	0.00	...	60
3	0.73	...	109
4	0.03	...	-41

TABLE VIII
FINAL RESULTS OF FUZZY LOGIC (FL) METHOD.

No.	P33			...	$\sum$bx
	P	W	V		
1	1.00	0.0155	0.0155	...	0.1047
2	1.00	0.0155	0.0155	...	0.0902
3	0.21	0.0155	0.0033	...	0.0231
4	1.00	0.0155	0.0155	...	0.0716

Note: Point (P), Weights (W), and Value (V).

$\sum$bx using Eq. (9).

$$\sum bx = (P33 * WP33) + \ldots + (P73 * WP73). \quad (9)$$

Next, Table IX shows the dataset for the cx group to be processed using the slope and RM methods. The results from the calculation are presented in the slope column of Table X. Moreover, the RM method is later

TABLE IX
DATASET FOR CX GROUP.

No.	P51			
	1	...	6	...
1	3000	...	1500	...
2	2000	...	3000	...
3	5500	...	6000	...
4	4000	...	6000	...

TABLE X
FINAL RESULTS OF THE SLOPE METHOD.

No.	P51					$\sum$cx
	Slope	P	W	V	...	
1	14.29	1.00	0.078	0.008	...	0.0360
2	171.43	0.08	0.078	0.001	...	0.0047
3	28.57	0.50	0.078	0.004	...	0.0242
4	342.86	0.04	0.078	0.000	...	0.0108

Note: Point (P), Weights (W), and Value (V).

TABLE XI
DATASET OF DX GROUP.

No.	P67	
	Reference + Std	Reality
1	5.25	5
2	52.50	0
3	26.25	30
4	10.5	10

TABLE XII
FINAL RESULTS OF EUCLIDEAN DISTANCE (ED) METHOD.

No.	P67			$\sum$dx
	ED	P	W	
1	0.25	1.00	0.031	0.0310
2	52.50	0.00	0.031	0.0001
3	3.75	0.07	0.031	0.0021
4	0.50	0.50	0.031	0.0155

Point (P) and Value (V).

applied to determine the point. The P is multiplied by the W and stored in the V as the final value of P51. It is followed by the application of Eq. (10) to determine the final value for the overall $\sum$cx.

$$\sum cx = (P51 * WP51) + \ldots + (P79 * WP79). \quad (10)$$

Table XI shows the dataset for the dx group processed using the ED and RM methods. The results are presented in the ED column of Table XII. The RM method is subsequently applied to determine the point. Moreover, P is multiplied by the W and stored in the $\sum$dx as the final value of P67.

TABLE XIII
PROPOSED DECISION VALUES (DV).

No.	Name	Performance (DV)	Level
1	Building A	0.99	Gold
2	Building B	0.69	Silver
3	Building C	0.57	Bronze
4	Building D	0.37	Bronze

F. Proposed Alternative Decisions

This section describes the proposed alternative decisions generated by the DSM-GBRS model using Eq. (11). The focus is on all buildings, and the results are presented in Table XIII. Moreover, the assessment provides more detailed information in evaluating green building performance through the categorization into four treatment types. Performance is placed on a range of 0 to 1. Building A has the highest at 0.99, while Building D records the lowest at 0.37.

$$DV = \sum ax + \sum bx + \sum cx + \sum dx. \quad (11)$$

G. Verified and Valid Decision Support Model-Green Building Rating System (DSM-GBRS)

Verification and validation tests are used [15, 25] to evaluate the DSM-GBRS model. The verification test is conducted to assess the accuracy of the model in line with the theory used with a focus on four elements, including formula, variable, procedure, and results. A $VeTi$ score of 1.0 is assigned to each element when the model and reference match. Therefore, the similarity between model and reference for ax, bx, cx, and dx is assessed using Eq. (12). In this formula, Ve represents the average value of verification tests, $\sum_{(i=1)}^{n} VeTi$ donates the sum of all verification test results, and n is the total number of the elements. The results in Table XIV show that the Ve is 1.0, showing the DSM-GBRS model is well-developed and accurate.

$$Ve = \frac{\sum_{i=1}^{n} VeTi}{n}. \quad (12)$$

The model is validated by comparing the values obtained with real field data based on the range described in Table XV. A $VaTi$ score of 1.0 is assigned to each element when the model and real field data match. The results show that all 83 parameters are validated, and the average Va obtained using Eq. (13) is 1.00. In this equation, Va represents the average value of a sets of variables $VaTi$, $\sum_{(i=1)}^{n} VaTi$ donates the sum of all validation test results, and n is the total number of the elements. It shows no discrepancies between the model

TABLE XIV
MODEL VERIFICATION.

Sub-Model	Element	i	Model	Ref.	$VeTi$
ax	Formula	1	1	1	1.00
	Variable	2	72	72	1.00
	Procedure	3	1	1	1.00
	Result	4	0–1	0–1	1.00
bx	Formula	5	4	4	1.00
	Variable	6	2	2	1.00
	Procedure	7	3	3	1.00
	Result	8	0 – 1	0 - 1	1.00
cx	Formula	9	2	2	1.00
	Variable	10	4	4	1.00
	Procedure	11	2	2	1.00
	Result	12	14.29–571,428.57	14.29–571,428.57	1.00
dx	Formula	13	2	2	1.00
	Variable	14	4	4	1.00
	Procedure	15	3	3	1.00
	Result	16	0.25 - 52.5	0.25 - 52.5	1.00
				Ve	1.00

Note: conventional group (ax), crisp group (bx), time series group (cx), and distance group (dx).

TABLE XV
MODEL VALIDATION.

i	Element	Model	Real	$VaTi$
1	P01	Y/N	Y/N	1.00
...	...	...	...	...
79	P79	$3000 \leq x \leq 13000$	> 0	1.00
...	...	...	...	...
83	P83	Y/N	Y/N	1.00
			Va	1.00

TABLE XVI
SUMMARY OF VALIDATION MEASUREMENT.

		Value		
		T	F	
Variable	T	TP (83)	FN (0)	Sensitivity (1.00)
	F	FP (0)	TN (0)	Specify (0.00)
		NPP (1.00)	NPN (0.00)	

Note: True (T), False (F), True Positive (TP), False Negative (FN), False Positive (FP), True Negative (TN), Number of Positive Predictions (NPP), and Number of Negative Predictions (NPN).

and the real data, implying 100% accuracy.

$$Va = \frac{\sum_{i=1}^{n} VaTi}{n}. \quad (13)$$

According to Table XVI, the measurement focuses on variables and values that have two comparable types, such as True (T) and False (F). The comparison matching pairs are True Positive (TP), False Negative (FN), False Positive (FP), and True Negative (TN). The sensitivity value of the model is 1.00, showing the existence of accurate parameter values without any discrepancies. The Number of Positive Predictions (NPP) value of 1.00 also signifies that the parameters are 100% correct, while the Number of Negative Predictions (NPN) value of 0.00 indicates that the values are 100% correct. Therefore, the data generated by the model are confirmed to be in line with the outputs compared to the existing parameters in the field.

IV. CONCLUSION

In conclusion, the research produces two results based on the questions formulated. First, the 83 parameters related to policy, retrofit, construction, and utilization aspects are identified and typically addressed using conventional methods. The parameters are further categorized into four groups, including ax as Boolean, bx to represent crisp, cx for time series, and dx to show distance. Each group is later subjected to FL, mathematical, and conventional treatments.

Second, the DSM-GBRS model is developed to evaluate green building performance. It uses the RM method to compare the parameters across different buildings. The Tsukamoto FIS method is also applied to handle Fuzzy values within the model. Moreover, a slope linear calculation is used to address the issues associated with time series data. The ED method is also used to handle the distance values within the model.

Previous studies primarily focus on conventional methods, but the present research provides a more detailed evaluation of green buildings by splitting the methods into different categories. However, certain limitations need to be acknowledged. First, the dataset used is synthetic. Second, the slope calculation method adopted is linear. Lastly, the trapezoidal membership function used in fuzzy analysis primarily focuses on linear sets. Hence, future studies can collect data through questionnaires in real-world settings, use non-linear slope methods to capture accurate trends when dealing with non-linear data and adopt Gaussian curve MF to obtain more flexible values.

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AUTHOR CONTRIBUTION

Writing—original draft, M. A. B. W. and D. N. U.; Methodology, M. A. B. W. and D. N. U.; Formal analysis, M. A. B. W. and D. N. U.; Analysis result review, D. N. U. All authors have read and agreed to the published version of the manuscript.

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APPENDIX

The Appendix can be seen in the next page.

TABLE A1
POLICY PARAMETERS.

Code	Name	Detail	Raw Value	Point
P01	Public Transport	Supporting public transport	Y/N	2
P02	Energy Management	Energy-saving policy	Y/N	3
P03	Paint Material	Eco-friendly paint purchasing policy	Y/N	2
P04	Paper Material	Eco-friendly paper purchasing policy	Y/N	2
P05	Reusable Goods	Used goods distribution policy	Y/N	1
P06	Cleaning Material	Eco-friendly air freshener policy	Y/N	3
P07	Plastic Restriction	Plastic use prohibition policy	Y/N	1
P08	Water Saving	Having a water-saving Standard Operating Procedure (SOP)	Y/N	1
P09	No Smoking Commitment	Commitment to a smoke-free environment policy	Y/N	1
P10	Waste Management	Waste management policy	Y/N	1
P11	Wastewater Management	Wastewater management policy	Y/N	1
P12	Expert Management	Legal entity or expert-powered management	Y/N	1
P13	Retrofit Expert Certified	Certified experts for retrofitting	Y/N	1
P14	Maintenance Operation	Having an SOP for operations and maintenance organizational structure	Y/N	1
P15	As Built Drawing	Having as-built drawings	Y/N	1
P16	Building Management Performance	Carrying out maintenance according to SOP with good performance	Y/N	1
P17	Operational Log Book	Documenting results and operational parameter data in a logbook	Y/N	1
P18	Periodic Maintenance	Conducting regular building inspections	Y/N	1
P19	Emergency Procedure	Having an emergency response SOP	Y/N	1
P20	Maintenance Training	Maintenance training for managers	Y/N	2
P21	Excellent Service Training	Providing training for excellent service	Y/N	2

TABLE A2
RETROFIT PARAMETERS.

Code	Name	Detail	Raw Value	Point
P22	Air Conditioner (AC) Setting	AC and non-AC room setting	Y/N	2
P23	AC Standard	Temperature control at 25°C $\pm$1°C and relative humidity at 60% $\pm$10%	Y/N	1
P24	Switch Area Coverage	Having one switch for every 30 m^2	Y/N	1
P25	Electrical Load Grouping	Having a kWh meter for each group of electrical loads	Y/N	1
P26	Building Management System (BMS)	Having a centralized air conditioning system with a BMS	Y/N	2
P27	Renewable Energy Source	Using renewable energy sources	Y/N	1
P28	Ground Water Meter	Installing the water meter on the groundwater output system	Y/N	1
P29	Saving Water Consumption	Calculating water conservation plans in the form of a water balance sheet	Y/N	1
P30	Water Fixture Planning	Planning to procure water-saving products	30	4
P31	Free Smoke Commitment	Commitment to a smoke-free environment	Y/N	1
P32	Separated Smoking Area	Smoking areas separated from the building	Y/N	2
P33	Ozone Depletion Potential (ODP)	Regulation of ODP refrigerant	[0.0, 1.0]	2
P34	Global Warming Potential (GWP)	Regulation of GWP refrigerant	[0, 3500]	2
P35	Reduce Reuse Recycle (3R) Commitment	Commitment to the 3R principles	Y/N	1
P36	Rubbish Bin Provision	Rubbish bins for both individual and communal use	Y/N	1
P37	Temporary Garbage Place	Availability of a temporary garbage place	Y/N	2
P38	Independent Waste Management	Waste management is carried out independently or by a third party	Y/N	1
P39	Waste Volume Recording	Recording of waste volumes	Y/N	1

TABLE A3
CONSTRUCTION PARAMETERS.

Code	Name	Detail	Raw Value	Point
P40	Initial Working Plan	Construction project work initiation planning	Y/N	1
P41	Continuing Project Improvement	Having continuous project improvements	Y/N	1
P42	Data Integration Building	Integrating data with the BMS	Y/N	1
P43	Innovate Green Construction	Innovation for eco-friendly construction	Y/N	1
P44	Innovate Green Operation	Innovation for eco-friendly building operations	Y/N	1
P45	Fuel Efficiency	Implementing fuel efficiency for construction equipment	Y/N	1
P46	Construction Technology	Optimizing technology in construction equipment	Y/N	1
P47	Safety Material Construction	Protection against falling construction materials	Y/N	1
P48	Expected Waste Calculation	Calculating construction waste	Y/N	1
P49	Waste Sorting	Sorting construction waste by type	Y/N	1
P50	Danger Waste Location	Providing a dedicated location for hazardous waste materials	Y/N	1
P51	Waste Usage	Monitoring of the last six months (m3)	10 (1) ... 10 (6)	1
P52	Waste Construction Principle	Applying the 3R principles to construction waste	Y/N	1
P53	Copy Shop Drawing	Submitting a copy of the shop drawings	Y/N	1
P54	Copy List Approval Material	Submitting a copy of the material approval list	Y/N	1
P55	Testing And Commission Report	Reporting testing and commissioning results	Y/N	2
P56	System Tool Operation Report	Reporting the results of equipment system usage training	Y/N	1
P57	Main Equipment Warranty	Warranty certificate for major equipment	Y/N	1
P58	Manual Tools Documentation	Possessing operation and maintenance manuals for equipment systems	Y/N	3
P59	Valid As Build Drawing Report	Submission of valid as-built drawings	Y/N	4

TABLE A4
UTILIZATION PARAMETERS.

Code	Name	Detail	Raw Value	Point
P61	Energy Usage	Monitoring of the last six months (Rp)	5000 (1) ... 4500 (6)	2
P62	Lift Maintenance Scheduling	Performing regular maintenance on lifts	Y/N	1
P63	Average Energy Increasing	10% saving of reference	5000	1
P64	Recommissioning	Performing re-commissioning every six months	Y/N	3
P65	No Addition Ground Water Volume	No additional groundwater sources added after construction	Y/N	2
P66	Water Meter Procedure	Compliance of the water meter, including its functionality	Y/N	2
P67	Product Fixtures	Comparing reference and reality products	12 and 10	4
P68	Water Usage	Monitoring of the last six months (Rp)	1000 (1) ... 1200 (6)	2
P69	Average Water Increasing	10% saving of reference (m3)	1000	1
P70	Ground Water Percentage	Use of well water at a maximum of 20%	Y/N	1
P71	Max Water Lab Month	Last date of the laboratory	5/4/2022	1
P72	Temp	Room temperature	22°C	2
P73	Humidity	Room humidity	55%	2
P74	No Smoking Warning	Warning about smoking hazards and smoking areas separated from the building	Y/N	1
P75	Waste Sorting	Carrying out waste sorting	Y/N	3
P76	Rubbish Bin Provision	Providing trash bins	Y/N	3
P77	Temporary Garbage Dump	Providing temporary garbage dump	Y/N	1
P78	Full Waste Dump Checking	Ensuring that waste does not accumulate at the temporary storage facility	Y/N	1
P79	Waste Usage	Monitoring of the last six months (m3)	10 (1) ... 10 (6)	1
P80	Recycled Water Lab	Checking the quality standards of treated wastewater from the wastewater treatment plant	Y/N	2
P81	Green Building Socialization	Awareness-raising about eco-friendly buildings	Y/N	1
P82	Green Achievement Publication	Information board about the building’s sustainability	Y/N	1
P83	Customer Satisfaction Survey	Operational and maintenance survey	Y/N	4

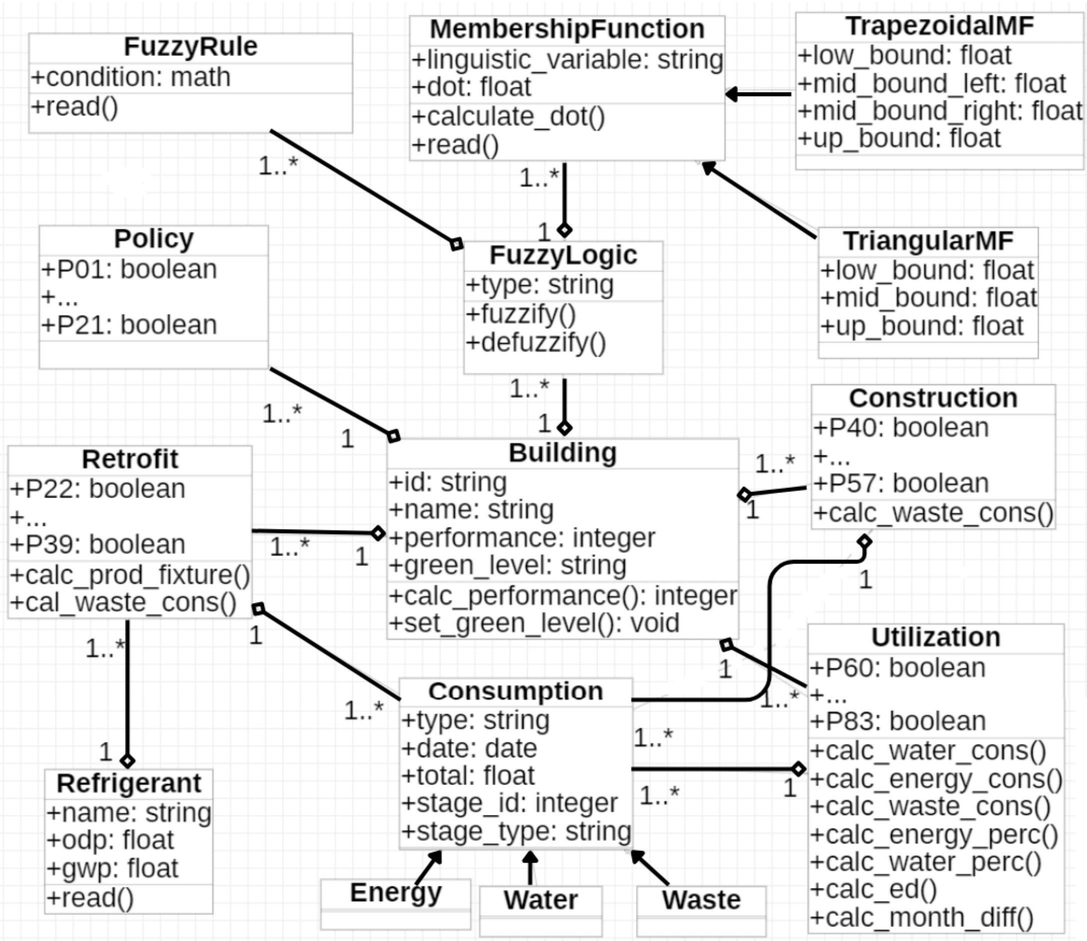

Fig. A1. Class Diagram for Decision Support Model-Green Building Rating System (DSM-GBRS).

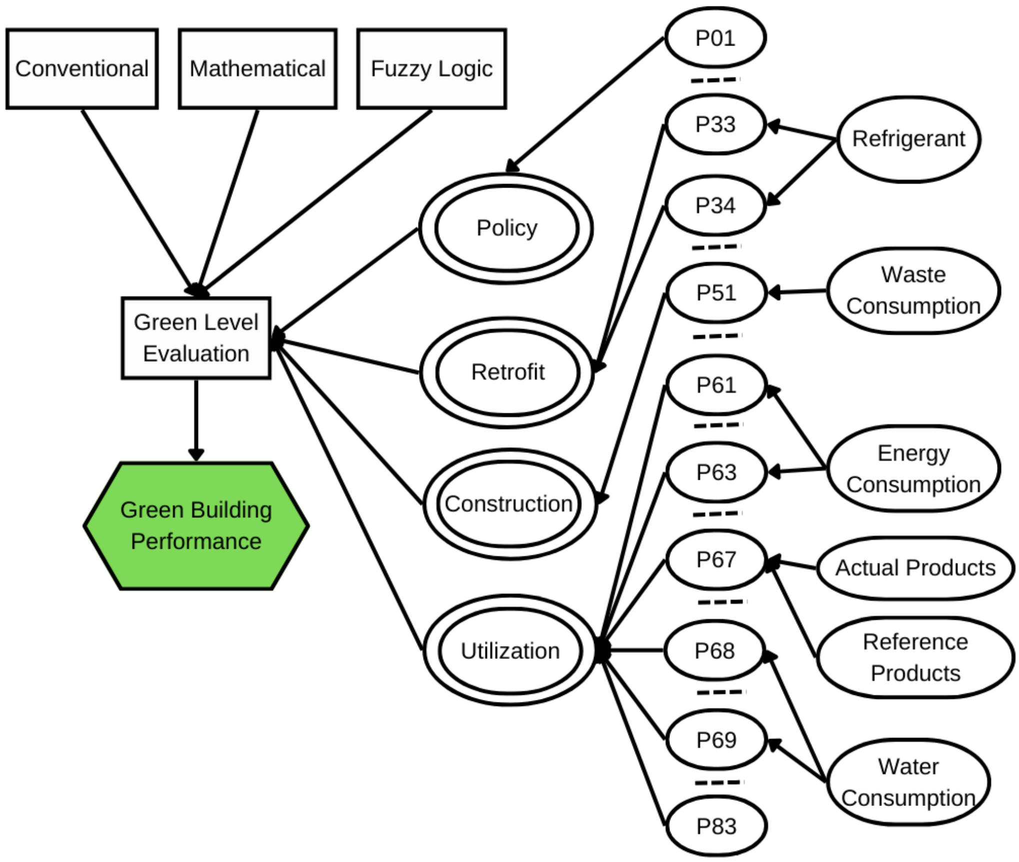

Fig. A2. Influence diagram to show parameter relationship.

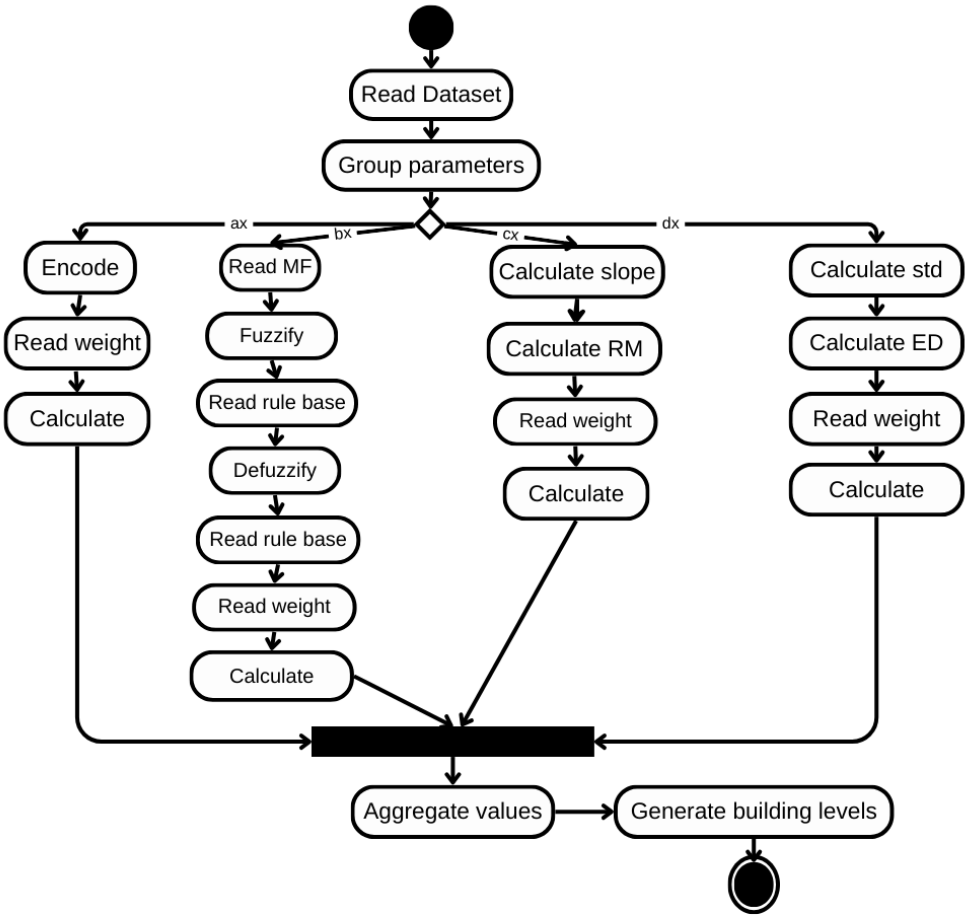

Fig. A3. Activity Diagrams (AD) of model algorithm.