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USING FUZZY COGNITIVE MAPS FOR MODELING ENVIRONMENTAL ASPECT OF SUSTAINABLE DEVELOPMENT IN CONSTRUCTION PROJECTS

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ABSTRACT
The pillars of sustainable development are representing the interface between environmental, economic, and social sustainability. Sustainable development is a method of planning and managing construction projects to reduce the effect of the construction process on the environment so that there is a balance between environmental capabilities and the human needs of present and future generations. Usually, Environmental sustainability is most important and effective in construction projects. The environment suffers from significant negative impacts as a result of the implementation of construction projects; therefore, this study aims to identify the effecting factors on environmentally sustainable development. The methodology of this study used fuzzy cognitive maps (FCMs) because of adopted simulation approach, after selecting the factors that have RII more than 65% and determine causal relationship between factors by applying fuzzy logic using MATLAB program. Then the effecting factors were analyzed and ranked by static and dynamic analysis. The results showed the static analysis of effecting factors on ESD in first quarter are characterized by influential and affected by other factors of (ESD), were include ($C_{2.4}$, $C_{4.6}$, $C_{1.6}$, $C_{2.1}$, $C_{3.3}$, $C_{3.7}$, $C_{3.6}$, $C_{6.2}$), When comparing between dynamic analysis and RII of the factors, it has been noticed a difference in the importance. This is an essential finding in the understanding that dynamic analysis considers the interactions between factors, while the RII takes the reasons independently and neglects interactions between them. The study has provided recommendations for the application of (FCM) model that was proposed depend on these factors in building projects to improve the environment and reduce its negative effects.
Keywords: *Fuzzy Cognitive Map, Sustainable Development, Static Analysis, Dynamic Analysis, Relative Importance Index.*

1. Introduction

Environmental sustainability is one of the essential principles of sustainability, which warrants that the quest for satisfying our needs should not compromise the quality of the environment, and the ecosystem should be sustained for the sake of future generations. Incorporating environmental sustainability principles in operations can enhance organizations' value and make digitalization more valuable(Feroz et al., 2021; Kasayanond et al., 2019).

The concept of sustainable development aimed at solving modern problems and preventing them in the future was developed in order to find ways out of the situation that has arisen at the border of the 21st century. The term "Sustainable Development" comes from the English language, and it can be translated as steady, sustained, developing, and continuous development. More than a hundred expressions of this concept can be found in the literature. Its most commonly used expression is from the 1987 lecture entitled "Our Common Future". According to him, "Sustainable development" means development that is carried out without harming the needs of the present generation without harming the needs of future generations. The concept of Sustainable Development of the United Nations, which is now widely recognized throughout the world, was approved in 1992 in Rio de Janeiro, which was considered one of the largest meetings of world leaders (Uralovich et al., 2023).

Under the conditions of modern urbanization, one of the main sources of environmental pollution includes project developers and title holders of buildings and structures. Such entities not only consume energy resources, but also produce a tremendous amount of carbon dioxide emissions and solid waste. In order to ensure sustainable development of urban and rural areas of the regions, by maintaining citizens high standard of living, an inalienable requirement will be to maintain stabilization of the state of natural systems and environmental quality (Dzhidzhelava & Fedina, 2020).

According to the United Nations Development Programmed (UNDP), between the years of 2000 and 2016, the number of people worldwide without access to electricity decreased to below one billion and was reduced from 22% to 13%. The UN has predicted that the global population growth rate will decline from +1.0% in 2020 to +0.5% in 2050 and will exceed 10 billion in 2100. Yet as the global population grows, so will the necessity for a_ordable energy. Capitalizing on renewable energy technologies and in energy saving, promoting best practices for increasing Negawatts, and ensuring energy for all constitutes a set of major goals, not only for the Energy Union of the EU, but as well for the sustainability development goals (SDG) of UNDP. Increasing infrastructure and improving technology to allow affordable, green, and efficient energy worldwide will enable the growth and support the environment (Fokaides et al., 2020).

The research team then considered how sustainability was studied in construction projects. One important study demonstrated how construction projects are undertaken to attain more sustainable buildings and infrastructure. Sustainable construction typically introduces a focus on the reduction of harm to the environment, and might incorporate elements such as the prevention, reuse, and management of waste, with direct benefits to society, and with less focus on profitability (Gayen et al., 2024; Kiani Mavi et al., 2021).

Sustainability in construction is no longer considered as an add-on factor; it has undoubtedly turned into a necessity in order to respond to the existing challenges such as global warming and rarity of resources as well as the need to achieve more competitive construction industry (Orieno et al., 2024) (Jiya & Georgina, 2023).

The environment suffers from negative impacts resulting from the implementation of construction projects due to the limited use of natural resources in construction, such as wind energy, solar energy, hydropower, building materials, ventilation, and the proportion of green spaces compared to the total area of the project.

This study aimed to model the factors that achieve environmental sustainability in construction projects using fuzzy cognitive maps that depend on the simulation method by static and dynamic analysis. This study is considered an addition to the field of knowledge to achieve sustainable projects.

2. Literature Review

Many studies were conducted in the field of environmental sustainability development ESD in construction projects. The study of (Nasirzadeh et al., 2020) were used six guidelines for assessing the green building such as, appropriate land use (ASD), energy efficiency and conservation (EFC), water conservation (WAC), material sources and cycles (MRC), air quality and space comfort (IHC), and building environmental management (BEM). These are representing a benchmark for green buildings; a check is carried out to determine the rating of the building. The evaluation process is conducted by distributing questionnaires. The fuzzy system and Matlab application were used in this study to model various factors affecting the social sustainability of a project. The results showed that the analysis by MS Excel and modelling with a fuzzy system in the Matlab application gave the same expected values. The effecting factors on social dimension of sustainability were identified firstly, and the interactions among of these factors were also identified then dynamic and static analysis to determine the influencing factors. Finally, the factors that should receive the highest attention to improve the social sustainability performance of construction projects are determined using static analysis.

The (Abdel-Basset et al., 2021) study concern on aspect and indicators of sustainable design for GBs in developing countries to reach the positive aspects of project sustainability, such as energy conservation and natural resources, management of water, adapt to the environment, and achieve the user requirement. Delphi method was used to identify the dimensions and their indicators furthermore providing priority among sub-indicators. The analytical hierarchy process AHP was conducted to determine the relative importance index RII and assess the dimensions and indicators. The results shows that the water efficiency aspect is the most important, with a weight of 0.33, while the energy efficiency aspect is the least important for GBs in developing countries, with a weight of 0.10. It was concluded there are a set of administrative implications for applying sustainable development strategies in GB.

The study of (Gayen et al., 2024) aimed to explores the environmental effects of renewable energy and exploring their role in dedicating sustainable development. The solar energy, wind energy, hydropower, and biomass energy, were analyzed and assessing to identified their advantages and challenges in mitigating greenhouse gas emissions, reducing environmental harm, and fostering long-term sustainability. Also, this study explores several technologies inspired by these energy sources, such as solar energy, aeration, smart networks, and their latest contributions to decline environmental risk. There are several barriers stand in the way of development, including the deficit of governments and organizations to finance renewable energy sources. The factors contributing to increase the sustainable energy, evaluate the challenges, and explore the potential for a more sustainable energy future. This study review article comprehensively examines the originality within the sustainable energy aspect, offering valuable insights into the latest advancements and their implications for a more sustainable energy future.

(Horzela-Miś & Semrau, 2025) addressing role of renewable energy and storage technologies in sustainable development. The methodology of this study depends on simulation in the construction industry, A 26-year simulation was conducted to analyze the execution of a PV system in an industrial setting. The research evaluated energy efficiency, cost saving, and environmental benefits by modeling energy consumption, production, and storage dynamics. The feasibility of financial was determined using performance indicators such as return on investment, payback period, and levelized cost of electricity. The study concluded that PV system mitigates electricity expenses and reliance on grid power, achieving a payback period of approximately 9.4 years, reduce CO_2 emissions. Moreover, the PV adoption enhanced energy independence, covering 53.3% of the company's energy needs while minimizing operational costs.

The study of (Datta et al., 2023) aimed to fill gap between architecture, engineering, and construction (AEC) sectors by integrate various technologies, methodologies, and concepts. 46 factors were identified associated with benefits and 21 factors engage with obstacles were obtained. Most effected factors are promoting carbon emission reduction and improvement material wastage reduction that top environmental benefits of implementing BIM in sustainable construction projects. The popular economic benefits were enhancing design efficiency, minimizing the overall project costs, and improving productivity, while the most important social benefit was improving project safety and health performance. On the other hand, the main barrier to BIM implementation in sustainable construction projects its insufficient of experts. Thus, the findings assist the BIM and sustainability integration's benefits and barriers for a better and sustainable construction industry.

In 2020 (Onubi et al., 2020) investigate the impact of green construction site practices on environmental performance of construction projects in Nigeria. The impact of three green building site practices namely energy management, materials management and waste management on environmental performance were analyzed. 168 questionnaires forms were adopted to site managers and project managers. The data collections were analyzed using partial least squares-structural equation modelling. The results shows that waste management has an insignificant effect on environmental performance, while materials management and energy management have positive effects on environmental performance. Also, the results indicate that not all sustainable construction site practices lead towards the attainment of environmental performance. The study has both theoretical and practical implication that helps policy makers and contractors to better understand the relationships that exists between these variables of sustainable construction site practices as well as environmental performance. This is essential in order to come out with a better plan for their projects and formulation of appropriate policies.

The main objective of study of (Alola et al., 2023) address the role of non-renewable energy efficiency and renewable energy in environmental sustainability in India from period 1965 to 2018. The Dynamic Autoregressive Distributed Lag (DyARDL) approach was used; the empirical evidence shows that non-renewable energy efficiency and renewable energy utilization promotes environmental sustainability through an increase in the load capacity factor. The effects of financial development and trade impede environmental sustainability through a decrease in the load capacity factor. The output show that the relationship between income and load capacity factor are characterized by an inverted U-shape. This suggests that the load capability curve (LCC) hypothesis is not valid for India. Given the overall findings of this study, it is suggested that policymakers should promote energy efficiency and renewable energy technologies as the ultimate policy measure to mitigate the accumulation of CO_2 emissions and other significant climatic changes in India.

Most of previous studies have addressed the role of renewable energy and its impact on sustainable environmental development in the construction sector. Various techniques and methodologies were used, the most prominent of which are (fuzzy logic, Delphi method, analytical hierarchy process, etc.) to achieve the main objectives represented by sustainable environmental aspects in the field of construction. It was concluded that there are factors that positively affect environmental sustainability and reduce negative impacts on the environment, which are recommended to be taken into consideration in the planning, design and implementation stages of construction projects. While this study aimed to model the environmental factors of sustainable development through the use of fuzzy knowledge maps that depend on the simulation method and conducting static and dynamic analysis of the factors that most affect the sustainable environment. This study is considered a complement to previous studies and a new addition to the field of knowledge by proposing a model of fuzzy knowledge maps, especially since few previous studies used fuzzy logic in factor analysis and did not present or propose a model of fuzzy inference maps and comparison between static and dynamic analysis.

3. Fuzzy cognitive maps

Table 1 illustrated definitions of term fuzzy cognitive map FCM which is related to the current study.

Table 1 - Definition of FCM

Author	Country	**Definition**
(Jiya & Georgina, 2023; Nápoles et al., 2018)	Belgium	A mixture of neural networks, cognitive mapping and fuzzy logic as a form to define details of systems distinguished by causality, uncertainty and complicated approaches.
(Yoon & Jetter, 2017) (Jiya & Georgina, 2023)	USA	A semi-quantitative system modelling technique that is used in technology management to capture, synthesize and analyses expert and stakeholder knowledge for the purpose.
(Bhutani & Kumar, 2015) (Winanda et al., 2024)	India	Reasoning networks represented by directed graphs. A directed graph describes (Fcm) with feedback, which includes a group of concepts and directed weighted arcs linking concepts. The signed weights related to the directed arcs illustrate the kinds and the causalities magnitudes among nods.

FCMs are most beneficial when the data are unsupervised in its initial form (Jahantigh et al., 2018). There are two basic features(Papakostas et al., 2012).

A. Causal relationships between nodes are not clear rather than using signs to prove negative or positive causes.
B. Dynamic systems characterize by feedback, Fig. 1 shows a FCM eight edges and five nodes (factors). Each interconnection between two nodes Ci and Cj has a weight Wij, that strength of Wij indicates how strongly factor Ci affect factor Cj. The sign of Wij indicates whether the relationship between factors Ci and Cj is direct or inverse(Stylios & Groumpos, 1998). Therefore, three possible types of causal relationships between two nodes Ci and Cj(Furfaro et al., 2010). Therefore, using fuzzy cognitive maps in modeling sustainable environmental factors reduces negative environmental impacts and reduces energy consumption, in addition to improving ventilation and internal lighting of the building, by modeling the primary and secondary factors and identifying the interconnected relationships between them.

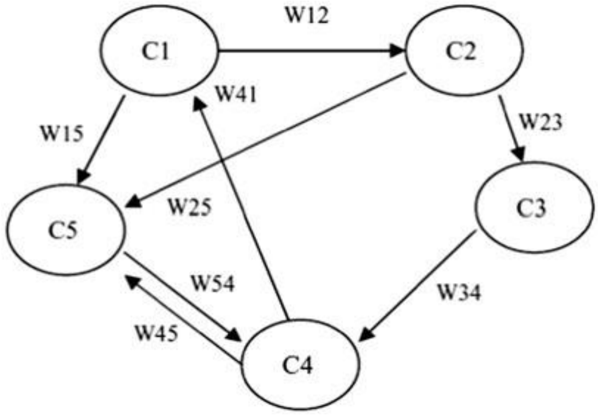

Fig. 1. An example of FCM

When:

$W_{ij} > 0$, it indicates a direct causal relationship.

$W_{ij} < 0$, it indicates an inverse causal relationship.

$W_{ij} = 0$, it indicates no relationship exists.

4. Methodology of study

Fig. 2 represents the methodology of study was followed to achieve the aim of this study.

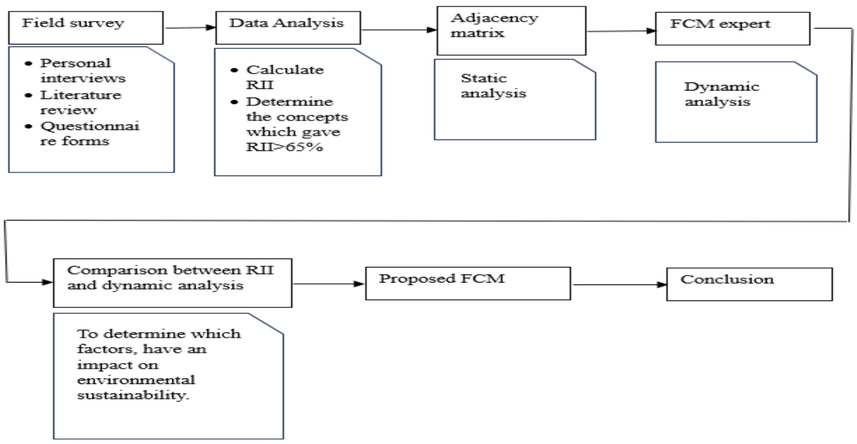

Fig. 2. Methodology of study

5. Field survey

The following steps were conducted to determine the RII for effecting factors on ESD:

a) Personal interviews

The personal interviews were conducted with owners, consultant, and contractors those with experience in the construction field.

b) Previous studies and literature

Most of factors and information were have been taking through literature reviews, which arranged between period 2019 to 2025.

c) Questionnaires form

The questionnaire forms were distributed on 100 respondents, those working in public and privet sectors. The respondents' have multidisciplinary such as civil, environment, electrical, etc.

4.1 Time limitation: The historical information covered the period from 2019 to 2025.

4.2 Spatial limitation: This study was limited to residential and industrial projects.

6. Data analysis

The SPSS program was used to determine the arithmetic men and Eqs. 1 and 2 were used to calculate the RII, with a five-point Likert scale quantified(Jarkas & Mubarak, 2016).

$$RII= \sum \frac{W}{AN} * 100 \qquad (1)$$

RII=$\frac{5m_5+4m_4+3m_3+2m_2+m_1}{5N}$ (2)

Where:
W: Wight of item, range from 1 to 5
A: Highest wight (5 in 5-point Likert scall)
N: Total number of respondents
(m1; m2; m3; m4; and m5): Number of respondents who selected (very low, low, medium, high, very high) respectively, and level of relative importance is describe in Table 2.

Table 2 - Level of relative importance

Value	Importance level	
0.81≤RII≤1	Very high	VH
0.61≤RII≤0.8	High	H
0.41≤RII≤0.6	Medium	M
0.21≤RII≤0.4	Low	L
0≤RII≤0.2	Very low	VL

Fig. 3 shows the academic degree of respondents and refers to the verity of scientific degree, and about half of study sample have B.Sc. degree.

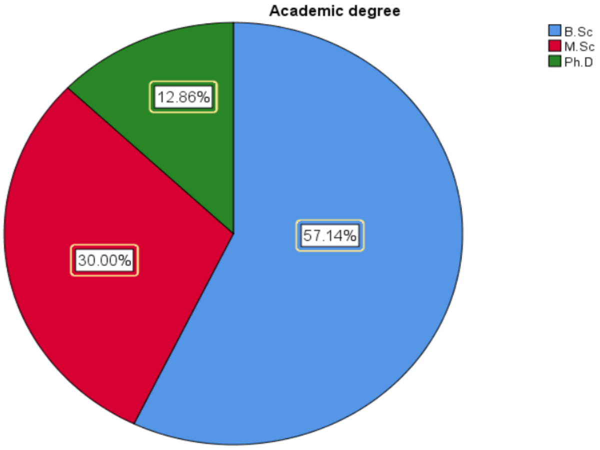

Fig. 3. Academic degree of respondent

41.43% of study sample have experience in the field side it arranged between 11 – 15 years, that indicate the responders have a sufficient expert in construction projects, as shown in Fig (4).

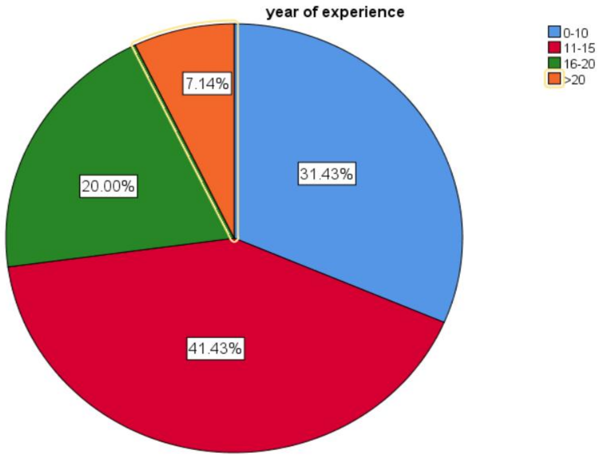

Fig. 4. Years of experience in construction

The study sample includes various specializations such as, civil, electrical, Mechanical, environmental and other. Civil engineering takes a higher percentage by 48.57%, as shown in Fig. 5.

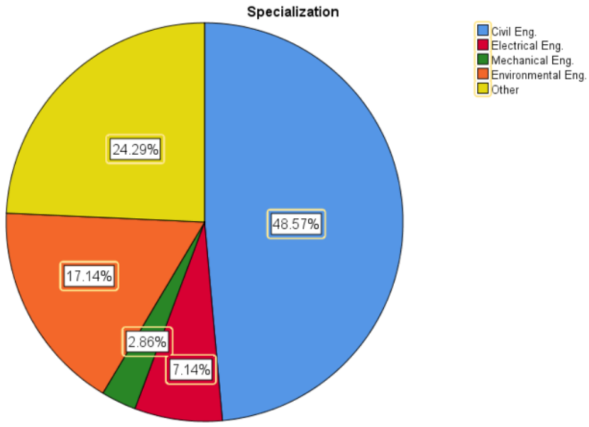

Fig. 5. Engineering specialization of study sample

Table 3 illustrates the (RII) of each affecting factor on environment sustainable development, these factors were classified in to six categories. The most important factors from land use are (Conservation of natural reserves, Balance between building area and green area, Taking into account urban density) range in RII (0.70 - 0.82). Whereas the energy related factors are (Use of renewable electricity source, shape and orientation in design to facilitate nature lighting, use reflective roofs or light color to reduce cooling need, use alternative energy source such, solar, wind, biomass, tidal power, and geothermal energy) range in RII (0.74- 0.88). Then material related factors are (using locally produced materials, adopt reused and recycle materials, use materials with zero or low off- gassing, use materials characterize with high durability, using natural materials, use renewable materials) arranged between (0.70 -0.83). The most significant factors from water management are (reduce water pollution, using water to produce alternative energy, dams' construction) range in RII (0.82- 0.86). Whereas the indoor air quality related factors include (use cleaning supplies during project operation) range in RII (0.68). Finally, the occupant health and comfort related factor involves the accessible natural light to building and Noise insolation by 0.77 and 0.74 respectively.

Table 3. RII of effecting factors on ESD

Factors	**Discerption**	**RII**
C1	Land use related factors	
C1.1	Floor area of project compared to land area used	0.57
C1.2	Effect of project on the soil around it	0.54
C1.3	The impact of the project on the recreational value of the land	0.54
C1.4	Conservation of natural reserves	0.82
C1.5	Balance between building area and green area	0.79
C1.6	Taking into account urban density	0.70
C1.7	Taking into account green areas when establishing the project	0.55
C1.8	Site selection that suits with nature of project	0.5657
C2	Energy related factors	
C2-1	Use of renewable electricity source	0.88
C2-2	Shape and orientation in design to facilitate nature lighting	0.74
C2-3	Use reflective roofs or light color to reduce cooling need	0.80
C2-4	Use alternative energy source such, solar, wind, biomass, tidal power, and geothermal energy	0.77
C3	Materials related factors	
C3-1	Use raw materials that can be easily extracted	0.50
C3-2	Using locally produced materials	0.78
C3-3	Adopt reused and recycle materials	0.83
C3-4	Use materials with zero or low off- gassing	0.82
C3-5	Use materials characterize with high durability	0.70
C3.6	Using natural materials	0.75
C3.7	Use renewable materials	0.88
C4	Water management related factors	
C4-1	Dual plumbing design for water reuse or a gray water system	0.50
C4-2	Rainwater collection facilities	0.57

C4-3	Reduce water pollution	0.86
C4-4	Point of use hot water heating system used for distant location	0.46
C4-5	State of the art irrigation controllers used to conserve water	0.45
C4.6	Using water to produce alternative energy	0.82
C4.7	Construction of dams	0.82
C5	Indoor air quality related factors	
C5-1	Low emitting materials used in the interior	0.52
C5-2	Use cleaning supplies during project operation	0.68
C5-3	Installing the CO, CO2, monitoring system	0.42
C5-4	Use operable windows for natural ventilation	0.50
C5-5	Use moisture control system	0.46
C6	Occupant health and comfort related factor	
C6-1	Accessible natural light to building	0.77
C6-2	Noise insolation	0.74
C6-3	Use low toxicity materials	0.54

7. Result and discussion

After determining the (RII) of each factor on environmentally sustainable development and select the factors that have RII more than 65%, the causal relationship between factors and their interaction will be analyzed. Fuzzy cognitive map FCMs can be used as tools for static and dynamic analysis. Five experts working in public and privet sector, have been interviewed. They have at least 15 years of experience in civil engineering as illustrated in Fig. 6.

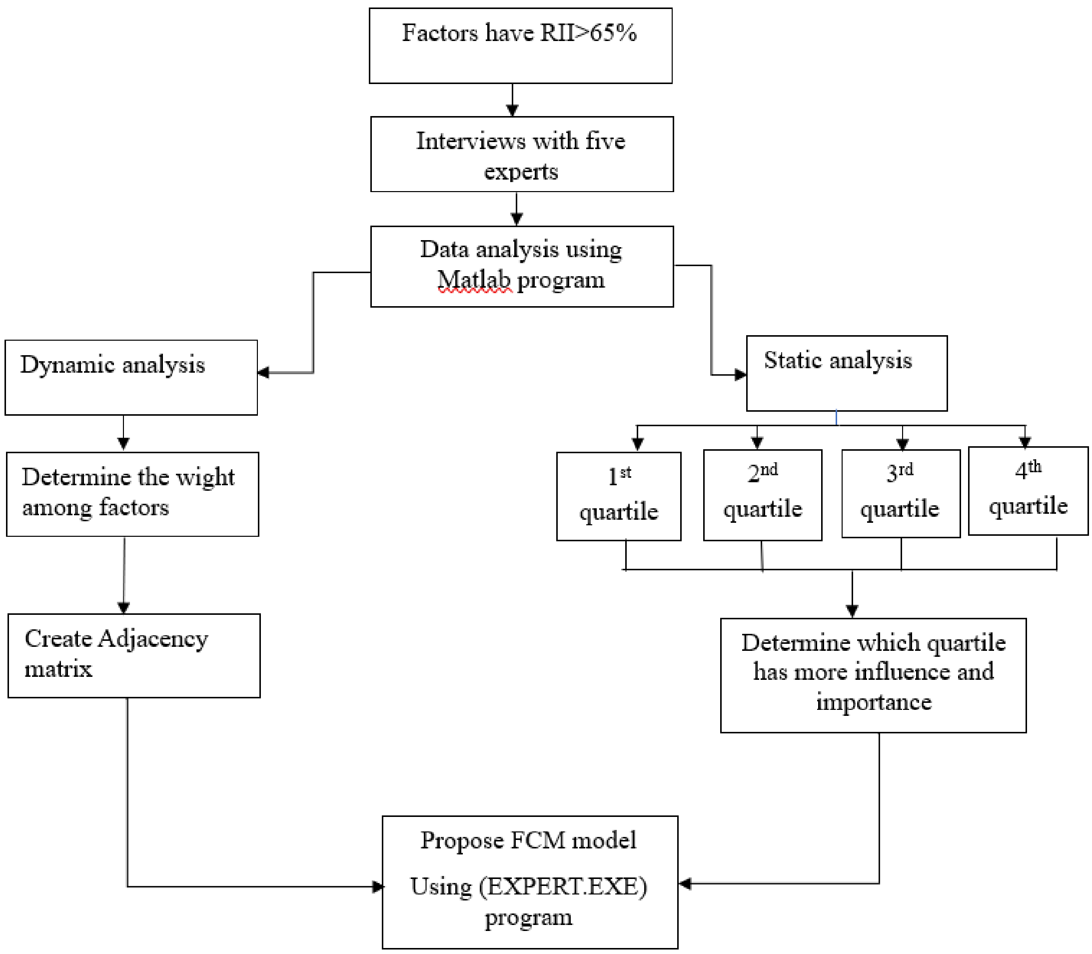

Fig. 6. Flowchart of fuzzy logic process

The experts were asked to investigate the relationship among factors by linguistic variables as shown in Fig. 7.

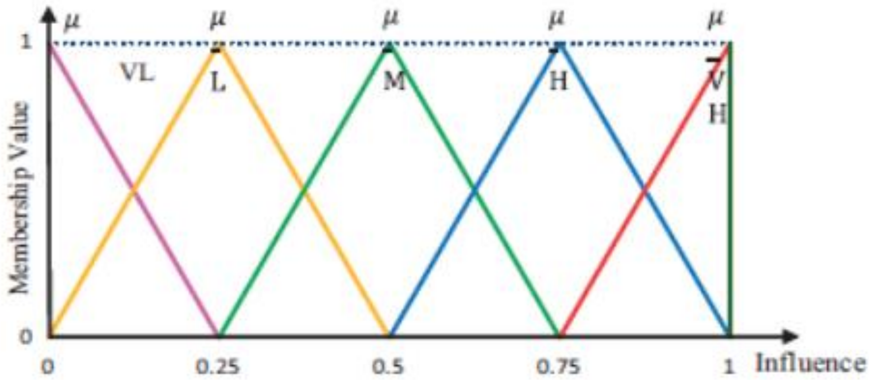

Fig. 7. Membership function of five linguistic variable

Matlab program was used to analyze the answer of the experts, Mamdani model represent the most common types of fuzzy. Defuzzification technique was used in fuzzy inference to determine the output. Fig. 8 shows the fuzzy inference method's determination, involve the aggregation (max), and center of gravity (de-fuzzification). The results indicate the combined output of the expert opinions that made up the fuzzy number.

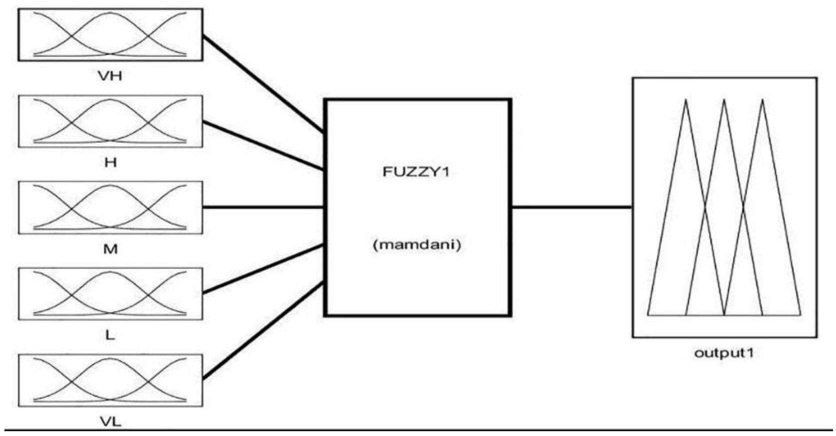

Fig. 8. Fuzzy inference of Mamdani method(Alhilli & Rezoqi, 2021)

To facilitate this process the example was applied to calculate the weight of factors (1.4) (Conservation of natural reserves) on the factor (1.5) (Balance between building area and green area). The number of experts that have chosen (VH), (H) and (M) is one, three, and one, respectively. Fig 8, shows the weight of answer extracted by using the number of each linguistic variable: (VH, H, M, L, VL) divided by the number of expert answers. To formulate expert answers using IF-THEN rules (Alhilli & Rezoqi, 2021) as follows:

In order to formulate expert answers, the IF-THEN rules were used as follows:

IF (INPUT is VH) then (OUTPUT is VH) with weight of (1/5).

IF (INPUT is H) then (OUTPUT is H) with weight of (3/5).

IF (INPUT is M) then (OUTPUT is M) with weight of (1/5).

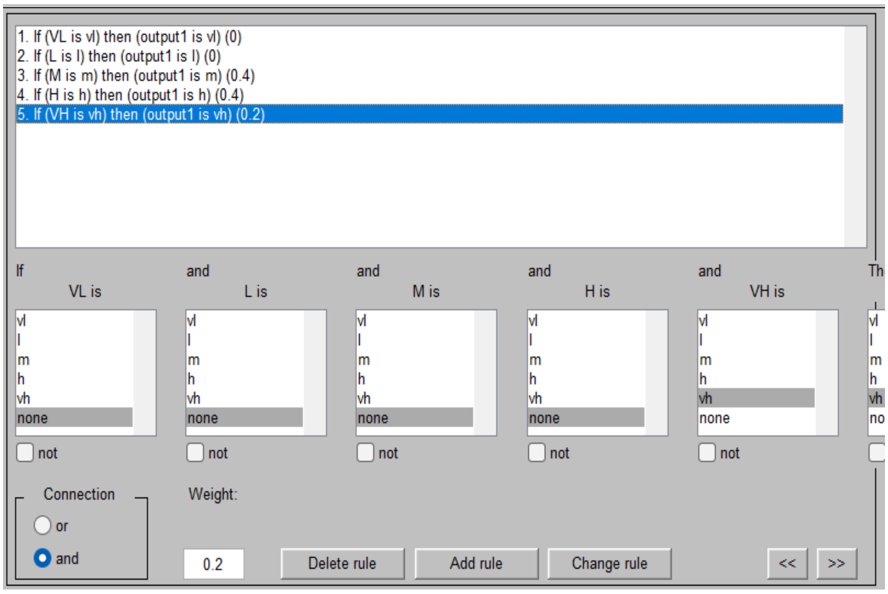

Fig. 9. If then rule experts' opinion

Finally, the max limits of the linguistic variables were determined (1; 0.747; 0.5; 0.247; 0), and Fig. 10, shows the defuzzification by the center of gravity method, the influence weight between C1.4 and C1.5 is equal to (0.633). Nevertheless, all the weights of the interrelationships among the factors were calculated as shown in Table4.

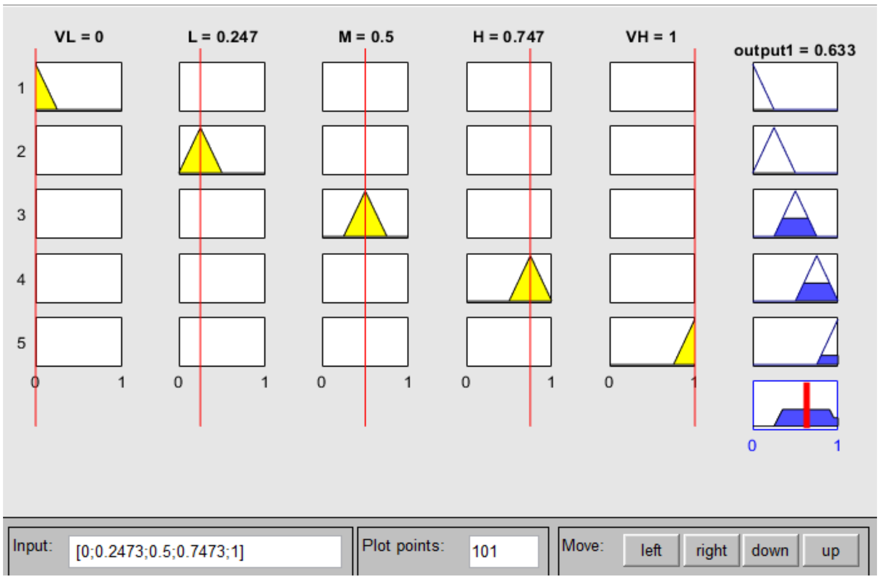

Fig. 10. Defuzzification and aggregation process between C1.4 and C1.5

Table 4 - Adjacency matrix of interrelation weight

	C1.4	C1.5	C1.6	C2.1	C2.2	C2.3	C2.4	C3.2	C3.3	C3.4	C3.5	C3.6	C3.7	C4.3	C4.6	C4.7	C5.2	C6.1	C6.2
C1.4	0	0.723	0.51	0.839	0.725	0	0.725	0	0.798	0.808	0	0.808	0.833	0.839	0.51	0.833	0	0	0
C1.5	0.633	0	0.839	0	0.665	0	0	0	0	0	0	0	0	0	0	0	0	0.775	0.56
C1.6	0.64	0.839	0	0.576	0	0	0.596	0	0.806	0.756	0	0	0.808	0.84	0.851	0.56	0	0.623	0.727
C2.1	0.833	0	0.632	0	0	0	0.842	0	0.803	0.91	0.886	0.833	0.92	0.92	0.851	0.765	0.739	0	0
C2.2	0	0	0.632	0	0	0.842	0	0	0	0	0.725	0.576	0.445	0	0	0	0	0.51	0
C2.3	0.797	0	0	0	0	0	0	0	0	0	0	0.445	0	0	0	0	0	0.;92	0
C2.4	0.63	0	0.694	0.839	0	0	0	0	0.798	0.91	0	0.92	0.839	0.723	0.887	0.839	0.64	0	0
C3.2	0.63	0	0	0	0	0	0	0	0	0	0.725	0.803	0.576	0	0	0	0	0.421	0
C3.3	0.841	0	0	0.633	0	0	0	0.695	00	0.808	0.91	0.92	0.839	0.51	0.921	0.775	0	0	0
C3.4	0.643	0.395	0.723	0	0	0	0	0	0.817	0	0	0.723	0.725	0.808	0	0	0	0	0
C3.5	0.841	0	0	0	0	0	0.92	0	0	0.884	0	0.794	0.576	0	0	0	0	0.821	0
C3.6	0.841	0	0	0.797	0	0	0	0.576	0.91	0.921	0.63	0	0.84	0.797	0.808	0.797	0.84	0.858	0
C3.7	0.839	0	0.839	0.92	0	0	0.92	0.576	0.8	0.806	0.695	0.839	0	0.82	0.839	0.665	0.695	0.423	0
C4.3	0.723	0	0.723	0	0	0	0.695	0	0	0.92	0	0.797	0.797	0	0	0	0	0	0
C4.6	0.576	0	0	0.92	0	0	0.689	0	0.91	0.841	0	0.839	0.725	0	0	0.839	0	0	0
C4.7	0	0	0	0.92	0	0	0	0	0	0	0	0	0.689	0	0.921	0	0	0	0
C5.2	0.445	0	0	0	0	0	0.576	0	0.797	0.756	0	0.445	0	0	0	0	0	0.725	0
C6.1	0	0.839	0.5	0	0	0.725	0	0	0	0.855	0	0.797	0.576	0	0	0	0	0	0
C6.2	0	0	0.723	0.725	0	0.841	0	0	0	0	0	0	0	0	0	0	0	0	0

The effecting factors on ESD are analyzed by two distinct approaches static and dynamic analysis. the Eqs.3, 4, 5 and 6 were used to analysis and normalized the final value of the factors(Nasirzadeh et al., 2020; Patro, 2015), as shown in Table 5.

CE(OWi)=IN(OWi)+OUT(OWi) (3)

$IN(OWi)$=$\Sigma wikmk$=1 (4)

$OUT(OWi)$=$\Sigma wkimk$=1 (5)

Where:

(wik) and (wki) = Values of the arcs.

UN(0Wi) = Sum of the absolute column values

IN (OWi) = Concerning both nodes in the matrix describes the number of nodes causally impacting node Ci.

OUT(OWi) = Number of concepts that node Ci causally influences;

CE(OWi) = Relative importance index (RII) of concept Ci in static analysis (FCM).

$$Ci(scale) = \frac{(Ci - Cmin)}{(Cmax - Cmin)} \quad (6)$$

Table 5 - Static analysis of factors

Factor	SUM-OUT	SUM-IN	(SUM-OUT) scale	(SUM-IN) scale
C1.4	8.951	9.912	0.817	0.932
C1.5	3.472	2.796	0.236	0.163
C1.6	8.622	6.815	0.782	0.597
C2.1	9.934	7.169	0.921	0.636
C2.2	3.73	1.39	0.264	0.011
C2.3	1.242	2.408	0.000	0.121
C2.4	8.719	5.963	0.792	0.505
C3.2	3.155	1.847	0.202	0.061
C3.3	7.852	7.439	0.700	0.665
C3.4	4.834	10.175	0.381	0.961
C3.5	4.836	4.571	0.381	0.355
C3.6	9.615	10.539	0.887	1.000
C3.7	10.676	10.188	1.000	0.962
C4.3	4.655	6.257	0.362	0.537
C4.6	6.339	6.588	0.540	0.573
C4.7	2.53	6.073	0.137	0.517
C5.2	3.744	2.914	0.265	0.176
C6.1	4.292	5.156	0.323	0.418
C6.2	2.289	1.287	0.111	0.000

Fig. 10 shows the final value of the factors after the static analysis. The x-axis refers to the aggregate of the factors IN, while the y-axis refers to the aggregate of the factors OUT. However, the higher x-axis value of the factor, the degree of influence of other factors on the factor increases.

First Quarter: The effecting factors on ESD that belong to this quarter are characterized by being influential and affected by other factors of (ESD). However, the results showed that the factors effecting of ESD in this quarter include (Taking into account urban density, using water to produce alternative energy, adopt reused and recycle materials, Conservation of natural reserves, use renewable materials, using natural materials, use of renewable electricity source, Use alternative energy source such, solar, wind, biomass, tidal power, and geothermal energy)

Second-quarter: The factors effecting on ESD that belong to this quarter are characterized as uninfluential. The results analysis showed there are no factors that belong to this quarter.

Third-quarter: The factors in this quarter are characterized by uninfluential and unaffected by other factors.

In the fourth quarter: These factors are characterized as having an influence on other factors of ESD. moreover, it is unaffected by other factors. The factors that included within this quarter, which are (Reduce water pollution, Construction of dams, use materials with zero or low off-gassing).

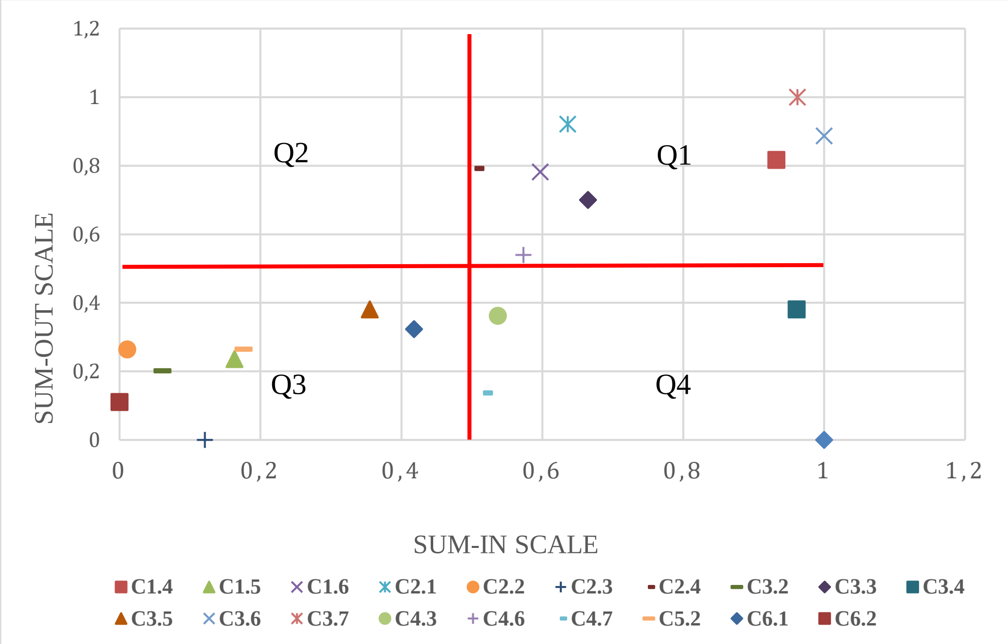

Fig. 11. Static analysis of FCM

According to approach of FCM, a fuzzy result from the typical range [0,1] has to be assigned to both concepts as its primary activation degree in the approach. Also, a fuzzy result from the typical range [−1,1] must be assigned to both arcs as the causal relationship between nods. The experts usually assign the two mentioned fuzzy values using linguistic variables. A (m × m) matrix can show the current connections between the concepts in a (FCM) with m nodes, named an adjacency matrix (E). Three probable types of mutual relations can exist between different nods, when wij > 0, it indicates a positive causality; wij < 0, it indicates a negative causality; and wij=0, which represent no the connection(Khanzadi et al., 2018).

The Eq.7 represents both nodes is computed by summarizing the impacts of all the other nodes and squashing the overall influence using a barrier function "f"(Papakostas et al., 2012).

$$(c_i)^{r+1} = f((ci)^r + \sum_{j=1<j\neq i}^{n} c_j^r w_{ji} \qquad (7)$$

Where:

$(ci)r$+1= node weight ci at a simulation step r+1.

$(ci)r$ = node weight cj at simulation step r.

cjr = Node weight cj at time r,

$w(ji)$ = Interrelation value of the node cj to node ci

f = Function of objective

In the simulation approach it can be compare the result using the following various functions or choose the adequate function according to the model issue. Eq.8 represent Sigmoid activation function is appropriate for qualitative and quantitative issues which output an increase, decrease or stability(Leibovich-Raveh et al., 2018; Nápoles et al., 2018) . as shown in Fig. 11.

$$f\,x = \frac{1}{1+e^{-c1(x-c2)}} \qquad (8)$$

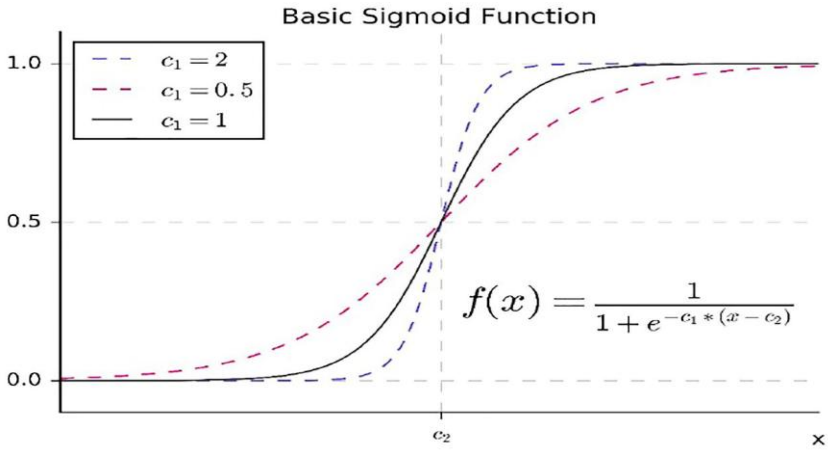

Fig. 12. Sigmoid activation function with C1 and C2 parameters(Leibovich-Raveh et al., 2018)

The formula of deduction in Eq$_s$. 7 and 8 were used to conduct dynamic analysis by simulation. The results were extracted by applying (FCM EXPERT.EXE) program, as fallowed:
1. Turn on the program (FCM EXPERT.EXE) and import a file (raw.csv). which, was created by Matlab program.
2. The weight of values are normalized by select Sigmoid activation function, as shown in Fig. 12, always returns a value between 0 and 1, with slope equal to 1.

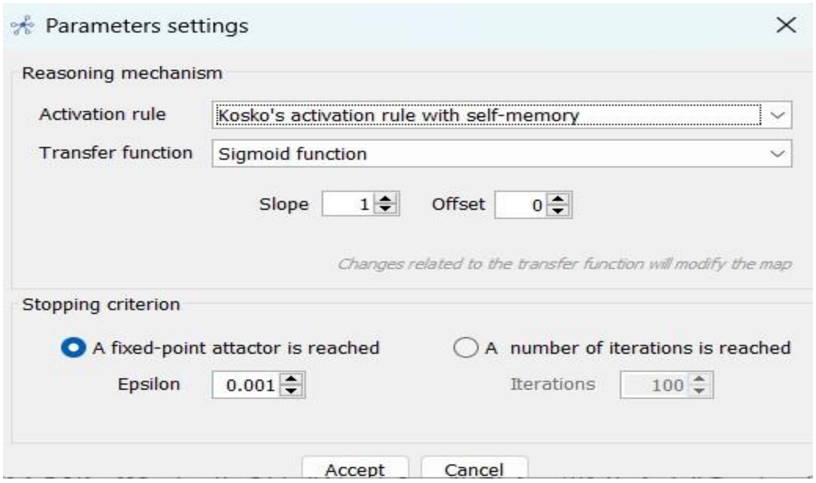

Fig. 13. Inference rule selection

3. The RII that has been calculated in Table 3 was adopted as data entry for the values of concepts in. Fig. 14.

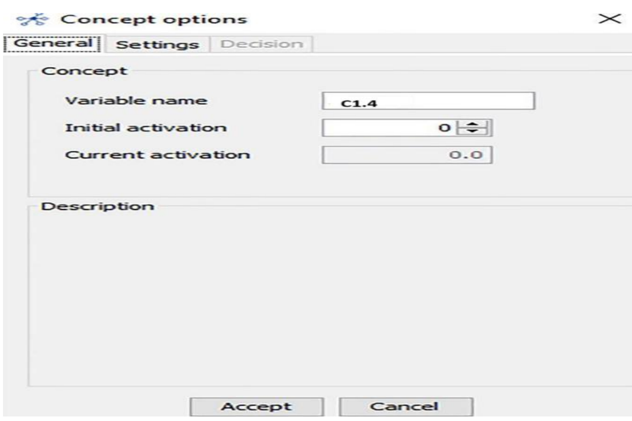

Fig.14. Data entry of factors

4. Fig. 15 shown the weights of influential in ESD by Performed the simulation analysis. And the results have been reached after 6 iterations, then export the results to an excel sheet file.

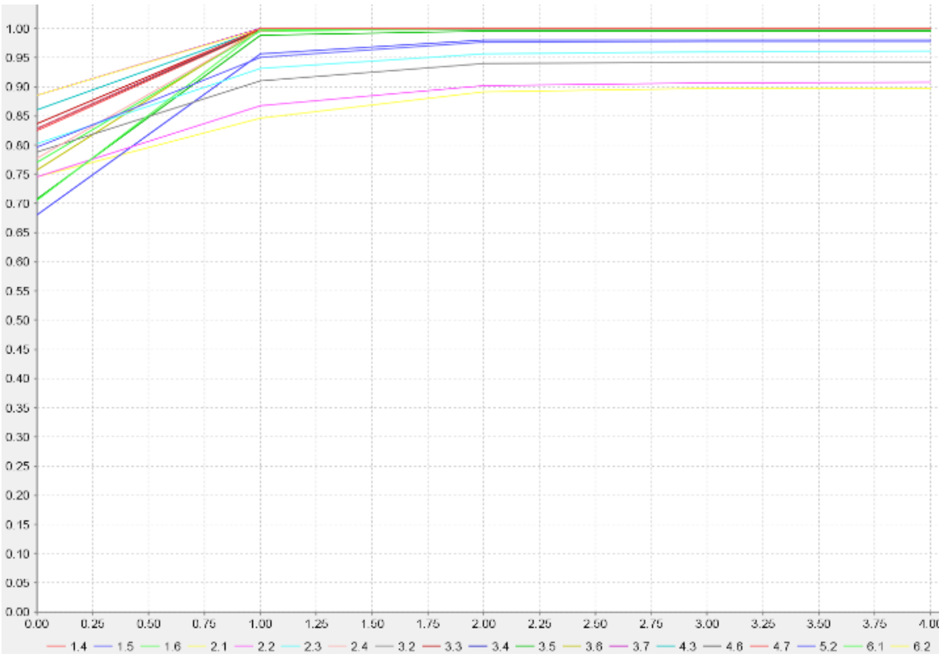

Fig. 15. Simulation of effecting factors

Fig. 16 represents a comparison between the RII of the effecting factor of ESD and weights of the causes' interactions, as determined by the dynamic analysis. Where schedule change has influence (1). On the other hand, the C1.6, C3.5, C5.2 are (0.99, 1,0,98) respectively, while in RII is (0.7). This mean the interaction between factors of ESD are affected in both RII and dynamic analysis.

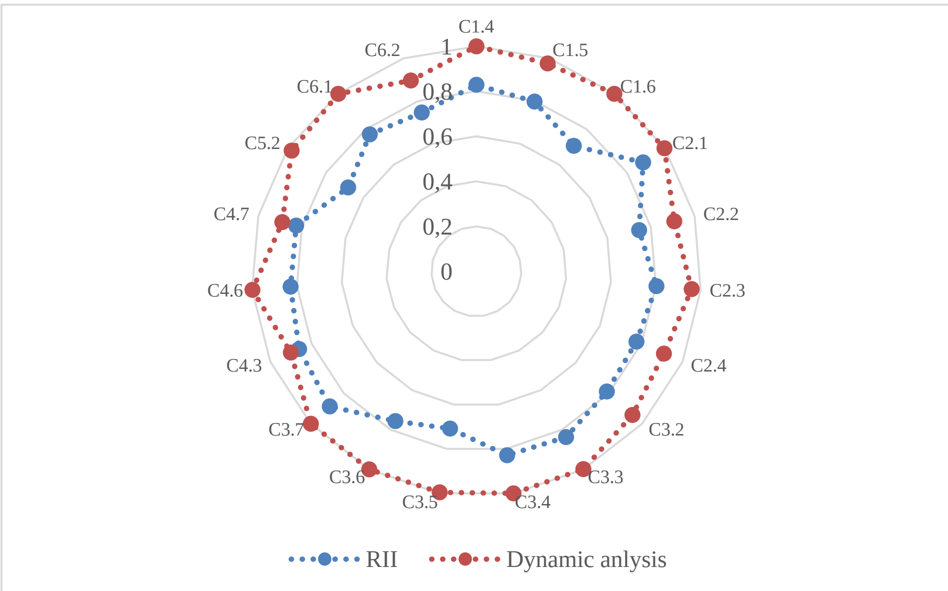

Fig. 16. Effecting factors comparison between RII and dynamic analysis

8. FCM proposed

The fuzzy cognitive map was proposed, which is created based on weights among factors, its use depends on the importance and priority of interrelationships. For example, Fig.16 shows the influence of the factor (C1.5) balance between building and green area failure to a high degree on the concepts, namely (C1.6) taking into account urban density, (C1.4) conservation of natural reserves, (C 3.4) use materials with zero or low off- gassing and (C6.1) accessible natural light to building. On the other hand, these factors are the root causes of the factor (C1.5).

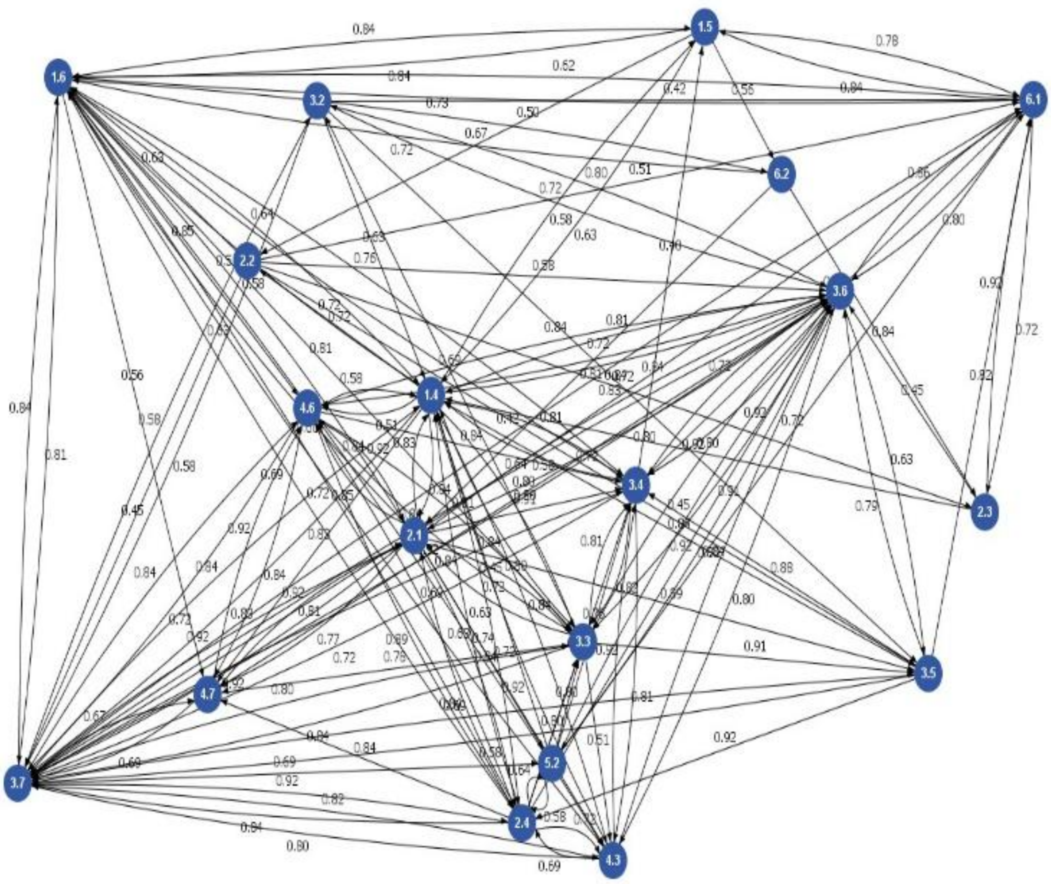

Fig. 17. Proposed FCM

9. Conclusions

There are six main factors effects on ESD namely (land use related factors(C1), energy related factors(C2), materials related factors(C3), water management related factors(C4), indoor air quality related factors(C5), occupant health and comfort related factor(C6)). These factors depend on 19 subfactors according to RII such as (C1.4, C1.5, C1.6, C2.1, C2.2, C2.3, C2.4, C3.2, C3.3, C3.4, C3.5, C3.6, C3.7, C4.3, C4.6, C4.7, C5.2, C6.1, C6.2).

The static analysis it can be classified factors into four quartiles, the first quartal characterized by being influential and affected by other factors of (ESD), include eight sub factors (C2.1, C3.6, C1.6, C3.7, C1.4, C3.3, C4.6, C2.4). While, the dynamic analysis clarifies the interrelationship and importance among factors. It concluded there are differences between RII and dynamic analysis, this is an essential finding in the understanding that dynamic analysis considers interactions between factors, while RII takes the reasons independently and neglects interactions between them.

The fuzzy knowledge model can achieve environmental sustainability in the implementation of construction projects by modeling the most important environmental factors that have the least impact on the environment. The proposed model enables decision makers to model sustainable environmental factors by classifying the factors into six main factors and nineteen secondary factors, and through it the relationships between these factors are determined based on importance and priority.

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