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# Interpretive Structural Modeling (ISM) Analysis of Green Building Rating Criteria in Iran

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**Abstract**
As a driver of national development, the construction industry has in recent decades gained substantial environmental importance due to its extent and effects on life, business, and the environment. Due to its economic, social, and environmental impacts, the construction industry has been discussed extensively in the sustainable development literature, contributing to development of Green Building Rating Systems (GBRSs) worldwide. This study introduces some of the most popular GBRSs and employs a Multi- Criteria Decision Making (MCDM) approach to investigate the evaluation indices of GBRSs. GBRS indices were obtained through a comprehensive literature review. To validate the identified indices, 400 questionnaires were handed out to respondents, with 260 completed questionnaires being returned. The responses were statistically analyzed, identifying twenty important indices, which were modeled using Interpretative Structural Modeling (ISM) and categorized using MICMAC analysis. The ISM model showed that the barriers arising from unique characteristics of a region were the main GBRS factor in Iran.

**Keywords:** *Analysis, Green Building Rating Criteria (GBRSs), Interpretative Structural Modeling (ISM), Construction Industry*

## Introduction

Iran is in need of sustainable development due to an energy consumption rate above the global average, the rapid consumption of non-renewable energy resources such as oil and gas, and an architectural identity crisis. Enabling sustainable development requires the implementation of certain infrastructures. There is a need for a system to evaluate and control such development. Such standards could handle urban challenges in Iran and help save fuel and non-renewable energy resources, control air pollution, and minimize construction waste (Nouri Segherlou and Ghobadian, 2022). Most building rating systems adopt a comprehensive approach to building performance or society; whereas some only consider easily accessible or evaluable aspects. Rating systems help users to make decisions and encourage owners to cooperate. Such systems could also offer recommendations on the combination of green elements in the design and construction of buildings with flexible criteria. Numerous Green Building Rating Systems (GBRSs) have been developed since the introduction of the Building Research Establishment Environmental Assessment Methodology (BREEM) (1990) and the 1992 Rio Earth Summit (Majrouhi Sardaroud et al., 2017). Today, environmental aspects influence almost all human activities, particularly in the business and industrial sectors, and represent a focal point for citizens, governments, and even international relations. The United Nations named the 2005-2014 period as the Decade of Education for Sustainable Development. This can be an environmental

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warning as the United Nations cautioned the international community to further enhance sustainable development (Majrouhi Sardaroud et al., 2017). The construction industry is a major consumer of resources and source of waste in the world. It involves a set of socioeconomic activities that can negatively impact health by reduction of natural resources (for construction), greenhouses gas emissions, and construction noise and waste (Lu et al., 2019). Buildings in current societies protect humans from intense incidents while imposing environmental and health impacts. Green architecture was an emerging discipline upon revelation of the environmental impacts of buildings (Motawa and Carter, 2013). Green buildings (GBs) or sustainable buildings are constructed, renovated, operated, maintained, and destroyed using healthier models with more efficient resources (Chen et al., 2022). Lu et al. (2019) argued that many green construction-associated organizations adopted greenness principles upon global greenization. Ismaeel and Kassim (2023) reported that GBs reduce $CO_2$ emissions, energy consumption, water consumption, and construction waste by 34%, 25%, 11%, and over 80 million tons, respectively. In fact, the global GBs movement appeared to create a better environment and alleviate the adverse environmental impacts of humans. GB projects have higher costs than conventional buildings since GB materials are rarely offered in the market and require more expensive electronic, mechanical, and piping equipment. Organizations supporting GBs stated that the higher GB construction costs are repaid by improved environmental performance since the building value is higher, and GB occupants enjoy higher degrees of comfort (Lu et al., 2019). Green construction influences building prices (Fuerst and McAllister, 2011), reduces carbon emissions (Shuai et al., 2018), saves energy for retrofitting (Castleton et al., 2010), improves health and efficiency (Singh et al., 2010), and provides higher comfort for occupants (Zhang and Altan, 2011).

Through a new approach to buildings and their surroundings, GBs seek to minimize the negative consequences of construction to protect air, water, and the earth and is associated with the optimal selection of construction materials and novel environmental practices. Developers, investors, and corporations construct GBs using GBRSs and distinguish their buildings from others in a global approach. Marchi et al. (2021) argued that in recent decades, governments and the associated organizations issued GBRSs to rate buildings based on green construction standards and receive original greenness certificates. Today, no GBRS guarantees that all three objectives of sustainability, environmental performance improvement, and economic improvement can be achieved at the same time. However, environmental impacts should be lowered by 80% by 2050. Global reports suggest that residential buildings account for nearly 40% of global energy consumption. The design, construction, utilization, and reconstruction of buildings are essential for reducing energy consumption. These challenges in the energy literature require new and effective technologies, new standards, and reconsideration of building requirements. Such a comprehensive perspective of energy saving in buildings requires high-performance and energy-saving buildings. Green regulations and standards could strongly contribute to the development of green, sustainable buildings. Developed countries with more GB experience have developed efficient criteria and standards for their climates and issued certificates for buildings based on the scores. Such certificates often evaluate all types of buildings and can be applied to a variety of buildings, including newly constructed and/or totally reconstructed buildings, commercial buildings, schools, and interior/exterior components. A review of these standards may help define effective criteria for GB development in Iran (Majrouhi Sardaroud et al., 2017). There are many and varied criteria that affect the rating of GB and their identification and analysis can give a clear view to the managers of public and private organizations and executive bodies to continuously evaluate their green building and use the evaluation output as input. Participate in green and effective developments. Due to the fact that the proposed criteria for GB ranking are complex and multi-dimensional, so far a general model of indicators and the relationship between them has not been presented. Achieving the appropriate model of green building rating criteria requires their identification and evaluation based on scientific methods. The current research tries to measure the key criteria of green building ranking in the form of a comprehensive analytical-combination model including Interpretative Structural Modeling (ISM). The output of this research helps managers of public and private organizations and executive bodies to have a clear and quantitative picture of green building rating criteria by using the ISM technique. In the present research, firstly, by reviewing and examining some studies, a number of green building ratings were identified in green construction projects, and then, using the ISM method, to quantitatively analyze the relationships and interaction between specific factors. became Also, to check the applicability of the proposed method, green construction projects in Tehran were investigated. In the continuation of the current research, based on scientific study and tracking, the following goals have been compiled to investigate, which contributes to the literature in four aspects:

1) Identifying and distinguishing green building rating criteria for green building projects in Iran;
2) Examining the interdependence of green building rating criteria and their effects on each other in Iran;
3) Using the MICMAC diagram to classify and analyze the power of penetration and the degree of dependence of the main rating criteria of the green building;
4) Finally, the development of an analysis model of the main criteria in the evaluation of green building rating criteria in Iran.

## Literature Review

The construction industry is very large and includes more than millions of people in a wide variety of engineering occupations, technical personnel, skilled tradesmen and skilled trades operations. Construction is a high-risk industry that includes a set of activities related to construction, modification, or repair. The construction industry, like all industries, has its own technical language. The common language of the entire industry includes a correct understanding of the language about structures, components and elements, familiarity with specialized and technical language and creating a strategy for interpretation. Modern methods of construction are a wide range of technologies, including prefabricated construction or on-site construction. While the distinction between construction and production has obvious overlap or close connection. Modern construction methods that include a wide range of processes and technologies that include prefabrication, off-site assembly and various forms of supply chain specifications, which under controlled conditions allow control of time frames and accuracy in forecasting dates. Completion and limited access to the site and lower risk factors enable that features such as specific objectives, performance of specific tasks, specific beginning and end, resources being consumed for the construction of a project are defined. The purpose of modern construction is to make a difference in carrying out large and unique projects that require time, money, labor, equipment and materials and examples of all kinds of resources. Modern building is the design cycle of building materials, parts, information systems and management practices to create a safe and healthy environment that facilitates and predicts future changes and possible adaptation to eliminate the recovery of all systems, parts and materials (Nouri Segherlou and Ghobadian, 2022).

## Green Building Rating Systems (GBRS)

The concept of green building originated from the growing awareness of sustainable development since the 1960s (Zhang et al., 2019).This concept refers to the strategy of reducing the environmental impact of buildings, as well as increasing the well-being of humans, society, environmental health, and total life costs. Green building is a holistic technique to achieve sustainability during the life cycle of a project. A recent analysis predicts that the number of green building projects will double every three years. However, green building implementation varies widely from one country to another, depending on drivers, barriers, and phases of the local green movement. Green building rating systems (GBRS) are tools for evaluating a building's performance, including its environmental impact, based on a defined series of criteria that typically cover energy performance, site selection, water efficiency, indoor air quality, and material use. The principles of construction waste management are usually a subsection of the materials section. The result of the assessment leads to an overall standard rating, and based on the total score, it is awarded a green building certification label. National and regional governments have adopted various policies to encourage green building projects, including economic returns for green building projects. For example, regional governments in Mainland China provide incentives based on the level of green building certification a project has received and the gross infrastructure area (GFA). In Hong Kong, approved BEAM Plus projects have benefited from a 10% GFA facility since 2011 (Iqbal et al., 2023).

## Research on Criteria Affecting the Green Building Rating Systems

Historically, the Club of Rome, a Non-Governmental Organization (NGO) founded in Rome, Italy, in 1968, proposed green construction toward sustainable development. It evaluates the pressing global challenges and requested a number of researchers at the Massachusetts Institute of Technology to research economic and population growth. The club reported the Limits to Growth in 1972, which predicted for the first time that economic growth would not continue indefinitely due to the finite natural resources, particularly oil. The Club of Rome's the Mankind at the Turning Point report published later in 1974 suggested that the international community could control many environmental and economic disasters. The Rio Earth Summit held in 1999 argued that development was destroying the environment and would endanger life on earth; i.e., the world ecosystem would no longer be able to regenerate the environment, and animals and biological species could not continue to live the same life (Majrouhi Sardaroud et al., 2017). The city of the Century Conference in Berlin, 2000, defined sustainable urban development as "improvement of quality of life in a city, including environmental, cultural, political, institutional, organizational, and socioeconomic improvement, without tensions arising from over-reduction of natural capital and regional debts on the future generations". This aims to establish a trade-off between materials, energy, and finances for it plays a key role in future decisions on urban development. Construction is a large socioeconomic sector in Europe that, combined with the constructed space, significantly influences the natural environment. These two factors have become keys to global sustainable development. Adopting sustainability concepts to reduce energy waste and environmental pollution in architecture led to green construction. This approach emphasizes the location of a building relative to the local and global ecosystems (Doan et al., 2017). Improving overall energy efficiency during a building's lifetime is the most important goal of green construction, and it is based on decisions that address the negative environmental and human impacts of buildings. GBRS is a model for evaluating building performance, including environmental impacts, based on a set of criteria often covering energy performance, location selection, water efficiency, interior air quality, and material use. To develop GBs, several instruments have been designed worldwide, including Leadership in Energy and Environmental Design (LEED), the Building Research Establishment Environmental Assessment Methodology (BREEM), and Green Building Council of Australia (GBCA), each with a set of GB rating indices. A building is scored based on base performance in each index and the total score obtained from the sub-indices (Olubunmi et al., 2016). Therefore, it can be said that it is necessary to identify the effective indicators in order to rank the green building. During the recent years, many researchers identified the indicators that are effective on the rating of green buildings. Among others, we can mention Ghafouri and Mirjalili's research (2018). Ghafouri and Mirjalili (2018) introduced economic, social and technological factors as the most important criterion for the development of green construction, which has been effective in the implementation of green construction and its ranking. Khojagi (2018), in his research entitled "identification and ranking of factors affecting the implementation of green buildings using the DEMATEL method" identified and ranking the factors influencing the implementation of green buildings with the help of a questionnaire with experts, the researcher's experience and also the background of the research. which has 3 dimensions (economic factors, technical and technological factors and social and cultural factors) and 29 indicators. In order to measure the effectiveness of each of the dimensions in relation to each other, a questionnaire of the mentioned dimensions was designed based on DEMATEL's technique and analyzed with BT DEMATEL's software. The results of the research indicate that the economic factors are the most effective and the technical and technological factors of the project are the most effective. In this regard, Hashemi Rabari and Mirjalili (2017), in their research entitled "investigation of green project management indicators in the energy efficiency of hotels in yazd city", stated that green project management is a key component in the agenda of project compatibility with environmental issues. Examining this issue in Iran is necessary due to the limited energy resources. As a developing country, Iran has an urgent need to optimize energy consumption and planning in this field. One of the ways to optimize energy consumption is to design buildings with a green approach. Among the important buildings that directly and indirectly affect the environment and are related to the approach of sustainable development dimensions are hotels, which have destructive effects on the environment due to the high use of energy resources, with the consumption of non-renewable energy, excessive use of water. , the production of waste materials has led to the aggravation of the existing challenges. In order to achieve the goals of sustainable development, it is possible to build green hotels and use the LEED standard as a suitable policy and plan to promote sustainable tourism and optimize energy consumption to prevent pollution caused by fossil fuel consumption and increase profits. Energy saving in buildings. Since in order to realize this and to build and transform the existing hotels into green hotels, research should be done in this regard, as an example, the hotels of Yazd city were studied to check the indicators of green project management and energy efficiency. The results show that in most hotels, attention has been paid to saving in lighting system management, but no attention has been paid to waste management. An another research, Molazadeh Yazdani (2017) dealt with recommendations about the green building rating system and introduced designers to the principles and strategies of sustainable design that go beyond the existing rating systems in hot climates. The evaluation aims to create a new approach for regional coordination among the three existing systems and developing systems with the ability to adapt and fit the context. Also, Majroi Sardroud et al. (2016), in their research entitled "evaluation of the rating criteria of green buildings in the current standards of the world and a proposal for the formulation of the Iranian standard", some of the most widely used rating systems of green buildings in the world have been introduced. Then, the evaluation indicators in these systems, which show the degree of compliance with environmental issues and sustainable development, have been identified and investigated. In the following, by examining the challenges of using the mentioned standards and the need for education on environmental issues, implementation solutions and suggested indicators for the development of green building standards in Iran are presented. Lu et al. (2019) evaluated the impacts of green construction on construction waste management and green building ratings. They argued that buildings significantly impact human life and construction is not only a business, but also an environmental challenge. The impacts of green construction on waste management were examined using semi-structured interviews and a hybrid approach. The results showed that green construction could not reduce construction waste management, which was attributed to the design of GBRSs and a lack of incentive to improve waste management. Varma and Palaniappan (2019) compared GBRSs in North America, Europe, and Asia, arguing that GBRSs are a practical instrument for sustainable development in the construction industry. Green building rating meets user demands, preserves natural resources, and reduces environmental degradation. They comprehensively compared ten GBRSs in North America, Europe, and Asia and evaluated sustainable development goals, selecting two Indian green building schemes. Zhang et al. (2019) evaluated renewable energy in GBRSs and reported that green buildings could help address environmental degradation, economy, and society. There have been numerous GBRSs developed worldwide for evaluating buildings and issuing green building certificates. Renewable energy is essential for achieving green buildings by reducing fossil fuel consumption and GHG emissions. However, they have a major difference in renewable energy evaluation in GBRSs. There was a comprehensive review of renewable energy evaluation methods in GBRSs to help investors, users, and policymakers to better understand GBRSs and take steps toward developing GBs. Berawi et al. (2019) reviewed stakeholder views on GB rating in Indonesia and demonstrated that the Indonesian government and Council of Green Buildings should evaluate GBs to adopt GB and encourage practitioners to receive green permissions. Freitas et al. (2018) reviewed GBRSs in the Swedish market and reported a comparative analysis of four GBRSs. The GBRSs were evaluated in different aspects, including certification process, construction cost, educational requirements, and classification/rating practices. They used the SWOT matrix to identify strengths, weaknesses, opportunities, and threats.

Despite extensive research on green building rating criteria, common methods have major violations that limit the use of common techniques, especially when the goal is to analyze the relationships between green building rating criteria. According to the investigations, it was found that the methods used so far have only discussed the importance and evaluation of decision-making options and have not analyzed the power of influence and dependence, improving the decision-making system and developing the model. Based on this, according to the research gap, there is a need for a method that, in addition to evaluating decision-making options, analyzes the power of influence and dependence, improves the system, and develops the model. Therefore, the aim of the present study is to use the ISM method to analyze the relationships between green building rating criteria and its modeling. Considering that green building rating criteria is a complex and multi-dimensional concept, so far a general model of indicators and the relationship between them has not been presented. Achieving the appropriate model of green building rating criteria requires identifying and evaluating green building rating criteria based on scientific methods. The current research tries to measure the key criteria of green building ranking in the form of a comprehensive analytical-combination model including interpretive structural modeling (ISM). The Interpretive Structural Modeling (ISM) method analyzes the relationship between indicators by analyzing the criteria at several different levels and determines the relationship between the indicators that are individually or in a group that are dependent on each other, and by analyzing the criteria in several different levels, it analyzes the relationship between the indicators. In general, it can be said that the design of an ISM is a method to investigate the effect of each variable on other variables; This design is a comprehensive approach to measure communication and is used to develop the model to enable the overall research objectives. ISM is a method to create and understand the relationships between the elements of a complex system. In other words, ISM is an interactive process in which a set of different and related elements are structured in a comprehensive model. The ISM methodology helps a lot to establish order in the complex relationships between the elements of a system and helps in identifying the internal relationships of variables. Finally, a suitable technique for analysis and ISM can be to prioritize and analyze the effect of one variable on other variables. It can also prioritize and determine the level of the elements of a system, which helps managers to better implement the designed model (Yu, 2023). Based on this, according to the realized importance, this study contributes to the literature in four aspects and its most important innovations are presented: 1) identifying and distinguishing the main criteria in the rating criteria of green buildings in Iran; 2) Investigating the interdependence of the main criteria in evaluating the rating of green buildings and their effects on each other; 3) using the MICMAC diagram to classify and analyze the power of influence and the degree of dependence of green building rating criteria in Iran; 4) And finally, the development of an analysis model of the main criteria in the evaluation of green building rating criteria in Iran. To achieve the realized aspects, a systematic literature review is developed to identify the main criteria in the review of green building rating criteria. Then, a hierarchical network structure with the paths of the main criteria in the review of green building rating criteria is created using ISM method to show the main criteria in the review of green building rating criteria in interdependencies. Also, a classified analysis is applied to evaluate the driving force and interdependence of the main factors of green building ranking. Therefore, the main rating factors of green buildings in Iran related to the project objectives are determined based on the ISM-MICMAC method. The results of this study provide a better understanding of the interdependencies of the main factors of green building rating criteria in Iran and are useful for researchers and practitioners in the green building industry.

## Methodology

The primary objective of the present research was to model and analysis of green building rating criteria in Iran. To achieve this goal, a combination of quantitative and qualitative methods was used, as it enhanced the justification and validation of the data. The quantitative approach was based on data collected through questionnaire-based surveys, while the qualitative approach relied on formal interviews with experts in the field. Subsequently, the modeling of effective criteria for ranking green buildings in Iran was conducted using the ISM and MICMAC approaches. The adopted method for the current study was classified into three stages, as illustrated in Figure (1). In the first phase, a comprehensive literature survey was conducted to identify the green building rating criteria in construction industry Iran. As a result, 20 criteria that affect the execution process of green building rating criteria in construction industry Iran have been extracted. To validate the selected criteria (validity and reliability), a questionnaire was prepared and distributed among active construction companies in the Tehran metropolitan area. The companies were qualified by the Management and Planning Organization. The total number of active construction companies in Tehran is 214. Due to the impracticality of accessing the entire population, the Cochran formula was employed to determine the sample size, resulting in a sample size of 137 members. The questionnaires were distributed among 137 members both in person and non-face-to-face, with 30 experts providing complete responses in the pilot study. Of the respondents, 53% had work experience ranging from 5 to 10 years, while 47% had experience ranging from 10 to 20 years. Approximately half of the professionals held degrees in architecture or urban planning, 27% were civil engineers, and 23% were other types of engineers. Approximately 45% of the respondents held a master's degree, while 32% held a bachelor's degree, and 23% held a doctoral or postdoctoral degree. To ensure the validity of the questionnaires, face validity was employed by presenting the designed questionnaire to experts, and its validity was confirmed. Subsequently, to assess the reliability of the questionnaire, Cronbach's alpha coefficient was utilized, with a generally acceptable value above 0.70. Using the data obtained from the questionnaires and the statistical software Statistical Package of Social Science (SPSS), the reliability coefficient was calculated using Cronbach's alpha method. The obtained Cronbach alpha value for this questionnaire was 0.811, indicating that the questionnaire had acceptable and suitable reliability. The results of the examination and validation of the criteria led to the identification of twenty ranking criteria for green buildings in Iran. Subsequently, through structural-interpretive modeling and MICMAC analysis, the relationships among the criteria were graded, and the research model was illustrated and presented. As shown in Figure (1), in the first stage, the proposed criteria for ranking green buildings in Iran were identified qualitatively through a systematic review of research literature. A specific number of criteria were identified based on the conducted reviews, and for the sake of reliability, their decision-making validity was evaluated and finally confirmed by expert specialists. In the second phase, the implementation of structural-interpretive modeling was addressed. ISM was employed as a proficient approach to establish textual relationships between the proposed criteria for ranking green buildings in Iran. In the third stage, MICMAC analysis classifies the criteria into different categories based on their influence and dependence.

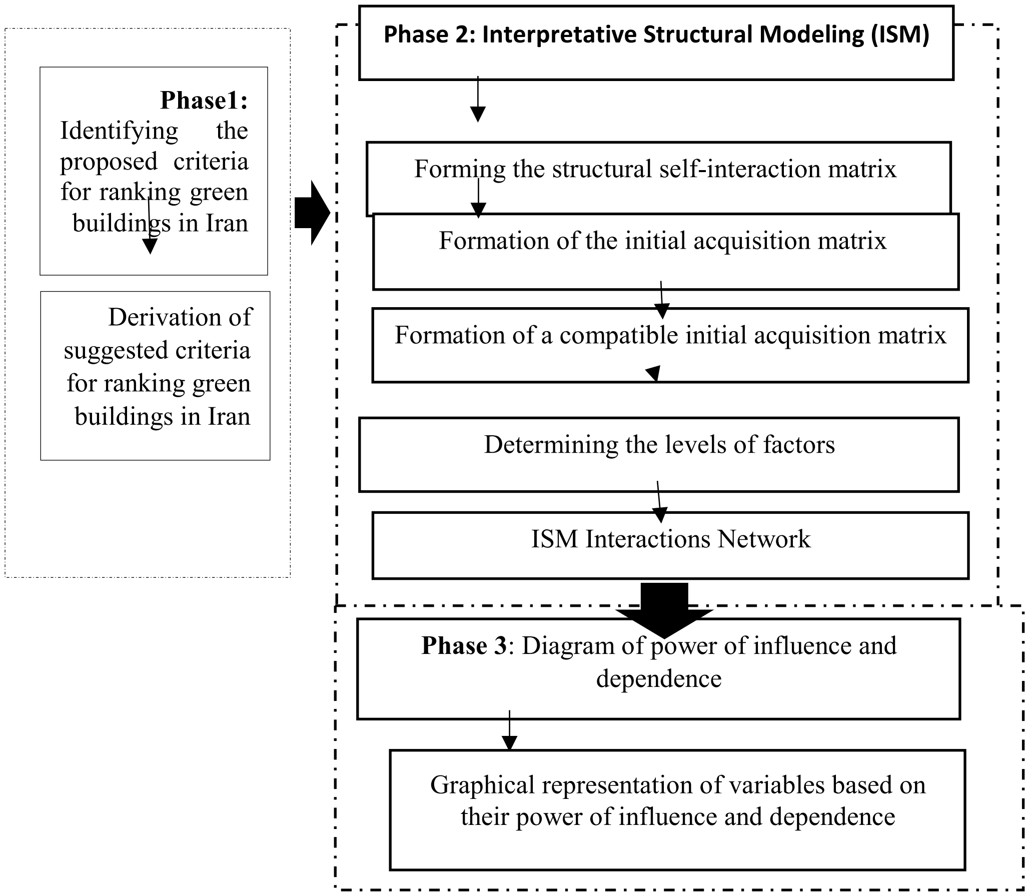


Figure 1: *Schematic of the Methodology*

**Interpretative Structural Modeling (ISM)**

Harary et al. (1965) and Warfield (1974) mathematically developed ISM. based on graph theory. ISM establishes a hierarchical structure equations model based on complex elements. Once the structure equations model is analyzed by the relevant experts, a directed graph is plotted to describe the contextual relationships between elements. ISM identifies and analyzes relationships between specific variables and graphically and verbally describes a problem, system, or area of study is described in a precise model. Following the pairwise comparison of variables, a Structural Self-Interaction Matrix (SSIM) is constructed. The SSIM becomes a Reachability Matrix (RM) whose transitivity is evaluated. Transition insertion produces a matrix model. The ISM development stages are as follows (Ahmadi and Zare, 2021; Akbarifar et al., 2024; Ardehi et al., 2023; Torabi, 2021; Firoozi nia et al., 2023; Ghalamsiah et al., 2021; Iqbal et al., 2023; Toudeh Bahambari et al., 2022;Mostafazadeh and Haghighat Monfared, 2021; Toudeh Bahambari et al., 2022):

1) Listing the factors relating to the system.
2) Constructing an SSIM: pairwise comparisons of the criteria by experts.
3) Obtaining the initial RM: transforming the symbols of the SSIM into 0s and 1s to obtain an initial RM.
4) Consistency of the RM: establishing the internal consistency of the initial RM. For example, if variable 1 leads to variable 2, and variable 2 leads to variable 3, then variable 1 should lead to variable 3. Otherwise, the RM should be modified. This consistency is added to the initial RM using secondary relationships that may not exist.
5) Determining the levels of variables: input (antecedent) and output (reachability) sets of criteria are calculated. Then, the common factors are determined. The criteria for which the output set (reachability) is the

same as the intersection has the highest level. Once this variable(s) has been identified, their rows and columns are excluded from the matrix, repeating the process for the other criteria. The outputs and inputs are obtained from the consistent initial RM, where the number of 1-elements in each row represents the output and the number of 1-elements in the column represents the input.

6) Plotting the interaction network: An interaction network is plotted based on the levels of criteria and their relationships. The ISM interaction network is plotted using the levels of criteria. The relationship between variables i and j would be denoted by a directional arrow (Naeini Peikani et al., 2021).

## MICMAC Analysis

Based on the effects and dependencies of variables, MICMAC analysis enables further evaluation of the range of each variable and classifies variables into autonomous, driver, dependent, and linkage (Karimikia et al., 2023; Yu, 2022).

## Results

The barriers were modeled and analyzed using ISM and MICMAC analysis. The ISM approach is described in the following:

## Implementing ISM

**Phase 1:** Identification of indices: Drawing on a qualitative methodology, the indices were extracted from a literature review, as shown in Table (1).

Table 1. *Indicators studied in the research*

| Code | Index | Average Score |
|---|---|---|
| C1 | Climatic details | 4.000 |
| C2 | Land use | 3.733 |
| C3 | Region-specific conditions | 4.133 |
| C4 | Building facade performance | 3.800 |
| C5 | Ecological site development | 4.067 |
| C6 | Material storage and recovery | 3.533 |
| C7 | Sustainable regional development | 3.600 |
| C8 | Recycled materials | 3.600 |
| C9 | Quality management | 4.333 |
| C10 | Building density | 3.733 |
| C11 | Innovation | 3.933 |
| C12 | Construction cost reduction | 3.600 |
| C13 | Initial cost reduction | 3.533 |
| C14 | Thermal performance of buildings | 4.133 |
| C15 | Water consumption control/monitoring | 4.067 |
| C16 | Operation-time cost reduction | 3.733 |
| C17 | Wastewater management | 3.733 |
| C18 | Waste reduction | 3.800 |
| C19 | Pollution reduction | 3.733 |
| C20 | Renewable materials | 4.000 |

**Phase 2:** Forming the structural self-interaction matrix (SSIM): The SSIM was developed based on the responses and the pairwise comparisons of the criteria by experts. It consisted of twenty dimensions with the following instruction: If a factor in row i leads to the factor in column j (V), if a factor in column j leads to a factor in row i (A), if both factors lead to each other (bidirectional relationship between factors i and j) (X), and if no relationship exists between the row and column factors (O). The responses collected from the questionnaires were aggregated, concluding the data using ISM and constructing the SSIM. Table (2) reports the SSIM based on non-parametric methodologies.

Table 2.
*Structural Self-Interaction Matrix (SSIM)*

| | C20 | C19 | C18 | C17 | C16 | C15 | C14 | C13 | C12 | C11 | C10 | C9 | C8 | C7 | C6 | C5 | C4 | C3 | C2 | C1 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | V | V | V | V | O | V | V | V | V | V | O | V | V | V | V | V | V | A | X | |
| **C2** | V | V | V | O | O | V | O | O | V | V | O | V | V | V | V | O | V | A | | |
| **C3** | V | V | V | V | V | V | O | V | V | V | O | V | V | V | V | O | V | | | |
| **C4** | V | V | O | O | O | X | V | X | O | V | X | X | X | X | X | X | | | | |
| **C5** | V | O | O | O | O | O | V | V | O | V | V | V | V | V | V | | | | | |
| **C6** | A | O | O | O | O | O | V | V | V | V | A | X | V | O | | | | | | |
| **C7** | V | O | O | O | O | V | V | V | O | V | O | A | V | | | | | | | |
| **C8** | A | O | O | O | O | O | V | V | O | V | A | A | | | | | | | | |
| **C9** | A | O | O | O | O | A | V | V | V | V | A | | | | | | | | | |
| **C10** | V | O | O | O | O | O | V | V | O | V | | | | | | | | | | |
| **C11** | A | O | O | O | V | V | V | V | O | | | | | | | | | | | |
| **C12** | A | A | A | O | O | O | O | O | | | | | | | | | | | | |
| **C13** | A | A | A | A | X | A | A | | | | | | | | | | | | | |
| **C14** | A | O | A | O | V | O | | | | | | | | | | | | | | |
| **C15** | A | A | A | V | V | | | | | | | | | | | | | | | |
| **C16** | A | O | A | A | | | | | | | | | | | | | | | | |
| **C17** | O | O | X | | | | | | | | | | | | | | | | | |
| **C18** | V | A | | | | | | | | | | | | | | | | | | |
| **C19** | V | | | | | | | | | | | | | | | | | | | |
| C20 | | | | | | | | | | | | | | | | | | | | |

**Phase 3:** Initial RM: The initial RM should be constructed by transforming SSIM elements into 0s or 1s based on the following instruction:

- ❑ If cell ij is V, it becomes 1; the opposite cell becomes 0.
- ❑ If cell ij is A, it becomes 0; the opposite cell becomes 1.
- ❑ If cell ij is X, it becomes 1; the opposite cell also becomes 1.
- ❑ If cell ij is O, it becomes 0; the opposite cell also becomes 0.

Table 3.
*Initial RM*

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 |
| **C2** | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 1 |
| **C3** | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 |
| **C4** | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 1 | 1 |
| **C5** | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| **C6** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C7** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 1 |
| **C8** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C9** | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 1 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C10** | 0 | 0 | 0 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 0 | 1 | 1 | 0 | 0 | 0 | 0 | 0 | 1 |
| **C11** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |
| **C12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C13** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **C14** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 |
| **C15** | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 1 | 0 | 0 | 0 |
| **C16** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C17** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 1 | 0 | 0 |
| **C18** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 1 |
| **C19** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 1 | 0 | 1 |
| **C20** | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 0 | 0 | 0 |

**Phase 4:** Consistent initial RM: The initial RM should have internal consistency. For example, if variable 1 leads to variable 2 and variable 2 leads to variable 3, variable 1

should lead to variable 3; otherwise, the initial RM should be modified. This consistency is added to the initial RM using secondary relationships that may not exist. Table (4) shows the adaptive initial RM, where cells 1* represent relationships that were added to the RM.

Table 4.
*Consistent initial RM*

| | C1 | C2 | C3 | C4 | C5 | C6 | C7 | C8 | C9 | C10 | C11 | C12 | C13 | C14 | C15 | C16 | C17 | C18 | C19 | C20 | Power of influence |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **C1** | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 |
| **C2** | 1 | 1 | 0 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 1 | 1* | 1* | 1 | 1 | 1 | 1 |
| **C3** | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 |
| **C4** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1* | 1* | 1* | 1 | 1 | 0 |
| **C5** | 0 | 0 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 0 | 0 | 1* | 1 | 0 |
| **C6** | 0 | 0 | 0 | 1 | 1* | 1 | 1* | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 0 | 0 | 1* | 1* | 0 |
| **C7** | 0 | 0 | 0 | 1 | 1* | 1* | 1 | 1 | 1* | 1* | 1 | 1* | 1 | 1 | 1 | 1* | 1* | 0 | 1* | 1 | 0 |
| **C8** | 0 | 0 | 0 | 1 | 1* | 1* | 1* | 1 | 1* | 1* | 1 | 0 | 1 | 1 | 1* | 1* | 0 | 0 | 1* | 1* | 0 |
| **C9** | 0 | 0 | 0 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1* | 0 | 0 | 1* | 1* | 0 |
| **C10** | 0 | 0 | 0 | 1 | 1* | 1 | 1* | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1* | 1* | 0 | 0 | 1* | 1 | 0 |
| **C11** | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 1* | 0 | 1 | 0 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 0 | 0 |
| **C12** | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 |
| **C13** | 0 | 0 | 0 | 1 | 1* | 1* | 1* | 1* | 1* | 1* | 1* | 0 | 1 | 1* | 1* | 1 | 0 | 0 | 1* | 1* | 0 |
| **C14** | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 1 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **C15** | 0 | 0 | 0 | 1 | 1* | 1* | 1* | 1* | 1 | 1* | 1* | 1* | 1 | 1* | 1 | 1 | 1 | 1* | 1* | 1* | 0 |
| **C16** | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1 | 0 | 0 | 1 | 0 | 0 | 0 | 0 | 0 |
| **C17** | 0 | 0 | 0 | 1* | 0 | 0 | 0 | 0 | 0 | 0 | 0 | 1* | 1 | 1* | 1* | 1 | 1 | 1 | 0 | 1* | 0 |
| **C18** | 0 | 0 | 0 | 1* | 0 | 1* | 0 | 1* | 1* | 0 | 1* | 1 | 1 | 1 | 1 | 1 | 1 | 1 | 0 | 1 | 0 |
| **C19** | 0 | 0 | 0 | 1* | 0 | 1* | 0 | 1* | 1* | 0 | 1* | 1 | 1 | 1* | 1 | 1* | 1* | 1 | 1 | 1 | 0 |
| **C20** | 0 | 0 | 0 | 1* | 0 | 1 | 1* | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 0 | 0 | 1 | 0 |
| **The degree of dependence** | 1 | 1 | 0 | 1 | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 | 1* | 1 | 1 | 1 | 1 | 1 |

**Phase 5:** Partitioning of levels: The input (antecedent) and output (reachability) criterion sets are calculated. Then, the common factors are determined; the criterion for which the output (reachability) set is the same as the intersection with the highest level. Once this variable(s) has been identified, the corresponding row(s) and column(s) are excluded from the RM, repeating the process for the other criteria. The outputs and inputs are extracted from the consistent initial RM. Here, the number of 1-cells in each row represents the output and the number of 1-cells in each column stands for the input. Table (5) shows the levels of the factors.

Table 5.
*Factor Levels*

| Criterion | Output | Input | Subscription | Level |
|---|---|---|---|---|
| **C1** | C1C2C4C5C6C7C8C9C10C11C12C13C14C15C16C17C18C19C20 | C1C2C3 | C1C2 | 9 |
| **C2** | C1C2C4C5C6C7C8C9C10C11C12C13C14C15C16C17C18C19C20 | C1C2C3 | C1C2 | 9 |
| **C3** | C1C2C3C4C5C6C7C8C9C10C11C12C13C14C15C16C17C18C19C20 | C3 | C3 | 10 |
| **C4** | C4C5C6C7C8C9C10C11C12C13C14C15C16C17C18C19C20 | C1C2C3C4C5C6C7C8C9C10C11C13C14C15C16C17C18C19C20 | C4C5C6C7C8C9C10C11C13C14C15C16C17C18C19C20 | 2 |
| **C5** | C4C5C6C7C8C9C10C11C12C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15 | C4C5C6C7C8C9C10C13C15 | 8 |
| **C6** | C4C5C6C7C8C9C10C11C12C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15C18C19C20 | C4C5C6C7C8C9C10C13C15C19C20 | 5 |
| **C7** | C4C5C6C7C8C9C10C11C12C13C14C15C16C17C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15C20 | C4C5C6C7C8C9C10C13C15C20 | 8 |
| **C8** | C4C5C6C7C8C9C10C11C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15C18C19C20 | C4C5C6C7C8C9C10C13C15C19C20 | 5 |
| **C9** | C4C5C6C7C8C9C10C11C12C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C11C13C15C18C19C20 | C4C5C6C7C8C9C10C11C13C15C19C20 | 3 |
| **C10** | C4C5C6C7C8C9C10C11C12C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15 | C4C5C6C7C8C9C10C13C15 | 8 |
| **C11** | C4C9C11C13C14C15C16C17 | C1C2C3C4C5C6C7C8C9C10C11C13C15C18C19C20 | C4C9C11C13C15 | 4 |
| **C12** | C12 | C1C2C3C4C5C6C7C9C10C12C15C17C18C19C20 | C12 | 1 |
| **C13** | C4C5C6C7C8C9C10C11C13C14C15C16C19C20 | C1C2C3C4C5C6C7C8C9C10C11C13C14C15C16C17C18C19C20 | C4C5C6C7C8C9C10C11C13C14C15C16C19C20 | 1 |
| **C14** | C4C13C14C16 | C1C2C3C4C5C6C7C8C9C10C11C13C14C15C17C18C19C20 | C4C13C14 | 2 |
| **C15** | C4C5C6C7C8C9C10C11C12C13C14C15C16C17C18C19C20 | C1C2C3C4C5C6C7C8C9C10C11C13C15C17C18C19C20 | C4C5C6C7C8C9C10C11C13C15C17C18C19C20 | 3 |
| **C16** | C4C13C16 | C1C2C3C4C5C6C7C8C9C10C11C13C14C15C16C17C18C19C20 | C4C13C16 | 1 |
| **C17** | C4C12C13C14C15C16C17C18C20 | C1C2C3C4C7C11C15C17C18C19C20 | C4C15C17C18C20 | 3 |
| **C18** | C4C6C8C9C11C12C13C14C15C16C17C18C20 | C1C2C3C4C15C17C18C19 | C4C15C17C18 | 6 |
| **C19** | C4C6C8C9C11C12C13C14C15C16C17C18C19C20 | C1C2C3C4C5C6C7C8C9C10C13C15C19 | C4C6C8C9C13C15C19 | 7 |
| **C20** | C4C6C7C8C9C11C12C13C14C15C16C17C20 | C1C2C3C4C5C6C7C8C9C10C13C15C17C18C19C20 | C4C6C7C8C9C13C15C17C20 | 5 |

**Phase 6:** ISM interaction network: The ISM interaction network was plotted based on the factor levels. The relationship between variables i and j would be represented by a directional arrow. The final diagram was plotted by excluding the repeated cases and using the partitioned levels, as shown in Figure (2).

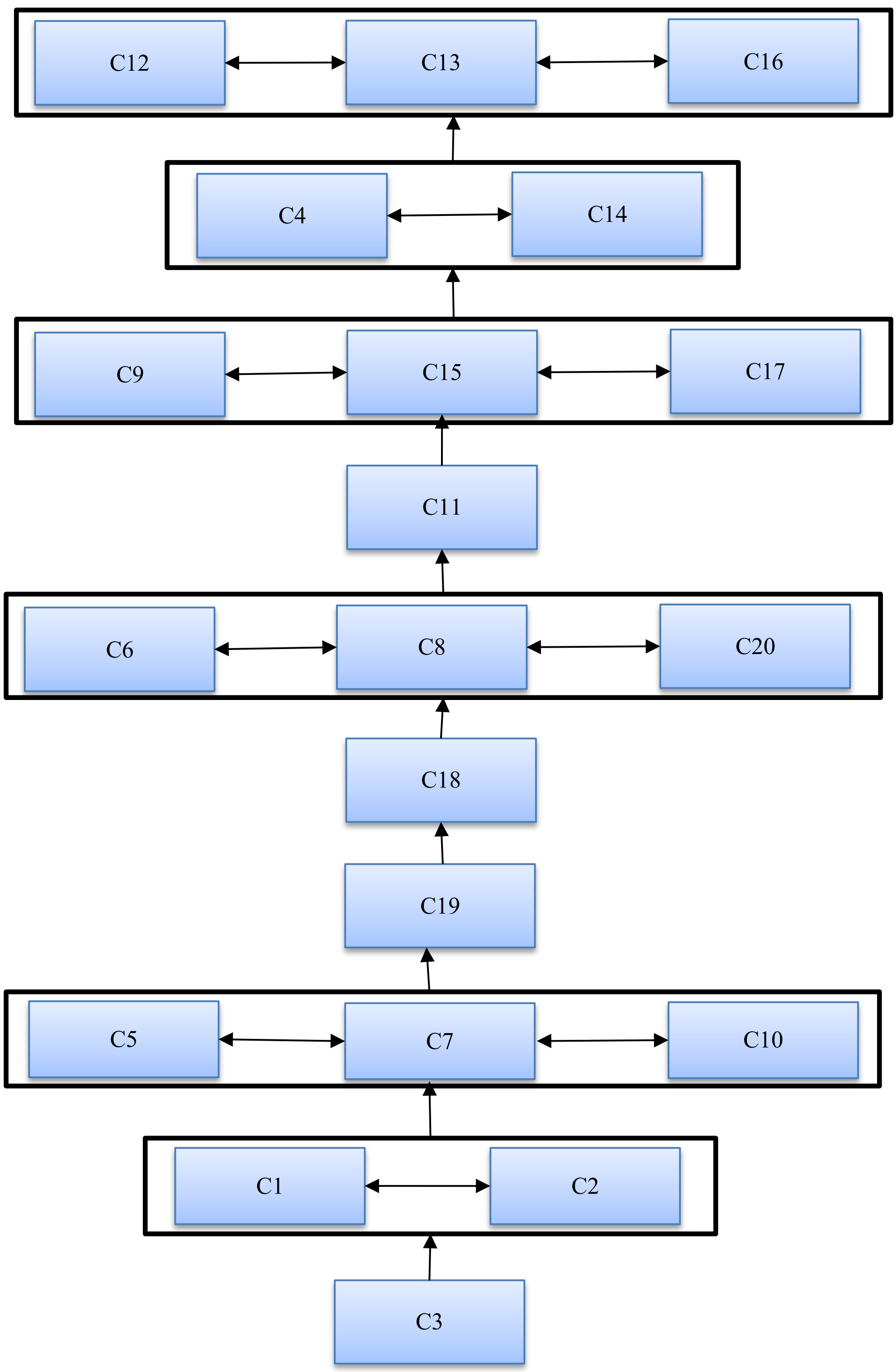

Figure 2. *Schematic of the Methodology*

According to Figure (2), the research model includes 10 levels, and index Region-specific conditions (C3) is at level 10 and is the most influential index. In fact, this index directly affects Climatic details (C1) and Land use (C2). Construction cost reduction (C12), Initial cost reduction (C13) and Operation-time cost reduction (C16) are at level one, which are the most influential criteria.

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The research model can be shown in terms of power of influence and dependence as Figure (3). Accordingly, criteria (C1), (C2), (C3) and (C18) are independent variables. These variables have low dependence and high directivity, in other words, high influence and low influence are the characteristics of these variables. Criteria (C11), (C12), (C14), (C16) and (C17) are dependent variables. These variables have strong dependence and weak direction. Basically, these variables have high influence and little influence on the system. The rest of the criteria are linkage, these variables have high dependence and high guiding power, in other words, the effectiveness and effectiveness of these criteria is very high, and any small change on these variables causes fundamental changes in the system.

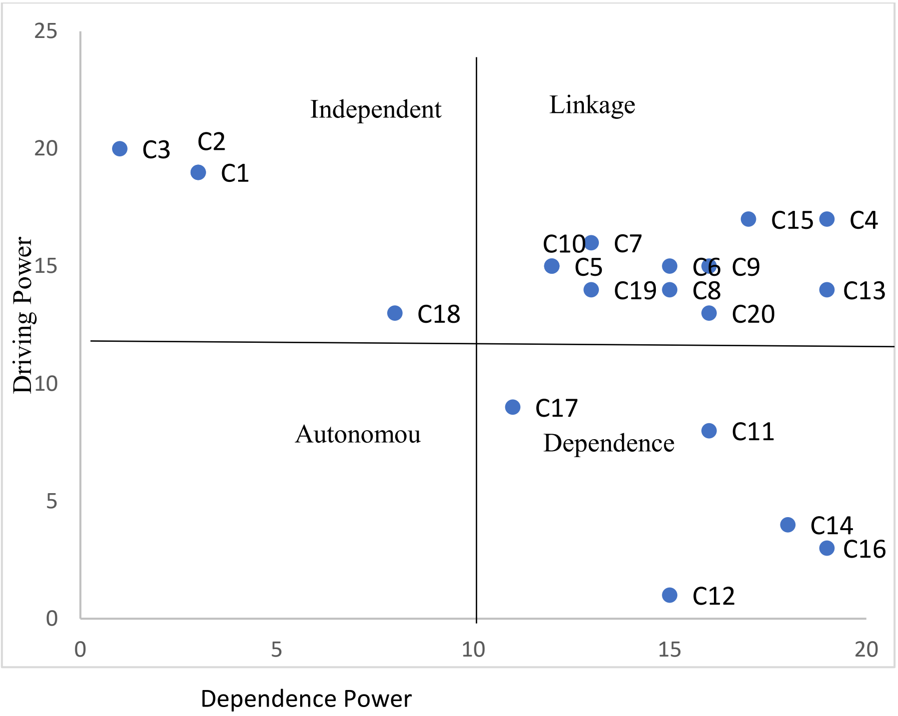


Figure 3. *Clustering of green building rating criteria in Iran*

## Conclusions and Recommendations

In the field of sustainable development, green buildings play an important role in reducing environmental impacts and improving resource efficiency. To evaluate the sustainability of buildings, various rating systems have been developed, of which the Green Building Rating Criteria (GBRSs) is one of the most widely used. In Iran, where the construction industry is growing rapidly, the implementation of GBRS is necessary to ensure that buildings meet certain environmental standards. In this regard, according to the importance of the subject, in the current research, interpretive structural modeling (ISM) analysis has been used to analyze and evaluate GBRSs in Iran. Green Building Rating Criteria (GBRSs) serve as a pivotal benchmark for assessing the environmental performance of buildings, encompassing a spectrum of considerations from energy efficiency to water usage, and material sustainability. The adoption of GBRSs within Iran's burgeoning construction landscape is not merely a response to global sustainability trends but a critical measure aimed at mitigating the environmental footprint of its urban development. As the nation confronts challenges such as water scarcity and energy consumption, the role of GBRSs transcends regulatory compliance, steering the architectural and construction sectors towards practices that preserve natural resources and enhance the quality of the built environment. The integration of these criteria underscores a broader commitment to environmental stewardship, setting a foundation for the sustainable growth of Iran's urban spaces. Through GBRSs, Iran is navigating a path that aligns its development objectives with the principles of sustainability, demonstrating a proactive approach to environmental conservation and sustainable urban planning. Green Building Rating Criteria (GBRSs) serve as a pivotal benchmark for assessing the environmental performance of buildings, encompassing a spectrum of considerations from energy efficiency to water usage, and material sustainability. The adoption of GBRSs within Iran's burgeoning construction landscape is not merely a response to global sustainability trends but a critical measure aimed at mitigating the environmental footprint of its urban development. As the nation confronts challenges such as water scarcity and energy consumption, the role of GBRSs transcends regulatory compliance, steering the architectural and construction sectors towards practices that preserve natural resources and enhance the quality of the built environment. The integration of these criteria underscores a broader commitment to environmental stewardship, setting a foundation for the sustainable growth of Iran's urban spaces. Through GBRSs, Iran is navigating a path that aligns its development objectives with the principles of sustainability, demonstrating a proactive approach to environmental conservation and sustainable urban planning. Interpretive Structural Modeling (ISM) represents a robust methodology crafted to dissect and understand the complexities of systems by examining the relationships between individual components within that system. Central to ISM's utility is its capacity to unveil how different elements are interlinked, thereby offering a structured framework through which to view their hierarchy and influence on one another. This methodology employs matrices to encapsulate these relationships, facilitating a visual representation of how criteria interact and influence the system as a whole. In the realm of Green Building Rating Criteria (GBRSs), applying ISM enables stakeholders to parse through the myriad of sustainability measures, prioritizing them in a manner that reflects their interdependencies and impact on green building performance. This approach not only streamlines the decision-making process but also enhances the strategic planning of sustainable building practices by illuminating the pivotal criteria that should be the focus of attention. Through ISM, the intricate web of criteria governing green buildings is methodically organized, providing a clear pathway for the evaluation and enhancement of sustainable construction. The study on GBRSs in Iran employed the Interpretive Structural Modeling (ISM) framework as a sophisticated Multi-Criteria Decision Making (MCDM) tool to dissect and analyze the intricate web of criteria that underpin green building standards. To embark on this analytical journey, researchers meticulously gathered data encompassing various GBRSs operational within Iran. This preliminary data collection was supplemented by insightful interviews with seasoned experts in the green building arena, aiming to distill the essence of key criteria that shape sustainable building practices. Leveraging the ISM methodology, the research team endeavored to construct a hierarchical model that encapsulates the nuanced relationships among these identified criteria. This model was crafted through a rigorous process of synthesizing expert opinions, ensuring a consensus-driven understanding of how different green building criteria interact and influence each other within the context of Iran's unique environmental and architectural landscape. This methodical approach not only illuminated the hierarchical dynamics of GBRSs but also paved the way for a deeper understanding of the critical factors driving green building design in Iran, setting a precedent for future research and policy-making in sustainable construction.

This groundbreaking study utilizing Interpretive Structural Modeling to dissect Green Building Rating Systems in Iran offers a nuanced lens through which to view the future of sustainable construction within the region. The insights garnered reveal not only the immediate benefits of prioritizing energy efficiency and water conservation but also lay the groundwork for a more integrated approach to green building practices. As we navigate the findings, it becomes evident that there is a compelling need for the evolution of GBRSs to include a broader spectrum of sustainability criteria, such as the incorporation of renewable energy sources and the adoption of efficient waste management techniques.The implications of this research extend beyond the confines of academic inquiry, serving as a catalyst for transformative change within Iran's construction sector. By highlighting the interdependencies among various sustainability criteria, this study equips policymakers, builders, and developers with the knowledge required to forge a more sustainable path forward. It encourages a shift in focus towards holistic building design, where the interplay between different green criteria is carefully considered to achieve optimal environmental performance. Looking ahead, there is a fertile ground for further research to expand upon the foundational ISM model developed in this study. Exploring the application of this model in different geographical and cultural contexts could yield invaluable insights into the global practices of sustainable construction. Moreover, integrating emerging technologies and innovative materials into future iterations of GBRSs could further enhance their effectiveness.

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