Research Annals of Industrial and Systems Engineering

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Res. Ann. Ind. Syst. Eng. Vol. 1, No. 1 (2024) 34–41.

Paper Type: Original Article

Evaluation of Factors Affecting the Successful Implementation of Green Buildings Based on the Combined Fuzzy DANP and IPA Approach

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Citation:

Received: 25 June 2024 *Revised: 23 August 2024* *Accepted: 20 October 2024*	Nayer, A., & Jahan, A. (2024). Evaluation of factors affecting the successful implementation of green buildings based on the combined fuzzy DANP and IPA approach. *Research annals of industrial and systems engineering, 1*(1), 34-.

Abstract

Green buildings play a key role in the sustainable development of the construction industry, helping reduce environmental impacts and optimize energy consumption. This study is aimed at evaluating the factors affecting the successful implementation of green buildings using a combination of the fuzzy Delphi method, fuzzy DANP, and Importance-Performance Analysis (IPA). The statistical population includes ten experts from Simin Stone Façade Construction Company, selected through purposive sampling. The research findings indicate that environmental benefits, energy consumption, resource utilization, and economic benefits are among the key factors affecting the success of green buildings. The fuzzy DANP analysis results show that energy consumption is the most influential factor on other indicators, while waste generation has the highest interconnection with other factors. Furthermore, the IPA analysis identifies waste generation as a critical weakness requiring immediate improvement. By presenting a comprehensive evaluation framework, this study can assist policymakers and construction industry stakeholders in optimizing the design and implementation of green buildings.

Keywords: Green building, Multi-criteria decision-making, Fuzzy delphi, Fuzzy DANP, Importance-performance analysis.

1 | Introduction

The construction industry plays a major role in meeting social needs and improving quality of life. In addition, buildings consume a significant amount of energy during construction and throughout their life cycle, causing negative environmental impacts [1]. The emergence of green building theory offers a solution to this issue and has been recognized as a preferred approach for development in the construction industry [2]. A green

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https://doi.org/10.22105/raise.v1i1.39

building refers to a structure designed to minimize its impact on the natural environment while maximizing the use of renewable resources throughout its lifecycle, including design, construction, operation, maintenance, renovation, and demolition. Green buildings enhance health, safety, comfort, and environmental awareness. They have become a competitive alternative to conventional buildings since they consume 35-40% less energy, incur lower operational costs, and provide a healthier and more efficient living environment [3].

Achieving sustainable green building design is essential for reducing environmental impacts and increasing energy efficiency. This involves the use of eco-friendly materials, improving indoor environmental quality, conserving resources, and promoting waste and consumption reduction measures [4]. Evaluating and assessing green buildings is crucial for advancing sustainable development. As noted, residential buildings consume a significant portion of energy, land, and natural materials, contributing to environmental pollution. Energy consumption in Iran has been increasing exponentially, with a 270% rise over the past two decades. One fundamental solution for reducing fossil fuel usage, land consumption, and natural material extraction is the implementation of green buildings. Green buildings reduce the use of natural sand and soil and are often constructed using fine industrial and mining waste materials. Unfortunately, unlike many other countries, Iran currently lacks localized green building standards [5]. Therefore, developing a comprehensive and localized evaluation system within the framework of green building indicators in Iran is a crucial necessity. This research was conducted to achieve this objective by identifying key factors influencing green buildings, discussed in the following sections.

Environmental benefits

The construction phase inherently alters the environment, and any delay in completion exacerbates its negative effects. Furthermore, noise disturbances from construction machinery, traffic, and the emission of particles from excavation and truck loading have direct impacts on the respiratory systems of both humans and animals [6]. Each stage in a building's lifecycle affects the environment to some extent, but the key phase is design and development. In the long term, if only the quality and cost of a building are considered without evaluating whether the design and construction process causes pollution and environmental damage, it will not only result in significant financial losses for companies but also lead to irreversible damage and disasters for the natural environment. Therefore, it is essential to integrate environmental benefit factors into the green design evaluation system and select building designs better aligning with the environment.

Energy consumption

Reducing energy waste generated during the design and construction process is a crucial issue that must be addressed. Only by minimizing energy loss and implementing energy-saving and reduction concepts through design selection can the demands of the current era of development be met, thereby enhancing the practical value of green buildings [7]. Green buildings can reduce energy consumption by up to 30% compared to conventional buildings [8].

Resource utilization

The heavy burden that the construction phase of a project imposes on the environment and society includes the exploitation of natural materials for construction storage, such as cement, timber, steel, and glass, eventually turning into waste [6]. The use of resources should be maximized in building design and construction processes. Irrational use of resources accelerates resource depletion, intensifies secondary pollution, and increases company costs. Therefore, in the process of constructing the green building design evaluation system, it is necessary to incorporate resource utilization as an evaluation criterion [7].

Economic benefits

The development and design of buildings are essential for corporate growth and social progress. Strong economic benefits can enhance the development of companies and society. A good building design should not only focus on the appearance and functionality of the building but also consider the overall construction cost and its economic advantages, which are crucial for both businesses and society [7].

Based on a review of papers and research, the key indicators influencing the successful implementation of green buildings were extracted. These indicators consist of nine criteria categorized into four dimensions, as presented in *Table 1*.

Table 1. Green building indicators.

Description	Sub-Criteria	Criteria
Amount of emission of exhaust gases from the building during construction and operation	Emission of exhaust gases	Environmental benefits
Amount of waste generated during construction and demolition of the building	Waste generation	
Amount of noise generated during construction activities	Construction noise	
Utilization of energy in the building, such as the use of renewable energy	Use of renewable energy	Energy consumption
Comparison of energy costs with building performance	Optimized energy cost	
Type of materials, equipment, and tools used in the building that are environmentally friendly	Use of environmentally friendly materials and equipment	Resource utilization
Amount of materials that can be recycled	Material recycling rate	
Ability of the building to withstand natural disasters such as earthquakes, floods, or storms	Resistance to natural disasters	Economic benefits
Costs associated with reducing the environmental impact of the building	Environmental costs of construction	

2 | Research Methodology

This is an applied study in terms of purpose and a survey one in nature. The statistical population consists of experts from Simin Stone Façade Construction Company. Using a purposive sampling method, ten experts with over ten years of experience in construction, holding positions as project managers, site supervisors, and building engineers, were selected. To achieve the research objectives, fuzzy Delphi [9], [10], fuzzy DANP, and IPA techniques [11] were employed. The fuzzy Delphi method was used to confirm and localize the research criteria, the fuzzy DANP method was applied to assess influence and dependence relationships and determine the importance of factors, and the IPA method was utilized to evaluate the criteria for organizational focus.

3 | Research Findings

In this section, the fuzzy Delphi method was employed to validate the research factors. Initially, the criteria and sub-criteria influencing the successful implementation of green buildings, extracted from the research background, were presented to experts for scoring based on the scale in *Table 4*. Experts were also asked to suggest any additional criteria they considered relevant. Then, using the fuzzy Delphi method, all factors were confirmed, and three additional criteria were identified and validated by the experts.

Table 4. Fuzzy Delphi results for criteria.

Status	Non-Fuzzy Mean	Fuzzy Mean	Sub-Criteria Symbol	Sub-Criteria	Criteria
Confirmed	0.750	(0.55,0.8,0.9)	A1	Emission of exhaust gases	Environmental benefits
Confirmed	0.742	(0.5,0.75,0.975)	A2	Waste generation	
Confirmed	0.750	(0.525,0.775,0.95)	A3	Construction noise	
Confirmed	0.850	(0.65,0.9,1)	A4	Internal health of the building*	
Confirmed	0.725	(0.475,0.725,0.975)	B1	Use of renewable energy	Energy consumption
Confirmed	0.767	(0.55,0.8,0.95)	B2	Optimized energy cost	
Confirmed	0.783	(0.575,0.825,0.95)	B3	Use of natural light*	
Confirmed	0.725	(0.5,0.75,0.925)	C1	Use of environmentally friendly materials and equipment	Resource utilization
Confirmed	0.725	(0.5,0.75,0.925)	C2	Material recycling rate	
Confirmed	0.725	(0.5,0.75,0.925)	C3	Durability and longevity of materials*	
Confirmed	0.767	(0.575,0.825,0.9)	D1	Resistance to natural disasters	Economic benefits
Confirmed	0.708	(0.475,0.725,0.925)	D2	Environmental costs of construction	

*The criteria marked with an asterisk (*) were identified by experts.

Based on the results of the fuzzy DANP method, presented in *Table 7* and *Table 8*, among the main criteria, energy consumption (B) has a causal and influential nature, while the other three criteria –environmental benefits (A), resource utilization (C), and economic benefits (D)– are effect criteria with dependent characteristics. Among the sub-criteria, the use of renewable energy (B1), exhaust gas emissions (A1), and optimized energy costs (B2) are classified as causal factors with higher influence. On the other hand, the material recycling rate (C2), construction noise (A3), and resilience to natural disasters (D1) are categorized as effect factors with higher dependency. Moreover, based on the D+R and D-R values, the network relationship map of the criteria was drawn, as shown in *Fig. 1*. Criteria above the horizontal axis have a causal nature, while those below the axis are dependent factors. Waste generation (A2) was identified as the most interconnected criterion with other research factors. Besides, *Table 7* presents the final weight of the criteria. Among the main criteria, environmental benefits ranked first with a weight of 0.2978, followed by resource utilization at 0.2865, economic benefits at 0.2233, and energy consumption at 0.1924. Among the sub-criteria, resilience to natural disasters ranked first with a weight of 0.1547, followed by the material recycling rate at 0.1296, and construction noise at 0.105.

Table 7. Influence and dependency of main criteria.

Type of Criteria	Di-Ri	Di+Ri	$(Ri)^{defuzzy}$	$(Di)^{defuzzy}$	Code	Criteria
Effect	-0.018	-0.018	0.609	0.590	A	Environmental benefits
Cause	0.117	0.117	0.471	0.588	B	Energy consumption
Effect	-0.079	-0.079	0.611	0.533	C	Energy consumption
Effect	-0.020	-0.020	0.493	0.473	D	Energy consumption

Table 8. Influence and dependency of sub-criteria.

Type of Criteria	Di-Ri	Di+Ri	$(Ri)^{defuzzy}$	$(Di)^{defuzzy}$	Code	Criteria
Cause	0.397	3.091	1.347	1.744	A1	Emission of exhaust gases
Effect	-0.139	4.087	2.113	1.974	A2	Waste generation
Effect	-0.735	3.756	2.246	1.511	A3	Construction noise
Cause	0.307	3.517	1.605	1.912	A4	Internal health of the building
Cause	0.499	3.322	1.411	1.911	B1	Use of renewable energy
Cause	0.387	3.373	1.493	1.880	B2	Optimized energy cost
Cause	0.174	3.0814	1.455	1.629	B3	Use of natural light
Cause	0.170	3.429	1.629	1.799	C1	Use of environmentally friendly materials and equipment
Effect	-0.765	3.866	2.316	1.550	C2	Material recycling rate
Effect	-0.200	3.175	1.687	1.487	C3	Durability and longevity of materials
Effect	-0.426	3.387	1.907	1.481	D1	Resistance to natural disasters
Cause	0.330	2.569	1.119	1.449	D2	Environmental costs of construction
Cause	0.397	3.091	1.347	1.744	F2	Private institutions
Effect	-0.139	4.087	2.113	1.974	F3	National support
Effect	-0.735	3.756	2.246	1.511	G1	Product quality characteristics
Cause	0.307	3.517	1.605	1.912	G2	Product quantity characteristics

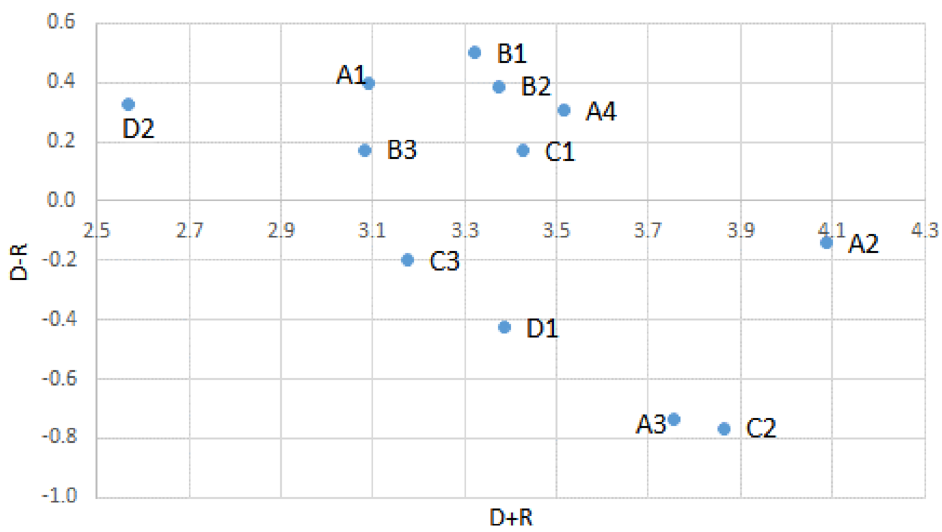

Fig. 2. Map of causal relationships of criteria.

Table 9. Final weight of criteria.

Final Rank of Sub-Criteria	Final Weight of Sub-Criteria	Symbol of Sub-Criteria	Sub-Criteria	Final of Sub-Criteria	Criteria
12	0.0476	A1	Emission of exhaust gases	0.2978	Environmental benefits
5	0.0845	A2	Waste generation		
3	0.1050	A3	Construction noise		
11	0.0607	A4	Internal health of the building		
10	0.0625	B1	Use of renewable energy	0.1924	Energy consumption
8	0.0661	B2	Optimized energy cost		
9	0.0638	B3	Use of natural light		
6	0.0704	C1	Use of environmentally friendly materials and equipment	0.2865	Energy consumption
2	0.1296	C2	Material recycling rate		
4	0.0866	C3	Durability and longevity of materials		
1	0.1547	D1	Resistance to natural disasters	0.2233	Energy consumption
7	0.0686	D2	Environmental costs of construction		

Next, the research factors were analyzed by the IPA method. Accordingly, 12 sub-criteria were presented to experts, who assessed the current performance of building construction for each criterion on a scale of 1 to 5. The geometric mean of the scores was then calculated, and based on the obtained values, the IPA matrix was drawn, as shown in *Fig. 3*. The following sections provide an analysis of the matrix.

Quadrant 1 (focus here): the waste generation criterion (A2) falls into this quadrant. It is considered highly important by respondents; however, its performance level is relatively low. This quadrant indicates a fundamental weakness within the organization that requires immediate attention for improvement. In fact, efforts to enhance this area should be given the highest priority, as it represents a critical deficiency.

Quadrant 2 (keep up the good work): the criteria of construction noise (A3), material recycling rate (C2), durability and longevity of materials (C3), and resilience to natural disasters (D1) are located in this quadrant. These criteria are highly important to respondents, and at the same time, the organization's performance in these areas is at its highest level. Therefore, this positive trend should be maintained and continued. This quadrant represents the organization's key strengths, which must be preserved.

Quadrant 3 (low priority): the criteria of exhaust gas emissions (A1), use of renewable energy (B1), use of natural light (B3), and use of environmentally friendly materials and equipment (C1) fall into this quadrant. They are rated low in both importance and performance. Although the performance level is low in this area, managers should not focus excessively on it, as these criteria are not highly significant. Limited resources should be allocated here.

Quadrant 4 (waste of resources): the criteria of indoor health quality (A4), optimized energy cost (B2), and environmental costs of construction (D2) belong to this quadrant. They hold low importance but exhibit relatively high performance. Respondents are satisfied with the organization's performance in these areas; however, managers should recognize that current efforts toward these criteria are unnecessary and excessive. In other words, the resources allocated to these criteria exceed the required amount and should be redirected elsewhere.

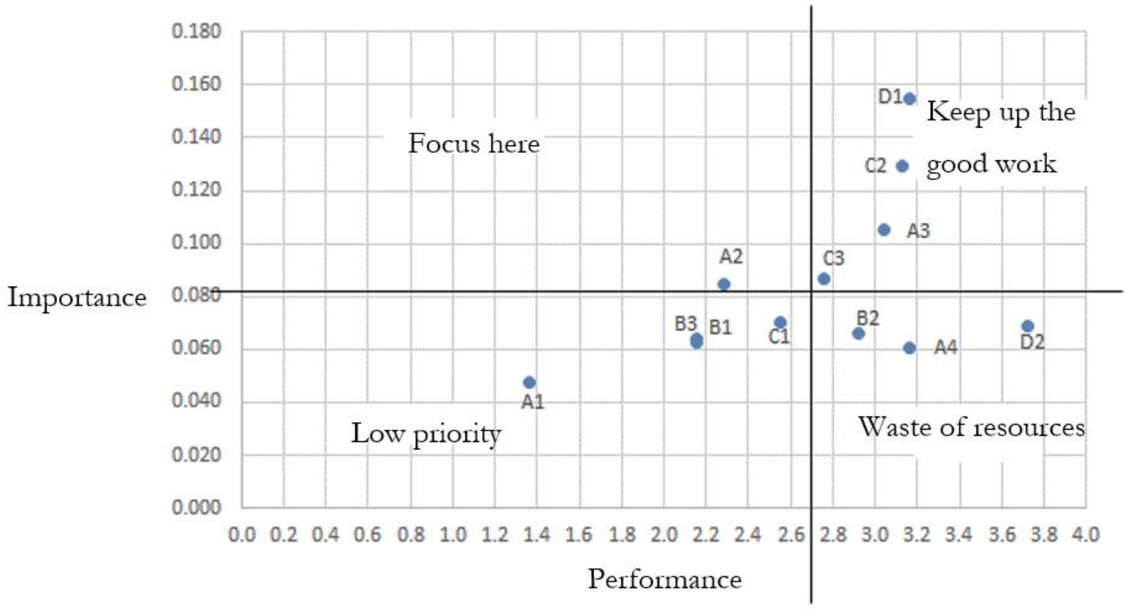

Fig. 3. Importance-performance analysis matrix.

4 | Conclusion

In recent decades, the focus on sustainable construction and the application of green building principles has grown significantly due to their environmental, economic, and social implications. In this context, identifying the key success factors in implementing green buildings can enhance construction quality, optimize resource consumption, and mitigate environmental pollution. This study, employing a hybrid approach of fuzzy Delphi, fuzzy DANP, and Importance-Performance Analysis (IPA), delves into these critical factors. The findings reveal that the successful execution of green buildings is shaped by four primary criteria: environmental benefits, energy consumption, resource utilization, and economic advantages. Moreover, the fuzzy DANP method establishes energy consumption as the most influential factor affecting other criteria, while waste generation emerges as the most interconnected variable within the system.

One of the most important findings of the current study is the key role of environmental and economic criteria in the success of green construction projects. The IPA results revealed that some criteria, such as waste generation, require immediate attention and performance improvement, while others, such as resilience to natural disasters and material recycling rates, have satisfactory performance and should be maintained. These findings highlight the necessity of focusing on critical criteria and developing strategies to mitigate environmental impacts. In this regard, it is recommended that policymakers and construction project managers develop and implement strategies to reduce waste generation, optimize energy consumption, and increase the material recycling rate.

Moreover, the research results indicate that several challenges hinder the implementation of green buildings in Iran, including the lack of local standards, insufficient financial and policy support, and the high cost of sustainable materials. These issues may reduce the willingness of investors and developers to execute green projects. Thus, it is crucial for the government and relevant institutions to develop incentive and support policies for green building development. Providing financial facilities, formulating national standards and offering specialized training to engineers and construction professionals, as well as advancing innovative technologies in this field can play a significant role in promoting green buildings.

Overall, this study provides a comprehensive framework for evaluating and prioritizing the factors influencing green buildings, serving as a practical guide for policymakers, researchers, and construction industry professionals. Future research is recommended to explore the impact of emerging technologies such as artificial intelligence, blockchain, and the Internet of Things (IoT) on the successful implementation of green buildings. Moreover, conducting comparative studies between Iran and other countries could help identify successful models and develop suitable localized strategies.

Conflict of Interest

The authors declare no conflict of interest.

Data Availability

All data are included in the text.

Funding

This research received no specific grant from funding agencies in the public, commercial, or not-for-profit sectors.

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