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ARTICLE

A Study on Factors Influencing Cost Management in Green Building Construction

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ABSTRACT

Green buildings represent a crucial solution for reducing carbon emissions in the construction sector, which accounts for approximately one-third of global energy-related emissions. However, high initial costs remain a significant barrier to widespread adoption of sustainable construction practices. This study addresses the critical gap in understanding how cost factors interconnect throughout the entire lifecycle of green building projects. Using a comprehensive life cycle approach combined with Interpretive Structural Modeling (ISM) and MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) methodologies, this research examines 20 key factors influencing green building construction costs across four major phases: planning and design, construction and building, maintenance and recovery, and policy and environment. The analysis reveals that "Policy Support" functions as the primary root cause factor, exerting the strongest influence on green building design, certification requirements, and operational strategies. Energy-saving technologies and green construction standards emerge as critical mediating factors within the system hierarchy. The ISM analysis constructs a seven-level hierarchical structure, while MICMAC classification identifies independent, dependent, and interactive factor categories based on their driving power and dependence relationships. This research provides the first systematic mapping of cost factor interdependencies in green building projects, offering both theoretical advancement in cost analysis methodologies and practical guidance for governments, developers, and investors. The framework enables stakeholders to optimize cost efficiency, prioritize regulatory interventions, and develop strategies that promote economically viable sustainable construction practices.

Keywords: Green Building; Cost; ISM-MICMAC

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1. Introduction

According to the 2023 UNEP "Emissions Gap Report," emissions from the building sector have been identified as an important issue. The building sector accounts for about one-third of all energy-related emissions. Among them, operational emissions account for 26%, and embodied emissions generated during the production of construction materials such as steel and cement account for an additional 7%. To meet the carbon neutrality scenario by 2050, operational emissions from buildings need to be reduced by about 50% by 2030[1–6].

To achieve this goal, green buildings have emerged as an effective solution. Green buildings contribute to reducing the overall carbon emissions of buildings and improving environmental impacts through optimized design, the use of sustainable materials, and energy-efficient systems. Specifically, green buildings emphasize not only the operational efficiency of buildings but also the environmental impacts throughout the building's life cycle[7–13].

Therefore, studying the cost influencing factors throughout the entire life cycle of green buildings in China and analyzing them by dividing them into the planning stage, design stage, construction stage, maintenance stage, and demolition stage of construction projects will be an important research method to promote the development of green buildings[14–21].

On the other hand, the initial cost investment in the planning and construction stages of green buildings is generally relatively high. However, by analyzing cost management factors, establishing an effective cost management system, and increasing the incremental effect, the total cost throughout the entire life cycle of a green construction project can be lower than that of traditional buildings[22–31]. While we understand the financial impact of green buildings during their lifetimes, the relationships between various influencing factors are still not understood. Researchers usually focus on just one cost factor rather than examining how they are linked as projects move from one phase to another. That's why exploring how these factors are related can help develop better and unified approaches to controlling costs in green buildings.

To further promote the development of green buildings, based on the current research situation of green buildings, this paper constructs a model of the relationships among influencing factors, analyzes the influencing factors of cost management in green buildings, and selects the main factors that have a significant impact on the costs of green buildings. It provides certain reference value for promoting the development of green buildings and can contribute to minimizing the costs of green buildings[32–40].

Research on the cost of green buildings has often split up the costs or overlooked the entire life cycle of the building. In addition, there is a lack of understanding about how these factors depend on one another, especially when examined through ISM and MICMAC approaches. This research fills this gap by identifying the main cost drivers and studying how they relate to one another[41–43].

Research Question: What drives the total cost of green building over its lifespan and how are these factors connected in a hierarchy?

Hypotheses:

The policy factor is the most important cost driver.

Environmental standards and energy-saving technologies help companies save costs by working together.

The goal of this research is to formulate a framework that examines the various factors affecting costs in green building projects, using the ISM-MICMAC method. It strives to determine the most important places where actions can be taken to enhance cost efficiency and support green construction practices[44–46].

With the world focused on reducing carbon emissions and saving resources, it's important to study the costs involved in building green. Through examining both direct and indirect costs, the study offers important advice to decision-makers on how to manage resources, lower costs and design better policies for using green building technologies by many[31, 47–52].

This research follows a systematic five-section framework to analyze green building cost management through ISM-MICMAC methodology. The Introduction establishes the research problem, objectives, and hypotheses regarding sustainable construction cost factors. The Materials and Methods section outlines the literature review process and integrated ISM-MICMAC analytical approach. The Results section presents the identification of 20 cost-influencing factors, their life cycle classification, and hierarchical relationship analysis. The paper concludes with Specific Recommendations for stakeholders and Conclusions synthesizing theoretical contributions and practical implications.

2. Materials and Methods

This study employed a systematic approach to examine life cycle cost factors in green buildings and their interrelationships to develop effective cost management strategies. The research methodology integrates four complementary analytical techniques: (1) comprehensive literature review to extract cost-influencing factors from existing studies, (2) Interpretive Structural Modeling (ISM) to establish hierarchical relationships among complex interdependent factors, (3) MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) analysis to categorize factors based on driving power and dependence characteristics, and (4) factor influence assessment to formulate practical cost reduction recommendations for green building stakeholders.

This methodology diagram 1, presents a streamlined eight-step research process for analyzing green building cost factors, beginning with objective formulation and literature review, progressing through factor identification and classification, and culminating in integrated ISM-MICMAC analysis. The framework systematically transforms research objectives into actionable conclusions through structured factor screening, hierarchical modeling, and dependency analysis to provide comprehensive insights into green building cost management.

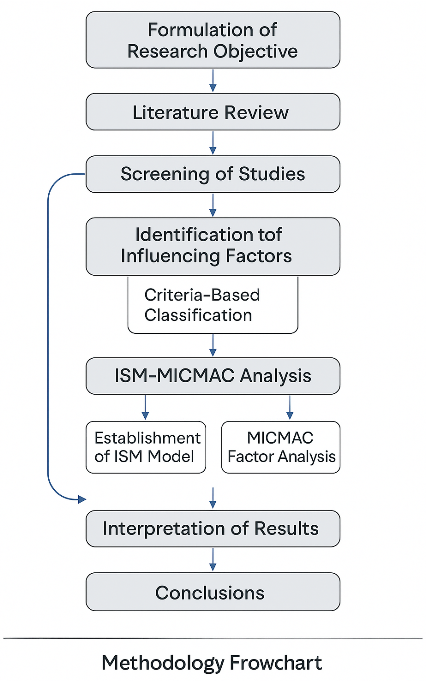

Figure 1. Methodology Flowchart.

This flowchart 2, illustrates the systematic research methodology employed to identify and analyze cost-influencing factors in green building projects through an integrated ISM-MICMAC framework. The process begins with comprehensive literature review (724 studies), progresses through factor extraction and life cycle classification, applies ISM hierarchical modeling and MICMAC dependency analysis, and concludes with policy recommendations and strategic insights for sustainable construction cost management.

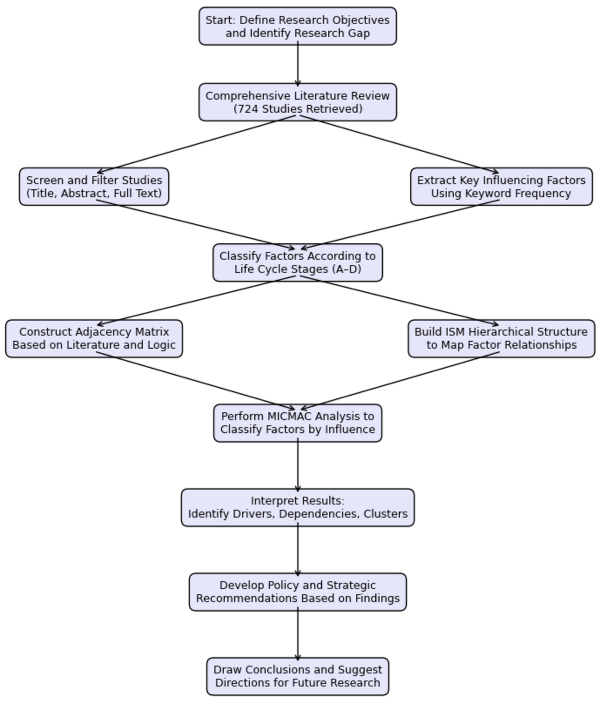

Figure 2. Methodology Flowchart for ISM-MICMAC Analysis of Green Building Cost Factors.

2.1. The Whole Life Cycle of Buildings

As the popularization of green buildings spreads, the differences between green buildings and traditional buildings are becoming increasingly prominent. However, the cost control problem of green buildings still faces difficulties, and it is essential to consider the whole life cycle of buildings to solve this problem. The whole life cycle of a building includes all stages from planning, design, construction, operation, maintenance, to demolition. By comprehensively evaluating the influencing factors occurring in this process, the possibility of cost reduction can be explored. The research achievements on the whole life cycle of green buildings, the influencing factors of the whole life cycle costs of green buildings, and the analysis of the whole life cycle costs of green buildings are as follows.

2.1.1. Research on the Whole Life Cycle Area of Buildings

First, looking at the research on the whole life cycle area of buildings, Song mentioned, based on the whole life cycle theory of green buildings, that green buildings have obvious advantages over traditional buildings in both the operation and maintenance stages [48]. These buildings perform well over a long period by using less energy and causing less harm to the environment and it is believed they can be used more widely in future projects. In addition, Zuo J evaluated the costs and benefits of green buildings from the perspective of the life cycle [49]. He especially reviewed the application cases of the life cycle evaluation of green buildings and the evaluation of life cycle costs in Australia, and proposed the limitations of the currently used life cycle cost calculation methods and the future research directions to complement them.

Gluch comprehensively considered the whole life cycle costs of construction projects and proposed five cost optimization stages [41]. In the planning and design stage, maintenance and operation costs should be minimized. In the bidding and winning stage, it is necessary to prevent additional costs from occurring. In the construction stage, it is important to ensure the construction quality to reduce subsequent repair costs. Finally, in the operation and management stage, the goal is to improve the utilization efficiency of the building. This approach can contribute not only to cost-effective management but also to enhancing the economic viability and sustainability of construction projects.

These three studies provide important insights into evaluating and managing building costs from the perspective of the life cycle, and can especially serve as useful guidelines for formulating cost management and optimization strategies for green buildings.

2.2. The Whole Life Cycle Costs of Green Buildings

Next, looking at the research related to the influencing factors of the whole life cycle costs of green buildings, the studies by [46], and Hwang show a complementary approach in the analysis of the influencing factors of the whole life cycle costs of green buildings [43]. ZHANG focused on the transformation and upgrading of the construction industry through the TOE framework and used the ISM-MICMAC method to analyze the hierarchical relationships and key factors of each cost influencing factor [44]. He tried to understand the cost structure based on the driving factors and the degree of dependence, and thus proposed the core mechanism of green building cost management.

In contrast, Hwang I derived 28 influencing factors of the whole life cycle costs of green buildings through literature review and questionnaire survey analysis, and applied the DEMATEL-ISM model to analyze the important indicators of cost control. He derived suggestions from the aspects of correlation and comprehensive value, and verified the validity of the system through case studies, thus improving the practical applicability.

These two studies analyze the important elements of green building cost management from multiple perspectives, providing important insights for improving the cost efficiency of green buildings and achieving sustainable development.

2.2.1. Analysis of the Whole Life Cycle Costs of Green Buildings

Finally, regarding the analysis of the whole life cycle costs of green buildings, Wang F studied the influencing factors of the increased costs of green buildings from four aspects: project location, technical measures, project region, and the timing of conducting the feasibility study, and identified four key influencing factors: ”energy conservation”, ”indoor environment”, ”project concept”, and ”government-related policies” [50]. Based on this, methods to reduce the costs of green buildings were proposed.

Research conducted by Dwaikat and Ali demonstrates that comprehensive life cycle cost evaluation of green buildings reveals significant long-term financial implications, with operational and maintenance expenditures reaching approximately 3.6 times the initial investment in design and construction phases [31]. Their analysis indicates that energy-related expenses constitute 48% of the total life cycle financial commitment, with this percentage escalating beyond 60% when evaluated against operational expenditures alone. These findings underscore that energy efficiency optimization represents the most critical factor in green building cost management strategies. Furthermore, Gopanagoni's investigation emphasizes that life cycle assessment methodologies provide the most economically viable approach for evaluating long-term building-related costs [50]. This comprehensive study developed an 80-year life cycle financial framework for green buildings utilizing advanced cost calculation methodologies. The findings revealed that future operational costs exceed initial construction investments by 5.7%, with energy expenditures comprising 67% of the complete life cycle budget allocation.

These empirical findings highlight the critical significance of comprehensive cost analysis in green building projects and identify the essential components required for effective long-term financial management strategies.

Comprehensive examination and synthesis of existing literature demonstrates that green building research and whole life cycle cost analysis remain central to contemporary academic investigation, yielding substantial scholarly contributions. Nevertheless, the majority of current studies exhibit geographical limitations, focusing primarily on hierarchical relationship analysis among green building influencing factors within individual national contexts, thereby constraining the breadth of research applicability. This investigation identifies a critical research advancement opportunity, specifically noting the insufficient integration of green building principles with whole life cycle cost methodologies across Korean and international literature sources. Particularly significant is the inadequate examination of influencing factors affecting whole life cycle costs in green building projects. Consequently, comprehensive research addressing the influencing factors of whole life cycle costs in green buildings necessitates further scholarly investigation and represents a distinct departure from existing research paradigms.

3. Results

3.1. Identification of Influencing Factors of the Whole Life Cycle Costs of Green Buildings

In the beginning, this study looked for literature by searching RISS and Science Direct with the keywords "green buildings," "life cycle costs," and "green construction costs." This search resulted in 724 articles that were relevant and published over the years 2014 to 2024. To maintain the quality and relevance of the literature, we used a number of exclusion criteria. Only studies that did not discuss costs or different life cycle stages were removed after reading the titles and abstracts, leaving 159 for further analysis. After that, studies published in non-peer-reviewed areas, with fewer than 10 citations or lacking proper research design were omitted. Afterwards, papers that were not solely about cost management in green building were removed during full-text review, ending up with 40 quality studies. These were used to identify and compile the 20 most important factors affecting the industry.

Table 1 summarizes the 20 most important factors that affect the price of green building construction. To help with classification, analysis and modeling, each factor is given a code (A1 to D5) during the study. Categories are created for the codes depending on their various functions.

Table 1. Twenty Factors That Play a Role in Determining the Life Cycle Costs of Green Buildings, along with the Assigned Codes (A1–D5), Used Throughout the Research.

Number	Cost Influencing Factors of Green Buildings
A1	Material Costs
A2	Design Costs
A3	Certification Costs
A4	Energy-Saving Technologies
A5	Comprehensive Improvement of Building Quality
A6	Green Building Design
A7	Additional Costs for Green Building
A8	Construction Costs
A9	Demolition Costs
A10	Green Construction Technologies and Standards
A11	Green Comprehensive Standards
A12	Savings in Green Operational Costs
A13	Costs for Improving Energy Efficiency
A14	Post-Operational Costs
A15	Costs for Enhancing Building Environmental Quality
A16	Environmental Differences

Table 1. *Cont.*

Number	Cost Influencing Factors of Green Buildings
A17	Green Building Certification System
A18	Green Building Ratings
A19	Policy Support
A20	Waste Disposal

3.2. Classification of the Influencing Factors of the Whole Life Cycle Costs of Green Buildings

The factors from **Table 1** are grouped in **Table 2** by the main stages of a building's life cycle: A (Planning and Design), B (Construction and Building), C (Maintenance and Recovery) and D (Policy and Environment). A1, B1 and C1 are examples of factor codes that include the test's stage and the number of the item.

Table 2. Classification of Green Building Cost-Influencing Factors Across Four Major Life Cycle Stages: Planning & Design (A), Construction & Building (B), Maintenance & Recovery (C), and Policy & Environment (D).

Classification Number	Category of Influence Factor	Number	Cost influencing factors of green buildings
A	Planning and Design	A1	Material Costs
		A2	Design Costs
		A3	Certification Costs
		A4	Energy-Saving Technologies
		A5	Comprehensive Improvement of Building Quality
		A6	Green Building Design
		A7	Additional Costs for Green Building
B	Construction and Building	B1	Construction Costs
		B2	Demolition Costs
		B3	Green Construction Technologies and Standards
		B4	Green Comprehensive Standards
C	Maintenance and Recovery	C1	Savings in Green Operational Costs
		C2	Costs for Improving Energy Efficiency
		C3	Post-Operational Costs
		C4	Costs for Enhancing Building Environmental Quality
D	Policy and Environment	D1	Environmental Differences
		D2	Green Building Certification System
		D3	Green Building Ratings
		D4	Policy Support
		D5	Waste Disposal

This study finally identified 20 influencing factors of the whole life cycle costs related to green buildings based on the whole life cycle assessment. These influencing factors encompass various stages that green buildings may encounter throughout their entire life cycle, namely from the initial planning and design stage to the construction and building stage, followed by the maintenance and recovery stage, as well as policy and environment-related elements. Considering the complexity and diversity of these influencing factors, it is crucial to accurately classify each factor into the appropriate stage. Only by accurately classifying them, can we fully analyze and pay attention to the role of each influencing factor at that specific stage. Therefore, this study classified the influencing factors from a systematic dimension taking into account the characteristics and roles of each influencing factor. As a result, the 20 influencing factors were finally organized into four main dimensions: planning and design, construction and building, maintenance and recovery, and policy and environment. This classification method helps to more clearly understand the importance and interrelationships of each factor in the whole life cycle of green buildings.

In the sorting process, in the first stage, the planning and design (A) stage, the environmental impact, economic benefits, and social sustainability of the building are comprehensively considered to minimize the negative environmental impact of the building throughout its entire life cycle. By adopting efficient resource utilization and energy-saving design, the consumption of construction materials and energy use are reduced as much as possible. This is to analyze the environmental impact of the building at each stage such as construction, operation, and demolition, in order to make more sustainable design decisions.

In the second stage, the construction and building (B) stage, green building technologies and construction standards are adopted to ensure that the construction process complies with the principles of green buildings, guarantee the efficient use of resources, and ensure that the construction quality meets the green building standards.

In the third stage, the maintenance and recovery (C) stage, various activities are guaranteed to maintain the building in good condition during its use. Through efficient maintenance management and recovery strategies, the focus is on reducing operating costs, decreasing energy consumption, and minimizing waste generation. When the building needs to be demolished or renovated, it includes tasks such as reducing the demand for new materials through the recycling and reprocessing of construction materials.

In the fourth stage, the policy and environment stage, it includes contents such as policies and regulations related to green buildings, environmental impact assessments, and policy support, aiming to promote the implementation and development of green buildings. Policy and environment factors not only include the government's support measures for green buildings but also involve monitoring and managing the environmental impact during the design, construction, and operation stages of the building. Through reasonable policy guidance and environmental management, the construction industry can meet economic development needs while effectively reducing the negative environmental impact.

3.3. Survey Subjects

According to this classification criterion, the factors influencing green buildings in each paper were identified, and the results are shown in **Table 3** as follows [1–39, 41].

Table 3. Factors Influencing the Construction Costs of Green Building [1–39, 41].

Impact Factors	A1	A2	A3	A4	A5	A6	A7	B1	B2	B3	B4	C1	C2	C3	C4	D1	D2	D3	D4	D5
Zhang [1]			O				O				O					O		O	O	
Chegut [2]	O	O		O	O	O					O	O								
Darko [3]	O	O	O				O						O	O	O		O	O	O	
Fuerst [4]	O	O	O	O	O	O		O	O	O	O	O	O	O	O	O	O	O	O	O
Miller [5]	O		O	O			O	O				O	O	O	O		O			O
Eichholtz [6]	O	O	O		O	O	O				O	O	O				O	O		O
Yoshida [7]		O	O	O	O	O	O			O	O		O	O	O		O		O	O
Fuerst [8]																O	O	O		O
Deng [9]	O	O					O				O					O		O		O
Kahn [10]		O		O			O				O					O	O		O	
Huppes [11]	O						O				O						O	O		
Sabapathy [12]	O	O	O	O	O	O	O		O	O	O	O			O		O	O		O
Ma [13]			O	O							O						O	O	O	
Chau [14]										O	O	O	O			O			O	
Ries [15]			O						O								O			
Kats [16]				O		O					O					O	O	O		
Yudelson [17]				O								O					O			O
Zuo [18]				O													O			O
Olubunmi [19]				O	O	O	O		O	O	O	O		O	O		O	O		
Rehm [20]		O					O									O	O			
Wang [21]	O	O		O	O		O				O		O			O			O	O
Chen and Gou [22]		O	O	O		O	O	O					O	O	O	O	O	O	O	O
Achini [23]	O	O	O	O	O	O					O		O				O			O
Wu et al. [24]	O	O		O		O	O	O			O		O	O	O	O	O		O	
Periyannan et al. [25]	O	O	O	O	O		O	O	O	O		O		O			O	O	O	O
Wang [26]										O									O	
Yin et al. [27]	O	O	O	O	O	O	O		O		O	O	O	O	O		O		O	O
Li et al. [28]						O	O					O	O				O	O	O	
Dwaikat and Ali [29]	O			O		O		O			O	O		O	O		O	O	O	
Son et al. [30]	O	O	O	O	O	O	O	O	O		O		O				O	O	O	O
Dwaikat and Ali [31]	O	O		O		O	O	O				O	O	O	O		O	O		
Wen [32]	O	O	O	O		O	O	O				O	O			O	O	O	O	O
Khoshbakht et al. [33]	O	O					O				O	O					O	O	O	
Illankoon and Lu [34]	O							O			O		O					O	O	
Illankoon and Lu [35]	O	O					O				O									
Gabay et al. [36]			O											O	O	O	O	O		
Abidin and Azizi [37]	O	O	O				O				O								O	
Liu et al. [38]			O	O							O			O	O					O
Huang et al. [39]				O				O			O		O							
Gluch [41]				O	O							O								
	21	21	18	24	12	19	16	23	11	7	7	25	16	17	14	13	28	21	20	17

4. Research Process Based on ISM-MICMAC

4.1. Set the Adjacency Matrix A

This paper adopts a method combining subjective judgment and the literature review method to construct the adjacency matrix. For some ambiguous relationships, a large number of literatures are consulted in this paper to determine whether there is a direct influence between the factors. For some intuitive situations, the judgment is directly made based on common sense theories (**Table 4**)[51–66].

Table 4. Ambiguous Judgments in Matrix A and Literature Support[51–66].

Influencing Factors	Influenced Factors	Influence	Related Literature
Material Cost (A1)	Construction Cost (B1)	No	Dodge[53]
Design Cost (A2)	Incremental Cost of Green Buildings (A7) Green Construction Technology and Standards (B3)	No No	Glaeser[55] Albouy[56]
Certification Cost (A3)	Cost of Improving Energy Utilization Efficiency (C2)	No	Johnson[57]
Energy-Saving Technology (A4)	Comprehensive Improvement of Building Quality (A5)	Yes	Wang[51]
Green Building Design (A6)	Cost of Improving the Quality of the Building Environment (C4)	No	Dodge[53]
Construction Cost (B1)	Later Operation Cost (C3)	No	Zhang[54]
Green Construction Technology and Standards (B3)	Energy-Saving Technology (A4)	Yes	Zhong[64]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Waste Emission (D5)	Yes	Chi Bin et al.[59]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Cost of Improving the Quality of the Building Environment (C4)	No	Darko[60]
Green Operation Cost Savings (C1)	Material Cost (A1)	Yes	RSMeans[63]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Design Cost (A2)	Yes	RSMeans[63]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Demolition Cost (B2)	Yes	Kibert[61]
Cost of Energy Utilization Efficiency (C2)	Material Cost (A1)	Yes	Khasreen et al.[58]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2)	Construction Cost (B1)	Yes	Khasreen et al.[58]

Table 4. *Cont.*

Influencing Factors	Influenced Factors	Influence	Related Literature
Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)			
Later Operation Cost (C3)	Green Building Grade (D3)	No	Newsham [57]
Building Environment (C4)	Material Cost (A1)	Yes	Spiegel [65]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Design Cost (A2)	Yes	Spiegel [65]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Demolition Cost (B2)	Yes	Akbarnezhad et al. [66]
Green Building Grade (D3)	Energy-Saving Technology (A4)	Yes	Raouf and Al-Ghamdi [62]
Certification Cost (A3) Energy-Saving Technology (A4) Green Building Design (A6) Construction Cost (B1) Green Construction Technology and Standards (B3) Green Operation Cost Savings (C1) Cost of Energy Utilization Efficiency (C2) Later Operation Cost (C3) Cost of Improving the Quality of the Building Environment (C4) Green Building Grade (D3) Policy Subsidies (D4)	Waste Emission (D5)	Yes	Liu et al. [52]
Policy Subsidies (D4)	Green Building Certification System (D2)	No	Albouy [56]

4.1.1. Material Cost (A1)

Material cost (A1) has no direct influence on construction cost (B1) and the cost of improving the quality of the building environment (C4). Although it is generally believed that the material cost of green buildings is high, in fact, the impact of this material cost on construction cost is limited. The construction cost of green buildings can be on par with or even slightly lower than that of traditional buildings, mainly due to the maturity of the supply chain and the progress of construction technology. Dodge pointed out that the material cost has no significant direct influence on the construction cost[3, 53]. In addition, Dodge also mentioned that although the material cost increases in the design of green buildings, it does not significantly increase the cost of improving the quality of the building environment[54].

4.1.2. Design Cost (A2)

Design cost (A2) has no direct influence on the incremental cost of green buildings (A7) and green construction technology and standards (B3). Glaeser (2024) stated that although there may be high investment in the design stage of green buildings, these design costs may not significantly increase the overall incremental cost of green buildings[55]. At the same time, Albouy also pointed out that there is no significant direct correlation between the design cost and green construction technology and standards[56]. Especially in terms of energy conservation, these designs cannot significantly reduce the construction cost[8].

4.1.3. Certification Cost (A3)

Certification cost (A3) has no direct influence on the cost of improving energy utilization efficiency (C2). Liu et al. pointed out that there is no significant direct correlation between the cost of green certification and the improvement of energy efficiency[52]. The certification does not directly bring about additional energy-saving effects, and the improvement of energy efficiency depends more on specific technical measures[6]. In addition, Newsham also emphasized that although certification is a symbol of standardization, the direct relationship between the certification cost and the improvement of the building's energy efficiency is limited [57].

4.1.4. Energy-Saving Technology (A4)

Energy-saving technology has a direct influence on the comprehensive improvement of building quality (A5). Wang's research shows that the adoption of advanced energy-saving technologies can significantly improve building quality [51]. For example, the overall durability and living comfort of the building can be improved through better thermal insulation and sealing performance.

4.1.5. Green Building Design (A6)

Green building design (A6) has no direct influence on the cost of improving the quality of the building environment (C4). Dodge mentioned that although green buildings have their unique features in design, the design improvements have not significantly increased the direct cost to enhance the quality of the building environment [53].

4.1.6. Incremental Cost of Green Buildings (A7)

The incremental investment in green buildings creates a compensatory mechanism through operational savings, significantly impacting overall building economics and construction costs (B1). Research by Khasreen, Banfill, and Menzies demonstrates that while green buildings require higher initial construction costs, energy-efficient design and sustainable material selection reduce long-term energy and maintenance expenses, subsequently lowering design costs (A2) and material costs (A1) [58]. This establishes that green building cost premiums represent strategic investments yielding measurable economic returns through operational efficiency gains [58].

4.1.7. Construction Cost (B1)

Construction cost has no significant direct influence on the later operation cost (C3) [58]. Dodge showed in the research that the additional expenditure in the construction stage of green buildings has not significantly reduced the later operation cost [54]. Although green buildings can save the use of energy and water resources as a whole, the investment in the construction stage is not the direct cause of these savings.

4.1.8. Green Construction Technology and Standards (B3)

Green construction technology and standards will have an impact on energy-saving technology (A4) and waste emission (D5). Based on the analysis of rough set theory, Zhong [64] pointed out that the adoption of green construction technology significantly reduces the emissions of construction slurry and wastewater, and at the same time can improve the energy use efficiency. This research has quantified the improvement of green technology on emission control and the return on investment of energy-saving technology [14]. Chi compared the waste management practices of LEED-NC 2009 certified projects in China and the United States and found that green certified projects have significant advantages in minimizing construction waste [59]. This advantage comes from the systematic control of the construction process by green standards, thus greatly reducing the amount of landfill and the emission of construction waste.

Green construction technology and standards (B3) have no direct influence on the cost of improving the quality of the building environment (C4). Darko pointed out that although green construction standards are helpful to improve the overall environmental quality of buildings, their influence does not directly come from significant cost investment, but more from the improvement of technology and operation processes [60].

4.1.9. Green Operation Cost Savings (C1)

Green operation cost savings will have an impact on material cost (A1), design cost (A2), and demolition cost (B2).

John Wiley pointed out that in order to achieve long-term operation savings, projects often carry out more precise cost optimization in the material procurement and design stages. The rationalization of this upfront investment is driven by the incentive of later operation savings. Green operation cost savings can reduce material cost and design cost [11]. Kibert proposed in his work that many green projects adopt modular and detachable structures to achieve lower operation costs, so as to repair or demolish them at a lower cost in the future [47]. This practice incorporates the logic of operation savings into the construction and life cycle management strategies, so green operation cost savings will reduce the demolition cost.

4.1.10. Cost of Improving Energy Utilization Efficiency (C2)

The cost of energy utilization efficiency will have a direct impact on material cost (A1) and construction cost (B1). The research by Khasreen et al. shows that the application of technologies to improve energy utilization efficiency, such as high-efficiency thermal insulation materials and photovoltaic systems, can significantly improve energy utilization efficiency, but it will also significantly increase the initial material cost and construction cost of green buildings [58].

4.1.11. Later Operation Cost (C3)

Later operation cost (C3) has no direct influence on the green building grade (D3). Newsham stated that although the low cost of green buildings during the operation stage is one of their advantages, it cannot significantly affect their certification grade [57]. The certification grade depends more on the standards in the design and construction stages.

4.1.12. Cost of Improving the Quality of the Building Environment (C4)

The cost of improving the quality of the building environment will directly affect material cost (A1), design cost (A2), and demolition cost (B2). Spiegel and Meadows pointed out in their green material selection manual that in order to achieve higher building environmental quality (such as improving indoor air quality and reducing VOCs emissions), the project parties need to use more environmentally friendly and high-performance materials, which directly increases the complexity and cost of material procurement and structural design. Akbarn used BIM to model the building demolition strategy and found that the more the design emphasizes the building environmental performance, the more material sorting, hazardous substance treatment, and reuse planning need to be faced in the demolition stage, and these requirements significantly increase the later demolition cost.

4.1.13. Policy Subsidies (D4)

Policy subsidies (D4) have no direct influence on the green building certification system (D2). Albouy pointed out that although policy subsidies can encourage builders to carry out green construction, in some cases, the existence of such subsidies is not sufficient to affect the certification decision of green buildings, especially in unfavorable market conditions [56].

4.1.14. Green Building Grade (D3)

The green building grade will affect waste emission (D5) and energy-saving technology (A4), and the green building grade will affect the comprehensive improvement of building quality and the later operation cost. Raouf and Al-Ghamdi proposed a framework for evaluating the quality performance of green buildings [62], covering the stages from design, construction to operation. The research shows that high-rated green buildings have better comprehensive quality performance in terms of structural durability, waste emission, and energy conservation than traditional buildings, and this improvement in technology is closely related to advanced certifications such as LEED or BREEAM.

4.1.15. Waste Emission (D5)

Waste emission will directly affect the comprehensive improvement of building quality (A5) and the later operation cost (C3). Rounce’s research revealed the non-conformance costs generated by construction waste and quality management mistakes in building design and construction [67]. These wastes not only increase the construction burden but also affect the overall quality of the project, leading to rework and a decline in structural performance. Jalaei et al. combined life cycle assessment with BIM modeling to prove that the treatment of each ton of construction waste will trigger additional variable costs (which can be as high as twice the traditional estimate) [68], and it will have a reverse effect on the operation stage through high maintenance and repair costs. If a building does not carry out effective waste optimization in the early stage, it will bear a high operation burden for a long time.

In addition, the remaining relationships can be directly judged based on common sense. First, from the perspective of direct influence, the promotion of energy-saving technology (A4) will inevitably lead to a reduction in the later operation cost (C3). Because the adoption of high-efficiency energy-saving technologies for the building envelope structure, air conditioning systems, lighting equipment, etc. can reduce the energy consumption of daily electricity, heating, cooling, etc., thereby reducing the water, electricity, and gas fees during the operation stage. In addition, mastering and applying advanced energy-saving technologies is often one of the important indicators for green building certification. Therefore, the higher the level of energy-saving technology, the easier it is to meet the evaluation standards and scoring requirements of the green building certification system (D2), and the two are positively correlated.

Better building quality (A5) results in greater initial additional costs for green buildings (A7) and the cost of improving building environmental quality (C4). Because of better materials, advanced construction and strict quality control, the overall costs for material, labor and supervision rise. Wang argue that superb thermal insulation, structural strength and comfort features in green buildings lead to higher costs initially but give great benefits over time [51]. To ensure a building performs well and lasts longer, more funds are required for energy saving cleaning and maintenance which leads to greater savings in green operations (C1). Enhanced energy efficiency and better occupant comfort often lead buildings to install systems such as variable frequency drives and waste heat recovery which tend to increase the costs of energy efficiency (C2) [52].

When building design optimizes the way a building faces, its walls, airflow and lighting, it greatly helps to decrease waste from construction (D5) and improve the use of resources. Raouf and Al-Ghamdi explain that when design strategies are carried out effectively, they help energy-saving technologies and lower the overall environmental impact over the building's life (A4) [62]. When the building is designed well, solar design and HVAC systems can be combined more easily which increases how efficiently the building is run. In addition, the strict criteria in green comprehensive standards (B4) influence green building design (A6), green construction technologies (B3) and the building's environmental rating (D3). As Chi Bin et al. note [59], fulfilling tough certification standards such as LEED and BREEAM contributes to improvements in design, construction and environmental management.

Externally provided policy incentives (D4) are adjusted in strength by environmental factors (D1) and the system of green comprehensive standards (B4). When projects are situated in sensitive ecological areas or follow tighter green rules, they are more likely to receive better support from the government, including tax breaks, easy loans or direct subsidies. Albouy points out that these financial approaches help reduce the initial costs and encourage more people to adopt green technologies in risky or costly cities [56].

Regarding indirect effects, material cost (A1) does not influence demolition cost (B2), green comprehensive standards (B4), later operational cost (C3), environmental differences (D1) or the green building certification system (D2). Dodge claims that the main factor in material costs is the choice of what to buy, not the choice of building structure or what happens after occupancy [54]. Likewise, there is no clear link between design cost (A2) and certification cost (A3), building quality improvement (A5), construction cost (B1), demolition cost (B2), building environment quality (C4) or certification grade (D3). As Glaeser explains [55], design investments happen up front and are planned carefully, whereas the results mentioned above are shaped by many factors that appear during construction and use of the building.

How much green certification costs does not have a clear effect on the building's certification level (D3). According to Newsham [57], while certification costs are important for auditing and verifying, the actual certification result is mostly influenced by the design, meeting benchmarks and using technology. Likewise, energy-saving technologies do not have an impact on incremental cost, construction cost, demolition cost, comprehensive standards, operational cost, environmental difference, certification systems, policy subsidies or waste emissions. They are often influenced by how the system is adopted and planned across its life, rather than by individual cost changes which is what Khasreen et al. found [58].

Even though A5—comprehensive improvement of building quality—results in less frequent maintenance and more content occupants, it does not impact incremental cost (A7), demolition cost (B2), later operational cost (C3), policy subsidies (D4) or waste emissions (D5). These results are influenced by the economic, structural and regulatory frameworks in society. Raouf and Al-Ghamdi claim that good results are achieved through many supportive steps at each stage, not just by connecting one factor to another [62].

Dark blue and dark red are used to represent that there is no direct influence judged according to the literature and that there is a direct influence judged according to the literature respectively, and light blue and light red are used to represent that there is no direct influence judged according to common sense and that there is a direct influence judged according to common sense respectively. Then, the heat map of the judgment of the adjacency matrix in this paper can be obtained as follows (**Figure 3**):

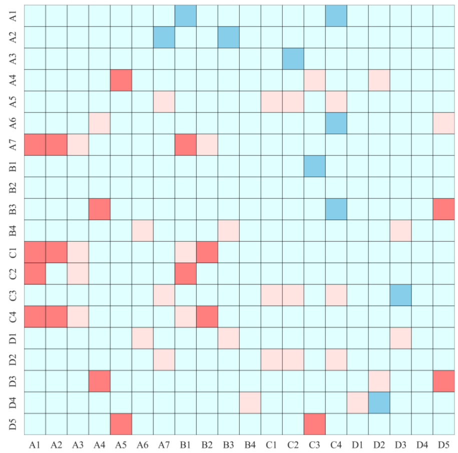

Figure 3. Adjacency Matrix Heatmap Used in ISM Modeling. The Matrix Shows the Directional Relationships Between 20 Cost-Influencing Factors of Green Buildings (A1–D5). Rows Represent Influencing Factors and Columns Represent Influenced Factors. Red Cells Denote the Presence of Direct Influence, and Blue Cells Indicate No Direct Influence. Darker Shades Are Based on Empirical Literature; Lighter Shades Reflect Conceptual or Theoretical Assumptions.

Figure 4 uses an ISM-based adjacency matrix heatmap to show the relationships between 20 green building construction cost factors, both direct and indirect. All factors are given a code, starting with A1 for planning and design, B1 for construction and building, C1 for maintenance and recovery and D1 for policy and environmental aspects. Each row in the matrix lists an influencing factor and each column shows a factor that is influenced. The coding system uses colors to show how the influence is determined: dark red means it is supported by literature, light red by expert judgment or logic, dark blue means it is not supported and light blue means it is not supported by theory. Using a tree diagram allows for the identification of main variables as well as dependent ones which supports the construction of the ISM hierarchy in the following analysis.

$$A=\begin{bmatrix}
0&1&1&1&1&1&1&0&0&1&0&1&1&0&1&1&0&0&0&0\\
1&0&0&1&0&1&0&0&0&0&1&1&0&1&0&1&1&0&1&1\\
1&1&0&0&0&0&0&1&1&0&1&1&0&1&1&1&1&0&1&0\\
0&1&1&0&1&0&0&0&0&0&0&0&1&0&1&0&0&1&0&0\\
0&0&1&1&0&0&0&0&0&0&1&1&1&0&1&0&0&0&0&0\\
0&0&1&1&0&0&0&1&0&1&0&1&0&1&1&0&0&0&1&1\\
1&0&0&0&1&1&0&0&1&1&0&1&1&0&0&1&0&0&1&1\\
0&0&1&1&1&0&0&0&0&1&0&1&0&1&0&1&1&0&0&0\\
0&0&0&1&1&0&0&1&0&0&0&0&1&0&1&1&1&0&0&1\\
0&0&1&1&0&0&0&0&0&0&0&0&1&1&0&1&1&1&1&0\\
1&1&0&1&1&0&0&1&1&0&0&0&1&0&0&1&0&1&0&1\\
0&0&1&0&0&0&0&1&1&0&1&0&0&0&0&0&0&0&0&0\\
0&0&1&1&0&0&1&0&1&1&1&0&0&1&1&1&0&1&0&0\\
1&0&1&1&1&0&1&0&1&0&0&0&0&0&1&0&0&0&1&1\\
1&1&1&1&0&1&1&1&0&1&1&1&0&0&0&0&1&0&0&0\\
1&0&1&0&0&0&1&0&1&1&0&1&1&0&0&0&0&1&0&0\\
1&0&1&0&1&0&1&0&0&1&0&1&0&0&0&0&0&1&1&1\\
1&1&1&0&0&0&1&1&1&1&1&1&1&1&1&0&0&0&0&0\\
1&1&0&0&1&1&1&0&1&1&0&0&1&1&0&0&0&1&0&1\\
0&0&0&0&0&0&0&1&0&1&1&1&1&0&1&0&1&0&0&0
\end{bmatrix}$$

Figure 4. The Composition of Matrix A.

Based on the factors related to green buildings that were previously determined, the relationships among these factors were systematically constructed, and the adjacency matrix A of green buildings was derived.

4.2. Calculate the Reachability Matrix M

In the Interpretive Structural Modeling (ISM) analysis, the reachability matrix M is used to represent the reachable relationships between different factors in the system. If there are *n* factors in the system, these factors can be represented as nodes, and their relationships can be described by an $n \times n$ adjacency matrix A, where the element a_{ij} indicates whether there is a direct reachable relationship from factor i to factor j. When $a_{ij} = 1$, it means factor i can directly influence (or reach) factor j; when $a_{ij} = 0$, it means factor i cannot directly influence factor j.

The reachability matrix M extends the ”direct reachability” relationship to ”indirect reachability,” meaning that if there is one or more paths through which factor i can ultimately influence factor j via intermediate factors, the corresponding element in M will also be marked as 1. Specifically, the process of constructing the reachability matrix M from the adjacency matrix A involves three steps:

4.2.1. Initialization of the Reachability Matrix

First, create an identity matrix I, where the diagonal elements are 1 and the rest are 0. The identity matrix I indicates that each factor can reach itself. Then, set $M = I + A$, combining direct reachability relationships with self-reachability relationships. At this stage, the elements in M that are 1 represent the node itself and the nodes it can directly reach.

4.2.2. Iterative Calculation

Expand the reachability relationships to all possible indirect paths by iteratively calculating

$$(A+I) \neq (A+I)^2 \neq \dots \neq (A+1)^K$$

Here, matrix multiplication is similar to ordinary matrix multiplication, but since the focus is on reachability rather than numerical values, the resulting elements are typically treated as Boolean values—i.e., if the multiplication result is non-zero, it is considered as 1.

4.2.3. Convergence and Stopping Condition

When $(A+1)^K$ no longer changes, i.e., $(A+1)^K = (A+1)^{K+1}$, it means no new indirect reachability paths are generated, and the reachability matrix has reached a stable state. At this point, $M = (A+1)^K$ is the final reachability matrix.Through literature review, this study identified the direct influence relationships among 20 influencing factors of green building construction costs and constructed the adjacency matrix A. By adding A to the identity matrix I and performing iterative power calculations, the study found that $(A+I)^3$ matched $(A+I)^2$ during the third iteration, i.e., $M = (A+1)^3$. The final reachability matrix M for the influencing factors of green building construction costs is shown below (**Figure 5**):

$$M = \begin{pmatrix}
1&0&1&0&1&0&0&0&0&1&1&1&1&1&1&0&0&1&1&0\\
1&0&0&0&0&0&0&0&0&0&1&1&1&1&0&1&0&1&0&0\\
1&1&1&0&0&0&0&0&1&0&0&1&0&0&0&1&1&1&1&1\\
0&1&0&0&0&0&0&0&1&0&1&0&1&1&1&1&0&0&1&1\\
0&0&0&1&0&1&1&0&1&0&0&1&0&1&0&0&0&0&0&0\\
0&1&0&0&1&0&0&0&1&1&0&0&0&1&1&0&1&1&1&1\\
0&0&0&1&1&1&0&1&0&1&1&0&1&0&0&0&1&0&1&0\\
1&1&1&1&0&0&0&1&0&0&0&1&1&0&0&0&1&0&1&0\\
0&0&0&0&1&1&1&0&0&1&0&0&0&1&0&0&1&0&0&0\\
0&0&0&1&0&1&1&1&0&1&1&0&1&1&0&1&0&0&0&1\\
1&0&1&1&1&0&0&0&0&0&1&0&0&0&1&1&0&0&1&0\\
0&1&0&0&0&0&0&1&1&1&1&1&0&0&0&1&0&0&0&0\\
0&1&0&1&0&1&0&0&0&0&1&0&1&1&0&1&1&1&1&1\\
1&0&1&0&0&1&0&0&1&0&0&1&0&1&1&1&1&1&0&0\\
0&1&0&1&0&1&0&1&0&1&0&0&1&1&0&0&0&0&1&0\\
1&1&0&0&0&1&0&1&1&0&0&1&1&0&1&1&1&1&0&0\\
0&1&1&0&0&0&1&0&0&1&1&0&1&1&0&1&0&1&1&1\\
1&1&0&1&1&1&0&0&1&1&1&1&0&1&1&0&0&0&1&0\\
1&0&1&0&1&1&1&0&1&1&0&0&0&0&0&1&1&0&0&1\\
0&0&1&0&1&0&1&0&1&1&0&0&0&0&1&1&0&1&1&0
\end{pmatrix}$$

Figure 5. The Composition of Matrix M.

4.3. Determining the Hierarchical Levels of Influencing Factors and Constructing the ISM Hierarchical Diagram

After obtaining the reachability matrix M, this study used it as the analytical foundation to extract the reachable set R(Ai) and the antecedent set Q(Ai) for each factor, thereby determining the hierarchical relationships among the factors and constructing the ISM hierarchical diagram. The specific steps for constructing the hierarchical diagram are as follows.

4.3.1. Extracting the Reachable Set R(Ai) and the Antecedent Set Q(Ai)

The reachable set $R(A_i)$ refers to the collection of all other factors that can be reached from factor Ai (**Table 5**). In M, the columns corresponding to the elements with a value of 1 in the i-th row represent $R(A_i)$. This reflects the scope of influence diffusion from the perspective of A_i. For example, if A_i is ”green building technology and standards,” and the i-th row in M has multiple 1s distributed across different columns, this indicates that A_i can influence these corresponding factors, such as ”material costs” or ”construction costs,” through direct or indirect pathways.

Table 5. The Hierarchical Division Process.

Level	Reachable Set	Antecedent Set	Common Set
L1	A1	A1, A5, A7, C1, C2, C3, C4, D2	A1
	A2	A2, A5, A7, C1, C3, C4, D2	A2
	A3	A3, A5, A7, C1, C2, C3, C4, D2	A3
	B1	A5, A7, B1, C1, C2, C3, C4, D2	B1
	B2	A5, A7, B2, C1, C3, C4, D2	B2
L2	A7	A4, A5, A7, C3, D2, D3, D5	A7
	C1	A4, A5, C1, C3, D2, D3, D5	C1
	C2	A4, A5, C2, C3, D2, D3, D5	C2
	C4	A4, A5, C3, C4, D2, D3, D5	C4
L3	A5	A4, A5, A6, B3, D3, D5	A5
	C3	A4, A6, B3, C3, D3, D5	C3

The antecedent set Q(Ai) refers to the collection of all factors that can reach Ai. In M, the rows corresponding to the elements with a value of 1 in the i-th column represent Q(Ai). This reflects the factors that influence the formation or manifestation of Ai. For example, if Ai is ”material costs,” and Q(Ai) includes ”policy support,” ”technical standards,” and ”environmental differences,” this indicates that these factors directly or indirectly determine the level of material costs.

4.3.2. Calculating the Intersection A(Ai)= R(Ai)∩Q(Ai)

The intersection A(Ai)=R(Ai)∩Q(Ai) represents all factors that can be reached through Ai and can also reach Ai. If A(Ai) equals R(Ai), it means the reachable set of Ai is equal to A(Ai), i.e., all factors reachable by Ai can also reach Ai. Such factors often appear at the top of the hierarchical structure because they exhibit a circular reachability relationship with their reachable objects and cannot be further stripped of higher-level influence paths.

4.3.3. Hierarchical Judgment and Factor Stripping

After identifying the factors that satisfy A(Ai)=R(Ai), these factors are classified as the highest level of the system. These top-level factors are often the ”result-type” or explicit factors that are influenced by other factors. In this study, the top-level factors include ”demolition costs,” ”design costs,” ”construction costs,” ”material costs,” and ”certification costs.” These factors lie at the end of the system’s influence chain, manifesting as explicit expenditures or outcomes that cannot be explained by higher-level factors.

After removing the identified top-level factors from R(Ai) and Q(Ai), the remaining factors are subjected to the same steps. Through iterative stripping, all factors are assigned to their respective hierarchical levels.

Through reachability analysis and hierarchical dissection of the 20 influencing factors, this study constructed an ISM hierarchical structure with up to seven levels, as shown in **Figure 6**. The diagram clearly displays the hierarchical positions and interaction pathways of the influencing factors within the system, providing a structured and intuitive reference for subsequent strategy formulation and management recommendations.

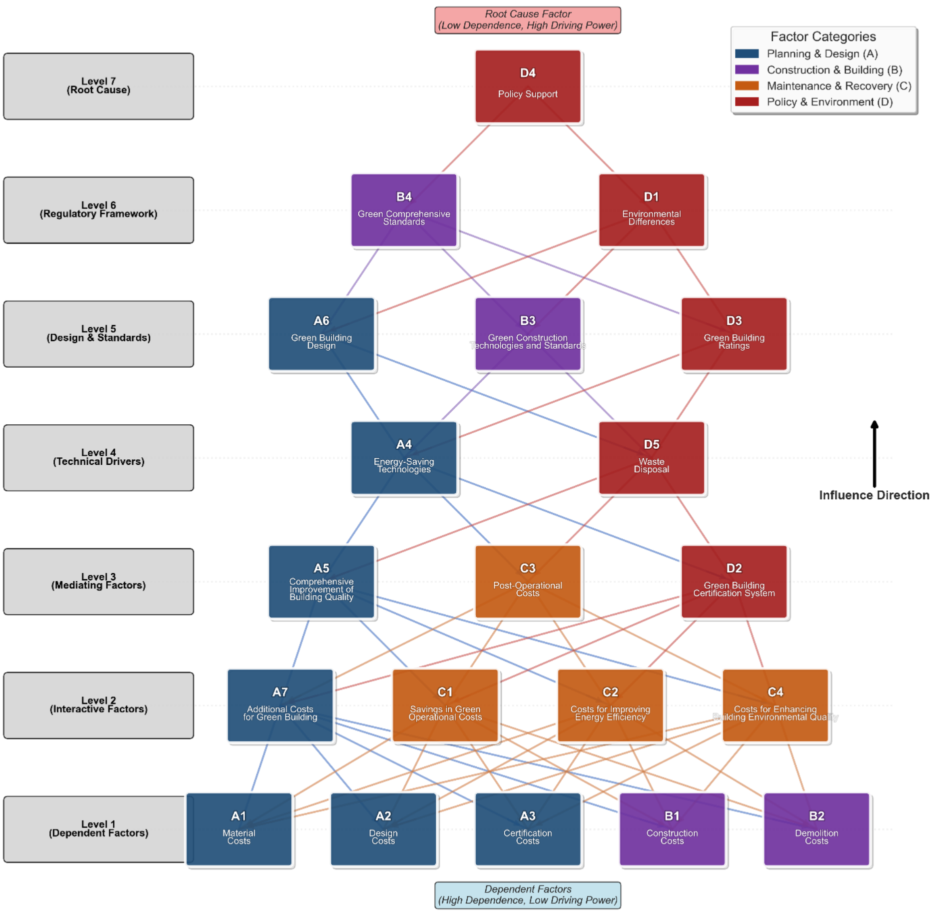

Figure 6. ISM Hierarchy Diagram of Green Building Construction Cost Impact Factors.

4.4. Analysis of the ISM Model for Influencing Factors of Green Building Construction Costs

From the ISM model, the influencing factors can be categorized into three types based on their roles and reachability characteristics: explicit influencing factors, implicit influencing factors, and root cause influencing factors.

Root cause influencing factors are located at the bottom layer and have direct or indirect impacts on other factors. In this study’s ISM model, ”government subsidies” is the only root cause influencing factor. During multiple rounds of hierarchical stripping, the ”government subsidies” factor consistently remained at the foundational level, exerting profound influences on the formation or existence of other factors.

At the top level, explicit influencing factors such as demolition costs, design costs, construction costs, material costs, and certification costs are present. These factors are located at the top because they are indirectly or directly influenced by lower-level factors (e.g., policies, environmental factors, green standards). To control green building construction costs, priority should be given to these explicit factors. For example, managing on-site personnel access, allocating construction labor, and procuring green materials and equipment in compliance with green building standards can directly and effectively control costs. The top-level factors represent the surface manifestations of cost issues, but their underlying causes often lie in the root causes and implicit factors.

Implicit influencing factors are located in the intermediate levels (L2–L6), such as green operational cost savings, costs for improving building environmental quality, and green building technology and standards. These factors are less foundational than root cause factors and less visible than explicit factors, but the ISM analysis reveals their transitional and mediating roles in the system, subtly influencing the performance of higher-level cost factors [55, 69].

4.5. MICMAC Analysis of Influencing Factors of Green Building Construction Costs

MICMAC (Matrix of Cross-Impact Multiplications Applied to Classification) methodology is employed to quantify the influence and dependence characteristics of factors identified within the ISM hierarchical structure. This analytical approach facilitates systematic classification of each factor as either a driver, dependent, autonomous, or interactive variable within the system framework.

Following the establishment of ISM hierarchical relationships, MICMAC analysis was implemented to determine the driving power and dependence levels of individual factors, providing enhanced understanding of their functional roles within the cost management system.

Driving power quantifies the extent to which a factor influences other system components, calculated as the sum of elements in the corresponding row of reachability matrix M. Higher row summations indicate stronger factor influence on other system elements. Conversely, dependence measures the degree to which a factor is influenced by other system components, determined by summing elements in the corresponding column of matrix M. Elevated column summations signify greater factor dependence on other system variables (**Figure 6**).

Table 6. Implicit Impact Factors in ISM.

Category	Influencing Factors	Frequency	Driving Power
Planning & Design	Material costs	9	1
	Design costs	8	1
	Certification costs	9	1
	Energy-saving technologies	14	8
	Comprehensive improvement in building quality	16	10
Construction	Green building design	10	6
	Additional costs of green buildings	13	6
	Construction costs	9	1
	Demolition costs	8	1
Maintenance & Recycling	Green construction technology and standards	10	6
	Comprehensive green standards	9	7
	Green operational cost savings	13	6
	Costs for improving energy efficiency	11	4
	Post-operation costs	16	10
	Costs for enhancing building environmental quality	13	6
Policy & Environment	Environmental differences	9	7
	Green building certification system	17	10
	Green building rating	14	10
	Policy support	7	6
	Waste treatment	13	7
Average		**11.4**	**5.7**
Category	**Influencing Factors**	**Frequency**	**Driving Power**

Through computational analysis of driving power and dependence values for each factor, a coordinate-based graphical representation was developed utilizing driving power and dependence as plotting parameters. The resulting quadrant-based classification system enables systematic categorization of factors into four distinct types based on their positional characteristics within the coordinate framework:

Independent factors: Characterized by high driving power and low dependence, these factors exert substantial influence on the system while remaining minimally affected by other variables, positioning them as primary system drivers and key leverage points for strategic intervention.

Dependent factors: Exhibiting low driving power and high dependence, these factors demonstrate significant susceptibility to external influences while possessing limited capacity to affect other system components, typically representing outcome variables or system endpoints.

Autonomous factors: Displaying both low driving power and low dependence, these factors maintain minimal system interaction, neither significantly influencing nor being influenced by other variables, often operating independently within the system structure.

Interactive factors: Demonstrating high driving power and high dependence, these factors experience substantial influence from other system components while simultaneously exerting significant influence on additional variables, functioning as critical system "hubs" that facilitate interconnectivity and information flow.

The analytical framework employed dependence as the horizontal axis and driving power as the vertical axis, utilizing the calculated mean values of driving power and dependence as the coordinate origin to systematically distribute the 20 identified factors across four distinct quadrants. The comprehensive results of this classification analysis are presented in **Figure 7**.

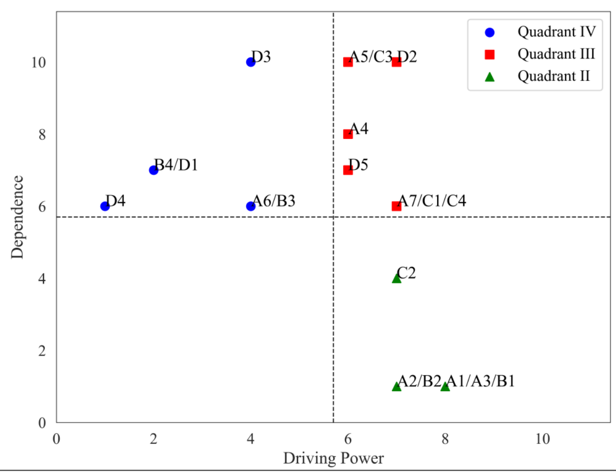

Figure 7. The Distribution Results of Driving Force and Dependency of Green Building Construction Cost Influencing Factors.

4.6. Analysis of MICMAC Results for Influencing Factors of Green Building Construction Costs

Independent factors include A6 (green building design), B3 (green building technology and standards), B4 (comprehensive green standards), D1 (environmental differences), D3 (green building rating), and D4 (policy support). These factors have strong driving power and weak dependence, guiding the system as key drivers and major influencers of green building construction costs. Effectively controlling and improving these factors will positively impact other factors, thereby effectively managing green building construction costs.

Dependent factors include A1 (material costs), A2 (design costs), A3 (certification costs), B1 (construction costs), B2 (demolition costs), and C2 (costs for improving energy efficiency). These factors have strong dependence and weak driving power, making them highly susceptible to other factors. Managing these dependent factors requires simultaneous control of key factors at higher or the same levels.

Interactive factors exhibit both strong driving power and dependence, playing active roles in the system. These include A4 (energy-saving technologies), A5 (comprehensive improvement in building quality), C1 (green operational cost savings), C2 (costs for improving energy efficiency), C3 (post-operation costs), C4 (costs for enhancing building environmental quality), D2 (green building certification system), and D5 (waste treatment). These factors occupy central positions in the system, significantly influencing both higher- and lower-level factors. They play pivotal roles in policy, technological, and standard changes.

5. Specific Recommendations

5.1. Financial Support and Incentives

According to the analysis, policy subsidies influence the system at the core level and the MICMAC matrix recognizes their significant power. Green buildings are costly to build initially, so governments can help by giving tax breaks, funding special subsidies and providing priority green loans. In the United States, developers are given LEED-based incentives at both the federal and state levels if they build according to set energy and sustainability standards. Entry cards to sustainability are seen as green building investments that meet the conditions under the European Union's Green Taxonomy Regulation, giving them access to green funding and a greater chance of being favored by analysts. Such tools can bring money into green infrastructure, encouraging more uptake and leading to lower operating costs in the future.

5.2. Policy Support

It is clear from ISM and MICMAC analyses that regulations, green building standards and environmental laws are the most important reasons for changes in cost and adoption. Building institutional strength involves governments requiring national green building codes, enforcing MEPS and choosing easy-to-follow compliance paths. Singapore's Green Mark scheme has led to all commercial buildings having mandatory energy efficiency, resulting in important savings of energy and carbon. Applying compliance, incentives and monitoring to policies can lead to major changes in the construction industry.

5.3. Technological Innovation Support

Factors in technology, for example energy-saving systems and ways of building, are recognized as important and capable of interacting. Authorities should encourage research cooperation between private and public sectors, set up innovation centers and award R&D tax credits to help develop new green building technologies. As an example, Germany's KfW Development Bank gives out low-interest loans and innovation grants to help improve passive building technologies and the efficiency of building envelopes. They help with the development of technology as well as control the expenses associated with operating the industry over time.

5.4. Public Awareness Campaigns

Study results reveal that public and investor views play a role in forming mid-tier ISM factors such as green building design and certification uptake. It is important to use nationwide awareness campaigns, host community workshops and launch green literacy programs to overcome any misunderstanding. Japan and Canada have introduced green public education which clarifies the concepts behind environmental design and points out its lasting financial and health perks. If the public learns about the cost and air quality benefits of these buildings, it can make the market and government take notice.

5.5. Demonstration Projects

Making green construction practical can be achieved by highlighting the results of pilot projects. Governments ought to co-pay for and display flagship buildings that showcase low-cost green technology, certifications and ways to reuse old buildings. In the UAE, the Masdar City project is seen as a regional example of sustainable urban development and the same is true for China's Tianjin Eco-City. These cases give local stakeholders, policy designers and construction firms helpful examples of how to balance costs and sustainability goals.

The results of this study reinforce and extend findings in the existing literature by highlighting "Policy Support" as the most influential driver of green building cost management. This aligns with previous studies such as Raouf and Al-Ghamdi [62] and Khasreen et al. [58], which emphasized the role of regulatory frameworks and governmental incentives in promoting sustainable construction. Additionally, the identification of interactive mediators such as green design (A6) and energy-saving technologies (A4) is consistent with empirical evidence presented by Smith, who found that design-stage interventions significantly affect long-term operational efficiency.

Unlike many earlier studies that focused on isolated cost elements or single-phase analysis, this research applies an integrated life cycle perspective to categorize influencing factors. This holistic view allows for a deeper understanding of systemic cost drivers throughout all stages of a green building's development.

From a methodological standpoint, the application of Interpretive Structural Modeling (ISM) combined with MICMAC analysis offers a structured and hierarchical understanding of factor interrelationships. This distinguishes the present study from approaches such as Analytic Hierarchy Process (AHP) or regression modeling, which, while effective in weighting factors or identifying correlations, do not visualize hierarchical cause-effect relationships. Previous works such as Chi Bin et al. and Jalaei et al. employed AHP and fuzzy logic methods [59, 68], which were useful in prioritizing sustainability criteria but lacked the explanatory depth of ISM's multilevel structure.

Thus, this study not only corroborates prior findings but also contributes methodologically by modeling dynamic interdependencies, offering a decision-support framework for policymakers, developers, and researchers aiming to optimize green building cost structures.

6. Conclusions

In this study, we used a life cycle approach combined with ISM and MICMAC analysis to look at 20 factors affecting cost management in green building construction. The factors were sorted into four stages: Planning and Design, Construction, Maintenance and Recovery and Policy and Environment. The study was built by combining a literature review with expert validation which allowed the creation of a hierarchical model and an evaluation of how important and dependent each factor is.

The analysis proved that "Policy Support" (D4) plays the biggest role among the root cause factors, indicating that governmental policies, incentives and rules shape the costs of green buildings the most. MICMAC analysis also found that policy-related factors are in the group with the highest driving power and the lowest dependence. Environmental differences (D1), green standards (B4) and green building design (A6) were found to interact with the other elements in the system. On the other hand, items such as material costs (A1) and construction costs (B1) were labeled as highly dependent results affected by early planning and regulatory factors.

Identifying and modeling the major cost influences on green buildings was the primary research objective which was achieved. The study solved the research gap by looking at connections between different factors, rather than studying each one alone which was a common problem in earlier research. The research question was answered by outlining a hierarchy that explains the relationships between factors throughout the building's life cycle. The hypotheses were also met; policy turned out to be the chief cause of higher costs and the link between green standards and energy-saving technologies was proven.

The theory adds to the cost analysis field by applying a multi-level systems view using ISM-MICMAC. Unlike AHP and regression methods, this model helps explain the different cause-effect patterns throughout the product's life cycle. In practice, the study results guide governments, developers and construction companies to focus on early actions, well-coordinated rules and supportive policies.

A drawback of this study is that the matrix is built through human judgment and thus may not include all important factors from outside the literature reviewed. In the future, researchers could use dynamic models (such as system dynamics) or compare regions to check and build upon this framework.

In short, the research gives us a useful decision-support model that helps us better grasp green building cost structures and also guides us in developing economically sound and environmentally sustainable construction methods.

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Conflicts of Interest

The authors declare no conflict of interest.

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