MCDM Framework for Ranking Barriers to Green Roof Implementation in India

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Abstract: Urbanization presents challenges such as energy consumption, social inequality, pollution, and resource depletion, straining urban systems. With the UN predicting a large urban population by 2050, sustainable urban environments are crucial. Green roofs, offering benefits like storm water management and reduced urban heat island effect, are a sustainable solution. However, their adoption faces significant obstacles in India. This paper uses an Integrated Multiple Criteria Decision Making (MCDM) approach to tackle these challenges. Key issues like climate variability, regulatory barriers, and lack of awareness are identified through a literature review. The Analytical Hierarchy Process (AHP) organizes decision criteria hierarchically and performs pairwise comparisons for importance. The Decision-Making Trial and Evaluation Laboratory (DEMATEL) method uncovers causal relationships among challenges. Stakeholder and expert engagement ranks challenges based on climate suitability, water availability, and policy support. The process includes data collection, pairwise comparisons, consistency checks, and sensitivity analysis. AHP and DEMATEL methodologies reveal that climate variability, regulatory barriers, and lack of awareness are primary challenges to green roof adoption in India. Sensitivity analysis confirms the robustness of these rankings. The framework offers a systematic approach to addressing obstacles in green roof implementation, promoting sustainable urban development. Prioritizing interventions and involving stakeholders aims to overcome barriers and accelerate green roof adoption, enhancing environmental resilience and urban sustainability in India and beyond.

Keywords: AHP; Decision making; DEMATEL; Green rooftop; MCDM

1. Introduction

Urbanization in the world has given rise to enormous challenges associated with energy consumption, social inequality, air and water pollution, and resource depletion resulting in a massive strain on urban systems. The process of global urbanization has engendered significant difficulties linked to the consumption of energy, disparities in social structures, as well as the pollution of air and water, alongside the depletion of resources, all of which collectively impose considerable pressure on urban infrastructures. Projections by the United Nations (UN) suggest that by 2050, approximately one-third of the global populace will be residing in urban areas. Consequently, it becomes imperative to undertake substantial reforms in the planning and administration of urban environments to guarantee the sustainable progression of cities[1)].

In recent times, green roofs have gained growing prominence as sustainable solutions on a global scale. Research on green roofs has revealed numerous social, environmental, and economic benefits. There is compelling evidence that green roofs offer a variety of advantages, including managing storm water, mitigating the urban heat island effect, fostering urban vegetation and wildlife habitats, extending roof lifespan, improving air and water quality, enhancing quality of life, reducing building energy costs, mitigating noise pollution, promoting recreational activities, and increasing green spaces and aesthetic appeal in urban environments. Additionally, by enhancing water quality, green roofs alleviate the burden on water treatment facilities in their respective areas. As a result of these benefits, many countries have begun integrating green roofs into their building designs, leading to a growing number of installations worldwide[2)]. Green roofs are essentially roofs adorned with various types of vegetation or plants, intended to yield numerous social, economic, and environmental advantages. This architectural concept aims to promote greenery atop buildings to garner a range of benefits. Generally, a green roof consists of various essential components, such as vegetation, substrate, filtration layer, drainage elements, insulation, root barrier, and waterproof membranes. The careful selection of each component is crucial for optimizing the performance of green roofs and maximizing their benefits. Every component holds equal significance and contributes significantly to the overall efficacy of green roofs in a given area their diverse benefits, green roofs are experiencing growing adoption across many nations[3,4]. Green roofs have the potential to transform roof surfaces into valuable urban assets by efficiently managing natural resources like rainwater and sunlight, which are often overlooked and wasted. They effectively regulate heat gain on rooftops and can mitigate carbon dioxide emissions from vehicles, thereby reducing a significant pollutant in urban environments[5]. The potential of green roofs in India is extensive, offering promising solutions to a range of environmental and urban issues while also delivering diverse social and economic advantages. As environmental awareness grows and initiatives for sustainable urban development gain momentum, the adoption of green roofs is anticipated to increase in India. This trend is set to provide inventive responses to urban challenges, ultimately cultivating a more environmentally friendly and adaptable future[6].

1.1 Why to adopt Green Roof tops

Green roofs absorb solar radiation, thereby reducing the urban heat island effect. The room temperature of a floor directly below a green roof is decreased by approximately 2°C[7]. The layers of a green roof effectively retain rainwater, slowing down surface runoff and reducing the volume of storm water. Even thin extensive green roofs can significantly decrease annual runoff by half and lower peak flow discharge to match average rain intensity, with a delay of 20–30 minutes. Plant leaves on green roofs trap dust particles from the surrounding air, promoting a healthier environment and potentially reducing the need for healthcare services, resulting in collective cost savings[8]. Green roofs also offer sound attenuation, reducing ambient noise levels by around 10–20 dB[9]. Ecologically, green roofs serve as havens for birds, insects, and other urban wildlife, potentially creating green corridors for natural habitats[9].

1.2 MCDM Approaches

In the context of this research paper could be instrumental in systematically evaluating and prioritizing the barriers/challenges associated with green roof installation[10]. These MCDM techniques offer complementary strengths in structuring decision problems[11], assessing interrelationships among criteria, and deriving consensus-based rankings. The AHP method[12] allows for the hierarchical structuring of decision criteria[13] and their pairwise comparisons to determine their relative importance[14]. In the context of green roof installation challenges, criteria such as climate variability[15], water availability[16], initial investment costs[17], maintenance requirements[18], regulatory constraints[19], supply chain challenges, policy support[20], community engagement[21], and waste management[22] could be identified and hierarchically organized. Stakeholders, including experts in environmental science, urban planning, engineering, and policymaking, could then provide pairwise comparisons of these criteria based on their perceived significance. The AHP method[23] would enable the aggregation of these judgments to derive overall priority weights for each challenge criterion.

By integrating the AHP and DEMATEL methods within the broader MCDM framework, the research can provide a comprehensive and nuanced understanding of the challenges to green roof installation in India.

1.3 Literature review with Research gap

Green roofs, also known as vegetated roofs or eco-roofs, have gained significant attention globally as a sustainable solution for urban environmental challenges. In rapidly urbanizing countries like India, where cities face pressing issues of climate change, urban heat island effect, water scarcity, and air pollution, the adoption of green roofs holds immense potential. However, the successful implementation of green roofs in India is impeded by various challenges, ranging from technical feasibility to policy constraints. Several studies have highlighted the importance of employing an Integrated Multiple Criteria Decision Making (MCDM) approach to systematically evaluate and prioritize challenges to green roof installation in India. Researchers emphasized the need for structured methodologies to assess the feasibility of green roofs in Indian cities, considering factors such as climatic suitability, structural requirements, water availability, and cost-effectiveness[24]. The significance of MCDM techniques like Analytical Hierarchy Process (AHP)[25] and Technique for Order of Preference by Similarity to Ideal Solution (TOPSIS)[26] in ranking challenges and identifying key barriers hindering green roof adoption[27]. The role of stakeholder engagement and policy informatics in promoting green roofs in India. They emphasized the importance of involving diverse stakeholders, including government agencies, urban planners, architects, developers, and community members, in decision-making processes related to green roof initiatives[28]. Furthermore, studies emphasized the need for policy interventions and regulatory frameworks supportive of green infrastructure development to overcome challenges such as zoning restrictions, building codes, and financial incentives[29].

Overall, the literature underscores the importance of adopting an Integrated MCDM approach[30] to address the multifaceted challenges of green roof installation in India.

By systematically evaluating criteria, engaging stakeholders, and informing policy development, such an approach can facilitate informed decision-making, efficient resource allocation, and the promotion of sustainable urban development practices in Indian cities.

The current body of literature underscores the significance of utilizing an Integrated Multiple Criteria Decision Making (MCDM) approach to assess obstacles to green roof implementation in India. However, there are notable gaps in research that persist. Firstly, there is a scarcity of studies specifically employing MCDM techniques to prioritize challenges within Indian urban contexts, necessitating customized frameworks tailored to address India's unique socio-economic, climatic, and regulatory dynamics. Secondly, while stakeholder engagement is pivotal for successful green roof endeavors, there is insufficient analysis of stakeholder perspectives, especially within India. Thirdly, existing assessment metrics predominantly focus on technical aspects, neglecting socio-cultural, aesthetic, and ecological facets pertinent to Indian cities. The development of more inclusive metrics is imperative to comprehensively evaluate green roof challenges. Furthermore, there is limited examination of the policy environment governing green roof adoption in India, warranting research to identify policy gaps and opportunities for reform. Lastly, there is a paucity of studies scrutinizing the long-term sustainability and resilience of green roofs in Indian urban areas, emphasizing the need for research evaluating their enduring environmental, social, and economic impacts and tackling its challenges.

1.4 Research Objectives

This research is carried out to achieve following objectives:

1. Identification of barriers to Green Roof Implementation in Indian context
2. Priorities these barriers using MCDM methods.

The methodology adopted for identification and to prioritize barriers is explained in following section 2.

2. Materials & methods

This paper employs a structured approach (Fig. 1) to identify and prioritize the challenges related to green roof implementation in the Indian context. It begins with an extensive literature review to extract insights from existing studies, reports, and publications on green roof installation, MCDM methodologies, and urban sustainability in India. Key barriers are then identified and categorized through stakeholder consultations and expert input, addressing technical, economic, environmental, regulatory, and social factors. The criteria for evaluating these challenges are selected based on their relevance, measurability, and significance, considering aspects such as cost-effectiveness, structural feasibility, water

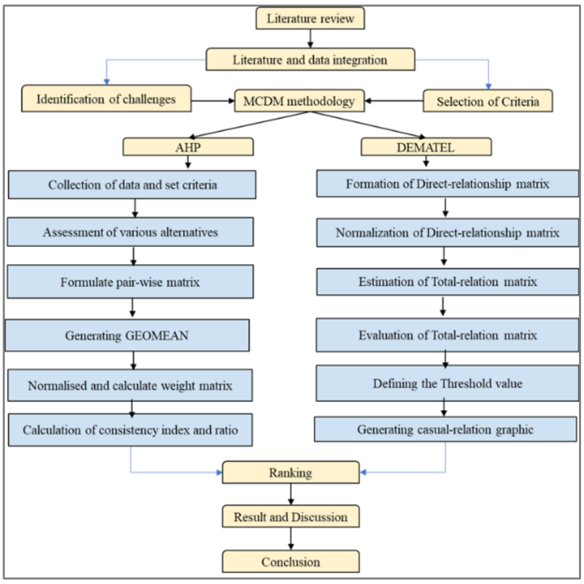

Fig. 1: Research methodology

availability, climate suitability, policy support, and stakeholder engagement. Initially, 20 barriers were identified, and through expert consultation, 11 crucial barriers were shortlisted, which are essential for the study's completeness. Subsequently, an appropriate MCDM methodology, such as AHP and DEMATEL techniques are chosen to rank the barriers based on the selected criteria. Data analysis involves assigning weights to criteria, scoring challenges against each criterion, and aggregating scores to derive overall rankings. Sensitivity analysis is conducted to assess the robustness of the rankings, while validation is performed through comparison with expert opinions and empirical evidence. The results are interpreted to identify priority challenges and provide insights for decision-making, resource allocation, and policy development aimed at promoting sustainable urban development through green roof initiatives in India. The methodology concludes with a discussion of findings, limitations, and recommendations for future research and practice in the field.

DEMATEL is a methodology used for analyzing complex systems and decision-making processes by visualizing and quantifying the causal relationships among different factors or variables[31)]. DEMATEL was developed in the 1970s and has since been widely used in various fields such as management[32)], engineering[33)], economics[34)], and environmental studies[35)]. It provides a systematic and quantitative approach to analyze the cause-and-effect relationships within complex systems, helping decision-makers understand the structure of the system and prioritize interventions or decisions accordingly[36)]. The DEMATEL methodology typically involves the following steps:

Step 1 - Initialize the direct - relationship matrix.

Experts or stakeholders assess the causal relationships between these factors. They indicate whether one factor directly influences another, and to what extent. This information is typically represented in a matrix format, where the rows and columns correspond to the identified factors, and the cells contain the degree of causal relationship between them. This matrix is called the direct-relationship matrix. The decision maker first assess the correlation between the groups of attributes based on the influence of each criteria with a certain scale.

0 - No influence

1 - Low influence

2 - Medium influence

3 - High influence

4 - Very high influence

Matrix based on expert judgments, data analysis, or other relevant information. Each cell in the matrix represents the strength of the relationship between the corresponding pair of criteria.

Step 2 - Normalization of direct-relation matrix.

Based on the pairwise comparison, with the below formulae (1) need to normalize the above formulated matrix. The direct-relationship matrix is then normalized to eliminate the influence of scale differences between factors, ensuring comparability. This normalization process typically involves dividing each element in the matrix by the sum of the absolute values of its row.

Step 3 - Estimation of Total-relation matrix.

Using the normalized direct-relationship matrix, total effects and direct effects of each factor are calculated. Total effects refer to the sum of the direct and indirect effects of a factor on all other factors, while direct effects represent the direct influence of a factor on others. The Identity matrix is used for the estimation by using the below equation(2).

Step 4 - Evaluate the sum of rows and columns in the total relation matrix.

Based on the calculated total effects and direct effects, an influence matrix is constructed. The total relation sum of the columns and rows has to be estimated by using the equation (3). This matrix provides a clear representation of the causal relationships among factors, highlighting influential factors and their interrelationships.

Step 5 - Defining the Threshold value.

Based on the average elements in the Total matrix, Threshold value is estimated. The influence matrix is interpreted to identify influential factors and their interdependencies. Factors with high total effects or high direct effects are considered significant, indicating their importance in the decision-making process or system.

Step 6 - Formulation of the causal-relation graphic.

It provides information to identify the most important criteria and their influence levels in order to recognize the driving variables of the considered problem in a complex system, and design for reasonable measures to take care of the issues based on the attribute type and in influence level.

$$Y = k \cdot A \tag{1}$$

Where,

$$k = \frac{1}{\max\limits_{1\le i\le n}\left(\sum_{j=1}^{n} a_{ij}\right)} (i, j = 1,2, \dots, n)$$

$$T = Y(I-Y)^{-1} \tag{2}$$

$$\begin{aligned} R_i &= \left[\sum_{j=1}^{n} t_{ij}\right]_{n\times 1} = [t_i]_{n\times 1}, i = 1,2,\dots,n \\ C_j &= \left[\sum_{i=1}^{n} t_{ij}\right]_{1\times n} = \left[t_j\right]_{n\times 1}, j = 1,2,\dots,n \end{aligned} \tag{3}$$

$$\alpha = \frac{\sum_{i=1}^{n}\sum_{j=1}^{n}\left[t_{ij}\right]}{N} \tag{4}$$

2.1 Analytical Hierarchy Process

STEP 1: Collect Data related to criteria’s set for assessment for various alternatives.

Data related to the criteria set for assessment and the various alternatives are gathered. This data can include quantitative information such as numerical measurements, costs, or performance metrics related to each criterion and alternative. It can also include qualitative information such as expert judgments, stakeholder preferences, or subjective assessments of the alternatives' performance with respect to each criterion.

STEP 2: Formulate pair-wise comparison matrix for various criteria “A1 Matrix”.

Decision-makers are asked to compare each criterion with every other criterion in terms of their relative importance. This comparison is done using a scale that typically ranges from 1 to 9, where 1 represents equal importance and 9 represents extreme importance. The preferred value is provided in Table 1. The comparisons are based on the decision-makers' judgments or expertise.

Table 1. Level of preference weight

Value	Preference
1	Equally Preferred
2	Equally to moderately Preferred
3	Moderately Preferred
4	Moderately to strongly Preferred
5	Strongly Preferred
6	Strongly to very strongly Preferred
7	Very strongly Preferred
8	Very strongly to extremely Preferred
9	Extremely Preferred

Formulation of Pair-Wise Comparison Matrix: Based on the pairwise comparisons, a pair-wise comparison matrix (A1 matrix) is formulated for each criterion. In this matrix, the elements represent the relative importance of one criterion compared to another. The diagonal elements are always 1 since a criterion is perfectly equal to itself. The off-diagonal elements are filled based on the pairwise comparisons made by decision-makers.

STEP 3: Check consistency of the matrix.

AHP includes a consistency check to ensure the reliability of the pairwise comparisons. If inconsistencies are detected, decision-makers may need to revise their judgments to improve consistency.

Step 3.1 Calculate Geometric Mean Row-wise

Step 3.2 Normalize weight matrix by dividing each value by its sum to get A_2 Matrix

Step 3.3 Calculate weighted A1 matrix and name it as A_3 matrix ($A_3 = A_1 \times A_2$)

Step 3.4 Calculate weighted normalized A3 matrix and name it as A_4 matrix ($A_4 = A_3 / A_2$)

Step 3.5 Calculate Consistency Index and ratio by equation (5) using Table 2.

$$CI = (\lambda_{max} - n)/(n - 1) \tag{5}$$

Table 2. Random consistency index

n	1	2	3	4	5	6	7	8	9	10	11
RI	0	0	0.58	0.9	1.12	1.24	1	1	1	1.5	1.5

If the consistency index is more than 0.1 then you are not consistent in your statements of pairwise comparison. Then modify initial pairwise comparison matrix and once again calculate Consistency ratio.

3. Results & Discussions

The integration of AHP and DEMATEL methodologies has provided a comprehensive understanding of the obstacles hindering the implementation of green roofs in India. By engaging stakeholders and consulting experts, a systematic approach was employed to assess and rank the identified challenges, elucidating their interconnectedness and significance. Different stakeholders like environmental science, urban planning, engineering, and policymaking experts having more than 10 year of field experience were selected. Total 6 experts from the industry and 2 experts from academia were chosen to fill pairwise comparison matrix.

3.1 DEMATEL approach

Through DEMATEL methodology, the research analyzed factors influencing waste management practices, evaluating their impact on the overall system and categorizing them into cause-and-effect groups (Fig. 2 & Fig. 3) The results indicate that several factors primarily contribute to the challenges within the domain. Waste Management emerged as the most significant cause, with a Ri+Cj score of 4.139 and a Ri-Cj score of 0.624, securing the top rank (Table 3, Table 4, Table 5). This underscores the critical importance of effective waste management strategies in addressing the overarching challenges faced. Following closely behind, Regulatory Hurdles, Maintenance Challenges, Policy Support, and Economic Considerations were also identified as prominent causes, reflecting the multifaceted nature of the challenges at hand. On the other hand, the research identified several factors as consequences or effects of the challenges within the domain. These factors, although influenced by the aforementioned causes, also play a significant role in shaping the overall landscape. Lack of Awareness and Education emerged as the most prominent effect, highlighting the importance of educating stakeholders and raising awareness to address existing challenges effectively. Other notable effects included Technical Expertise, Climatic Variability, Social Acceptance, Supply Chain Issues, and Water Availability, all of which contribute to the complexities within the domain. The integrated approach of AHP and DEMATEL methodologies has provided a nuanced understanding of the challenges hindering green roof implementation and waste management practices in India. These findings offer valuable insights for stakeholders to develop targeted interventions, allocate resources effectively, and formulate evidence-based policies to address the multifaceted challenges effectively.

Employing AHP, the research highlighted economic considerations as paramount, emphasizing the critical role of financial viability in implementing green roofs. Climatic variability, regulatory hurdles, and technical expertise followed closely, underscoring the diverse range of challenges spanning environmental, legal, and technical domains. Surprisingly, waste management ranked lowest, shedding light on the intricate landscape of factors influencing waste management practices, including economic viability, climate-related challenges, regulatory frameworks, and technical proficiency.

These findings offer valuable insights for stakeholders to allocate resources efficiently, design targeted interventions, and develop evidence-based policies. However, the apparent disparity in waste management's ranking emphasizes the need for a holistic approach, considering broader contextual factors beyond the immediate domain. Future research could explore underlying mechanisms driving these hierarchies and identify potential synergies among factors to enhance decision-making processes and waste management strategies.

Table 3. Direct relationship matrix

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11	Sum
Climatic Variability (F1)	0	0	1	0	0	1	3	1	2	1	0	9
Lack of Awareness and Education(F2)	2	0	1	0	1	0	1	0	2	2	2	9
Economic Considerations (F3)	1	1	0	0	0	0	2	1	1	4	2	11
Regulatory Hurdles(F4)	1	1	0	0	0	1	1	0	0	0	2	5
Technical Expertise (F5)	0	1	0	0	0	0	2	0	0	0	1	4
Water Availability (F6)	3	0	0	0	0	0	1	0	1	0	1	3

Maintenance Challenges (F7)	2	2	3	0	3	4	0	2	1	1	1	17
Supply Chain Issues (F8)	0	0	1	0	0	0	0	0	1	0	0	2
Social Acceptance (F9)	1	1	0	1	0	2	1	0	0	3	1	9
Policy Support (F10)	1	4	4	1	0	0	1	0	3	0	1	14
Waste Management (F11)	0	2	2	2	1	1	3	0	2	1	0	14
Sum	11	12	12	4	5	9	15	4	13	12	11	97

Table 4. Estimation of Total-relation matrix

Factors	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1	0.1	0.1	0.2	0	0.1	0.2	0.3	0.1	0.2	0.18	0.09
F2	0.2	0.2	0.2	0.1	0.1	0.1	0.2	0.1	0.3	0.27	0.23
F3	0.2	0.3	0.2	0.1	0.1	0.1	0.3	0.1	0.2	0.4	0.25
F4	0.1	0.1	0.1	0	0	0.1	0.2	0	0.1	0.08	0.18
F5	0.1	0.1	0.1	0	0	0.1	0.2	0	0.1	0.06	0.11
F6	0.2	0.1	0.1	0	0	0.1	0.2	0	0.1	0.08	0.11
F7	0.3	0.3	0.4	0.1	0.2	0.4	0.2	0.2	0.3	0.26	0.22
F8	0	0	0.1	0	0	0	0	0	0.1	0.04	0.02
F9	0.2	0.2	0.1	0.1	0.1	0.2	0.2	0	0.1	0.29	0.16
F10	0.2	0.4	0.4	0.1	0.1	0.1	0.3	0.1	0.3	0.24	0.23
F11	0.2	0.3	0.3	0.2	0.1	0.2	0.4	0.1	0.3	0.25	0.16

Table 5. Ranking of factors

Factors	Ri+Cj	Ri-Cj	Group	Rank
Climatic Variability (F1)	3.435	-0.287	Effect	8
Lack of Awareness and Education (F2)	3.993	-0.095	Effect	6
Economic Considerations(F3)	4.334	0.107	Cause	5
Regulatory Hurdles(F4)	1.756	0.375	Cause	2
Technical Expertise (F5)	1.753	-0.123	Effect	7
Water Availability (F6)	2.618	-0.551	Effect	11
Maintenance Challenges (F7)	5.123	0.356	Cause	3
Supply Chain Issues (F8)	1.102	-0.401	Effect	10
Social Acceptance (F9)	3.752	-0.316	Effect	9
Policy Support (F10)	4.621	0.309	Cause	4
Waste Management (F11)	4.14	0.624	Cause	1

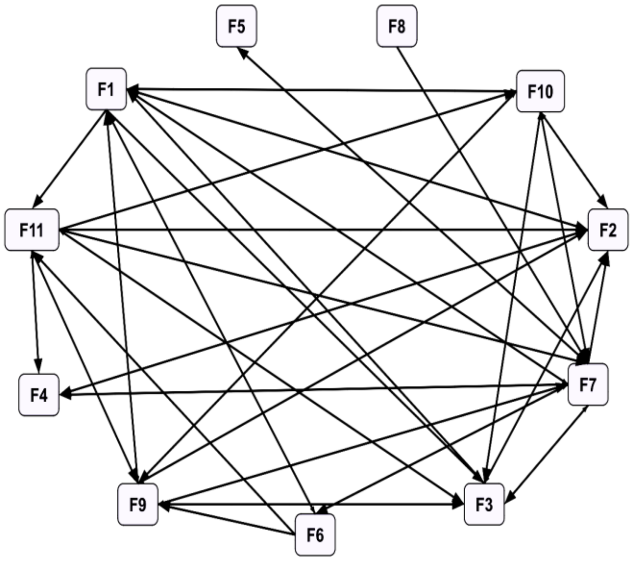

Fig. 2: Formulation of the causal-relation graphic

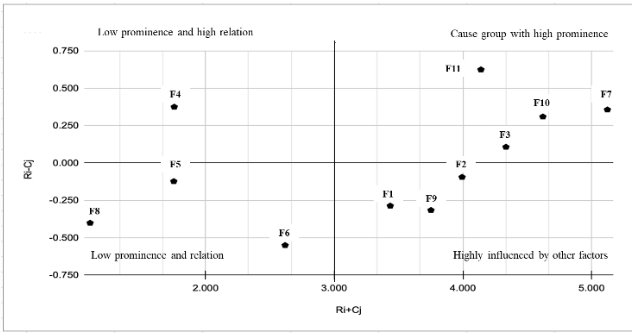

Fig. 3: Network Relationship Map having 4 group

3.2 AHP approach

The Analytic Hierarchy Process (AHP) method was applied to prioritize eleven factors impacting the system, with their geometric means and normalized priority weights (A2) calculated to determine their relative importance. Economic Considerations (F3) emerged as the most critical factor, with the highest geometric mean (1.577) and a normalized priority weight of 0.134, ranking first(Table 6, Table 7). This indicates that economic considerations are deemed the most influential in the decision-making process. Climatic Variability (F1) and Regulatory Hurdles (F4) followed, with geometric means of 1.505 and 1.105, and priority weights of 0.128 and 0.094, ranking second and third respectively. These factors are also considered highly significant, suggesting that both climatic factors and regulatory challenges play crucial roles.

Lack of Awareness and Education (F2), with a geometric mean of 1.531 and a priority weight of 0.13, ranked fifth, highlighting its importance but to a slightly lesser extent than the top three factors. Technical Expertise (F5) shared the same geometric mean (1.105) as Regulatory Hurdles but ranked fourth, indicating that technical skills are also essential for the system's success.

Water Availability (F6), Supply Chain Issues (F8), and Policy Support (F10) ranked sixth, seventh, and eighth, respectively, with geometric means of 1.134, 0.882, and 0.782, and corresponding priority weights of 0.097, 0.075, and 0.067. These factors are moderately important but not as critical as the top-ranking ones. Maintenance Challenges (F7), Social Acceptance (F9), and Waste Management (F11) were identified as the least critical factors, with the lowest geometric means (0.553, 0.769, and 0.798) and priority weights (0.047, 0.065, and 0.068), ranking ninth, tenth, and eleventh respectively.

The consistency index (CI) of 0.147 and the consistency ratio (CR) of 0.0971 indicate that the pairwise comparisons made during the AHP process were consistent and reliable, as the CR is below the acceptable threshold of 0.1. Overall, the AHP analysis highlights the prominence of economic considerations, climatic variability, and regulatory hurdles as the most influential factors, suggesting that strategic efforts to address these areas could significantly enhance system performance and resilience.

Table 6. Pairwise comparison matrix

FACTORS	F1	F2	F3	F4	F5	F6	F7	F8	F9	F10	F11
F1	1	1	3	1	1	3	5	1	2	1	1
F2	1	1	1	1	3	1	3	1	2	3	2
F3	0.33	1	1	3	1	1	5	2	3	5	1
F4	1	1	0.33	1	3	1	3	1	1	1	1
F5	1	1	1	0.33	1	1	3	1	1	1	3
F6	0.33	1	1	1	1	1	2	1	3	2	1
F7	0.2	0.33	0.2	0.33	0.33	0.5	1	2	1	1	1
F8	1	1	0.5	1	1	1	1	1	1	1	1
F9	0.5	0.5	0.33	1	1	0.33	1	1	1	1	2
F10	1	0.33	0.2	1	1	0.5	1	1	1	1	2
F11	1	0.5	1	1	0.33	1	1	1	1	0.5	1

Table 7. Ranking of factors

Factors	Geomean	Weight (A2)	Rank
F1	1.505	0.128	2
F2	1.531	0.13	5
F3	1.577	0.134	1
F4	1.105	0.094	3
F5	1.105	0.094	4
F6	1.134	0.097	6
F7	0.553	0.047	9
F8	0.882	0.075	7
F9	0.769	0.065	10
F10	0.782	0.067	8
F11	0.798	0.068	11
	Average	12.466	
	CI	0.147	
Consistency Ratio		0.0971	

3.3 Sensitivity Analysis

Performing sensitivity analysis is essential for evaluating the reliability of decisions made by evaluators. This process involves analyzing the effects of different combinations of decision criteria weights, including cases where weights are equally distributed and others where specific criteria are given more emphasis. By doing so, a clearer understanding of how varying the weights impacts the decision-making process is achieved. In this analysis, 20 unique scenarios are created, each involving a 5% decrease in the weight assigned to the most important criterion. Despite these changes, the overall ranking of the factors remains unaffected (Fig. 4), confirming the model's stability and robustness.

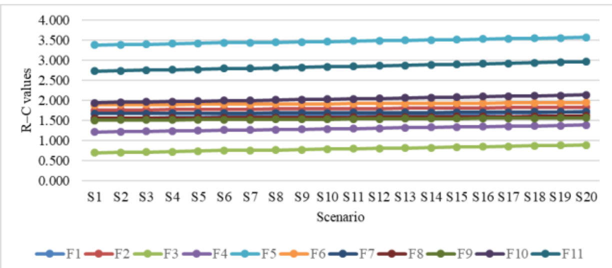

Fig. 4: Sensitivity Analysis

3.4 Implications and Recommendations:

To address the climatic and regulatory challenges facing the adoption of green roofs in India, policymakers should first develop comprehensive guidelines and standards for their installation and maintenance. These guidelines should be tailored to the country's diverse climate zones and building types, offering technical specifications for materials, plant selection, drainage systems, and insulation. Clear standards will ensure the long-term sustainability of green roofs while maximizing their environmental benefits, such as improved air quality, storm water management, and energy efficiency. By providing detailed frameworks, policymakers can help professionals and developers implement green roofs with greater consistency and quality.

Introducing financial incentives and subsidies is another critical measure to encourage widespread adoption. Offering tax breaks, grants, and low-interest loans to property owners, developers, and architects who integrate green roofs into their designs will reduce the financial burden associated with installation. Further incentives could be introduced for using locally sourced materials and native plant species, which not only promote biodiversity but also reduce project costs. Such financial support mechanisms will drive higher adoption rates, making green roofs a more appealing and cost-effective option for urban developers.

To ensure that green roofs become a standardized practice, policymakers could mandate their inclusion in the construction of new commercial and public buildings in urban areas. By integrating green roofs into building codes and urban planning regulations, especially in cities with limited green spaces and high pollution levels, local governments can ensure consistent implementation. This approach will facilitate the transformation of cities into more resilient, environmentally friendly spaces, addressing both short-term environmental needs and long-term sustainability goals.

Additionally, significant investment in research and development for climate-adaptive green roof technologies is essential. Policymakers should fund pilot projects across various cities, demonstrating how green roofs can be customized for India's diverse climates, including arid and monsoon-prone regions. Data from these projects can be used to refine regulations and develop localized solutions that enhance the effectiveness of green roofs in mitigating environmental challenges such as heat islands and flooding.

Public awareness and education campaigns are vital for promoting the benefits of green roofs. Governments should partner with NGOs, universities, and professional associations to raise awareness among homeowners, developers, architects, and urban planners about the environmental and economic advantages of green roofs. Certification programs for green roof designers and installers should be developed to ensure high-quality construction and maintenance, helping green roofs achieve their full potential in urban environments.

Comprehensive data collection and monitoring programs should be implemented nationwide to assess the long-term performance of green roofs. Monitoring parameters such as storm water management, energy savings, and biodiversity benefits will provide policymakers with critical data to make evidence-based decisions and refine regulations. This data-driven approach will also help optimize the design and functionality of green roofs, ensuring their efficiency and effectiveness in different urban settings.

Incorporating green roofs into broader urban planning and storm water management strategies is another key step. Policymakers should include green roof infrastructure in zoning laws, green building certifications, and urban resilience plans. A citywide, integrated approach will allow green roofs to contribute to flood mitigation, temperature regulation, and air quality improvement, enhancing the overall sustainability and resilience of urban environments.

Collaboration between government agencies, private developers, academic institutions, and civil society organizations is also essential. Creating engagement platforms and fostering public-private partnerships (PPPs) can facilitate coordinated efforts and secure funding for large-scale green roof projects. These partnerships will enable the sharing of knowledge and resources, fostering innovative solutions to address India’s unique urban challenges. Lastly, developing a legal framework that outlines ownership and maintenance responsibilities is crucial for the long-term sustainability of green roofs. Regulations should clarify the roles of building owners in maintaining green roofs and ensure that financial support is available for long-term upkeep. Additionally, policies should encourage the use of native plant species to enhance urban biodiversity and contribute to air quality improvement efforts, making green roofs a vital component of broader environmental strategies.

By expanding on these specific recommendations, policymakers will be better equipped to drive the adoption of green roofs in India, contributing to urban resilience, improved air quality, and sustainable development.

4. Conclusions

The integration of the AHP and DEMATEL methodologies has provided invaluable insights into the challenges hindering the installation of green roofs in India. Through systematic evaluation and prioritization, stakeholders have gained a comprehensive understanding of the factors influencing green roof adoption. AHP analysis has identified critical decision criteria, guiding stakeholders to prioritize interventions effectively. Meanwhile, DEMATEL has unveiled intricate interrelationships among challenges, offering a holistic perspective on green roof implementation dynamics. This combined approach offers a structured framework for decision-making and policy formulation, empowering stakeholders to develop targeted strategies for overcoming barriers. Continuous stakeholder engagement and refinement of the decision-making framework are vital for addressing emerging challenges and opportunities. By leveraging these insights, India can expedite the transition towards sustainable urban development, fostering environmental resilience and improving urban life quality for future generations.

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