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# Key Barriers and Feasibility of Implementing Green Roofs on Buildings in Malaysia

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**Abstract:** The implementation of green roofs in buildings offers various environmental, social, and economic advantages. Despite Malaysia's rapid urbanization, green roofs are not commonly integrated into existing or new buildings, which limits their potential benefits. Identifying the reasons behind this lack of implementation is crucial to promoting the widespread implementation of green roofs. Although previous works have explored barriers in developed urban areas, little attention has been given to Malaysia, where green roof implementation is still in its early stages. To address this research gap, our study aims to investigate the key barriers to implementing green roofs in buildings in Malaysia. Additionally, the study aims to assess the feasibility and level of support for green roof implementation in Malaysia. We utilized a combination of literature review, questionnaire surveys, and structured face-to-face interviews. Through the utilization of both normalization and the Relative Importance Index (RII) analysis, the findings highlight the presence of three primary barriers that impede the effective implementation of green roofs in Malaysia. Notably, the key barriers are: high/additional construction costs, high/increased maintenance costs, and lack of owner/client interest. Understanding and prioritizing these root causes can empower building owners, developers, and policymakers to develop effective strategies for green roof implementation. Our findings offer valuable insights for promoting sustainable development in Malaysian buildings and contribute to the advancement of green roof practices in the country.

**Keywords:** green buildings; green roofs; barriers; Malaysia



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## 1. Introduction

Civil engineering plays a vital role in developing infrastructure to meet economic challenges. Nowadays, civil engineering technology has been introduced to address current challenges effectively. With the growing global concern for sustainable development and environmental conservation, implementing green technologies in the building industry has become imperative. Green buildings stand out due to their positive impact on the environment. They provide a more sustainable and economically friendly alternative to traditional building systems. Among the innovative eco-friendly practices, green roofs have emerged as a promising solution to mitigate the adverse impacts of urbanization and climate change [1–7].

Green roofs, characterized by their vegetative coverings atop building structures, offer multifaceted benefits ranging from managing stormwater runoff to enhancing energy efficiency and providing valuable green spaces within urban environments. A green roof is a highly effective Best Management Practice (BMP) and one of the recently developed low-impact development (LID) techniques that manage overflow at the source by storing water within its layers, delaying hydrological reactions, and promoting evapotranspiration [5,8]. A green roof can be described as a structural system incorporating different layers (such as waterproofing, drainage, soil, and vegetation) installed on top of a standard roof. The two

main types of green roofs are extensive and intensive [6,9,10]. Extensive green roofs offer several advantages over intensive ones, including lower capital and maintenance costs and reduced water requirements. They are lightweight and often do not require additional structural support. Additionally, extensive green roofs can be installed on steeper slopes, and the construction methods are technically straightforward and suitable for larger roof areas. Green roofs can mitigate urban hardscape issues by covering a building with a living plant layer. Urban environments can experience natural cooling processes and water treatments similar to less built-up areas, promoting a healthier and more sustainable urban environment [3].

The development and implementation of green roofs have gained widespread attention due to their ability to protect the environment and mitigate the effects of global warming, particularly in developed countries [9,11]. Similarly, in subtropical and tropical regions, the implementation of green roofs offers a compelling scenario that intertwines environmental benefits with unique challenges stemming from the distinct climatic and ecological characteristics of these areas [6]. In these warm and often humid climates, the adaptation of green roofs can significantly transform urban landscapes while improving environmental problems [12,13] and addressing critical sustainability concerns, such as incorporating recycled waste materials into the design [3,10]. Green roofs provide a promising solution for temperature regulation in subtropical and tropical regions, where temperatures consistently lean toward the warmer spectrum. The presence of vegetation acts as a natural insulator, helping to cool indoor spaces and reducing the reliance on energy-intensive air conditioning systems. As a result, green roofs contribute to improved energy efficiency [7,14,15] and promote more sustainable urban development [10]. Moreover, green roofs effectively combat the urban heat island (UHI) effect [7,16] that often plagues subtropical and tropical cities. The excessive heat generated by urban surfaces can be mitigated by the natural cooling properties of vegetation. By absorbing and releasing heat, green roofs help regulate temperatures in built-up areas. This cooling effect enhances urban comfort and mitigates health risks associated with extreme heat, thereby contributing to the overall well-being of city residents. One of the key advantages of green roofs in these climates is their capacity to manage stormwater effectively [3]. Given the prevalence of heavy rainfall, especially during monsoon seasons, green roofs can serve as natural sponges that absorb rainwater and gradually release it. By doing so, green roofs alleviate the strain on local drainage systems, mitigate the risk of flooding, and enhance overall stormwater management strategies.

However, implementing green roofs is not without challenges [11,17]. Lack of proper design and suitable guidelines regarding the installation of green roofs have been recognized as barriers [18]. Other factors include the high initial costs, a scarcity of experimental data, and inadequate awareness of the long-term advantages [19]. The implementation of green roofs in subtropical and tropical countries introduces a complex interplay of barriers centered around maintenance and elevated costs. These challenges are closely interwoven with the distinctive climatic characteristics of these regions and the economic dynamics that shape them. The rapid growth characteristic of tropical and subtropical climates may necessitate more frequent upkeep to prevent overgrowth and ensure the green roofs remain visually appealing and structurally sound. Moreover, proper structural design is vital, given the potential weight of vegetation and accumulated rainwater. Cultural acceptance and societal acceptance also play a role in the scenario. Engaging with local communities to raise awareness about the benefits of green roofs and aligning designs with cultural preferences can enhance the chances of successful implementation. In navigating these barriers, a balanced approach is crucial. Effective planning, meticulous plant selection, investment in robust irrigation systems, and a clear maintenance strategy can help overcome barriers. Although the upfront and ongoing cost might be substantial, the potential reward, ranging from environmental benefits to energy efficiency and aesthetic enhancements, underscores the value of green roofs in subtropical and tropical regions. As these barriers

are acknowledged and proactively addressed, green roofs can contribute meaningfully to sustainable urban development in these climatically rich zones.

Numerous barriers have been addressed through various research and initiatives dedicated to improving the implementation of green roofs worldwide, including in subtropical and tropical countries. Zhang and He [20], in their work, concluded that green roof implementation faces several barriers, including a lack of government policy support, insufficient technological advancement, inadequate assessment of the potential economic benefits, and individual unwillingness to implement green roofs. Chen et al. [21] conducted a practical survey and case study to understand the root causes behind the limited implementation of green roofs in urban China. They identified several key barriers impeding the widespread implementation of green roofs, including the increased maintenance cost associated with green roofs, higher design and construction expenses, inadequate planning and arrangement for the use of green roofs, and a lack of incentives for developers to incorporate green roofs in their projects. Similarly, Zhang et al. [22] also identify the lack of promotion and incentives from the government and the increase in the maintenance costs associated with extensive green roofs as the key barriers hindering the promotion of extensive green roofs for existing buildings in Hong Kong. Meanwhile, Hossain et al. [23] reveal that the key barriers to implementing green roofs in Bangladesh are a lack of knowledge and misconceptions about this technology among professionals in the building industry. These barriers hinder the widespread implementation of green roofs, despite their potential benefits in the country. They highlight the importance of understanding and addressing the misconceptions and knowledge gaps within the building industry to promote the broader implementation of green roofs in Bangladesh and contribute to more sustainable building practices and reducing greenhouse gas emissions.

The Malaysian building industry has also recognized the numerous benefits of green roofs in terms of environmental impact, hydrological performance, and aesthetic satisfaction [24,25]. However, in Malaysia, the implementation of green roofs is still in its early stages, and specific properties have not fully embraced their use. Although some localized green roof projects exist in Malaysia, the overall implementation remains limited due to multifaceted barriers. Various works have identified several key barriers to implementing green roofs in Malaysia. These include the relatively high cost and technical complexities [25,26], high costs of green roof materials, and a lack of research [27]. Another set of barriers involves a lack of awareness, education, and information regarding the benefits of constructing green buildings [28]. A significant hurdle in implementing green roofs is the constraint posed by limited local expertise and a shortage of experienced professionals in the field [25,27,29]. It is indicated that lack of experience among maintenance crew regarding green roofs leads to poor system installation. This is because the construction of a green roof needs at least one expert in this industry to prevent the destruction of green roof installation [29]. In a study by Ismail et al. [30], the barriers to implementing green roofs in densely populated urban areas of Malaysia, specifically within high-rise residential buildings, were examined. The research delved into residents' awareness of rooftop gardens in the Klang Valley and tackled related issues. The findings exposed a range of barriers, including construction costs, maintenance problems such as leaks, and design and structural robustness concerns. Meanwhile, a study conducted by Zahir et al. [31] aimed to assess the perceptions and comprehension of Malaysian architects regarding green roof implementation issues and to gauge their level of readiness and acceptance. The analysis examines diverse research approaches and practices concerning factors influencing architects' perspectives on incorporating green roofs within Malaysia's construction industry. The study identified nine significant barriers to green roof implementation: skepticism among local architects about the benefits; absence of policies and guidelines coupled with government non-enforcement in building by-laws; barriers in persuading clients; the novelty of technology causing supply shortages and cost escalation; limited expertise in green roof technology; concerns over leakages, reduced roof lifespan, and additional structural

loads; apprehensions about unknown risks; architects' lack of proactive role in advocating green roofs; and insufficient demand in the Malaysian construction market.

Although previous works provide valuable insights into implementing green roofs in Malaysia, there is still room for more research to deepen our understanding of these challenges and potential solutions. Additional research could delve deeper into the barriers faced by different stakeholders, such as architects, engineers, and developers. This would provide a more nuanced view of the barriers and help identify tailored solutions for each group. Furthermore, new research is compelling to validate and replicate previous findings in a different context to ensure robustness and generalizability. Research that builds upon existing findings, takes a more comprehensive approach, engages stakeholders, and focuses on practical implications could contribute significantly to promoting successful green roof implementation in Malaysia. Hence, the primary objective of this study is to investigate the key barriers to implementing green roofs in buildings in Malaysia. Knowing the key barriers is essential for devising effective strategies, encouraging sustainable building practices, and realizing the numerous environmental, economic, and social benefits they offer. By addressing these barriers, stakeholders can unlock the full potential of green roofs as a valuable tool for urban sustainability and resilience. Additionally, the study aims to assess the feasibility and level of support for green roof implementation in Malaysia. Through this, we seek to understand the current perception and level of acceptance of green roofs in Malaysia and identify potential areas for improvement or initiatives to promote their implementation in buildings.

## 2. Materials and Methods

### *2.1. Data Collection Methods*

The data for this study was gathered through a comprehensive approach, incorporating a literature review, a questionnaire survey, and structured face-to-face interviews with professionals engaged in green roof projects. The literature review provided a robust theoretical basis for identifying potential barriers. Questionnaire surveys allowed for the collection of data to assess the significance of each potential barrier. Additionally, structured face-to-face interviews were conducted to allow for more comprehensive and detailed responses from participants. This format encourages interviewees to provide nuanced explanations and elaborate on their answers. This multi-pronged methodology ensured a thorough and well-rounded exploration of the barriers hindering the implementation of green roofs in Malaysian buildings.

### *2.2. Literature Review*

This study employs the systematic literature review (SLR) method to generate a comprehensive analysis of a compilation of potential barriers to implementing green roofs in the existing body of literature. Following the PRISMA methodology (Preferred Reporting Items for Systematic Review and Meta-Analyses) [32], the review involves four distinct phases: identification of documents (articles), document screening, assessment of document eligibility, and presentation of the refined list of documents.

The initial step in PRISMA involves document identification, utilizing the Scopus databases as the primary source. This database was selected due to its established reputation and widespread usage in systematic reviews [33]. Keyword-based searches were employed to extract relevant outcomes, ensuring alignment with the study's scope. The search primarily revolved around Boolean keywords (barriers OR challenges OR constraints) AND green AND (roof OR roofs) AND (adoption OR integrating OR implementation) targeting Title-Abstract-Keywords sections. Subsequently, during the second phase, or document screening, the focus was confined to English-language articles published from 2000 to 2023. The third phase pertains to document eligibility, during which articles identified in the previous step were shortlisted based on abstracts and keywords. The search was conducted from April 2020 until July 2023, yielding 181 results. The ultimate selection of articles was contingent upon their incorporation of themes related to barriers in green

roof implementation, involving a visual examination of the title, abstract, and conclusion. Finally, 26 articles were retrieved and analyzed. The limited number of articles obtained from the search can be attributed to the combination of a specific focus on barriers to implementing green roofs, the strict selection process involving visual examination of key sections, and the possibility of a relatively smaller pool of research in this specific context. After a comprehensive review, 14 potential barriers are identified, as shown in Table 1.

**Table 1.** Overview of potential barriers to implementing green roofs on buildings in Malaysia.

| Code | Barriers | Key References |
|---|---|---|
| B1 | High/Additional design cost | Chen et al. [21]; Hossain et al. [23] |
| B2 | High/Additional construction cost | Mahdiyar et al. [9]; Shafique et al. [19]; Chen et al. [21]; Hossain et al. [23]; Mustaffa et al. [25]; Chee et al. [26]; Ismail et al. 2015 [30]; Liu et al. [34] |
| B3 | High/Increase in maintenance cost | Chen et al. [21]; Zhang et al. [22]; Hossain et al. [23]; Mustaffa et al. [25]; Liu et al. [34]; Bashir et al. [35]; Matos Silva et al. [36]; Alim et al. [37]; Yao et al. [38]; Brudermann et al. [39] |
| B4 | Lack of knowledge | Mahdiyar et al. [9]; Shafique et al. [19]; Hossain et al. [23]; Brudermann et al. [39]; Sangkakool et al. [40] |
| B5 | Lack of awareness about sustainable environment/benefits | Pratama et al. [17]; Hossain et al. [23]; Mustaffa et al. [25]; Esa et al. [28]; Faisal and Elsaadany [41] |
| B6 | Lack of owner/client interest | Zhang and He [20]; Hossain et al. [23] Mustaffa et al. [25] |
| B7 | Not included in the building code | Shafique et al. [18]; Hossain et al. [23]; Mustaffa et al. [25]; Zahir et al. [31]; Faisal and Elsaadany [41], |
| B8 | Lack of incentive from the government for developers | Zhang and He [20], Chen et al. [21], Zhang et al. [22], Hossain et al. [23]; Sangkakool et al. [40]; Zeadat [42] |
| B9 | Lack of incentive from the government to owners of existing buildings | Zhang and He [20]; Hossain et al. [23] |
| B10 | Increase in structural loading | Hossain et al. [23]; Zahir et al. [31]; Brudermann et al. [39]; Ezema et al. [43]; Zambrano-Prado et al. [44]; Palanisamy et al. [45]; |
| B11 | Difficulties in design | Shafique et al. [18]; Hossain et al. [23]; Ismail et al. [30]; Joshi and Teller [46] |
| B12 | Construction difficulties | Hossain et al. [23]; Ezema et al. [43] |
| B13 | Lack of expertise/skilled manpower | Pratama et al. [17]; Hossain et al. [23]; Mustaffa et al. [25]; Rahim et al. [27]; Chow and Abu Bakar [29]; Zahir et al. [31]; Sangkakool et al. [40]; Abdul Rahman et al. [47] |
| B14 | Require regular maintenance | Hossain et al. [23]; Zambrano-Prado et al. [44] |

### *2.3. Questionnaire Survey*

The questionnaire survey was divided into two sections. The first section asks questions concerning the barriers to implementing green roofs in buildings in Malaysia. A questionnaire survey was created based on the barriers in Table 1 to examine their significance in affecting the implementation of green roofs on buildings in Malaysia (i.e., Section 1). After that, there was a section (i.e., Section 2) about the support provided to carry out the green roof systems, in which the feasibility of green roofs was assessed. Table 2 shows the questions used in Section 2.

The target groups of the survey include developers, architects, engineers, surveyors, and academia, as shown in Table 3. This can allow different views from the target groups and compare their views [21,22]. The most populous group of respondents comprises professionals in private/government building companies such as contractors and consultants, comprising 78% of the total respondents. Conversely, academics from university settings represent the smallest subset, accounting for 5% of the total respondents.

**Table 2.** The survey questions used to assess the feasibility of green roof systems.

| Code | Please Indicate to What Extent You Agree or Disagree with the Statement |
|---|---|
| F1 | How familiar are you with green roofs? |
| F2 | How often do you see green roofs in Malaysia? |
| F3 | Have you ever been involved in a project with green roofs? |
| F4 | Do you agree the government should promote green roofs in Malaysia? |
| F5 | Do you agree green roofs are feasible to implement for existing buildings? |
| F6 | Do you agree green roofs are feasible to implement for newly developing buildings? |
| F7 | Do you support the implementation of green roofs? |
| F8 | Would you support constructing green roofs on the building where you live? |

**Table 3.** Demographic profile of respondents.

| Designation | Percentages (%) | Years of Working Experience (%) | | |
|---|---|---|---|---|
| | | ≤5 Years | between 6–10 Years | >10 Years |
| Developers | 17 | 29 | 14 | 57 |
| Architects, engineers, surveyors | 78 | 57 | 26 | 17 |
| Academia | 5 | 0 | 0 | 100 |

The distribution of years of work experience among the different respondent groups is crucial in enhancing the comprehension of the study's findings. For developers, the allocation of respondents across various levels of experience (≤5 years, between 6 to 10 years, and over 10 years) offers a nuanced perspective on how experience might correlate with their responses. The substantial presence of developers with over 10 years of experience (57%) implies a significant representation of seasoned professionals who have witnessed the evolution of the field. Their responses are likely to provide insights into long-term trends, industry shifts, and the barriers that have emerged over time. Meanwhile, the smaller proportion of developers with ≤5 years (29%) might illuminate the experiences and viewpoints of newcomers, shedding light on the current concerns and aspirations of those just entering the profession. The middle ground of 6 to 10 years (14%) offers a unique glimpse into a phase where professionals are likely grappling with a transition from early career challenges to more mature perspectives.

In the context of architects, engineers, and surveyors, the division by years of experience similarly enriches the study's findings. With 57% of respondents having ≤5 years of experience, the voices of those newly inducted into these professions can be heard distinctly. Their perspectives might reflect recent changes in the industry, technological advancements, and emerging trends that have caught the attention of newer practitioners. The segment with 6 to 10 years of experience (26%) embodies professionals who have surpassed the initial learning curve and are likely dealing with mid-career challenges. Their insights could encompass a phase of specialization, project management responsibilities, and possibly a shift in their outlook. Notably, the smaller proportion of respondents (17%) with over 10 years of experience could offer a perspective informed by years of experience, one that may emphasize issues related to mentorship, succession planning, and the broader trajectory of their fields.

The academia group, with a distinctive distribution of experience, presents an intriguing contrast. The complete absence of respondents with ≤5 or 6 to 10 years of experience indicates that the academic realm is predominantly represented by those with over 10 years of experience (100%). This concentrated group is likely composed of senior scholars, tenured professors, and seasoned researchers. Their perspectives can provide invaluable insights into the long-term dynamics of the academic landscape. With their extensive experience, they might offer commentary on shifts in educational paradigms, research trends, and the changing role of academia in shaping their respective fields.

A total of 150 surveys were sent out to different groups of respondents, and 100 completed surveys were returned, with a response rate of 67%. The Likert scale was used in the questionnaire for both sections to help respondents present their opinions. The Likert scale is commonly used for rating the relative significance of individual factors by examining experts' opinions. The respondents were invited to give their opinion on the relative significance of each barrier in hindering the implementation of green roofs in new and existing buildings in Malaysia as well as the feasibility of green roofs. The respondents were invited to judge the significance degree of each listed barrier, with "1" being graded as strongly disagree, "2" as disagree, "3" as neutral, "4" as agree, and "5" as strongly agree. The collected survey data were analyzed using descriptive analysis and statistics, including the mean (average score given by respondents), standard deviation (measure of variability in responses), and non-variability (measure of consensus among respondents) tests. In addition, the Relative Importance Index (RII) was determined using Equation (1). The normalization test is employed to standardize various variables onto a shared scale. In contrast, *RII* evaluates the relative significance of these standardized variables. The integration of these methodologies provides a comprehensive understanding of the factors being examined.

$$RII = \frac{\sum_1^5 W_i X_i}{A \sum_1^5 X_i} \quad (1)$$

where, $i$ = index of response category ($i$ = 5, 4, 3, 2, 1), $W_i$ = weight given to the $i$th response, $X_i$ = frequency of the $i$th response, and $A$ = is the highest weight (i.e., 5 in this case).

## 3. Results

### *3.1. Barriers to Implementing Green Roofs in Malaysia*

The results in Table 4 present the normalized ranking of barriers to the implementation of green roofs on buildings in Malaysia. These barriers are evaluated based on three criteria: mean, standard deviation (SD), and non-variation (NV). The results highlight that the respondents consider high/additional construction costs and increased maintenance costs to be the most significant barriers to implementing green roofs in Malaysian buildings. The lack of owner/client interest follows closely behind. The relatively high levels of consensus among respondents for all three barriers indicate that these are generally acknowledged barriers to promoting green roof adoption in Malaysia.

**Table 4.** Normalized Ranking of Barriers to Green Roof Implementation on Malaysian Buildings.

| Barriers | Mean | SD | NV | Rank |
|---|---|---|---|---|
| High/Additional construction cost | 4.10 | 0.798 | 0.700 | 1 |
| High/Increase in maintenance cost | 4.01 | 0.858 | 0.750 | 2 |
| Lack of owner/client interest | 3.99 | 0.870 | 0.750 | 3 |
| Require regular maintenance | 3.92 | 0.981 | 0.640 | 4 |
| Lack of incentive from the government for developers | 3.86 | 0.995 | 0.572 | 5 |
| Lack of incentive from the government to owners of existing buildings | 3.81 | 0.992 | 0.562 | 6 |
| High/Additional design cost | 3.80 | 0.932 | 0.700 | 7 |
| Increase in structural loading | 3.74 | 0.939 | 0.685 | 8 |
| Construction difficulties | 3.74 | 0.991 | 0.580 | 9 |
| Lack of knowledge | 3.73 | 0.839 | 0.682 | 10 |
| Lack of awareness about sustainable environment/benefits | 3.72 | 0.900 | 0.680 | 11 |
| Not included in the building code | 3.68 | 0.920 | 0.670 | 12 |
| Lack of expertise/skilled manpower | 3.62 | 0.885 | 0.540 | 13 |
| Difficulties in design | 3.60 | 0.932 | 0.650 | 14 |

The high/additional construction cost emerges as the most significant barrier to implementing green roofs on buildings in Malaysia. With a mean score of 4.10, respondents have a substantial agreement regarding its importance. The relatively low SD of 0.798 indicates

a high level of consistency in the responses, and the NV value of 0.70 further supports the consensus. Rank 2 highlights the barriers of high/increased maintenance costs, which received an average mean score of 4.01. This demonstrates that respondents consider ongoing maintenance expenses to be a noteworthy barrier to green roof implementation. However, the higher SD of 0.858 indicates a wider range of opinions within the respondent pool. This variation in perceptions suggests that although many acknowledge the barrier's importance, there are differing viewpoints on the extent of the impact. Nonetheless, the NV score of 0.750 underscores that a substantial majority, 75% of respondents, shares a common understanding of the increased maintenance costs as a barrier. Taking the third position is the barrier of lack of owner or client interest, with an average mean score of 3.99. This barrier is perceived as slightly less significant than the previous two; however, it still underscores the importance of stakeholders' engagement. The higher SD of 0.870 indicates a diversity of perspectives among respondents, possibly influenced by various factors shaping their perceptions. Despite this, the NV score of 0.750 indicates a strong consensus among 75% of respondents regarding the significance of owner or client disinterest as a barrier. The lack of interest from building owners and clients may lead to limited demand for green roofs, thereby hindering their implementation.

Ranked fourth, the requirement for regular maintenance is considered a notable barrier to implementing green roofs, with a mean score of 3.92. The higher SD of 0.981 suggests some variability in respondents' views, and the NV value of 0.640 indicates a moderate level of consensus. The need for consistent upkeep and monitoring of green roofs may be perceived as a barrier, especially if building owners are not prepared for ongoing maintenance responsibilities. Ranked fifth, the lack of government incentives for developers is perceived as a barrier, with a mean score of 3.86. The absence of supportive policies and incentives from the government might discourage developers from incorporating green roofs in their projects. The rest of the barriers are ranked accordingly as illustrated in Table 4, and their respective mean scores, SDs, and NV values provide insights into the perceived importance and level of consensus among respondents. These results emphasize various barriers that must be addressed through targeted policies, incentives, and awareness campaigns to promote the widespread implementation of green roofs in Malaysia.

Table 5 presents a comprehensive overview of the barriers that impede the implementation of green roofs in Malaysia, as identified through the RII analysis. The top three RII ranking results demonstrate a congruent ranking pattern with the findings in Table 4, which were obtained through the normalization analysis. The high ranking obtained for cost-related issues, lack of interest, and the need for maintenance underscores the financial and awareness barriers that need to be addressed to promote the implementation of green roofs effectively.

**Table 5.** Relative Importance Index (RII) of Barriers to Green Roof Implementation on Malaysian Buildings.

| Barriers | RII | Rank |
|---|---|---|
| High/Additional construction cost | 0.820 | 1 |
| High/Increase in maintenance cost | 0.802 | 2 |
| Lack of owner/client interest | 0.798 | 3 |
| Require regular maintenance | 0.782 | 4 |
| High/Additional design cost | 0.760 | 5 |
| Lack of incentive from the government for developers | 0.758 | 6 |
| Lack of incentive from the government to owners for existing building | 0.752 | 7 |
| Lack of knowledge | 0.748 | 8 |
| Lack of awareness about sustainable environment/benefits | 0.746 | 9 |
| Increase in structural loading | 0.744 | 10 |
| Construction difficulties | 0.744 | 11 |
| Not included in the building code | 0.738 | 12 |
| Difficulties in design | 0.724 | 13 |
| Lack of expertise/skilled manpower | 0.724 | 14 |

At the forefront of the list in Table 5 is the "high/additional construction cost" barrier, marked by a substantial RII value of 0.820. This high score underscores the financial burden of implementing green roofs in the country. Such costs include not only the initial construction expenses but also ongoing maintenance and potential adjustments to existing building designs. This financial concern is mirrored by the adjacent barrier, "high/increase in maintenance cost", which earns an RII value of 0.802. This emphasizes the long-term financial commitment required for maintaining green roofs and reflects a consistent theme of financial constraints throughout the barriers.

The "lack of owner/client interest" barrier comes next, with an RII value of 0.798. This highlights the importance of fostering awareness and understanding among building owners and clients about the benefits of green roofs. Demonstrating the advantages of energy efficiency, aesthetics, and environmental impact could stimulate more interest and support for their implementation. Beyond financial concerns, other noteworthy barriers include the "require regular maintenance" issue, which carries an RII value of 0.782. This emphasizes the need for consistent and meticulous upkeep to ensure the long-term success of green roofs. On the regulatory front, barriers such as "not included in the building code" (RII: 0.738) and "lack of incentive from the government for developers" (RII: 0.758) underscore the need for policy support and standardized guidelines to encourage green roof implementation. Interestingly, the barriers associated with knowledge and awareness, such as "lack of knowledge" (RII: 0.748) and "lack of awareness about sustainable environment/benefits" (RII: 0.746), though slightly lower in RII values, still indicate their significance. This suggests that enhancing education and communication efforts about the advantages of green roofs could play a pivotal role in overcoming multiple barriers simultaneously. In conclusion, the RII values in Table 5 highlight the hierarchy of barriers to implementing green roofs in Malaysia and emphasize the interconnected nature of these barriers. Addressing these issues requires a multi-faceted approach encompassing financial strategies, regulatory frameworks, awareness campaigns, and educational initiatives. The insights derived from the RII values can guide policymakers, architects, and stakeholders in devising effective strategies to promote successful and widespread green roof implementation nationwide.

### *3.2. The Feasibility and Support for Green Roofs*

In addition, this study aimed to analyze the sample's degree of knowledge about implementing green roofs in Malaysian buildings. The survey results indicate that a significant portion of the respondents, 17%, expressed their lack of familiarity with green roofs. Similarly, when asked about the frequency of encountering green roofs in Malaysia, 30% of the participants disagreed, suggesting that they do not come across green roofs often in the country. These findings highlight the need for further awareness and promotion of green roofs in Malaysia to enhance their visibility and understanding among the population.

Furthermore, the survey results reveal an overwhelmingly positive response toward green roofs among the participants. A significant 72% of the respondents have been involved in projects incorporating green roofs, indicating a considerable level of experience and engagement in such initiatives. Furthermore, an overwhelming majority of 98% of the participants agree that the government should actively promote green roofs in Malaysia. This high level of support from the public suggests a strong desire for sustainable and eco-friendly practices in the country's building and urban development. Additionally, the survey indicates a near-unanimous consensus on the feasibility of implementing green roofs for existing and new buildings. An impressive 99% of the respondents agree that green roofs can be successfully integrated into existing buildings, showcasing their potential as a viable option for retrofitting urban structures. Equally, 99% agree that incorporating green roofs in newly developing buildings is a practical and feasible approach to promoting sustainability in urban planning and the built environment. The support for green roofs is further reinforced by 98% of the participants expressing their approval. This high level of endorsement reflects a strong inclination towards sustainable and environmentally

friendly building practices. Lastly, an overwhelming 99% of the respondents favor constructing green roofs on the buildings where they live, signaling a keen interest in personal involvement and commitment to green initiatives. This sentiment indicates a willingness among residents to embrace green roofs as a viable option for enhancing the environmental sustainability and overall livability of their living spaces.

## 4. Discussion

The analysis of survey data on barriers hindering the implementation of green roofs in Malaysia, using both normalization and the Relative Importance Index (RII) methods, has revealed insightful findings. This study has identified three key barriers to implementing green roofs on buildings in Malaysia: "high/additional construction cost", "high/increase in maintenance cost", and "lack of owner/client interest". These findings collectively shed light on the complex dynamics surrounding the implementation of green roofs in Malaysia. The consistency between the RII values, mean scores, and normalized values across these top-ranked barriers underscores their significance in influencing decisions related to green roof implementation. Policymakers, urban planners, architects, and stakeholders interested in promoting sustainable building practices can leverage these findings to devise targeted strategies. Addressing these barriers might involve a combination of financial incentives, educational/awareness campaigns, innovative construction practices, and collaborative efforts to change perceptions and priorities. Ultimately, overcoming these barriers can pave the way for a more environmentally friendly and sustainable built environment in Malaysia. The findings are explained as follows.

### *4.1. High/Additional Construction Cost*

According to the results, the "high/additional construction cost" has been ranked as the top barrier and is widely acknowledged as the most significant barrier to implementing green roofs in Malaysia. This barrier has emerged as the most significant barrier with an RII value of 0.820. The corresponding mean score of 4.10 indicates that survey participants, on average, perceive the additional construction cost associated with green roofs as a major impediment. The relatively low standard deviation (SD) of 0.798 suggests a relatively consistent agreement among respondents regarding this barrier. The normalized value (NV) of 0.700 indicates that this barrier also had a relatively high score. The consistent alignment of these metrics underscores the significance of financial concerns in implementing green roofs. The high RII value implies that this barrier is substantial and warrants careful attention to promote green roof implementation.

Although the construction cost is a one-off [21], integrating green roofs during the construction phase often involves additional expenses, including installing specialized materials, waterproofing systems, and irrigation infrastructure [42]. These added costs can be perceived as a significant financial burden for developers, builders, and property owners. Given the competitive nature of the building industry, stakeholders may prioritize cost-saving measures, which can lead to green roof initiatives being overlooked or excluded from building plans. Furthermore, although green roofs offer numerous long-term environmental and energy-saving benefits, the initial investment required for their installation might not yield immediate financial returns. Building owners and developers often focus on short-term profitability and may hesitate to allocate resources for projects with a more extended payback period. This short-sighted approach can hinder the widespread implementation of green roofs despite their potential for cost savings and environmental advantages in the long run. Similarly, the barrier is also a common barrier to implementing green roofs in urban China, as revealed by Chen et al. [21]. In both countries, there might be limited awareness and understanding of the long-term benefits of green roofs. Stakeholders, including building owners, developers, and even regulatory authorities, might not fully comprehend the potential cost savings and environmental advantages of green roofs. This lack of awareness can lead to underestimating the overall value of such sustainable building features.

### 4.2. High/Increase in Maintenance Cost

Following closely is the barrier related to an increase in maintenance costs, with an RII value of 0.802. The mean score of 4.01 indicates that respondents perceive ongoing maintenance expenses as noteworthy. The slightly higher SD of 0.858 suggests that although the overall perception is relatively consistent, there might be some variability in individual opinions. The NV of 0.750 indicates a moderate raw score for this barrier. The RII value reinforces the significance of long-term costs as a potential deterrent to implementing green roofs. This finding highlights the need for strategies to address and mitigate these maintenance-related concerns.

Green roofs require regular maintenance to ensure their optimal performance and longevity. This finding aligns with previous works by Chen et al. [21] and Zhang et al. [20], which identified maintenance cost as a key barrier to implementing green roofs on buildings in China and Hong Kong. The additional maintenance activities, such as irrigation, pruning, and pest control, incur ongoing costs for building owners and managers. This increase in maintenance expenses can be perceived as a significant financial burden, especially if building stakeholders are not adequately prepared for the ongoing costs [21]. Implementing green roofs is a long-term investment in sustainable building practices. However, building owners and managers not prepared for the ongoing maintenance commitment may perceive it as a liability rather than an asset. The reluctance to commit to long-term maintenance can lead to neglect and diminished benefits from green roofs over time. In addition, the financial benefits of green roofs, such as energy savings and improved building insulation, often manifest over the long term. However, the immediate costs associated with maintenance might overshadow the long-term advantages, affecting the perceived return on investment (ROI) for building owners. This skewed perception of ROI can hinder the widespread implementation of green roofs.

### 4.3. Lack of Owner/Client Interest

The third-ranked barrier, lack of owner/client interest, carries an RII value of 0.798. With a mean score of 3.99, it is evident that respondents recognize a lack of enthusiasm or awareness among building owners or clients regarding green roofs. The higher SD of 0.870 suggests a relatively broader range of opinions compared to the previous two barriers. The NV of 0.750 reflects a moderate raw score for this barrier. The RII value indicates that although this barrier is significant, it is slightly less pronounced than the previous two barriers. Nevertheless, the finding points to the importance of education, outreach, and advocacy efforts to increase awareness about the benefits of green roofs.

Many building owners and clients may have limited awareness and understanding of the benefits and value of green roofs. Green roofs offer numerous advantages, such as energy savings [15], improved building insulation, and enhanced aesthetics. However, if these benefits are not effectively communicated, potential adopters may not perceive green roofs as valuable investments. The lack of knowledge about the long-term benefits and the absence of a genuine acknowledgment of the presence of public green spaces [47] may lead to a lack of interest in incorporating green roofs into building projects. Moreover, Pratama et al. [17] have emphasized that within ASEAN countries, raising public awareness about green roofs remains the most formidable barrier to their implementation. This lack of awareness could lead to diminished interest among property owners or clients. This finding corresponds with the outcomes of the perception survey carried out in this study, wherein 17% of participants expressed unfamiliarity with green roofs. Similarly, 30% of the participants reported infrequent encounters with green roofs in the country.

### 4.4. Feasibility of Green Roofs

In terms of feasibility, the survey results were remarkably positive. A vast majority of 99% of the respondents agreed that green roofs are feasible for existing buildings and new buildings. This indicates a high level of confidence in the practicality and viability of green roofs in various scenarios. The respondents' support for implementing green roofs

was also overwhelming, with 98% agreeing. This demonstrates a widespread endorsement of green roof initiatives and their potential contributions to environmental sustainability and urban resilience. Moreover, an overwhelming 99% of the participants indicated their willingness to support the construction of green roofs on the building where they live, signifying strong personal support and enthusiasm for incorporating green roofs into their immediate living environments.

### 4.5. Study Implications

The findings of this study, which focus on the barriers of "high/additional construction cost", "high/increase in maintenance cost", and "lack of owner/client interest" in implementing green roofs in Malaysia, offer valuable insights that complement and enrich the barriers identified in previous works by Mustaffa et al. [25], Chee et al. [26], Rahim et al. [27], Esa et al. [28], Chow and Abu Bakar [29], Ismail et al. [30], and Zahir et al. [31]. By examining these barriers in conjunction with the prior findings, a more comprehensive and nuanced understanding of the barriers to implementing green roofs in Malaysia can emerge.

To address the barriers posed by the elevated construction and maintenance costs associated with implementing green roofs, a series of strategic approaches can be adopted by local authorities. Firstly, a prudent choice of materials can significantly impact cost considerations [10]. Opting for locally sourced and readily available materials that align with specific climatic conditions can lower material costs. Additionally, selecting plant species that thrive in the local environment and require minimal maintenance can curtail ongoing upkeep expenses [48]. This strategic plant selection also diminishes the need for extensive irrigation, further reducing operational costs over time.

Moreover, the utilization of waste materials presents a compelling strategy to significantly reduce the construction costs associated with implementing green roofs. By repurposing waste materials that would otherwise require disposal, construction projects can tap into cost-effective alternatives for crucial components of green roof systems. For instance, discarded or recycled materials such as crushed concrete, reclaimed wood, and industrial byproducts can serve as lightweight and durable substrates, drainage layers, and even planting mediums [8]. This not only diminishes the need for purchasing expensive, conventional materials but also minimizes waste disposal expenses. Additionally, the integration of waste materials aligns with sustainable practices, contributing to the overall environmental and financial viability of green roof projects. As a result, the strategic incorporation of waste materials lowers upfront construction expenses and reflects a forward-thinking approach that underscores the economic benefits of resourcefulness within the realm of green roof implementation. Additionally, the incorporation of waste and recycled materials aligns seamlessly with sustainable practices, amplifying the overall environmental and financial viability of green roof initiatives. This approach echoes a resource-efficient philosophy that resonates with the push for waste and recycled materials adoption, as endorsed in prominent guidelines such as the Green Building Index (GBI) and the Green Technology Master Plan (GTMP). By promoting the use of waste and recycled materials in the construction of green roofs, these policies recognize the multifaceted benefits, ranging from cost savings to waste reduction and environmental conservation. As such, the strategic embrace of waste materials drives down construction expenditures and underscores a proactive stance in promoting sustainable construction practices, aligning coherently with the objectives articulated in influential frameworks such as the GBI and GTMP.

On the contrary, maintenance planning is equally vital in cost mitigation. Crafting a detailed and structured maintenance plan during the early stages ensures that upkeep is consistent and preventative, preventing more substantial and costly repairs. Training maintenance personnel to understand the unique demands of green roofs can also be cost-effective. A knowledgeable maintenance crew can carry out routine tasks effectively, potentially reducing reliance on external contractors for specialized services.

The current study's focus on owner and client interest highlights the crucial role that awareness and education play in driving demand for green roofs. The Malaysian government has undertaken a comprehensive initiative to promote green practices and sustainable development, spanning multiple periods including the Tenth Malaysia Plan, Eleventh Malaysia Plan, and the Twelfth Malaysia Plan. This commitment is exemplified by the establishment of the National Green Technology Policy (NGTP) in 2009, which has spurred various measures to foster green development [25]. These measures encompass a range of initiatives such as green incentives, financing schemes, procurement strategies, and the introduction of green rating systems such as the Green Building Index (GBI). These systems evaluate the environmental impact and performance of buildings, townships, and infrastructure projects. Notably, the Green Technology Financing Scheme (GTFS) was introduced in 2010 to encourage involvement in green technology-based projects, renewable energy, recycling, and waste management initiatives. Moreover, income tax exemptions, import duty, sales tax exemptions, and investment tax allowances have been introduced to incentivize green development. The "MyHijau" program, launched in 2012, is a platform for businesses to promote eco-friendly products and services, further advancing the country's aspirations for environmentally conscious practices [25]. Nevertheless, even with the government's introduction of initiatives and incentives, there remains a limited level of enthusiasm among property owners and clients to embrace the implementation of green roofs. Therefore, local authorities should launch comprehensive awareness campaigns to educate property owners and clients about the multifaceted benefits of green roofs. Here, the local authorities should not only highlight the environmental advantages but also the potential long-term cost savings and improved property value.

Overall, the survey results demonstrate a high level of awareness, support, and optimism toward green roofs among the respondents. The overwhelmingly positive responses on feasibility, support for implementation, and personal willingness to have green roofs on their buildings underscore the potential for further growth and promotion of green roof projects in Malaysia. These findings can serve as a valuable reference for policymakers, urban planners, and stakeholders in the building industry to develop targeted strategies and initiatives to advance the implementation of green roofs and foster a more sustainable and eco-friendlier built environment in Malaysia.

## 5. Conclusions

Numerous barriers hinder the promotion of green roofs in both existing and new buildings in Malaysia. This study aimed to identify the most encountered barriers. The top three key barriers are highlighted as "high/additional construction cost", "high/increase in maintenance cost" and "lack of owner/client interest". These barriers were found to persist throughout the entire building life cycle, affecting the planning and design, construction and operation, and management stages. The paper's analysis provides substantial evidence supporting these findings. The overwhelmingly positive response from the survey participants underscores the need for further advocacy and implementation of green roof projects to drive positive environmental change and enhance the resilience of urban areas. As the world increasingly faces environmental challenges, the widespread enthusiasm for green roofs offers promising prospects for a greener and more sustainable future.

This study has paved the way for meaningful change, yet the journey toward more sustainable urban development remains ongoing. To further elevate the impact of this study, several future research avenues are proposed. Future research endeavors could delve into an in-depth analysis of context-specific barriers to green roof implementation in Malaysia. The study could encompass barriers stemming from the tropical climate, local building regulations, the availability of suitable vegetation, and the influence of cultural factors. Investigating these barriers would contribute to a comprehensive understanding of the hurdles faced in the Malaysian context and offer practical insights for stakeholders engaged in sustainable urban planning and development. In addition, future research could showcase successful green roof projects within Malaysia or other regions with

similar contexts. Analyzing case studies and identifying best practices could provide practical guidance for overcoming barriers and achieving successful outcomes in green roof implementation.

Furthermore, future research is necessary to identify effective critical success factors (CSFs) for overcoming the key barriers uncovered in this study. By addressing these barriers, Malaysia is anticipated to establish a green built environment, fostering the widespread implementation of extensive green roofs. The study offers compelling evidence underscoring the importance of finding solutions to mitigate the barriers surrounding the utilization of green roofs, thus contributing significantly to creating a sustainable urban environment.

Nevertheless, the study focuses on specific regions or urban areas within Malaysia, which could lead to results that might not be universally applicable to the entire country due to varying environmental, climatic, and socioeconomic conditions. Additionally, the study's scope might not encompass all possible barriers and feasibility factors, potentially overlooking certain crucial aspects that could influence the successful implementation of green roofs in diverse contexts across Malaysia. Therefore, although the study provides valuable insights, its findings should be interpreted within the context of the selected geographical areas and factors considered, recognizing the need for further research to validate the applicability of its conclusions on a broader scale. Another limitation of the study could be its potential underrepresentation of local community perspectives. Although the study might extensively analyze technical, economic, and environmental aspects, it might not thoroughly capture the opinions, preferences, and cultural nuances of the people who would be directly impacted by the implementation of green roofs. Neglecting the insights and concerns of the local community members could result in an incomplete understanding of the practical barriers and acceptance of green roofs within the Malaysian context. Therefore, to gain a more holistic understanding of the barriers and feasibility, future research should consider incorporating qualitative methods that delve into the social dynamics and community viewpoints to ensure a well-rounded evaluation of the potential implementation.

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