Kulasekara, G., Mallawaarachchi, B.H. and Damsari, A.G.U., 2023. Assessment of design and construction related factors influencing maintainability of green roofs: A case of high-rise buildings in Sri Lanka. In: Sandanayake, Y.G., Waidyasekara, K.G.A.S., Ramachandra, T. and Ranadewa, K.A.T.O. (eds). *Proceedings of the 11th World Construction Symposium*, 21-22 July 2023, Sri Lanka. [Online]. pp. 250-259. DOI: https://doi.org/10.31705/WCS.2023.21. Available from: https://ciobwcs.com/papers/

ASSESSMENT OF DESIGN AND CONSTRUCTION RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS: A CASE OF HIGH-RISE BUILDINGS IN SRI LANKA

G. Kulasekara[1], B.H. Mallawaarachchi[2] and A.G.U. Damsari,[3]

ABSTRACT

Poor design and construction practices can significantly impact the future maintainability of green roofs in high-rise buildings. While previous studies have focused on green roof construction and design features, this research specifically evaluates the effects of design and construction related factors on maintainability of green roofs, with a focus on high-rise buildings in Sri Lanka. The study begins by reviewing literature on green roofs, their maintainability, and the design and construction factors that influence maintainability. The identified factors were used as a basis for evaluating the effects of design and construction on future maintainability of green roofs. A deductive approach is adopted within a quantitative research design, utilising a survey strategy. A questionnaire survey was conducted among 58 experienced construction professionals, while four expert interviews are conducted to gather additional insights. Data analysis techniques include the Relative Importance Index and content analysis. As derived through analysis, initial cost and roof design were identified as design-related key factors, while cost of construction and availability of machinery and materials were the construction related key factors influencing maintainability of green roofs. Accordingly, the study proposed strategies to enhance the maintainability of green roofs in Sri Lankan high-rise buildings focusing on cost effectiveness, design effectiveness and effective management of green roofs. As a main implication, this research contributes to the development of sustainable and maintainable green roofs in Sri Lanka by providing valuable insights for the construction professionals and policy makers in the country.

Keywords: *Design and Construction; Green Roofs; High-rise Buildings; Maintainability.*

1. INTRODUCTION

The construction industry has a significant impact on the environment, and the building sector has a strong potential to protect it (Sandanayake, 2022). Sustainable construction aims to minimise the environmental impact of a building throughout its lifespan, while

[1] Undergraduate student, Department of Quantity Surveying, University of Vocational Technology, kulasekarammg@gmail.com
[2] Senior Lecturer, Department of Facilities Management, University of Moratuwa, harshinim@uom.lk
[3] Lecturer, Department of Facilities Management, University of Moratuwa, udatharadamsari@gmail.com

also improving its economic viability, comfort, and safety (Mahamadu et al., 2016). The principles of sustainable construction have been divided into four pillars: social, economic, biophysical, and technological. According to Vidyaratne and Melagoda (2018), green roofs, which are becoming increasingly popular in Sri Lankan high-rise building and it has gained increasing attention as a sustainable solution for development projects, as they offer numerous environmental benefits such as reducing energy consumption, mitigating the urban heat island effect, and improving air quality. However, poor design and construction can significantly impact the future maintainability of green roofs (Mohanta & Das, 2022). Moreover, one of the critical aspects that need to be addressed is the future maintainability of green roofs, particularly in high-rise buildings (Chew et al., 2019). The maintainability of green roofs refers to the ease of maintenance and the ability to sustain the desired functionality over time. However, the challenge of maintainability is more significant in high-rise buildings due to the added complexities associated with access, logistics, and safety (Ganisen et al., 2015). Therefore, enhancing the maintainability of green roof construction is important since Sri Lanka's construction industry is booming, with luxury apartments, hotels, and shopping complexes being developed in the city and suburbs (Pathirana & Munasinghe, 2021). Further, the government is also promoting sustainable construction to minimise the industry's impact on the environment.

Considering above, this research aimed to evaluate the effect of design and construction on future maintainability of green roofs specialising the high-rise buildings in Sri Lanka. Accordingly, two objectives were formulated:

I. To identify design and construction related factors influencing maintainability of green roofs,

II. To determine the significant design and construction related factors influencing maintainability of green roofs of high-rise buildings in Sri Lanka, and

III. To propose strategies to enhance the future maintainability of green roofs of high-rise buildings in Sri Lanka.

By developing an understanding of the critical factors affecting the maintainability of green roofs, this research will contribute to the development of sustainable and maintainable green roofs in Sri Lanka.

2. LITERTAURE REVIEW

Green roof has been proposed as the sustainable practice to mitigate the adverse effects of urbanisation (Huang & Poullain, 2011). A green roof is a vegetative layer that is intentionally installed on top of a building's roof, either partially or fully, to provide environmental benefits such as reducing urban heat island effect, managing storm water runoff, improving air quality, and reducing energy consumption (Huang & Poullain, 2011). It typically includes a waterproofing layer, a drainage layer, a filter layer, a growing medium, and vegetation. Green roofs properly designed, constructed and maintained, are beneficial socially, environmentally and fiscally (Meulen, 2019).

The green roof operation and maintenance system is considered to be an observable factor, and the lack of maintenance seems to be an additional challenge to the green roof implementation as the roof garden may not function as expected. Maintenance capability is one of the most important factors to consider when designing a building, as it is

essential to maximise the overall performance of the building, including quality and cost (Ganisen et al., 2015).

2.1 MAINTAINABILITY OF GREEN ROOFS

Maintainability of green roofs is an essential factor that determines the success of a green roof project in the long term. Maintainability refers to the ease and effectiveness with which a system, product, or process can be maintained or repaired over time (Wang et al., 2016). It is a measure of how easily and quickly maintenance tasks can be performed, how often maintenance is required, and how much effort and resources are needed to keep the system or product in good working condition. Green roofs require regular maintenance to ensure that they remain healthy and functional (Cascone, 2019). Proper maintenance is necessary to prevent damage, enhance the longevity of the roof, and maximise the environmental benefits that green roofs provide.

2.2 FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS

Considerations of the maintenance management of a facility at the planning and design stage are of utmost importance for the facility's future performance attributes and life cycle cost management (Samaraweera & Gunawardhana, 2020). The demand for modern facilities to strive for higher performance standards means that prudent decisions must be made at the planning and design stage, as they will have a residual effect and vital impact on the facility's future maintainability. Accordingly, the factors that influence the maintainability of green roofs can be broadly categorised into design-related factors and construction-related factors.

2.2.1 Design Related Factors (DRFs) Influencing Maintainability of Green Roofs

Design related factors (DRFs) can significantly impact the ease of maintenance, the cost of maintenance, and the longevity of green roofs (Allnut et al., 2014). Lack of attention to maintainability considerations at the design stage may lead to difficult and costly operation to users; hence users' expectation may not be achieved (Huang & Poullain, 2011). It is crucial to identify and address these DRFs during the initial design phase to ensure the long-term maintainability and sustainability of green roofs. By doing so, it can significantly reduce the cost and effort required to maintain green roofs, making them a more viable and sustainable option for high rise buildings. Table 1 identifies the DRFs that can influence the maintainability of green roofs.

Table 1: Design related factors influencing maintainability of green roofs

Factor Code	Factor	Sources
DRF1	Initial cost	[1] [4]
DRF2	Roof design	[3] [4]
DRF3	Roof structure's lifespan	[4]
DRF4	Design parameters	[2] [3] [4]
DRF5	Material & physical properties	[2] [4] [5]
DRF6	Wastage percentage	[4] [5]
DRF7	Available technological aspects	[3] [4]
Sources:	[1] (Alattyih et al., 2020); [2] (Cascone, 2019); [3] (Chew et al., 2019); [4] (Conejos & Chew, 2020); [5] (Klein, 2018)	

Under DRF4, it has been focused about irrigation system, drainage system, wind exposure and sun exposure conditions when designing a green roof. Apart from that, plant type and soil condition have been considered under DRF4. These factors play a significant role in determining the ease of maintenance, cost of maintenance, and longevity of green roofs. For example, DRF1, which refers to the initial cost, can indirectly influence maintainability (Alattyih et al., 2020). Higher initial costs may allow for the integration of more advanced technologies and efficient design features that can simplify future maintenance tasks. Similarly, DRF2, which pertains to roof design, can influence the accessibility of different roof areas, making maintenance activities easier or more challenging (Chew et al., 2019). By considering these factors, it is possible to design green roofs that are not only aesthetically pleasing but also easy to maintain and sustain over the long term.

In the context of high-rise buildings, specific design considerations may be required to address the unique challenges associated with their height and structural complexity (Vidyaratne & Melagoda, 2018). These considerations may include safe access points for maintenance personnel, efficient water and drainage systems, and appropriate plant selection that can withstand the exposure to wind and sun at greater heights. By incorporating these design-related factors into the planning and design of green roofs in high-rise buildings, their maintainability can be enhanced.

2.2.2 Construction Related Factors (CRFs) Influencing Maintainability of Green Roofs

Construction related factors (CRFs) play a crucial role in the maintenance of green roofs, and their influence should be considered during the planning and installation phases (Conejos & Chew, 2020). In this context, this paper identifies some of the key CRFs that influence the maintainability of green roofs as shown in Table 2.

Table 2: Construction related factors influencing maintainability of green roofs

Factor Code	Factor	Sources
CRF1	Structure and weight of the roof	[1] [3] [5]
CRF2	Cost of the construction	[1] [2] [3]
CRF3	Availability of machinery and materials	[1] [3] [4]
CRF4	Availability of experts related to green roof construction	[3] [4]
CRF5	Risk factors in green roof construction	[1] [3] [6]
CRF6	Rules and regulations	[1] [3]
CRF7	Availability of labour and technology	[3] [4]
Sources:	[1] (Allnut et al., 2014); [2] (Blackhurst et al., 2010); [3] (Carpenter, 2014); [4] (Cascone, 2019); [5] (Rabe, 2013); [6] (Vidyaratne & Melagoda, 2018)	

According to Table 2, considering these CRFs during the design and installation of green roofs can help ensure that they are easy to maintain and provide long-lasting benefits. For example, CRF1, which refers to the structure and weight of the roof, can influence the overall stability and load-bearing capacity of the green roof. Adequate structural support is essential for the long-term maintenance of the green roof in high-rise buildings (Allnut et al., 2014). Similarly, CRF5, which relates to risk factors in green roof construction, is particularly relevant to high-rise buildings (Carpenter, 2014). The construction process at

greater heights may involve additional safety measures and precautions to protect both workers and the green roof itself. According to Vidyaratne and Melagoda (2018), to achieve the maintainability complications specific to high-rise buildings, it is essential to consider the unique challenges posed by their height, accessibility, and exposure to environmental elements. This may include incorporating advanced irrigation and drainage systems, employing specialised equipment for maintenance tasks at heights, and implementing monitoring systems to detect and address issues promptly. Addition to that, under the CRF5, there are several types of risk factors that influence the construction and maintainability of green roofs such as structural risk, vegetation risk, maintenance access risk, climate risk, health and safety risk, and waterproofing and leakage risk (Intact Public Entities Incorporation, 2021). Since all these factors affect to the maintainability of green roofs, CRF5 includes all these risk types, highlighting the importance of considering and mitigating these risks during the construction phase of green roofs. In summary, DRFs focus on the planning and design of the green roof, while CRFs focus on the installation and construction phase. Both design-related and construction-related factors are important in ensuring the maintainability of green roofs.

3. RESEARCH METHODOLOGY

This section outlines the research methodology adopted to achieve the aim of developing an effective design and construction strategy for enhancing the future maintainability of green roofs of high-rise buildings in Sri Lanka. The deductive research approach under quantitative research design was adopted for this study as it enables the researcher to quantify the factors influencing the maintainability of green roofs. Survey approach was adapted as the suitable research strategy.

Data collection for this study was done mainly through a questionnaire survey, which was focused on identifying the most significant factors influencing maintainability of green roofs which are associated to design and construction stages. Under the questionnaire survey, Likert scale method was included to identify the DRF and CRF significance level to maintainability of green roofs in Sri Lankan high-rise buildings. The questionnaire was distributed among eighty (80) construction professionals, such as Architects, Engineers, Quantity Surveyors, Project Managers and Facility Managers, who are working in building construction projects in Sri Lanka. The sample of respondents were selected by adopting convenient sampling technique. From 80 distributed questionnaires, 58 were collected with the response rate of 74%. Additionally, 04 expert interviews were conducted with selected respondents to identify strategies to enhance the future maintainability of green roofs. The collected data were analysed by using Relative Important Index (RII) and content analysis techniques.

RII is a type of relative importance analysis that is used to find out the amount of contribution made by a particular variable to the prediction of a criterion variable both by itself and in combination with other predictor variables (Rajgor et al., 2016). Figure 1 shows the formula used to calculate the RII.

$$RII = \frac{\sum(W \times n)}{(N \times A)} \qquad (01)$$

where, W= Weight given by each factor by respondents, n=Frequency of responses, A=highest weight, N= Total frequency of responses (total number of respondents)

Expert interviews were conducted to explore the strategies for enhancing the future maintainability of green roofs in high-rise buildings in Sri Lanka. Semi-structured interviews were conducted with four experts in Sri Lankan construction industry with expertise in green design and construction. Under the semi structured interviews, experts were questioned based on their experiences of maintaining green roofs in high rise buildings and gathered their ideas to improve the maintainability of green roofs. Table 3 presents the profile of expert interviewees.

Table 3: Respondent profile of expert interviews

Code	Interviewee	Experience (Years)
R1	Quantity Surveyor	10
R2	Project Manager	15
R3	Project Engineer	10
R4	Resident Manager	20

Content analysis technique was used to analyse the data collected through expert interviews.

Data analysis and key research findings are presented below.

4. DATA ANALYSIS AND FINDINGS

As per the factors identified under the literature review, this section identifies the critical design related and construction related factors influencing maintainability of green roofs in the context of high-rise buildings in Sri Lanka by analysing the relative importance of the factors. Finally, strategies were proposed by considering the critical DRFs and CRFs related to the maintainability of green roofs.

4.1 DESIGN RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

Factors identified under Table 1 are ranked as per the relative importance as shown in Table 4. Design-related factors (DRFs) are key considerations that influence the maintainability of green roofs. This section focuses on ranking the DRFs that have the most significant impact on the maintainability of green roofs in high-rise buildings in Sri Lanka. Through the use of a Relative Importance Index (RII), the study aims to provide valuable insights into the relative importance of these factors, enabling architects, engineers, and building professionals to make informed decisions during the design phase to enhance the maintainability and overall performance of green roofs.

Table 4: Ranking of DRFs as per RII

Factor Code	Factor	RII	Rank
DRF1	Initial cost	0.814	1
DRF2	Roof design	0.800	2
DRF3	Roof structure's lifespan	0.790	3
DRF4	Design parameters	0.786	4
DRF5	Material & physical properties	0.783	5
DRF6	Wastage percentage	0.779	6
DRF7	Available technological aspects	0.745	7

According to Table 4, it is emphasised that the initial cost of the green roof obtained the highest rank (RII=0.814). During the green roof design stage, it is necessary to analyse the maintenance of water, waterproofing membrane, root barrier, drainage layer, filter layer, substrate, and plants. Green roofs involve various new aspects compared to conventional buildings, and initial investment costs need to be considered. The second rank with an RII of 0.800 was obtained by roof design where the lifespan of roof structure received the third (RII=0.79). Under these factors, it considers the load capacity, pitch, shading and rain shadow from adjacent structures, hot/cold air emissions from air conditioning units and other equipment, height of parapet walls, and safe access to install and maintain the green roofs. The fourth rank (RII=0.786) was obtained by the design parameters since it is important to analyse the suitability of the country's environmental impact during the green roof design. The fifth rank and sixth rank were obtained by the wastage percentage (RII=0.783) and available technological aspects (RII=0.779) respectively. Green roofs involve many new aspects compared to conventional roofs and the selection of sustainable materials for a particular design with appropriate physical properties is a necessary factor considered. The last rank (RII= 0.745) was obtained by the availability of machinery, tools, and computer-aided technology. Green roofs are a new concept in many countries, and some necessary tools and equipment may not be readily available.

4.2 CONSTRUCTION RELATED FACTORS INFLUENCING MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

Factors identified under Table 2 are ranked as per the relative importance as shown in Table 5. Construction-related factors (CRFs) are key considerations that influence the maintainability of green roofs. This study focuses on identifying and ranking the CRFs that have the most significant impact on the maintainability of green roofs in high-rise buildings in Sri Lanka. Through the use of a Relative Importance Index (RII), the study aims to provide valuable insights into the relative importance of these factors, enabling architects, engineers, and building professionals to make informed decisions during the design phase to enhance the maintainability and overall performance of green roofs.

Table 5: Ranking of CRFs as per RII

Factor Code	Factor	RII	Rank
CRF1	Structure and weight of the roof	0.790	3
CRF2	Cost of the construction	0.821	1
CRF3	Availability of machinery and materials	0.803	2
CRF4	Availability of experts related to green roof construction	0.786	4
CRF5	Risk factors in green roof construction	0.755	6
CRF6	Rules and regulations	0.769	5
CRF7	Availability of labour and technology	0.741	7

As per Table 5, the cost of constructing a green roof obtained the highest rank (RII=0.821), indicating that it is generally more expensive than traditional roofs due to the various types of membranes, water management systems, technical applications, and proportional involvement required. Availability of machinery and materials obtained the second rank (RII=0.803) since some roof applications and equipment may not be readily

available in the industry, and investors may need to import the required items as per their requirements. Structure and weight of the roof obtained the third rank (RII=0.790), while availability of experts related to green roof construction obtained the fourth rank (RII=0.786), as various new concepts and modern technology are applied in green roof construction, requiring the involvement of professionals like architects, engineers, and designers. Rules and regulations acquired the fifth rank (RII=0.769) as high-rise building construction may require special rules and regulations due to the location or security requirements.

Risk factors in green roof construction obtained the sixth rank (RII=0.755) since investors and construction firms in the country may be hesitant to invest in such projects due to the various risks and lack of experience. Finally, the availability of skilled labour and technological aspects in the country obtained the seventh rank (RII=0.741) as the shortage of skilled labour is one of the main issues in the construction industry currently. Accordingly, various strategies were proposed to enhance the maintainability of green roofs of high-rise buildings in Sri Lanka as described subsequently.

4.3 STRATEGIES OF ENHANCE THE MAINTAINABILITY OF GREEN ROOFS OF HIGH-RISE BUILDINGS IN SRI LANKA

As proposed by experts in the industry, various strategies are proposed under 03 key areas: (i) Cost effectiveness, (ii) Design effectiveness, and (iii) Effective management, to improve the maintainability of green roofs in Sri Lankan high-rise buildings. The categorisation of strategies was based on the recommendations and insights provided by experts in the industry. Through the expert interviews conducted as part of this research, professionals with extensive experience and knowledge in green roof construction and maintenance were consulted. These experts identified and suggested strategies that would contribute to enhancing the maintainability of green roofs in high-rise buildings in Sri Lanka. To ensure a comprehensive coverage of the various aspects influencing maintainability, the strategies were organised into these three categories. The categorisation allows for a systematic approach in addressing different factors that can impact the long-term viability and ease of maintenance of green roofs. Accordingly, Table 6 summarises the proposed strategies.

Table 6: Strategies to improve maintainability of green roofs in high rise buildings Sri Lanka

No	Strategies	R1	R2	R3	R4
1	***Cost effectiveness***				
1.1	Properly analysing about size and location of green roof	√	√	√	√
1.2	Select the most effective green roof installation system	√	-	√	√
1.3	Considering life cycle cost (LCC)	√	√	√	√
1.4	Properly analysing the usage of natural resources	√	√	√	√
2	***Design effectiveness***				
2.1	Considering load capacity of green roof systems	√	√	-	√
2.2	Considering reparability of green roof systems	√	√	√	√
2.3	Easy access to the roof	√	-	√	√
2.4	Effective space allocation for green roof	√	√	√	-
2.5	Storm water management	√	-	√	√
2.6	Selecting most suitable plants for the location	√	√	√	√

No	Strategies	R1	R2	R3	R4
3	***Effective management***				
3.1	Finding local and foreign material suppliers	√	-	√	√
3.2	Utilising experienced professionals and skilled man power	√	√	-	√
3.3	Using suitable machinery and equipment in installation	√	√	√	√

During an interview, most of the respondents emphasised the significance of minimising and controlling costs related to green roofs. They unanimously agreed that factors such as size, installation method, and life cycle cost are crucial for ensuring the maintainability of green roofs. Design effectiveness also affects to the maintainability of green roofs and all the experts have highlighted that system reparability and plant selection should be considered when designing the green roof in high-rise buildings. Moreover, majority of the respondents pinpointed the necessity of effective management to improve the maintainability of green roofs of high-rise buildings.

5. CONCLUSIONS

Sustainable construction aims to minimise the environmental impact of a building throughout its lifespan, while also improving its economic viability, comfort, and safety. Green roofs have gained increasing attention as a sustainable solution for development projects, as they offer numerous environmental benefits such as reducing energy consumption, mitigating the urban heat island effect, and improving air quality. However, poor design and construction can significantly impact the future maintainability of green roofs, particularly in high-rise buildings. The maintainability of green roofs refers to the ease of maintenance and the ability to sustain the desired functionality over time. In Sri Lanka, where the construction industry is booming, the government is promoting sustainable construction to minimise the industry's impact on the environment. This study explored the significant design and construction related factors influencing future maintainability of green roofs of high-rise buildings in Sri Lanka. As derived through analysis, initial cost and roof design have been identified as design related key factors, while cost of the construction and availability of machinery & materials were identified as the construction related key factors influencing to the maintainability of green roofs. Finally, various strategies were proposed to enhance the maintainability of green roofs of high-rise buildings in terms of their cost effectiveness, design effectiveness and effective management.

Since, green roofs are one of the effective strategic to reduce these adverse effects of high-rise buildings and provides several benefits to the environment and reduces the impact of the urbanisation, this study has shown that considerations of the maintainability of green roof in green buildings need to be given utmost attention at the design and construction stages. Thus, the outcomes of this study can be used as a basis to let construction professionals in the building industry as well as policy makers to take actions towards implementing a national level strategy for green roof construction in Sri Lanka.

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