

ADAPTATION OF DESIGN-FOR-MAINTAINABILITY FACTORS FOR GREEN WALLS IN GREEN BUILDINGS IN SRI LANKA

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Abstract. A Green Wall (GW) is an important green infrastructure element due to its numerous social, economic, and environmental benefits. However, in the Sri Lankan context, maintenance effectiveness of GW is often not adequately considered during the design stage. Poor maintenance practices and design-related maintenance challenges adversely affect a building's long-term sustainability and performance. Therefore, the Design for Maintainability (DfM) concept needs to be integrated from the early design stages of the GW to enhance maintainability, operational efficiency, and long-term environmental performance. This explores the adaptation of key factors that integrate DfM in the Green Wall System (GWS) within green certified buildings in Sri Lanka. A two-stage methodology was adopted. First, a comprehensive literature review was conducted to identify primary DfM factors, and semi-structured interviews were conducted with 12 experts to demonstrate the challenges of the GW maintenance in Sri Lanka. Qualitative content analysis was used to analyse the interview data, and expert responses were systematically converted into relative importance values to develop radar charts for factor comparison. The study identified five primary DfM factors applicable to the GW: structural, safety, cost, compliance, and environment, and secondary factors related to the GW. These insights provide valuable guidance for industry professionals to improve the design effectiveness and maintainability of GWs in Sri Lanka.

Keywords: *Design for Maintainability; Green Building; Green Wall; Maintainability; Sustainability*

1. Introduction

Integrating green infrastructure, such as a Green Wall (GW), is crucial for achieving economic, environmental, and social benefits (Umar et al., 2024). Teotónio et al. (2021) described that GWs are more important than green roofs because they can double the ground footprint of a building. Regular maintenance ensures the structural integrity and optimal performance of the Green Wall System (GWS) (Othman & Kamal, 2023). Maintainability, which is determined by the ease, cost, safety, and precision with which maintenance can be carried out (Sani et al., 2025), should be integrated early in GW design to address lifecycle-related challenges and ensure long-term performance (Chew et al., 2025). However, limited research has explicitly examined how the Design for Maintainability (DfM) principle can be effectively integrated into GW design, particularly within the Sri Lankan context. Therefore, this study aims to systematically identify and critically examine DfM factors affecting the long-term sustainability of GWs in the Sri Lankan context through expert insights.

2. Literature Review

2.1. OVERVIEW OF GREEN WALLS

GWs are also referred to as a Vertical Greening System (VGS), as they support plant growth on the building envelope with vertical structure, growing medium, and integrated irrigation (Manso & Castro-Gomes, 2014). GWs are primarily divided

into two categories: Green Facades (GF) and Living Walls (LW) (Van der Meulen, 2019). According to Farrokhirad (2020), GFs grow on climbing or hanging plants supported directly or indirectly by the building structure. Palermo and Turco (2020) identified that LWs comprise a modular and continuous system, including an irrigation system, growing media, and drainage systems. According to Palermo et al. (2023), the LWs are broadly classified based on the method of application of GWs. GFs are further subdivided into three main types: direct, indirect, and the flowerpot system (Farrokhirad, 2020).

LWs can be classified into four system types, namely the climber system, cassette system, planter box system (Chew & Conejos, 2016), and pocket system (Soon et al., 2016). The planter box system comprises modular planting boxes installed along a structural wall, allowing for organized vegetation growth (Dominici et al., 2022). Cassette systems utilize horizontally arranged, pre-planted containers assembled to form a continuous green surface (Goel et al., 2022). Climber systems support upward plant growth from ground level using a guiding structure (Chew & Conejos, 2016). According to Soon et al. (2016), the pocket system utilizes layered fabric substrates for lightweight installation. A continuous LW system utilizes permeable planting substrates separated from the structural wall by a framed void, enabling plant growth while improving system performance and ease of maintenance (Azkorra-Larrinaga et al., 2023). According to Farrokhirad (2020), the direct GF is directly attached to the structural wall and does not require a continuous support system; however, the indirect GF incorporates a separate support structure that increases system resistance. The flowerpots system involves hanging planted shrubs around the building as part of the façade to form a green curtain (Farrokhirad, 2020). Figure 1 illustrates the types of GWs commonly used in building applications.

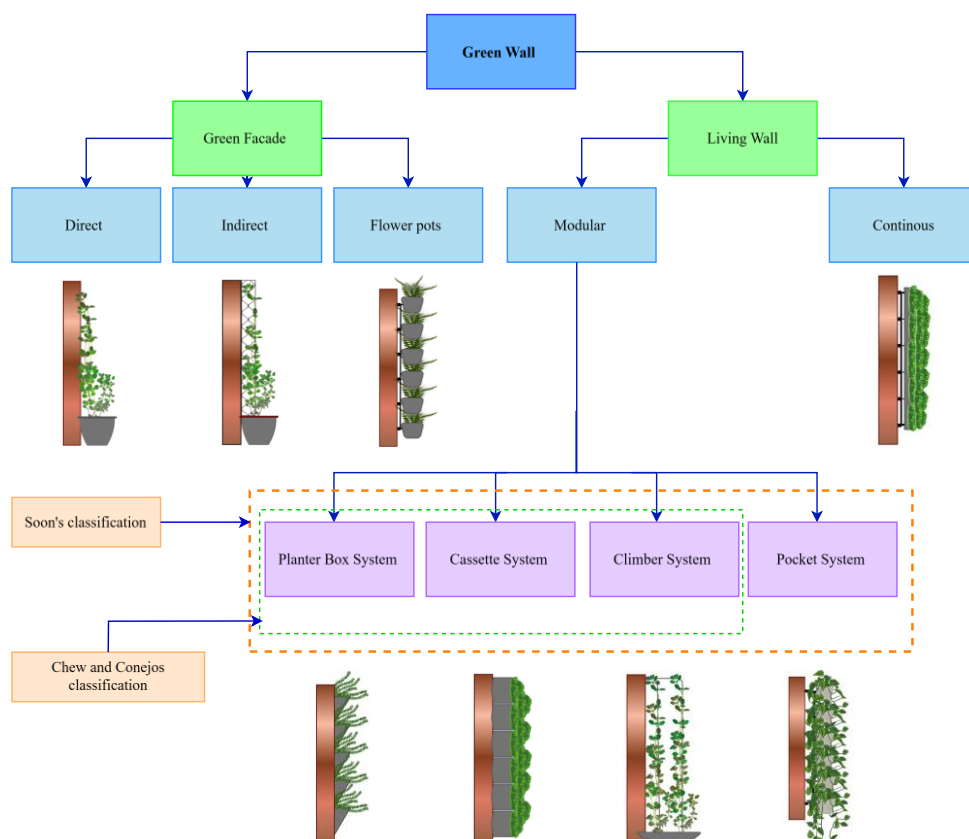


Figure 1, Classification of the GWS

The adaptation of GWs in Sri Lanka remains relatively limited compared to global implementation (Galagoda et al., 2018). The performance of GWs is strongly dependent on design quality, as improper design leads to increased maintenance difficulties, system failures, and reduced building service life (Implementation Guide-line Walls and Green Roofs in Vietnam, 2024).

2.2.1 Benefits of GWs

Different studies emphasize the benefits of GWs can only be sustained through effective maintenance practices (Goel et al., 2022). Table 1 summarizes the benefits of the GWS as identified in the literature by various authors.

Table 1 Summary of GWS benefits identified in the literature

Benefits	Authors						
	1	2	3	4	5	6	7
Thermal comfort	√	√	√		√		√
Reduce the heat island effect	√						
Energy efficiency	√	√	√				√
Acoustic comfort		√	√	√		√	
Indoor environmental quality		√	√		√	√	
Aesthetic appearance				√		√	
Improve Well-being				√	√	√	
Increase productivity				√			
Legend: √ = Benefit reported in the study							

Source: 1.Chew et al.(2019), 2.Shao et al. (2021), 3.De Silva et al. (2021), 4.Goel et al. (2022), 5.Shushunova & Korol (2023), 6.Farrokhirad & Gheitarani (2024), 7. Ahmadi et al. (2025)

2.2.2 Operational and Maintenance Challenges of Green Walls

The GWS faces significant limitations that impact its sustainability and scalability. Although GWs offer substantial environmental and aesthetic benefits, their practical implementation is hindered by technical, operational, environmental, and economic challenges, as outlined in Table 2.

Table 2 Summary of GWS challengers identified in the literature

Challengers	Authors				
	1	2	3	4	5
Irrigation failures		√	√		
Water leaks	√	√			√
Pest infestation			√	√	
Structural corrosion	√				
Lack of nutrients	√				
Limited accessibility			√		
Safety risk	√				
Complex system layout	√				√
Plant mortality			√		
Maintenance difficulties	√	√	√	√	

Lack of skilled labours				√	
High cost of maintenance	√		√	√	√
High cost of installation	√		√	√	√
Climate condition	√	√	√		

Source: Manso & Castro-Gomes (2015), 2. Segovia-Cardozo et al. (2019), 3. Wilkinson et al. (2021), 4. Madushika et al. (2022), 5. Perini & Rosasco (2013)

2.2. MAINTAINABILITY AND DESIGN FOR MAINTAINABILITY

Maintainability refers to the ease, safety, and cost-effectiveness with which maintenance activities can be performed to retain or restore system performance (Chew et al., 2018). Research consistently indicates that many maintenance issues arise due to inadequate consideration of maintainability during the design stage (Chew, 2021). Jaafar and Liyana Othman (2016) highlighted the importance of building maintainability in achieving cost savings and enhancing facility functionality. During the design stage, project designers have greater flexibility to incorporate changes that enhance building maintainability, improve accessibility, increase safety standards, and reduce both maintenance downtime and costs (Attobrah et al., 2021). Integrating maintainability aspects into the design stage helps to reduce building maintenance requirements in the building components (Othman & Kamal, 2022) and minimize long-term maintenance costs by reducing labour, time, and material expenditures required throughout a building’s life cycle (Sani et al., 2025). Moreover, DfM supports sustainability objectives by reducing construction resource consumption and minimizing replacement frequency, aligning with GB certification criteria (Weerasinghe et al., 2023). Seng and Husain (2025) identified that structural, safety, environmental, and cost factors are the main factors that influence the long-term sustainability of GW maintenance. Ultimately, DfM is more important for extending the life cycle and improving the occupants’ health, safety, and satisfaction (Lindström et al., 2024). Although previous studies have examined GW performance, maintenance challenges, and general design considerations, explicit attention to DfM, particularly within the Sri Lankan context, remains limited. This study synthesizes expert insights to identify and examine key maintainability-oriented design factors influencing the long-term performance and sustainability of GWs in Sri Lanka, aligning documented challenges with DfM factors to show how early design decisions can reduce long-term maintenance burdens.

3. Research Methodology

This study adopted a qualitative research approach to explore how DfM factors influence GWS performance in Sri Lanka. The methodology was developed to ensure both theoretical grounding and practical relevance by integrating insights from the literature with expert knowledge. The study was carried out in two main stages to address the research question. A comprehensive literature review was conducted to identify the primary DfM factors relevant to GW design. The outcomes of this stage facilitated the development of an initial list of maintainability-related design factors and guided the development of the subsequent data collection instrument. To capture context-specific insights and validate the applicability of the identified factors, semi-structured interviews were conducted with 12 experts in the field of GWs. A purposive sampling method was used to select the sample group, and participants were chosen based on their professional experience and knowledge of GWS in Sri

Lanka. The secondary factors were derived from the challenges experts faced during the maintenance and operation of GWs. The interview data were analyzed using qualitative content analysis. Expert responses were coded under the identified DfM factors. The Relative Importance Value (RIV) calculates the proportion of experts mentioned in each factor.

$$RIV = \frac{\text{Total mentions of the secondary factor}}{\text{Total mentions of all factors, primary factor}}$$

Microsoft Excel was used to organize and code the interview responses systematically, which facilitates the categorization and interpretation of qualitative data (Erlingsson & Brysiewicz, 2017). The profile of the interviewees is shown in Table 3.

Table 3 Profile of expert interviewees

Interview Code	Designation	Experience
P1	Supervisor – Landscaping	5 Years
P2	Engineer – Maintenance	10 Years
P3	Supervisor – Facilities management	5 Years
P4	Engineer – Mechanical	6 Years
P5	Supervisor – Landscaping	5 Years
P6	Engineer – Maintenance	10 Years
P7	Supervisor -Maintenance	9 Years
P8	Chief engineer	10 Years
P9	Engineer – Mechanical	6 Years
P10	Supervisor - Landscaping	5 Years
P11	Assistant - Maintenance Engineer	5 Years
P12	Executive – Environmental Sustainability	6 Years

This study employed an expert's judgment approach; therefore, sample adequacy was determined by the level of expertise rather than numerical size. The selected 12 experts collectively represent over 5 years of professional experience across GWs. During the interviews, responses began to repeat the same challenges, indicating data saturation. The remaining interviews confirmed consistency in expert judgement, supporting the adequacy of the sample size.

4. Research Findings

The literature review revealed that the primary DfM factors are design, safety, cost, compliance, and environmental. After the literature findings, the secondary factors revealed that maintenance challenges associated with the GWs could be systematically categorized into different categories. The frequency-based analysis of expert responses describes a strong consensus on the critical influence of DfM factors on long-term maintainability.

4.1 ANALYSIS AND DISCUSSION

Based on the literature review and expert findings, several DfM factors influencing GWS were identified. The key factors are categorized and summarized in Table 4.

Table 4 Summary of primary and secondary DfM factors

Primary factors	Secondary factors
Structural	durability, waterproofing, corrosion resistance, replacement ability, effective drainage, and expandability
Safety	accessibility, fall protection, adequate working space, hazard prevention, and easy inspection
Compliance	maintenance guidelines, checklist, and knowledgeable employees
Cost	initial cost, maintenance cost, replacement cost
Environmental	plant suitability, root growth control, soil condition, biological threats, and environmental stresses

The findings reveal that durability-related issues are one of the most critical considerations in the design and maintenance of GWS. All participants, P1-P12, identified structural durability as an important secondary parameter affecting system performance. Durable structural components enable GWS to withstand continuous exposures to environmental conditions while minimizing the need for frequent repair or replacement. However, the potential for system expandability and replaceability was also identified as receiving comparatively less attention.

Figure 2 illustrates the RIV of structural factors in GWS design and maintenance. Durability received the highest weighting (0.16), highlighting its critical role in ensuring long-term system performance under environmental exposure. Waterproofing, corrosion resistance, replacement ability, irrigation effectiveness, and drainage effectiveness were assigned equal moderate values (0.147), reflecting their collective contribution to structural reliability and plant health. Expandability was rated lowest (0.107), including the fact that scalability and future adaptability are comparatively less prioritized in the current implementation. The radar chart visually emphasizes durability as the dominant concern, while expandability remains underrepresented among structural considerations.

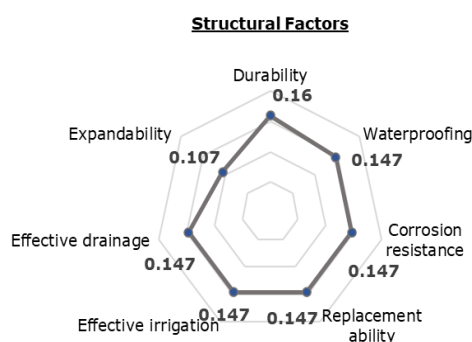


Figure 2 Relative Importance of Structural-Related DfM Factors for GW

Figure 3 presents the RIV of safety factors in GWS design. Accessibility (0.128) and hazard prevention (0.128) emerged as the most critical considerations, reflecting the need for safe user interaction and risk minimization. Adequate space (0.2) and ease of the inspection (0.2) were moderately emphasized, highlighting the importance of maintaining sufficient working areas and ensuring regular monitoring. Fall prevention (0.164) received comparatively lower weighting, suggesting that while important, it is less prioritized relative to other safety aspects. The radar chart

demonstrates that accessibility and hazard prevention dominant safety related concerns, whereas fall prevention is underrepresented in current implementations. The relative influence of these safety factors is present in Figure 3.

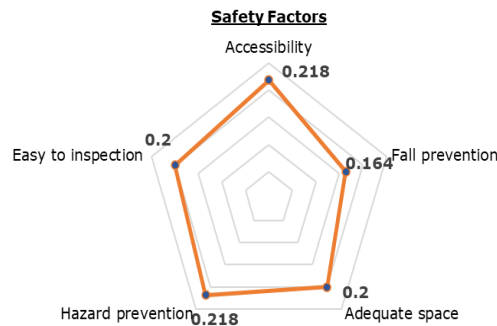


Figure 3 Relative Importance of Safety-Related DfM Factors for GW

Compliance-related factors were also identified as a significant contribution to the long-term maintainability of GWS. The findings highlighted the importance of knowledgeable personnel and structured maintenance practices to ensure system sustainability. All participants emphasized the role of skilled maintenance staff in conducting regular inspections, managing plant health, and identifying system defects. The results also highlighted the significant role of human expertise in maintaining GWS effectively (0.353). However, the emphasis on formal maintenance tools like checklists and standardized guidelines was less pronounced. The availability of knowledgeable in-house employees strongly influences maintainability, as skilled personnel can conduct proper inspections and maintenance and manage plant health. Checklists (0.324) and maintenance guidelines (0.324) contribute to system sustainability by standardizing maintenance procedures, while knowledgeable employees (0.353) play the most significant role in ensuring compliance and effective implementation. The comparative significance of these factors is shown in Figure 4.

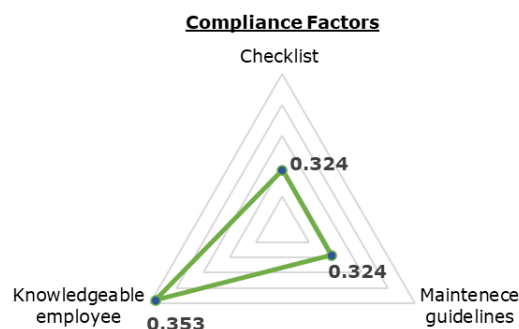


Figure 4 Relative Importance of Compliance-Related DfM Factors for GW

Figure 5 illustrates the RIV of cost factors that maintain the maintainability of GWS. Initial installation cost (0.293) and long-term maintenance cost (0.293) were identified as the most critical challenges, reflecting participants' concerns about upfront investment and ongoing expenditures. Structural replacement cost (0.268) was moderately emphasized, while material availability (0.146) received the lowest weighting, indicating that sourcing durable materials is comparatively less prioritized. These findings highlight the need for incorporating life-cycle cost analysis into

design decisions to balance initial investment with long-term sustainability. Maintenance costs are driven by continuous monitoring, plant replacement, preventive and corrective maintenance, whereas material availability and replacement costs further shape the feasibility of long-term system upkeep.

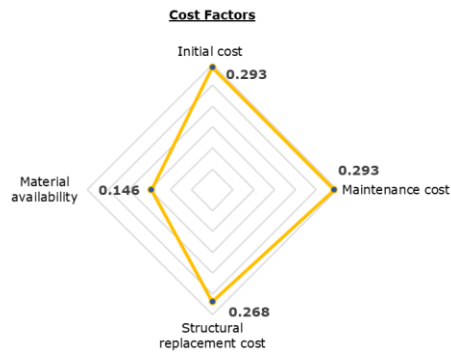


Figure 5 Relative Importance of Cost-Related DfM Factors for GW

Environmental factors also represent a critical external influence on GW maintainability. Plant suitability and biological threats (0.226) are the most impactful secondary factors of GW maintainability. Participants P1-P12 identified biological threats and inappropriate plant selection as a major concern affecting system sustainability. Selecting plant species that are well adapted to local climate conditions was considered essential for improving plant survival and reducing maintenance frequency. Biological threats such as pests, diseases, and invasive species can negatively impact plant health and increase maintenance requirements. Root growth control is also important to prevent structural damage. Additionally, soil conditions and environmental stressors such as temperature variations, wind exposure, and rainfall patterns influence plant survival and overall system performance. However, participants P2, P3, and P10 identified certain biological threats and soil conditions (0.170) as relatively less critical compared to other environmental factors. The comparative significance of these factors is shown in Figure 6.

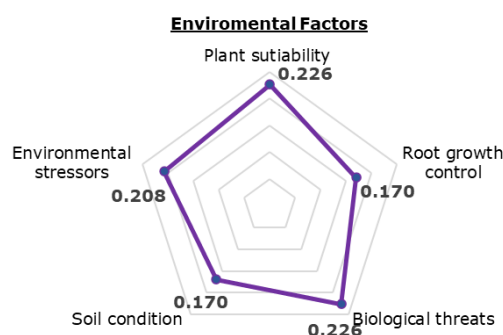


Figure 6 Relative Importance of Environmental-Related DfM Factors for GW

Overall, the figure below demonstrates that structural durability, maintenance accessibility, hazard prevention, employee expertise, initial installation cost, maintenance cost, plant suitability, and biological threats are the most effective DfM factors to be carefully considered during the design stage to ensure long-term operational success in GWS. Figure 7 illustrates the summary of all DfM factors of GW.

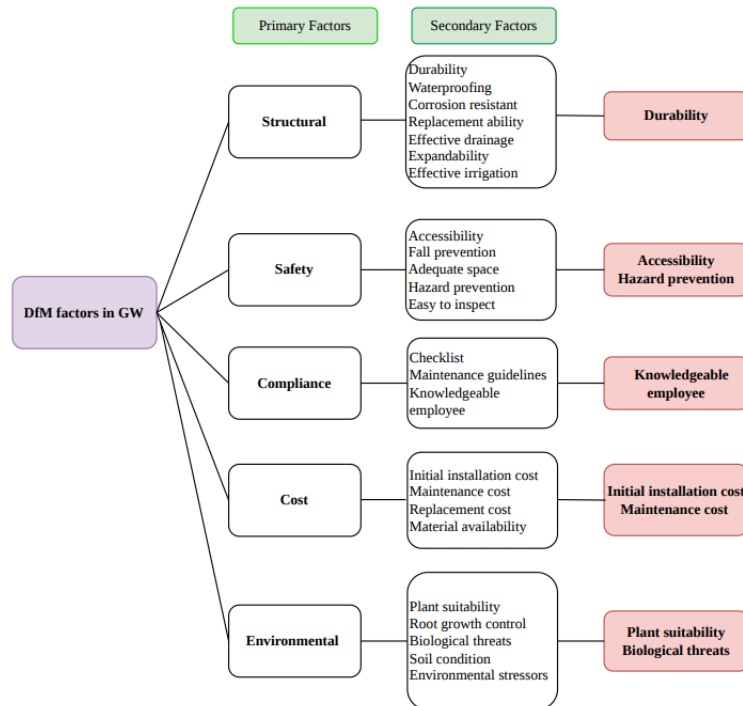


Figure 7, Summary of major DfM factors of the GWS

These dimensions closely align with existing international knowledge on GWS performance. The strong emphasis on structural durability, waterproofing, corrosion resistance, drainage, replacement ability, and expandability confirms the argument in GW research by Atiyat et al. (2025) and Perini et al. (2011). Similarly, Manso and Castro-Gomes (2014) identified safe accessibility, fall protection, adequate working space, and easy inspection. Lee Yung Seng and Siti Hamidah Husain (2025) identified that effective GW maintainability depends on clear maintenance guidelines, skilled personnel, and life cycle cost awareness, while environmental factors such as plant suitability, root control, soil condition, and climatic resistance confirm that GW functions as a living system requiring context-sensitive design, as noted by Conejos et al. (2019) and Lumbierres et al. (2024). Overall, the results show that DfM must integrate structural, safety, compliance, cost, and environmental considerations at the design stage linking GWs in Sri Lanka.

5. Conclusion

This study explored the integration of DfM factors that influence the long-term performance of the GWS in Sri Lanka. The findings reveal that GWS maintainability is primarily shaped by structural, safety, compliance, cost, and environmental considerations. Among these, structural durability, maintenance accessibility, hazard prevention, knowledgeable maintenance personnel, installation and maintenance cost, plant suitability, and biological threats emerged as the most critical factors affecting system sustainability. The results highlighted that inadequate consideration of these factors can lead to operational inefficiencies, increased maintenance requirements, and reduced system performance over time. This study contributes to the growing knowledge on sustainability building systems by providing a structural

understanding of maintainability- related factors for GWS within the Sri Lankan context. The findings offer practical insights for designers and facility managers to support more maintainable and sustainable GW implementations. In addition to its practical implementations, the study also addresses the limited body of knowledge on maintainability-oriented GW design in developing countries. Additionally, comparative studies across different climate regions and building types could enhance the framework and support the development of standardized maintainability design models for GWs. Future research should focus on developing standardized maintenance guidelines and integrating smart monitoring technologies to improve long-term system performance.

7. References

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