




Original Article

Literarily Capturing Key Factors Influencing the Long-Term Sustainability of Green Wall Maintenance in Malaysia



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Abstract

Green building and sustainability are current social concerns. The global construction industry is actively promoting the implementation of sustainable green development, with Malaysia being one of the countries that places significant emphasis on these initiatives. Green walls are a crucial building component that closely aligns with sustainability and energy efficiency. Buildings in Malaysia have begun to adopt this well-known. However, despite Malaysia's adoption of this technology in buildings, the Malaysian construction industry still considers it a novelty. Therefore, this study aims to capture the key factors influencing the long-term sustainability of green wall maintenance in Malaysia. A qualitative literacy search was used to collect the needed data and was grounded in a systematic literature review (SLR) approach. The PRISMA process is followed, and the outcome is produced. The findings highlight the key factors influencing the long-term sustainability of green wall maintenance in Malaysia, including plant selection, irrigation and water management, structural and system integrity, environmental factors, cost and budget management, and human factors and expertise. The outcome of the research can help propose a comprehensive maintenance strategy for green walls in Malaysia and lead to a reduction in operation and maintenance costs.

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1. Introduction

Environmental sustainability has become the most focused area globally. The rise of natural hazards, climate change, and ecological degradation makes environmental sustainability important and popular in every industry. The construction industry is one of the most affected industries by ecological sustainability. To support and address the environmental issue and achieve sustainability, green walls are developed and applied in cities. Green walls refer to all systems that enable greening a vertical

surface, such as facades, walls, blind walls, partition walls, and others, with a selection of plant species, including all the solutions to grow plants on, up or within the wall of a building [1]. At a building scale, green wall systems can be used as a passive design solution contributing to a building's sustainability performance [1]. Green walls significantly improve air quality, reduce energy consumption, and enhance aesthetics [2]. Malaysia is in an urbanization period; rapid urbanization increases the application of green walls in the city, especially in high-rise buildings like apartments and office buildings.

The rise of the adoption of green walls in Malaysia has made the maintenance of green walls a critical challenge due to Malaysia's tropical climate. The features of a tropical environment are high humidity, frequent rainfall, strong sunlight, and high temperature [3]. These tropical climate features can't match the exciting maintenance procedures and plans from temperate climates such as Europe and America. Applying unsuitable maintenance plans for the green walls in Malaysia will cause resource waste and bring side effects, such as the death of the plant, mould growth, and other defects. Good and effective maintenance can ensure green walls' long-term functionality and sustainability and increase their performance. However, many internal and external factors can affect the long-term sustainability of green wall maintenance. Therefore, this study aims to identify the key factors influencing long-term sustainability of green wall maintenance in Malaysia from the literature and critical literature review approaches.

2. Literature Review

2.1. Concept of Green Wall

Green infrastructure is a trend in the world for addressing climate issues. More cities are adopting social and green infrastructure to increase resilience to natural hazards and the consequences of climate change [4]. As one of the components of green infrastructure, green walls play an important role in fighting climate change and environmental issues. Green walls, also known as vertical gardens, green facades, and living walls, are vertically established greening systems in buildings [5]. According to Manso and Castro-Gomes [1], several nomenclatures are used for all green wall systems. Some use the term "vertical garden", others call them "vertical greening systems," "green vertical systems" or "vertical greenery systems (VGSs)." In fact, the concept of green walls refers to all systems that enable greening a vertical surface (e.g., facades, walls, blind walls, partition walls, etc.) with a selection of plant species, including all the solutions to grow plants on, up or within the wall of a building [1]. The green wall has a more complex design than the concrete wall due to the components and system. The essential elements for a green wall are vegetation, a substrate, an irrigation system, a waterproof membrane, and a support system [5,6].

According to Abdeen and Rafaat [7], green walls can be subdivided into two main systems: living walls (LWS) and green facades. The distinction between green facades and living walls is that green facades have climbing plants that grow along the wall covering it; living walls need materials and technology to support more plants for growth along the surface [1]. Living walls can be defined as designed, built, and maintained vegetation elements that potentially have multi-functional and deliberate environmental benefits for their built surroundings [8]. A living wall is a system that uses modular panels with vegetation and is usually equipped with an irrigation system and a fertilisation system. Green facades have different systems from living walls. The plants of green facades are climbing and hanging plants. The plants grow on the vertical surface upwards or downwards to avoid being hung at a certain height and influence the aesthetics [1]. There are two types of green facades, which are direct or indirect; living walls can also be classified as continuous and modular [9].

2.2. General Approach of Green Wall Maintenance

Green wall maintenance plays a significant role in ensuring long-term sustainability. Effective maintenance is essential to optimise resource efficiency, preserve indoor environmental quality, and prolong the lifespan of green technologies like green walls. Some maintenance approaches can be applied to achieve efficient maintenance for a green wall. First is preventive maintenance. Preventive maintenance is a proactive approach that includes routinely planned maintenance to stop facilities and equipment from malfunctioning. People can determine preventive maintenance as the maintenance of devices, machines, or systems before a failure occurs [10]. It is a planned maintenance schedule. It is suitable for all types of buildings and building elements because it helps prevent breakdowns and ensures the continuous performance of buildings and green technologies like green walls.

Unlike preventive maintenance, predictive maintenance is a maintenance strategy that relies on data analytics, sensor technology, and machine learning algorithms to predict equipment failures before they occur, enabling organisations to schedule maintenance activities [11] proactively. The use of computerised systems such as Computerised Maintenance Management System (CMMS) and Building Management System (BMS) can support predictive maintenance well in providing data and the current condition of equipment and building elements, like green walls.

Besides that, reliability-centred maintenance (RCM) is widely used for green wall maintenance. RCM is a systematic approach to evaluating and optimising maintenance strategies for physical assets. It is a corporate-level maintenance strategy implemented to optimise a company or facility's maintenance program. The maintenance strategy is optimized to achieve the aim and objective, such as cost reduction, safety improvement, efficient maintenance, and long-term sustainability.

Maintenance is important for buildings and green technologies. It optimizes resource efficiency, ensures indoor environmental quality, and prolongs the lifespan of the system and building structure. Those are the most significant advantages of a building with green technologies and a green wall. Green maintenance is a current practice that will ensure sustainability aims are achieved. Therefore, proposing and performing good and efficient maintenance is crucial and inescapable.

3. Methodology

This paper adopts the research method of systematic literature review. It collects academic papers, conference papers, books, journals, and authoritative industry reports in related fields from relevant platforms such as Scopus, Web of Science, Springer, and Google Scholar. The time limit is set between 2015 and 2024 and uses keywords such as "green wall," "maintenance," "long-term sustainability," and "green wall maintenance," for comprehensive retrieval. In the retrieval, we focus on the cases and the actual implementation. This paper selects green walls as the research object of the literature review to explore the key factors influencing the long-term sustainability of green walls. The systematic literature review method can integrate theoretical research in related fields, comprehensively review the existing research foundation, and adopt a structured comprehensive search strategy to capture the latest trends in related fields as comprehensively as possible.

Carefully read and analyse the references that can be retrieved, explore their research methods, research objectives, research results, research cases, etc., and extract helpful literature as the basis for this study. The extracted data is then organised and synthesised to identify the key factors influencing the long-term sustainability of green wall maintenance. Patterns and relationships were identified, and different studies were compared to highlight similarities and differences in methods and results. By combining the analysis of academic papers, conference papers, and industry reports, this paper aims to provide a comprehensive overview of the topic and valuable insights into the field.

A Systematic Literature Review (SLR) is a review that collects multiple research studies and summarises them to answer a research question using rigorous methods. Through the systematic literature review (SLR), researchers can bring these factors to the attention of experts for discussion, regardless of their agreement or unique perspectives on them. In discussing these factors, experts might point out some new aspects that they have figured out by their experience and that are valuable for this study. [Figure 1](#) shows the Preferred Reporting Items for Systematic Reviews and Meta-Analyses (PRISMA) process used in the data collection process for SLR, along with the total number of articles included in this study.

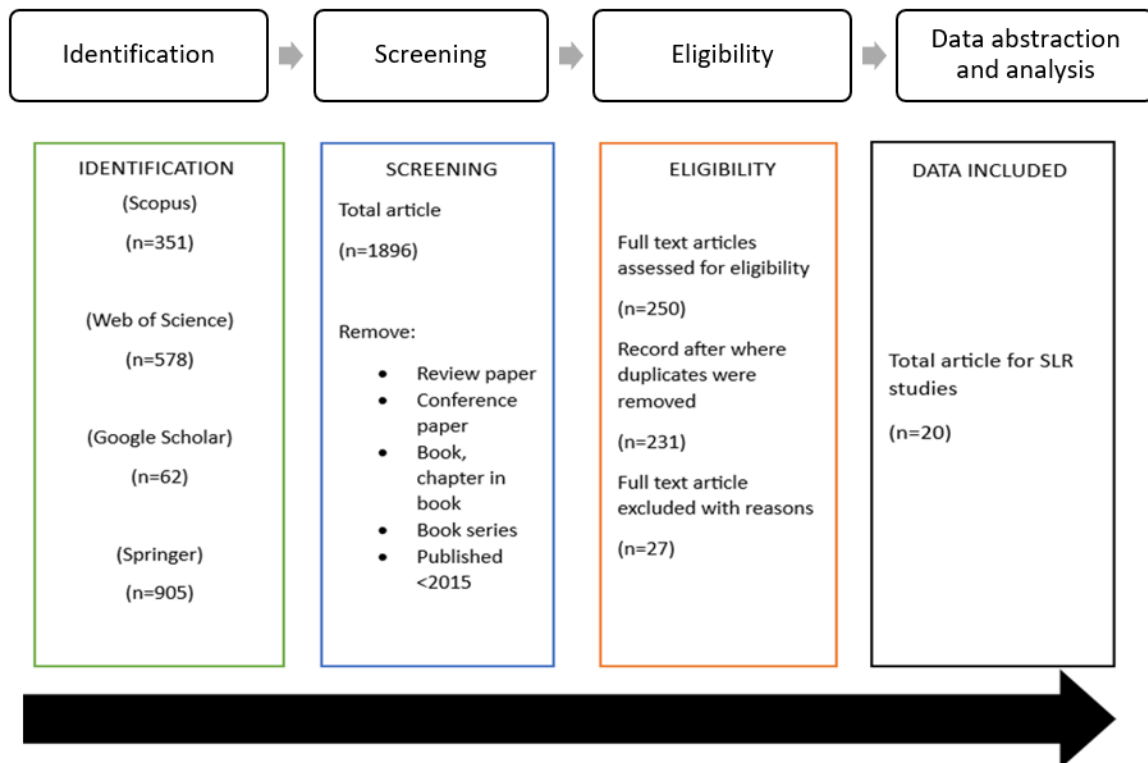


Figure 1: PRISMA Process for Systematic Literature Review (SLR).

[Figure 1](#) shows four (4) steps available for the PRISMA process. First is identification. Four (4) main databases were used to review: Scopus, Google Scholar, Springer Link, and Web of Science. The reason for using these four databases as main article and journal resources is because of their quality and rich articles and journals that relate to the topic. By using the keywords “green wall”, “maintenance”, “long-term sustainability”, and “green wall maintenance”, the process yielded a result of 351 articles from Scopus, 578 articles from Web of Science, 905 from Springer Link, and 62 articles from Google Scholar.

The second step of PRISMA is screening. In this process, including or excluding articles according to the criteria determined by the authors with the assistance of databases has been done. According to [Table 1](#), some requirements are excluded and included to find suitable articles for this study. A total of 1896 articles were collected after the identification process. The result was 250 articles after the screening stage. Non-English articles published before 2015 were excluded. The document type included is only research articles, and the subject area is engineering.

Table 1: The criteria for inclusion and exclusion.

CRITERIA	INCLUDES	EXCLUDES
Publication Time	2015-2024	<2015
Document Type	Research articles	Journals (systematic review), review papers, conference proceedings, chapters in books, book series, books
Subject Area	Engineering and Built Environment	Other than engineering and the built environment
Language	English	Non-English

Next is “eligibility,” a process that includes or excludes articles manually according to the authors’ specific criteria. The retrieved articles were thoroughly reviewed, excluding any articles that did not meet these criteria. The full-text articles assessed for eligibility are 250. Before the eligibility process, 19 duplicate documents were removed and turned into 231 articles. After eligibility, a total of 27 articles is left. The total number of 204 articles that are related to “Green Wall” but not related to “Maintenance” or related to “Maintenance” but not on “Green Wall” are excluded manually.

The final step is data abstraction and analysis. A total of 20 articles were evaluated, reviewed, and checked, and the results are shown in [Table 2](#). The chosen articles match the objective and question of the study and match the research keywords. The studies were then extracted to identify relevant themes and sub-themes for the current research by reading the titles, abstracts, and then the full texts of the articles. A thematic analysis was conducted to identify themes related to factors influencing safety cultures. The main issues, similarities, and differences highlighted and portrayed in the 8 articles were identified and categorised.

Table 2: SLR results based on year, country, number of published articles, title of journal, and rankings.

Year	Country	Number of published articles	Title of Journal	Journal Impact Quartile
2016	Singapore	1	Structural Survey	-
2019	Singapore	1	FACILITIES	Q3
	China	1	Journal of Cleaner Production	Q1
	Spain	1	Sustainability	Q2
2020	Turkey	1	International Journal of Advanced and Applied Sciences	Q4
2021	Australia	1	Journal of Building Engineering	Q1
	Singapore	1	Buildings	Q2
2022	Germany	1	Ecological Engineering	Q2
	Italy	1	Sustainability	Q2
	Malaysia	1	Engineering Construction and Architectural Management	Q1
	Italy	2	International Journal of Life Cycle Assessment	Q2
2023			Building and Environment	Q1
	Australia	1	Sustainability	Q2
	Sri Lanka	1	Energy & Buildings	Q1
	Cyprus	1	Journal of Building Engineering	Q1
	India	1	Light and Engineering	Q4
2024	Sri Lanka	1	Built Environment Project and Asset Management	Q3
	Netherlands	2	Journal of Building Engineering	Q1
			Developments In the Built Environment	Q1
	Egypt	1	Open House International	Q3

The review managed to obtain 20 selected articles from different databases from 13 countries: Singapore, China, Spain, Malaysia, Turkey, Australia, Germany, Italy, Sri Lanka, India, Cyprus, Egypt, and the Netherlands. Table 2 shows the number of published articles related to factors that influence the maintenance of green walls in 13 countries from 2015 to 2024. Overall, Singapore and Italy were leading countries in published articles 10 years back with three (3) articles, followed by Sri Lanka, the Netherlands, and Australia with two (2) articles, and other countries like Malaysia, China, Spain, Turkey, Germany, India, Cyprus, and Egypt with just one (1) article within 10 years. Table 2 shows the SLR results based on year, country, number of published articles, title of journal, and rankings. The details for each article on the SLR study are shown in Table 3. Most articles obtained in the SLR study using the PRISMA approach have an excellent reputation in the Journal Impact Quartile, as shown in Table 2.

4. Result

4.1. Key Factors Influencing the Long-Term Sustainability of Green Wall Maintenance

For the findings of the SLR, maintenance management theory from Adolfo Crespo Márquez [12] is used. A maintenance management theory focuses on optimising maintenance strategies to ensure infrastructure reliability, efficiency, and cost-effectiveness over time and other objectives. This theory matches this study because effective green wall maintenance plays a significant role in the management of green walls. A great and effective long-term sustainable green wall maintenance plan has been produced by identifying and exploring the key factors and best practices of green wall maintenance. A structured maintenance plan can minimise the failure of the green wall and reduce its defects. Identifying key factors influencing green wall maintenance is under the planning and assessment step, which is the early-stage step of maintenance management. It is initial for the next actions in the whole maintenance management process.

Table 3 shows the critical literature review on factors influencing green wall maintenance from 2015 to 2024. Twenty articles were selected and analysed via the PRISMA process. Six (6) main themes and seven (7) sub-themes were created using thematic analysis. The six (6) main themes are plant selection, irrigation and water management, structural and system integrity, environmental factors, cost and budget management, and human factors and expertise. The sub-themes are Component and Materials (CM) and Design Consideration (DC), Climate Adaptation (CA), Microclimate Management (MM), Training and Knowledge (TK), and Monitoring System (MS). CM and DC are under structural and system integrity, CA and MM are under Environmental Factors, and TK and MS are under Human Factors and Expertise.

4.1.1. Selection of Plants

Plant selection is the first step in installing a green wall on a building, and as such, it plays a critical role in influencing the maintenance of the wall. The selection of plants for green walls must be according to the local conditions, such as weather, climate, and temperature; it is important, especially for tropical countries like Malaysia, which have high humidity, frequent rainfall, strong sunlight, and high temperatures [3]. The selection of plants can significantly impact maintenance conditions, particularly in terms of cost.

Table 3: SLR results on factors of green wall maintenance from 2015 until 2024.

Authors	Plant Selection	Irrigation and Water Management	Structural and System Integrity		Environmental Factors		Cost and budget management	Human Factors and Expertise	
			CM	DC	CA	MM		TK	MS
[13]		/	/	/	/		/		
[14]		/					/		
[3]	/						/		
[15]									/
[16]	/								
[17]								/	
[18]						/			
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[29]				/					
[30]							/		
[31]		/		/			/		
Structural and System Integrity CM- Component and Material DC- Design Consideration		Human Factors and Expertise TK- Training and Knowledge MS- Monitoring system		Environmental Factors CA- Climate Adaptation MM- Microclimate Management					

4.1.2. Irrigation and Water Management

Efficient water management is essential for green wall sustainability. In Malaysia's tropical climate, excessive watering can result in root rot and other plant diseases, while insufficient watering can also lead to plant death in green walls. However, compared to other green infrastructures like green roofs, green walls require frequent irrigation and nutrient supply [32].

4.1.3. Structural and System Integrity

Structural and system integrity will relate to the design of the green wall, components, materials, and the supporting system. The most common construction materials used were metal, which IS aluminium and steel, and plastic [6]. Due to the high humidity and heavy rainfall in Malaysia, durable and weather-resistant materials are recommended for use. Design consideration is also a significant factor that will influence green wall maintenance. The green wall designer, landscape architect or person responsible for designing green walls must create a proper design while considering all factors and future planning.

4.1.4. Environmental Factors

Malaysia, well known as a tropical climate country, presents challenges for green wall maintenance. This is because Malaysia's high humidity can promote rapid plant growth, requiring more frequent pruning to maintain the wall's appearance and prevent overcrowding. Besides that, heavy rainfall during the monsoon season necessitates robust drainage and water management systems to avoid waterlogging and root rot. Conversely, irrigation systems must be carefully calibrated during drier periods to ensure that plants do not suffer from water stress. Due to the Malaysian climate issue, flexible maintenance strategies that can adapt to changing weather conditions throughout the year are necessary. For now,

most of the current systems originate from temperate climate countries, which are countries that have four seasons and may not perform as well in a tropical climate, leading to the future maintenance of green walls [13].

4.1.5. Cost and Budget Management

Cost and budget are the most influential factors that influence green wall maintenance. This is because an allocation budget for that purpose supports any maintenance work on the green wall. Proper cost and budget management enables the whole maintenance to go successfully. In Malaysia, the green wall is a new technology. Thus, the cost of installation, materials, and maintenance of the green wall is higher than that of the usual wall or technology due to the lack of demand. Typically, the same company bundles and performs green wall installation and maintenance services. According to Chew and Conejos [14], the high maintenance cost is a barrier to vertical greenery development since developers perceive unwillingness to implement systems, as they will eventually bear the high maintenance costs and prolonged maintenance issues.

4.1.6. Human Factors and Expertise

Human factors and expertise are significant factors that influence green wall maintenance. Human factors and expertise refer to the maintenance staff, labour, and knowledge of maintenance and green walls. Expertise and knowledge in sustainable landscape or maintenance management are important for effective maintenance. Maintenance of green walls is a complex task. It requires specific knowledge that unskilled workers may not have developed, affecting their ability to identify, understand, and avoid the risks associated with specific maintenance tasks [33].

5. Conclusion

Through Systematic Literature Review (SLR), six (6) main themes and six (6) sub-themes are successfully created and developed. The six (6) main themes are plant selection, irrigation and water management, structural and system integrity, environmental factors, cost and budget management, and human factors and expertise. The six (6) sub-themes are components and materials (CM), design consideration (DC), climate adaptation (CA), microclimate management (MM), training and knowledge (TK), and monitoring system (MS). Twenty articles were systematically reviewed from four databases: Google Scholar, Scopus, Web of Science, and Springer Link, following the PRISMA methodology. The study found that cost and budget management are the greatest factors influencing green wall maintenance, followed by irrigation, water management, and plant selection. The findings collected by SLR can help provide a better understanding of factors that could influence the maintenance activities of green walls and help promote the use of green walls in Malaysia's buildings. This contribution allows professionals and experts in the green wall industry to take relevant factors into account and develop maintenance plans that aim to reduce operation and maintenance costs and support long-term sustainability.

Declaration of Conflict of Interest

The authors declared no conflict of interest with any other party on the publication of the current work.

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