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Sustainable Urban Development in Malaysia: Enhancing Green Roofs with Integrated Technologies

Yien Yu Tang[1]*, Youcef Slimani[2], Mukhtar Ali Al-Ghazal[3], Gaurav Talukdar[4], Amit Kumar Maharjan[5]

[1]Environmental Engineering Program, Curtin University, CDT 250, Miri, Malaysia
[2]University of Boumerdès Faculty of Technology Frantz fanon City-Boumerdes, Algeria
[3]College of Engineering, Al-Mergib University, Al-Mina Street - Al-Khoms, Libya
[4]Kansas Geological Survey, University of Kansas Lawrence, Kansas, 66045, USA
[5]Organization for Public Health and Environment Management, Lalitpur Metropolitan City – 10, Nepal

*Correspondence: yienyutang@gmail.com

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ABSTRACT: Urbanization and population density surges globally have triggered environmental challenges, with the construction sector notably contributing to greenhouse gas emissions and high energy consumption. Urban expansion has exacerbated issues, converting green spaces into impermeable structures and heightening flood risks. Green roofs have emerged as an eco-friendly solution, excelling in stormwater management, mitigating the urban heat island effect, enhancing air quality, reducing noise transmission, preserving biodiversity, extending roof lifespan, and augmenting aesthetics. They absorb rainwater, decreasing stormwater runoff, yet entail higher installation and maintenance costs and potential fire hazards compared to conventional roofs. In Malaysia, government policies and incentives drive green roof adoption, particularly in residential, commercial, and institutional buildings, predominantly of the intensive green roof type. Buildings undergo green rating tool evaluations for green certification. Despite progress, challenges persist, including expertise shortages, lack of design guidelines, limited research, low public awareness, and green roof component disposal issues. Addressing these demands significant government efforts, including robust policy development, increased support for local companies, expanded research initiatives, heightened public awareness, and optimized synergy with other technologies. Integrating green roofs with solar panels and utilizing greywater for irrigation can reduce energy and water consumption concurrently, showcasing potential for comprehensive and sustainable urban development.

KEYWORDS: Green roof; Malaysia; pros and cons; challenges

1. Introduction

The global challenge of climate change and depletion of natural resources has intensified due to rapid urbanization and development. As the world's population grows and economies expand, urbanization is on the rise, with an anticipated global urbanization level of 83% by 2030. This trend is driving the demand for high-rise buildings in urban areas to accommodate the increasing population, leading to the degradation of natural landscapes. For instance, Kuala

Lumpur saw a significant reduction in green space from 24,222 hectares to 14,386 hectares in 2012. The decline in green areas poses multiple issues, including floods, the urban heat island effect, loss of biodiversity, air pollution, and noise pollution [1–3]. Recognizing the need to ensure environmental quality for future generations, the United Nations established 17 Sustainable Development Goals in 2015, aiming to protect the environment while promoting social and economic development sustainably [4]. Given that buildings contribute to 30% of greenhouse gas emissions and 40% of global energy usage [5], the construction industry plays a crucial role in pursuing sustainability. To address these challenges, innovative and green technologies are being adopted in building construction to enhance sustainability and combat climate change. Green roofs (GR), covering 20-25% of urban areas, have gained prominence as a suitable solution with considerable impacts on social, economic, and environmental aspects [6]. Integrating statistical data into the narrative strengthens the understanding of the scope and urgency of the issues posed by urbanization and underscores the significance of sustainable development goals.

GR, also known as living roof, eco-roof, vegetated roof or rooftop garden, is a kind of green technology that either a flat or sloped roof is partially or fully covered with vegetation and growing media in addition to serving as a fully operational roof [6]. The first GR can be referred back to 500 BCE, which is the Hanging Gardens in Babylon. Nonetheless, green roofs were mainly used as ornamental and representational features from ancient times to the 18th century. The situation changed in the late 19th century when the seeds of herbaceous plants grew naturally on the roof and lasted for the subsequent decades. The roof was built with mixed sand, gravel, and tar to produce a fire-resistant and waterproof membrane. As a result of its functions and durability, GR received well recognition in the early 20th century and has become a popular urban design tool for many cities around the world [7]. GR has shown its great properties in stormwater management [8], mitigating urban heat island effect [9], improving air quality [10], reducing noise pollution [11] and enhance urban ecology [12]. In recent years, Malaysia also approaches GR technology, but progress is still lagging behind other Asian countries. The objective of this paper is to discuss the application of GR in Malaysia. This paper provides a brief explanation of the concept, design, pros and cons of GR technology. Besides, the current status, government policies and strategies, and limitations of GR in Malaysia are also covered. Lastly, future challenges and recommendations are also included to further improve the current technology so that it can be greener and more sustainable..

2. Green Roof Design and Technology

Waterproof membrane is the most crucial element in the GR as it prevents infiltration from the high water content of top layers. Thus, water tightness is the fundamental characteristic of the membrane. The anti-root membrane provides resistance to root penetration that can physically or chemically damage the waterproof membrane, leading to infiltration into the structure. Following the anti-root membrane, a protective layer is positioned to ensure the integrity of the underlying layers, capable of withstanding loads and strains throughout the entire phase. To accommodate the preference of most vegetation for a ventilated and non-waterlogged environment, the drainage layer incorporates small moisture-retention reservoirs and voids, effectively eliminating excess water from the substrate. This facilitates the equilibrium of air and water content, ensuring optimal ventilation for the roots. Additionally, as water content decreases, the overall weight of the structure diminishes, reducing the risk of mechanical failure. Furthermore, the drainage layer contributes to enhanced thermal performance [11, 12].

Table 1 displays the differences among three types of GR. The aim of the filter layer, typically using geotextile material with water permeability, is to block the tiny particles of the upper layers from being washed and eventually clog up the drainage layer, affecting the performance of GR. The substrate layer is essential in determining the accomplishment of GR. The substrate layer, generally made up of sand, aggregate and organic matter, is designed to sustain the physical, chemical, and biological conditions necessary for proper vegetative development. The selection of plants should take the local climate and substrate condition into account in order to achieve the best performance. Horizontal and vertical forces such as wind pressure and wind action are also one of the considerations of the design [1, 13, 14]. The classification of GR depends on the depth of the substrate. As a result, it can be categorised as intensive green roof, extensive green roof and semi-intensive green roof. Deeper substrate allows a greater variety of plants, followed by a higher maintenance level and vice versa [14].

Table 1. Differences among three types of green roof.

	Intensive	Semi-intensive	Extensive	Reference
Depth (mm)	150-1200	120-200	<150	[2,19]
Weight (kg/m2)	200-500	25% above or below 150	60-150	[6]
Cost	High	Medium	Low	[2,19]
Maintenance	High	Medium	Low	[2,19]
Drainage Layer	No separate drainage layer	Separate drainage layer	Separate drainage system	[6]
Vegetation	Ornamental and Succulent plants	Ornamental, meadow species, turf grass and woody perennial	Ground-level plant	[6]

2.1. Intensive green roof.

Intensive green roof (IGR), also known as roof garden, has a thicker substrate layer from 150 to 1200 mm that can support a wide variety of larger growing media such as trees, shrubs, grasses and perennial herbs. It is commonly restricted to flat rooftops with a slope less than 10 degrees because it is designed as a public common area for recreational purposes. As a result of the diversity of plant selection and the requirement of additional structural reinforcement, drainage as well as irrigation to support the vegetation, the construction is more complex and leads to a high initial cost. Besides, frequent maintenance is needed by weeding, watering and fertilising. The intensive green roof on Menara TM is designed with a more substantial and diverse vegetation layer compared to extensive green roofs. Intensive green roofs typically feature a deeper growing medium, allowing for the cultivation of a variety of plants, including shrubs, trees, and even small gardens. Compared to conventional and extensive green roofs, IGR shows superior properties regarding stormwater management and contamination of pollutants (lead, copper, zinc and cadmium). In addition, it also provides a natural environment or habitat for wildlife in urban areas, particularly birds and insects, which in turn increase the aesthetic value of the building [1, 15, 17].

2.2. Extensive green roof.

The extensive green roof (EGR) typically features smaller, drought-tolerant plants planted in a shallow soil layer with a depth below 150 mm. Due to the limitations imposed by the thin substrate layer, the range of plant options is constrained, with grasses, mosses, herbs, and sedum species being common choices for the majority of extensive roofs [1, 15, 16]. EGR construction is straightforward and well-suited for larger rooftops with slopes of up to 45 degrees [1, 15]. Unlike intensive green roofs (IGR), EGR is lighter, eliminating the need for additional structural support during construction, thereby reducing capital costs. Consequently, EGR is particularly suitable for retrofitting projects where minimal adjustments to existing structures are preferred. With lower water requirements for vegetation, EGR necessitates only minimal maintenance in terms of fertilization using commercial products. However, it's important to note that EGR has limitations. It is not accessible to the public, and in terms of energy performance and stormwater management, it is not as efficient as IGR [1, 16, 18]. Various horticultural methods, such as prefabricated vegetation mats, shoot planting, seed sowing, and the establishment of spontaneous vegetation, can be employed for implementing EGR [18].

2.3. Semi-intensive green roof.

Semi-intensive green roof (SIGR), also called simple intensive green roof, is the transitional phase between IGR and EGR which offers a higher aesthetic value and better ecological effect than EGR but with a lower cost compared to IGR simultaneously. The thickness of the substrate for SIGR ranges from 12 cm to 20 cm, depending on the type of vegetation planted on the roof. The suitable vegetation for SIGR includes lawn, ground-covering plants, grasses, small herbaceous plants and small shrubs. Regular maintenance of SIGR is necessary for trimming, fertilising and irrigation based on the plants' local climate and water demand. Apart from providing a richer habitat, SIGR also has greater thermal resistance than EGR, which is a crucial aspect of modern low-energy construction [18, 19].

3. Advantages of Green Roof

3.1. Stormwater management.

The adoption of GR is an effective solution for flooding issues in urban areas as it can temporarily store stormwater runoff. Once the plants uptake the rainwater infiltrated into the substrate layers, the water is either stored in the vacuoles to maintain homeostasis or released to the air through evapotranspiration. The absorption of rainwater in GR lengthens the delay of runoff, reduces the peak flow rate as well as the total volume of runoff entering into the storm drainage system and discharges the excess water that has been retained in the substrate layer slowly over a longer time frame [20, 21]. Previous study [22] conducted a study in China to evaluate the stormwater retention capacity. The study showed the effectiveness of GR in stormwater management with an average retention rate of 77.2% and an annual volume runoff retention of 758.7 mm. Another research stated that the green roof could decrease the peak discharge of runoff in the 22-70% range compared to the conventional roof. The reduction in peak flow rate positively correlates with the depth of the green roof [23].

3.2. Urban heat island effect and energy consumption.

Figure 1 illustrates the protective effect of green roofs on buildings from direct sunlight. Urban heat island effect (UHIE) is a phenomenon resulting from urbanisation. It has commonly occurred in urban areas where the temperature is relatively warmer compared to the surrounding rural areas because of the heat absorption by buildings. UHIE can significantly affect the health and comfort of the general public, increasing energy needs and electricity costs to cool the buildings. GR can combat the issue of UHIE as the vegetation can create a milder microclimate that cools the surrounding environment through the evapotranspiration process, where solar radiation is absorbed for biological functions and converted to latent heat.

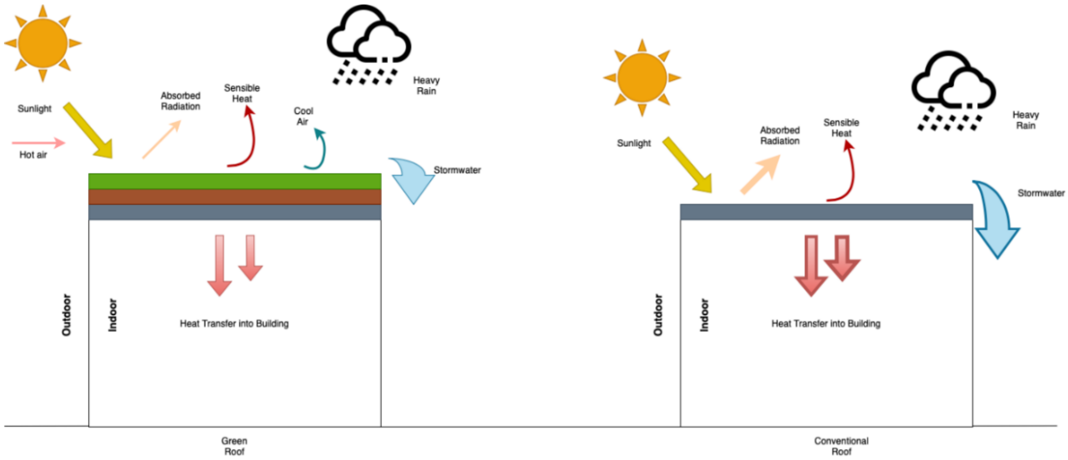

Figure 1. The protection effect of green roof on buildings from direct sunlight.

Apart from evapotranspiration, the plants can shade the surface of buildings, enhance the surface albedo and emissivity and boost the building insulation in order to achieve the cooling effect [24, 25]. [26] discovered that implementing GR can lower the urban temperature in Chicago, Illinois, by as higher as 3℃. The study conducted in Adelaide concluded that GR with a 30% coverage area of the total roof area could reduce the surface temperature by 0.06℃, and the reduction is much better with increasing height from the ground level. As the result of the cooling effect provided by GR, the electricity consumption is reduced by 2.57 W/m^2.day in the study area [27].

3.3. Noise reduction.

Noise pollution in urban areas is one of the environmental concerns that brings severe impact to human health and life quality. The rigid or nearly rigid building skins in cities reflected the sound between opposite building facades and on the street surface, resulting in the amplification of sound pressure level. GR can act as an absorber, moderate diffracting sound waves over the roof and limit sound transmission, thus reducing the sound level. It is found that EGR can lower the sound level by 40 dB while IGR can lead to a more significant noise reduction between 46 and 50 dB [20, 28, 29].

3.4. Mitigate air pollution.

Air pollution is a critical environmental issue resulting from rapid development. The air pollutants in urban areas consist of carbon dioxide, carbon monoxide, nitrogen oxides, lead, ozone, particulate matter and sulphur dioxide. The vegetation on GR can absorb the pollutants like carbon dioxide via stomata in the photosynthesis process, capture the particulate matter and degrade the organic matter like poly-aromatic hydrocarbon substance through phytoremediation. The shading effect can minimise the occurrence of photochemical reactions that form pollutants like ozone. Moreover, the cooling effect reduces the energy consumption of the building, resulting in lower emissions from the power plant [30]. According to the study conducted by [31] in Chicago, 19.8 hectares of GR can eliminate 1675 kg of air pollutants in a year, with 52% of ozone, 27% of nitrogen oxides, 14% of particulate matter and 7% of sulphur dioxide in total. The removal rate of GR per hectare in a year is 85kg.

3.5. Increase life expectancy and property value of buildings.

Direct exposure to solar radiation might cause damage to the waterproof membrane of the conventional bituminous roof layer, but it is avoidable under the protection of plants and growing media. They aid in minimising the diurnal temperature variation of the external building surface so that the buildings can experience less stress from daily expansion and contraction [20, 25]. It can be evidenced by the research done by [32] that the maximum temperature of tile surface can have a drop of 5.2℃ through the GR effect. Hence, GR usually has a lifespan of more than 50 years, much longer than the conventional roof, which generally lasts 10 to 20 years [25]. Furthermore, GR can provide the public aesthetic pleasure with a greenery and nature space that can help relax and relieve stress [33]. Other than aesthetic value, GR can promote urban agriculture and boost food production to reduce food insecurity. It is indicated that IGR is suitable for deep-rooting vegetables like tomatoes. In contrast, bean, cucumber, pepper, basil, chive, lettuce and kale with shallow root are proven to produce a significant yield in EGR [7, 34].

3.6. Boost urban ecology

GR has shown its effectiveness in improving urban ecology by preventing habitat loss in urban areas. It helps in strengthening environmental quality, conserving biodiversity and providing connection within urban areas. It can play the role of wildlife corridor in urban areas with high density that connect the fragmented habitat so that the wildlife can move between these spaces. It is assumed that EGR and IGR may account for 15% and 30% of the ecological benefits as natural habitats, respectively [7, 35]. A study conducted in Hong Kong revealed that 94 vascular plant species and 16 bird species, including 6 migrant species, were recorded on EGR in two years. It is believed that the propagules of the plants were carried by the wind and birds [36]. 254 beetles and 78 spider species, with 18% and 11% of rare species, respectively were found in 17 GRs in Basel, Switzerland as well [20].

4. Disadvantages of Green Roof

4.1. High installation and maintenance costs.

One of the drawbacks of GR construction is the initial and maintenance cost is expensive. The installation cost for GR can be much higher than the conventional roof. The cost can be varied on the material selection, location, components, types and the number of labours. The average installation costs for IGR, SIGR and EGR per m^2 are 409USD, 147USD and 112USD respectively. It was reported that the installation cost of GR was over 1795 m^2 roof area in Washington, DC, is 27% higher than the costs of regular roof construction. Generally, GR requires high maintenance, especially for plant health, so that the GR can function properly in a longer time frame and prevent fire hazards. Nutrient, irrigation requirements and material replacement should be considered in the maintenance cost. For EGR, SIGR and IGR, the average annual maintenance cost per m^2 are 4.84USD, 8.78USD and 5.64USD correspondingly [7, 25, 35].

4.2. Fire hazard.

The vegetation fully covering the GR poses a fire risk to the building and adjacent structures. The main reason that leads to fire is the poor maintenance of GR without removing the debris and dead parts of plants that act as additional fuel loads that capture and support the spreading of fire. Limited irrigation also decreases the moisture, which could worsen during the hot summer or droughts. The fire can spread horizontally through thermal radiation, conduction and convection. The GR in Portland were found to be subject to a fire event in 2018. There was a case that happened during the summer of 2018, which was caused by the sparking of a nearby transformer and started on a poorly maintained vegetated roof with dried, overgrown plants. At the same time, another case happened on an EGR in London, possibly due to cigarette ignition [37–39].

5. Current Status of Green Roofs in Malaysia

Table 2 summarises the detail of GR implemented in Malaysia. Residential, commercial and institutional buildings are Malaysia's three common types of buildings with GR initiatives. Among them, residential building is found to have the highest implementation rate, which consists of 46.7%, followed by commercial building at 43.3%, and the lowest is the institutional building which accounts for 10%. GR is most frequently constructed in the residential building because the residents may have a sense of appreciation and ownership to maintain and monitor their garden as they pay the maintenance fee. Besides, any development should include at least 10% of green space in the design, as stated in the Green Area Planning Guidelines of Act 172. Thus, adopting GR can help comply with the requirement in the highly-dense urban area with land scarcity issues. The majority of the commercial building with GR is office. This might be attributed to the rising interest from corporate building owners in adding value to their property through the advantages brought by GR. In addition, they would like to involve and support the green agenda in Malaysia, which is a current trend in the central business district area. Museum is the most prevalent institutional building with GR initiatives, as the design can boost the aesthetic value by enhancing the beauty and uniqueness of the building. Thus, the design can act as one of the attractions for the public to visit the museum, and the entrance fees can be the maintenance cost for the GR. Currently, the intensive green roof is the dominant type of GR in Malaysia. However, more extensive green roofs will be implemented in the future due to their lower maintenance requirement [40, 41].

Table 2. Summary of green roof implemented in Malaysia.

Green Roof Project	Location	Building Type	Green Roof Type	Accessibility	References
Menara Mesiniaga	Selangor	Commercial	Extensive	Non-accessible	[41]
Islamic Art Museum	Kuala Lumpur	Institutional	Extensive	Public access	
KLIA Covered Integrated Parking	Kuala Lumpur	Commercial	Intensive	Public access	
Suasana Sentral Condominium	Kuala Lumpur	Residential	Intensive	Private access	
Ministry of Finance	Putrajaya	Institutional	Extensive & Intensive	-	[2, 40]
Putrajaya International Convention Centre	Putrajaya	Institutional	Extensive & Intensive	Public access	[2, 40]
Hilton & Le Meridien	Kuala Lumpur	Commercial	Intensive	Private access	[41]
Mewah Oil Headquarters	Selangor	Commercial	Intensive	Private access	
Putrajaya City Hall	Putrajaya	Commercial	Extensive	-	[2, 40]
Malaysian Design Technology Centre	Selangor	Institutional	Extensive	Private access	[41]

Green Roof Project	Location	Building Type	Green Roof Type	Accessibility	References
Serdang Hospital	Selangor	Institutional	Intensive	-	[2]
The Tamarind	Kuala Lumpur	Residential	Intensive	Private access	[41]
The Maple	Kuala Lumpur	Residential	Intensive	Private access	
Secret Garden	Kuala Lumpur	Commercial	Intensive	Public access	
Setia Eco Villa	Kuala Lumpur	Residential	Intensive	Private access	
Faculty of Social Sciences and Humanities, University Kebangsaan Malaysia	Selangor	Institutional	Extensive	-	[2, 40]
Idaman Residence	Kuala Lumpur	Residential	Extensive	Private access	[41]
Casa Desa Condominium	Kuala Lumpur	Residential	Intensive	Private access	
The Saffron	Kuala Lumpur	Residential	Intensive	Private access	
Park Seven Condo	Kuala Lumpur	Residential	Extensive	Private access	
Oasis Ara Square	Kuala Lumpur	Commercial	Extensive	Accessible	
Riana Green East	Kuala Lumpur	Residential	Intensive	Private access	
Rice Museum	Kedah	Institutional	Extensive	Public access	
Sime Darby Oasis	Selangor	Commercial	Extensive	-	[2, 40]
KL Sentral Park	Kuala Lumpur	Commercial	Intensive	-	[2, 40]
Ritze Perdana 2	Selangor	(Residential/ Commercial)	Intensive	Private access	[41]
Kiara 9	Kuala Lumpur	Residential	Intensive	Private access	
Menara Binjai	Kuala Lumpur	Commercial	Intensive	Private access	
Swiss Garden Residences	Kuala Lumpur	Residential	Intensive	Private access	
Newcastle University of Medicine Malaysia	Johor	Institutional	Extensive	-	[2, 40]
Heriot-Watt University Malaysia	Putrajaya	Institutional	Extensive	-	[2, 40]

6. Green Roof Policies, Measures and Incentives in Malaysia

Up to date, there is still lacking formal policy for implementing GR in Malaysia. However, green roof, as one of the green technologies, has been indirectly mentioned in national policies such as National Green Technology Policy and National Policy on Climate Change. In response to the global sustainable development goals, Malaysia launched National Green Technology Policy in 2009. The policy aims to reduce energy consumption while promoting economic development, boost the widespread green technology industry and increase its economic value to Malaysia, enhance Malaysia's competitiveness of green technology globally and public commitment to the adoption and innovation of green technology, ensure sustainable development, and raise public awareness and application on green technology through education. This national goal has made significant progress and improvement in the energy, building, transportation, and water and waste management sectors. For the building sector, the policy emphasised the implementation of green technology throughout the life cycle of the building, including construction, management, maintenance and demolition. National Policy on Climate Change has the purpose of increasing the country's ability to withstand the effects of climate change through management practices that improve renewable energy and energy efficiency. The key action includes encouraging the construction of green buildings in various sectors by considering low or zero-energy concepts in new building design and construction, retrofitting existing buildings to produce renewable energy and implementing energy efficiency systems, building energy-saving practices and introducing green building index (GBI) [40, 42, 43].

Table 3 shows different green building tools implemented in other countries. GBI is a green rating tool created by the Malaysian Institute of Architects (PAM), the Association of Consulting Engineers Malaysia (ACEM), under the support of the Malaysia Green Building Confederation in April 2009. It is the first systematic framework that assesses the building's environmental design and performance, emphasising six main criteria: energy efficiency, indoor environment quality, sustainable site planning and management, materials and resources, water efficiency, and innovation. The implementation of GR is classified as SM12 under the criteria of sustainable site planning and management in the GBI system. Two points can be received after the construction of GR. The buildings were assessed once in three years, and thus they should be well-maintained in order to keep their GBI rating.

Table 3. Different green building tools implemented in different countries.

Country	System	Year	Criteria	References
United Kingdom	Building Research Establishment Environmental Assessment Method (BREEAM)	1990	1. Management 2. Health and Wellbeing 3. Energy 4. Transport 5. Water Consumption and Efficiency 6. Materials 7. Waste 8. Pollution 9. Land use and Ecology 10. Innovation	[44]
United States	Leadership in Energy and Environmental Design (LEED)	1998	1. Sustainable Site 2. Water Efficiency 3. Energy and Atmosphere 4. Materials and Resources 5. Indoor Environmental Quality 6. Innovation in Design	[44]
Australia	Green Star	2003	1. Management 2. Indoor Environmental Quality 3. Energy 4. Transport 5. Water 6. Materials 7. Land Use and Ecology 8. Emissions 9. Innovation	[44]
Singapore	Green Mark	2005	1. Energy Efficiency 2. Water Efficiency 3. Environmental Protection 4. Indoor Environment Quality 5. Other Green Features and Innovation	[44,52]
Malaysia	Green Building Index	2009	1. Energy Efficiency 2. Indoor Environment Quality 3. Sustainable Site and Management 4. Materials and Resources 5. Water Efficiency 6. Innovation	[44,52]
Korea	Green Standard for Energy and Environmental Design (G-SEED)	2011	1. Land Use and Transportation 2. Energy and Pollution 3. Materials and Resources 4. Water 5. Management 6. Ecology 7. Indoor Environment Quality	[53]

Malaysian Carbon Reduction and Environmental Sustainability Tool (MyCREST) is another type of green rating tool established by the Construction Industry Development Board (CIDB), aiming to measure and minimise the effect of carbon emissions and environmental consequences on the built environment in Malaysia. This is accomplished by taking a comprehensive approach that integrates the socio-economic elements of sustainability into urban development and the built environment. Design, construction and operation and maintenance are the three criteria that need to fulfil in order to obtain the MyCREST certification award. GR is one of the ways to evaluate and protect the natural ecology of landscape components. GR serves as a carbon storage technology that leads to a reduction in carbon emission by capturing the carbon dioxide, and thus points can be earned through the application of GR. There are other green rating tools developed in Malaysia from 2009 to 2019, including Green Real Estate (GreenRE), Malaysia Public Work Department Green Rating Scheme (pHJKR), Sustainability Index (SUSDEX), and Sustainable INFRASTAR [40, 44, 45].

In order to facilitate the growth of green building or GR, incentive is one of the critical driven factors to attract the stakeholders to consider using green technology in their projects. There are two types of green building incentives: external and internal. The definition of internal incentive is that the beneficiaries can make their own decision whether or not they want to be incentivised based on their interest, while the external incentive compels the beneficiaries to meet the special requirement before they receive any incentives. The external incentive, supported mainly by local government, can be further classified into financial and non-financial incentives. The financial incentive is a kind of monetary subsidiary to the beneficiaries. The Green Technology Finance Scheme (GTFS), a soft loan incentive programme unveiled by the Malaysian government in 2010, was introduced to attract local businesses and developers to actively participate in green technology development projects [46, 47]. The programme has successfully made a trend to have greener and more sustainable buildings by local companies with the evidence that over 30% of the submissions or 137 buildings had been certified as green buildings using the GBI rating system in 2013 compared to 2009. Persuasion and inspirational incentives is a kind of internal incentives that the Malaysian government has denoted as a sign of commitment and leadership. They converted four iconic buildings in Malaysia: the Kuala Lumpur Securities Commission building, the Diamond Building, Putrajaya, Green Technology and Water, and LOE Energy Office Building GreenTech Malaysia into green buildings. Malaysia government also allocated incentives for adopting green buildings in National Budget 2010, highlighting that (i) the owner of GBI awarded building is exempted from the tax equivalent to the total extra capital expenses required to earn the certificate. This exemption can fully offset the statutory income of the annual assessment. It applies to both new and retrofitted buildings. (ii) Individuals who purchased buildings and residential properties awarded GBI certification from real estate developers were eligible for a waiver on stamp duty when transferring ownership of the property. The exemption amount was equivalent to the additional cost of acquiring the GBI certificate. It is important to note that this incentive was only be granted once, specifically to the initial owner of the property. However, this non-transferability requirement associated with green building incentives, specifically tax-related incentives, reduces non-owner occupiers' interest as they are not qualified for tax exemption. Besides, the registration fee, GBI facilitator, and consultancy costs are not part of the tax incentives [44, 47].

7. Major Challenges

Despite the proven long-term benefits of Green Roofs (GR) to the social, economic, and environmental aspects, Malaysia lags behind countries like Singapore and Hong Kong in implementation. The key issue lies in the shortage of local expertise and a limited number of experienced GR professionals in Malaysia. Design flaws, attributable to the absence of standardized design guidelines, compound operational challenges. Furthermore, the scarcity of specialized companies with skilled crews for installation and maintenance exacerbates the situation. Thorough consideration of the weight and storage capacity of each GR component is crucial for proper construction, yet this aspect often lacks comprehensive study. Maintenance responsibilities in Malaysia typically fall on building workers without sufficient GR knowledge, leading to increased risks of roof leakage and structural damage. Detecting persistent leakage issues becomes challenging and more costly compared to conventional roofs. Insufficient GR suppliers contribute to higher material costs, escalating the overall installation expenses in Malaysia compared to other countries. Limited local research on the effectiveness of GR, particularly in using different plant types and growing media tailored to local conditions, results in low awareness among the public and companies, hampering investments in GR. The disposal of GR components, particularly those incorporating polymers as drainage and filter layers, poses an environmental concern, contributing to plastic pollution despite containing 40% recycled polypropylene. Additionally, the lack of cooperation among involved parties further compounds issues, leading to faulty GR and loss of investments as responsible monitoring and management post-construction are neglected [2, 3, 48].

8. Future Challenges and Prospects

In order to achieve successful implementation of GR in Malaysia, the policymaker should develop a comprehensive GR policy and it should be strengthened at the government and municipal levels. The government should also provide more incentives to encourage and attract local companies to support the GR project on a larger scale, not only in residential buildings but also in commercial and institutional buildings. A proper design standard and guideline should be proposed by taking the reference from other countries and modifying it based on the local condition. Malaysia can learn and adapt from the success and failure experienced by other countries, particularly Singapore, that have similar climate conditions to Malaysia. Besides, the government should offer training and technical assistance to increase the amount of expertise in designing and maintaining the GR. More research should be conducted by creating a GR research team or association to fill the knowledge gap. The study can be focused on the factors that impact the effectiveness of GR in achieving the benefits, specifically on the suitability of the plant types, substrate layers, and the potential problem that led to the failure of GR. Other than that, they should also find a more eco-friendly and cost-effective replacement for polymer materials. The results that have been obtained and any information regarding the GR should be shared with the public to increase their awareness of how they can be beneficial from applying GR [2, 3, 40, 48, 49].

Currently, there is a new trend in bio-solar GR, which is the integration between GR with photovoltaic (PV) solar panels. The performance of PV has a negative correlation with the temperature. Through the combination, the PV can take advantage of the GR as it can boost the PV's efficiency and performance by cooling the PV's surface and lowering the surrounding temperature through evapotranspiration. On the other hand, PV can reduce the exposure to sunlight on the GR and the high evaporation rates of the plants through the shading effect [49, 50]. For the irrigation source, it is suggested to use greywater as a substitute for fresh water to minimise water consumption. Besides, there is less requirement for vegetation fertilising as the grey water is rich in nutrients. Simultaneously, GR can serve as a sustainable and cost-effective remediation technology to treat greywater through phytoremediation. However, more research needs to be done so that it can be a more promising and sustainable green technology in the future [49, 51].

9. Conclusion and Recommendation

Malaysia grapples with pressing environmental issues like global warming, floods, biodiversity loss, air, and noise pollution due to rapid urbanization. The building sector, a significant contributor to greenhouse gas emissions and energy consumption, holds promise for sustainability. Green roofs (GR), comprising layers like vegetation, substrate, filter, drainage, water storage, protection, waterproof, anti-root membrane, and roof deck, offer a potential solution. GR types (IGR, EGR, and SIGR) vary based on substrate thickness, impacting plant selection, cost, and maintenance frequency. GR benefits include stormwater management, reduced building temperatures, lower energy consumption, air pollutant removal, noise reduction, increased roof lifespan, enhanced property value, and improved urban biodiversity. Challenges, such as high construction costs and fire hazards, persist despite long-term offset potential. Malaysia adopts GR in residential, commercial, and institutional buildings, with IGR dominating but a shift to EGR due to lower maintenance requirements. National Green Technology and Climate Change Policies drive GR adoption. Green rating tools (GBI, MyCREST, GreenRE, pHJKR, SUSDEX, and Sustainable INFRASTAR) assess green building performance. The government incentivizes local companies for GR projects. Overcoming challenges, including limited expertise, design standards, suppliers, research, public awareness, GR component disposal, and stakeholder cooperation, requires strengthened policies, standard guidelines, increased incentives, technical support, and more studies. Integration of solar PV with GR and greywater for irrigation merit thorough exploration. Stakeholders must monitor and maintain GR to ensure long-term socio-environmental-economic benefits and sustainability.

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Conflicts of Interest

The authors declare no conflict of interest.

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