

## APPLICABILITY OF GREEN FAÇADES WITHIN HIGH-RISE BUILDINGS IN URBAN BUILT ENVIRONMENTS

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<http://doi.org/10.46754/jssm.2024.10.009>

Received: 1 February 2024

Accepted: 4 August 2024

Published: 15 October 2024

**Abstract:** Challenges related to urban sustainability can be creatively solved by adding more green infrastructure in the form of vertical vegetation. The constructed environment of urban areas presents a few economic, environmental, and social difficulties. Environmental problems such as noise, water, and air pollution caused by the construction industry is one of the difficulties. Consequently, building green façades is one strategy for addressing climate change issues. This research examines how green façades can be used in high-rise buildings in urban settings. The study has the following goals: (i) To determine the potential benefits of green facades for tall buildings in urban built environments and (ii) to investigate major challenges to using green facades in high-rise structures in Malaysia. This research adopts a quantitative research methodology, distributing 116 questionnaires through Google Forms to architectural firms in the state of Selangor. 46 responses were received. Frequency analysis determined that green façades significantly influenced economic factors, specifically in increasing property value. Additionally, they contribute to environmental aspects such as urban environment and sustainability, shading potential, and thermal insulation. Socially, green facades are perceived as a means to provide a better environment for society. However, practitioners in the field have encountered challenges, particularly in the maintenance of buildings and the construction costs associated with implementing green façades in urban built environments. Consequently, recommendations for future research have been proposed considering these findings.

Keywords: Green façades, benefits, challenges, high-rise buildings, sustainability.

### Introduction

Green Façade (GF) is one of the terms for vertical greenery. All vertical greenery classifications have similar meanings as they are generally defined as plants growing on vertical surfaces (Leong *et al.*, 2021). According to Wood *et al.* (2014), a green wall or vegetated façade is a system where plants grow on a vertical surface, like a building façade, in a controlled fashion and with systematic maintenance. Green façades can be two-dimensional, constructed by cables, ropes, and meshes, or three-dimensional, shaped by rigid frames and cages. It is considered a living technology that performs an active role in a building operation (Aung *et al.*, 2023). Green façades act as a passive system through four mechanisms namely shading, insulation,

evaporative cooling, and mitigating the effects of wind (Coma *et al.*, 2014). Gunawardena (2021) proposed that green facades developed along two pathways: Sheltered environments (building scale) and exposed environments (urban neighbourhood scale). There are three main categories of green facades: Traditional green facades, double-skin green facades, and perimeter flowerpots. In general, the traditional green facade uses building facade wall material as a support for plants to climb vertically. Double-skin green facade is where the green facade layer is separated from the existing building facade by an air space, making it appear like double skin. Perimeter flowerpots are where shrubs are planted and grown around

the building (Wong & Baldwin, 2016). Double-skin green facades are suitable for high-rise buildings and can be easily constructed along the building facade. Green facades and living walls are often confused as the same thing since they are both vertical greenery systems. Both are defined separately by Radić *et al.* (2019). Green facades have their plants rooted in structural supports fastened to the wall itself; living walls are self-sufficient systems that are attached to the exterior or interior of a building. Besides, Gunawardena (2021) describes the green facade as placed on a host or wall with limited growing media or contained in a planter. On the contrary, the living wall covers the vertical surface of the wall with the growth substrate. A cross-section view of both vertical greening is shown in Figure 1.

**High-rise Buildings**

A high-rise building is a multi-story structure where the majority of occupants rely on elevators for transportation to their desired floors. Additionally, a key feature of high-rise buildings is their considerable height, exceeding the accessibility of conventional firefighting methods and significantly impacting evacuation procedures.

Nowadays, traditional horizontal urbanisation utilises vast tracts of land. To use a smaller area of land, Malaysian developers followed the global trend of vertical urbanisation. Vertical urbanisation via high-rise buildings allows for

more efficient energy usage and conservation of our environment and climate (Chang, 2022). The presence of vertical greenery on the facades of high-rise buildings is a widely endorsed approach in situations with limited land availability. In densely populated urban areas where land is a precious commodity, the construction of tall buildings has demonstrated its benefits.

**Urban Built Environment**

According to Dandotiya (2019), an urban environment is the ecosystem of an urban area where its residents interact with biotic and abiotic factors. Biotic factors refer to living things such as plants and animals while abiotic factors refer to non-living components such as water, soil, and atmosphere. An urban area is described as the region surrounding a city (National Geographic, 2023). Urban built environment refers to human-made conditions, where landscape, architecture, urban planning, public health, sociology, and anthropology take place. Urban built environment is associated with many economic, environmental, and social challenges. One of the challenges is to identify environmental issues such as air, water, and noise pollution caused by the construction sector (Chong *et al.*, 2023). A sustainable urban built environment aims to reduce negative impacts and create positive impacts for the natural environment, economies, human health, and equity.

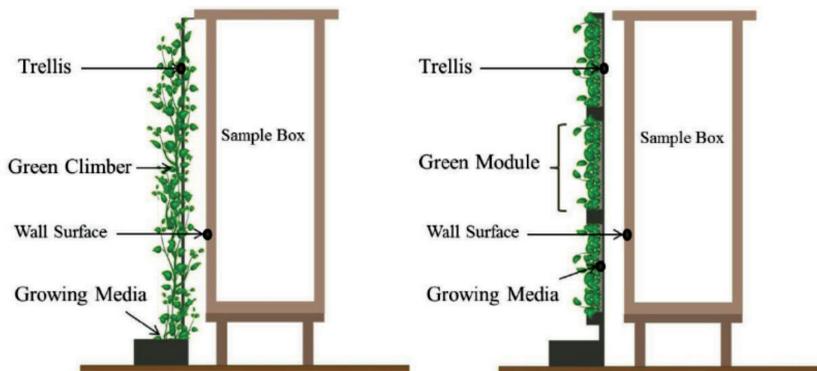


Figure 1: Green façade (left) and living wall (right)  
 Source: Mohammad Shuhaimi *et al.* (2022)

### ***Sustainable Building***

Kats (2003) describes a green or sustainable building using main resources like energy, water, materials, and land more efficiently than buildings that are just constructed to code. The adoption of sustainability input allows green or sustainable buildings to contribute to improved health, comfort, and productivity of people.

In Malaysia, there's a public awareness and interest regarding how buildings influence the environment, worker productivity, and public health. According to Shafii and Othman (2007), both the public and private sectors have begun to demand buildings that optimise energy use, promote resource efficiency and improve indoor environmental quality. Construction stakeholders such as developers, owners, and insurers are starting to value and market the benefits of sustainable buildings. The main characteristic of sustainable design is the incorporation of various green building features. The features include a green and smart façade which reduces the dependence on artificial lighting and cooling systems. It further creates the opportunity to reduce energy consumption, improve occupant comfort, and create long-term financial benefits (PropertyGuru Malaysia, 2023).

### ***Common Benefits of Green Façade Application within High Rise Buildings***

According to Chafer *et al.* (2021), a green façade provides environmental benefits and sustainable solutions for new and existing buildings. The implementation of such a system reduces energy demand by mitigating urban heat islands and cooling down public spaces, sequesters carbon, improves acoustics, reduces particulate matter concentration, promotes biodiversity, and other intangible benefits to human health, society, and culture. The benefits of green façades can be categorised into three aspects: Economic, environmental, and social.

### **Economic Aspect**

#### ***Noise Absorption***

Green facades can reduce noise in urban built environments (Wood *et al.*, 2014). Wong *et al.* (2009) observed that the sound absorption coefficient increases with greater greenery coverage. The green facade can absorb and dissipate sound waves from external elements from 2.5 dB to 3.0 dB. Knifka *et al.* (2023) found that green facades could lower noise pollution in urban built environments, improving the health and well-being of people.

#### ***Potential Energy Saving***

The vertical greenery of green facades saves energy through four fundamental mechanisms: Interception of solar radiation, thermal insulation, evaporative cooling, and acting as a windscreen (Wong & Baldwin, 2016). Leong *et al.* (2021) stated that energy efficiency can be improved if the roofs and walls of tall buildings are covered with plants, as there is a significant external temperature regulation. The insulation and shading benefits of green facades reduces energy use for heating or cooling (Aung *et al.*, 2023). Urban Heat Island (UHI) is a major influence on building energy demand and energy security. Thus, reducing the UHI effect will result in energy savings (Bakhshoodeh, *et al.*, 2022). However, it still depends on the measurable climate zone. Additionally, the energy requirement on the green facade itself is quite low due to its natural growth pattern (Wood *et al.*, 2014).

#### ***Suitable for Retrofitting Projects***

Lundegren (2016) describes one of the worthwhile factors while evaluating green façades, which is the possibility of retrofitting them to existing walls. A green facade has less load compared to green walls; further allowing the installation of such vertical greenery to be efficient. Hong *et al.* (2019) added that

retrofitting is technically less challenging and can save cost and installation time. Retrofitting green facades brings energy and cost savings, and brings positive impacts on maintenance and the environment. Building Information Modelling (BIM) can aid in green facade decision-making based on the simulated energy performance data and key features associated with the client's expectation and consideration for retrofitting the building.

### ***Create Job Opportunities***

The adoption of green facades by the public and private sectors can stimulate the economy (Basdogan & Cig, 2016) by catalysing the creation of new business and job opportunities (Leong *et al.*, 2021). For example, the construction sector will see a demand for expertise in integrating green façade into building design.

### ***Increase Property Values***

According to Hop and Hiemstra (2013), green facades can increase the value of real estate, specifically for outdoor living spaces. Green elements also provide productive places to live and work (Wood *et al.*, 2014). This increase in a building's value or rental yield facilitates a return on the investment of the initial green facade installation. Knifka *et al.* (2023) also reference previous studies that show property values can benefit from the introduction of regulatory incentives, along with green rating and labelling systems. Additionally, Radic *et al.* (2019) point out that green façades are economically viable and offer favourable returns on investment over time.

## **Environmental Aspect**

### ***Urban Environment and Sustainability***

A green facade can reduce and control the temperature in urban areas filled with tall buildings. Greening the building with vegetation can rebuild the environmental conditions in dense urban areas (Rakhshandehroo *et al.*, 2015). In terms of sustainability, past researchers

identified green facades as a significant influence on climate stress and cost reduction (Radic *et al.*, 2019). Incorporating greenery in facades can mitigate the urban heat island effect because it reduces air temperature (Wong *et al.*, 2009). Wood *et al.* (2014) describes other benefits, namely reduction of urban heat island effect, air quality improvement, carbon sequestration, aesthetic appeal, positive psychological impact on urban dwellers, boosting biodiversity by creating natural animal habitats, and sound deadening.

### ***Shading Potential***

According to Aung *et al.* (2023), green facades function as natural shades that reduce solar radiation that reaches the surface of a building. The leaves of climbing plants function like ventilation blinds that block the sun's rays, which then cools the building, further contributing to energy saving (Wong & Baldwin, 2016). Pérez *et al.* (2014) argues that this will alleviate environmental impacts such as climate change.

### ***Evaporative Cooling***

Evaporative cooling is an essential environmental benefit of vegetated facades in urban areas (Sheweka & Mohamed, 2012). As it accomplishes energy savings in buildings during warm periods. This achieved through the evaporation and respiration of plants over time. During a hot sunny day, the green façade's cooling effect transfers the heat pathways (Bakhshoodeh *et al.*, 2022). The reduction of air and surface temperature results in lowering the demand for energy needed for cooling. Sensible and latent heat reduction measures achieve cooling outcomes (Convertino *et al.*, 2021).

### ***Thermal Insulation***

The vegetation on green facades have effective thermal resistance that provide insulation benefits, which lowers the internal temperature of the building (Mohammad Shuhaimi *et al.*, 2022; Aung *et al.*, 2023). Green façades and the normal building facades work together as a thermal buffer to reduce heat loss and further

improve air quality and reduce wind sheer. Pérez *et al.* (2014) mentioned the insulation properties of green facades allow the reduction of building energy consumption along with its environmental impact on the public.

### ***Blockage of Wind***

Coma *et al.* (2014) characterised green façades as a passive system with four mechanisms including the ability to interact with and influence wind patterns. This is done by blocking the wind from the normal façade; thus, prolonging its life (Radić *et al.*, 2019). However, blockage of wind is not much concern in Malaysia due to its climate characteristics.

### ***Improve Air Quality***

Bano and Dervishi (2021) found that incorporating greenery into building façades can assist in raising air quality. Plants remove gaseous pollutants from the air by producing oxygen (O<sub>2</sub>) and using carbon dioxide (CO<sub>2</sub>) through photosynthesis (Aung *et al.*, 2023; Kumar *et al.*, 2023). Plants with dense foliage or textured leaf surfaces trap microscopic particles and remove them from the air. Nitrogen and ozone are also absorbed from the air. Green façades can be a solution to clean the air in cities that lack space to plant foliage (Radić, Dodig & Auer, 2019).

### ***Biodiversity Enhancement***

Green façades contribute to biodiversity, create a sense of well-being and improve the aesthetic value of the built environment, according to Zalejska-Jonsson *et al.* (2023). They can become habitats for urban wildlife, making them a favourable way to support the biodiversity of cities (Pérez *et al.*, 2014; Mayrand & Clergeau, 2018; Knifka *et al.*, 2023).

### ***Rainwater Retention Improvement***

Rainwater is the primary method of plant irrigation in green facades (Leong *et al.*, 2021). As the vegetation covers the exterior of the building, green facades act as an additional layer

that absorbs excess rainwater from penetrating the interior façade. This absorption of water by green facades can extend the life of the underlying masonry if it is properly waterproofed and separated by a layer of air (Haggag, 2010). According to Sheweka and Mohamed (2012), the management of rainwater can be improved by evaporative cooling.

### **Social Aspect**

#### ***Improve Human Health and Well-being***

According to Leong *et al.* (2021), plants can enhance human health and well-being. The restorative influences of plants lead to stress reduction, enhance patient recovery rate and higher resistance to illness (Sheweka & Magdy, 2011). Valeryevich (2021) describes green façades as bringing positive impacts and generates pleasant psychological comfort. Wood *et al.* (2014) says green façades enhances the quality of life by providing relief from a polluted urban landscape.

#### ***Provide Better Environment***

Green façades improve the environment by enhancing air renewal. Some plant species are also able to absorb harmful pollutants through their leaves and roots (Aung *et al.*, 2023). Vegetation could provide a better environment in terms of health, quality, education, awareness, and biodiversity. Leong *et al.* (2021) described the benefits green façades in social terms as they can provide a better environment for the people by shaping the urban microclimate. Green façade also tends to provide a cooler outdoor microclimate that benefits pedestrians (Wood *et al.*, 2014).

#### ***Aesthetically Pleasing***

Vertical greenery is aesthetically pleasing due to its enhancement of the architectural design (Bano & Dervishi, 2021). Green façades cover unappealing sights such as deformed structure surfaces and the mechanical and electrical elements of the building. Green façade can also be a form public art (Radić *et al.*, 2019).

The aesthetic enhancement that a green façade brings to a building can also increase the value of the property. Wood *et al.* (2014) also describes green façades as a pleasant visual environment, especially for pedestrians.

### **City Branding**

A green façade adds identity to a building (Radic *et al.*, 2019) and be used in city branding (Leong *et al.*, 2021). Apart from its stunning visual effect, green façade can create awareness of the importance of environmental science. Clients and builders can use this awareness to promote their commitment to environmental and sustainable development goals (Wong & Baldwin, 2016).

### **Educational Effects**

Green façades, living walls, and vertical greenery systems raise awareness of the importance of ecology (Radic *et al.*, 2019) and promote sustainability. They can also be employed as a tool for ecological observation, the cultivation of plants and vegetables, and as a method of building protection (Sheweka & Magdy, 2011).

## **Challenges in Applying Green Facades**

### **Construction Cost**

It can be expensive to construct and upkeep the technology and equipment of green facades. The selection of plants can also affect the cost of green facades. Leong *et al.* (2021) found that green façades constructed from steel mesh are the most expensive, which deters their implementation. However, green façades tend to have an overall lower cost compared with other vertical greenery systems like living walls (Perez *et al.*, 2014; Bakhshoodeh, 2022).

### **Lack of Technical Knowledge**

Although green facades are not new innovations, not all construction workers are familiar with them (Leong *et al.*, 2021). Unskilled workers might result in poor construction outcomes such as delays, oversights, and possible damage

to the building façade. Knifka *et al.* (2023) described social challenges as among the main obstacles to green façade implementation such as lack of information, awareness (i.e., different perceptions of aesthetics), and knowledge. This leads to uncertainties, concerns, and prejudice among stakeholders such as clients, developers, and architects.

### **Potential Growth in Insect and Pollen**

Although a thick layer of vegetation on a building can create an attractive habitat for insects (Wood *et al.*, 2014), birds, and small animals, it could have a negative impact on the structure. The increase of insects in the vicinity of a building raises fears of attacks and infestations (Chew *et al.*, 2019). In addition, pollen from flowers can affect the health and well-being of those who are sensitive or allergic (Leong *et al.*, 2021). For this reason, approval and regulations must be followed when choosing plants.

### **Damage to Building Façade**

Leong *et al.* (2021) raises concerns about green facade plants causing micro damage to a building. Evergreen plants on a green façade can protect buildings from heavy rainwater but climbing plants can exacerbate existing cracks as they find their way into the gaps.

### **Competition with Alternative Solutions**

Green façades now face competition from other solutions to urban built environment issues. Living walls are becoming increasingly popular (Coma *et al.*, 2017; Chafer *et al.*, 2021) due to their sustainability in terms of materials.

### **Lack of Policy and Standard**

The lack of uniform industry standards and regulations for sustainable façade poses a challenge. Green Building Index (GBI) and Green Real Estate (GreenRE) are the two green building assessment tools designed and developed for the Malaysian framework. They take into account Malaysia's tropical weather,

environmental and development context, and cultural and social needs (Usman & Abdullah, 2018). However, both rating systems are just evaluation tools instead of standards for vertical greening. The codes will only ensure safety while installing such vegetation on high-rise buildings. The lack of policy and standards deters developers from adopting green façades due to fears of faulty design (Leong *et al.*, (2021).

### ***Plant Selection and Local Climate Consideration***

The selection of suitable plants is a dependent factor in the success of a green façade. Suitability to local climate conditions, growth characteristics, flexibility, and air purification capabilities are among the factors that should be considered when choosing plants (Wang *et al.*, 2020; Aung *et al.*, 2023).

### ***Maintenance***

Maintenance can be an essential factor in determining the effectiveness of a green façade (Aung *et al.*, 2023). Without the proper maintenance, plants can deteriorate and leading to a reduction of their benefits. Given that the efficacy of a green façade's performance is contingent on the type of plants used, as noted by Perini *et al.* (2021), the health and condition of these plants should not be overlooked. Designing a green façade would require the test of time and certain maintenance, and can be more challenging for high-rise buildings exposed to environmental factors such as hot climate.

### ***Methodology***

To explore the advantages and challenges of green façades in high-rise structures, a quantitative approach was employed. This involved distributing questionnaires via Google Forms to gather comprehensive insights into the research questions. Participants were required to answer and evaluate the questions using a Likert scale ranging from 1-Not Agree, 2-Less

Agree, 3-Average, 4-Agree, and 5-Most Agree. The targeted respondents were registered architects in Selangor, whose details were accessible through the *Pertubuhan Akitek Malaysia* (PAM) Directory. There are 540 architectural firms across Malaysia, with 165 of them in Selangor, and these firms constituted the study's population size. The research aimed for a 95% confidence level and a 5% margin of error with a 50% response distribution. To determine a representative sample, 116 survey participants were selected through stratified random sampling, using a sample size calculator available online. This paper used frequency analysis to interpret the data because it is useful in summarising large data sets and assigning probabilities. It is set as a graph or data to demonstrate the frequency of occurrence of each possible outcome of a repeatable event observed many times. It is a fundamental distribution that organises data from a population based on specific characteristics in a way that allows a person to understand the data and draw conclusions about the population (Kumar, 2011).

Whereas a statistical tool for determining the relative importance of several elements is the relative importance index (RII). This approach describes the likelihood of incidents and consequences on the project using a Likert scale of five points. An example of a five-point Likert scale is Strongly Disagree (1), Disagree (2), Neutral (3), Agree (4), and Strongly Agree (5). This technique shall be used to analyse all objectives of this paper. The higher the value of RII, the higher the ranking of the respondent (Rajgor *et al.*, 2016). The formula of the RII is shown below:

$$RII = \Sigma W / (A * N)$$

where:

W = the weighting given to each factor by the respondents (ranging from 1 to 5)

A = the highest weight (5 in this case)

N = the total amount of respondents

**Background Information**

Using an online sample size calculator, the questionnaire is emailed to 116 architectural firms in Selangor. This is the minimum sample size needed to achieve 30% of responses (Bryman, 2016). A total of 46 responses were obtained over three weeks, as shown in Table 1. The designation and years of working experience shall be the fundamental question of this survey. This section shall discuss the respondent’s designation in the construction industry.

**Designation**

According to Table 1, the respondents of the survey comprised junior architects, senior architects, project managers, principals/directors, design architects, technical specialists, and technical designers. 20 of the respondents are senior architects, which is the largest portion of responses at 43.5%, as shown in the table. Project managers make up the second largest group of respondents, at 10 or 21.7% of responses. This is followed by principal/director (7 or 15.2% of responses) and junior architect

(6 or 13% of responses). One design architect, technical specialist designer, and technical designer also responded.

**Years of Working Experience in the Construction Industry**

According to Table 2, 14 or 30.4% of the respondents have six to 10 years of work experience in the construction industry. The next largest group is made up of the 12 respondents who have more than 21 years of experience in the construction industry. The third largest group of respondents is the eight who have 16 to 20 years of experience. Six respondents each have less than 5 years or 11 to 15 years of working experience.

**Experience of Green Façades Implementation on High-rise Buildings**

According to Table 3, 60.9% or 28 respondents have no experience in green façades on high-rise buildings. The rest of the 39.1% of respondents

Table 1: Designation of respondents

Respondent Designation	Number of Respondent	Percentage (%)
Senior architect	20	43.48
Project manager	10	21.74
Principal/director	7	15.22
Junior architect	6	13.04
Technical designer	1	2.17
Technical specialist designer	1	2.17
Design architect	1	2.17
<b>Total</b>	<b>46</b>	<b>100.00</b>

Table 2: Respondents’ years of working experience

Years of Experience	Number of Respondent	Percentage (%)
< 5	6	13.04
6 to 10	14	30.43
11 to 15	6	13.04
16 to 20	8	17.39
> 21	12	26.09
<b>Total</b>	<b>46</b>	<b>100.00</b>

Table 3: Determination of respondents’ experience of green façade application on high-rise buildings

Experience	Number of Respondent	Percentage (%)
Yes	18	39.13
No	28	60.87
<b>Total</b>	<b>46</b>	<b>100.00</b>

report to have experience with green façades on high-rise buildings. Although 18 respondents have experience, 28 respondents who have not deal with green facades are still significantly important to the research to offer their view.

**Results and Discussion**

***Common Benefits of Green Façades Application within High-rise Buildings***

The benefits of green facades are categorised into three aspects: (i) Economic, (ii) environmental, and (iii) social.

***Economical Aspect***

Table 4 shows the relative importance index of the Economic Benefits of Green Façades within high-rise buildings in Selangor. The relative importance index (RII) can be calculated by gathering the number and level of responses in agreement. The ranking of each economic aspect’s benefits is rated based on the RII generated. No “Not Agree” response was recorded. The RII indicates all economic benefits within a range between 0.700 to 0.800. Table 4 displays the data of responses to questions on

noise absorption (RII = 0.730), potential energy saving (RII = 0.791), suitable for retrofitting projects (RII = 0.761), create job opportunities (RII = 0.709), and increase property value (RII = 0.796). The highest rank among all economic benefits of green facades is increased property, according to Knifka *et al.* (2023). This is followed by potential energy saving, suitable for retrofitting projects, noise absorption, and creating job opportunities.

Based on the analysis in Table 4, the top three economic benefits are increased property value, potential energy saving, and suitability for retrofitting projects. Green façades can increase property value by providing an environmentally pleasing workspace and living surroundings, which is why most respondents rated this as the highest rank.

Property owners and developers can use this information to make informed decisions about investing in green façades. Buildings with green facades could potentially save energy and lower operation costs. Green façades can reduce building temperature due to their vegetation absorbing excess heat. This can be the reason why potential energy saving is ranked in second

Table 4: Frequency, RII, and rank on economic benefits

Economic Aspect	Frequency of Scale					RII	Rank
	Not Agree	Less Agree	Average	Agree	Most Agree		
	1	2	3	4	5		
Noise absorption	0	4	18	14	10	0.730	4
Potential energy saving	0	4	5	26	11	0.791	2
Suitable for retrofitting projects	0	3	15	16	12	0.761	3
Create job opportunities	0	3	24	10	9	0.709	5
Increase property value	0	3	15	8	20	0.796	1

place. Retrofitting projects can boost building use, according to Hong *et al.* (2019). One of the main reasons that retrofitting project suitability is ranked in third place is because it can be an effective way to enhance building sustainability and aesthetics without the need for extensive construction. The RII suggests that respondents find green façades as a viable option for retrofitting to existing buildings.

Noise absorption and creating job opportunities are still valued economic benefits given their RII values within range of 0.7 to 0.8, which are the same as the top three economic benefits. The noise absorption benefit and the creation of job opportunities has the potential to improve the quality of life and improve the economy. However, it still depends on how the government and policymakers harness the potential of green facades.

**Environmental Aspect**

According to Table 5, blockage of wind has the lowest RII while others are above 0.750. Environmental benefits of green façades include urban environment and sustainability (RII = 0.878), shading potential (RII = 0.878), evaporative cooling (RII = 0.830), thermal insulation (RII = 0.878), blockage of wind (RII

= 0.661), improve air quality (RII = 0.817), biodiversity enhancement (RII = 0.796), and rainwater retention improvement (RII = 0.752). The highest-ranked environmental benefits are urban environment and sustainability, shading potential, and thermal insulation factors, which were agreed upon by 46 respondents. These three factors shared the same rank and were in line with the findings of Radić *et al.* (2019) and Aung *et al.* (2023). The next best-ranked environmental benefits are evaporative cooling, improved air quality, biodiversity enhancement, rainwater retention improvement, and blockage of wind.

Based on the analysis above, the top three environmental benefits share the same rank with the same RII, indicating they are equally important. The score of urban environment and sustainability suggests that green façades have a significant contribution towards a more sustainable and satisfying urban space. Shading potential, stems from the insulation features that will lower the heat within the building (Aung *et al.*, 2023). The high ranking of shading potential reveals its importance in tropical climates like Selangor. Urban environment and sustainability along with shading potential, thermal insulation received an RII of 0.878. The effectiveness of

Table 5: Frequency, RII, and rank on environmental benefits

Environmental Aspect	Frequency of Scale					RII	Rank
	Not Agree	Less Agree	Average	Agree	Most Agree		
	1	2	3	4	5		
Urban environment and sustainability	0	1	1	23	21	0.878	1
Shading potential	0	1	1	23	21	0.878	1
Evaporative cooling	0	4	2	23	17	0.830	4
Thermal insulation	0	0	1	26	19	0.878	1
Blockage of wind	2	10	12	16	6	0.661	8
Improve air quality	1	2	4	24	15	0.817	5
Biodiversity enhancement	1	3	2	30	10	0.796	6
Rainwater retention improvement	1	4	9	23	9	0.752	7

green façades in thermal insulation to regulate indoor temperature and lessen the need for air conditioning aligns with the findings of Wong and Baldwin (2016).

Other environmental benefits such as evaporative cooling and improved air quality have RII values of 0.830 and 0.817, respectively. These benefits are valuable in hot and humid climates like Selangor. Biodiversity enhancement and rainwater retention improvement have moderate RII scores, indicating the positive impact of green façades on biodiversity and water management. The lowest ranked environmental benefits is blockage of wind, where respondents did not consider it to be as relevant to other environmental benefits due to the climate characteristics of Malaysia.

**Social Aspect**

According to Table 6, different kinds of responses are received and rated regarding the benefits of implementing green façade in the social aspect. The frequency, relative importance index, and ranking of social benefits are concluded to display the data of respondents that include improving human health and well-being (RII = 0.830), providing a better environment (RII = 0.883), aesthetically pleasing (RII = 0.826), city branding (RII = 0.835), and educational effect (RII = 0.817). The highest-ranked social benefit is providing a better environment, which was mentioned by Aung *et al.* (2023). This is

followed by city branding, improved human health and well-being, aesthetically pleasing, and educational effect, which are in line with the findings of Radić, Dodig, and Auer (2019). All social benefits are relatively essential by having an RII value in the range of between 0.817 and 0.883.

In Table 6, the top three social benefits are providing a better environment, city branding, and improved human health and well-being. Quality of life visual appeal are enhanced by adopting green concepts such as green façades. Respondents imply that improving human health and well-being has a valuable impact on the people living in urban, in line with the findings of Wood *et al.* (2014). The other two social benefits, aesthetically pleasing and educational effect, rank fourth and fifth, respectively with RII scores above 0.80. This suggests that respondents appreciate and recognise the potential for green façades to serve as educational tools for sustainable practices.

**Challenges in Implementing Green Facades**

Table 7 lists the main challenges in implementing green facades classified into several areas: (i) Green façades construction cost, (ii) lack of technical knowledge, (iii) possible growth in insects and pollen, (iv) damage to building façades, competition with alternative solution, (v) lack of policy and standard, and (vi) plant selection and local climate consideration.

Table 6: Frequency, RII, and rank on social benefits

Social Aspect	Frequency of Scale					RII	Rank
	Not Agree	Less Agree	Average	Agree	Most Agree		
	1	2	3	4	5		
Improve human health and well-being	0	1	6	24	15	0.830	3
Provide better environment	0	0	1	25	20	0.883	1
Aesthetically pleasing	0	0	11	18	17	0.826	4
City branding	0	1	13	9	23	0.835	2
Educational effect	0	3	9	15	19	0.817	5

Table 7: Frequency, RII, and rank of challenges

Challenges	Frequency of Scale					RII	Rank
	Not Agree	Less Agree	Average	Agree	Most Agree		
	1	2	3	4	5		
Green façades construction cost	0	1	3	14	28	0.900	2
Lack of technical knowledge	3	5	5	14	19	0.778	4
Possible growth in insect and pollen	2	6	12	14	12	0.722	7
Damage to building façades	2	6	9	17	12	0.735	6
Competition with an alternative solution	1	6	22	11	6	0.665	8
Lack of policy and standard	0	3	13	14	16	0.787	3
Plant selection and local climate consideration	2	3	10	15	16	0.774	5
Maintenance	0	2	0	12	32	0.922	1

The data of respondents has been summarised in frequency, RII and rank based on given challenges such as green façades construction cost (RII = 0.900), lack of technical knowledge (RII = 0.778), possible growth in insect and pollen (RII = 0.722), damage to building façades (RII = 0.735), competition with alternative solution (RII = 0.665), lack of policy and standard (RII = 0.787), plant selection and local climate consideration (RII = 0.774), and maintenance (RII = 0.922). The highest ranked challenge is the maintenance factor, which agrees with Aung *et al.* (2023). This is followed by green façades construction cost, and lack of policy and standards, which are in line with Leong, Yeap, and Ang (2021). The fourth highest ranked challenge is lack of technical knowledge, followed plant selection, and local climate consideration, damage to building façades, possible growth in insects and pollen, and competition with alternative solutions.

The main challenges to implementing green façades within high-rise buildings in Selangor are maintenance and construction cost, with RII scores of 0.922 and 0.900, respectively. These are the only two challenges

with RII values above 0.90 while others are below 0.80. The rank of maintenance suggest that respondents feel that ongoing work and updates are challenging. According to Aung *et al.* (2023), the maintenance challenges can influence the effectiveness of green façades. Respondents' concern about construction costs highlights the financial challenges associated with implementing green façades. This concern has been mentioned by Leong *et al.* (2021) in terms of wire mesh material cost. It can influence the determination of developers and building owners to choose green façades solutions.

Lack of policy and standard is also another significant challenge that ranked third with a RII value of 0.787, aligning with the findings of Leong *et al.* (2021). This challenge can be improved by providing clarification and adopting green façades to boost the trend. Besides, lack of technical knowledge, plant selection, and local climate consideration, damage to building façades, possible growth in insects and pollen, and competition with alternative solutions are also perceived as challenges even though their RII scores are low compared to the top two challenges.

## Conclusions

Based on the overall benefits of the green façade described in this paper, most of the respondents agree that providing a better environment, urban environment and sustainability, shading potential, and thermal insulation are the main considerations. The economic benefits of green façades have an average relative importance rate of 0.757, which is the lowest compared to social and environmental benefits. The respondents also shared the most possible challenges in dealing with green façade applications such as maintenance and green façade construction costs.

In a nutshell, the implementation of green façade in Selangor high-rise buildings is likely on track and encouraging. Green façade has potential to be a promising vertical greenery solution for urban built environments in terms of economic, social, and environmental aspects. It serves as one of the approaches to deal with climate change and sustainability as it aligns with the researchers' inputs and concerns. In addition, its implementation could be part of the input for green buildings to get certified by meeting green building index criteria.

Although there are certain barriers to their implementation, one must look at the bigger picture by having practical strategies along the way to increase the implementation of green façade in the context of Malaysia. Thus, there is a crucial need for regulatory and technological support to drive sustainability in urban development. Both public awareness, better enforcement of green building policies, and standards are rated by respondents are equally significant. This is consistent with Leong *et al.* (2021), which indicates the need to raise awareness among the public and ensure existing green building policies and standards are essentially enforced. It emphasises how crucial enforcement and education programs are.

For future research, other researchers should consider studying other urban built environments in other states or even suburbs to determine whether the research outcomes are different. Besides, the method of research

should be extended to qualitative research for better in-depth discussions with respondents who have experience in the field.

## Acknowledgements

The authors are grateful to the Department of Quantity Surveying from the Faculty of Engineering and Quantity Surveying (INTI IU) for providing the opportunity to carry out this research. The authors also appreciate any constructive comments from reviewers and are solely responsible for any mistakes in this article.

## Conflict of Interest Statement

The authors declare that they have no conflict of interest.

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