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# URGING GREEN RETROFITS OF BUILDING FAÇADES IN THE TROPICS: A REVIEW AND RESEARCH AGENDA

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## ABSTRACT

Green building development creates many opportunities for meeting the United Nation's Sustainable Development Goals (SDGs). However, most green buildings are new builds rather than retrofitted existing buildings. This may become an impediment for green development progress, as the issues of deforestation and land preservation remain unresolved. Green retrofitting of building façades is one of the most effective passive design strategies and permits perennial benefits for building energy performance, cost savings, and positive environmental impacts. There are a wide range of façade retrofit technologies readily available on the market at relatively low cost that require little installation time and yet can achieve similar energy performance levels as new green buildings. Notwithstanding these advantages, the uptake rates for these are moderately low. The challenges to widely implementing façade retrofitting of Malaysian office buildings are foreseen as holistic and include not just engineering and construction activities, but also social, economic, environmental, and governmental support. This paper aims to review the focus and direction of green development in the Malaysian construction industry and subsequently propose a research agenda for the rapid adoption of green façade retrofitting for local office buildings. The research agenda will commence with a survey on key factors that impede the uptake of green façade retrofitting, and then conducts energy simulations for contemporary green facade technologies (GFTs) using Building Information Modelling (BIM) software. It finally develops a decision-making tool for GFT selection based on simulated energy performance data and the key factors associated with building owners' considerations and expectations of façade retrofitting. The final research output is expected to act as a catalyst to spur green development progress by identifying the real issues faced by the prevailing construction industry.

*Keywords:* Building facade; Decision-making; Energy saving; Green retrofit; Simulation

## 1. INTRODUCTION

The growth of urban populations has great impacts on regional climatic systems, biodiversity, ecosystem productivity, and carbon emissions. According to the United Nations (2018), 68% of the world's population will be living in urban city by 2050, contributing to a serious urban warming issue that is a significant variable in the prediction of energy demand in urban regions.

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In general, approximately 50% of energy goes to cooling buildings, and the cooling system in Malaysia accounts for 57% of its energy demand (Santillán-Soto et al., 2019). Hence, increasingly dense urban populations anticipate the rapid growth of energy consumption in buildings due to the corresponding increase in general cooling demand.

In view of environmental deteriorations due to urbanization, green building and sustainability have become dominant techniques in modern construction. Much effort has been dedicated to the development of green buildings in almost every region. Nonetheless, the existing phenomena shows green buildings are mostly new builds rather than retrofitted from the existing building stocks. In fact, existing buildings, particularly non-residential buildings, create significant amounts of greenhouse gasses with serious consequences for the environment.

Building retrofitting is expected to dominate the construction market due to being more resource-efficient by avoiding both demolition and rebuilding, which generate large amounts of waste (Sun et al., 2018). It involves only modifications of existing buildings, often with installations of new building envelopes and advanced mechanical building systems for better energy efficiency. Yang and Lim (2007) indicated that the cost of retrofitting is only about 30% to 50% the cost of demolition and reconstruction. It is expected that these current cost savings will only grow with the evolution of more advanced retrofit technologies in the market. Although retrofitting is perceived as a cheaper solution, the installation of advanced but immature building mechanical systems can be great risks in terms of operational breakdown and uncertain future maintenance cost. Conversely, the alteration of building envelopes is far more beneficial for long-term value. The latest green technologies available for building envelopes, especially for building façades, demonstrate more stable energy and cost reductions, although some of these strategies require a longer payback period. A wide range of green façade technologies (GFTs) are readily available in the market that require lower investment and less installation time and yet exhibit similar energy performances as newly constructed green buildings. Notwithstanding these advantages, the uptake rates of GFTs are moderately low in the Malaysian construction industry.

Malaysia is currently a developing country experiencing rapid urbanization (Ibrahim et al., 2018) that needs to review its existing focus on green development and determine an appropriate direction for its construction industry to meet sustainability goals. The awareness, perceptions, and expectations of building owners about façade retrofitting in existing office buildings in Malaysia should receive attention as well. Building energy performance analyses of contemporary GFTs are also crucial to assess whether these solutions are valuable enough to warrant building owners' investments. Decision-making guidelines for GFT selection would assist building owners in their investment decisions based on GFT energy performance evaluations and other factors associated with their concerns and expectations.

This paper first reviews the progress of green development in Malaysia by evaluating the existing focus and direction implemented for achieving sustainability goals. Subsequently, it presents a research agenda with a strategized methodology focusing on Malaysian office building retrofitting. The three important objectives in the research agenda are: (1) the identification of key factors that impede the uptake of green façade retrofit; (2) evaluation of the energy performances of the latest GFTs using BIM software; and (3) the development of a decision-making tool for GFT selection based on validated energy performance data and other factors associated with the building owners' considerations and expectations.

## 2. FOCUS AND DIRECTION TOWARD SUSTAINABILITY GOALS

Resolving energy inefficiency issues in existing buildings should be a paramount energy goal of every country. One of the urban cities in Malaysia—Kuala Lumpur—now faces an agingbuilding problem. Its old buildings, especially non-residential ones, are at risk of low thermal performance and high energy consumption. Despite their lack of insulation, high air infiltration, and solar heat gain, these buildings from the 1970s are still in use today. In fact, the peak electricity load for cooling purposes in existing buildings can be up to triple in the urban areas compared to new buildings (Papanastasiou et al., 2013). To solve energy inefficiency issues for these existing buildings, a greener solution would be building retrofitting rather than demolition and reconstruction. The current statistics on the Green Building Index (GBI) certified buildings in Malaysia for non-residential new construction (NRNC) versus non-residential existing building (NREB) is 254:16 (GBI, 2019), signifying a poor building retrofit experience in the Malaysian construction industry.

Retrofitting existing buildings is the ideal option to undergird environmental, social, and economic sustainability. On the environmental pillar, this option not only preserves lands and forests but also can reduce site waste and carbon emission. On the social and economic pillars, retrofitting saves cost and installation time and involves less complicated work. While retrofitting, the risk of worker cost and tenant decanting is low compared to demolition and reconstruction. According to Chia (2017), Danish buildings apparently saved approximately 50% energy per square meter for heating after the revisions of the Building Code for retrofit.

Building retrofitting that integrates both building envelopes and active building systems, such as solar panels, indeed to target zero or nearly zero building energy consumption. However, this integrated solution is frequently used in government funded projects and often fails to attract many other investors. The Building and Construction Authority (BCA) Academy in Singapore is one of the retrofitted Zero Energy Buildings (ZEBs) funded by the government. The Singapore government also launched the Green Mark Incentive Scheme for Existing Buildings (GMIS-EB) in 2009 to encourage building owners or developers to adopt energy-efficient retrofitting strategies in their existing buildings. The stated scheme has targeted at least 80% of all existing buildings to be Green Mark–certified by 2030 (National Environment Agency, 2019).

Based on a set of globally adopted retrofit measures, building envelopes have shown tremendous contributions as energy-conserving measures across all building types compared to other building mechanical systems, such as smart Heating, Ventilating, and Air Conditioning (HVAC), renewable energy, metering, and sensors (Hong et al., 2019). Advanced building systems, such as smart cooling, used to be high-risk in terms of operational breakdown and uncertain future maintenance cost. Blumenfeld and Thumm (2014) brought over 40 years of experience from both the public and private sectors to review the return of investment on building mechanical systems and envelope design, and they realized that building owners tend to: (a) overinvest in active building systems; (b) underinvest in passive envelope design; and (c) underestimate the maintenance costs of complex building active systems. Ng and Akasah (2011) identified the building system problems faced by the Malaysia Energy Center, testifying that the inefficiency of the cooling system, air movement, and chillers prevented the building from achieving a zero Building Energy Index (BEI). This masterpiece ZEB in Malaysia now possesses another green label—“nearly” ZEB—due to its building system failures. Despite the building system breakdown, its energy-efficient facade and other passive ZEB design features remained functioning to support the building in a low-energy mode. In fact, the tangible benefits of a low-energy façade are more established than those of advanced building systems.

External walls and windows are the biggest surfaces exposed to solar radiation and usually contribute the highest cooling load to a building. Façade retrofit is thus undeniably one of the most effective passive design strategies that permits definite, perennial benefits due to its stable system. Façade alteration can directly increase building energy performance, provide instant cost saving on electricity bills and maintenance, and subsequently contribute to positive environmental impacts.

Perhaps the Malaysian government intended to target high percentage of existing buildings to be GBI-certified, a combination of green façade retrofit strategies should be prioritized for the sake of rapid adoption by building owners on a large scale. The government should target attracting numerous existing building owners to attain at least “certified-rated” NREB for their own buildings, rather than the less probable “platinum-rated” NRNC under GBI certification. The main obligation is to create awareness among building owners to prioritize building façade retrofit before the installation of other building systems to ensure high returns on their investments. The additional building systems, such as advanced cooling systems, renewable energy systems, and smart automation systems, can be considered when financially permitted. The conceptual framework, as shown in Figure 1, illustrates why green retrofitting of building façades is a worthwhile focus and what is the sensible direction to speed up green development progress toward achieving sustainable city transformation goals in Malaysia.

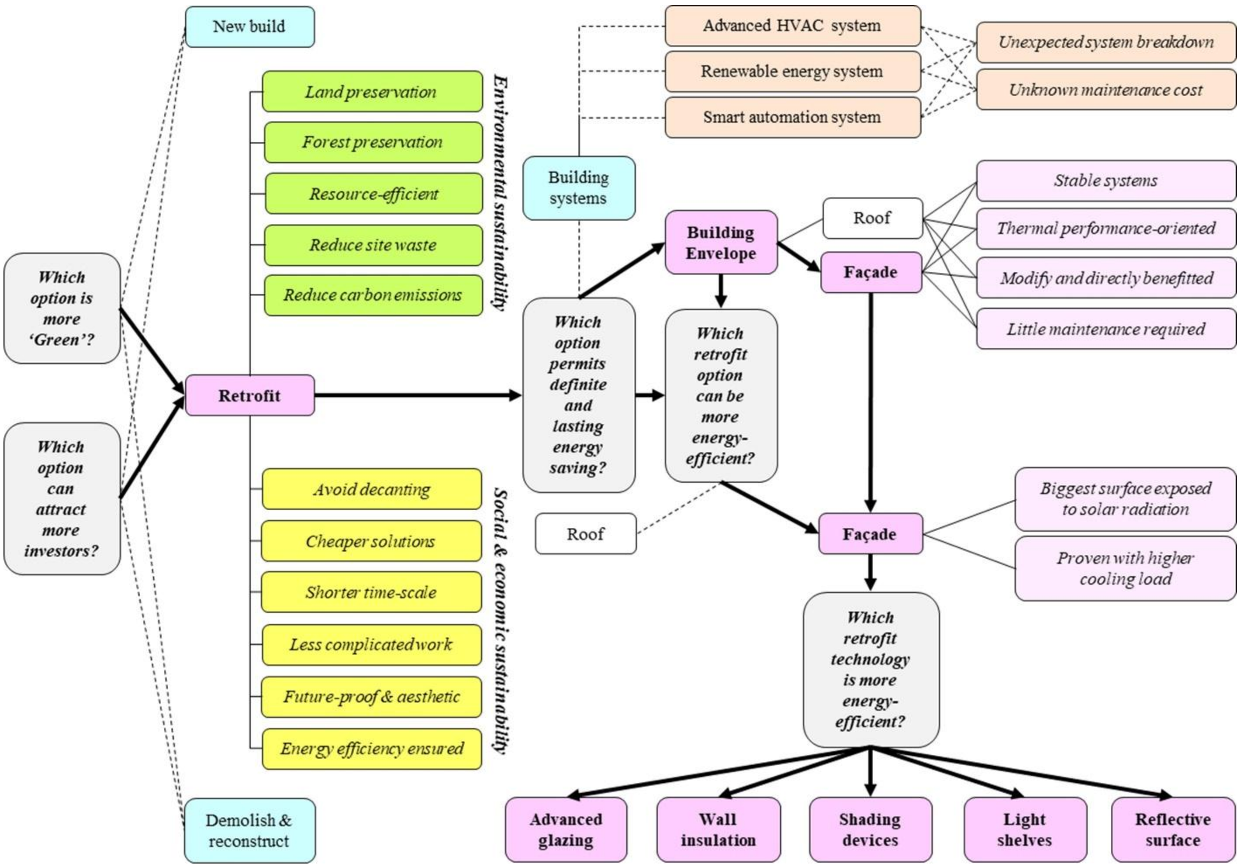


Figure 1 Green retrofit of building façade is the primary focus and direction toward the sustainable city transformation goal

## 3. EXPLORING BUILDING STAKEHOLDERS’ INSIGHTS

Due to the large scale of existing office buildings in Malaysia, decision-making in green façade retrofitting is not easy. The key factors that impede local office building owners’ decisions in green façade retrofitting are so far not fully understood. According to Basten et al. (2019), the major inhibiting factors in green building concept implementation include the uncertainty of the cost benefits, low levels of engineering knowledge, and a lack of governmental incentives. Sanguinetti (2012) also claimed that the potential challenges of façade retrofitting are associated with the reliability of energy performance data of the retrofitted projects and the uncertainty of cost implications for building life cycles.

Not surprisingly, the level of environmental knowledge and the level of awareness of current GFTs are perceived as low among local office building owners. Their investment interests, expectations of government incentives, the conditions of their existing buildings, and their readiness for green retrofitting are also significant factors to be explored. The latest GFTs available in the local market and their energy performances and cost implications for building life cycles are strongly encouraged to be publicized for local building owners' consideration.

## 4. MEASURES OF GREEN FAÇADE RETROFIT

Façade design has become one of the best strategies that makes significant impact on building energy performance. The design characteristics of façade retrofitting are analogous to façade design. However, façade retrofit design may be limited by fixed or difficult-to-amend building parameters (e.g., building orientation and floor-to-floor height). Green façade retrofitting aims for a solution that is energy-efficient and that provides indoor comfort, productive lighting, and an appropriate acoustic environment by reducing the use of mechanical and electrical systems for lighting, ventilation, etc. Garmston (2017) stated that the costs and long-term nature of façade retrofitting are strategic while the design of the façade can be intricate and multidisciplinary.

Façade retrofitting decisions can range from window upgrades to much more complex modifications. By adopting well-proven technological solutions in building retrofits, the primary energy demand and associated emissions could be efficiently reduced by 40% to 50% (Ferrari & Beccali, 2017). There are five major GFTs in the retrofit market: (1) low-emissivity (low-e) glazing; (2) wall insulation; (3) shading devices; (4) light shelves; and (5) surface reflectivity. Despite each of these five GFTs being highly energy-efficient, an optimal energy performance by the combination of them has not been fully investigated. Hong et al. (2019) reported that wall insulation had the most significant benefits in energy savings; however, the research by El-Darwish and Gomaa (2017) disclosed that solar shading was the most energy-efficient strategy. Zhang et al. (2011) discovered that wall insulation and low-e glazing are comparatively more economical to apply as opposed to solar photovoltaic (PV) panels or heat-pump technologies. These strategies should be applied on a large scale to guarantee significant energy improvements. According to Ali et al. (2018), the application of double-glazing material combined with shading devices can reduce energy consumption by nearly 50%. Chia (2017) supported this finding, stating that a single layer of acrylic glass could save up to 53% of the electricity consumption of a Jakarta office building, and the façade temperature dropped from 51$^{o}$C to 34$^{o}$C in a Spanish office building with the installation of shading devices. As a result, there is a need to further investigate the energy performance and cost benefits of these advanced GFT implementations in Malaysia. The following sub-sections detail the characteristics of the five aforementioned GFTs and their applications in local green buildings.

### 4.1. Advanced Glazing

Low-e coating is normally used in green buildings and can have an emittance as low as 4% of the energy possible at its temperature, therefore reflecting 96% of the incident long-wave, infrared radiation. Such glazing material is designed to optimize energy flows for solar heating, daylighting, and cooling. However, the energy performances of low-e glazing windows can often be vague, as they involve nearly every technical parameter supplied with the window. This technology has been applied in the Ministry of Energy, Green Technology and Water – Low Energy Office (LEO) Building, the Malaysian Energy Center Green Energy Office (GEO)

Building, and the latest Energy Commission (EC) Diamond Building in Malaysia (Tharim et al., 2018).

### 4.2. Wall Insulation

Wall insulation is referred to a thermally insulated layer between the brick cavity of the external wall, usually involving the use of: (a) expanded polystyrene; (b) mineral wool; or (c) polyurethane foam to protect a building from the exterior environment. Air or gas also act as wall-insulating layers to slow the movement of heat through the wall. The aforementioned Malaysian LEO Building uses aerated lightweight concrete walls that involves air or gas mixtures in a cement slurry and fine sand for the formation of concrete blocks. The GEO Building in Malaysia uses thermal walls with rockwool insulation that can reduce heating or cooling costs by up to 40% (Aminuddin et al., 2012).

### 4.3. Shading Devices

The most common and effective shading devices range from awnings, vertical and horizontal fins, recessed windows, and vegetation for solar heat gain reduction. In fact, moveable, vertical, and horizontal shading fins are suitable for all building orientations. Advanced shading screens or fabrics can be applied to façades with either a fixed or retractable function to reduce solar heat gain. Singapore’s nature park—Gardens by the Bay—is a good example of utilizing automated shading screens or light redirection systems that integrate solutions for controlling light and solar heat gain. This system can substantially reduce solar heat gain by more than 30% when partially deployed and up to 70% when fully deployed (Tensinet, 2016). It is thus expected to effectively decrease electricity loads and address human comfort issues such as thermal comfort and glare.

### 4.4. Mirror Light Shelf

A “light shelf” refers to a passive architectural device with a horizontal surface mounted inside or outside a building. Direct sunlight can cause glare near windows while leaving areas further in dark. Mirror light shelves can reflect natural daylight onto the ceiling and distribute it more evenly and deeply within a space, making the indoor lighting more comfortable with no glare (Aminuddin et al., 2012). At the same time, the diffuse daylight is cooler inside the building. Exterior shelves are generally having greater shading effects than interior ones. A combination of exterior and interior shelves, however, usually provides an even illumination gradient. The EC Diamond Building and GEO Building in Malaysia both apply 50% daylight mirror light shelves for cooler daylight.

### 4.5. Reflective Surface

Light-color building materials, such as Integral Coloring Treated Concrete (Scofield, n.d.) and other external wall finishes, are proven to have high solar reflective indices (SRIs). The SRI is measured on a scale of 0 to 1.0: 0% reflective (0) to 100% reflective (1.0). Generally, materials that appear to be light-colored in the visible spectrum have high solar reflectance and vice versa. As discussed before, the mirror light shelf design provides high-SRI reflective surfaces and highly reflective ceiling paint to distribute daylight deeper into buildings.

## 5. RESEARCH METHODOLOGY AND EXPECTED OUTPUT

To achieve the three objectives specified in the research agenda, a mix of quantitative and qualitative research approaches will be adopted to collect and compile the primary data. The following sub-sections describe the strategized methodology focusing on the green façade retrofitting of Malaysian office buildings.

### 5.1. Interviews of Building Stakeholders

Face-to-face interviews targeting 15 office building owners and 15 green building consultants will be conducted to address the first research objective: identifying the key factors that impede the uptake of green façade retrofitting in local office buildings. The significant points in the interview discussions will include, but are not limited to: (1) general knowledge and awareness of GFTs; (2) reliability of energy performance data; (3) unrealistic cost data; (4) government incentives; (5) limited investment capital; (6) building conditions; and (7) end-users' interests and expectations. NVivo software will be adopted to analyze the interview data from different stakeholders' perspectives. The key factors that impede the uptake of green façade retrofitting are expected to be: (1) a lack of knowledge and awareness about GFTs; (2) the reliability of energy performance of different GFT combination; and (3) the cost and payback period of façade retrofitting.

### 5.2. Energy Performance Simulation

The second research objective, that is, the energy performance simulation of different GFT combinations, will be conducted using ArchiCAD BIM software. The simulation will be carried out based on the combination of the five latest GFTs applied to façade retrofitting: (1) enhanced glazing; (2) wall insulation; (3) shading devices; (4) light shelves; and (5) reflective surface materials. To initiate the energy simulation, a BIM model of a typical office building will first be developed. Next, data for each GFT, including material thickness, thermal conductivity, solar transmittance, retrofit cost per square meter, opening size, etc., will be collected as the input for the energy simulation modeling. Variables such as building orientation, building systems installed, and surrounding temperature will be fixed at a few potential settings for the simulation studies to compare the building energy performances purely based on the GFT combination factors. The analysis of the energy performance for a typical office building will then be conducted based on the following scenarios:

| | |
|---|---|
| Scenario A: | Typical Building without GFT |
| Scenario B: | Scenario A + GFT combination 1 |
| Scenario C: | Scenario A + GFT combination 2 |
| Scenario D: | Scenario A + GFT combination 3 |
| | ⋮ |
| Scenario *n*: | Scenario A + GFT combination *n* |

For each simulated scenario, the output, including energy performance reports (MWh/m$^2$ per year), retrofit costs, life cycle costs (MYR/m$^2$), and payback period, will be generated. An analysis of the simulated output will be presented in bubble-chart format through a nominal group technique, as shown in Figure 2. The energy performance and cost-related data in Figure 2 are not the actual results.

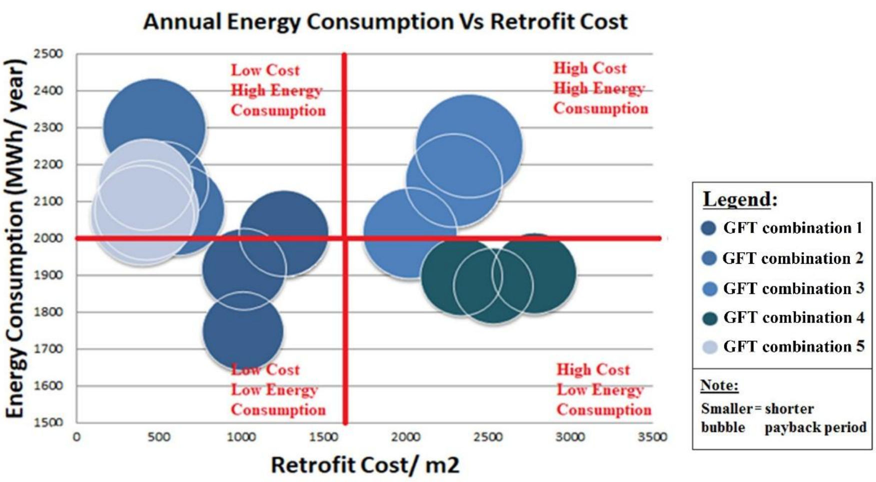


Figure 2 A sample bubble chart demonstrating the relationships between energy performances, retrofit cost, and payback period of different green façade technologies (GFTs)

### 5.3. Development of Decision-Making Tool

The last research objective, that is, to develop a decision-making tool for the selection of GFT combinations, will be established based on the interview results and validated energy performance data for each designated scenario. A sample decision matrix, as shown in Figure 3, is expected to be delivered to provide local building owners a clearer understanding about green façade retrofit benefits and the available choices. Building owners should then be able to make appropriate retrofit decisions based on their existing building conditions, affordability, individual interests, and other factors using this tool.

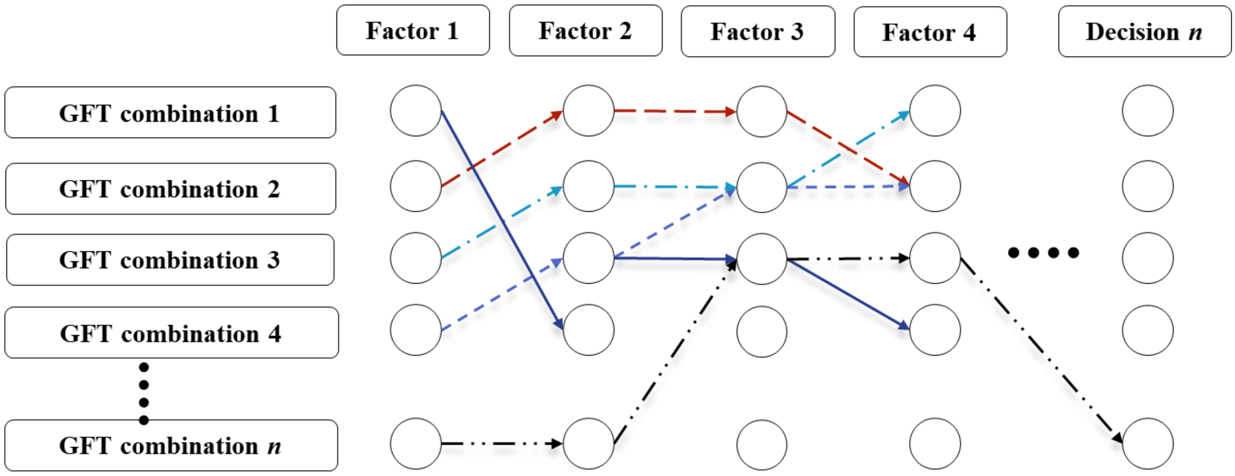


Figure 3 A sample decision matrix for the selection of GFT combinations based on building energy performance, building conditions, investment capitals, end-user's expectations, and many other factors

## 6. CONCLUSION

Retrofitting existing buildings can afford to reach optimal energy savings depending on implementing the right strategies. A variety of advanced green technologies available for façade retrofitting can save up to 50% of a building's energy consumption, which is similar to the savings of a newly constructed low-energy building. Existing office building owners can only show interest in green façade retrofitting if its tangible benefits in energy and cost saving are made clear for each available GFT. The final decision matrix for GFT selection will serve as a foundation to educate existing building owners about the stated benefits of façade retrofitting and subsequently allow them to make investment decisions based on their affordability, existing building conditions, the energy performances of each GFT combination, and many other factors. They should always seek to prioritize retrofit strategies in passive design, especially in green façade design, and simplify active building systems while considering the tangible benefits of their retrofit decisions. The research prospect focusing on façade retrofit strategies may attract many potential investors to contribute at least "certified-rated" NREB under GBI Malaysia. A successful scenario would be many rapidly emerging sustainable cities in the country. This research does not intend to depreciate the value of advanced building systems but prioritizes and promotes a more established strategy in building retrofitting for large-scale implementation.

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