PVC Mesh as Adaptable Recycled Textile Waste towards Innovative Tropical Building Façade

Azlan Ariff Ali Ariff[1,2], Muhammad Zharfan Mazdi[2], Ana Paula Delos Santos Ilagan[3], Nur Zawani Shafie[4]

[1] Postgraduate Studies, College of Built Environment, Universiti Teknologi MARA Shah Alam, Shah Alam, 40450, Malaysia
[2] School of Architecture and Interior Architecture, College of Built Environment, Universiti Teknologi MARA Cawangan Selangor, Kampus Puncak Alam, 42300 Bandar Puncak Alam, Selangor, Malaysia
[3] College of Engineering, Architecture, and Technology, University of Perpetual Help System DALTA, Alabang-Zapote Avenue, Pamplona 3, Las Piñas City, 1740 Philippines
[4] Creative and Art Industries, Architecture and Planning Building, University of Auckland, Auckland CBD, Auckland 1010, New Zealand

azlanariffwork@gmail.com, mzharfanm@gmail.com, ilaganap@gmail.com, nzawani@georgevic.com.my
Tel:+603-32586226

Abstract

Textile fibres are commodity materials that society will continue to use in large quantities for various applications yet also generate massive waste. Through coating application, upcycled textile waste has significant potential in building construction. The purpose of this study is to demonstrate the usage of PVC mesh textile waste as a novel textile facade for Malaysian structures. Content analysis is used to analyse various textile façade constructions that perform architectural tasks. The overall conclusion found that PVC mesh covers all features in balance as a creative building façade that responds to the needs of the Malaysian tropical climate.

Keywords: Textile waste, Building façade, Recycled material, Textile facade

DOI: https://doi.org/10.21834/aje-bs.v8i24.436

1.0 Introduction

In Malaysia, the issue of excessive textile waste resulting from the mass production of textiles is a significant concern. However, there is potential to address this issue by upcycling synthetic waste. Recent research has focused on repurposing industrial textile waste or recovering worn fabrics to produce recycled fibres (Patti et al., 2020). These recycled fibres can then be used as fillers in composites, along with coated fibreglass or coated foils (Paul et al., 2021).

In Malaysia's fashion industry, efforts are made to recycle consumer textile refuse and close the loop. This practice entails accumulating post-consumer textile waste and reusing it to manufacture new items (Radhakrishnan, 2021). Developing textile facades for the exteriors of buildings is one area where this strategy shows promise.

Textile façades have some advantages over traditional building facades. Their ability to be used in free-form designs is a significant advantage, allowing for greater flexibility and creativity in building aesthetics (Shareef & Al-Alwan, 2021). The lightweight nature of textile materials makes them simpler to handle and install, reducing the building's overall weight and load (Monticelli & Zanelli, 2021). Furthermore, textile facades are comparatively low-maintenance, requiring less effort and resources than conventional building materials (Singh, 2021).

Malaysia can resolve the issue of excessive textile waste while also reaping the benefits of this innovative approach to building design by repurposing textile waste into recycled fibres and employing them in textile facades. In addition to promoting sustainability, this fosters the development of a circular economy in the textile and construction industries.

1.1 Research Question

The research question for this paper is as below:
What are the main functions of façades, and how do they react to tropical climates?
What potential of textile waste can be developed into a textile facade?
What is the best type of textile façade that can be used for construction in Malaysia?

1.2 Research Aim & Objectives

The research aims to establish the use of PVC mesh textile waste as an innovative material for constructing textile facades in Malaysia. The objective of this study is; to study the use of façade and how it responds to the tropical climate, to identify the properties and specifications of the textile facade, and to determine the optimal form of textile facade for use in Malaysian buildings. This justifies the significance of this study, as it satisfies both the environmental sustainability requirements of the textile manufacturing process and the production of products with multiple applications.

2.0 Literature Review

2.1 Textile Waste as a Recyclable Material

The general public, the manufacturing industry, and consumers can all provide textile waste such as fibre, textile, and apparel. Some synthetic fibres do not biodegrade, resulting in soil and surface water contamination problems (Peller et al., 2019). Cotton fibres naturally decompose, releasing methane as a byproduct and contributing to global warming (Degenstein, 2018). Textile recycling is an ideal way to reduce the environmental impact of commonly used products (Pichardo et al., 2018), with an innovative application as a building facade construction material being one of the viable options. By recycling textile waste, the impact on the environment can be reduced. Recycling saves energy and water, reduces the need for basic materials, and reduces the environmental effects associated with textile production (Pandey et al., 2020).

Textile refuse is capable of both downcycling and upcycling (Arana et al., 2020). Downcycling is the process of transforming textiles into lower-value products, such as insulation materials and cleaning linens (Yalcin-Enis et al., 2019). Although downcycling extends the lifespan of fabrics and reduces pollution, it does not preserve the materials' original quality or value. On the other hand, upcycling transforms textile refuse into higher-value products through inventive design and repurposing (Kagitci, 2021).

There is an increasing market demand for sustainable and recycled textiles. Demand for products produced from recycled textile materials is fueled by the desire of consumers and businesses for eco-friendly products (Rathore, 2023). This provides businesses with opportunities to innovate and develop sustainable textile recycling technologies and products, thereby contributing to the development of a circular economy (Radhakrishnan, 2021). A circular economy is one in which materials are used and recycled continuously, minimising waste and resource consumption (Coppola et al., 2023). Incorporating recycled textile materials into new products makes the industry more sustainable and resource-efficient (Cainelli et al., 2020).

Textile waste treated as recyclable material can be a valuable resource that helps reduce environmental impact, conserve resources, and contribute to a circular economy by recycling textile refuse. Critical steps towards a more sustainable and waste-free textile industry include the development of efficient recycling processes, expanding recycling infrastructure, and creating a market demand for recycled textiles, especially in building construction which consumes a massive amount of materials.

2.2 Defining Building Facade

Facades are a component of a building's envelope that supports exterior architectural features; they have evolved to satisfy various functional and climatic needs (Kaewpeela et al., 2020). They provide structural support for the windows, doors, cladding, and decorative features. Facades considerably contribute to the overall aesthetics and character of a building, enhancing its visual appeal and architectural design (Elmokadem et al., 2019). They have evolved to meet diverse functional and climatic requirements. In terms of functionality, building facades provide essential support and defence by providing insulation, security, and structural integrity, acting as a barrier between the interior and exterior environment (Sandak et al., 2019). From a climatic aspect, facades are designed to accommodate various environmental conditions. They consider solar radiation, wind exposure, temperature fluctuations, and humidity levels (Barrelas et al., 2023). Façades effectively incorporate shading devices, ventilation apertures, and insulation materials to address these climatic requirements (Ciampi et al., 2023). Operationally, facades can be defined as a vital component of a building's envelope, supporting architectural features, contributing to aesthetics, and meeting diverse functional and climatic needs through insulation, security, structural integrity, and incorporating ventilation apertures and insulation materials to address environmental conditions effectively.

2.2.1 Plays A Pivotal Role in Energy Efficiency

A facade plays a significant role in energy efficiency by reducing solar heat gain, which reduces the building's cooling requirements and energy expenditures due to decreased energy consumption (William et al., 2021). They provide insulation, reducing heat transfer from the exterior to the interior in warm weather and minimising heat loss in frigid weather (Sarihi et al., 2021). This insulation contributes to energy efficiency by creating a comfortable indoor climate and reducing the need for excessive heating or cooling. Proper design, construction, and sealing of the facade components improve the overall air tightness of the building envelope (Moghtadernejad et al., 2020). An airtight facade prevents air leakage, reducing heating or cooling losses and improving energy efficiency (Mabuchi et al., 2019). Applying insulation on the facade, advanced glazing systems, natural lighting optimisation, ventilation strategies, and the integration of renewable energy can significantly reduce energy consumption and carbon footprint and create more sustainable and environmentally friendly built environments.

2,2,2 Shield Against Natural Threats

Facades shield building occupants from wind, rain, temperature, humidity extremes, and corrosion, which has proven valuable over many decades (Athauda et al., 2023). They serve as a barrier against water infiltration, protecting the structure's structural integrity and preventing costly water damage (Moghtadernejad et al., 2020). Fire is another natural threat that facades safeguard against. It is possible to design facade materials and systems with fire-resistant properties that prevent the spread of flames and pollution (Sandak et al., 2019). Fire-rated glazing, fire-resistant cladding, and appropriate compartmentalisation through facade design contribute to the building's overall fire safety, allowing occupants more time to evacuate safely and minimising damage due to fire breakout (Torero, 2022). In addition to these natural hazards, facades can protect from environmental factors such as pollution and ultraviolet radiation. Facade systems with UV-resistant glazing can safeguard occupants and interior finishes from damage caused by ultraviolet rays (Li & Zanelli, 2021). High-quality facade materials and coatings are resistant to the effects of pollutants, thereby preventing their entry into the building and preserving interior air quality.

2.2.3 Allows Natural Ventilation

Various facade treatments, including architectural elements, porous coverings, and automated windows, admit natural ventilation into buildings, ensuring that inclement weather does not compromise the comfort of building occupants (Roig et al., 2023). Cross ventilation, in which fresh air enters through one side of a building and departs through the opposite side (Nasrollahi & Ghobadi, 2022), can be encouraged through façade designs. Facades should be designed to take advantage of prevailing winds for adequate airflow while considering the sun's path to optimise daylighting (Kabošová et al., 2022). In addition to interior space layout and room connectivity, the placement and size of openings are crucial for accomplishing cross ventilation. Excellent facades facilitate fresh air flow into and out of interior spaces, fostering air circulation and enhancing indoor air quality. Natural ventilation has numerous advantages. It removes stale air, pollutants, and odours from the indoor environment, improving air quality (Osaro et al., 2022). This is especially essential in working and living spaces where pollutants and odours accumulate. By permitting moist air to escape and bringing in drier outdoor air, natural ventilation can also help regulate humidity levels. Facades can effectively harness natural airflow and daylight to enhance occupant comfort, energy efficiency, and well-being. This integrated approach aligns with sustainable building practices and creates healthy and enjoyable spaces for occupants.

2.2.4 Provides Acoustic Insulation

The acoustic insulation properties of a building's facade may be affected by the materials used to construct it. Composite materials consisting of layers of differing densities can also improve acoustic insulation (Caniato, 2020). A well-designed facade exterior skin provides greater acoustic comfort for the building's occupants than a conventional building facade. The acoustic comfort does not compromise necessary ventilation, air exchange, or visual connection to the outdoors. A well-designed facade will consider factors such as the orientation of the building, the positioning of windows and apertures, and the use of seals and gaskets to minimise air gaps and potential sound leakage points (Klingenberg, 2020). Proper installation and construction methods, including sealing joints and cracks, are necessary to guarantee the facade's effectiveness in reducing sound transmission (Mateus & Pereira, 2023). In addition to preventing sound transmission, facades can integrate sound absorption elements to reduce internal reverberation and improve sound quality within the building (Caniato, 2020). This can be accomplished by utilising sound-absorbing materials such as perforated panels, acoustic fabrics, or specialised acoustic treatments to the façade (Kagitci, 2021). Facades can contribute to acoustic insulation by using suitable materials, incorporating sound-absorbing elements, contemplating proper design and construction techniques, and employing appropriate glazing systems. Facades provide a more tranquil and comfortable interior environment by minimising exterior sound transmission.

2.2.5 Gives The Structure Life

As a result of cutting-edge technology and intricate production methods, facades are highly resistant to natural elements such as wind loading and precipitation (Zhao et al., 2022).

Compared to commonly used exterior paints, these can appear smudged, attract grime and dust, and are durable and resistant to the elements. These characteristics make them extraordinarily durable, enduring decades. New materials, concepts, and designs for building facades continue to reveal various structural possibilities.

2.3 Façade Performance Attributes

As part of the building envelope, the primary purpose of facades was to provide environmental isolation, shield the structure from the effects of the hostile environment, and satisfy the building's aesthetic requirements (Moghtadernejad et al., 2019), which are covered in detail in the subsections below.

Table 1. Primary performance attributes of building envelopes

Safety	Sustainability	Human Comfort	Durability and Maintenance	Cost Efficiency
Resisting mechanical and environmental loads, natural and artificial hazards	Energy efficiency	Visual Comfort (appropriate view of outside by proper window arrangement)	Provisions to avoid premature failure of the system before the end of service life	Initial costs of design and construction
Security	Use of renewable resources	Aesthetics	Provisions to resist deterioration caused by an aggressive environment	Operation costs
	Environmental footprint	Heating and cooling needs	The expected service life of each system in a specific environment	Costs of rehabilitation and maintenance works
		Natural ventilation and indoor air quality	Ease of access for inspection and rehabilitation works	Costs of dismantling
		Daylight control		
		Acoustics		

(Source: Moghtadernejad et al.,2019)

Facades prolong the life of a structure by reducing condensation on interior surfaces, preventing moisture penetration, and allowing excess humidity to evacuate outside (Moghtadernejad, 2020). Durability considerations, such as functional, environmental, and economic requirements, should be incorporated into the facade's design to predict its performance over its service life under specified severe environmental conditions. These facade performance characteristics can be used as a baseline to evaluate the adaptability of a material for use in climate-responsive facades.

2.4 Tropical Climate Responsive Building Facade

In tropical climates, glass and solid walls, shading and reflectance, views, and solar control can reduce carbon emissions and increase indoor thermal comfort and workplace productivity (Hwang & Chen, 2022). The high humidity and frequent precipitation of the

Malaysian tropical climate present challenges for building facades. Façades must be able to endure the mechanical and environmental loads found in tropical environments, such as wind, rain, and earthquakes, as well as tolerate changes in movement caused by moisture, temperature variations, and structural trends (Moghtadernejad et al., 2020). The strategy to resist these climatic threats consists of proper building massing and alignment, the optimal window-to-wall ratio (WWR), the use of high-performance glass, and exterior shadings applications. (Talip et al., 2021, Alsehail & Almhafdy, 2020). By including a high-performance façade with high levels of insulation, simple design solutions that have a predictable influence on energy consumption can remove the need for cooling and boost indoor thermal comfort (Kamal, 2020). Façade textiles can provide climate adaptability by providing solar protection, rain protection, and ventilation regulation.

2.5 Textile Facade

Figure 1: ETFE coated foil (Eden Project UK)
(Source: www.shuttershock.com)

Textile facades are a novel type of screen and fabric architecture that, in addition to contributing to architectural aesthetics, ease of application, and economical prices, can be utilised as a shading device, thermal insulation, and light permeability during the day and night (Monticelli & Zanelli, 2021). Textile materials and foils are increasingly used as part of the building envelope. Textiles used in facades are lighter than conventional building materials such as concrete and masonry. This quality makes them suitable for tall structures, reducing structural load and permitting greater design flexibility (Singh, 2021). They can be stretched and tensioned over frameworks to create curved or irregularly shaped facades. Textile façades are readily replaceable or adjustable, allowing for future adaptability and renovation options. The lightweight character of textile façades makes installation and maintenance simpler (Rege, 2023). Textiles offer various design options, allowing for originality and creativity in building facades. Different colours, patterns, textures, and translucency options are available, allowing architects to design visually enticing and distinctive building facades that enhance the architectural character of the structure. Textiles used in facades can provide controlled light transmission, allowing natural light to enter the building while minimising pollution and heat gain (Kocaağa, 2022). Translucent or mesh-like materials can filter light, creating a pleasant interior environment and decreasing the need for artificial lighting (Rege, 2023). Textiles with specialised coatings or treatments can resist ultraviolet radiation, repel water, and maintain performance in humid environments (Kocaağa, 2022).

In recent years, a few significant instances with a broad usage spectrum and several prospective applications have been identified. The examples include the Eden Project in the United Kingdom, which utilises ETFE (Ethylene Tetra Fluoro Ethylene) as the main building envelope, ASU SkySong Innovation Center Pavilion, United States using PTFE (Polytetrafluoroethylene) to cover 50,000 square feet of conical-shaped tensile structure and application of PVC coated polyester membrane roof at Bus Station Konigsbrunn, Germany. Textile facades can adapt and respond to varying climate conditions between countries. With established performance, the potential of a textile facade to respond to Malaysia's tropical climate can be investigated.

Figure 1: PVC-coated polyester membrane roof (Bus Station Konigsbrunn)
(Source: www.pinterest.com)

2.6 Use of Textile in Malaysian Building Facades

Coated materials, such as glass fibre-coated PTFE (Polytetrafluoroethylene), ETFE (Ethylene Tetra Fluoro Ethylene), and polyester-coated PVC (Polyvinyl Chloride), are the most widely used membrane of construction materials in Malaysia. In current architecture projects, the coating is used on 90% of all membrane materials.

2.6.1 PTFE (Polytetrafluoroethylene) coated fibreglass

Glass fibre-coated PTFE, recognised as one of the membrane materials due to its endurance, is the most favoured material for residential constructions. The material with high light transmission and mechanical resilience of glass fibres provides superb long-term protection and resistance to pollutants (Flor et al., 2022). They can endure extreme temperature fluctuations, high humidity, and heavy precipitation without degrading or losing performance. This durability ensures that the textile façade can withstand exposure to the elements over time.

The fire resistance and over 30 years of operational life of PTFE membrane material (Ezue & Brisibe, 2023) make it a lasting choice and functional textile that offers better protection against other textiles, chemical resistance, super incombustibility, resistance to UV radiation (Aly, 2023), and light reflecting qualities. PTFE’s strong UV resistance protects it from the effects of the environment and sunlight (Singh, 2021). They resist fading, deterioration, and ageing, ensuring that the textile facade remains intact and functional for an extended period. Routine cleaning with water and gentle detergents is sufficient to maintain the membrane in excellent condition (Kamal, 2020). PTFE membranes can provide a viable option for constructing visually appealing and long-lasting textile facades in Malaysia.

2.6.2 ETFE (Ethylene Tetra Fluoro Ethylene) coated foil

ETFE-coated foil provides architects with design flexibility, enabling them to construct distinctive and dynamic facades (Karaman, 2019). The material can be distended or shaped into various forms, including domes, cushions, and intricate geometries. Its lightweight nature enables the construction of visually striking and distinctive large-span structures and innovative architectural designs (Elmokadem & Elballah, 2019). The ETFE-coated foil has exceptional light transmission properties, permitting sunlight to pass through it (Karaman, 2019). This feature reduces the need for artificial lighting during the day while creating a well-lit and aesthetically pleasing indoor environment. ETFE’s translucent nature allows light diffusion, reducing glare and creating a comfortable and pleasant environment, leading to energy savings (Kamal, 2020).

ETFE is a desired substance due to its self-extinguishing capabilities. It has both a mechanical and a high level of incombustibility (Flor et al., 2022). Despite minimal insulation, ETFE allows 95 per cent more light penetration and can regulate solar heat by adding ETFE foils to the material (Gezer & Aksu, 2021). ETFE has a service life of over 30 years and is resistant to the weather (Liu et al., 2022). ETFE is a recyclable material that conforms to green construction practices. At the end of its life, ETFE-coated foil can be recycled and repurposed to produce new materials, reducing waste and minimising environmental impact (Karaman, 2019). ETFE-coated foil provides a lightweight, durable, and aesthetically pleasing solution for textile facades in Malaysia, thereby contributing to energy-efficient and sustainable building design. ETFE is a cost-effective, user-friendly material with excellent properties for large-scale applications.

2.6.3 PVC (Polyvinyl Chloride and Coated Polyester)

PVC (Polyvinyl Chloride) and its derivatives (Polyvinyl Chloride), PVDF (Polyvinylidene fluoride), Teflon-coated fibreglass, and silicon-coated fibreglass are some of the membrane types that have been evaluated based on cost and performance and widely employed in the construction industry (Alioglu & Sirel, 2018). Compared to other textile facade materials, PVC mesh is a cost-effective alternative and has a lifespan of over 25 years (Singh, 2021). Its relatively lower price, durability, and minimal maintenance make it a suitable material and an attractive option for budget-conscious building projects (Krylova et al., 2022). Regular cleaning with water and mild detergents can help preserve the appearance of the material and remove any accumulated grime and contaminants. PVC mesh's minimal maintenance characteristics reduce the need for extensive maintenance, resulting in cost savings.

By reducing the direct sunlight entering a structure, PVC mesh can control solar heat. The mesh functions as a shading element, reducing the need for cooling systems and mitigating heat gain (Tafreshi & Alemi, 2023). This can contribute to energy savings and improve the thermal efficacy of the building. Besides providing adequate shading, PVC mesh also provides a degree of transparency that permits natural light to enter the interior of a building (Tabor & Tushar, 2019). Excellent light transmission eliminates the need for artificial lighting by admitting diffused natural light. This creates a well-lit and aesthetically appealing interior while preserving a connection to the outdoors. The lattice pattern adds a distinctive aesthetic element, giving the façade a modern and contemporary appearance. Polyester coated with PVC and PVDF are the most prevalent waterproofing materials to protect outdoor areas (Maity et al., 2023). They resist abrasion and transmit between zero and twenty-five per cent of light (Singh, 2021). Polyester textiles coated with PVC are appropriate for demounted constructions due to their elastic cracking resistance (Alioglu & Sirel, 2018). Since they are recyclable, they have a low environmental impact and require minimal maintenance (Singh, 2021).

3.0 Methodology

This study employs the following approaches to analyse the collected data. Initially, internet-sourced journal articles are gathered, and data about textile facades are analysed. From 232 reviewed journal articles on the textile facade in Malaysia, the focus is narrowed to 141 papers on the recyclable textile facade in Malaysia and 42 documents on PVC mesh textiles. Concerning this study, only fourteen journal articles offer critical analyses of PVC mesh textiles. The data obtained from these papers are tabulated into a synthesis matrix analysis that provides a clear picture of how the textile facade could be optimised according to each aspect as the optimal form of textile facade for use in the climate of Malaysia. Due to the rarity of textile facade implementation in Malaysia, the analysis is based on the response of the properties of each material to the local climate. The content analysis concentrates on three factors when selecting the optimal textile facade for tropical climates: material durability, light transmission, and cost-effectiveness. These factors are derived from the literature review on tropical-responsive facades and serve as the benchmark for evaluating each textile facade.

4.0 Findings

This chapter presents the data acquired and analysed from journals and Internet sources. The data is presented in tables for each material specification and radial charts for data analysis and synthesis into straightforward model guidance. The analysis focuses on mechanical strength, cracking resistance, durability, load bearing, light transmittance, and cost efficiency.

4.1 Specification and Analysis of PTFE Membrane.

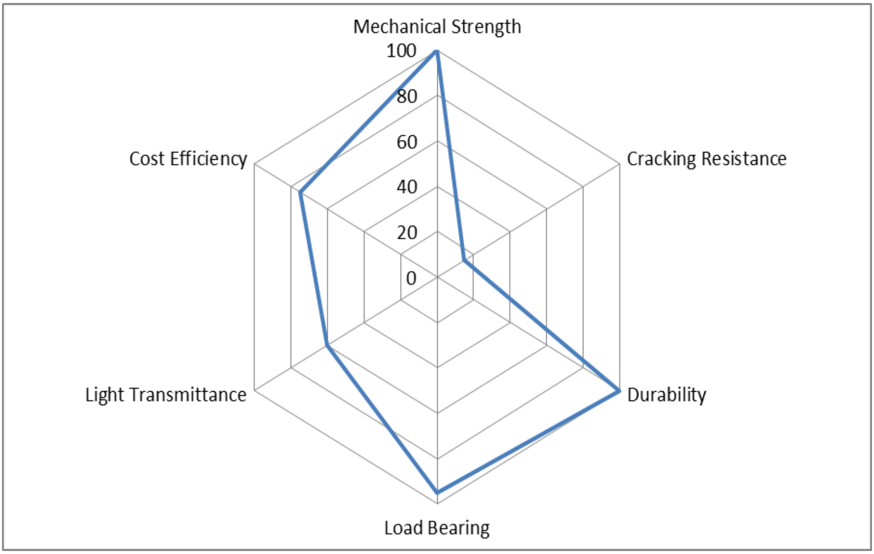

Fig 1: Properties of PTFE coated Fiberglass membrane

Fibreglass with a Teflon coating is a popular alternative to polyester with a PVC coating and is frequently chosen for more valuable and costly projects. PTFE has a translucency coefficient ranging from 15 to 40 per cent, reflecting between 68 and 75 per cent of the incident light to produce a balanced, shadow-free colour light. This material has a lifespan of 30 to 40 years when manufactured and installed following applicable standards.

Woven PTFE is an alternative form of PTFE, a fluoropolymer fabric composed of PTFE with high strength. It has the same characteristics as PTFE, including durability, strength, and flexibility. PTFE has a low elasticity factor with poor flexibility. Its distinctive feature combines excellent light transmission and water resistance with the ability to withstand repeated flexing and folding (Beccarelli, 2015).

The PTFE membrane's unique properties make it an excellent choice for projects that require high weather resistance and fire protection. Sheerfill is a composite membrane comprised of fibreglass and coated with PTFE, obtainable in various strengths and light transmission rates and offering solutions for small and large structures.

Table 2. PTFE specification

Specifications	Sheerfill I	Sheerfill II	Sheerfill V
Thickness (mm)	1	0.8	0.5
Weight (kg/m^2)	3	1.2	0.95
Solar Transmission (%)	10	12	16
Solar Absorption (%)	73	73	74

4.2 Specification and Analysis of ETFE Membrane.

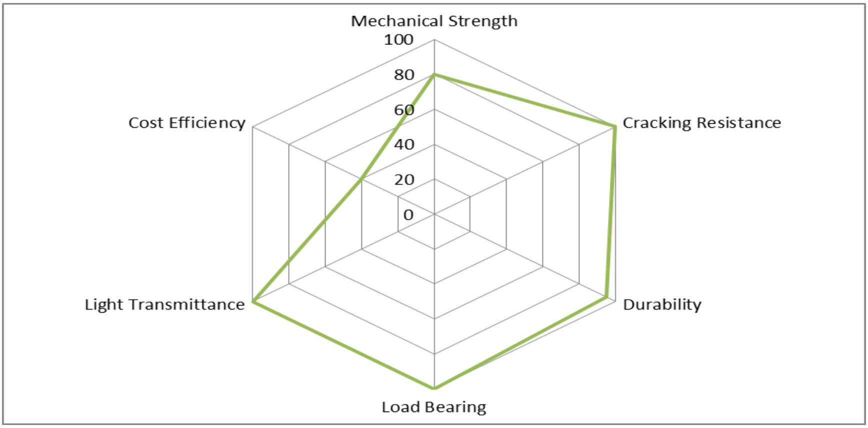

Fig. 2. Properties of ETFE film

Table 3. Comparison of ETFE and Glass

	ETFE Film			Glass	
Light transmittance (%)	Single Layer	Double Layer	Triple Layer	Single Layer	Doubl e Layer
Weight (kg/m^2)	0.35	0.7	1.05	15	30
Visible Light Transmittance (%)	90.5	82.4	75.4	88.9	79.6
Ultra Violet Transmittance	83.5	71.5	62.3	61.4	45.5
U-Value (w/m^2K)	5.8	2.6	1.7	5.9	2.9

ETFE is a transparent foil with excellent mechanical properties and a high fire protection factor that can replace glass (Lamnatou et al., 2018). ETFE films can be shaded and imprinted to provide a range of colour tones and opacity levels to cover existing facades like curtain walls and rooftops. ETFE film with a single layer offers protection against sunlight and brightness, security, and acoustic insulation. ETFE has a life expectancy of 25 to 35 years and is a relatively inexpensive material. This material transmits 85% of light.

Table 4.1Specifications of ETFE film Types

Light transmittance (%)	Transparent	Matte	Printed	White	Blue	UV Cut
Visible Light	90.5	91.7	63.2*	40.5	80.3	87.3
Ultra Violet	83.5	88.2	58.2*	1.0	75.4	36.9
Sun Light	91.9	90.4	63.7*	50.1	86.9	88.9

4.3 Specification and Analysis of PVC Membrane.

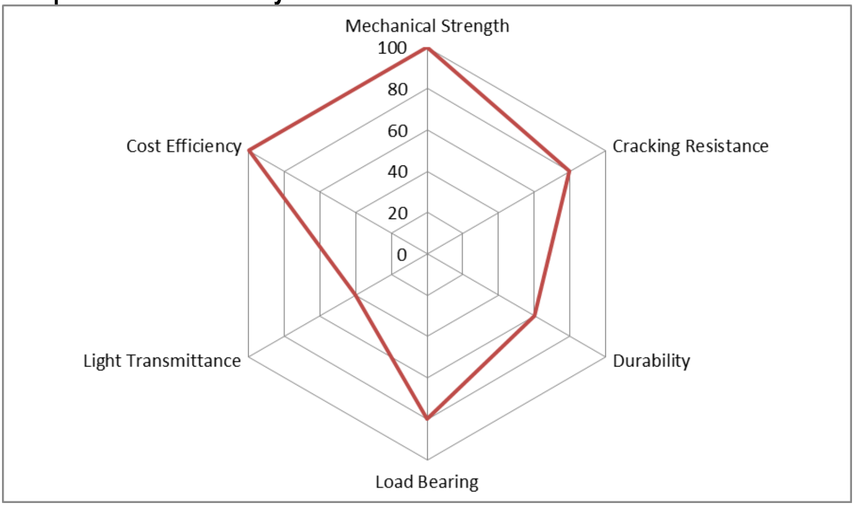

Fig. 3. Properties of PVC mesh

Polyester with a PVC coating is one of the most widely recognised structural textures. Its focal points are dexterous, rip-resistant, and highly flexible. The material is regarded as cost-effective, with a lifespan of 15 to 20 years. Vinyl Coated Polyester PVC is ideal for permanent or temporary tensile structures. It is resistant to changes in temperature and humidity, and the coating prevents staining and discolouration. PVC mesh offers a variety of technical and economic benefits due to its insulation and solar protection properties, as well as its wind and rain resistance and low cost of maintenance (Singh, 2021).

As an advantage of the fluidity and softness of its materials, PVC facade systems are adaptable to various functions and activities due to their adaptability and uniqueness. The membrane and structure of the object weigh less than 5 kilograms per square meter. The flexible properties of PVC mesh enable the creation of planar and organic forms. It is possible to create special effects using lights and their transparency.

Climate control and energy savings are two of the most significant benefits of the PVC mesh system. Depending on the chosen colour, PVC mesh as a cladding material will reduce the flux heat density by 18% to 25%. This fabric will also prevent overheating during sweltering tropical weather, reducing energy consumption by 64% while providing privacy and control visibility to building occupants.

4.3 Systematic Data Analysis

Table 4. Comparison of PTFE, ETFE and PVC Mesh Membrane on thermal and light penetration

Material	Weight (kg/m^2)	Visible Light Transmission (%)	Thermal Resistance (m2.'C/W)	Embodied Energy (kWh/m^2)
Clear Glass 6mm	14.4	85%	0.16	73.6
PTFE Coated Fiberglass	0.81	21%	1.03*	14.4**
ETFE foil (0.2mm) 1710kg/m^3	0.34	95%	0.16	4.83
PVC Coated Polyester (0.5mm)	0.84	26%	0.17	18.3**

Table 5. Comparison of PTFE, ETFE and PVC Mesh Membrane on thermal and light penetration

Material	PTFE	ETFE	PVC
Weight (g/m^2)	800	87.5	750 (Type I)
Tensile Strength warp/weft (N/50mm)	3500/3500	64/56	3000/2800
Cleaning	Self Cleaning	Self Cleaning	Easier with a top coat
Lifespan (Years)	> 25	50	15 - 20
Foldable	bad	bad	very good
Fire Retardant (DIN 4102)	A2	-	B1

5.0 Discussion

The finest material for the textile building facade in Malaysia is chosen based on its performance in terms of its strength, durability, lightweight, aesthetic, cost-effectiveness, and ease of maintenance. PVC mesh has the most significant advantages regarding flexibility, durability, and aesthetic value. PVC mesh is suitable for flexibility due to the fluidity and suppleness of the materials. In addition, this material is regarded as cost-effective in terms of maintenance and durability, with a lifespan of approximately 15 to 20 years. In addition to being an ideal solution for permanent or transient tensile structures, it is appropriate for structures with short and long spans. Organic shapes can be produced for aesthetic value because the material is soft and requires a frame or structure to accentuate the shape.

Alternatively, special effects can be created with additional light and colour by utilising the transparent properties of materials. Even though ETFE satisfies all the criteria mentioned above, its high light transmittance makes it unsuitable for tropical climates due to the quantity of heat proportional to the increased light penetration, causing thermal discomfort for building occupants. Regarding adaptability to tropical climates, PVC mesh has an advantage over ETFE. The material is available in numerous finishes and is modifiable.

6.0 Conclusion & Recommendations

The study focuses on textile waste as an innovative material for building facades due to its vast potential for combating the problems associated with excessive textile waste on a global and local scale. The literature review focuses on building facades and responses to the tropical climate of Malaysia. Content analysis provides systematic observation to understand better, thereby providing a qualitative analysis of the textile facade that provides a better understanding of the qualities of the selected study materials, specifically the PTFE, ETFE, and PVC mesh textile facade. The table combines the data collected from each study to facilitate systemic comparative analysis. According to the analysis, PVC mesh is the finest material for tropical climates because it requires minor maintenance and lasts 15 to 20 years. As a result of their fluid nature and malleable, flexible material properties, organic shapes can be created when installed on a frame or structure. PVC textile mesh is the most viable material to be used as an innovative textile facade for future sustainable buildings in the tropical environment of Malaysia.

Acknowledgement
This research paper was made viable by the Centre of Studies for Architecture of Universiti Teknologi MARA in collaboration with the University of Perpetual Help System Dalta, Philippines and the University of Auckland.

Article Contribution to Related Field of Study
The establishment of the use of PVC mesh textile waste as an innovative material for textile facades presents opportunities for architecture in Malaysia to investigate PVC mesh as a viable textile facade material for future building exteriors due to its adaptability to tropical climates. Both eco-sustainability of the textile manufacturing process and the creation of valuable commodities can be achieved simultaneously.

Authors Declaration
This article is an extended version of the original conference paper published in the E-BPJ, Vol 7 No. 20, June 2022, 377-383.

References

Alioglu, T., & Sirel, A. (2018). The Use of Textile-Based Materials in Shell System Design in Architecture and an Evaluation in Terms of Sustainability. *Journal of Contemporary Urban Affairs, 2*(3), 88-94.

Alsehail, A., & Almhafdy, A. (2020). The Effect of Window-to-Wall Ratio (WWR) and Window Orientation (WO) on the Thermal Performance: A preliminary overview. *Environment-Behaviour Proceedings Journal, 5*(15), 165-173.

Aly, N. M. (2023). Fire protective textiles. In *Advances in Healthcare and Protective Textiles* (pp. 203-258). Woodhead Publishing.

Arana, C., Franco, I. B., Joshi, A., & Sedhai, J. (2020). SDG 15 life on land: A review of sustainable fashion design processes: Upcycling waste organic yarns. Actioning the Global Goals for Local Impact: Towards Sustainability Science, Policy, Education and Practice, 247-264.

Athauda, R. S., Asmone, A. S., & Conejos, S. (2023). Climate Change Impacts on Facade Building Materials: A Qualitative Study. *Sustainability, 15*(10), 7893.

Barrelas, J., Silva, A., de Brito, J., & Tadeu, A. (2023). Effects of Climate Change on Rendered Façades: Expected Degradation in a Progressively Warmer and Drier Climate—A Review Based on the Literature. *Buildings, 13*(2), 352.

Beccarelli, P. (2015). The design, analysis and construction of tensile fabric structures. In *Biaxial Testing for Fabrics and Foils* (pp. 9-33). Springer, Cham.

Cainelli, G., D'Amato, A., & Mazzanti, M. (2020). Resource efficient eco-innovations for a circular economy: Evidence from EU firms. *Research Policy, 49*(1), 103827.

Caniato, M. (2020). Sound insulation of complex façades: A complete study combining different numerical approaches. *Applied Acoustics, 169*, 107484.

Ciampi, G., Spanodimitriou, Y., Scorpio, M., Rosato, A., & Sibilio, S. (2021). Energy performance of PVC-Coated polyester fabric as novel material for the building envelope: Model validation and a refurbishment case study. *Journal of Building Engineering, 41*, 102437.

Coppola, C., Vollero, A., & Siano, A. (2023). Developing dynamic capabilities for the circular economy in the textile and clothing industry in Italy: A natural-resource-based view. *Business Strategy and the Environment*.

Degenstein, L. (2018). Biodegradable vs. non-biodegradable textiles: Environmental impacts under standard landfill conditions. *Journal of the Home Economics Institute of Australia, 25*(1), 18-23.

Elmokadem, A., Wassef, A., & Elballah, M. (2019). Analytical Study for the Visual Appearance of Tensile Membrane Structure. *Port-Said Engineering Research Journal, 23*(2), 1-10.

Ezue, O., & Brisibe, W. G. (2023). Structural Systems in Enveloping a Sport Complex. *International Journal of Technology and Systems, 8*(1), 14-27.

Flor, J. F., Liu, X., Sun, Y., Beccarelli, P., Chilton, J., & Wu, Y. (2022). Switching daylight: Performance prediction of climate adaptive ETFE foil façades. *Building and Environment, 209*, 108650.

Gezer, H., & Aksu, G. A. (2021). Assessment of Textile Architecture from a Sustainability Perspective. *Architectural Sciences and Technology*, 143.

Hwang, R. L., & Chen, W. A. (2022). Identifying relative importance of solar design determinants on office building façade for cooling loads and thermal comfort in hot-humid climates. *Building and Environment, 226*, 109684.

Kabošová, L., Chronis, A., Galanos, T., Kmeť, S., & Katunský, D. (2022). Shape optimisation during design for improving outdoor wind comfort and solar radiation in cities. *Building and Environment, 226*, 109668.

Kaewpeela, P., Raksawin, K., & Suthasupa, S. (2020). Identity on the Facade of Roi Et Provincial Hall. *Asian Journal of Environment-Behaviour Studies, 5*(15), 29-42.

Kagitci, E. (2021). *Upcycling textile waste from the fashion industry as a sustainable building material for architectural design*. (Master's Thesis, Politecnico Di Milano).

Kamal, M. A. (2020). An investigation into tensile structure system: construction morphology and architectural interventions. *Journal of Building Materials and Structures, 7*(2), 236-254.

Kamal, M. A. (2020). Recent Advances in Material Science for Facade Systems in Contemporary Architecture: An Overview. *American Journal of Civil Engineering and Architecture, 8*(3), 97-104.

Kamal, M. A. (2020). Technological interventions in building facade system: energy efficiency and environmental sustainability. *Architecture research, 10*(2), 45-53.

Karaman, S. (2019). *The energy performance evaluation of Etfe (Ethylene tetrafluoroethylene) cusion systems integrated on the south façade of a hypothetical test room and comparison of it with glass façade systems* (Master's thesis, Fen Bilimleri Enstitüsü).

Kocaağa, M. (2022). Variables Affecting The Performance Of Facade Systems In Architecture. *Research & Reviews in Engineering*.

Klingenberg, K. (2020). Passive House (Passivhaus). *Sustainable Built Environments*, 327-349.

Krylova, V., Jucienė, M., & Dobilaitė, V. (2022). Functionalisation of polyvinylchloride textile surface with thin films of silver oxide by chemical method. In *FIM 2022: International conference" Functional inorganic materials 2022": abstract book*. Vilnius university press.

Lamnatou, C., Moreno, A., Chemisana, D., Reitsma, F., & Clariá, F. (2018). Ethylene tetrafluoroethylene (ETFE) material: Critical issues and applications with emphasis on buildings. *Renewable and Sustainable Energy Reviews, 82*, 2186-2201.

Li, Q., & Zanelli, A. (2021). A review on fabrication and applications of textile envelope integrated flexible photovoltaic systems. *Renewable and Sustainable Energy Reviews*, *139,* 110678.

Liu, J., Xu, C., Ao, X., Lu, K., Zhao, B., & Pei, G. (2022). A dual-layer polymer-based film for all-day sub-ambient radiative sky cooling. *Energy, 254*, 124350.

Mabuchi, Y., Ichinose, M., Chaloeytoy, K., & Yamauchi, R. (2019, July). Influence of air leakage from building façade on the energy efficiency of air conditioning system in Tropic Asia. In *IOP Conference Series: Earth and Environmental Science* (Vol. 294, No. 1, p. 012051). IOP Publishing.

Maity, S., Singha, K., & Pandit, P. (2023). 4 Speciality coatings and laminations on textiles. *Smart and Functional Textiles*, 151.

Mateus, D., & Pereira, A. (2023). The strong influence of small construction errors on sound insulation of buildings with heavyweight concrete structure: A Portuguese case study. *Building Acoustics*, 1351010X231162811.

Moghtadernejad, S., Mirza, M. S., & Chouinard, L. E. (2019). Facade design stages: issues and considerations. *Journal of Architectural Engineering, 25*(1), 04018033.

Moghtadernejad, S., Chouinard, L. E., & Mirza, M. S. (2020). Design strategies using multi-criteria decision-making tools to enhance the performance of building façades. *Journal of Building Engineering, 30*, 101274.

Monticelli, C., & Zanelli, A. (2021). Material saving and building component efficiency as main eco-design principles for membrane architecture: case-studies of ETFE enclosures. *Architectural Engineering and Design Management, 17*(3-4), 264-280.

Nasrollahi, N., & Ghobadi, P. (2022). Field measurement and numerical investigation of natural cross-ventilation in high-rise buildings; Thermal comfort analysis. *Applied Thermal Engineering, 211*, 118500.

Okafor, C. C., Madu, C. N., Ajaero, C. C., Ibekwe, J. C., Nzekwe, C. A., Okafor, C. C., ... & Nzekwe, C. A. (2021). *Sustainable management of textile and clothing. Clean Tech Recycl,* 1, 70-87.

Osaro, F. O., Cookey-Gam, A., & Iyerefa, S. (2022). Usefulness Of Building Ventilation. *International Journal of Innovative Environment, 10*, 25-32.

Pandey, R., Pandit, P., Pandey, S., & Mishra, S. (2020). Solutions for sustainable fashion and textile industry. *Recycling from Waste in Fashion and Textiles: A Sustainable and Circular Economic Approach*, 33-72.

Patti, A., Cicala, G., & Acierno, D. (2020). Eco-sustainability of the textile production: Waste recovery and current recycling in the composites world. *Polymers, 13*(1), 134.

Paul, P., Mishra, R., & Behera, B. K. (2021). Acoustic behaviour of textile structures. *Textile Progress, 53*(1), 1-64.

Peller, J. R., Eberhardt, L., Clark, R., Nelson, C., Kostelnik, E., & Iceman, C. (2019). Tracking the distribution of microfiber pollution in a southern Lake Michigan watershed through the analysis of water, sediment and air. *Environmental Science: Processes & Impacts, 21*(9), 1549-1559.

Pichardo, P. P., Martínez-Barrera, G., Martínez-López, M., Ureña-Núñez, F., & Ávila-Córdoba, L. I. (2018). Waste and recycled textiles as reinforcements of building materials. *Natural and Artificial Fiber-Reinforced Composites as Renewable Sources, 89*.

Radhakrishnan, S. (2021). Circular Economy in Textiles and Fashion. In *Circular Economy* (pp. 163-202). Springer, Singapore.

Rathore, B. (2023). Textile Industry 4.0: A Review of Sustainability in Manufacturing. *International Journal of New Media Studies (IJNMS)*, *10*(1), 38-43.

Rege, S. (2023). *Textiles and Architecture| Woven into Dimensions of Temporality, Craft, Drapery, and Technology* (Doctoral dissertation, University of Washington).

Roig, O., Cuerva, E., Pardal, C., Guardo, A., Isalgue, A., & Lopez-Besora, J. (2023). Thermal Assessment of a Ventilated Double Skin Façade Component with a Set of Air Filtering Photocatalytic Slats in the Cavity. *Buildings, 13*(2), 272.

Sandak, A., Sandak, J., Brzezicki, M., Kutnar, A., Sandak, A., Sandak, J., ... & Kutnar, A. (2019). Designing building skins with biomaterials. *Bio-based building skin*, 65-97.

Sarihi, S., Saradj, F. M., & Faizi, M. (2021). A critical review of façade retrofit measures for minimising heating and cooling demand in existing buildings. *Sustainable Cities and Society, 64*, 102525.

Shareef, R. A., & Al-Alwan, H. A. S. (2021, February). Sustainable textile architecture: history and prospects. *In IOP Conference Series: Materials Science and Engineering* (Vol. 1067, No. 1, p. 012046). IOP Publishing.

Singh, S. (2021). ArchiTextile: A Review on Application of Textiles in Architecture. *Journal of Textile & Apparel Technology & Management (JTATM), 12*(1).

Tabor, J., & Tushar, G. (2019). Building and Construction Textiles. *High Perform. Tech. Text.*

Tafreshi, F., & Alemi, B. (2023). Energy-efficient design of building facade, inspired by human skin. *Proceedings of the Institution of Civil Engineers-Energy, 176*(2), 105-119.

Talip, M. S., Shaari, M. F., Ahmad, S. S., & Sanchez, R. B. (2021). Optimising Daylighting Performance in Tropical Courtyard and Atrium Buildings for Occupants' Well-being. *Environment-Behaviour Proceedings Journal, 6*(16), 93-102.

Torero, J. L. (2022). The building envelope: failing to understand complexity in tall building design. In *Rethinking Building Skins* (pp. 341-357). Woodhead Publishing.

William, M. A., Suárez-López, M. J., Soutullo, S., & Hanafy, A. A. (2021). Building envelopes toward energy-efficient buildings: A balanced multi-approach decision making. *International journal of energy research, 45*(15), 21096-21113.

Yalcin-Enis, I., Kucukali-Ozturk, M., & Sezgin, H. (2019). Risks and management of textile waste. *Nanoscience and biotechnology for environmental applications*, 29-53.

Zhao, W., Chen, J., Hai, T., Mohammed, M. N., Yaseen, Z. M., Yang, X., ... & Xu, Q. (2022). Design of low-energy buildings in densely populated urban areas based on IoT. *Energy Reports, 8*, 4822-4833.