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The Adaptability of PVC Mesh as Recycled Textile Waste towards Innovative Tropical Building Façade

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Abstract

Textile fibres are commodity materials that will continue to be required in vast numbers for various applications by society but accumulate colossal waste. Upcycled textile waste possesses high potential in building construction through coating application. This research aims to establish the use of PVC mesh textile waste as an innovative textile facade for Malaysian buildings. Content analysis is conducted to evaluate different textile façade construction performing architectural functions. The overall result concludes that PVC mesh covers all aspects in balance as an innovative building façade responding to the needs of the tropical climate setting in Malaysia.

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

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1.0 Introduction

The excessive amount of textile waste due to the mass manufacture of textiles is a significant problem in Malaysia. Regarding this issue, the current situation can be manipulated by the idea of upcycling synthetic wastes. Recently, research has focused on the possibility of repurposing industrial textile waste, or recovering worn fabrics, to create recycled fibres that can be utilised as fillers in composites with coated fibreglass or coated foils. The fashion industry in Malaysia has adopted the recycling of waste from textile products by closing the loop, which refers to the recycling and repurposing of post-consumer trash (Radhakrishnan, 2021). A new product from this practice possesses vast potential in building façade applications by implementing textile façades. Textile façade is preferred over conventional building façades as it offers many other benefits such as free-form usage, lightweight materials, and ease of maintenance.

1.1 Research Question

The research question for this paper is as below:
What is the primary use of façades, and how do they respond to tropical climates?
What are the potentials of textile waste that can be developed into a textile facade?
Which is the best form of textile façade that can be used for building in Malaysia?

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1.2 Research Aim & Objectives

The aim of the research is to establish the use of PVC mesh textile waste as an innovative material for the use of textile facades for buildings in Malaysia. The objective of this study is; to study the use of façade and how it responds to the tropical climate, identify the properties and specification of textile façade and analyse the best form of textile façade that can be used for building in Malaysia. This justifies the significance of this study; by meeting the requirements of both environmental sustainability of the textile manufacturing process and the production of commodities with flexible uses.

2.0 Literature Review

2.1 Textile Waste as a Recyclable Material

Textile waste, such as fibre, textile, and apparel, can be obtained from the general public, the manufacturing industry, and customers. Some synthetic fibre materials do not disintegrate naturally, causing soil and surface water contamination issues. Cotton fibres disintegrate naturally but release methane as a by-product, increasing global warming (Degenstein, 2018). Textile recycling is an ideal solution to lessen the environmental effect of widely used products (Pichardo et al., 2018), with an innovative application as building facade construction material being one of the viable alternatives.

2.2 Defining Building Facade

Façades are a part of a building's envelope that supports the structure's external architectural features; they have evolved to meet various functional and climatic requirements (Kaewpeela et al., 2020).

Plays A Pivotal Role in Energy Efficiency

A façade plays an important part in energy efficiency by reducing solar heat gain, which reduces the building's cooling demands, resulting in lower energy expenditures by lower energy consumption.

Shield Against Natural Threats

Facades protect building residents from wind, rain, temperature, humidity extremes and corrosion, which has been shown to be a valuable attribute over many decades.

Allows Natural Ventilation

Admission of natural ventilation into buildings is accomplished in various facade treatments, including architectural elements, porous skins, and automated windows, ensuring building occupants' comfort is not compromised by adverse weather conditions.

Provides Acoustic Insulation

Compared to a traditional building façade, a well-designed façade exterior skin delivers a high level of acoustic comfort to its occupants. Acoustic comfort does not compromise the needed ventilation, air exchange, and visual connection with the outside.

2.3 Façade Performance Attributes

The primary function of façades as part of the building envelope was to provide environmental isolation, protect the structure from the effects of the harsh environment, and satisfy the building's aesthetic criteria (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 deteriorations 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	● Costs of dismantling

	● Daylight control ● Acoustics	rehabilitation works

(Source: Moghtadernejad et al.,2019)

Façades help a structure last longer by reducing condensation on interior surfaces, preventing moisture penetration, and allowing excess humidity inside the building to escape outside (Moghtadernejad, 2020). Durability concerns such as functional, environmental, and economic needs should be incorporated into the façade design considerations to forecast the performance of the façade over its service life under specified harsh environmental conditions. These facade performance attributes are the critical aspects that can be developed as the baseline to assess the adaptability of material to be used as climate-responsive facades.

2.4 Building Façade in Response to Tropical Climate

In dealing with tropical climate settings, building design with the accomplished culmination of glass and solid, shading and reflectance, view, and sun control significantly reduce carbon emissions and improve indoor thermal comfort and productivity at work. Façades must withstand the relevant mechanical and environmental loads of tropical settings such as wind, rain, and earthquake, have good fire resistance, and allow for changes in movements caused by moisture, temperature variations, and structural movements (Moghtadernejad et al., 2020). Integrating the high-performance façade with high levels of insulation can eliminate the requirement for cooling and increase indoor thermal comfort by adapting simple design solutions that have a predictable impact on energy consumption. The strategy includes proper building massing and alignment, ideal window-to-wall ratio (WWR), use of high-performance glass, and application of exterior shadings (Talip et al., 2021, Alsehail & Almhafdy, 2020).

2.5 Textile Facade

Textile facades are a new type of screen and fabric architecture that can be used as a shading device, thermal insulation, and light permeability during night and day, besides their contribution to architectural aesthetics, ease of application, and economic costs (Monticelli & Zanelli, 2021). The use of textile materials and foils as part of the building envelope is becoming increasingly popular. A few notable examples have been recognised with immense usage spectre and various potential applications in recent years. The examples include Eden Project in 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. Across the different countries, textile facades can adapt and respond to various climate conditions. With proven performance, the viability of textile facade can be explored to respond to the Malaysian tropical climate

2.6 Application of Textile for Building Facades in Malaysia

The most extensively utilised membrane of construction materials in Malaysia are coated materials, such as glass fibre coated PTFE (Polytetrafluoroethylene), ETFE (Ethylene Tetra Fluoro Ethylene), and polyester coated PVC (Polyvinyl Chloride). Ninety per cent of all membrane materials utilised in current architecture projects are coated.

PTFE (Polytetrafluoroethylene) coated fibreglass

The most preferred material for residential projects is glass fibre coated PTFE, which is acknowledged as one of the membrane materials due to its durability. With the mechanical resistance of glass fibres, the material with excellent light transmission provides perfect long-term protection and resistance against pollution (Flor et al., 2022).

PTFE membrane material is durable due to its fire-resistance feature and over 30 years of proven operating life. It is a textile material that is beneficial because of its textile material protection, chemical resistance, super incombustibility, ultraviolet light resistance, and light reflection properties. Environmental factors and ultraviolet radiation have less impact on PTFE due to its high level of UV resistance (Singh, 2021).

ETFE (Ethylene Tetra Fluoro Ethylene) coated foil

ETFE is a high-translucency material that is also cost-effective, easy to use, and offers the ideal properties for large-scale projects. It is a desired substance due to its self-extinguishing capabilities. ETFE 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 solar heat can be regulated by adding ETFE foils to the material. ETFE has a working life of over 30 years and is weather-resistant.

PVC (Polyvinyl Chloride and Coated Polyester)

PVC (Polyvinyl Chloride) and its derivatives (Polyvinyl Chloride), PVDF (Polyvinylidene fluoride), Teflon coated fibreglass, and silicon-coated fibreglass is some of the membrane types that have been evaluated based on cost and performance, and mostly used in the construction sector (Alioglu & Sirel, 2018). The PVC coating material is economical and has a working life of more than 25 years.

Admission of diffused natural light removes the need for artificial lighting by providing excellent light transmission. The most prevalent waterproof materials are polyester coated with PVC and PVDF to protect outdoor areas. They are resistant to abrasion and have zero to twenty-five per cent light transmittance (Singh, 2021). With their elastic cracking resilience, PVC-coated polyester textile materials are suitable for demounted constructions (Alioglu & Sirel, 2018). Due to their recyclable nature, they also have a low environmental impact and only require minimal maintenance (Singh, 2021).

3.0 Methodology

This research adopts the following strategies in analysing the collected data. Firstly, journal articles are collected from internet sources, and data related to the textile facades are being analysed. From a total of 232 journal articles reviewed on the textile facade in Malaysia, the focus is narrowed further on the recyclable textile facade in Malaysia, which totalled 141 papers to 42 papers discussing PVC mesh textiles. With specification to this study, only 14 journal articles provide critical studies on PVC mesh textiles. The data obtained from these papers are tabulated into synthesis matrix analysis providing a clear idea of how the textile façade could be optimised in the best way according to each aspect as the best form of textile façade to be used in Malaysia climate. Due to the scarcity of textile facade implementation in Malaysia, the analysis is made based on the properties of each material in response to local weather. The content analysis focuses on three factors that must be addressed when choosing the best form of textile façade responding to tropical climate settings: material durability, light transmittance and cost-efficiency. These factors are derived from the literature review on tropical-responsive facades and become the baseline in assessing each of the textile facades.

4.0 Findings

This chapter presents the data collected from journal and internet data and analysis. The data is represented in tables for each materials specification and radial charts for data analysis and synthesis into simple model guidance. The synthesis covers mechanical strength, cracking resistance, durability, weight lighter, light transmittance, and cost.

4.1 Specification and Analysis of PTFE Membrane.

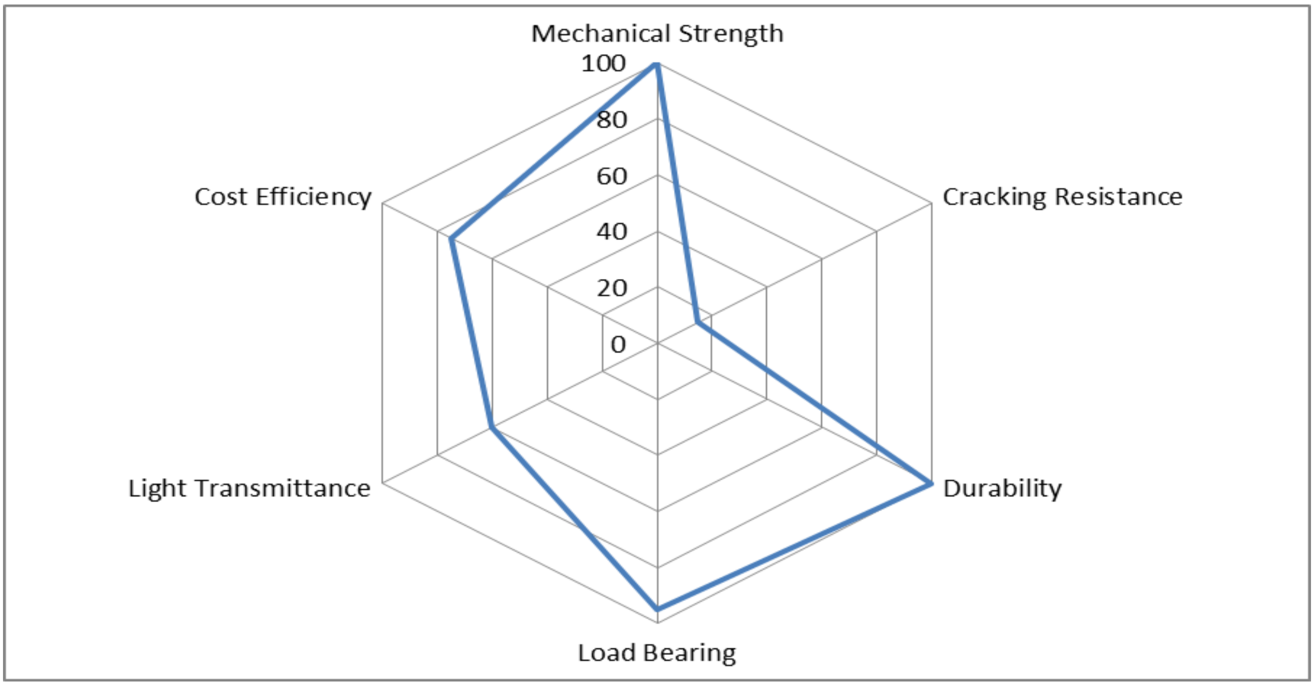

Fig 1: Properties of PTFE coated Fiberglass membrane

Teflon-coated fibreglass is a popular substitute for PVC-coated polyester and is often chosen for more valued 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, providing a balanced colour light devoid of shadows and glare. This material has a life span of 30-40 years when produced and installed following required standards.

Woven PTFE is another version of PTFE, a fluoropolymer fabric made with high-strength PTFE. It offers the same attributes as PTFE, such as durability, strength, and flexibility. PTFE has a low elasticity factor and flexes poorly. Its unique characteristic combines good light transmittance and water resistance with the ability to withstand repeated flexing and folding (Beccarelli, 2015).

The unique properties of the PTFE membrane make it an excellent choice for projects requiring high weather resistance and fire protection. Sheerfill is a composite membrane composed of fibreglass and coated with PTFE, available in different strengths and light transmittance levels, offering solutions for small and large-scale buildings.

Table 2. PTFE specification

Specifications	Sheerfill I	Sheerfill II	Sheerfill V
Thickness (mm)	1	0.8	0.5
Weight (kg/m²)	3	1.2	0.95
Solar Transmission (%)	10	12	16
Solar Absorption (%)	73	73	74

4.2 Specification and Analysis of ETFE Membrane.

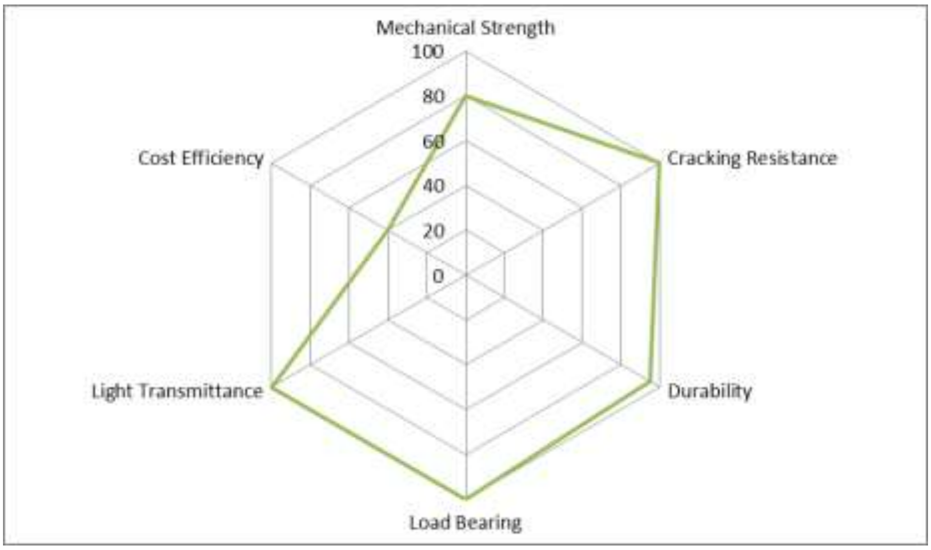

Fig. 2. Properties of ETFE film

Ethylene Tetrafluoroethylene, or ETFE, is a transparent foil that can substitute glass with superb mechanical properties and a high fire protection factor (Lamnatou et al., 2018). ETFE films can be shaded and imprinted to provide various colour hues and varying degrees of opacity to cover existing facades such as curtain walls and rooftops. Single-layer ETFE film offers protection against daylight and glare, providing security and acoustical insulation. ETFE has a 25-35 year life expectancy and is a relatively inexpensive material. This material has an 85% light transmission.

Table 1. 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

Table 3. Comparison of ETFE and Glass

	ETFE Film			Glass	
Light transmittance (%)	Single Layer	Double Layer	Triple Layer	Single Layer	Double Layer
Weight (kg/m²)	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/m²K)	5.8	2.6	1.7	5.9	2.9

4.3 Specification and Analysis of PVC Membrane.

PVC-covered polyester stands out amongst the most widely recognised structural textures. Its focal points are pliable, tear-resistant, and have high flexibility. The material is viewed as economical, with a life expectancy of between 15 to 20 years. Vinyl Coated Polyester PVC is ideal for permanent or temporary tensile structures. It is resistant to temperature variations and humidity conditions, and the coating helps prevent stain and streaking. PVC mesh offers a variety of technical and economic advantages from its insulation and solar protection characteristics and the durable performance against wind and rain at minimal maintenance cost (Singh, 2021).

The versatile and unique characteristic of facade systems using PVC allows various adaptations to many functions and activities due to its fluid nature resulting from the flexibility and softness of its materials. The lightweight property of its membrane and structure is less than 5 kg per square meter. The flexible properties of PVC mesh allow the possibility of designing with planar and organic shapes. Special effects can be created using lights and their transparent quality.

Climatic comfort and energy saving are among the most substantial advantages of the PVC mesh system. PVC mesh as a cladding material will reduce the flux heat density by 18-25%, depending on the colour selected. This fabric will also prevent overheating during hot tropical weather, lowering the energy consumption by 64% while at the same time providing privacy to building occupants with controlled visibility.

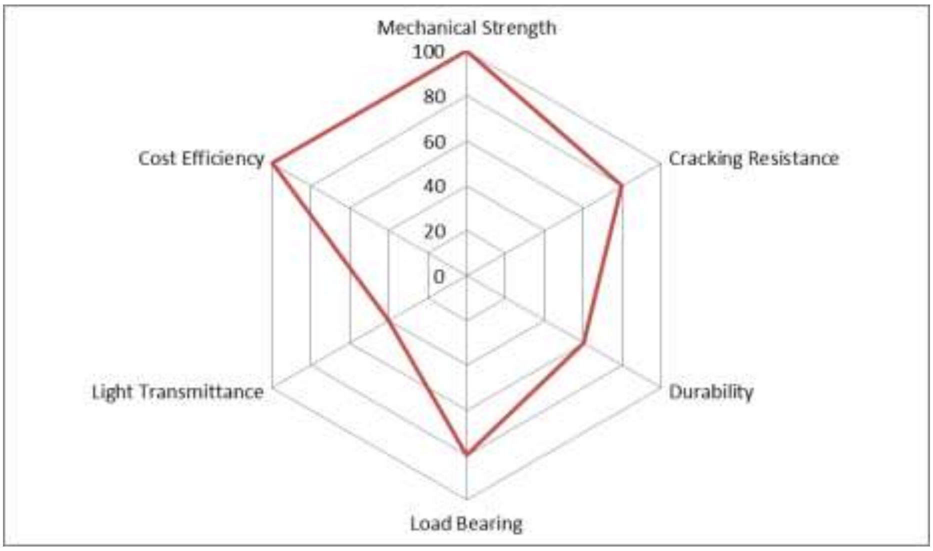

Fig. 3. Properties of PVC mesh

4.3 Systematic Data Analysis

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

Material	Weight (kg/m²)	Visible Light Transmission (%)	Thermal Resistance (m2.'C/W)	Embodied Energy (kWh/m²)
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/m³	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/m²)	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 top coat
Lifespan (Years)	> 25	50	15 - 20
Foldable	bad	bad	very good
Fire Retardant (DIN 4102)	A2	-	B1

5.0 Discussion

The selection of the best material for the textile building façade in Malaysia is evaluated by each material's performance on its strength, durability, lightweight, aesthetic, cost efficiency, and maintenance. In conclusion, PVC mesh has the most advantages in terms of flexibility, durability, and aesthetic value. For flexibility, PVC mesh is suitable because of its fluid nature and the softness of the materials. In addition, the cost of maintenance and durability of this material is viewed as economical, with a life expectancy of roughly 15-20 years. For instance, it is reasonable for short- and long-span structures besides providing an ideal solution for permanent or temporary tensile structures. Organic shapes can be created for aesthetic value because the material is soft and needs to create a frame or structure to enhance the shape.

On the other hand, special effects can be created with additional light and colour using materials' transparent properties. Although ETFE covers all the aspects discussed above, its high light transmittance is not suitable for tropical climates due to the amount of heat that is proportionate to the high penetration of light, thus causing thermal discomfort for the building occupants. Therefore, PVC mesh has an advantage over the ETFE in responding to tropical climates. The material comes in many finishes and can be customised.

6.0 Conclusion & Recommendations

The study is primarily on textile waste as an innovative material for building façades due to its immense potential to be explored in combating the issues surrounding excessive textile waste globally and locally. The literature review covers the aspects of building façades and responses to the Malaysian tropical climate. Content analysis provides a systematic observation to understand better, thus providing a qualitative analysis of the textile façade that provides a better understanding of the qualities of the chosen study materials, namely PTFE, ETFE, and PVC mesh textile façade. The data gathered from each study are combined into the table to facilitate systemic comparative analysis. Based on the analysis, PVC mesh is the best material that suits the tropical climate setting by having the most economical maintenance with a durable lifespan of between 15 to 20 years. Organic shapes can be created because of their fluid nature and flexible soft material properties when installed onto a frame or structure. Covering all of these aspects in balance, PVC textile mesh is the most viable to be used as an innovative textile façade for future sustainable buildings in the tropical setting of Malaysia.

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Paper Contribution to Related Field of Study
The establishment of the use of PVC mesh textile waste as an innovative material for textile facades provides opportunities for architecture in Malaysia to explore PVC mesh as part of viable textile facade material for future building skin due to its suitability in response to tropical climate. Both eco-sustainability of the textile production process and the development of valuable commodities can be concurrently satisfied.

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