Article Review: Fabric Façade: An Intelligent Skin

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Abstract

The façade of a building serves various functions. It defines the architectural aesthetics of the building while separates the interior space from the public outside and the another important role is to protect the interior from environmental conditions which is related to energy performance of building. Nowadays, the use of fabric in vertical façade is widely applied to the building due to the advantages of the lightness and environmental efficiency properties. This article aims to review the use of fabric façades in building as intelligent skin. Several recent research works found that textile vertical façades not only provide attractive structures with architectural expression but also environmental efficiency and economically attractive. The presented case studies show the tremendous variety of fabric façade applications which is possibly the new approaches to sustainable building solutions in the future.

Keywords: Fabric façade, Membrane structures, textile vertical façade

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Introduction

The external facade plays a very important role in building function. It serves various purposes, the façade forms the outer envelope which not only separates between interior space and the outside climate but also defines the architectural aesthetics of the building. Moreover, as the increasing energy efficiency in building has become a major areas of social concern, this enforces designers to combine the use of energy efficient materials together with the technical solution in order to maximize material savings.

In previous times, skin façade is part of the main structural system because it has to resist the external loads and absorb wind energy, thus tube and bracing structures have been often integrated in the façade especially in high-rise building. This is always restrict the architectural wish of transparency. Until recently, the structure system between the building and the skin façade becomes more independent. This consequently allows the new approach of façade design possibilities, especially in the field of using tensioned membrane structures.

Membrane structure is a common type of lightweight construction, it offers the ability to be applied to curved surfaces and free-form envelopes, which are increasingly used in contemporary architecture. Furthermore, the use of fabric membrane as a vertical skin façade is not only to provide a light barrier of building, but also create economic and sustainability advantages compared to conventional building materials.

Textile Vertical System

There is a difference between the term ‘façade’ and ‘envelope’ of building. The term façade traditionally describes the vertical plane of building, whereas the term envelope refers to the building enclosure.

The façade system usually consists of the façade cladding which is supported by a primary or secondary structure covered with various materials such as glass, metal, timber and also membrane, known as ‘textile vertical system’. If membranes are used for entire envelope, the main requirements are high-stability and a good mechanical strength due to wind action and change in temperature (Figure 1a). If membranes are used as a cladding layer of existing façade system, they have to provide environmental protection such as rain, wind and sun and serve as a communication tool at the same time (Figure 1b).

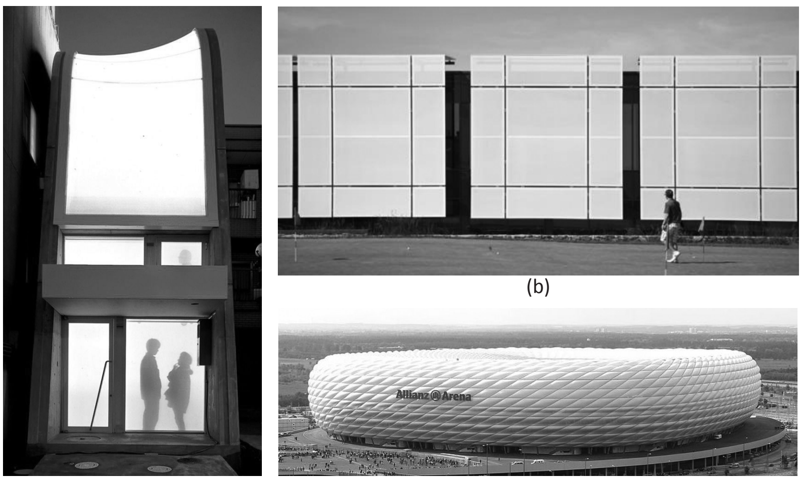
(a) (b)

Figure 1. The applications of textile vertical system.
(a) The National Space Center, Leicester, UK.
(Source: https://s-media-cache-ak0.pinimg.com)
(b) Shopping Center, Deichmann en Essen, Germany.
(Source: https://corpsite.deichmann.com)

The integration of membrane as textile vertical system can be done by various different construction techniques (Altomonte, 2004):

(1) The erection of membrane on reinforced concrete (or steel or wood) substructure. The textile membrane completely wraps entire building envelope or by stretching between substructure (Figure 2a). (2) The textile membrane can be assembled as a panel and installed on a substructure. In this case, the membrane wraps only the vertical building envelope (Figure 2b). The another technique is (3) the installation of a pneumatic structure. Air-supported cushions with two, three or multi-layers of ETFE (Ethylene tetrafluoroethylene) are assembled and integrated on building façade (Figure 2c).

There are two principal construction methods for erection of ETFE façade system, by mechanically pre-stressed system and pneumatically pre-stressed system (Schiemann & Moritz, 2010). Nevertheless, Most of the ETFE facades were erected by pneumatically pre-stressed system (the cushions are pre-stressed by internal pressure) due to the less tensile strength of ETFE-foil (5500 – 7000 psi) in comparison to the other textile membrane materials.



(a) (b) (c)

Figure 2. The different construction techniques of textile vertical system.
(a) Single-Family House, Tokyo, Japan.
(Source: https://s-media-cache-ak0.pinimg.com)
(b) Textile façade of the Royal Spanish Golf Federation's Centre, Madrid, Spain.
(Source: http://sergeferrari.marsdesign.com)
(c) Allianz Arena Stradium, Munich, Germany.
(Source: https://www.dlubal.com)

Table 1. The properties of some materials.
(Source: Mendonça, 2010)

Material	Weight (kg/m^2)	Visible light transmission	Thermal resistance ($m^2.^\circ C/W$)	Embodied Energy (kWh/m^2)
Clear Glass 6 mm	14.40	85%	0.16	73.6
Polycarbonate Clear Panel (10 mm)	2.00	83%	0.32	48.4**
PVC coated polyester (0.5 mm)	0.84	26%	0.17	18.3**
PTFE Coated fiberglass	0.81	21%	1.03*	14.4**
ETFE foil (0.2 mm) 1710 Kg/m^3	0.34	95%	0.16	4.83

*R.E. Shaeffer, 1996.
** Deduced values by Mendonça (2005) (considering just the embodied energy to make the two components of the material and excluding manufacture).

The textile vertical façade system is a prefabricated technology similar to traditional panel curtain walls. After the precast fabric panels are transported to construction site, they are preassembled and pre-tensioned into the frame which corresponds to the perimeter of the façade. The textile façades have a unique feature, they are not flat but have the hyperbolic or parabolic shape, their edges can be flexible by running ropes, cables in the sleeves or put the tubes in hems for generating rigid borders.

Textile Membrane : The Intelligent Skin

Textile membrane materials play an important role to achieve the demands on efficient architecture, both energy-efficient and cost efficient, which are the key factors for sustainability. Textile membranes have very low mass per area which is a significant weight reduction compared to the alternative conventional materials. According to the research conducted by Mendonça (Mendonça, 2005), the strategy of "mixedweight" solution, combination of light- weight and heavyweight constructive solutions, was explored. The results revealed that a lightweight solution can reduces overall weight of building up to 90% whereas a mixedweight can be of 50%, with consequent reduction on Embodied Energy and Transport Energy that allow an overall energy cost reduction of approximately 60%. Hence, the use of fabric membranes in lightweight façade could be considered as 'intelligent skin' when compared to glass which shown in Table 1.

The use of membranes allow for larger deflections compared to glass or polycarbonate and no expansion or movement joints are needed within the membrane covering compared to rigid solutions (Cremers, 2015). This potential advantage could be applied to the building envelope such as roof structures and façades. An obvious example is the Eden Project in Cornwall designed by Nicholas

Grimshaw (Figure 3). The cladding consist of inflated membrane cushions made of ETFE, each cushion weight approximately 2 – 3.5 kg/m^2, which means less than 2% of equivalent glass cladding, while the entire pillow system weighs only 10 – 50% of conventional glass-façade structure (Robinson, 2005).

There are many types of architectural fabrics in common use today, the two principal types have found success as membrane material for envelopes: PVC-coated polyester and PTFE-coated glass fabric, both of them are part of 90% of materials used in membranes (Drew, 2008). PVC-coated polyester tends to be used more often than PTFE-coated glass fabric. However, each material has its advantages and disadvantages which need to be considered of each project. The general comparative properties of common membrane materials are shown in Table 2.

Although fabric material is not effective high insulation but it can be applied as the external shading device, with the additional advantage of a reduced weight, that protects from excessive solar radiation, as well as offer a unique and aesthetic aspect of building. The outstanding application is fabric façade system of Mesa Arts & Entertainment Centre in Arizona (Figure 4a), the 65-PTFE shade panels are created to offering a reduction in room temperatures, these fabric shade elements are twisted into hyperbolic shapes to resist the wind loading on the fabric. The another excellent example of innovative fabric façade design is the three-dimensional-shaped sails façade of the National Library in Riyadh (Figure 4b). The fabric façades are made of PTFE-coated glass fibre membrane which allows only 7% of incident solar radiation, while the white membranes gently distribute the light throughout the entire interior space. Moreover, the fabric façade is combined with ventilation and cooling system which improves thermal comfort and significantly reduces energy consumption (Aksamija, 2016).

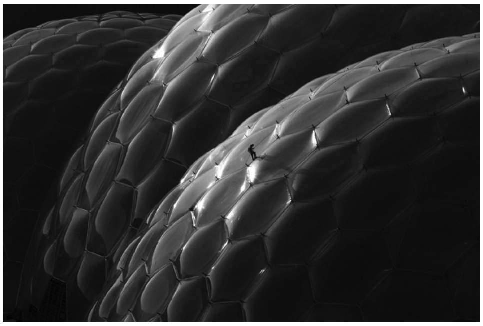


Figure 3. Eden Project, Cornwall, UK.
(Source: https://autrecarnetdejimidi.files.wordpress.com)

Table 2. General comparative properties of materials for common tensile membrane.
(Source: Blum, Bögner-Balz & Nemoz, 2004; Houtman, 2003)

Material	PVC	PTFE	ETFE
Weight (g/m^2)	750 (type I)	800	87.5
Tensile strength warp/weft (N/50 mm)	3000/2800	3500/3500	64/56
Cleaning	easier with top coats	self cleaning	self cleaning
Life span (years)	> 15 - 20	> 25	50
Foldable	very good	bad	bad
Fire retardant (DIN 4102)	B1	A2	-

(a) (b)

Figure 4. Fabric façade for sun and wind protection.
(a) Fabric façade of the Mesa Arts & Entertainment Centre, Arizona, USA.
(Source: https://www.fabritecstructures.com)
(b) Fabric façade of National Library in Riyadh, Saudi Arabia.
(Source: https://s-media-cache-ak0.pinimg.com)

Figure 5. Fabric façade on high-rise tower.
(a) Burj Al Arab, Dubai
(Source: http://www.building-enclosure.com)
(b) Air Traffic Control Tower, Vienna Schwechat Airport, Austria.
(Source: https://image.architonic.com)

Textile fabric materials also used for several high quality tensioned facades such as Burj Al Arab hotel and Vienna Schwechat Airport. The 200 m-high atrium of Burj Al Arab hotel is covered with a double-layered PTFE-coated fiber glass fabric façade, 2 skins of PTFE separated by an air gab of 500 mm, and pre-tensioned over a series of trussed arches. The membrane material not only has excellent resistance against the extremes of UV radiation, temperature variation, sandstorms and fire but also allows the light enter into the atrium and gives an impressive ambient (Figure 5a). The 107 m high Air Traffic Control Tower at Vienna Schwechat Airport (Figure 5b) is the another interesting example, the translucent fiberglass fabric with PTFE coating covers the steel skeleton of the tower shaft which is rotated approximately 45°, the membrane's biaxial tension increases the tower's stability by prevents it from flapping in the wind. Due to the membrane's translucency, it also provides a massive image projection surface when illuminated internally at night (Schmid, 2007).

PVC and PTFE-coated fabric are always used as single layer membranes which are relatively high U-value due to the relatively low mass and thickness. Hence, the single layer membranes are mainly used as an exterior façade which separate between the interior and exterior or just for sun and rain protection rather than being a thermal barrier. To provide a better thermal performance with U-value reduction, it can be done by constructing multi-layer inflated membrane cushions, using ETFE foils.

ETFE foil can be supplied as a single layer membrane or as a series of pneumatic cushions made up of 2 – 5 layers. The main feature of ETFE in comparison to glass is light transmission, a single ETFE foil transmits 94 – 97% of visible light, higher than the equivalent 89% of single glazing, a 2-ETFE layer cushion transmits approximately 76% of visible light, which is similar to the amount transmitted by a typical double glazed unit (Dimitriadou, 2015). Furthermore, by using multi-layer of ETFE foils, the thermal resistance can reach a U-value of 2.49 W/m^2K at 2-layer and 1.18 W/m^2K at 5-layer (Tritthardt, 1999, pp. 14-19). The comparison of thermal transmittance (U-value) and total solar energy transmittance (G-value) of ETFE cushions and insulating glazing units is shown in Table 3.

The thermal and optical properties of the ETFE cushions can be approved by application of frit patterns on the layer. According to research conducted by E.A. Dimitriadou proved that the fritted double ETFE cushion can provide more comfortable interior conditions than double glass. The experiment also indicates that the glass-covered box consumed a total of 11.13 kWh, which is more than that was consumed by the fritted double ETFE-covered box, 11.07 kWh, this means that fritted double ETFE cushions can successfully replace glass in building under cold weather setting conditions (Dimitriadou, 2015). The largest structure of ETFE cushions in the world is the Water cube located in Beijing (Figure 6). The structure composed of 22,000 steel members and contained more than 3,000 cushions but weighting only 100 kg/m^2 (Pohl, 2008). The external layer of ETFE cushions are composed of several layers of blue and transparent ETFE film while the internal cushions are composed of interior foils with reflective and low emissivity frit which varies from 10 to 60%. Both systems work together and combine with the vented cavity system, this provides excellent thermal insulation (LeCuyer, 2008). As a result, the water cube achieved energy efficient design by reducing energy costs of 30% and artificial lighting of 55% (Radwan & Osama, 2016, pp. 178-189).

New Trends in Future

The fabric façades, composed of transparent and translucent materials, play an important role for the building envelope as they not only allow more light inside building but also offer the energy efficiency improvement. Three common types of material have been realized: PVC-coated polyester fabric, PTFE-coated polyester glass fabric and ETFE foil, all of them offer interesting application possibilities. PVC and PTFE-coated fabric are always found in single or double layer application whereas ETFE foils are used in multi-layer cushions.

Currently, trends of building's envelopes are going in the direction of dynamic and adaptive arrangement, which are related to the climatic context (Barozzi, Lienhard, Zanelli & Monticelli, 2016, pp. 275-284). Due to the lightweight and translucent properties, textile membranes therefore are adapted in kinetic facades in order to create the efficient sun-shading device which is related to the solar altitude angle. A notable example of external adaptive sun-shading façade is the Al-Bahar Tower in Abu Dhabi (Figure 7a), a responsive facade system, inspired by traditional mashrabiya. Each unit of façade's panel comprises of a series of stretched translucent PTFE fabric and controlled by a building management system which is stimulated in response to sun's movement during the day. According to the design estimate, the system should reduce solar gain by more than 50% and cooling loads by as much as 25% (Kolaveric & Parlac, 2015).

Table 3. Comparison of Thermal and Solar transmittance for glazing units and ETFE cushions. (Source: Salz & Schepers, 2006)

Material	U-value (W/m^{2}K)	G-value
6mm monolithic glass	5.9	0.95
6-12-6 double glazing unit (DGU)	2.8	0.83
6-12-6 high performance double glazing unit (DGU)	2.0	0.35
2 layer ETFE cushion	2.9	0.71-0.22*
3 layer ETFE cushion	1.9	0.71-0.22*
4 layer ETFE cushion	1.4	0.71-0.22*

*with frit

Figure 6. Water cube, Beijing, China.
(Source: http://c1038.r38.cf3.rackcdn.com)

(a) (b)

Figure 7. Kinetic Ttextile Façade System.
(a) Al-Bahar Tower, Abu Dhabi, UAE
(Source: http://www.designboom.com)
(b) IBA-Softhouse, Hamburg, Germany
(Source: http://www.knippershelbig.com)

The kinetic textile façade can also be adapted to living house as demonstrated in the IBA-Softhouse in Hamburg (Figure 7b). The dynamic textile façade of the house consists of 32 membrane strips made of PTFE-coated glass fibre, each strip is covered with flexible photovoltaic cells. The textile membrane façade is moveable and turns towards the sunlight, optimizing the sunlight for energy production. Besides, the translucent twisted textile also provide shade in the summer, while during the winter, minimise energy loss and allow light to pass into the rooms.

In conclusion, the tremendous variety applications of textile membrane facades show the great potential not only for architectural expression but also in the ability of building's energy demand reduction which is the key factor towards future development for sustainable design solutions.

References

Aksamija, A. (2016). *Integrating innovation in architecture: Design, methods and technology for progressive practice and research.* John Wiley & Sons Ltd: United Kingdom.

Altomonte, S. (2004). *L'involucro architettonico come interfaccia dinamica (The architectural envelope as dynamic interface)*. ALINEA: Firenze.

Barozzi, M., Lienhard, J., Zanelli, A., & Monticelli, C. (2016). *The sustainability of adaptive envelopes: Developments of kinetic architecture. Procedia Engineering, 155*, 275-284.

Blum, R, Bögner-Balz, H., & Nemoz, G. (2004). Material properties and testing. In B. Forster, & M. Mollaert (Eds.). (Eds.). European design guide for tensile surface structures. TensiNet: Brussels.

Cremers, J. M. (2015). Fabric structures in architecture: Environmental impact of architectural fabric structures. Woodhead Publishing: Boston, MA.

Dimitriadou, E. A. (2015). *Experimental assessment and thermal characterisation of lightweight co-polymer building envelope materials*. (Doctor of Philosophy Thesis). University of Bath.

Drew, P. (2008). *New tent architecture*. Thames & Hudson: New York.

Houtman, R. (2003). There is no material like membrane material. In M. Mollaert et al., (Eds.). Designing tensile architecture. *Proceedings of TensiNet Symposium*. Vrije Universiteit Brussel: Brussel.

Kolaveric, B., & Parlac, V. (2015). *Adaptive, responsive building skins, in building dynamics: Exploring architecture of change*. Routledge Taylor & Francis: London & New York.

LeCuyer, A. (2008). *ETFE: Technology and design*. Birkhäuser Architecture, Basel; Boston.

Mendonça, P. (2005). *Living under a second skin – environmental impact reduction strategies of solar passive buildings in temperate climates*. (Doctorate Thesis). Civil Engineering Engineering school, University of Minho.

Mendonça, P. (2010). *Low-span lightweight membranes in housing – environmental and structural potentialities*. Structures and Architecture – Cruz (Ed.). Taylor & Francis Group: London.

Pohl, E. B. (2008). *Watercube: The book*. Bilingual (Ed.). DRP: Barcelona.

Radwan, A. N., & Osama, N. (2016). *Biomimicry, An approach, for energy efficient building skin design*. *Procedia Environmental Sciences, 34*, 178-189.

Robinson, A. L. (2005). *Structural opportunities of ETFE (ethylene tetra fluoro ethylene)*. (Masters Thesis). Massachusetts Institute of Technology, USA.

Salz, C., & Schepers, H. (2006). *Arup's ETFE material not*e. n.d.: London, UK.

Schmid, G. (2007). Membrane cladded air traffic control tower (Vienna: Job report). In H. Bögner-Balz, & A. Zanelli. *Ephemeral architecture: Time and textiles*. Milan: Libreria CLUP.

Schiemann, L., & Moritz, K. (2010). *Textiles, polymers and composites for buildings: Polymer foils used in construction.* Woodhead publishing: UK.

Shaeffer, R. E. (1996). *Tensioned fabric structures: A practical introduction*. American Society of Civil Engineers: New York.

Tritthardt, J. (1999). Textile fassadensysteme. Perspektiven eines neuen Baukonzepts. *Baukultur, 2*, 14-19.