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ADVANTAGES OF LIGHTWEIGHT TENSIONED COATED FABRICS AND FOILS FAÇADES FOR THE BUILDING SECTOR

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Summary. This paper reviews the advantages of lightweight tensioned coated fabrics and foils applied to the existing building sector in order to improve the insulating/shading performance of the external building envelope. The paper describes the main systems developed in the last few years in this field such as pneumatic façades, double curved membrane façades and flat tensioned façades (prefabricated textile panels or tensioned on-site). In addition, the paper analyses the range of foils, coated fabrics and open mesh coated fabrics commonly in use, such as ETFE, Polyester/PVC, Fibreglass/Silicone, Fibreglass/PTFE and ETFE foils.

1 INTRODUCTION

Recent energy-saving European policies in the building sector have led to a rapid increase in the demand for insulating and shading products. It has been estimated that the market for refurbishment of existing European buildings is currently 545 billion Euros per year which represents 30% of the total building sector output. The improvement of the external building envelope represents a crucial aspect in order to achieve the expected thermal performance required by the new targets for the building sector[1].

2 THE TRADITIONAL EXTERNAL VERTICAL CLADDING BUILDING SYSTEMS

Currently, the external vertical cladding market is characterised by several systems based on a wide range of cladding panels made of bricks, ceramics, natural and reconstituted stone, high-pressure laminates, composite materials, aluminium, zinc, steel, fibre-cement board, or durable exterior woods. Due to their reduced material efficiency, these systems show several critical aspects in terms of environmental assessment.

The considerable weight of the cladding panels, which for terracotta claddings and sunscreens can reach 50kg per square meter, requires adequate supporting frames and anchoring systems which can be considerably expensive with not-insignificant environmental loads. In addition, the additional loads could compromise the structural performance of the existing buildings with unpredictable consequences in case of earthquakes.

3 LIGHTWEIGHT TENSIONED MEMBRANE FAÇADES

Lightweight façades realised through the use of tensioned coated fabrics and foils can be classified in the dry assembled building systems with a high degree of prefabrication. The elements are generally prepared at workshops, partially pre-assembled, numbered and transported to the construction site, where they are put together to form units for erection in a further preassembly process[2]. Lightweight tensioned membrane façades are characterised by several distinguishing aspects such as the intrinsic lightweight and efficient use of the materials, reduced environmental impacts (especially when recyclable materials are used), cost-effective alternatives for flat or complex 3D surfaces, good safety behavior in case of fires or earthquakes and a level of insulation (light, heat and noise) which can be progressively improved with specific surface treatments (Low-E coatings, reflective patterns, micro-perforated surfaces etc.) or additional insulating layers and materials.

Figure 1: Detail of the textile façade designed by M. Majowiecki for the two-floor exhibition hall at the Bologna exhibition Centre, 1999.[3]

Their use in the building industry has considerably increased over the last ten years following the first successful examples of enclosed fabric envelope such as the Schlumberger

Cambridge Research Centre in 1984[4] and one of the first uses of fabric exclusively for façades, the two-floor exhibition hall at the Bologna exhibition Centre in 1999[3], Figure 1.

There are three main systems for tensioned membrane façades currently on the market: pneumatic facades, double curved membrane façades and flat tensioned façades.

3.1 Pneumatic façades

Pneumatic façades use air under pressure to achieve the required load bearing capacity. In addition, the pressurised air chamber considerably increases the insulating performance, which can progressively be improved with multiple layers. Compared with double- or triple-glazed façades, the thermal performance is considerably compromised by the dimensions of the air chambers, which allow a not-insignificant movement of the enclosed air with consequent energy losses due to convection. The cushion are generally obtained by welding together two or more layers and then fixing them to a rigid boundary through keder rail profiles. The efficiency of the system, in terms of overall weight per square metre, is strictly related to the ratio between the area of each cushion and its perimeter: the bigger the cushion, the more efficient the system. The main limit to the dimensions of the cushion is its thickness, which is directly related to the curvature of the membrane and its stress state under the same pressure. To overcome this limit, the shape of the cushion is generally a rectangle in which primarily the short direction influences the tension in the material. A similar effect can be achieved using supporting cables or frames arranged in a wide supporting net which reduces the tension in the membrane, Figure 2. Fritted patterns can block out solar radiation, thereby cutting down on cooling costs during the summer. They are commonly printed on the external layer in order to maximize the effect. Recent projects such as the Dolce Vita shopping complex, in which includes north-light-like roof cushions and the Duales System Pavilion at Expo 2000 Hannover have shown the potential of static and dynamic patterns printed on multiple layers.

Figure 2: The pneumatic envelope of the Finmeccanica pavilion designed for the Farnborough Airshow , 2006.[5]

3.2 Double curved membrane façades

Double curved membrane façades achieve the required load bearing capacity through the double curvature of the surface and the pretension introduced into the membrane. The level of prestress depends on the material and geometry chosen with the stress state required inversely proportional to the level of curvature of the surface. The shapes in use reproduce the most common geometries for tensile roofs[2] such as high point structures (Royal Artillery Barracks, London), ridge and valley structures (Unilever building, Hamburg, Figure 3) awnings (King Fahd National Library) and arch structure (Basketball Arena, London).

According to the performances required, which can vary from the simple shading of the façade to a complete water and air tight insulated envelope, the membrane material can be chosen within a wide range of products which cover all the main types of fabrics currently in use in architectural structures.

Figure 3: The double curved membrane façades developed for the Unilever building in Hamburg.[6]

3.3 Flat tensioned façades

The structural performances of flat membrane façades rely on the pretension introduced into the membrane and its ability in recovering from temporary deflections due to external loads such as the wind pressure/suction. Despite the intrinsic low load bearing capacity due to the absence of double curvature, this type of façade is extremely attractive to the market due to the reduced thickness of the systems (which can be less than 5cm if no insulation and ventilation is required) and its similarities with the more traditional external cladding systems.

There are two main building principles currently in use for flat tensioned façades: in the first case the façade is realised connecting the membrane to a set of supporting profiles which have been previously fixed to the façade; in the second case the fabric and the rigid boundary frame are preassembled into modular panels in the workshop and then fixed to the façade.

Like for pneumatic cushions, the efficiency of the system is strictly related to the incidence of the supporting metal profiles. Unfortunately, due to the industrial costs of a new extrusion matrix, these systems are generally based on standard profiles mainly developed in order to optimise the manufacturing and mounting process (corners, windows, intermediate support of the membrane etc.) with no attention to the environmental impacts due to specific technical choices (i.e. modular panels require twice the boundary profiles used for an equivalent façade assembled on site).

A key aspect of this type of façade is the details developed in order to accommodate the applied loads through a temporary deflection of the membrane. These details are covered by several patents such as the Texo® system (based on an aluminum modular frame and a silicon elastomer which acts as a spring), the Profil Tension System (based on aluminum profiles combined with plastic clamping profiles derived from the advertising sector) and the Facid system (based on a metallic keder clamped on the fabric and tensioned into the ribbed aluminum supporting profile). Self-tensioning systems based on the thermo-shrinking of the membrane are currently under development.

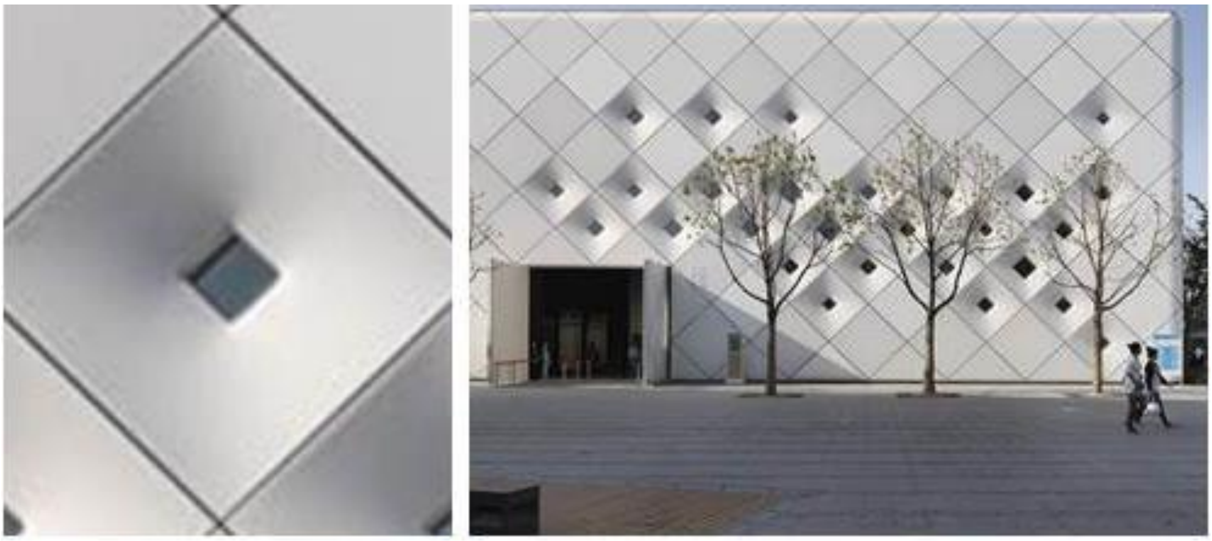

Figure 4: The modular façade for the Expo Shangai 2010 based on the Texo® system[7].

4 COATED FABRICS AND FOILS

Tensioned membrane façades are based on the use of flexible and thin materials in the form of coated and uncoated woven fabrics or polymer foils. As in the biological acceptation of the term, tensioned membrane façades have to satisfy a wide range of requirements which go beyond the mechanical properties and have to consider safety aspects, the influence on the environmental aspects of the enclosed space and the durability of the whole system under the expected weathering conditions. The most relevant engineering textiles for this field are mainly based on polyester, PTFE and glass fibres coated with PVC, PTFE, THV or silicone.

In case of façades designed for solar protection, the same fibres and coatings can be used to obtain open mesh coated fabrics which allow the modulation of the amount of radiation reflected, absorbed and transmitted through different weaving patterns and coatings.

Transparent envelopes can be easily obtained through the use of clear or fritted foils such as PVC, PE, THV and ETFE.

4.1 PVC-coated polyester Fabric

Polyester-PVC is one of the most used textile membrane in the building industry due to the good compromise of price and performance. The five types of polyester woven fabrics cover a wide range of tensile strength suitable for all the main structural applications. In addition, thanks to a relatively good flex cracking resistance, this type of fabric is successfully used also for deployable structures. The main limitations of PVC-coated polyester fabrics are related to the light transmittance, the resistance to soiling and the long-term stability (which, however, can be considerably increased through top coats mad from fluoride lacquer).

Its successful use for tensioned façades is well-documented by a wide range of projects all over the world where cost-effective solutions and short to medium service life are required, such as most of the recent projects for the Olympic Games in London. Furthermore, its use for temporary pavilions is widely supported by the possibility of recycling the coated fabric, thereby reducing its environmental impacts.

4.2 THV-coated polyester Fabric

The use of THV coatings as replacement for PVC is quite recent in the building industry with little data and examples regarding their use. Compared with PVC coatings, THV offers a better behaviour in terms of weathering resistance, self-cleaning properties, light transmittance and UV resistance with the advantage of a similar manufacturing process and equipment.

4.3 PTFE-coated glass-fibre fabric and mesh

Considered one of the most durable membrane materials, glass-fibre fabric coated with PTFE is the most recommended material for permanent projects with an expected service life over 25 years. The material, characterised by a good light transmittance, combines the advantages of the PTFE coating, which provides excellent long term stability and resistance to soiling, with the mechanical resistance of the glass fibres. However, the relatively high cost of the material, especially compared with Polyester-PVC, combined with the additional manufacturing and installation costs due to its low flex cracking resistance, has reduced its use for temporary and low budget projects and for highly double curved surfaces.

PTFE-coated glass-fibre fabrics have been used for several high quality tensioned façades such as the Berlin Brandenburg Airport and the Burj Al Arab Hotel in Dubai.

4.4 Silicone-coated glass-fibre fabric

The disadvantage of PTFE-coated fabrics, which are susceptible to wrinkling, is overcome by using clear or opaque silicone treated with additives. Silicone shows an excellent light transmittance, flex cracking performance and resistance against chemical attack and UV radiation, and it does not become brittle. One disadvantage is that its surface charges up statically and attracts dirt. In addition, the high cost of the raw material and the relatively complex and expensive manufacturing process (the material has to be vulcanised or glued) reduces its use in architecture.

Due to the price and the performance, Silicone-coated glass-fibre fabrics are mainly used for permanent applications such as the Zenith concert hall in Strasbourg.

4.5 Coated and uncoated PTFE fabric

The main properties of PTFE fabrics are their extremely high flex cracking resistance, light transmission, long-term stability and resistance to soiling, which make it the most recommended material for convertible structures, especially when uncoated and with no budget restraints. Its relatively infrequent use for façades is mainly due to the high price of the raw material. However, the potentialities of PTFE fabrics are clearly expressed by recent project such as the façades of the clusTEX research pavilion in Milan and the NRW Bank travelling exhibition ship.

4.6 ETFE foil

ETFE is one of the most stable chemical compounds and its films are largely employed in the building industries due to the very good long-term stability, resistance to soiling and high light transmittance. The mechanical strength is relatively good, especially considering that the material is not reinforced by a woven support, and makes ETFE foils suitable for load bearing envelopes characterised by small spans or supported by cables. The best known ETFE façade is the Beijing Aquatics Center, however, the material has been recently used for single layer projects such as the Unilever building in Hamburg

4.7 PVC foil

PVC foils are characterised by an extremely poor mechanical resistance, long-term stability and resistance to soiling. The optical properties, which deteriorate soon despite the initial transparent and clear aspect, are inferior if compared with ETFE, especially considering specific wavelengths. However, the flexibility of the material and the extremely low cost, make PVC foils a valid alternative for indoor or temporary applications. One of the most relevant projects is the façade for the Finmeccanica Pavilion designed for the Farnborough International Air Show, see Figure 2.

4.8 PE foil

PE foils do not present any relevant property for the building sector except for the extremely low price, which compensates for its very poor UV and soiling resistance. For this reason its use is mainly confined to greenhouses and the agricultural field with no relevant permanent projects in architecture. However the film has been successfully used for temporary pavilions and installations such as the Mobile Action Space in Berlin.

4.10 THV foil

THV foils offer a good flex cracking resistance and long-term stability comparable with those provided by ETFE foils. However its optical properties and resistance to soiling are considerably lower than ETFE. Although it can be easily welded with high frequency welding machines, its use in architecture is quite sporadic due to the lower mechanical and tearing resistance which reduce its use over medium and large spans.

5 ADVANTAGES

5.1 Technical

Like for other uses of membranes in architecture, the advantages in the use of tensioned fabrics and foils for external claddings are related to the efficient use of the materials with no concerns for bending and buckling with the only exception being the rigid boundary profiles, when used. In addition, the use of a membrane envelope intensifies the level of industrialization of the construction, reducing the number of processing phases and workers involved in the building on-site, and increases the proportion of factory-built components which are only assembled on-site. This has several advantages in terms of efficiency (1 to 10 m^2 of material processed for each hour of work, according to the material and the type of joints chosen) and quality of the final product.

Figure 5: Installation of the Torium Shopping Center pneumatic ETFE façade[8].

The manufacturing of the fabric panels is executed in safe and clean spaces by highly specialised workers and specific equipment such as computerised cutting tables and welding machines. The manufactured membrane can be easily packed, stored and shipped due to the reduced weight and volumes of the fabric once folded. Thanks to the relatively low transportation costs, the packed façade can be delivered all over the world using trucks, railways, waterways of even aeroplanes when required, virtually with no limits in terms of logistics.

Once on site, the assembly process is relatively fast and efficient due to the high level of accuracy of manufacture, the adjustable boundary details and the reduced weights and volumes to be handled, which require less (and smaller) lifting equipment. In addition, there are no limitations in terms of combination with others building materials such as steel, aluminum, wood, reinforced concrete, composites etc.

Finally, tensioned membrane façades can provide maintenance benefits using self-cleaning materials and top coatings, and other intrinsic advantages in terms of inspection and substitution of the components.

The result is an overall cost-effective product able to compete with the main traditional solutions and materials currently in use for planar and complex three-dimensional façades.

5.2 Environmental

The intrinsic efficiency and lightness have a direct influence on the environmental impacts due to the reduced amount of natural resources, energy and waste produced compared with traditional cladding system. However, the membrane's low mass per area is not directly synonymous with reduced environmental impacts due to the substances and energy consumptions often required during the manufacturing of the main architectural coated fabrics and foils. For this reason, several studies and certifications [9,10,11] have recently investigated the impact of tensioned membrane structures according to a life cycle approach which assess the environmental impacts associated with all the stages of a product's life from-cradle-to-grave[12].

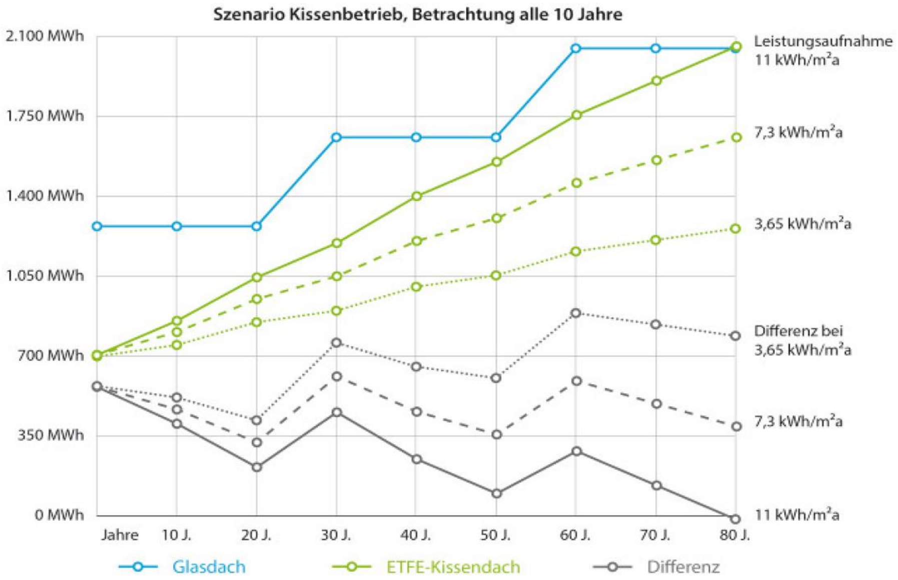

Figure 6: Comparison of Primary-Energy-Calculation for a Glass roof compared with an ETFE Cushion-Roof for a project in Munich[16]

Another insidious aspect which has to be considered is the energy consumption during the operation of the buildings, which, for pneumatic structures, is inevitable, associated with the energy consumption required to maintain the adequate air pressure[13], although potentially this can be partially provided by energy produced from photovoltaics.

Despite uncertain aspects, several recent works [14,15,16] have shown the high potential of lightweight membrane structures in reducing the environmental loads in the building sector. In addition, further advantages are related to the accurate design of the boundary and supporting profiles which can be reduced due to the bigger spans and the minor permanents loads[17].

Thanks to their reusable connections, the components of the façade can be easily disassembled and recycled (ETFE foils and PES/PVC fabric are entirely recyclable) or reused (such as the bags produced by the famous brand Freitag from recycled fabrics).

Finally, tensioned membrane envelopes can be successfully used in order to improve the thermal performances of existing buildings reducing the heating/cooling costs thanks to better insulation and shading of the external façade. For specific projects, a further advantage could be obtained through the use of high quality self-cleaning surfaces which reduce the use of cleaning products.

5.3 Comfort

One of the main challenges of the building sector in recent years is focused on the reduction of the running costs and the environmental impacts without compromising the levels of comfort. Despite the critical aspects related to the use of lightweight membrane envelopes, mainly due to their intrinsic low thermal inertia and their complex building physic driven by radiation input and losses, several recent projects have shown the advantages of membrane façades in new buildings and retrofittings[18, 19].

In addition, when the translucency of the façade is not a priority, it has been shown that the thermal properties of tensioned membrane envelopes can be progressively improved with a wide range of additional layers such as the latest translucent aerogel mattress or the more traditional sandwich systems based on fibrous insulating material, such as in the Chatham Maritime Food Court, developed by Architen Landrell[20]. The use of fibrous insulating material can considerably improve the acoustic insulation of the envelope and it is generally combined with open mesh fabrics or micro-perforated foils in order to increase the acoustic absorption properties of the envelope, thus reducing the reverberation time which generally affects large spaces. Specific research in this field has been carried out in recent years at the Eindhoven University of Technology[21].

The use of tensioned façades for retrofitting is generally combined with the need to improve the shading of the external wall and/or protect additional external insulation. The shading performance of coated fabrics and nets has been measured in several combinations[22] and can be successfully applied to reduce the solar gains during the summer. A correct design of the envelope should find the appropriate compromise between a waterproof and airtight envelope and a good level of natural ventilation in order to reduce potential risks of condensation.

Finally, membrane envelopes offer an excellent way to provide a good level of natural illumination, which, however, has to be carefully considered in order to provide the correct balance between direct and diffuse light, an adequate color of the light and a good perception of the inside/outside[23].

5.2 Safety

The high level of prefabrication of tensioned membrane façades can lead to a considerable reduction of the of manufacturing activities carried out on site, which are reduced to the mere assembly of components and the final installation. The reduced weight and volumes managed have positive impacts on the installation process which is generally quicker and based on smaller lifting equipment. But the safety aspects of tensioned membrane envelopes are not solely restricted to the building phase. The work of Kawaguchi[24] has shown the remarkable advantages due to the flexibility and lightweight of membrane ceilings and envelopes in the case of earthquakes. ETFE foils provide similar safety benefits when used as a replacement for (brittle) glass in overhead situations, such as atria. In addition coated fabrics and foils have a good fire behavior and have been successfully approved in several projects. In particular PVC coated polyester fabrics will self-extinguish quickly upon removal of the heat source and the use of specific additives prevents the formation of flaming droplets. On the other hand, glass-based fabrics are classified as non-combustible materials. In case of fire the seams connecting the membrane panels immediately above or adjacent to the area of the fire will open creating an hole in the envelope through which the intense heat and smoke is discharged[25].

6 CONCLUSIONS

In summary this paper aims to present the recent developments in the design and manufacturing of tensioned coated fabrics and foils façades. The paper describes the main systems and materials currently in use and analyses their main technical, environmental, comfort and safety advantages.

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