Tents, Sails, and Shelter: Innovations in Textile Architecture

Tania Garbe

Editor
Werner Lang
Aurora McClain
Tents, Sails, and Shelter: Innovations in Textile Architecture

Tania Garbe

Based on a presentation by Dr. Jan Cremers

Introduction

As designers we are continuously confronted with sobering statistics about the built environment and the severity of its contribution toward CO₂ emissions and resource depletion. We know that building construction uses 17% of the world’s fresh water supply, 40% of its fossil fuels and manufactured materials, and 25% of the world’s wood harvest.¹ As a result, contemporary designers have become increasingly committed to ecological design principles with the intention of producing a built environment that is more in tune with its natural surroundings. Construction materials are constantly being reassessed and redesigned to be more sustainable. Textile structures can play an important role in sustainable architecture, stepping lightly on the land while using fewer material and energy resources for fabrication and shipping.²

Textile architecture has the potential to reduce solar gain, cooling loads, and peak electricity demands, resulting in lower energy costs for buildings. Membranes can be designed to be easily dismantled, reducing the amount of post-construction refuse. They are extremely flexible, and in combination with photovoltaic cells they can even produce their own energy. But perhaps the most welcome architectural contribution of modern textiles is their ability to transform the aesthetics of sustainable architecture and inspire exciting new forms.

Membrane materials and applications

History

Building with membranes is not a new art. Creating shelter from textiles or animal skins was one of the first methods that humans devised to protect themselves against the elements. Ancient cultures used textiles first for clothing and then for tent structures, creating basic shelters from simple membranes. Some cultures even developed highly elaborate structures from combinations of membranes, like the Mongolian gers. In modern architecture, fabric was utilized predominantly for shading devices and temporary structures. It was not until the mid-twentieth century that designers like Frei Otto in Germany began trying to optimize membrane structures in order to create long-lasting buildings. More recently, this approach has driven the search for materials that can serve multiple functions, providing shade while also stabilizing geometries, to create more efficient structures.

Current technologies: ETFE and PTFE/Glass

The advent of plastics and PVC coated materials has led to innovations in textile
performance that have brought membrane architecture into the forefront of sustainable design. Recent efforts have focused on the development of more hi-tech materials based on fluoropolymers, like PTFE, poly tetrafluoroethylene coated glass fibers, or ETFE, a transparent foil made from a copolymer of ethylene and tetrafluoroethylene (Figure 2). Teflon is the DuPont brand name for PTFE, which is known for its durability and anti-stick properties. As a foil (ETFE) it is also UV transmittant and resists UV degradation. ETFE and PTFE have a variety of unique qualities that make them desirable for membrane structures and versatile as an alternative to glass.

Light transmittance

New textile fabrics offer varying degrees of transparency and light transmittance. Many recent architectural applications of textiles can be found in stadiums and sports arenas. Approximately 80% of all new stadium roofs use membrane construction. One reason for this is the demand for high light quality in a stadium. Membranes offer an affordable way to provide durable, light-transmitting roof structure. For example, the Olympic Stadium in Berlin received an innovative new membrane roof as part of a retrofit for the latest world cup (Figure 3). Von Gerkan, Marg & Partner specified a double layer of PTFE-coated glass fabrics for this purpose. The two layers are separated by a 4.5m gap for technical equipment, while the outermost layer acts as a rain screen. The lightweight outer membrane is only 1.5 mm thick, yet is sturdy enough to support human occupation for construction and repair.

Greater Spans

One main advantage of using membranes over glass is that membranes are capable of spanning very large distances. The benefit is greatest with fabrics, which are capable of structural spans of over 200 feet. However, foils can also be used to span distances greater than those possible with glazing, especially in the horizontal direction. Membrane constructions can also be stabilized by pre-stressing and pressurizing pillow-like cushion structures. For example, at the Clarke Quay Redevelopment Project in Singapore, Will Alsop Architects and Hightex Group used an ETFE film membrane to cover an old shopping street and convert it into a shopping mall. Here, the membranes were inflated like cushions, with an over-pressurized interior stabilizing the surface and allowing it to span a much greater distance than normal. If the cushion size required is very large, a cable net can be used to further increase the span of structures.

Building image

Textile architecture can also be used to create an aesthetically interesting facade. The material’s ability to take on sinuous and unusual forms while still transmitting light makes it well suited to the creation of original facades that help to create a unique image. The textile envelope of the Burj Al Arab in Dubai has become iconic, relating the building to an Arabic tent at a vast scale (Figure 4). The facade uses a two-layer PTFE glass fiber membrane, with each piece of fabric measuring 2500 meters square.

Flexibility

The lightweight nature of textile materials affords them a great amount of flexibility in their construction and removal. Since membranes are inherently flexible, they are also particularly well suited for use in temporary or operable structures that can open and close. The ‘Josefsburg’ Kufstein is a castle in Austria that hosts several open air concerts per year. Because of the frequent risk of rain, a roof was required that could be closed quickly, even in the middle of a performance. The solution was to create an operable structure that can be closed in only 3 minutes (Figure 5). For this project the architects chose a new, very flexible, pure fluoropolymer fabric with a fluoropolymer coating. An additional concern in this project was the stringent building code requirements for the historic structure. The decision to use a textile construction ensured that the historic architecture and appearance of the ‘Josefsburg’ castle would not be dramatically altered.

Figure 3: Roof of the Olympic Stadium: Berlin, Germany

Figure 4: Burj Al Arab: Dubai, UAE

Figure 2: PTFE and ETFE membranes
Rapid construction

Another important advantage of textile architecture is that it allows for rapid assembly and construction. Membranes arrive on site as modular units or packages. Once these units are installed, they can quickly be ‘unwrapped’ and secured, greatly reducing the time and cost for construction.

Thermal insulation

One very exciting emerging possibility in membrane engineering is the potential for incorporating thermal insulation. Membrane producers have tackled the challenge of creating thermally insulative membranes with very high R-values. At the visitor centre for Alnwick Garden, a profile was developed that could clamp together several materials at the same time. In this case, PTFE glass fabrics were combined with ETFE foil to create a very high level of thermal insulation. Since the system used lightweight foils, it required less structure and was able to overcome the safety hazards that are normally associated with having glass overhead. If a thin membrane structure were to break and fall, it is unlikely that any harm would be done to the visitors below. Further insulative properties can be achieved using membranes to create thermal buffers or climatic envelopes as described below.

Climatic envelopes

At the Center for Gerontology in southern Germany, a secondary skin membrane was used to create a thermal buffer or climatic envelope that moderates temperature and energy use for the building (Figure 1). The membrane shelters a standard post and rail facade and an external concourse for circulation. The membrane protects visitors from extreme weather along this exterior circulation around the building. In this project it was very important to the architect that the membrane form an almost invisible skin, allowing a visual connection between interior and the exterior. The exterior membrane facade creates a very transparent causeway while creating providing an intermediate temperature zone that helps to reduce energy consumption.

Form/Sculpture

Another advantage of using membranes rather than glass is that fabrics have the ability to create any free-form shape. This allows membranes a degree of flexibility that can be appropriate to sculpture or art. One example is the work of Anish Kapoor, who recently created a membrane sculpture called Marsyas for the turbine hall of the Tate Modern (Figure 6). The piece is 180 meters long and consists of 3 rings that act as a framework for a draped PVC coated polyester fabric membrane. In another project, OMA created a massive, helium filled balloon that served as the roof for a temporary structure. The balloon rested on the simple metal walls of the structure at night, but during the day the balloon was partially released so that light could be allowed in from the edges.

Printing/Fritting

One functional and aesthetic attribute of membranes is that their surfaces can easily be fritted or printed upon. Dot fritting on a membrane can help to create shade and increase reflectivity, while printed text or patterns can also add a graphic component to a structure. Textiles are also quickly becoming used on buildings as an income producing and eye-catching advertising method. In other instances printing or fritting can introduce a sculptural and meaningful component to membranes. At the M11 Terror Attack Memorial in Madrid, an internal ETFE screen displaying messages to the victims of the attack is suspended from a translucent cylinder of glass bricks, acting as the central sculptural piece (Figure 7). Light is allowed to filter through the messages and into the structure, thereby lighting the underground space beneath it.

Durability

PTFE fabrics have remarkable self-cleaning characteristics and incredible durability, making them considerably more desirable for shading applications than typical awning materials. PTFE fabrics stay clean and white for longer, which causes them to have greater reflectivity over the entire life span of the material. The beautiful interior light qualities and exterior image of the Burj Al Arab would not be possible without such a self-cleaning, highly durable, reflective fabric. The same qualities also apply to ETFE foils.

Low emissivity and infrared mirroring

Low emissivity (Low-E) surfaces are surfaces that reduce infrared radiation from warmer to cooler surfaces by reflecting a significant amount of radiant heat. This can potentially raise the R-value, or lower the U-factor value,
of a building envelope made of these materials. Low emissivity coatings are a standard technology for glazing, and have now been developed for PTFE glass materials.

At the Suvarnabhumi Airport in Bangkok, a low-E coated PTFE glass has been used as an interior layer paired with an outer layer of PTFE/glass that reflects up to 70% of solar radiation was used on the outside (Figure 9). The real advantage of PTFE over glass in this case is that it does not gather any dirt, and therefore its reflectivity remains constant over the lifetime of the product. Other materials get dusty, making them unable to maintain the same reflectivity over time, which is crucial to the energy balance of the building. The membrane architecture of the Bangkok airport consists of three layers, each of which is 10810,000 square meters in area. The designers chose to condition only the spaces used for human occupation, thereby reducing the required cooling loads. Since very high temperatures occurred in the upper areas of the membrane canopy, it was very important to apply a low-E coating to the surface facing the interior, so that the membrane would not act as a huge overhead radiator.

Another important quality of low-E PTFE materials is that they mirror radiation in the same part of the far-infrared spectrum. This leads to an interesting effect in the Bangkok Airport. When looking up to the roof, one can feel the cold that is radiating from the floor. In this case it acts like a mirror for long-wave infrared light, but not for visible light.

**Innovations in membrane systems**

Research and development has led to several recent innovations in membrane architecture. The most exciting recent developments include integrated photovoltaics, translucent thermal insulation, standardized elements, and functional coatings for membranes.

**Integrated photovoltaics**

The world’s first flexible photovoltaic modules integrated into high performance membranes have been developed in a product called PV Flexibles (Figure 9). Until recently, PVC was the only transparent membrane that was seriously studied for integration with photovoltaics. Unfortunately, PVC has proven to be unusable because of its relatively poor durability for long-term use. Since long-term use is essential in PV applications so that users can see returns on their investments, researchers have found more suitable substrates with longer lifespans. The durable, self-cleaning, UV-resistant polymers ETFE and PTFE have allowed the integration of PVs into translucent and transparent membranes for roofs, facades, and canopies. PV Flexibles can either be laminated between two layers of an ETFE foil, or bonded to a translucent PTFE membrane. They are extremely thin, highly flexible, and very light photovoltaic cells composed of extremely flexible amorphous silicon thin-film solar cells embedded in a fluoropolymer film. The resulting photovoltaic cells are only one micron thick and come as a roll that can be cut to length (Figure 10). These new flexible photovoltaic modules are well suited for use on membrane structures, which often have large surfaces with high sun exposure. It is finally possible to put PVs on surfaces that cannot accommodate heavy, conventional, rigid solar panels. Not only do these systems make it possible to produce electricity on flexible surfaces, but in translucent building components they can also reduce the solar heating by providing shading of interiors and thereby minimize cooling loads and energy consumption.

**Translucent thermal insulation for membranes**

Because of the low material thickness of membrane structures and the high levels of light transmission frequently desired, high thermal insulation has previously been difficult to achieve with membranes. The most promising solution is the use of translucent silica-aerogel. Aerogel is a highly efficient thermal insulator which also transmits light well.

Solarnext AG and Hightex Group worked with the Georgia Institute of Technology on their Solar Decathlon Entry of 2007 to design a roof that was highly insulative and allowed for high light-levels within the structure. The solution was to create an ETFE pillow structure filled
with Aerogel (Figures 11 and 12). The pillow structures also included an ETFE waterproofing layer, because the structure needed to be frequently assembled and disassembled. The result was an insulative assembly that performs four times better than standard insulation. Thermal blankets incorporating Aerogel can also be applied to PTFE glass fabrics, creating very thin material layers with very high insulation values.

**Standardized membrane elements**

Membrane manufacturers have begun to standardize their membrane components, creating modules that make construction considerably easier and more cost efficient. The intention is to create modules that are similar to window units, but made out of membrane instead of glass. One significant advantage that membrane units have over glass window assemblies is that they offer a greater variety of options in terms of size. Such standardized membrane elements were applied in a project for the Bergwacht (Mountain Rescue Center) in Bad Toelz, Germany (Figure 13). This building envelope is comprised of around 400 prefabricated, standardized membrane pieces that were assembled on-site.

**Innovative functional coatings**

Exceptional properties that until recently have only been available for glass, like low emissivity and selective light transmission, have been developed for membranes. These coatings work with clear ETFE foils. Low-E coatings can also be applied on PTFE coated fiberglass, like at the airport in Bangkok. Transparent selective functional coatings are able to reduce the near infrared part of the sun’s spectrum while still transmitting most of the visible spectrum. This technology is particularly useful for translucent membrane structures in hot climates, like the Dolce Vita Tejo shopping mall project currently under construction in Lisbon, Portugal (Fig. 14). In the future, innovations in functional coatings will result in high levels of control over the energy characteristics of membrane materials.

**Conclusion: the future of membranes**

Textile architecture will play a key factor in the future of intelligent building envelopes, since it can create energy-producing and energy load-reducing surfaces. The role of membranes in a sustainable built environment will continue to change as new advances are made and technologies discovered. Currently, building surfaces and envelopes are often treated only as inert systems that function passively.
to protect us from the elements. However, building surfaces are likely to play a much more important role in the future. Off the Grid: Sustainable Habitat 2020 recently predicted that the integration of electronics and biochemical properties in building materials could lead to a shift where building surfaces are thought of as sensitive skins that are "alive and act as membranes to harness energy." In this role, membranes have the potential to become transporters of air, water, and light, helping to lead the built environment on a path towards energy independence and sustainability.

Figure 13: Architects Thomas Herzog + Partner: Bergwacht Bad Toelz, Germany

Figure 14: Dolce Vita shopping mall: Lisbon, Portugal
Notes


Figures

Figure 1: Hightex, D-Rimsting 2008
Figure 2: Hightex 2008Seer, Ulli, D-Icking (from “Membrane Structures”, KM Koch/ Prestel)
Figures 3-5: Hightex, D-Rimsting 2008
Figure 6: www.flickr.com by ultrahi
Figures 7-8: Hightex, D-Rimsting 2008
Figures 9-12: Solarnext AG/ Hightex Group, D-Rimsting 2008
Figure 13: Verena Herzog-Loibl, Solarnext 2008
Figure 14: Promontorio Architects, P-Lisboa

References


Further Reading


Biography

Jan Cremers is the Director of Envelope Technology at Solarnext AG / and Hightex Group, Rimsting (Germany).

He studied at the University of Karlsruhe from 1991-1999, at which time he received the 1st prize in the building network competition for the Diploma of the Year. He has also studied Architecture and management at Westminster University, London, UK.

In 2006 he received awards for his outstanding doctoral thesis: “Applications of Vacuum Insulation Systems in the Building Envelope Alliance of Friends of the Technical University in Munich” from both the Technical University in Munich and the Marshall Foundation.

Jan Cremers has lectured frequently at the Technical University of Munich School of Architecture on topics concerning membranes and facade construction. He is a regular reviewer for the referenced international magazine Solar Energy, official journal of the International Solar Energy Society. Since 2008 he is a full professor of Building Technology and Integrated Architecture at the University of Applied Sciences Hochschule für Technik in Stuttgart, Germany.