TEXTILE-BASED ARCHITECTURE

Exploring the State-of-the-Art

Speaking Notes

Slide 1 - Title

<u>Aim</u>

This lecture will provide an introduction to textile-based architecture. It will examine case studies, and provide an overview of its current uses and future developments.

Slide 2 – Sections

The lecture is divided into four sections:

1. **Introduction to textile-based architecture**, which will present the development of textile architecture and give case studies to demonstrate its uses
2. **ETFE – An architectural wonder material**, which will focus on ETFE (Ethylene TetraFluoroEthylene) as the dominant emerging architectural textile
3. **Textiles for sustainable buildings**, which looks at the sustainability of textiles and how they can be used for sustainable building designs
4. **Advancing the state-of-the-art**, which will give two in depth case studies and examine future developments.

INTRODUCTION TO TEXTILE-BASED ARCHITECTURE

Development of textile architecture

Slide 4 – Contents

This section of the lecture will give an introduction to the evolution of textile-based architecture, tracking it from its origins, through to the development of new materials and advanced applications.

It will examine case studies that demonstrate the flexibility of textile-based architecture and will equip you with a basic knowledge of the different parameters that need to be considered for working with these materials.

Slide 5 – Early steps (1)

Whilst textile-based architecture is increasingly popular, the basics are not new. At their most simple, textile architecture requires just a support frame and a fabric.

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Tents are the oldest form of textile architecture, with the advantage of being light, and easy to convert or dismantle, whilst also providing protection against the elements.

Here we have a traditional Mongolian Yurt, still used today. Such structures have been used by nomads in in the steppes of Central Asia for more than 3,000 years. Construction takes around two hours, and when deconstructed, the materials can be carried to a new location.

The yurt is made up of a round outer wall of latticed wood, with a door frame and roof structure made of poles. Traditionally, the frame would then be covered with a felt material, though today, more modern materials are also used.

Slide 6 – Early steps (2)

But textiles also have a longstanding history if being integrated into more elaborate architecture. Perhaps one of the most famous structures in the world, the Roman Colosseum, one had a textile roof.

The *velarium* ('awning', from *velum* 'curtain' in Latin) provided shade for spectators, as well as protection from rain. The *velarium* was retractable and was operated by sailors who would pull the strips of fabric over a net structure, made of ropes.

As well as providing protection, the *velarium* had a hole in the centre, and the fabrics sloped towards this hole, to bring wind circulation into the Colosseum, thus providing ventilation for the crowds.

Slide 7 – New materials

The twentieth century witnessed significant further development of textile-based architecture. The invention of advanced fabrics, combined with developments in engineering and computer-aided design, have opened a wealth of new possibilities in terms of form and scale.

Exhaustive research into man-made plastic membranes took place during the 1950s and '60s, gradually converging on a small number of promising materials. The new membranes were far superior to their predecessors and could endure weathering and stretching, meaning they could be used for permanent buildings and installations. The result has been a proliferation of textile-based architecture, using a variety of plastics with different advantages in terms of strength, flexibility and transparency.

Slide 8 – Membrane materials (1)

A variety of plastics can be used for textile-based architecture with different qualities such as strength, flexibility and transparency. Here are a selection of plastic fabrics which are often used in architectural applications, each with different qualities.

Slide 9 – Membrane materials (2)

Different materials have different strengths, longevity and transparency, as well as different levels of fire resistance. The characteristics required for the building in question will impact upon the choice

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of fabric to use. If strength is the main criteria, then polysulfone or glass fabrics are the preferred materials, however, a trade-off must be made against other qualities such as transparency and light transmittance.

	Load bearing capacity (tensile strength)	**Fire Classification** (according to DIN 4102-1)	**Resistance to environmental exposures** (chemical/biological)	**Resistance to cross-breaking** (folding, retractability)	**Light Transmittance**	**Transparency**
Material/Unit	*[kN/m]*	*[class]*	*[high/med./low]*	*[high/med./low]*	*[%]*	*[yes/no]*
PVC/Polyester-fabric (Type V)	**high (190/166)**	B2 or B3	medium	medium	up to 10	no
Silicone/Glass-fabric (Type G VII)	**high (170/158)**	B1	medium	medium	up to 25	no
PTFE/Glass-fabric (Type G VII)	**high (170/158)**	**A2** or B1	**high**	low	up to 14	no
Fluoropolymer fabrics (ETFE/PTFE/FEP)	medium (80/80)	B1	**high**	**high**	**up to 40 - 85**	no
ETFE-foil (250 µm)	low (13/13)	B1	**high**	low	**up to 90**	**yes**

Fundamentally, the choice of material will reflect the requirements of the building.

Slide 10 – Building components

Plastic textiles can be used for a number of applications and act as different building components. The most typical, though by no means the only, are building envelopes, roofs, skylights, façades, canopies and freestanding sculptures.

Slide 11 – Applications

In particular, plastic fabrics have been used for monumental and iconic architecture, and are widely applied in the sectors of sports, travel, industry, leisure, culture and commerce.

Slide 12 – Kind of pre-stress / Mechanical (1)

Fabrics must be stressed when used as a surface in buildings, and there are two main ways of doing this. The first is with mechanical pre-stress, where the fabric is pulled over a supporting framework and is held in place, like a tent.

Mechanical pre-stress can be applied to a membrane by stretching it from its edges or by supporting it with wire cables, light weight steel or aluminium to maintain shape and stabilisation. This enables a flexible single layer membrane to span large areas.

It was only in the last century that advances in structural mathematics and engineering made it possible for lightweight textile-based architecture to take on new forms, and operate on a much larger scale.

This early example shows a building from the 1950s, where PVC-PES fabric has been used to create an open-air canopy in the Rheinpark, Cologne.

Slide 13 – Kind of pre-stress / Mechanical (2)

Here is another example with PTFE glass at the Volkswagen Customer Centre, at their headquarters in Wolfsburg. The canopy shields a carpark where buyers can get into cars, where both customers and car are protected from rain and direct sunlight, whilst also allowing enough light through so that electronic lighting is not needed.

Slide 14 – Kind of pre-stress / Pneumatic

The other type of pre-stress is pneumatic pre-stress, where air is used to fill cushions of the plastic fabrics. These cushions are made up of at least two pieces of plastic, with other layers sometimes being used to add additional functionalities such as greater sound or heat insulation. This example was built in 1970 for the EXPO '70 World's Fair, with the intention of being futuristic, transparent and communal. As pneumatic pre-stress involves inflating individual cushions, this requires a modular, pre-fabricated approach.

Slide 15 – Degree of pre-fabrication

The type of material and how it is to be used will impact upon the manufacturing of fabrics. For a mechanical pre-stress, such as the VW customer centre, a single large piece of fabric is needed, and will need to be manufactured as one piece and transported to the site for installation. For pneumatic pre-stress, each cushion acts as an individual module. But not all modules need to be cushions. The image on the right is of the upcoming SWATCH and OMEGA Headquarters, in Biel, Switzerland, where each square is filled with a pre-fabricated sheet of ETFE plastic.

Slide 16 – Textile function / Monofunctional

In some cases, fabrics are used for a single function only, and in other cases, they have multiple functions. In this example, a PTFE glass membrane is being erected as a curtain wall around an Elevator test Tower in order to improve aesthetic qualities and aerodynamics.

Slide 17 – Textile function / Multifunctional (1)

Whilst in this example, the UNIQLO building in Osaka, Japan, two-layer ETFE cushions on the building façade are used to provide weather protection and thermal insulation, but they are also integrated with LEDs, which allow the modules to change colour to have a striking building aesthetic.

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Slide 18 – Textile function / Multifunctional (2)

Another example is of the AWM carpark in Munich, where three layer-ETFE cushions have photovoltaics integrated into them. The cushions act as the roof to the carpark, whilst also generating electricity.

Slide 19 – Temporary structures

Installations with fabrics can also be either temporary or permanent. Because they are often modular, such structures are easy and quick to install compared to other structures. The Coca Cola Pavilion was an interactive structure built for the London 2012 Olympic Games. Each panel was made out of ETFE foils, and integrated with technologies that could react to the movements of visitors. The façade consisted of 230 LED illuminated ETFE cushions, with 40 cushions having built-in audio speakers, equipped with motion sensors, allowing visitors to create sounds through physical interaction with the structure.

Slide 20 – Permanent structures

Alternatively, they can be permanent structures such as the Piotrkowska Street tram station in Lodz, Poland. Few inner-city infrastructures have a well-developed aesthetic, but here, the ETFE foil used here protects commuters from the weather, but has also been died with a striking design that acts like a large stained-glass window. Printing can be also be used to manipulate the light transmission properties of ETFE, or for branding purposes.

ETFE – AN ARCHITECTURAL WONDER MATERIAL

Characteristics and qualities of ETFE

Slide 22 – Contents

The next section will focus on Ethylene TetraFluoroEthylene, or ETFE, plastics, which are becoming the most widely used for architectural purposes, and has large potential benefits for sustainable buildings.

Slide 23 – 'A wonder material' (1)

Of the new high performance plastics which we've looked at, ETFE has become the material of choice for many architects. It has been described as a 'wonder material' due to its physical properties, which make it an extremely versatile, durable and sustainable option, with a wide range of possible functions and applications. ETFE (ethylene tetrafluoroethylene) is closely related to PTFE (polytetrafluoroethylene or Teflon), and is available as a flexible transparent film.

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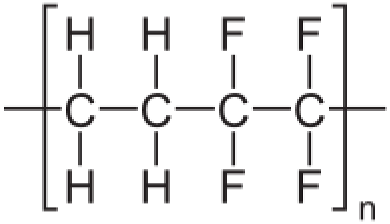
Clear ETFE film lets in more light than glass, and is a better heat insulator, giving energy savings or around 30% when used in buildings.

ETFE is dirt-resistant and rain water is enough to keep it clean, dispensing of the need to pay for cleaners and cleaning materials. Additionally, if torn or damaged it can easily be repaired.

Sound waves are more likely to be absorbed by ETFE than reflected, creating pleasant room acoustics with insulation values of about 10 decibel.

<u>Structural formula</u>



Slide 24 – 'A wonder material' (2)

ETFE is a super-lightweight material: in some buildings made of ETFE, the mass of the air inside is greater than that of the structure itself. ETFE film weighs only around 1-3% of an equally-sized glass panel, and a double layered cushion less than 5% of conventional (6mm) glass. This means structural support can be much more slender, opening up new design possibilities while reducing material use, build time and costs.

Slide 25 – Light transmission (1)

ETFE lets in more visible and ultraviolet light than glass, producing bright and welcoming indoor spaces. Practically the whole light spectrum passes the material unfiltered and creates a near-natural lighting atmosphere.

Slide 26 – Light transmission (2)

ETFE foil can be printed upon in order to control light transmission, and different patterns can also limit visibility through the plastic to hide building interiors.

Slide 27 – Durability

ETFE has high resistance to chemical damage from pollutants and is resilient to UV rays and weather effects. The material has been extensively researched and tested and it is anticipated that the material has a life expectancy in excess of 50 years, maintaining its tensile strength for more than 20 years, with a loss of around 15% after 15 years.

Slide 28 – Multi-layered ETFE

As already discussed, ETFE can be used in single-layer sheets, with mechanical pre-stress over a supporting structure, or it can be used in multi-layer cushions. These cushions are then inflated, or 'pneumatically stressed'.

The type of inflation depends on the type of structure in which the ETFE is being used. For permanent structures, it is important that the cushions do not deflate over the building's lifespan. To this end, the cushions are kept inflated using air pumps.

For buildings or structures with a shorter expected lifespan, cushions can be inflated and sealed without the need for ongoing air and pressure control.

Slide 29 – Thermal insulation

ETFE can be very highly effective for thermal insulation. The more layers of plastic used, the higher the thermal insulation qualities of the ETFE.

Thermal transmittance is expressed as Watts per square metre kelvin, where the lower the figure, the better the insulation.

Slide 30 – Fire retardancy

ETFE has low flammability and low ignitability. In case of fire, the plastic melts and tears a hole in the plastic, allowing hot gases and smoke out of the structure.

The plastic itself is not flammable, and the drops cool quickly, helping to limit the spread of the fire.

Slide 31 – Comparison with glass

Glass has been one of the most widely used construction materials, though it is energy intensive to produce. Glass has been used for iconic buildings, where it has been used for illumination and where its flexibility (size, colour) has been an advantage.

ETFE can act as a replacement for glass in certain uses, but it is more environmentally friendly and energy efficient to produce.

Of course, ETFE also has some disadvantages compered to glass, primarily focused on strength. ETFE can be punctured with sharp objects, so needs to be used at a level where it cannot be reached. If it is torn, it can be repaired with heat welding.

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TEXTILES FOR SUSTAINABLE BUILDINGS

Using ETFE for passive and active design

Slide 33 – Textile architecture and sustainable buildings

In the following section, we will examine how textile materials, and ETFE in particular, can be used for sustainable buildings. It will explore the sustainability of ETFE itself before examining how it can be used for both passive and active building design. In particular, it will present the use of ETFE for building-integrated photovoltaics and the use of advanced photovoltaic technologies.

One such example is presented here. This is the German Pavilion at the Expo Milan 2015. The structures (referred to as 'solar trees') are made of ETFE, with organic photovoltaics integrated, acting as both a shade and a source of electricity generation.

Slide 34 – ETFE Sustainability

One of the reasons why textile-based architecture has become increasingly prominent is because of its possibilities for sustainable use.

ETFE is a recyclable plastic, meaning that it can be re-used at the end of its life. Additionally, if it is damaged, it can be repaired quickly through heat welding, compared to glass where a whole panel must be replaced.

Compared to glass and other construction materials, textile plastics are not so energy intensive to produce, with reduced CO2 emissions compared to alternatives. Because the material is lightweight, there is also less need for heavy structural elements to hold it in place.

ETFE is highly transparent, allowing nearly the full light spectrum through and creating a natural lighting environment. This can reduce the need for additional, electrical, indoor lighting.

When used as air-filled, ETFE is as efficient as double glazed glass, and triple-layered (and above) cushions have higher insulation performance.

This versatility makes ETFE an ideal material for use in both active and passive sustainable buildings.

Slide 35 – Passive and active design

When discussing the sustainability strategy of a building, we can discuss either passive or active design.

Passive design means that a structure is directly using natural energy, for example wind flows, sunlight or heat transfer, without the use of electricity.

For example, a building may simply have large windows in order to maximise sunlight, or may use wooden or fabric shades to provide temperature regulation.

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In this example, ETFE has been used for the rainforest hall at Zurich Zoo, where the ETFE roof lets through enough sunlight for the plants to grow, whilst also providing insulation to keep the internal temperature up.

Active design either uses electricity or produces it to achieve its desired result, generally referring to the integration of solar panels into building façades and components.

Slide 36 – ETFE for passive design

The versatility of ETFE lends itself to solar control and shading. Through printing and other techniques, the transparency of ETFE can be modified to allow in more or less light, acting as a solar shield where needed.

The San Mamés Football Stadium, home of *Athletic de Bilbao*, is an example of a building which uses textile materials for passive design purposes. The roof of the stadium uses layers of transparent foil with a lightweight aluminium frame to ensure maximum penetration of sunlight onto the pitch, while protecting spectators from rain.

Part of the canopy is not transparent, protecting spectators from sunlight to ensure comfort in the summer.

Slide 37 – ETFE for active design

A trend for textile architecture is the integration of new technologies, combining applications to make multifunctional building elements.

The flexibility of ETFE means that it can be used in different sizes and spans. When integrated with technologies, the ETFE has to be used in a modular way.

For example, an ETFE roof or façade can also be made up of multifunctional modules of various sizes, with integrated photovoltaic cells to act as a source of renewable energy, whilst also providing protection from the elements.

Slide 38 – Photovoltaics

Most photovoltaics which are used in buildings are 'building-applied' photovoltaics. That is, the PV technologies are put onto an existing building surface.

This approach is used when there is a desire for sustainable electricity generation through PV without requiring major changes to an existing building structure. Building applied PV means that buildings can generate electricity through simple retrofitting.

Comparatively, 'building integrated' photovoltaics are where PV is integrated directly into the building as a structural element with additional functions.

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Slide 39 – BIPV Rationale

Building-integrated photovoltaics (BIPV) replace existing building parts, and are generally planned at the construction phase of a new project. They can also be integrated into existing buildings by replacing parts of the building. BIPV is generally used for roofs, skylights and façades, but it can also be integrated directly into windows and other components.

The main rationale for BIPV is that building owners can save money through the generation of electricity that can be used at the point of use, also contributing to a more robust, decentralised energy grid.

This rationale, of course, also applied to building applied PV. However, the extra advantage of building integrated, over building applied PV, is that the total cost can be reduced by reducing the amount being spent on building materials. Rather than paying for roof tiles, with additional material and installation costs for building applied PV, solar producing roof tiles could be used.

An additional advantage is that many people consider building integrated PV to have better aesthetics than building applied PV, as the technology is not so obvious and does not stand out as much.

Slide 40 – PV types

Photovoltaic technologies have developed significantly over the past decades, driven by political impetus to move towards renewable energies. Although the basic science behind photovoltaics has been known since the mid-1800s, the commercial application of the technology began only in the 1950s slowly building momentum until a boom in the 1990s and after.

Correspondingly, PV technologies have advanced in performance and new technologies have also developed, with new characteristics.

The first generation of photovoltaics are based on silicon wafers, achieving a performance of around 18-20% efficiency, though the record is 26.7% These first generation cells are the dominant solar cells on the market, as they are very stable and their high performance is long proven. However, first generation cells are energy intensive to produce, and have limited design applications as the cells are rigid.

Second generation solar cells include thin film solar cells, using amorphous silicon, Copper indium gallium selenide (CIGS), or Cadmium telluride (CdTe) with a performance efficiency of 10-15%. By avoiding silicon wafers, second generation solar cells use fewer resources and are cheaper to produce. Second generation cells can be produced on flexible substrates so they are more flexible than first generation, but they remain quite energy intensive to produce and some use rare materials.

New types of thin film solar cells are mostly just emerging from the experimental/pilot production stage. They include organic PV which uses organic materials, such as polymers. Polymer solar cells can be produced using widely available materials, but they are not yet as stable or as efficient as the other technologies.

However, new materials named Perovskites, with hybrid organic-inorganic composition, have demonstrated record laboratory efficiencies of around 20% after three years of development.

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Improving their stability is now a major preoccupation of researchers, and there are big hopes that they will soon enter the market, competing with the other commercial technologies

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Slide 41 – BIPV and ETFE

Most of the building integrated photovoltaics used until now have been based on first generation PV technologies, with the use of some inorganic thin film cells.

For use in textile architecture-based BIPV products, second generation solar cells are most frequently used, as first generation (crystalline silicon) solar cells have limited flexibility.

This use is growing as the technological performance of second generation cells has improved, and designers are coming to appreciate the benefits of second generation PV, over the more efficient first generation technologies.

The main benefit is higher material flexibility, which means second generation PV can be used for applications where PV is embedded into other materials, and when design and aesthetic concerns are paramount.

Slide 42 – Organic based PV

As photovoltaic technology gets more advanced it is becoming increasingly well suited for use with flexible membranes.

Organic photovoltaic cells use a transparent semiconductor and slim as a substrate, which is both transparent and flexible. This creates all sorts of new design possibilities, including the use of different colours and shapes.

Their added flexibility means that they can be integrated into even more construction materials, and whilst other technologies remain more efficient overall, organic PV works better at low light levels, providing new opportunities and markets.

Improvements in solar cell efficiency will continue to make them more commercially attractive.

The image shows again a close-up of the German Pavilion at EXPO Milan, showing lightweight organic PV printed cells, laminated between two layers of ETFE film and suspended from a net of steel cables.

Slide 43 – Regulatory aspects

As with any building component, new PV technologies need to be proven safe before being used. Any PV technology being used should be checked for CE marking, showing that the product has been assessed as being safe.

This means that the product complies with relevant European Directives. Where a harmonised standard exists, then it is mandatory for the product to meet the relevant criteria and display the CE mark.

But for new technologies where no harmonised standard exists, then certification is optional. It is important to check the safety of any new component.

Slide 44 – PV Standards

BIPV is covered by a number of standards, including standards to ensure module safety under the Low Voltage Directive, to verify durability, and to ensure that the properties of photovoltaic systems meet the requirements as specified in the European *Construction Product Regulation* (CPR) CPR 89/106/EEC.

Slide 45 – Further development

There are significant future opportunities for building integrated photovoltaics, but there will not be a one-size fits all solution. The optimum technology will need to be considered for each application. For some buildings, a necessity for flexibility will require the use of new, flexible and light cells, whereas for others, highly-efficient, but inflexible first generation cells may be the best option.

When working with building integrated photovoltaics, standards and regulations need to be checked. They are constantly updating to respond to new technologies and applications, but it is essential to ensure that any technology being used is safe.

New, flexible thin-film PV technologies are a perfect match for textile-based architecture, and a number of new applications will undoubtedly be developed between the PV and construction sectors.

ADVANCING THE STATE-OF-THE-ART

The future of sustainable textile architecture

Slide 47 – Contents

This final section will build upon the previous parts of this presentation in order to show case studies of state-of-the-art constructions using textile architecture, and will give a glimpse of newly developing technologies and the potential future of the market.

The section will start with two case studies, both in Munich, of the integration of photovoltaics and of façade lighting.

Slide 48 – PV Integration

As we have seen, ETFE can be integrated with photovoltaics, however, there are currently only a few examples in the world. Generally, when used, they have been used for roof structures. Every building using ETFE and PV together has to use unique parts as there are no standardised ETFE/PV elements, or modules.

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Slide 49 – Case study: AWM Carport Munich (1)

One of the most successful cases is the roof of the AWM waste disposal department carport in Munich, Germany. It was designed by Munich architects Ackermann & Partner and completed by Taiyo Europe in October 2011.

The client sought a sustainable and robust solution to replace the previous roof which had partially collapsed under heavy snowfall. Due to its durability and self-cleaning properties, ETFE was considered a suitable material for the new roof, providing the space below with natural lighting and ventilation. To increase the sustainability of the structure, the design integrates flexible photovoltaic cells. This enables the generation of decentralised, renewable energy to power the building.

Slide 50 – Case study: AWM Carport Munich (2)

In total, 220 three-layer ETFE cushions cover the 8000m² roof. The lower layer of the cushion is printed to provide shading in the carport below during summer. The photovoltaic modules are mounted on the middle ETFE layer using mechanical fasteners, which retain some flexibility to avoid deformation caused by bending or stretching of the cushion. The transparent exterior layer provides protection to the photovoltaics while still allowing sunlight through. In order to easily repair or replace defected photovoltaic modules, this layer is fixed separately, and can be opened independently.

The cushions retain their shape by being filled with air. Three blower units ensure a constant air pressure within the cushions, with blown air entering through an inlet in the lower layer of each cushion. An air dryer prevents moisture build-up. The shape of the cushions prevents rainwater from collecting, which is removed by drainage pipes concealed within the structure. Snow can collect towards the lower edges of the cushions but does not compromise the structural integrity.

The ETFE cushions are held together by aluminium profiles. For installation, these profiles were screwed into a load-bearing steel frame built above the parking area. This frame was placed upon the existing structure, consisting of steel columns and girders.

Slide 51 – Case study: AWM Carport Munich (3)

The project is a milestone in the ongoing development of photovoltaic applications in combination with architectural membranes. The carport roof generates 140 Megawatt hours per year: enough to power the building's operations, including the air blower units, with additional power fed into the grid. Essentially a prototype when it was first conceived, the roof has already served as a model for similar designs.

Slide 52 – Façade lighting

A more common feature of ETFE architecture is façade lighting. Either via projection or through LEDs, the colour range and transparency options are nearly limitless. LED lighting devices and strategies in particular are increasing their presence in the market with new or extended

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functionalities. Generally LEDs are placed behind ETFE cushions, which diffuse the light to create a uniformly coloured surface.

Current systems demonstrate some limitations, however. While lighting is possible, image projection - integrating static or moving pictures - is not.

Slide 53 – Case study: Allianz Arena (1)

Home of Bayern Munich football club, the Allianz Arena is one of the most famous examples of architectural façade lighting. Illuminated by 300,000 LEDs, it was the first sporting arena in the world with a full colour changing exterior, which can be seen from up to 75 kilometres away. Designed by Swiss architects Herzog & de Meuron, the stadium is said to resemble an inflatable boat ("Schlauchboot" in German) which is also the stadium's nickname.

It was built for use during the 2006 World Cup, and as a permanent home for Munich's two football teams. Due to its striking design, the Arena has become a Bavarian landmark, distinguished above all by its translucent, glowing exterior. This unique skin could not have been realised in any material other than ETFE.

Slide 54 – Case study: Allianz Arena (2)

The stadium façade and roof is comprised of over 2,000 double-layer ETFE cushions. The diamond-shaped cushions are up to 17 metres in length, with a maximum size of about 40m^2 and an enclosed cushion volume of up to 25m^3. Due to the complexity of the geometry almost all cushions are unique.

The cushions are air supported. To maintain a constant pressure, air is blown into the cushions via a system of pipes, stemming from blower stations located in each corner of the stadium.

The ETFE film is printed with white dots, making the stadium appear white from a distance. Close-up this appears more transparent. Sufficient sunlight is transmitted to ensure grass growth on the pitch.

The façade can be illuminated by more than 300,000 LED lights which are located behind the cushions. The lenses are customised to scatter the light onto the surface of the rhomboids. Thanks to a new system installed in 2014, 16 million different colour shades are available, and can be used in combination. This flexibility means the arena's appearance can be customised for each event. The new system is also 60% more energy efficient than the previous technology, with the LEDs having a lifespan of 80,000 hours.

Slide 55 – Case study: Allianz Arena (3)

In case of snowfall, 12 pressure-monitoring points ensure the correct pressure adjustments within the cushions. This means the roof can withstand up to 1.6m of snow.

An innovative design element incorporated into the roof cushions is a self-draining system. This means that in the unlikely event of a loss of air pressure, water drains through the base of the cushions, preventing a dangerous build-up of water. Given that back-up blowers and emergency power supplies are in place, such a loss of pressure is extremely unlikely however.

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Slide 56 – Future growth potential

Ways are currently being sought to improve façade lighting, both in terms of performance and sustainability. Currently there are limitations in terms of what can be displayed on textile-based surfaces: only rudimentary patterns or shapes, without much detail. Additionally, façade lighting in all its forms is usually very energy intensive, raising concerns about environmental impacts.

Slide 57 – New developments

An innovative solution being explored is to integrate both photovoltaics and LEDs into the same ETFE module. The Module can generate and store electricity from sunlight during the day, which is then used to power the LEDs in the evening. By integrating a high density of LEDs, the module acts like a screen and is able to display complex images and video. This could open up new commercial pathways, for example in advertising.

Slide 58 – ETFE Multifunctional Modules

Each of the modules consists of two sheets of ETFE at front and back, with a sheet of LEDs and a sheet of organic PV modules. The LEDs and PV layers are separated by sheets of Ethylene-vinyl acetate (EVA).

Slide 59 – First demonstration

A first demonstration unit was installed at the Spanish National Renewable Energy Centre to give an initial impression of its performance. The demonstrator proved the concept, and provided feedback to improve the full scale demonstration.

Slide 60 – Demonstration

To test and monitor the newly developed Multifunctional Module in real conditions, four demonstration units were installed at ITMA Materials Technology in Avilés, Spain. Two of the modules put the PVs on top, with the LEDs showing between the gaps of the PV, while the other two reverse this by using different PV designs with the LED strips on top. The aim was to find the optimal configuration for providing a clear façade image, while maximizing electricity production from photovoltaic panels.

Slide 61 – Market potential

The new multifunctional module can answer the growing demand for façade elements which can be used for external screens, whilst also generating sustainable energy. Such screens can be used for advertisements, information and occasions for public viewings, such as sports matches and national events.

The market advantage compared to existing solutions is that the modules can generate electricity, providing multiple functionalities from one surface. Although a few years away from commercialisation, the module could be of interest for monumental façade lighting, particularly for stadiums, shopping centres and public buildings.

Slide 62 – Video

Note

A YouTube video has been integrated into the slides and should play, as long as an internet connection is present. If the video does not play through the PowerPoint, then it can be found here: https://www.youtube.com/watch?v=9E9iWST0YHM

Slide 63 – Summary

Textile-based architecture is becoming increasingly popular as a result of new material developments, as well as movement towards sustainable architecture.

Textile architecture can be implemented in many different manners, with numerous functionalities, making it perfect for monumental architecture. This has so far been the main growth-driver for the sector.

Further research and development will continue to improve material qualities, which will lead to the emergence of new products which can deliver new and exciting functionalities for architects.

Slide 64 – Further reading

Note

A selection of further reading has been provided, some of which can be assigned as reading for seminar discussions, or left as an optional activity for those who wish to find out more.

The book, *Textiles, Polymers and Composites for Buildings* (2010), edited by Goeran Pohl is the key text for an introduction to the area, and chapters are available through Elsevier's ScienceDirect. Chapter 6, 'Polymer foils used in construction' is especially relevant for ETFE.

A publication on the ETFE-MFM project, entitled, 'A multifunctional ETFE module for sustainable façade lighting: design, manufacturing and monitoring', will be published in the journal, *Energy and Buildings,* in early 2018.

Details on the two case studies can be found in *DETAIL Review of Architecture*. For the AWM Carport, see Volume 7-8 of 2013. For the Allianz Arena, see Volume 9 of 2005.

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