TEXTILE-BASED ARCHITECTURE
Exploring the State-of-the-Art
1. Introduction to textile-based architecture
2. ETFE – An architectural wonder material
3. Textiles for sustainable buildings
4. Advancing the state-of-the-art

Allianz Arena, Munich
Architect: Herzog & DeMeuron (Basel)
Source: Greenovate! Europe
I. INTRODUCTION TO TEXTILE-BASED ARCHITECTURE

Development of textile architecture
CONTENTS

- Early steps
- Membrane materials
- Building component
- Kind of application
- Kind of pre-stress
- Degree of pre-fabrication
- Textile functions
- Temporary or permanent

The Arc River Culture Pavilion, Daegu, South Korea
Architect: Asymptote Architecture, Hani Rashid (New York)
Source: Taiyo Europe
EARLY STEPS

- Tents are the oldest form of textile-based architecture – iron age (1200-600BC)
- Basic structure – fabric attached to a frame or support and supporting rope

*Traditional Mongolian Yurt*
*Source: Wikimedia, Creative Commons License*
EARLY STEPS

- More complex uses emerge, with integration into architecture
- Retractable velarium over the Roman Colosseum provided shade and protection from rain
- Slight slope towards centre causing air circulation for ventilation and cooling

Roman Colosseum, Artist’s impression
Source: Wikimedia, Creative Commons License
NEW MATERIALS

- Use of textiles becoming more widespread
- Development of new materials make textiles more robust and give additional functionalities
- Possible to integrate new technologies

Sony Centre, Berlin
Architect: Murphy/Jahn Architects (Chicago)
Source: Taiyo Europe
MEMBRANE MATERIALS

PVC / Polyester fabric
PVC / PES mesh

PTFE / Glass fabric
PTFE / Glass mesh

Silicone / Glass fabric
PTFE fabric

Fluoropolymer* fabric
Fluoropolymer* foil


* ETFE, PVDF, FEP, THV etc.
## MEMBRANE MATERIALS

Source: K. Moritz, Anhalt University of Applied Sciences, Manuscript 2011

<table>
<thead>
<tr>
<th>Material / Unit</th>
<th>Load Bearing Capacity (tensile strength)</th>
<th>Fire Classification (according to DIN 4102-1)</th>
<th>Resistance to Environmental Exposures (chemical/biological)</th>
<th>Resistance to Cross-Breaking (folding, retractability)</th>
<th>Light Transmittance (%)</th>
<th>Transparency [yes/no]</th>
</tr>
</thead>
<tbody>
<tr>
<td>PVC/Polyester-fabric (Type V)</td>
<td>high (190/166)</td>
<td>B2 or B3</td>
<td>medium</td>
<td>medium</td>
<td>up to 10</td>
<td>no</td>
</tr>
<tr>
<td>Silicone/Glass-fabric (Type G VII)</td>
<td>high (170/158)</td>
<td>B1</td>
<td>medium</td>
<td>medium</td>
<td>up to 25</td>
<td>no</td>
</tr>
<tr>
<td>PTFE/Glass-fabric (Type G VII)</td>
<td>high (170/158)</td>
<td>A2 or B1</td>
<td>high</td>
<td>low</td>
<td>up to 14</td>
<td>no</td>
</tr>
<tr>
<td>Fluoropolymer fabrics (ETFE/PTFE/FEP)</td>
<td>medium (80/80)</td>
<td>B1</td>
<td>high</td>
<td>high</td>
<td>up to 40 - 85</td>
<td>no</td>
</tr>
<tr>
<td>ETFE-foil (250 µm)</td>
<td>low (13/13)</td>
<td>B1</td>
<td>high</td>
<td>low</td>
<td>up to 90</td>
<td>yes</td>
</tr>
</tbody>
</table>

Preferred materials: PES or glass fabrics, PTFE-Glass fabrics, Fluoropolymer coatings or foils, Fluoropolymer fabrics, Fluoropolymer fabrics or foils, Fluoropolymer foils
BUILDING COMPONENTS

- Building Envelope
- Roof
- Skylight
- Façade
- Canopy
- Sculpture

Source: Taiyo Europe
APPLICATIONS

- Sports
- Travel
- Industry
- Leisure
- Culture
- Commercial

Source: Taiyo Europe
KIND OF PRE-STRESS

- MECHANIC PRE-STRESS
  - Project: Tanzbrunnen BUGA
  - Location: Cologne, Germany
  - Surface: 500 sqm
  - Function: Open Air Canopy
  - Architect: Frei Otto
  - Completion: 1957

Source: Heinze.de
KIND OF PRE-STRESS

- MECHANIC PRE-STRESS

- Project: VW Customer Centre
- Location: Wolfsburg, Germany
- Surface: 7,620 sqm
- Material: PTFE-glass
- Function: Entrance Canopy
- Architect: Henn Architects
- Completion: 2013

Source: Taiyo Europe
KIND OF PRE-STRESS

- **PNEUMATIC PRE-STRESS**

  - Project: EXPO 1970 Plaza Theme Pavilion
  - Location: Osaka, Japan
  - Surface: approx. 10,000 sqm
  - Material: PVC-Foil Cushions
  - Function: Plaza Roof (temporary)
  - Architect: Kenzo TANGE
  - Completion: 1970

Source: DAAS/Mori Art Museum
Manufacturing of big membranes in plant and subsequent installation on site

Modular-design with a high degree of pre-fabrication in plant

Source: Taiyo Europe

Swatch and Omega Headquarters, Biel Switzerland (Impression)
Architect: Shigeru Ban
Source: Dezeen
TEXTILE FUNCTION

- **MONOFUNCTIONAL**

- **Project:** ThyssenKrupp Elevator Test Tower
- **Location:** Rottweil, Germany
- **Surface:** 16,000 sqm
- **Material:** PTFE-glass meshes
- **Function:** Curtain wall (visual impression, aerodynamic improvement)
- **Architects:** Werner Sobek
- **Completion:** 2017 (under construction)

*Source: testturm.thyssenkrupp-elevator.com*
MULTIFUNCTIONAL

- **Project:** Uniqlo Shinsaibashi Building
- **Location:** Osaka, Japan
- **Surface:** 2,300 sqm
- **Material:** 158 ETFE-foil cushions (2-layers)
- **Functions:** Façade (weather protection, thermal insulation, LED screen)
- **Architect:** Sou Fujimoto
- **Completion:** 2010

Source: Taiyo Europe
MULTIFUNCTIONAL

- **Project:** Authority for Waste Management Carpark
- **Location:** Munich, Germany
- **Surface:** 8,000 sqm (3,000 sqm PV)
- **Material:** ETFE-foil cushions (3 layers) + PV cells
- **Function:** Roof (weather protection, electric power generation)
- **Architects:** Ackermann
- **Completion:** 2011

Source: Taiyo Europe
TEMPORARY STRUCTURES

- **TEMPORARY**

- **Project:** Coca Cola Pavilion “Beatbox“
- **Location:** London, UK (Olympic Games 2012)
- **Surface:** 1,300 sqm
- **Material:** ETFE-foils (2 layers)
- **Function:** Sculpture (walkable) with noise related LED-signals
- **Architects:** Asif Khan, Pernilla Ohrstedt
- **Completion:** 2012

Source: Taiyo Europe
PERMANENT STRUCTURES

PERMANENT

- Project: Tram Station
- Location: Lodz, Poland
- Surface: 3,500 sqm
- Material: ETFE-foils (single layer)
- Function: Platform Roof (rain protection, light transmission/colored skylight)
- Architects: Foroom sp. z o .oo
- Completion: 2015

Source: Taiyo Europe
2. AN ARCHITECTURAL WONDER MATERIAL

Characteristics and qualities of ETFE
CONTENTS

- ‘A wonder material’
- Light transmission
- Durability
- Multi-layered ETFE
- Thermal insulation
- Fire resistance
- Glass v. ETFE

*Masoala Rainforest Hall, Zurich Zoo*
Architect: Gautschi + Storrer Architects (Zurich)
Source: Zurich Zoo
ETFET (Ethylene TetraFluoroEthylene) is a fluorine-based plastic.

It is regarded as a ‘wonder material’:
- Lets in more UV wavelength;
- Dirt and water resistant, can be kept clean by rain fall;
- Easy to repair if damaged.

Fraunhofer Institute IBMT, Sulzbach, Germany
Architect: Hammeskreuse Architekten (Stuttgart)
Source: Taiyo Europe
‘A WONDER MATERIAL’

- Very lightweight – only 350g per square metre of film;
- Weighs only 1-3% of an equally-sized glass panel;
- Fewer structural support requirements due to low weight – lightweight steel support is sufficient;
  - Results in reduced carbon footprint;
  - Greater design capabilities.

Source: Taiyo Europe
ETFE has excellent light transmission qualities;
Film produces a bright, open space that can emulate the outdoors.

Source: MakMax
Light transmission can be controlled with different ETFE film types.

Source: MakMax
DURABILITY

- ETFE has high resistance to chemical and biological substances;
- Resilient to weather conditions, such as sun and wind damage;
- Can retain its strength and tensile strength for more than 20 years (15% loss after 15 years);
- ETFE is self-cleaning in rain and maintains its transparency.

Source: MakMax
MULTI-LAYERED ETFE

- Single-layer – Mechanical pre-stress over support structure

- Two- or three-layered, pneumatic stress:
  - Pressurisation – Maintain pressure through ventilation, used for permanent structures
  - Seal – Pressurised during inflation only, used for temporary structures

Source: MakMax
THERMAL INSULATION

- ETFE can be highly effective for thermal insulation
- Multi-layered chusions have higher insulation performance
- $W/m^2K = $ Watts per square metre kelvin.

Source: MakMax
FIRE RETARDANCY

- ETFE film has passed International standards in fire resistance
  - German code: DIN 4102-B1

- Low-flammability (B1 classification)
- Melting point is 275 Celsius
- Structural element opens if burned (outlet for hot gases and smoke emission: no flame spread)
- Foil melts away and drops are self expiring (d0-classification), solidifies quickly
- Low smoke emission (s1-classification)
- Material extinguishes immediately after losing contact with the fire
- Thin foil (0.1 – 0.3 mm) has an extremely low mass which is a major advantage in case of fire

<table>
<thead>
<tr>
<th>Test Method</th>
<th>Item</th>
<th>Class</th>
</tr>
</thead>
<tbody>
<tr>
<td>UL94</td>
<td>Flammability Rating</td>
<td>V-0 (250Nj)</td>
</tr>
<tr>
<td>DIN 4102</td>
<td>Ignitability</td>
<td>Class B-1</td>
</tr>
<tr>
<td>JIS A 1322</td>
<td>Flame Retardancy</td>
<td>Class-1</td>
</tr>
<tr>
<td>JIS K 7201-2</td>
<td>Limiting Oxygen Index</td>
<td>29.1% (Non-flammable in air)</td>
</tr>
<tr>
<td>(ISO4589-2)</td>
<td></td>
<td></td>
</tr>
<tr>
<td>DIN EN 13501-1:2010-01</td>
<td>Fire behaviour</td>
<td>Class B-S1, d0</td>
</tr>
</tbody>
</table>

Source: MakMax
## COMPARISON: ETFE AND GLASS

<table>
<thead>
<tr>
<th>Thickness/Composition</th>
<th>ETFE Film</th>
<th>Glass</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Single-layer</td>
<td>Double-layer</td>
</tr>
<tr>
<td>Thickness/Composition</td>
<td>200μm</td>
<td>220μm + A300mm + 200μm</td>
</tr>
<tr>
<td>Weight (kg/m²)</td>
<td>0.35</td>
<td>0.70</td>
</tr>
<tr>
<td>Visible light transmittance (%)</td>
<td>90.5</td>
<td>82.4</td>
</tr>
<tr>
<td>Ultraviolet transmittance (%)</td>
<td>83.5</td>
<td>71.5</td>
</tr>
<tr>
<td>Weather resistance</td>
<td>****</td>
<td>←</td>
</tr>
<tr>
<td>Self-cleaning</td>
<td>****</td>
<td>←</td>
</tr>
</tbody>
</table>

Source: MakMax
3. TEXTILES FOR SUSTAINABLE BUILDINGS

Using ETFE for passive and active design
TEXTILE ARCHITECTURE AND SUSTAINABLE BUILDINGS

- ETFE sustainability
- Passive and active design
- ETFE for Passive Design
- ETFE for Active Design
- Building Integrated Photovoltaics
- PV Technologies

German Pavilion, Expo Milan
Architect: Schmidhuber + Partner (Munich)
Source: Taiyo Europe
ETFE SUSTAINABILITY

- ETFE is recyclable and easily repaired if damaged;
- Requires less fabrication energy than traditional building materials, reducing CO2 emissions;
- High transparency means ETFE can reduce the use of indoor lighting;
- Two- or three-layered ETFE has high insulation properties – can reduce heating costs;
- Versatility makes it viable for both passive and active sustainable design practices.
PASSIVE AND ACTIVE DESIGN

Passive
- Architecture with devices and infrastructure, that directly use natural forces to achieve a result.

Active
- Architecture with devices and infrastructure, that use or produce electricity to achieve a result.

Masoala Rainforest Hall, Zurich Zoo, Switzerland
Architect: Gautschi + Storrer Architects (Zurich)
Source: Zurich Zoo

AWM Carport
Architect: Ackermann und Partner Architekten BDA (Munich)
Source: Taiyo Europe
ETFE FOR PASSIVE DESIGN

- Roof includes several layers of foil within an aluminium frame to create an inflated panel;
- Portion of canopy is transparent to ensure maximum levels of sunlight;
- Outer section of the canopy covering the highest tiers of seating minimise solar transmission.
ETFE FOR ACTIVE DESIGN

- Integration of new technologies – photovoltaics
- Flexible: multiple configurations and uses possible
  - Different sizes and spans
  - Modular solutions with integrated technology

AWM Carport
Architect: Ackermann und Partner Architekten BDA (Munich)
Source: Taiyo Europe
PHOTOVOLTAICS

**Building Integrated Photovoltaics (BIPV)**

**Building Applied Photovoltaics (BAPV)**

*Planet Traveller Hostel, Toronto*
Source: theplanettraveler.com

*Offgrid solar system, Jaipur*
Source: indusreepower.com
BIPV RATIONALE

- Electricity generation at the same point of the electricity consumption
- Distributed energy grid – More robust
- BIPV replaces a building element – low added cost
- Multi-functionality:
  - Constructive element
  - Energy generator
- Improved aesthetics over BAPV

Solar Curtain Wall Pilot, Miami
Source: Konarka Technologies
Several PV technologies are available

- First generation: crystalline silicon – commercially dominant
- Second generation: thin film solar cells – utility scale PV systems, BIPV
- New emerging photovoltaics – just reaching market, pilot plant or experimental stage
First generation PV technologies have limited flexibility

New technologies offer flexibility and design options

Thin film technologies can be deposited on flexible substrates:

- Silicon based thin film
- Copper Indium Gallium Selenide (CIGS)
- Cadmium Telluride (CdTe)
- OPV

Source: Taiyo Europe
New thin film PV technologies use organic (conductive organic polymers or small organic molecules) or hybrid organic-inorganic materials

- Perovskites (hybrid) are a focus for researchers
- Can use transparent substrate and semiconductor layers (transparent and flexible)
- Offers design freedom (different colours, shapes, etc.)
- Can be integrated in different construction materials
- Same advantages of low-light and diffuse light performance than other thin films
- Still some technological challenges pending

Source: OPVIUS
REGULATORY ASPECTS

- Innovative materials need to be proven safe and durable before use in buildings
- CE marking – shows the product has been assessed to meet safety, health and environmental protection requirements
  - Comply with the relevant European Directives
  - Mandatory only if a harmonized standard exists
  - *However*: optional if a harmonised standard does not exist

- hEN (Harmonised European Standard)
- TAB (Technical Assessment Body)
- EAD (European Assessment Document)
- ETA (European Technical Assessment)
PV STANDARDS

- **EN 61730** – PV module safety qualification
  - Harmonised standard to comply with the Low Voltage Directive

- **EN 61215 (61646)** – Design qualification and type approval
  - Checks durability
  - Required by market

- **EN 50583** – PV in buildings
  - Check the essential requirements (CPR):
    - Provides a list of standards
    - Depends on the application

Source: ITMA Materials Technology
- Many opportunities for BIPV – optimum technology should be used for every application
- Standards for BIPV products are being developed and respond to new technologies and applications
- BIPV products can take advantage of emerging popularity of textile architecture
- Further development of BIPV will depend on synergies between construction and PV technologies

Source: solarbuildingtech.com
4. ADVANCING THE STATE-OF-THE-ART

The future of sustainable textile architecture
CONTENTS

- PV Integration
  - Case Study: AWM Carport
- Façade lighting
  - Case study: Allianz Arena
- New research: ETFE multifunctional modules
- Future growth potential

Source: allianz-arena.com
PV INTEGRATION

- ETFE & PV
  - Limited application so far for BIPV – primarily used for roofs
  - Only a handful of examples are found worldwide
  - No standardised elements

Source: Taiyo Europe
CASE STUDY: AWM CARPORT MUNICH

- Three-layer ETFE cushions with integrated, flexible PV installed in HQ of AWM – Munich waste disposal
- New roof installed to replace roof which collapsed under heavy snowfall
- Client wanted a green, sustainable solution, that could provide natural lighting and withstand heavy snowfall

Source: Taiyo Europe
CASE STUDY: AWM CARPORT MUNICH

- 8,000 square metre roof, made up of 220 air supported cushions, with air supply from air blowers
- Existing reinforced-concrete infrastructure, with steel columns carrying three-cord truss girders
- Transverse steel arches with tension rods and compression columns hold the cushions
- Lower layer of ETFE is printed to shade the carpark, middle contains PV, top is transparent – protects PV and lets sunlight through
- Mechanical fasteners (partly moveable and flexible) hold the PV layer to prevent damage to cells
- Upper layer is attached separately – easy to remove to access electronics if repair needed
- Ductwork and drainage pipes are concealed in the girders for removing rainwater

Source: Taiyo Europe
CASE STUDY: AWM CARPORT MUNICH

- Carport roof generates 140MWh per year – roughly equal to electricity needs of two Munich apartments – part of the energy is fed into the grid, part kept to power air pressure system.

Source: Google Maps
ETF & Façade Lighting
- Much more frequently used than PV integration, but has very high energy consumption
- Lighting devices are not usually integrated into the ETFE module – internal illumination illuminates the whole module
- Lighting is possible, but image projection is not

Source: Greenovate! Europe
CASE STUDY: ALLIANZ ARENA

- Process begins in early 2001 to provide a new stadium for Munich football teams FC Bayern Munich and TSV 1860 Munich, as well as German National Team
- Needed to increase seating and integrate more modern features
- Arena aimed to be a landmark for Bavaria, and visually attractive for attendees
- Construction begins in 2002, opens 2005, in time for 2006 World Cup

Source: allianz-arena.com
CASE STUDY: ALLIANZ ARENA

- Exterior is constructed of 2,784 rhomboid ETFE-foil air panels, pumped with dry air.
- Panels appear white from a distance, but become more transparent as you approach as they are covered in small white dots, but still allow in light for grass growth on pitch.
- 1,506 Façade panels can be illuminated in different colours using a total of more than 300,000 LEDs (c.200 per illuminate cushion).
- Original system could produce red, white and blue.
- New system (2014) can produce up to 16 million different colour shades.

CASE STUDY: ALLIANZ ARENA

- If there is snowfall, pressure monitoring points engage the inflation pumps to increase pressure in the cushions.
- Cushions on the roof have drainage tubes in case of excessive water or snow load – If cushions deflate they allow water to collect in the deflated cushion and be drained.

FUTURE GROWTH POTENTIAL

- Economical, low-cost compared to glass, plus self-cleaning
- Use of sustainable materials in buildings is expected to increase: ETFE is ecologically more sustainable – lightweight, almost 100% recyclable
- Further research can improve heat insulation properties and introduce new features and technologies
- Communicative building elements – marketing and branding, new functions

Beijing National Aquatics Centre
Architect: PTW Architects
Source: water-cube.com
NEW DEVELOPMENTS

- EU-funded project, developing a new ETFE module with PV and LEDs for energy generation and façade lighting

www.ETFE-MFM.eu
ETFE MULTIFUNCTIONAL MODULES

- Membrane material: ETFE foil
- Kind of pre-stress: Mechanical
- (Pre-)fabrication: High, Modular
- Functions:
  - Energy generation (oPV)
  - Projection screen (LED)
  - Weather protection (ETFE)
- Temporary/permanent: Permanent
- Building component: Façade (curtain wall)
- Application Sector: Variable

Source: ITMA Materials Technology
FIRST DEMONSTRATION

Source: CENER
Together, the modules make a screen which can be used for colouring for the façade and, with a large enough surface, displaying images.

The modules have been demonstrated on the ITMA Materials Technology building, in Avilés, Spain.
MARKET POTENTIAL

- Answers demand for façade elements that can be used as screens for advertisements, information, movies for public viewing
- Advantage: power generation through PV on surfaces which are not currently used for power generation
- Potential uses: Football stadiums, shopping centres, public buildings (museums, theatres, railway stations)

*Piccadilly Circus, London*
*Source: Wikimedia, Creative Commons License*
VIDEO

https://youtu.be/9E9iWST0YHM
Source: Greenovate! Europe
Textile-based architecture is becoming increasingly popular as a result of new material developments, as well as movement towards sustainable architecture;

Landmark qualities of ETFE buildings are so far the main drivers behind development of the sector;

Research and further development of materials will enable new products that can deliver new functionalities for architects.

Source: ITMA Materials Technology
FURTHER READING


- Case Study: AWM Carport

- Case Study: Allianz Arena
ACKNOWLEDGEMENTS

This module has been assembled by Greenovate! Europe EEIG (www.greenovate-europe.eu) within the context of the ETFE-MFM Project (www.ETFE-MFM.eu).

ETFE-MFM has received funding from the European Union’s Seventh Framework Programme for research, technological development and demonstration under grant agreement No.322459.

Thanks go to the members of the ETFE-MFM consortium for their collaboration: Taiyo Europe, ITMA Materials Technology, CENER, Acciona Infrastructures and OPVIUS.

This material is free to use for educational purposes, but may not be sold or distributed for commercial gain

© ETFE-MFM 2017
Contact: simon.hunkin@greenovate.eu