TensiNews

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Newsletter of the European based Network for the Design and Realisation of Tensile Structures

REPORT

TEXTILE ROOFS 2019
TENSINET SYMPOSIUM 2019

PROJECT

TEMPORACTIVE
An Ultra-Lightweight Temporary Pavilion

CONSTRUCTION DETAIL OF THE TEMPORACTIVE PAVILION, TEXTILESHUB POLIMI

Tensinet partners 2019

TensiNews INFO

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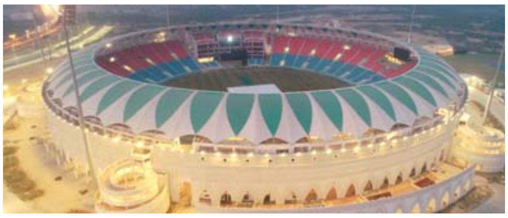

Edito

Dear Reader

A lot of exciting events happened in the first half of this year, Textile Roofs in Berlin and the Techtextil fair in Frankfurt took place, together with the award ceremony for the fifteenth Student competition 'Textile Structures for New Building'. The first prize for Macro Architecture is show herein.

Just before the summer we held our 6th TensiNet Symposium "Softening the Habitats" in Milan. If you had been there you certainly agree that it was a great success. We enjoyed three days with excellent presentations, we have seen contemporary or historical architecture and we have had many fruitful discussion. Again Josep Llorens was so kind to prepare a summary of the TensiNet Symposium and of Textile Roofs too.

Just in time during the night before the TensiNet Symposium a prototype was installed. This pavilion is a bending active structure cladded with printed PVC foil, and will now be used for further research. You will find a detailed report prepared by our colleagues from Politecnico di Milano in this TensiNews.

Two other research and innovation projects are presented too: a façade realised with organic PV applied on ETFE foil, and the development of new bio based material.

Beside the detailed information about the events this spring, this issue of TensiNews presents recent projects: the new aviary in a zoo in Belgium, textile façades in the USA and in Germany and a stadium in India. A retractable roof designed by Frei Otto in 1968 has got its second refurbishment.

Beginning of October the next great event of this year will be the combined Structural Membranes and IASS symposium Form & Force in Barcelona. During this symposium our next partner meeting and the annual general meeting will take place. You are kindly invited to join one of our working groups.

Please enjoy this issue of TensiNews and I hope I will meet you soon.

Yours sincerely,
Bernd Stimpfle

Forthcoming Events

Joined International conference **IASS SYMPOSIUM 2019 & STRUCTURAL MEMBRANES 2019** | *FORM and FORCE 2019* | *7-10/10/2019* | Barcelona, Spain | **http://congress.cimne.com/formandforce2019/frontal/default.asp**

Nonwovens Innovation Academy 2019
16–17/10/2019 | Deutsche Institute für Textil- und Faserforschung Denkendorf | **https://www.edana.org/education-events/conferences-and-symposia/event-detail/nonwovens-innovation-academy2019/**

International Conference on Advanced Building Skins | *28–29/10/2019* | Bern, Switzerland | **www.abs.green**

AACHEN-DRESDEN-DENKENDORF INTERNATIONAL TEXTILE CONFERENCE 2019
28–29/11/2019 | Dresden, Germany | **https://www.aachen-dresden-denkendorf.de/en/itc/**

TensiNet Meetings

TensiNet WG5 eurocode – meeting
26/09/2019 | Afnor, Paris

TensiNet Annual General Meeting &Partner Meeting 2/2019 | *08/10/2019 at 19.00* (during symposium Form and Force 2019)

Group photo of the TensiNet Symposium 2019 participants in front of the TemporActive Pavilion

Belgium

THE ANTWERP ZOO

A PLACE TO OBSERVE ANIMALS AT CLOSE DISTANCE

"I remember visiting the zoo some years ago and eating at the restaurant there. The experience was one of detachment from nature. With our project, we aimed at delivering an innovative visitor experience. We want visitors to feel close to the birds, apes and buffalos in their natural habitat."
Giuseppe Farris

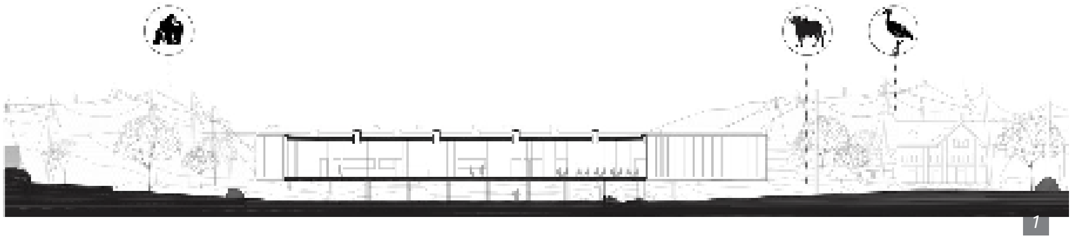

Figure 1. Section ©Studio Farris Architects

Since its founding, the Antwerp Zoo has been managed by KMDA, the Royal Zoological Society of Antwerp.

In 2013 KMDA has appointed ELD NV (architects, engineers, project managers & cost controllers) to create a new masterplan and to act as supervising and steering architect for the realization of a new restaurant, aviary, and apes- and buffalo-shelter.
For the design of the restaurant Studio Farris was the conceptual designer, while the savanna with Aviary was designed jointly by the team ELD/Studio Farris/Fondu landscape/Officium.

The site of the project is situated at the eastern side of the zoo, bordering a mostly residential neighborhood. The intervention defines the eastern boundary of the zoo, in continuity with its historical perimeter wall. On the zoo side, the restaurant opens up to the main plaza, facing historical pavilions. Visitors of the restaurant can enjoy observing the apes on one side and the buffalos and birds on the other side. In the new buffalo savannah more than 250 bird species live. A walk-through the aviary provides an unexpected experience bringing visitors close to the birds and buffalos.
For the design process Officium started with physical models at scale 1:100. Next more advanced numerical models were made for the simulations.

The structural system of **the bird's aviary** is first subdivided into primary structures forming a synclastic curved and rhombic net. This cable net is hold in shape by 8 masts of about 20m high, placed on a 3D hinge; the masts are hold back by 16 stay cables, which are anchored separately into the ground. From the mast 30 cables in V-shape and 25 stay cables are with secondary nets made of double curved anticlastic mesh nets of 35mm mesh size.

Along the boundary the mesh net is fixed continuously by rails or along existing and new buildings.
Officium designed the system in such a way that the primary structure is a stable system under its dead load before the filling secondary nets are attached.

The mounting of the net started with the primary structure only tensioned to 35 - 50% of the design value of the pretension. The filling nets, for which per field a special cutting pattern was created (to assure the design pre-tension at the end of the installation) were added between the primary net cables field by field. The structure was further tensioned after the filling net was fully installed. All outer stay cables and the cables of the primary net connected to the foundation have turn buckles. The tension force of these cables had been adjusted to the pretension as result of the numerical calculation.

The following loads (characteristic loads) have been considered: (1) pretension of the secondary net 0.5kN/m in the main directions of the cable net, which leads to the pretension forces in the primary cable structure, (2) self-weight of the secondary cable net 0.012kN/m² (surface area), (3) self-weight of the primary cable net 0.025kN/m² (projected area), (4) self-weight of the masts 340kN in total, (5) self-weight of the boundary rail 11kN in total, (6) a life load (three persons on 2m²) of 1.5kN/m², (7) snow load 0.5kN/m² (reduction factor considering the mesh 0.6, reduction in relation to the inclination according to DIN EN 1991-3, 5 different load dis-

Figure 2a/b: Physical model of the aviary ©Officium

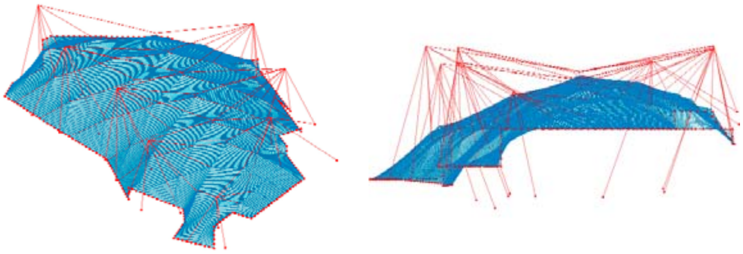

Figure 3.
a: Mast head ©Tri-Monta,
b: 3D hinge ©Marijke Mollaert,
c: support plates for the masts ©Tri-Monta

Figure 4. Analysis model showing the masts, supporting cables, the primary cable net and infill:
a: 3D-view,
b: elevation ©Rosemarie Wagner

"Working on and around listed monuments is always a challenging undertaking. ELD's long-standing professional relation with architectural restoration experts Origin proved fruitful in completing the restoration of these eclectic buildings successfully. Additionally, designing for a whole new user-group of wild animals was a very learning experience. Well-being of the animals was one of the design team's primary concerns while developing concepts together with their care-takers." Filip Declercq

(8) a wind load corresponding to a wind speed of v = 25m/s, velocity pressure q = 0.5kN/m², reduction because of the mesh 0.6, considered wind load qk = 0.3kN/m² with wind coefficients according to DIN EN 1991 - 4 for flat surfaces (wind examined in north, east, south and west direction).

The design is based on Ultimate Limit States, with combination factors according to DIN EN 1990 – 1 pretension γ_P = 1.35, self-weight γ_G = 1.35, life load γ_Q = 1.5, snow load γ_{QS} = 1.5 and wind load γ_{QW} = 1.5.

A stainless-steel mesh (AISI 316) with crimped ferrules is used. Natural greenery is growing on the mesh surface contributing to the natural feel of the environment and provided shaded areas on sunny days. The net is accessible for maintenance.

The visitors of the Antwerp Zoo are very enthusiastic about the unusual zoo experience in the aviary, the buffalo-savanna and the apes-area with their almost transparent roof. The Antwerp Zoo, with its upgrade and extension, stays a popular touristic attraction.

Figure 5a/b: Placement of the infills ©Tri-Monta, c: fully tensioned net ©Marijke Mollaert
Figure 6a/b: Greenery growing at distinct locations ©Marijke Mollaert

Marijke Mollaert
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Rosemarie Wagner
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Name:	The Antwerp Zoo
Location:	Koningin Astridplein 20-26, 2018 Antwerp
Project Year:	2017
Architects:	for the restaurant Studio Farris; for the savanna with aviary: the team ELD/Studio Farris/ Fondu landscape/ Officium, Origin architecture & engineering provided the expertise for restauration of the listed buildings
Engineering:	ELD for foundation and surrounding buildings: new restaurant, new stables, historic buildings, entrance + exit, Officium, with the participant of Rosemarie Wagner for the tensile net structure
Steel structure (aviary):	Tri-Monta
Execution consultant during realization:	Close-to-Bone
Size of the total structure:	Projected area: 2216.00m²

TEXTILE ROOFS 2019

Textile Roofs 2019, the twenty-fourth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 20–22 May, 2019 at the Archenhold Observatory, Berlin, and was chaired by Prof. Rosemarie Wagner (Karlsruhe Institute of Technology) and Dr.-Ing. Bernd Stary (Academus GmbH). It was attended by 75 participants from 14 countries covering four continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.

Lightweight design with Maffeis Engineering

M.Sc. Antonio Diaferia, Maffeis Engineering SpA, Solagna.

Antonio Diaferia presented three recent works of Maffeis Engineering, an international specialty design and structural engineering consultancy, based in northern Italy. The Volgograd Stadium, designed by the Arena Project Institute is one of the FIFA World Cup Russia 2018 stadiums. Its roof consists of a tensile bicycle wheel supporting PVC and ETFE membrane claddings. A summary description can be found in the TensiNews 34, p.5. Especially significant is the replacement of the planned polycarbonate panels by polyester and ETFE membranes, which resulted in a saving of 15 kp/m² of steel. *"With membranes, less steel"*, pointed out Mr. Diaferia.
Rising to a height of 246m the Thyssen Krupp test tower (TKT) in Rottweil is used to test and certify high-speed elevators. with a visitors' viewing platform at a height of 232m. The structure of the test tower consists of a thin reinforced concrete hollow tube with a diameter of 20.80m tapering in thickness from 40cm at the bottom to 30cm at the top. The envelope consists of a long-lasting PFTE coated, glass-fibre fabric that increases in transparency as it ascends the tower and reduces the solar radiation improving the durability of the concrete.
And the third work was the Khalifa International Stadium for the 2022 World Cup characterized by the compression ring formed by two inclined arches (Fig. 1).

Powerful tools for formfinding, statics and patterning of textile structures

Dipl.-Ing. Dieter Ströbel, technet GmbH.

The computer-aided design of membrane structures was summarized by Dr. Dieter Ströbel. He stated that computer models have to be correct, precise and complete for a realistic approach. They also have to be generated in a fast way, using information from many experts and applicable for mass production illustrated by the Mecca Tent City, Allianz Arena (Munich) and the Khan Shatyr Entertainment Centre (Adana).
The design process was exposed starting from the mixed form finding, based on the force density method combining stiff elements with the membrane. The operations involved and the results were reviewed, mentioning the definition of boundaries and nets, support forces, force distribution, stress distribution, contour lines and drainage, including the automatic generation of the primary structure, different net types and enslaved points or lines. As the second step of the design process, the non-linear structural analysis was presented, starting from initial values and based on a precise description of the material behaviour including the consideration of the shear and creep stiffness which steers the interaction between warp and weft. Special comments were devoted to the importance of the material directions, the gas law (for pneumatic structures), sliding/reinforcing cables (Fig. 2) and hybrid systems such as textile halls, cable meshes and cable nets.
The third main step is the patterning procedure based on the flattening of surfaces reducing distortions, keeping the cutting out waste as low as possible and minimizing the amount of work. Additional requirements are the compensation of the geometrically developed surface in order to establish the pretension, the correspondence of seam lines and the translation to cutting drawings provided with welding marks, cutting and system lines. Automatic patterning, mass production, attachments and printing are also possible.
Finally, the free Pre-Designer module was presented for the pre-design of textile membrane surfaces or cable nets, available at: https://www.technet-gmbh.com/en/support/downloads/downloads-easy/

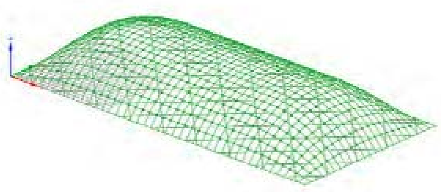


Figure 1: Dar Al-Handasah Consultants with Maffeis Engineering SpA, Taiyo Middle East and Pfeifer, 2014: Khalifa International Stadium, Doha.
Figure 2: The form-finding calculation finds the position of sliding/reinforcing cables (technet).
Figure 3: FLOPEC Building, Esmeraldas.

Smart wraps - Textile Façades

Katja Bernert, Mehler Texnologies, Low & Bonar.

Wrapping buildings was an interesting contribution of Katja Bernert. She illustrated this current application of textile membranes with several examples. Textile façades are a good choice because depending on the mesh size, the open mesh fabric allows the desired amount of light to come through. At the same time the penetration of rain can be minimized. In addition, the mesh density can be varied as desired to create a more or less intense visual barrier. With textile façades, buildings can appear in creative shapes and colours that cannot be achieved so easily and quickly with solid materials. For the aforementioned Volgograd Arena, Low & Bonar GmbH developed a specific type of blue and white coloured translucent membranes which feature the colours of the club which is to overtake the stadium after the FIFA world cup.
In the city of Esmeraldas on Ecuador's west coast, Flopec, the national oil company, decided to build a new head office building contributing to the urban landscape development (Fig. 3).
A steel construction has been enveloped with a 4.000m² textile seamless wrap that blends into the colour of the sky. It avoids mechanical and individual sun shading devices and reduces the wind loads. A huge opening on the building's ground floor frames the view of the ocean and opens the way to the beach huts situated directly behind the paved area. And, in addition, the façade can be used as a cinema screen in the evenings. See also for a description in the TensiNews 31, p. 9.

Lightweight membrane structures

Architect, Legally Certified Engineer, Univ. Lecturer, Dipl.-Dr.techn. Robert Roithmayr, formfinder GmbH.

"You are only able to see if you have knowledge" is the lapidary sentence with which Professor Roithmayr summarised his lecture. He focused on three basic steps of the structural membranes design, which are "get inspired, be creative and make it real", assisted by the formfinder software and database together with the Postgraduate Master of Engineering Program at the Donau Universität, Krems: www.donau-uni.ac.at/dbu/membrane.

He also exposed the rapidly retractable at any time "Bionic Umbrella" unique design for sun and rain protection (Fig. 4) and invited the audience to participate in the formfinder database https://membrane.online.

Assessment of details

Dr.Architect Josep Llorens, Barcelona School of Architecture.

There are different ways of approaching the structural behaviour of membranes according to the characteristics of the materials, material consumption, efficiency and visual expression, among many others (Fig. 5). The appropriate design of membrane structures should be based on the lightness and the ability to follow the load paths, provided they have the right combination of curvature and depth. Structural membranes, if not designed as such, end up as the cladding of an imposing steel structure totally disproportionate.

Professor Jürgen Hennicke, who unfortunately could not attend the 2019 Workshop, pointed out in the previous edition the need to develop an assessment method for detailing structural membranes.

Can a method be developed to assess the appropriateness of details? The principles and requirements of textile roofs may be used as criteria for assessment of detailing. *Details may be assessed qualifying the degree of fulfilment of each principle and requirement as good, fair or bad*. These criteria can also be scored and weighted, (although scoring and weighting are not recommended).

The principles and requirements were formulated at the 2010 edition of the Textile Roofs International Workshop and summarised at: https://www.textile-roofs.com/wp-content/uploads/2018/03/TR10-Report.pdf.

To shape or to form, that is the question

Nicolas Goldsmith, FTL Studios, NY.

Nicolas Goldsmith, the 2019 special guest lecturer, dared to approach the thorny problem of the design of the form. He distinguished "shape making" inspired free-forms that materialize directly a brilliant idea, from "form finding", a process from which the building is organized and the form is optimized. Several examples of the "form-finding" method were shown. The Empire City Casino Porte Cochere at Yonkers Raceway in Yonkers, New York is a FTL project that reflects the form-finding approach. It is a newly constructed porte-cochere with a pneumatic ETFE film roofing system (Fig. 6). The design started from a partial toroid form as an initial surface. A lattice shell with the same curvature throughout was developed using both, a digital and physical model, each showing different aspects and highlights.

Figure 4: Robert Roithmayr: Bionic umbrella.
Figure 5: Two different (opposite?) approaches to design the edges of membrane structures.
Figure 6: Studio V Architecture with FTL and Birdair, 2013: Porte-cochere, Empire City Casino, Yonkers, NY.
Figure 7: FTL Design Engineering Studio, 2008: Sun Valley Music Pavilion, ID.
Figure 8: FTL Design Engineering Studio, 2009: Skysong at ASU Campus, Scottsdale, AZ.

For the Sun Valley Pavilion the natural acoustics of the hypar form was used and, to reach the volume of space required, two shells were needed: an outer shell that is both structural and acoustical and an inner shell only for acoustics tuned like a musical instrument (Fig. 7).

The Sky Song at Arizona State University was inspired by the early 20th century American dancer Loie Fuller who created an amazing array of moving forms illuminated with coloured lamps, turning herself into constantly changing flowers of light. The form of the Sky Song was created using physical models that were later translated into digital models. Four pairs of conoids of revolution combined with trussed curved beams suspended from A-frame masts were arranged with rotational symmetry (Fig. 8).

At the end of the lecture, a quick look at a historical evolution of architecture revealed an almost linear progression from solid mass constructions to diaphanous skins. New membranes point towards the incorporation of multiple functions such as information systems, acoustic and thermal conditioning, energy harvesting, that is to say the customization of the envelope relative to the climate of the site, solar orientation and building needs. More details of the presentation and its examples can be found in: N.Goldsmith, 2018: "Mass to membrane", ORO Editions, Novato CA, whose purpose is "to take my personal investigations and observations in the field of lightness and to understand how to incorporate emerging technologies and the qualities of lightweight structures into an architectural mainstream".

Development of Membrane Structure Technology

Prof. Dr. Wujun Chen, Space Structures Research Centre, Jiao Tong University, Shanghai.

A comprehensive report about the development of structural membranes (1995-2019) for architecture in China was presented by Professor Chen.

1. The application of modern architectural membranes in China, although incipient, is developing rapidly favoured by some important events such as the Olympic Games, national Championships and International Exhibitions (Fig. 9). Main fields of application have been sports, business and public buildings. Materials used are PTFE, PVDF, PVF, ETFE and ePTFE among others and the typology includes mechanically tensioned and air-supported structures, cable-domes, spoke-ring cable structures and more.

2. Recent developments encompass more than sports and exhibitions and employ air-supported membranes, reinforced concrete shells, façades and aerogel insulation blankets. Additionally, membranes built around 2000 are being replaced.

3. The Committee for Membrane Structures in China was established in 2002 as a branch of the China Association of Spatial Structures. Its main responsibilities are to regulate, promote and lead the membrane structure industry by enrolling new members, establishing qualifications, training, disseminating and exchanging knowledge, awarding, promoting innovation and issuing specifications and guidelines.
4. The membrane structures industry is divided into that of materials (steel, cables and membranes) and engineering (design, manufacture and construction). A list of 12 technical specifications was provided and average price varies from 65 to 129€/m^2 according to the material, engineering conditions and business negotiation.
Professor Chen concluded that, although the application of structural membranes in China has not been extensive, the industry and technical specifications have been completely established. There is a need to promote specialization of the industry together with the realization of more architectural applications and improving some technical aspects such as fire protection. He ended up expressing the desire to exchange and cooperate.
Finally, a question was raised: why the roofs built around 2000 are being replaced instead of checking their characteristics, which would probably allow them to last longer? The answer clarified that the replacement affects the roofs of the public buildings when their warranty period (10 years) ends.

Material and process developments in fibre reinforced flexible and rigid composites

Dr.-Ing. Thomas Steigmaier, Deutsche Institute für Textil + Faserforschung.

The German Institute of Textile and Fibre Research is the Europe's largest textile research centre, founded under public law in 1921, for application oriented research from molecule to product. With three research centres and a production company (ITVP), it is connected to the Stuttgart and Reutlingen Universities. Most important fields of research are high performance fibres and yarns, smart textiles, functionalized textiles, finishing, medical technologies, lightweight design and fibre composites. Main applications are architecture, construction, health, care, mobility, energy, environment, production technologies, clothing and home textiles. Outstanding examples presented at the conference were sensor-yarn systems, printed-sensor systems, actuators, electronic textiles, cooling surfaces and solar thermal collectors with integrated energy storage.Through sensor-yarns, capacitance may be measured and therefore changes produced by stress, humidity, temperature, light and more can be recognized. An interesting application to the building stock, where insulation is impossible due to lack of space or monumental protection, is mildew prevention developing yarns with moisture sensitivity and heating functionalities.
To collaborate with robots, a sensor-mat has been developed. It switches the safety according to the position of the operator slowing down the machine when entering a danger area or stopping it when entering into the work area.
Another visionary development is the self-cooling surface, motivated by the increase of average temperatures, megacities and energy demand, that has been inspired by the hairs of Saharan silver ants (Fig. 10), "whose silver hairs reflect sunlight at the shorter wavelengths while in the mid-infrared range they help the ant's body exchange its heat to a cooler area, the sky" (G.Bernard).

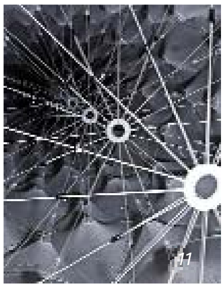


Figure 9: Guirui Theatre, 2019 Beijing International Horticultural Exhibition.
Figure 10: Saharan silver ant.

Figure 11: Tower 2, interior view: cones pulled inwards (A.Ingvartsen).

Shaping hybrids. Prototyping of new material systems

Prof.Dr.-Ing. Christoph Gengnagel, CITA-KADK/KET - UdK Berlin.

Professor Gengnagel showed two research projects exploring active bending in hybrid structures. Hybrid Tower Projects 1 and 2 are a reaction against the convention of stiff, static architecture. They ask what a structure would look like if built from soft materials that give way to forces in a controlled manner, embracing the ideas of resilience and adaptation (Fig. 11). A complete description can be found in: https://issuu.com/cita_copenhagen/docs/tower2_booklet_pages__for_issuu_
At the Department of Structural Design and Engineering of the Berlin University of arts a research has been carried out to develop a novel method to install elastic grid shells reported in TensiNews 34, p.16. Elastic grid shells, like the Multihalle in Mannheim, are highly efficient structures, able to cover large spans with very little material and embedded energy. In addition, the simplicity of these structures generates beautiful double-curved shell surfaces from slender and initially straight rods.
Nevertheless, the existing methods of installation are usually associated with significant complexity, cost and time. The investigated method, which uses a pneumatic falsework, greatly increases the speed of construction for large-span shells (up to 100m in a matter of days), which will have groundbreaking implications on construction costs and efficiency (even though the structure is doubled), with promising potential for applications in rapidly deployable event-halls and shelters. An animation of the installation can be found in: https://www.youtube.com/watch?v=OKe14VF03RM

Architecture fully fashioned

Prof.Dr.-Ing. Claudia Lüling, Universität Frankfurt.

At the "Building for the future" Department of the Frankfurt University of Applied Sciences, Professor Claudia Lüling develops research on alternative efficient structures with new composite materials made in the course of seminars that will soon be realized.
1 - 65 kp Lightweight pavilion (Fig. 12). Extremely light and made of a textile-foamed composite material, a four-meter-high, self-supporting, cone-shaped pavilion has being created in the form of a net mesh, inspired by the fibrous and sponge-like cattail plant Typha.
2 - Spacer Fabric Shell (Fig. 13). The lounge furniture "Spacer Fabric Shell" explores the load-bearing capacity of the foam composite in the form of an arc-shaped self-supporting grid shell. A reversed catenary of cured foam prevents bending. It is ergonomically shaped as a slightly oscillating seat with an acoustical atmosphere that invites to relax.
3 - With its insulation in hot and cold climates, the ZeltHAUS offers protection against natural disasters, in refugee camps or can serve as temporary accommodation in urban mega structures (Fig. 14).
4.- Spacer Fabric Pavilion (Fig. 15). The modular, lightweight textile pavilion shows innovative possibilities of textile construction using composite of textiles and foams. A self-supporting dome structure made of spacer textiles was designed and realized with a combination of folds and partial expansion of multi-layered textiles.
More projects supervised by Professor Claudia Lüling can be found at: https://www.frankfurt-university.de/de/hochschule/fachbereich-1-architektur-bauingenieurwesen-geomatik/kontakt/professor-innen/architektur/prof-dipl-ing-claudia-lueling/tab-designbuild/

Figure 12: 65 kp Lightweight Pavilion.
Figure 13: Spacer Fabric Shell.
Figure 14: Zelt Haus.
Figure 15: Spacer Fabric Pavilion.

Retractable Membrane Roofs

Nikolai Kugel, Architect, arch22.

A series of retractable roofs related with historical existing buildings or urban contexts were shown by its architect Nikolai Kugel. Their most relevant features are the accommodation to the pre-existences and characteristics of the retractable membranes, as well as the complexity of the driving systems.
In the Amphitheatre of Lavis (Fig. 16) the stage is covered by a permanent textile roof of 240m^2, spanned between a rounded concrete back board and a central arch bearing structure. This supporting arch spans 26m. It is anchored back to the hillside by cables arrayed in a fan-shaped way that guides the retractable part of the membrane roof covering 560m^2 of the audience area. The retractable membrane can be folded and bundled manually using ropes, winches and rack gears along the main supporting arch and protected by a transparent canopy. The roof of the stage is a membrane optically detached from the back board, offering to the spectators a great panorama of the opposite mountains. The sonically hard back board and the convex curved membrane roof are causing very good acoustics, distributing uniformly the sound through the audience.
More projects can be found at:
http://www.arch22.de/?page_id=1207 and http://www.kugel-architekten.com/ content.php?n=1

HF Welding by Forsstrom

Mikhail Wallin, Forsstrom HF AB.

The speaker presented Forsstrom as the world leading company at the HF welding arena. High frequency (HF) welding is the joining of materials by supplying HF energy in the form of an electromagnetic field (27,12MHz) and pressure to the material surfaces to be joined. PVC and PU are the materials most commonly used with HF welding. Advantages of HF welding are: repeatable, reliable, strong, durable, even welds, waterproof, multi-layer and environmentally friendly. Main accessories used by HF welding are the electrodes that can be standard, soft, lamella or supplementary. HF welding is the recommended technology by all leading PVC manufacturers of structural membranes because it is reliable and creates even welds with superior repeatability. The HF technology can also be used for a large number of other applications, such as: industrial, boat covers, military, pool liners, billboards, tarps, truck covers, oil booms, stretch ceilings, agriculture, tents and sports. The quality depends on the HF energy, % of the machine capacity related to the size of the electrode, pressure and cooling time. Forsstrom has developed ForFlexx, a unique and patented welding method to join flexible coated PVC and PU fabrics with metal attachments using HF welding and also to join two coated metal surfaces. Together with Formfinder Software GmbH in Austria, a development project is being carried out with the aim of developing alternatives to anchoring/attaching structures based on the ForFlexx technology (Fig. 17). More information at: www.forsstrom.com

ETFE & Printing - case studies

Dipl.-Ing. Björn Beckert, Fabritecture, "where dreams take shape".

The contribution of Björn Beckert started with the presentation of the capabilities of "Fabritecture", mentioning the project and management of membranes, frames, cables and specialised cladding. He focussed mainly on the possibility of printing ETFE for solar shading, back lit applications and aesthetics.
Two outstanding case studies were shown: the Oran Park Library façade, Sydney, (TensiNews 35, p.4) and the Elizabeth Quay Ferry Terminal, Perth (Fig. 18).

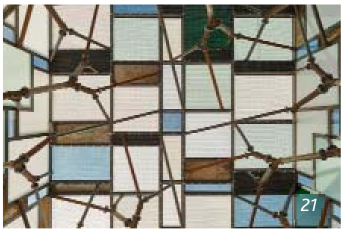
The speaker dared to predict the future pointing at: - greater variety of ink colours, water resistant inks for printing onto single skin applications, long-lasting inks for permanent application – no delamination, UV stable also for sensitive colours, stretch resistant inks – no cracking when under tension, studies on light transmission of different printing colours in different densities, custom art work printed onto ETFE and endless creative freedom!

The PCT CAN Santander Project

Ind.Eng. Feike Reitsma, IASO.

The multi-sports track of the PCT CAN (Scientific and Technological Park of Cantabria) has been covered with a textile roof supported by a steel structure to practice sports under adverse weather conditions but enjoying natural light (Fig. 19).
The total dimensions are 90x30x9m. The supporting structure is composed by 12 main trusses with a frame at each end. The roof is subdivided into 13 panels of Serge Ferrari TX30-III. Its total surface is 3.170m^2 (17,4% more than 90x30=2.700m^2). Valley cables tension the membrane and provide double curvature.
Referring to the appropriateness of the whole structure, one wonders why there are trussed

Figure 16: Kugel Architekten, 2012: Amphitheatre Lavis.
Figure 17: ForFlexx (Forsstrom) with R.Roithmayr: one corner plate in three different positions.
Figure 18: Elizabeth Quay Ferry Terminal, Perth.
Figure 19: C.Galiano with Arenas Asociados and IASO, 2017: PCT-CAN Sport pavilion, Santander.



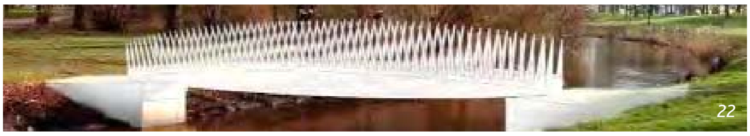


Figure 20: Technospan, 2019: Sahajmarg Spirituality Foundation Meditation Hall.
Figure 21: Karlsruher Institut für Technologie, 2019: "Mehr.WERT.Garten" Pavilion, Heilbronn.
Figure 22: Eindhoven University of Technology, 2015: Bio-based composite bridge.
Figure 23: Rottweil Test Tower: laserscan of the concrete column.
Figure 24: Installation of the joint participants' project.

	Total	SF		MEHLER		SIOEN		HIRAOKA		HEYTEX		SATTLER	
		m^2	%	m^2	%	m^2	%	m^2	%	m^2	%	m^2	%
2016	494000	235000	48	200000	40	36000	7	13000	3	10000	2	-	-
2018	414000	252000	61	92000	22	40000	10	10000	2	-	-	20000	5

Table 1: Membrane market for PVC coated fabrics in India (A.Sathar).

beams in bending instead of ridge cables in tension, and why the frames are not further apart, since the membrane allows it.

On the path to standardized membrane and tent structures: intermediate status and outlook

Dr.-Ing.Jörg Uhlemann, Universität Duisburg-Essen.

Dr.Jörg Uhlemann began his lecture with a short introduction to the Institute for Metal and Lightweight Structures-Essen Laboratory for Lightweight Structures (IML-ELLF), devoted to testing and research on material behaviour (including membranes), testing methods, measurement and simulation. He introduced existing standards for membrane and tent structures made of technical fabrics and foils in USA, China and Japan with special mention to the European standardization work led by the Committee CEN/TC 250/WG 5, predicting optimistically the issue of the "Eurocode for Membrane Structures" by 2024. He also mentioned relevant research activities such as the validation of design elastic constants through testing and analysis considering experimental measurement inaccuracies.

Acceptance of membrane architecture in India. A tour with Indian Projects

M.St.Abdul Sathar, Technospan Structures pvt ltd.

Abdul Sathar started by launching a truly compromising challenge: "We create any imaginable shape or form in any size". He provided market values for PVC coated fabrics in India (Table 1) and he showed a great variety of projects carried out in India by his company Technospan, with costs varying between 30 and 100€/m², dealing with cyclones and storms. The most impressive were the great meditation halls for a large number of participants (Fig. 20). He concluded that India is a huge size developing country that has a high potential for membrane structures, as long as failures due to poor design, workmanship and low quality materials are avoided. After asking how to overcome these difficulties, he formulates the needs:

- more awareness on membrane structures among architects, engineers and clients,
- workshops and training centres in India to develop an efficient network for quality projects,
- to implement standards and practices for design, engineering and working methodology and
- independent engineering companies to design and check the membrane projects.

Mehr.WERT.Garten - Form-finding of tree structures for building from waste

Rosemarie Wagner, KIT, Karlsruhe.

The Mehr.WERT.Garten (Added.VALUE.Garden) pavilion addresses the question how we can perform a paradigm shift in the way we use our resources, from the currently dominant linear economy (take, make, throw) towards a circular economy of closed and pure material cycles. Its objective is to proof that it is possible to design, detail and construct according to the principles of the circular economy. The pavilion building materials are separated into four groups:
(1) the load-bearing structure is largely made from reused steel originating from a disused coal-fired power plant in north-western Germany. It consists of four inclined supports that fan out like trees and are connected to each other by a rigid steel frame structure (Fig. 21).
(2) The façades and roof are clad in panels manufactured from recycled bottles glass and industrial glass waste.
(3) The furniture is built from recycled HDPE plastic waste, while the chairs are 3D printed from plastic household waste.
(4) The floor of the pavilion as well as the landscape design of the garden forms an assemblage of various reused and recycled materials and products made from mineral construction and demolition waste.
More at: https://nb.ieb.kit.edu/?p=6265

Bio-based composite pedestrian bridge

Patrick Teuffel, Innovative Structural Design, Eindhoven University of Technology.

The bio-based composite bridge aims to design and realize a 14m span pedestrian bridge made from fibre-reinforced polymers, that have a high percentage of bio-based content. The bridge has been installed over the river Domel, at the campus of the Eindhoven University of Technology to investigate the design potentials and structure challenges of bio-based fibre-reinforced polymers, which are relatively new materials in architectural and structural load-bearing applications (Fig. 22). Along with the design possibilities of the material, the entire design process and installation were presented together with the detailing, focusing on the evaluation of different structural typologies and the optimization of the selected geometry. Future research is expected such as adhesion fibres and resins, research on bio-based resins, environmental impact: more LCA's, cradle to cradle certificate, low cost circular composites, fire classification: now S4 ST2 SR2 (DIN 5510), M2 (NF P 92-501), moisture sensitivity and long-term behaviour and durability.

Monitoring membrane structures deploying terrestrial laser scanning

Sergey Ryklin & Son, Ryklin Engineering, Taiyo Europe & Technet.

The advantages of monitoring membrane structures were underlined: "Has your structure been built according to the specifications?". "Does your structure behave as it should?". Geometric discrepancies arise (frequently) due to: subsidence, the structure has not been built according to the design, the material does not behave as it should, failures, damages, etc.
Some notions regarding the features and influencing factors of terrestrial laser scanners were commented, remembering that they can only capture data within their field of view, so that several viewpoints are required to entirely document an object. Some examples were shown: the Veytaux energy plant in Switzerland, the Rottweil tower in Germany (Fig. 23), and the replacement of the Place Rogier roof in Belgium.

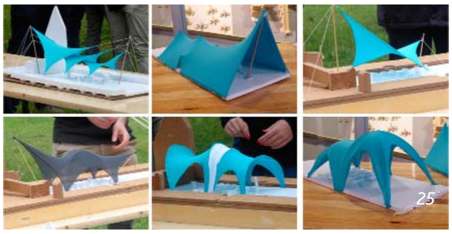


Figure 25: Results of the student's project: a membrane for the ruins of the Cistercian nunnery, next to lake Wutzsee in Lindow.

Joint participants' project

The "Joint participants' project" (Fig. 24) was led by Stev Bringmann, 3dtex GmbH, and installed and discussed during the workshop by the participants. It could be done thanks to the following contributions: Low & Bonar (Valmex® FR 700 MEHATOP N - TYPE I), Karsten Daedler e.K. (cutting of the panels and welding), Forsstrom (welding machine), Rhein-Ruhr Fundamente/Schraubfundamente (Foundations system M76/1300, Jackob Rope Systems (cables) and technet (software).

Student's Project: Spanning Centuries

The student's project was led by Prof. Rosemarie Wagner, KIT Karlsruhe. A membrane structure had to be designed in the garden area in front of the ancient ruin of the Cistercian nunnery next to lake Wutzsee in Lindow. The result of the design had to be provided with sketches, construction drawings and physical models and, for the presentation, the students were asked to describe the target, integration in the surroundings, material, form-finding, detailing and cutting pattern. The final review was attended by all the participants in the TR 2019 Workshop. Comments addressed to the appropriateness of the designs attending to the performance of structural membranes (does the design avoid bending?), functionality and adequacy to the configuration of the space (Fig. 25).

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TEXTILE ROOFS 2020 The Twenty-fifth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures, together with its 25th anniversary celebration, will be held on 18-20 May 2020. Its format will be similar to that of TR 2019, with seminar-style lectures and hands-on activities. The main objectives of the workshop are to provide fundamental information, as well as presenting the state-of-the-art in textile roof engineering. More information at: http://www.textile-roofs.de.

Darmstadt, Germany

ETFE MEETS OPV

AN INNOVATING MULTIFUNCTIONAL MODULAR CURTAIN WALL FOR THE TRANSFORMER STATION

Figure 1: MERCK Transformer Station, Darmstadt, Germany
1a: appearance of the original brick-façade
1b: appearance of the new curtain wall

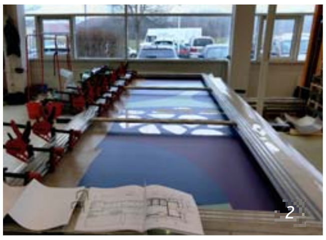
Building envelopes offer opportunities for the use of solar energy. Curtain walls are particularly suitable for the application of photovoltaic modules. Considering the fact that curtain walls are arranged separately in front of the building exterior wall, they allow a relatively simple application of photovoltaic modules, without paying particular attention to the aspects of building physics (thermal insulation, heat dissipation). Furthermore, a curtain wall enables the access, the connecting and the maintenance on PV-modules from the back. The presented project shows such a successful application. Here, organic photovoltaic (OPV) was applied to ornamental printed and pre-tensioned ETFE films. In combination with the lightweight profiles of aluminum, this resulted in a transparent and aesthetically appealing curtain wall that additionally generates electricity from renewable energies. The façade, finished at the beginning of 2018, is covering the transformer station, a one-story brick building, on the premises of the company MERCK KgaA in Darmstadt, Germany. The façade can be considered, therefore, as the world's first energy-efficient, digitally printed single-layer ETFE curtain wall equipped with OPV-elements. The innovative example shows where development could lead on this path.

Description of the pilot project

The project shows a modular design for curtain wall façades, which consists of the combination of ETFE- film and organic photovoltaic cells (OPV). Here, three different organic shapes of OPV elements were applied on the mechanically pre-tensioned ETFE film. The 64 membrane modules with aluminum frames form a curtain wall covering four sides of the existing transformer building on the premises of MERCK in Darmstadt in front of a wall made of fired bricks. The selected colours of the digital printing of the ETFE film follow the corporate identity of the company. Due to the relatively small area of the OPV the plant provides only a low power yield.
The small façade is, therefore, a pilot project, that should demonstrate the possibilities of this technology. The direction in which this technology goes is clear: the individual design of modular, aesthetically appealing multifunctional curtain walls. Topics include lightness, transparency, aesthetics, careful use of resources and solar energy generation.
The project uniquely combines aesthetics and multi-functionality. The result is a great architectural work of art with a high innovative standard.

Conclusion

The project shows the possibilities of building integration of photovoltaic (BIPV) in combination with transparent ETFE film, but it also shows the beginning of a construction method that will only mature to a trend-setting technology after going beyond initial teething troubles. However, the combination of PV and ETFE enables, like no other, the realization of modular, individual, multifunctional and aesthetically pleasing façades and roofs. The example also shows that requirements for aesthetics, transparency, lightness, load transfer, weather and fire protection, as well as the careful use of our natural resources and the solar energy production are achievable. Since the example refers to an open curtain wall, building physical requirements due to thermal insulation were not compulsory.





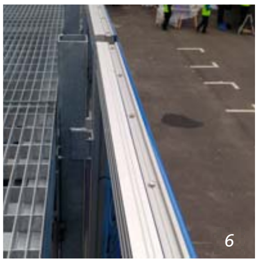


Figure 2: Assembly of the 64 frames in Taiyo Europe's workshop (standard size 4.2x1.3m, as shown here; special size 4.2x0.5m).
Figure 3: OPV-modules glued on the backside.
Figure 4: Connecting the OPV-modules.
Figure 5: Installation of the pre-fabricated façade-modules on site.
Figure 6: Detail of the finished façade, top view.

Currently the membrane construction industry is changing rapidly to the extent that modular constructions with mono- or multi-layered structures and multifunctional uses are now part of it. Due to their low weight per unit area and their multi-functionality, modular constructions also undoubtedly belongs to the field of lightweight structures. Such multifunctional modules are becoming increasingly important for architects and building owners, and, therefore, for the construction industry as well, as they allow very different applications and functional possibilities. However, they also lead to a major challenge for membrane construction companies, architects and structural engineers. This means that suitable production methods with appropriate quality assurance for modular multilayer structures must be present or developed, and the topics of building physics, fire and structural behaviour, but also production and assembly technologies of modular multilayer membrane structures are to consider in design and engineering, including all interactions.
Which membrane construction company is capable of producing a large number of uniform or even different modules economically and in terms of a needed high quality? Which structural engineer is also a specialist in building physics and photovoltaic and knows the element's stress-strain behaviour and its structural limits? Which architect can claim that he masters all relevant topics in such a way that he can present a harmonious execution planning of such modular constructions, without involvement of experts in the early phase of the planning process? The knowledge of all the elementary properties and requirements, but also their interactions, will increasingly determine the success of such modular membrane projects as well as the future of the planners and specialist companies involved in this new technology.

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Name of the project:	Merck Transformer Station
Location address:	Darmstadt, Germany
Client (investor):	Merck KGaA, Darmstadt
Year of construction:	2018
Design:	Henn Architects, Berlin
Structural Design:	Leicht, Munich
Contractor:	Taiyo Europe, Sauerlach
Supplier of the membrane material:	Nowofol Kunststoffprodukte, Siegsdorf
Supplier of the steel substructure:	Steelconcept, Chemnitz
Supplier of the OPV:	Opvius, Kitzingen
Manufacture and Installation:	Taiyo Europe, Sauerlach
Covered surface:	300m²
Number of modular frames:	64
Number of PV modules:	1,578 (3 types of organic shapes)

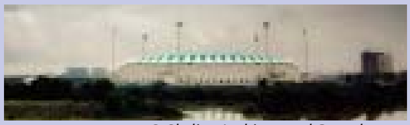
LOW & BONAR

TRANSFORMING MUNDANE PARKING WITH TEXTILE SHADES OF GREY

Miami, USA

CRICKET STADIUM

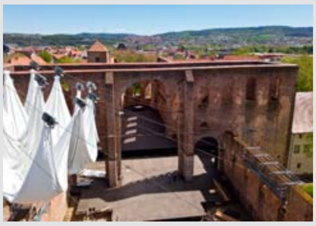
Lucknow, India

© Skyline Architectural Consultants

The international standard cricket stadium in Lucknow, Uttar Pradesh, is named after one of Lord Vishnu's names "Ekana". Initially it was known as just that: Ekana Cricket Stadium. On November 6th 2018, before the first international match, its name was changed to Bharat Ratna Shri Atal Bihari Vajpayee Ekana Cricket Stadium. With a seating capacity of 50.000, it is the third

3RD EDITION OF FREI OTTO'S RETRACTABLE ROOF



Bad Hersfeld, Germany

The convertible roof above the auditorium of the monastery ruins is a unique construction and was an architectural model for a variety of modern tent structures and roofs. Frei Otto was winner of an architectural competition for the festival cover in 1958. The project took 10 years to be put into reality. In 2018, the festival in Bad Hersfeld celebrated the 50th anniversary of the first installation. On this occasion the Bad Hersfeld-based company The FilamentFactory (formerly Performance Fibers) offered a special gift: a new edition of the membrane roof.

Car parks are often wrapped in costly façades of metal sheets for example. These common façade systems usually trigger an elaborate ventilation effort. Having a textile wrap with considerable open area means that the client can save a lot of effort and money on ventilation systems.
The textile façade does not count as an enclosure and hence the air ventilates freely.

The multi storey car park was designed by Stantec, the internationally operating interdisciplinary engineering and design firm. Together with the façade experts from structurflex they developed the design and colour concept for the tensioned façade. It is made of Mehler Texnologies TF400 vinyl coated polyester mesh. The tensile façade was installed in 2018.

FlexFaçades by structurflex is a specialist in tensile fabric façades and fabric cladding. The distinguished façade of the Miami car park provides protection from wind and solar glare. The façade in different shades of grey wraps the main visual parts of the building. At the same time people can still easily look to the outside.

Name of the project:	Miami Midtown 8 Tower
Location address:	NE 1st Ave, Miami, Florida, USA
Year of construction:	2018
Architects:	Stantec
Client (investor):	Kast Construction
Function of building:	multi-storey car park
Type of application of the membrane:	façade, covering concrete parapets, open spaces
Contractor for the membrane (Tensile membrane contractor):	structurflex
Supplier of the membrane material:	Low & Bonar GmbH
Manufacture and installation:	Flexfaçade by structurflex
Material:	Mehler Texnologies Valmex TF400, in different shades of grey

largest international cricket stadium in India. The actual stadium building carries elements of the city's Mughal architecture and a state-of-the-art sporting venue inside. The roof corresponds with the Mughal touch of the building in geometry and colour.
The form finding, analysis and manufacturing of the roof was done by Western Outdoor, a Mumbai based company which is led by Daler Singh. He recently won the National Entrepreneurship Award for his achievement in transforming the family owned metal workshop into an internationally operating tensile architecture company.

One step for this development was taken in Germany, when Daler Singh was one of the first Archineer graduates finishing his degree at the IMS Bauhaus Institute in Dessau.

Name of the project:	Bharat Ratna Shri Atal Bihari Vajpayee Ekana Cricket Stadium
Location address:	Ekana Sportz City, Sector 7 Gomti Nagar Ext, Amar Shaheed Path, Lucknow, Uttar Pradesh 226010, India
Year of construction:	2017
Architects:	Skyline Architectural Consultants
Client (investor):	Ekana Sportz City
Function of building:	cricket stadium
Type of application of the membrane:	grandstand canopy
Contractor for the membrane (Tensile membrane contractor)	Western Outdoor Structures Pvt Ltd
Supplier of the membrane material:	Low & Bonar GmbH
Manufacture and installation:	Western Outdoor Structures Pvt Ltd
Material:	Mehler Texnologies Valmex Type II, green and Valmex Type II N, Nano lacquering

25 years earlier the cover was replaced for the first time. Whereas the first change was done by Stromeyer, the actual replacement was manufactured and installed by Munich based globally active membrane specialist Velabran. Both renewals were of course done along the original design. The first and the second roof lasted remarkably long considering that the material had to endure a lot of movement. It is opened and closed at short notice and must withstand any weather condition. It is operated by 21 engines which are still the first set of machines from the original construction. They run along a cable net which interlinks the seven high points. The fabric has

about 1.500m². Between May and September it is installed above the audience, off season it is maintained thoroughly and stored in a container. The festival's organizing team and the audience appreciate that it still feels like sitting in an open air environment whereas a sudden rain doesn't intrude the spectacle.

Name of the project:	Bad Hersfeld Festival cover
Location address:	Am Markt 1, 36251 Bad Hersfeld
Year of construction:	originally 1968, 1st replacement 1994, actual replacement 2019
Architects:	Frei Otto
Cutting patterns of actual version:	formTL
Client (investor):	The FilamentFactory (formerly Performance Fibers)
Function of building:	ruins of a monastery hosting a festival
Type of application of the membrane:	convertible festival canopy
Contractor for the membrane (Tensile membrane contractor):	Velabran
Supplier of the membrane material:	Low & Bonar GmbH
Manufacture and installation:	Velabran
Material:	Mehler Texnologies VALMEX FR 900 OPAK

The participation of 145 attendees from 25 countries was a very satisfying result of the TensiNet Symposium entitled: Softening the Habitats. Sustainable innovation in Minimal Mass Structures and Lightweight Architectures. The attendance of all the stakeholders of the TensiNet Association and of very interesting new entries, including PhD candidates and students from various universities in Europe, gave evidence of the great interest in the theme of the conference, which dealt with sustainability in the building construction of ultra-light systems and membrane structures.

This TensiNet edition was hosted from the 3rd to the 5th of June 2019 at Politecnico di Milano in Milan, Italy. Organized by the TensiNet Association, it was the sixth in a series of symposiums that began in Brussels in 2003, followed by Milan in 2007, Sofia in 2010, Istanbul 2013 and Newcastle in 2016.

Main lectures

Over the three days, 7 keynote lectures and 53 presentations were given.On the first day, after the opening by Stefano Della Torre, the Dean of the Department of ABC of Politecnico di Milano, and Laura Daglio on behalf of the Italian Society of Technology of Architecture, the organizing committee of the sixth TensiNet symposium took the floor to welcome participants. Marijke Mollaert, professor at Vrije Universiteit Brussel, Bernd Stimpfle, partner at formTL GmbH, Carol Monticelli and Alessandra Zanelli, professors at Politecnico di Milano, introduced the conference's theme and the keynote speakers who opened the three plenary sessions.

Then, the **Soft Structures** plenary session was featured by keynote address by Christoph Paech (Director at Schlaich Bergermann Partner, Germany) and Julian Lienhard (Director at str.cture GmbH, Germany). **Christoph Paech** emphasized the major role of a comprehensive design approach in complex membrane construction, either moveable or fixed, by his lecture entitled "Moveable membranes – smart solutions in the field of architecture". Referring to sustainability, **Julian Lienhard** talked about a new application of the concept of simplicity in his lecture "New hybrids": we should push forward the boundaries of membrane construction by researching and experimenting a "massive appearance" that will therefore result in a saving of material and environmental resources, compared with traditional structures.

The second day session **Softening the environment** was featured by keynote lectures of Neven Sidor (Grihaw, UK), Maibritt Pedersen Zari (Victoria University of Wellington, New Zealand) and Norihide Imagawa (TIS&Partner, Japan). **Neven Sidor** introduced the different range of projects of the practice in his lecture "Innovative sustainability solutions in the Grimshaw & Partners Projects". Playing with the famous saying: "more reuse, less waste" or "more volume, less mass", his lecture confirmed that the development of tensile structures and also of pneumatic systems follows in the footsteps of the pioneers of these technologies. The lecture of **Maibritt Pedersen Zari** entitled "Biomimicry for regenerative built environments" was a powerful spur to consider Nature "as a teacher, as a mentor" in our daily life particularly when we design. The inspirational message coming from the career experience of **Nohiride Imagawa** and his lecture "Structure and Space of Serendipity brought by Materials for Art" enclosed the second day morning session. His way to see at structural design as a bond between material and space represents a very interesting approach both for architects and engineers.

Figure 1. Politecnico di Milano, hosting university for the 6th edition of the TensiNet symposium.
Figure 2. The plenary session during the mornings of the Symposium.

In the afternoon, the representatives of the TensiNet Working Groups shared the research's updates with a broader audience in an **Open Talk** moderated by Katja Bernert (Low and Bonar); the positive results of this very first working plenary meeting organization were many new potential insights, by crossing research boundaries, which could possibly spread out new research directions. And, as a consequence, that there is room to keep exploring interconnections between the researches of the Working Groups.

On the third day session **Soft Skins**, the plenary keynote lectures were given by Mette Ramsgaard Thomsen (Centre for IT and Architecture, KADK, Denmark) and Jan Knippers (Institute for Building Structures and Structural Design, Germany). The lecture of wide culture of **Mette Ramsgaard Thomsen**, entitled "Transformative Textile Architecture", on one side brought attention to the pivotal heritage of tapestries and tents in our cultures and, on the other, pushes forward the boundaries of design applications by demonstrating that today know how is appropriate to consider textiles as a model, through which we can perform a "new kind and lighter architecture".

Figure 3. Open Talk session.
Figure 4. Castello Sforzesco: Visiting the Asse Room with the Leonardo Da Vinci's Frescos (a) & enjoying the conference dinner (b).

As the organizing committee, we would like to thank everyone in participating and in contributing to the success of the conference. In particular, we would like to thank the sponsors, the supporters and the editorial board of the journal "Architectural Engineering and Design M anagement" for their endorsement and support of the event; the keynote speakers for their inspiring contributions; all the speakers for sharing their researches and all the attendees who at the end of the day made the event worthwhile and meaningful.

The event was supported by the Municipality of Milan and by the most relevant Italian industry associations, namely SidTa - Società Italiana della Tecnologia dell'Architettura, ISTeA - Italian Society of Science, Technology and Engineering of Architecture, ATE - Associazione Tecnologi per l'Edilizia, Ordine degli Architetti P.P.C. della provincia di Milano & Ordine degli Ingegneri della Provincia di Milano.

Sponsors of the symposium were: (platinum sponsors) ASMA GERME MEMBRAN, Canobbio, formTL GmbH, REDAELLI TECNA S.P.A., (golden sponsors) Sattler AG, 3M, VERSEIDAG-INDUTEX GmbH, TOP GLASS Industries S.p.A., Serge Ferrari S.A.S., (silver sponsors) Sioen Industries, Mehler Texnologies, (copper sponsors) CHUKOH CHEMICAL INDUSTRIES, Vector Foiltec, Formfinder Software GmbH & Dlubal Software GmbH.

Finally, **Jan Knippers** in his lecture "Novel Composite Building System inspired by Nature" encouraged us to explore new applications of codesign, which he considers one of the best ways to "unlock innovation in the building sector". Indeed today we must change the organization of construction processes, rather than change materials or tools, to have innovation.

TS2019
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REPORT

TensiNet Symposium

SOFTENING THE HABITATS MILAN 3RD-6TH JUNE 2019

The TensiNet Symposium "Softening the habitats. Sustainable innovation in minimal mass structures and lightweight architecture" was held in Milan in June 2019.

MATERIALS

According to what has become habitual in the last meetings, the ETFE foil is the subject of most papers related to materials with a greater concern for the solar radiation and extreme temperatures.

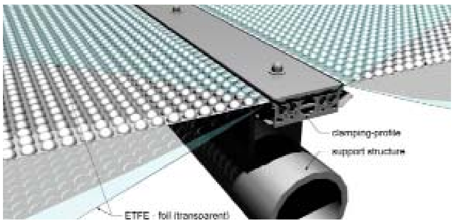
J. Cremers showed a new 3D foil based on the shed roof principle (saw-tooth roof) for sun protection (Fig. 1). The advantage of this approach is to block off the energy intensive direct sun light and to let in diffuse sunlight for the daylight quality into the building. This reduces the cooling energy loads and improves the thermal- and visual comfort inside the building. A selective prototype foil with a hemisphere geometry (diameter of 0. 02m) on a millimetre scale similar to a bubble wrap foil has been manufactured. The foil has first been printed with a flat printing pattern adjusted to the sun position and the spatially transformed geometry (hemisphere), and then the foil is spatially transformed. This allows to adjust the same geometry by simply varying the printing pattern according to the location. The main application setup of the new 3D foil would be between two foil layers (external and internal), this means that the minimum requirement is a three-layer foil construction.

Whereas the sustainability discourse was dominated by thoughts on material savings and durability, K. Bernert focussed on two other membrane environmentally compatible properties. On the one hand, membrane constructions soften our built environment by their shape and by their soft skills and on the other hand, membranes are adaptable. Fabric façades for example, are much more than just a textile wrap. The soft forms of a membrane façade are acoustically effective in the cities' micro climate and, additionally, they can easily be adapted to the user's changing needs. This adaptability is facilitated by smart properties as new membranes point towards the incorporation of multiple functions such as information systems, acoustic and thermal conditioning, wind protection, filtering or energy harvesting, that is to say the customization of the envelope relative to the climate of the site, solar orientation and building needs (Fig. 2).

Worried about the quality and eco-efficiency of membrane buildings, C. Monticelli applied three eco-efficiency principles aimed to verify the design choices:
1st principle: the comparison between the sum of the perimeters of the membrane modules with respect to the surface covered by the envelope.
2nd principle: the comparison between the weight of the membrane and the weight of the fixing system.
3rd principle: the comparison between the self-weight of the supporting structure of the membrane and the mechanical load.
The first two principles were verified analyzing 13 ETFE envelopes (roofs, façades or both). The results have been significant for optimizing the design but many other aspects and phases of the building life cycle require to be considered too to find the right balance among all of them.

M. Durka introduced a laminated membrane that consists of PVDF films reinforced with glass fibre mesh (called Fluoscrim™), developed to explore additional solutions for permanent architectural membrane structures. Technical issues that were key during the development stage were: ageing under artificial accelerated weathering tests, confectioning the membrane materials using high frequency (HF) welding techniques and biaxial properties of the membrane (Fig. 3). The preliminary test results gave promising information related to the use of Fluoscrim™ in projects where long-term high translucency wide span structures are envisioned. This material is now available for use in tensile architecture projects while some advanced properties are currently being optimized for a standard product offer. One important perspective to Fluoscrim™ material is the ability to be recycled to bring a more sustainable approach on material development for the tensile architecture construction industry.

E. Kriklenko in "Achieving complex bending-active structures from flexible planar sheets. Hybrid structure introducing the use of spacer fabrics in architectural field" presented a new structural system based on the interactive work between tensioned and bended elements equilibrating each other. They are made of soft materials in elastic sheets pre-stressed by active bending. Since all the materials are soft, each element of the system is unstable but, working together, they create a shell rigid enough to bear self-weight and additional loads.
This investigation falls within the field of complex bending-active continuous flexible sheet structures, whose principal acting elements are customized flexible sheets (based on spacer fabric) and a system of tensioned membranes, which deform the spacer sheet in a desirable, stable and resistant configuration (Fig. 4). In this way, light customized double curved surfaces easily assembled for multiple uses can be shaped.



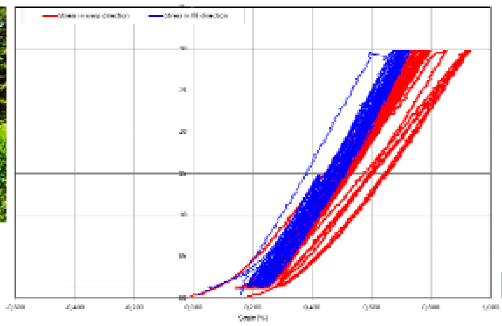


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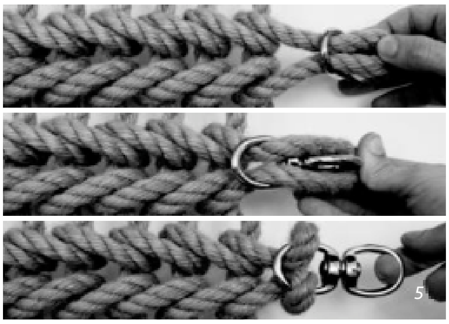
Figure 1: Protected installation of the 3D foil 250μm between ETFE transparent 200μm and ETFE transparent 200μm.
Figure 2: Exclusive customization: T.Berresheim with Mehler, 2015: Arthouse, Düsseldorf.
Figure 3: Biaxial test of FluoscrimTM (MSAJ procedure).



E. Clarke started from the possibility of designing the performance of knitted fabrics thanks to computational tools. She introduced a practical and computational trial to produce a knitted shading structure for a pavilion through a preliminary experimental process focussing on the practical knitting technique, in which the geometry and derived properties of a knitted stitch have been examined. She defined a rule to increase the number of stitches per course resulting in diagonal outer edges with a specific slope. Using this rule, three distinct geometric textile modules were defined with the possibility of combining them into different patterns. adapting them to the diverse program of the pavilion and its orientation within the project site. She also examined various structural techniques (Fig. 5).

"Coating of ETFE. Solar shading for architectural applications" was the topic of C. Maywald. He started from the need to enhance the user comfort and reduce cooling loads of the foils used for architectural applications. That's why he summarized the development of coating and printing on ETFE, as well as the different techniques for solar shading of ETFE cladding systems, including successful examples (Fig. 6).

In order to allow for the quality assessment of these coatings, he also introduced a new test procedure for coated ETFE.

In "Building Integrated Photovoltaic applications with ETFE-Films", K. Moritz described the design and installation of building integrated photovoltaic modules in combination with transparent structural membranes made of ETFE-films, illustrated by the transparent roof for the parking lot of the waste management services in Munich (Fig. 7). The total area of the roof made of ETFE-film cushions is about 9,600m^2 and the flexible translucent photovoltaic modules occupy an area if about 3. 000m^2. They are located in the air inflated interior volume of the ETFE-film cushions, safe from external exposures. The lower layer of the cushions is printed with a dot-pattern for shading. The decision for taking ETFE-film cushions for the cladding of the roof, instead of other materials like over-head glass panes, was based on their advantages.

In "Extreme Soft Skins: Multilayered ETFE for challenging environments" N. Jakica presented the optical and thermal characterization of multi-layered ETFE foils performed at the TextilesHUB - the Interdepartmental Research Laboratory at Politecnico di Milano. Studies include ETFE with advanced silk-screen printed coatings and coating patterns for various real case projects in challenging environments, covering both cold and hot extremes. Moreover, she presented an optimization process for improving the performance of ETFE layer compositions to mitigate high environmental stresses, provide optimal indoor comfort and reduce energy demand (Fig. 8). Finally, different ETFE systems implemented in three projects (St. Petersburg, Milan and Manama) were discussed together with possibilities for future improvements.

Figure 4: Scaled complex bending-active continuous flexible sheet structure model.
Figure 5: Attaching a closed stitch to a closed hardware.
Figure 6: A high reflective cushion system has been implemented with success in "The Avenues Mall", the largest shopping mall in Kuwait. It is based on a medium opacity ink printed on the inner surface of the uppermost foil in a 7mm hexagonal matrix pattern covering 84 % of the foil area.

A. Angelotti compared the heat transfer performance of double layer and triple layer pneumatic cushions, by taking the effective curved geometry of the cushions into account. To this

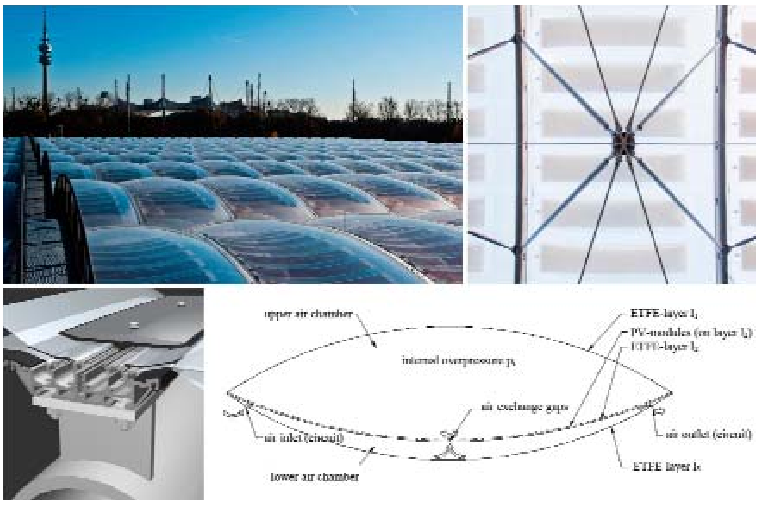


Figure 7: Building integrated photovoltaic application with ETFE films in the parking lot of the lorries for the waste management services, Munich, 2011. Notice in the isometric view of the clamping the separated upper and lower cushions for easy access and quick replacement.

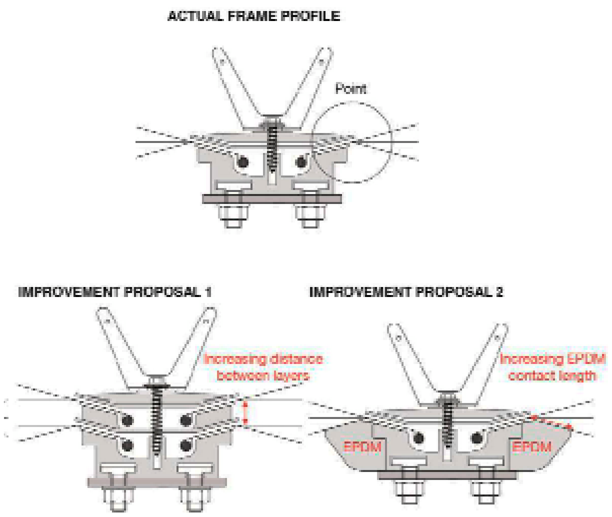


Figure 8: Improving joints of multilayered ETFE cushions for extreme climates.

purpose, an experimental study on two small vertical samples was performed (Fig. 9). It revealed that going from a single large cavity to two smaller ones almost doubles the overall thermal resistance of the cushion. It was also found that no calculation of thermal resistance of a vertical rectangular cavity is able to effectively portray the actual behaviour of the samples. In the future, new samples will be investigated together with the convection inside the cushions by means of CFD simulations, in order to better understand the air motion.

M. Rychtarikova introduced the audiovisual comfort in shopping streets covered by structural skins by analysing the impact of common glass and ETFE cushion systems on noise levels and sound reverberation (Fig. 10). The research was done using a parametric study to deduce how the height and width influence the acoustic quantities. Three basic street models were tested: (1) a street without any roof, (2) a street with roof made out of ETFE foil and (3) a glazed roof. The theoretical analysis was done in detail per octave band, in order to show the behaviour at low and high frequencies in the rooms separately. It has shown that, in cases where the ceiling is low, the selection of the material has a strong impact on the overall noise level. Furthermore, the positive impact of a ETFE roof structure, has been proven to be a better solution, not only in terms of noise, but mainly in terms of the reverberation time.

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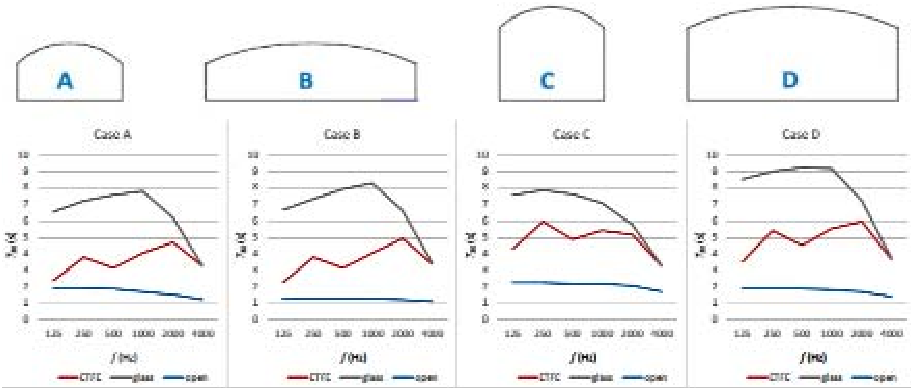

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Figure 9: Inflated experimental cushion. Notice the thermocouples and heat flux meters.
Figure 10: Average reverberation time in the four simulated cases.

DESIGN

D. Ströbel summarized three main steps to follow for the design of pneumatic structures. First is the form finding needed to create a feasible surface and based on the extension of the force density approach with additional constraints: chambers, internal pressure, volumes and reinforcements. The second step is the static analysis starting with the definition of the material properties. An internal pressure is fixed and the non-deformed geometry of the patterns can be calculated. If the pneumatically stressed membrane surface is attached to a bending stiff primary structure or combined with mechanically stressed membranes, their interaction has to be considered (Fig. 11). Third step is the patterning, dividing the form in different parts, optimizing the widths and using fast methods for compensation, seam allowances and welding marks. Evaluation of the patterning is also possible.

J-C. Thomas addressed the problem of an inflatable beam subjected to compressive and transverse loads. Inflatable beams are now well established for transverse loads, but the case of the combined axial and transverse loads has received few attention. The two loads cannot be superimposed because the axial loads modify the stiffness of the beam. So, new formulations for the bending and buckling of inflatable beams subjected to compressive forces were presented. Analytical formulas were proposed taking into account the effect of the internal pressure.

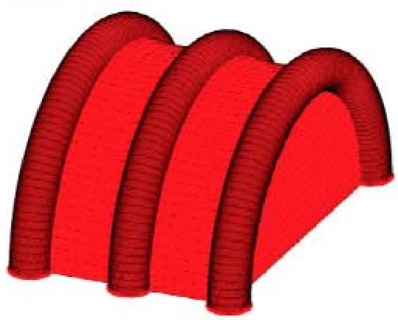

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Figure 11: Pneumatic tubes combined with mechanically stressed membranes.
Figure 12: JSWD Architekten, 2011: Q1 Building, Essen: 400.000 metal feathers as a brise-soleil for the 100% glazed façades.

M. Pedersen recalled biomimicry, meaning that it may be useful to examine examples of how the functions of ecosystems have been solved by living organisms. She seeks to create a qualitative complex map for designers and built environment professionals to relate ecosystem services with design strategies and case studies. She concluded that buildings and whole cities, should become active contributors to eco-sociological systems, rather than remaining unresponsive agents of the ecosystem degeneration. She warned however against mimicking aspects of living organisms that produce sustainable innovations without an understanding of the ecological context, because such innovations can easily become simple technological add-ons or substitution materials in conventional buildings (Fig. 12), missing the opportunity of changing the built environment and re-evaluating the nature of the relationship between people, their built environment and ecosystems.



Figure 13: The 36 pneumatic cushions of the BC Place Stadium in Vancouver start the folding process.
Figure 14: Koz Arena, Adana Stadium.
Figure 15: The moment of truth: does the pin fit?

REALIZATIONS

The realizations presented at the Symposium were representative of the state of the art and showed the diversification of applications from stadiums and sport halls to façades and auditoriums, courtyards and fantasies.

Ch. Paech introduced the basic principles of the design of retractable membrane structures, focusing on the detailed knowledge of the material behaviour and structural systems. He stressed the need for a comprehensive design approach spanning from architecture and structure to mechanical and electrical engineering. He illustrated these concepts with recent works by Schlaich Bergermann Partner, such as the retractable cushions of the BC Place Stadium in Vancouver (Fig. 13). It stands out because the retractable part of the roof consists of 36 pneumatic air inflated and pressure-controlled cushions of fluoropolymer coated PTFE fabric. The cushions were chosen instead of a single membrane to assure the all-year use of the stadium under the specific weather conditions of Vancouver. And the material was preferred for its extremely high translucency and excellent performance characteristics, especially in relation to the folding requirements.

One of the most realistic presentations of the Symposium has been: "Cable erection of the Adana stadium suspended roof" by E. Di Muro (Redaelli). The Adana stadium cable net roof is based on the bicycle wheel principle, using cable “spokes” connected to two cable tension rings (one upper & one lower) and one outer steel compression ring (Fig. 14). Due to the convex shape of the radial cables, the interconnecting elements between the upper and lower radial cables are flying masts and diagonals. The stadium has a capacity of 33.000 seats and its roof has a surface area of 24.000m^2 covered by a double curved prestressed PVC membrane supported by steel arches. The installation process was a challenging operation that required the greatest care and accuracy (Fig. 15). Its description was stellar.

Ph. Lussou was in charge of showing 3 textile envelopes that, in addition to the conventional advantages (translucency, mechanical strength, dimensional stability, durability, ease of fabrication, installation and maintenance), provide comfort and energy efficiency. The Miramas Athletics Stadium (Fig. 16) is the largest indoor athletic hall in France. It benefits from an incomparable luminous atmosphere thanks to the canvas that covers it, diffusing a homogeneous light at the heart of the project. This performance is achieved thanks to the use of a double membrane that provides diffused light, blocking sun glare and preventing shadows. The community gym “Julius-Hirsch-Sportzentrum” in Fürth (Fig. 17) has a membrane roof that spans the field and part of the secondary rooms. It is multilayered consisting of an outer membrane as weather protection, an air space varying from a 0. 5 to 2. 5m thick, a thin cover foil as humidity barrier, a thermal insulation, a small 4cm air gap and the inner membrane. It results in a 30% reduction of the electricity demand for artificial lighting when a dimming control is used. The auditorium of the CIRCA area in Auch is wrapped by a double skin system with insulation (Fig. 18). The distance between the two membranes is 250mm and insulation panels made of rock wool (160mm thick, U=0. 2W/m^2. K) are supported by the lower membrane. The advantage of this system is to preserve the aesthetics of the project while providing thermal and acoustic comfort comparable to what is obtained with conventional construction.

A single ETFE triangular cushion for the atrium of the new Lilienthalhaus in Brunswick was presented by B. Stimpfle (Fig. 19). In the initial design a glass roof was intended but its primary steel structure would have been very heavy and would have required a sprinkler system. That is why a lighter and cheaper alternative was chosen. The primary steel structure has been reduced to a perimeter steel frame placed on the concrete structure. The load carrying cables forming the cushion reinforcement are the only steel parts placed upon the atrium (Fig. 20). The cushion is three layered and covers an area of 430m^2. The upper and lower layers are supported by steel cables so that the maximum foil stress can be safely carried. They are not connected to the ETFE foil, so they can slide avoiding local stress peaks. And the installation has been easier and faster in comparison to the initially planned glass roof.

Figure 16: Miramas Athletics Stadium.

Figure 17: Julius-Hirsch-Sportzentrum, Fürth.

Figure 18: Auditorium of the CIRCA area, Auch.

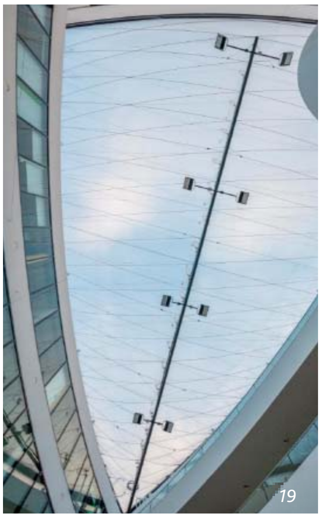


Figure 19: View from below of the Lilienthalhaus atrium roof. © www.hannokeppel.de
Figure 20: Lilienthalhaus: ETFE cushion with cable reinforcement. © www.hannokeppel.de

In his amazing lecture, N. Sidor presented projects with the rhetoric of the sustainability.

He stated 10 principles to save the planet:
1 More reuse, less waste. 2 More performance, less elements. 3 More volume, less mass.
4 More numbers, less rhetoric. 5 More heart.
6 More soft, less hard. 7 More renewable.
8 More storage, less leakage. 9 More inspiration. 10 More ingenuity.
His understanding of the application of these principles was illustrated with some projects, the most significant of which was the so called Sustainability Pavilion for the 2020 Dubai Expo (Fig. 21).

A great variety of special projects including sculptures and follies was shown by N. Imagawa, self-described as a surgical architect. He assessed them with his "Structural Energy of Material and Space Function" by categorizing, analyzing and summarizing the outcomes of more than 2,500 designs and comparing their efficiency until completion. He described the follies for EXO 90 (Osaka), the Mycal Sanda Pororoca Atrium and Roof Gardens (Sanda 1993), Kenneth Snelson's tensegrities and the hand crocheted huge net for 80 children (Fig. 22).

The textile façade for the Textil Akademie in Mönchengladbach, Germany, was shown by B. Stimpfle (Fig. 23). It is a pretensioned membrane and cable structure with valley and ridge cables. In order to allow the view from the class rooms to the outside, an open mesh material with 42% opening was chosen. This mesh is coated with silver PTFE, and gives a shiny surface to the project. The cables are the forming and load carrying elements which are vertically spanned along the façade. The development of the façade from the architectural concept to a shape that is suitable for membranes was explained, together with the supporting steel structure attached to the concrete wall, the almost invisible connection details, patterning process and the installation. More information on pages 26 and 27.

R. Canobbio described a difficult job at: "The tailored interior skin of Nuvola, Rome" (Fig. 24). Starting from a cloud (a true free form suspended in the air), a curved steel framework has been defined and enveloped by silicone coated glass-fibre fabric with an acoustic punch pattern to improve the sound absorption. At the request of the architects (M. & D. Fuksas) the joints were hidden in order that the surface is perceived as continuous as possible. The way to materialize the arbitrary shape consisted of slicing the cloud and define buildable sections in the yz, xz and xy planes. The final result was described by the speaker as "a cloud in prison". More information at TensiNews 32, p. 12-13 and DETAIL 4/2017, p. 32-39.

A. Angeleri showed the Auditorium 1919 Sacmi in Imola, enveloped by ETFE cushions (Fig. 25). The architects Di Fusco and De Rosa with Canobbio Textile Engineering took care of the executive design and construction of the cushions and their structural support. Particular attention was paid to defining the performance requirements of the ETFE cushions, their structural support and connections and the arrangements for the passage of technical systems. In addition, the performance characteristics of the materials was checked, particularly the determination of the thermal transmittance of the ETFE cushions performed by the Politecnico di Milano through the computational simulation "Optical and thermal characterization of a multilayer ETFE".

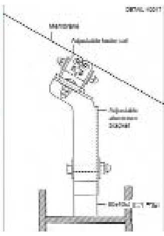
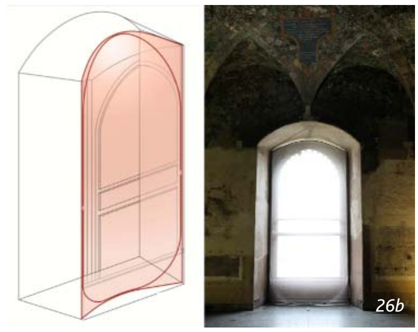


Figure 21a/b: Grimshaw Architects, Dubai Expo 2020: Sustainability Pavilion.
Figure 22: Hand-knitted net of various colours.
Figure 23a/b/c: Installation of the curtain-wall façade. Textil Akademie, Mönchengladbach. © a/b: formTL / c: thomasmayerarchive.de
Figure 24a/b/c/d: The "Nuvola". Believe it or not, the cloud, (fritter or potato) was built. Notice the adjustable hidden joints. © a/c : Studio Moreno Maggi / d: formTL
Figure 25a/b: EOSS Architettura with Canobbio, 2017: Auditorium 1919 Sacmi, Imola. © b: Studio Moreno Maggi

REFURBISHMENT

The previous TensiNet Symposium 2016 highlighted how membrane structures suit the preservation of architectural heritage requirements. Moving on, the visual and energetic comfort have been evaluated.

In "A tensile screen for the windows of Castello Sforzesco" E. Kolo presented an interdisciplinary methodology for implementing bespoke, low-impact, lightweight structures as additions to historical buildings with the aim of enhancing their performance in terms of visual, lighting and hygrothermal comfort. The study focused on the renovation of Sala delle Asse, one of the most relevant rooms of Castello Sforzesco in Milan. The design task was to produce self-standing vertical screens for the large-scale windows to reduce the amount of sunlight, as well as to block air drafts that bring humidity. The main challenge was the fragility of the context, since the borders of the screens had to be sealed without perforations in the vaulted edges of the windows. Thus, a textile-hybrid structure has been proposed due to its self-standing principle that would not require drilling on the vault (Fig. 26). An experimental campaign started by performing preliminary anemometric measures on the room and by modelling the luminance level based on the definition of the optical properties of the glazing surfaces. These analyses, combined with parametric simulations, gave results on the preferred position and optical requirements of the curtains.



R. d'Antonio addressed the possibility of managing the performance of historical buildings through the integration of membranes. The challenge was to predict the energetic behaviour of masonry structures combined with foils using dynamic simulation software, thus allowing the definition of the optimal technological configuration. The study focussed on a temporary membrane cover for the internal courtyard of the E. De Amicis School, a damaged and abandoned historic building in the city of L'Aquila (Fig. 27). The results have been relevant considering that the choice of membranes is often based on aesthetic and reversibility aspects whilst energy saving is not yet fully envisaged.

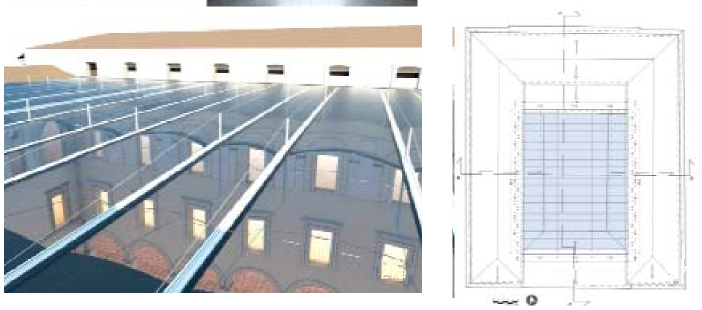


Figure 26a/b: First full-scale prototype installed in Sala delle Asse at Castello Sforzesco.
Figure 27: Temporary textile cover for the internal courtyard of the E.De Amicis School. 27a: Rendered image of the ETFE roof. 27b: Plan.

EMERGENCY SHELTERS

Given the growing need of emergency shelters and the adequacy of lightweight structures and soft skins, several papers addressed this issue. However, most did not assume the use for local materials and self-sufficient technology to avoid dependency and business.

D. Ledesma, from the Shelter Research Unit (International Federation of Red Cross and Red Crescent Societies) addressed the issue of anchoring emergency lightweight shelters (Fig. 28). Field tests have been conducted to address the question: 'what are the major aspects to consider using anchors in the humanitarian sector?'. Influence of soil, weather, type and combination of anchors, installation, orientation, inclination, depth, displacement and price have been measured. An extensive study of anchor usage, practice recommendations with step by step checklists and a handout for humanitarian field practitioners have been provided to identify the best anchoring option for their context of intervention.

S. Viscuso was concerned with providing shelter for progressive reconstruction with the "Multipurpose shelter - Type 2 (T2 MP)" (Fig. 29) designed and prototyped in the European collaborative project S(P)EEDKITS: http://www.textilearchitecture.polimi.it/multipurpose-unit.html. The T2 MP has a a covered area of $48m^2$, and a primary structure made of aluminium tubes with diameter of 35mm and thickness of 3mm. The envelope of the tent is made of three different parts: groundsheet fabric, tent fabric and shade net. The structural analysis revealed the limitations of the T2 MP in terms of compliance with both UNICEF targets and European regulation on temporary structures. So that further studies shall evaluate the use of different materials, (e. g. composite materials for the framework or for connectors), or more resistant aluminium to decrease the weight without losing the required safety.

N. Atawula demonstrated a design proposal for a refugee shelter that can be assembled in a few minutes without technical skills. It is based on a prefabricated "pneumatic sandwich" structure in such a way that a shaped "airbag" can be folded into very small size for storing

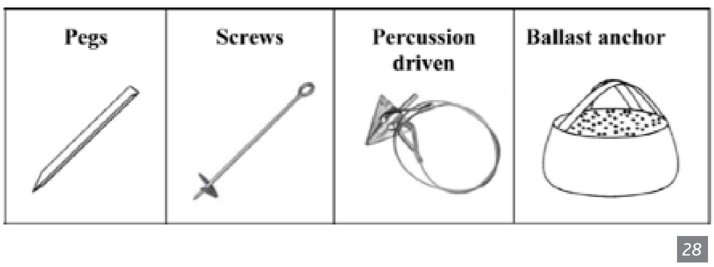


Figure 28: Low tech anchors for emergency lightweight shelters.
Figure 29: Multipurpose tent-Type 2 (T2 MP) developed in the S(P)EEDKITS project.

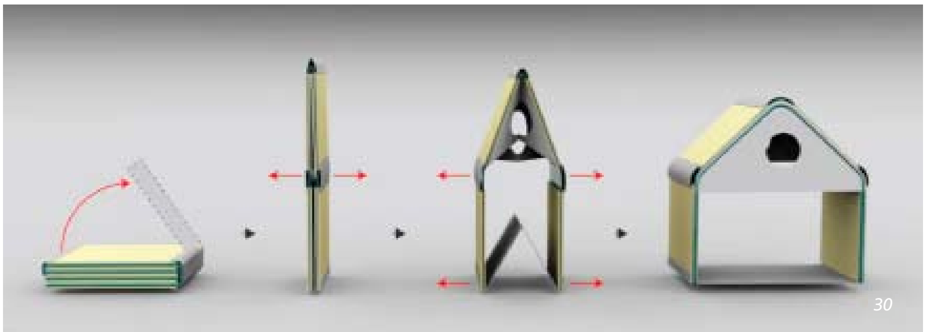


Figure 30: Refugee shelter with pneumatic structure: installation steps.
Figure 31: The FlexHab, an emergency shelter made with the new MadFlex composite material.

and transporting (Fig. 30). When needed, it can be set up by pumping air inside. The compression of the air and the tension of the envelope can support the structure itself. Lightweight timber panels are added to both sides to strengthen it. The main goal is ease of transport and quick assembly.

E. Teruzzi presented the FlexHab (Fig. 31), an application of MadFlex, a composite material panel with a sandwich-like structure. Thanks to its innovative mechanical features, the panel is flexible, even rollable, on one side and absolutely crushproof on the other. The preliminary analysis of different fields of application has shown the potential of MadFlex addressed to the critical context of disaster management for the construction of emergency shelters because it meets their specific requirements: adaptability to different weather conditions, reversibility, high performance, easy to transport, easy to storage, sustainability, affordability, flexibility and modularity, even though it is not a local material available on site.

EXPERIMENTAL PROTOTYPES

A fruitful session of the Symposium was devoted to experimental prototypes, many of which resort to active bending as a procedure to increase structural efficiency.

J. Lienhard addressed in "New hybrids" efficient solutions to respond to the challenges of today's architecture, discovering new fields of application for membranes. He defined hybrids as "a linkage of two parental systems of dissimilar nature into one coupled system" and highlighted the need for using computational capabilities to design complex geometries in a collaborative environment. He illustrated these concepts with a wide range of special applications, from academic exercises to exhibition pavilions, mobile surfing platforms and roofed motorways (Figs. 32 and 33). Changing the context, A. Rizzo showed the Manta Bay project: an above-ground textile pool composed of a tensioned membrane (PVC thermo-sealed) stabilized with the self weight of the water and held by a thin steel bracket that doesn't touch the membrane (Fig. 34). It is laid on a composed matchboard floor, an eco-friendly composite material, made with rice husk and virgin polymers. The design maintains the structure to a minimum size and the water always clean. It's easily used, maintained, installed and dismantled. The result is a shape typical of tensile surfaces never seen before in pools.

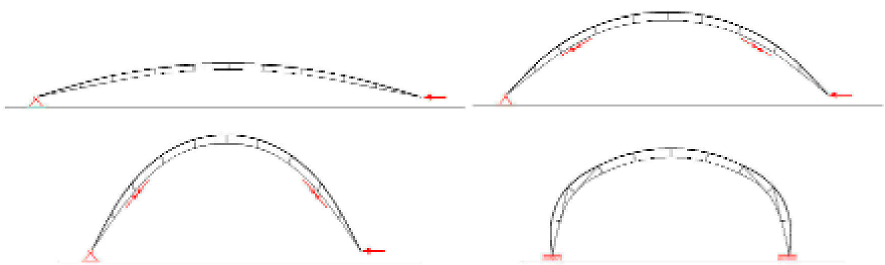


Figure 32: Textile hybrids at Hafencity University, Hamburg.
Figure 33: Danish Pavilion at the 16th Venice Architecture Biennale. (https://yuliyasinke.com/Isoropia)
Figure 34: The Manta Bay textile pool.
Figure 35: Politecnico di Milano, Textile Architecture Network, form TL & Canobbio, 2019: TemporActive Pavilion.
Figure 36: Bending sequence from the ground to the final geometry.
Figure 37: Restraining system made of stainless steel cables and turnbuckles and base.
Figure 38: Textiles are fundamental parts of architecture. J.Vermeer, 1659: "Girl reading a letter at an open window". Gemäldegalerie, Dresden.

C. Mazzola described the "TemporActive Pavilion", subtitled: "First loop of design and prototyping of an ultra-lightweight temporary architecture", another realistic presentation with added value, due to the opportunity of checking directly the prototype at the grounds of the University.
The "TemporActive Pavilion" is an ultra-lightweight temporary structure consisting of bending active GFRP arches, a restraining system made of stainless steel cables, and an ETFE translucent membrane envelope (Fig. 35) It was observed once again that both, the assembly procedure (Fig. 36) and detailing (Fig. 37), affect the behaviour of the prototype. More information on pages 24 and 25.

M. Ramsgaard dealt with the "Transformative Textile Architecture" research developed by the Centre for Information Technology and Architecture, Copenhagen. CITA is an innovative research centre exploring how the current digital culture impacts on architectural thinking and practice working through the conceptualisation, design and realisation of working prototypes. She mentioned two traditions for textile architecture: tents and lining of interiors (curtains and tapestry), that are part of the architectural scenario (Fig. 38), and looked for new ways to use textiles such as knitted fabrics, spacer fabrics, trans-materialisation, bespoke composite materials, hybrid structures, active bending, textile walls, substrates, sensors and, once again, the Hybrid Tower Project and the Isoropia (2018 Venice Biennale Pavilion).

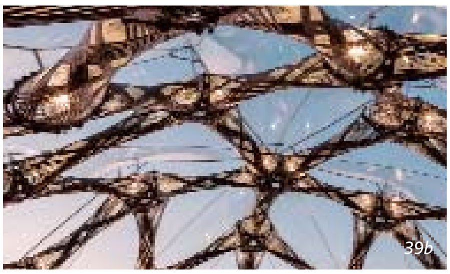


Figure 39a/b: Institute for Computational Design and Construction & Institute for Building Structures and Structural Design, University of Stuttgart 2019: BUGA Fibre Pavilion.
Figure 40: 3D panel generated by printing rigid 2D patterns onto flat pre-stretched fabric.

J. Knippers was worried about the current separation between design and construction through a linear organization that affects significantly the research development. Instead, Nature bases its design and construction principles on heterogeneity, adaptability, redundancy and multi-functionality. That's why he opted for the integration of all the actors involved, as a procedure to increase productivity, illustrated by the BUGA Fibre Pavilion, Bundesgartenschau, Heillbronn 2019. He demonstrated how combining cutting-edge computational technologies with constructional principles found in Nature enables the development of truly novel and genuinely digital building systems (Fig. 39). More information at: https://icd.uni-stuttgart.de/?p=22271.

T. Liddell in "Tension-actuated textiles for architectural applications" showed how dynamic 3D surface geometries may be generated by printing rigid 2D patterns onto pre-stretched fabric (Fig. 40). The resulting surfaces have aesthetic and structural properties similar to adaptable skins found in nature and, if scaled up, could bring a new degree of softness and adaptability to the built environment. They exhibit complex double-curvature and the final shapes are affected by the material elasticity, bending resistance and ambient temperature. although the principal factor is the initial 2D print-pattern itself, in which small variations result in different surface curvatures. The link between 2D-input and 3D-output geometry has been explored and several designs developed with performative qualities such as incidental bending and snap-buckling. The proposed shape-making technique is among the few fabrication techniques capable of generating complex surface curvature without the need for moulds, formwork or manual labour.

RESOURCES AND EDUCATION

M. Tamke introduced the InnoChain ETN network (www. innochain. net), a shared research training environment that examines how advances in digital design tools challenge building culture enabling sustainable, informed and materially smart design solutions. The network aimed to train a new generation of interdisciplinary researchers with a strong industry focus that can effect real changes in the way we think, design and build our physical environment.

R. Roithmayr approached the teaching of membrane architecture based on the Master's Program for "Tensile Membrane Structures" taught in the Danube Univesity, Krems, (https://www. formfinder. at/masters-program/) and the "formfinder" database/communication platform and glossary that includes case studies, products, experts, companies, impressions, map and types, available at https://membrane. online and https://www. formfinder.at/glossary-tag/ (both consultable with formfinder login).

The Working Group 18 "Environmentally Compatible Structures" of the IASS was represented by P. Vegh. Its mission is to cover the basic theoretical design problems associated with Environmentally Compatible Structures (ECS): "All buildings, structures, infrastructures, reconstructions, their use, materials and connected technologies, which minimize their environmental impact or contribution to outdoor and indoor environmental pollution during the whole life-span of the structure". https://iass-structures. org/WG18-Public

OTHER ACTIVITIES

Apart from the reported lectures, three other sessions were held in parallel:
• Design and simulation of soft structures;
• Performances and reliability of soft materials and
• Soft skins for the built environment for which the author refers to the **proceedings available at** the TensiNet website.

Other activities offered during the Symposium included the exhibition "In. tension", focused on the current changes in the field of tensile architecture and experimental prototypes scattered all around the campus, (especially the TemporActive Pavilion), the Open Talk, the TensiNet Partner Meeting, and, of course, the sumptuous conference dinner served at the Castello Sforzesco.

Josep Llorens
ETSAB/UPC

Milan, Italy

TemporActive

AN ULTRA-LIGHTWEIGHT TEMPORARY PAVILION

The TemporActive pavilion was installed for the first time in a pedestrian area in front of the Politecnico di Milano as Main Entrance Pavilion in occasion of the 6th TensiNet International Symposium 2019 "Softening the Habitats: Sustainable Innovation in Minimal Mass Structures and Lightweight Technologies", held at Politecnico di Milano from the 3rd to 5th June 2019 .

TemporActive is a temporary structure designed by the Interdepartmental Laboratory on Textiles and Polymeric Materials Research - TextilesHub of the Politecnico di Milano which oversaw the design and technical coordination of the project in collaboration with the engineering office formTL, responsible for structural design, and the company Canobbio Textile Engineering, responsible for engineering, manufacturing and installation. The pavilion experiments the combination of ultra-lightweight GFRP bending active arches, a restraining system made of stainless steel cables and a transparent membrane envelope. It consists of 2.00x7.00m self-supporting modules, reaching a maximum height of 3.50m, made of double-wing shape restrained arches that are designed to be structurally efficient and extremely lightweight, weighing only 50kg each. During the TensiNet Symposium 2019, seven modules were built in a tunnel-shape configuration, covering a footprint area of 100m².

Project description

The hybrid bending active system is connected to the ground by a platform made of GFRP H-section beams with adjustable legs and suspended ballast. The structural profile consists in a bundle of three GFRP 26x19mm tubes connected together with stainless steel connectors folded in a triangular shape and a stainless steel cables restraining system located in the inner part of the arch that contributes to increase the overall stiffness. Seven struts per module, made of coupled GFRP tubes 26x19mm, are placed in the topper part of the arches. The envelope was realized with a PVC Crystal 500µm film, printed at the top with two different patterns. Numerical form finding and structural analysis using the dynamic relaxation method (according to EN13782 - Temporary structures) were performed to verify the structural behavior of the ultra-lightweight structure.

Installation procedure

The pavilion was designed as an ultra-light bending active construction system, whose design and installation followed an experimental process aimed at testing a simplified and quick installation method for temporary architectures and, hence to promote multiple reuses.
The expertise of professionals specialized in the field of textile structures such as Canobbio Textile Engineering and formTL enabled to optimize the technical details and the installation procedure, allowing the assembly and disassembly of the structure in just three days. No high forces are necessary to bend the arches and to tension the restraining system, therefore no strong construction machineries were required for the installation. Given the innovative nature of the installation system, a construction workshop was organized for educational purposes the week before the conference. During the workshop, a group of students of the master's degree course "Design of Ultra-lightweight Building System (DULBS)" held by prof. Alessandra Zanelli at the Politecnico di Milano was trained to contribute to pre-assemble part of the structure. The assembly and disassembly activities were carried out by two teams of specialized installers: one who assembled the reversible platform that constitutes the basement of the structure and the other who handled the installation of the main structural system and the envelope. The erection procedure consisted in pre-assembling the straight arches with the un-tensioned restraining system on the ground and then bending the structural profiles, tensioning the inner cables and fixing the PVC Crystal membrane (Fig. 1).

Next steps

The temporariness of the project, mounted for few days/months and then disassembled, calls for a reflection on how encourage the reuse of the whole building after the first usage, in an environmental sustainability perspective.

Figure 1a/b/c. Erection of the pavilion.


Figure 3. Construction details.

An on-going doctoral research at the Department of Architecture, Construction Engineering and Built Environment (DABC) at Politecnico di Milano is investigating innovative and sustainable strategies: on the one hand, to lighten the structure and materials of temporary architecture; on the other hand, to apply a time-based and disassembly-oriented design approach, making feasible and cost-effective the multiple cycles of service life of a temporary membrane structure.
Further investigation deals with: a) the monitoring and implementation of the membrane skin for a longer service life (3-12 months, instead of 3 days of the first use); b) to measure the structural and environmental thermal and optical performances of the pavilion in order to validate the numerical models.


Figure 2a . Lateral (day) & 2b: frontal (night) view of the pavilion.

Round-Robin Exercise on temporary architecture

TemporActive pavilion is available to be moved, re-installed, and tested in the field of the TensiNet Network. The design team is willing to evaluate purpose of reusing it in the European context, in the following months.

Name of the project:	TemporActive
Location address:	Milan
Client (investor):	Politecnico di Milano - TextilesHub
Function of building:	Exhibition pavilion
Type of application of the membrane:	temporary
Year of construction:	2019
Design, Project development and Management:	TextilesHub, Politecnico di Milano, Italy Structural design: formTL, Germany Engineering, manufacturing and installation: Canobbio Textile Engineering, Italy
Supplier of the membrane material:	Giovanardi
Material:	PVC Crystal
Covered surface (roofed area):	$100m^2$

Institutional Partners: Comune di Milano, Politecnico di Milano, TextilesHub, TensiNet Association

Technical partners and suppliers: Canobbio Textile Engineering (printed membrane), Creative Cables (electric cables and lighting system), Ferrino s.r.l (closing textile walls), Garelli Inox (stainless steel cables and clamps), Giovanardi (recycled yarns furniture's), Next Tape (innovative electrical system), TopGlass Industries (GFRP tubes and beams).

Alessandra Zanelli
Carol Monticelli
Carlotta Mazzola
TextilesHub POLIMI
www.textilearchitecture.polimi.it

FLOWING GARMENT

Mönchengladbach, Germany

A SHIMMERING SILVER GARMENT ATTIRES THE NEW NORTH RHINE-WESTPHALIA TEXTILE ACADEMY
THE TAILORING & STEEL SUBSTRUCTURE OF THE TEXTILE ENVELOPE WERE CALCULATED BY FORMTL

A tailor-made dress nestles around the newly constructed building of the North Rhine-Westphalia Textile Academy in Mönchengladbach. Even from a distance the shimmering silver garment gives the training school for the textile and clothing industry a strong presence on the campus of Lower Rhine College. It thus conveys the Academy's learning content outwards, bringing to life the varied applications of textiles. At the same time, the transparent, seemingly moving membrane stands in strong contrast to the clear geometry of the three-storey cube that it envelopes. The building, built by slapa oberholz pszczulny | sop architekten, comprises a central atrium, teaching rooms and administrative offices along with an assembly hall. All window surfaces therefore lie hidden behind the membrane and only the entrance area appears uncovered, welcoming students and visitors with its generous glass façade.

Figure 1. Tailored textile envelope covering the building with only the entrance uncovered © thomasmayerarchive.de

Concept

While at first glance the textile façade appears to move around the cube in a uniform undulating movement, the picture becomes apparent upon closer examination as all the panels of the flowing garment differ in their respective tailoring. The required dynamic effect of the cover therefore had a significant effect on the method of construction. In addition to this, the architects wanted a supporting structure that was as slim and inconspicuous as possible. Both these parameters demanded precise planning and close coordination between all those involved in the project: the formTL engineers, responsible for cables, the steel substructure and membrane, thus worked hand in hand with the construction companies. The basis for the pretensioned façade was formed by formTL's formfound membrane-cable structure developed with valley and ridge. As forming and load-bearing elements, the cables are spanned along the façade from top to bottom into the valley and ridge so that the cables share the loads caused by wind suction and pressure (Fig. 2).

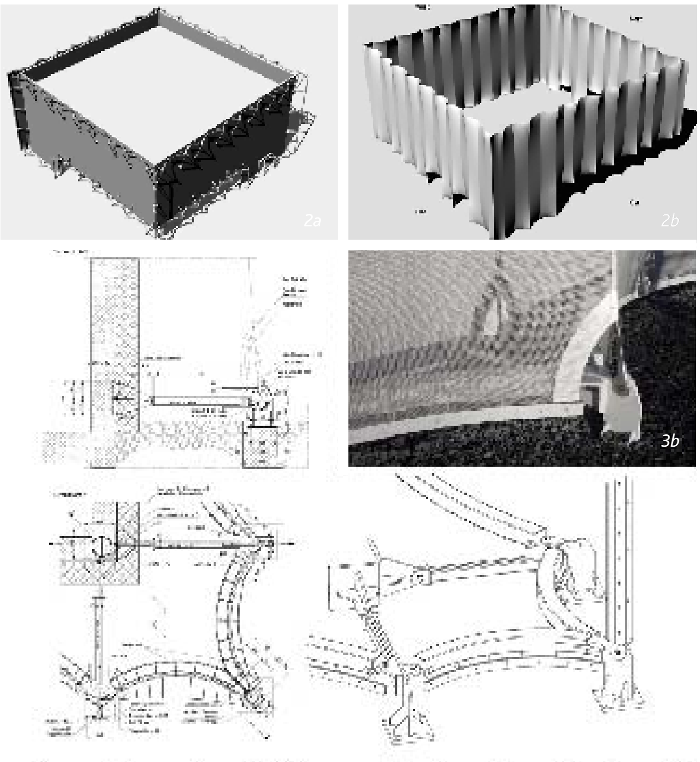


Figure 2a/b: Axonometry of the steel substructure and textile envelope © formTL
Figure 3a/b: Connection detail lower end drawings and picture © formTL

Designing the curtain wall façade skin

The approximately 2.100m² textile envelope consisting of individual panels undulates around the cube, alternating in front of and behind the cables. Both the cables and the membrane are fixed to a steel structure made from horizontal steel arches. Shaped from square hollow sections, the different curve radii lend a particular dynamic to the wave-shaped cover. At the top, they are anchored to the building by steel brackets and steel struts, the connections having hinged connections. The inclinded bracings were necessary guide to the load in the concrete structure in order to guarantee the stability of the curtain wall façade skin. At the lower end, the load is transferred directly into the floor plate and roof of the underground garage. Apart from the variously shaped panels of fabric and the sometimes large distance between the cover and the concrete structure, the penetration of the insulation on the exterior of the building also proved to be a challenge in terms of statics (Fig. 3).

Name of the project:	textile envelope for Textile Academy NRW
Location address:	Mönchengladbach, Germany
Client (investor):	Textilakademie NRW gGmbH
Function of building:	education
Year of construction:	2019
Architects:	slapa oberholz pszczulny | sop architekten, Düsseldorf/DE
Design, construction and approval planning, workshop planning for cables and membrane:	formTL ingenieure für tragwerk und leichtbau gmbh, Radolfzell/DE
Contractor of the membrane façade::	Koch Membranen GmbH, Rimsting/DE
Steel construction company:	Lamparter GmbH & Co. KG, Kaufungen/DE
Supplier of the membrane material:	Verseidag
Installation:	Montageservice LB GmbH, Hallbergmoos/DE
Material:	Steel: S355; Cables: Stainless steel spiral cables; Membrane: Verseidag B18909 GFM 4000-42 silver
Covered surface:	2.100m²

Figure 4. Minimising the visibility of connections, maximising the appearance of lightness © thomasmayerarchive.de
Figure 5. Night view © thomasmayerarchive.de

To give the garment an appearance as light as possible and to largely conceal the structure, the garment was not attached directly to the horizontal steel arches. Weld-on, curved steel strips form the visual terminator and enable the fabric panels to clamp elegantly and almost invisibly with clamping plates in front of the load-bearing arches. The welds of the individual panels are also barely visible they follow the vertically spanned valley and ridge cables. The cables have adjustable threaded fittings at their upper end with which the stiff fabric can be slightly readjusted. The fabric was structurally reinforced on the cut-outs membrane.

Day versus night

While during the day the building appears like a cloth-like form, even with a permeability of approximately 48 per cent, in the dark an exciting reverse effect manifests itself, for when the interior is illuminated, the variously sized window surfaces that are irregularly arranged across the façade come to light, creating a completely different and exciting look.

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BACTERIAL CELLULOSE BIOFILMS

a possibility for architectural membrane applications?

Architectural tensile membrane structures are temporary or limited-lifetime structures that are mostly made of composites with fossil-fuel based components (polyester, PTFE …) for which recycling is difficult. Considering the temporality of some structures, it becomes even more interesting to investigate grown and biodegradable alternatives.

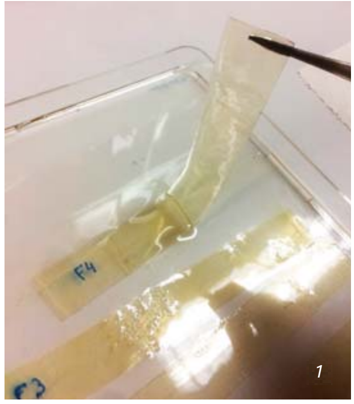

Figure 1. Retrieving samples after glycerol soaking © Bastien Damsin

The master thesis "Bacterial cellulose – New bio-composites based on bacterial cellulose for architectural membrane applications" by Bastien Damsin studied a methodology to couple biotechnological knowledge to architectural applications with a multidisciplinary academic and biohacking approach.
Bacterial cellulose, a sheet material grown at the surface of a culture liquid, is assessed for the first time in the light of an application as a structural membrane. The aim is to define whether bacterial cellulose could complement today's commonly used membrane materials.
A wide exploration of alterations of the plain material has been done with a focus on post-processing such as soaking, coating, heat pressing, creating composites and mixing.

The parameters are the growth temperature, the type of nutrients, the growth time and the post-treatments. In this research, self-grown cellulose biofilms are fermented by the bacteria *Komagataeibacter xylinus* at the surface of a liquid culture. While cellulose is mainly known as the structural component of plant tissues, some aerobic bacteria are also able to produce cellulose from a wide range of carbon and nitrogen sources. A pellicle of intertwined cellulose fibrils is created wherein the bacteria are embedded. When a sufficient thickness (about 0.05mm) is reached, the sheet is harvested and cleaned. As a general comment it must be specified that a uniform thickness is difficult to be achieved. Finally, the sheet is dried. The result is a pure cellulose biofilm without hemicellulose, pectin and lignin like in plants. It owes its high strength to a high purity, a high degree of polymerization and high crystallinity. A total of twenty-five different processing methods was tested.

Three alterations of bacterial cellulose were able to improve the strength of the sheet.
For each processing method 4 samples were tested to measure the tensile strength. The lowest strength per 4 tests was retained as '5%-fractile' value.
The bacterial cellulose samples soaked in a cross-linking agent Ethylene Glycol achieve a tensile strength of 2.6kN/m, the samples soaked in Ethylene Glycol Choline Chloride 3.3kN/m and the glycerol soaked 3kN/m. To obtain values comparable to currently used coated fabrics a higher thickness must be produced.
Experimental materials were also tested with respect to water absorbance, by placing samples in a water-filled plate. The weight of the samples before the test and after 48h was measured.
The coatings with beeswax and the heat pressing treatment reduce the value of absorbed water by respectively 28% and 38% after 48h, compared to the 102% value for the reference sample. A total water repellent material is not yet reached.
Also, the approach to make strong connections, has to be further researched.

Once the properties based on the testing of small samples are satisfying, the upscaling of the production process has to be considered.

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Figure 2. Tested samples © Bastien Damsin
Figure 3. wet sheets placed together and dried © Bastien Damsin

TECHTEXTIL STUDENT COMPETITION 2019

© Messe Frankfurt GmbH - Techtextil

In 2019 the Techtextil Competition for university students and young graduates has now been held for the fifteenth time. Competition works from the most diverse fields from all over the world were submitted. The range and variety of subjects in the total of work submitted was very high and covered inter alia material applications, building designs, usage concepts, environmental solutions, and assembly and construction concepts. At its session on 4 March 2019 the jury, totalling 6 members with Professor Stefan Schäfer as Chairman, awarded prizes out of all submissions to a total of 6 works in 4 different categories:
Micro-architecture, Macro-architecture, Urban Living – City of the Future and Material innovations.

You will discover a detailed evaluation of all prize-winning works on the TensiNet website https://www.tensinet.com/index.php/activities-networking/techtextil-student-competition or https://techtextil.messefrankfurt.com/content/dam/messefrankfurt-redaktion/techtextil/2019/downloads/Techtextil-Studentenwettbewerb2019_Broschuere.pdf

The Bubble

For the category Macro-architecture the First Prize went to the project The Bubble. The text below was taken from the evaluation of the jury:
Typical of pneumatically supported buildings are usually a significant synclastic curvature and geometrically protruding access points in the form of air locks.
This project, "Bubble", is quite different! The concept impressed the jury through its innovative modification of traditional construction methods which use the pneumatic load-bearing principle. In terms of its shape the "Bubble" is actually not really comparable with a bubble, but rather appears as a cuboid with cushion-shaped neckings. This cuboid has a square-shaped ground plan and a height of about 4 metres. The access points are integrated elegantly into the geometry and only become effective when the cuboid is in "use", i.e. is under light positive air pressure. Attracted by the unusual structure, the visitors are literally "sucked" into the interior and enter the inner space through the vertical, slit-like openings.
The logic of the openings can be seen in the composition of the structure. The pneumatic system consists of 16 interior modules, which are complemented by 4 square corner modules and 16 rectangular edge modules. Each of the edge modules is recessed on one side. Through the prevailing interior pressure these recessed areas are just sufficiently pressed together to prevent any escape of the interior air. On the other hand, they can be easily pushed aside and allow the visitor to enter.
The interior reveals a unique aesthetic to the visitor: a multitude of vertical tensioning ropes is revealed as careful structural components which lend the body its cuboid shape. The tensioning ropes allow an individual adjustment of shape to be made.
By just pulling on them it is possible to manipulate the whole shape individually; a pleasant effect, encouraging play with the shape.
The project is the result of two years of research work within the framework programme of the European Architecture Students Assembly (EASA).
The prototype was made completely by hand.

The Bubble
Hugo Cifre, Universidad Europea de Madrid / Espacio La Nube
Miguel Angel Maure Blesa, Universidad Politécnica de Madrid
www.espaciolanube.com
Video link https://vimeo.com/242623173