TensiNews

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

REPORT

STRUCTURAL MEMBRANES 2019

PROJECTS

FROM AZERBAIJAN, CYPRUS, ITALY, JAPAN, SPAIN, SWEDEN, UK...

X-MADRID SHELL, MADRID © HÉCTOR GÓMEZ RIOJA

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contents

Edito

Dear Reader

I hope this finds you well. We are all struggling under the actual situation, not knowing how big the impact will be for us personally, as well as for our industry.

The idea of TensiNet became reality in 1999 as a proposal for a European research project, which ran till 2004. TensiNet continued the established network of experts of our industry under the wings of Vrije Universiteit Brussel. Last year we decided to get on our own feet, and to transform TensiNet into an international non-profit association.

This TensiNews was meant to be the first issue published by the new founded association, and we wanted to present this here. But due to COVID-19 the appointment at the notary to sign the deed of incorporation had to be postponed till next month.

I wish you all the best, stay healthy, and enjoy meanwhile this issue of TensiNews.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

Please verify if events hasn't been cancelled or been replaced by a tele-conference due to COVID 19 virus

Textile Roofs 2020 | *18 – 20/05/2020* | Berlin, Germany | **www.textile-roofs.com**

IASS *Annual Symposium and Spatial Structures Conference 2020 - Inspiring the next generation* | *24 – 28/8/2020* University of Surrey, Guildford, UK | **https://www.surrey.ac.uk/iass-annual-symposium-and-spatial-structures-conference-2020**

VIII Latin American Symposium of tensile structures | *30/09 – 2/10/2020* | Buenos Aires, Argentina | **http://www.latensored.org/**

International Conference on Advanced Building Skins | *26-27/10/2020* | Bern, Switzerland | **www.abs.green**

TensiNet Meetings

TensiNet WG5 eurocode – meeting *27/05/2020* | Afnor, Paris

"TensiNet and Friends" at Advanced Building Skins | *26-27/10/2020* |

Fig. 1: Harry as we knew him: passionately explaining to students how membranes work
Fig. 2: One of Harry's signature projects: the innovative and renowned Marquee-modules

Harry Buskes

Founder of Carpro, 19/12/1955 - 16/11/2019

An impressive man

If you have met him
You will not forget him
A centipede making plenty of plans
A creative mind that stimulates
Coming up with a multitude of original ideas
Weaving ingenuity with beauty
Always willing to learn
Always sharing his vast practical knowledge
And friendship

He appreciated what you were trying to reach
Working with him always added an extra dimension

A few months ago
He showed a model 'to do something with it'
It will remain a dream
And whatever could happen to it
It will always be elaborated with a lot of appreciation
Huge appreciation
For whom we miss

Marijke Mollaert, Niels De Temmerman and Lars De Laet, Vrije Universiteit Brussel

Fig. 3: Harry contemplating the behaviour of a test sample
Fig. 4: Beauty and simplicity designed by Harry with Maxime Durka (Sioen) and Marijke Mollaert (VUB) for Architect@Work

1

Figure 1: Prospective 3D render of the pavilion © Monica Armani Architects

Trento, Italy

ECONOMY FESTIVAL PAVILION 2016

The idea of a bespoke pavilion for the Trento Economics Festival

The first edition of the Trento Economics Festival has been organized for the first time in 2006 with the ambition of providing a link between economists and the general public through a series of events, meetings and interviews designed to make economics understandable to people from a different background. The first editions of the festival has been hosted using commercial temporary structures such as marques and commercial products able to provide a cost-effective protection from the weather.

After ten years, it became clear that the solutions adopted became inadequate to the size and reputation of the event which attracts famous international speakers and thousands of visitors every year. The numbers for the last edition includes 204 invited speakers and 114 events available in live streaming.

Autonomous Province of Trento asked to Monica Armani to design a pavilion able to meet the growing expectations and requirements. The result is an innovative concept based on a temporary architecture to be installed and disassembled in few hours and to provide an identity to the international event. After the successful collaboration for the engineering and detailing of the pneumatic façade of the RCS pavilion for EXPO 2015, Monica Armani, Maco Technology srl and the University of Nottingham joined their experience in this field to develop an innovative concept based on rigid loadbearing portals and a pneumatic envelope.

Design concept

The design concept developed by Monica Armani is based on a construction system traditionally used for saw-tooth roofs and adapted to the temporary architecture in order to provide a practical way to create modular structures with accurate details obtained by means of a competent mix between technical innovations and building materials linked to the local traditions and to innovative manufacturing companies. The architect successfully designed a large design object which became a “special place” to be used to present people and stories to the public in the beautiful landscape of Trento and its province. Originally designed for the Trento Economics Festival 2016, the pavilion is currently used to host several other cultural events across the entire year.

The peculiar design is characterized by a set of timber portal frames linked to the local timber industry and by saw-tooth roofs and inflated membrane cladding inspired by the alpenglow which paints the Dolomites with a reddish glow after sunset or before sunrise.

The pavilion is the last achievement of the project TEMPO, a collection of products, exposition stands and buildings designed by Studio Armani for temporary applications in order to address the contemporary trends in architecture characterized by rapid social changes with the consequent rapid evolution of the users’ requirements which hardly fit the traditional approaches in construction.

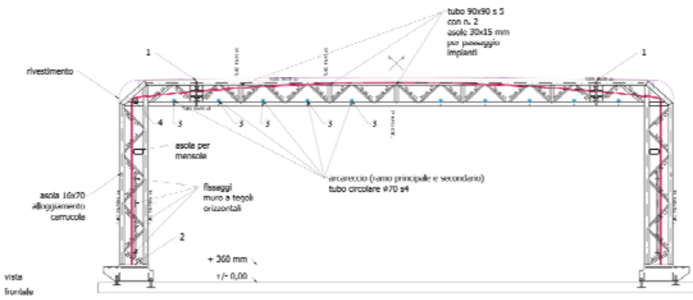
Load bearing structure

The structure has an overall cuboid shape which measures 11,84mx24,72m in plan with a maximum height of 4,16m. The seven loadbearing portals are arranged on an orthogonal grid and maintained at a prefixed distance (5.12m) by means of a set of purlins.

Each portal measures 11,84mx4,16m and it is made of a steel truss realized with steel (S275) square hollow sections welded together and reinforced with steel plates 10mm and 15mm thick. The top and bottom cords are obtained using a profile 90mmx90mm with a thickness of 5mm, the diagonals are made of a profile 30mmx30mm, 3mm thick. The portals are connected to the basement through pinned connections aligned with the orthogonal direction of the structural grid in order to help the installation of the portals which are assembled at ground level and then lifted from the horizontal to the vertical position. The steel trusses are cladded with a timber finish with a thickness variable between 15mm and 20mm.

There are 24 purlins in total, 4 between each pair of portal frames. Each purlin is obtained using steel hollow circular tubes (∅101,6mm, 5 and 6mm thick; ∅70mm, 4mm thick) and has a peculiar Y fork at each end designed to increase the lateral stability of the structure.

The lateral stability is also increased by a set of sandwich panels made of timber (20+54+20mm) bonded (polyurethane adhesive) with corrugated metal sheets (A55-P770-G6 HI-BOND 0,8mm thick) placed along the longitudinal lateral walls.



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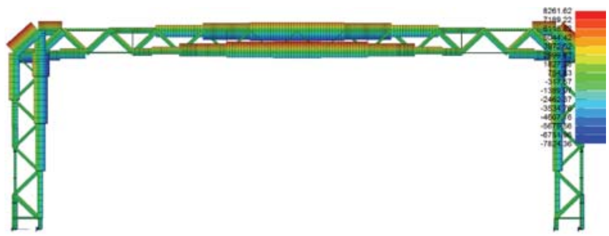

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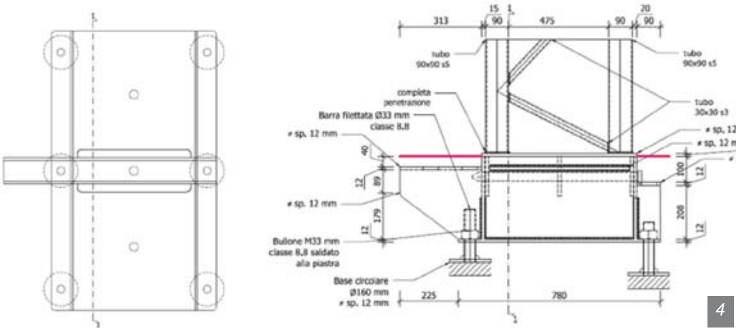
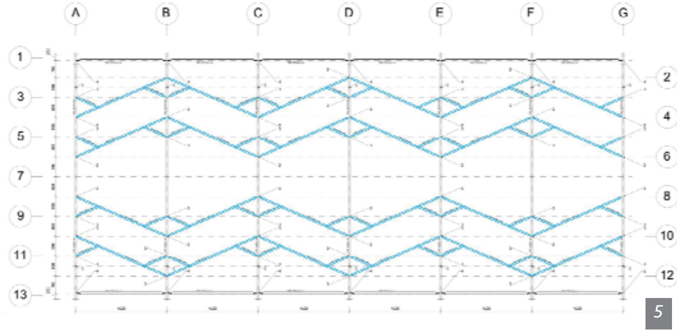
Figure 2: Cross section of the loadbearing portal frame © Monica Armani Architects.
Figure 3: Axial stress distribution in the loadbearing portal frame © Maco Technology srl.





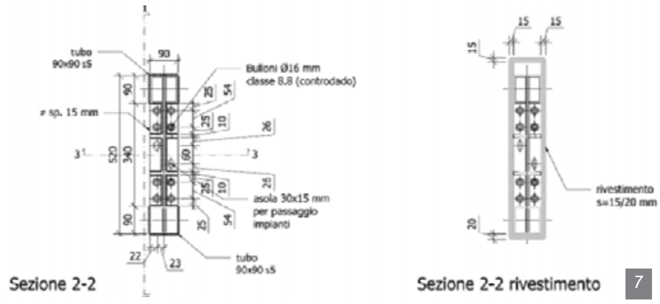


Figure 4: Detail of the connection between the portal frame and the basement
© Monica Armani Architects.
Figure 5: Plan view of the pavilion and arrangement of the purlins
© Monica Armani Archi tects.
Figure 6 a/b/c : Inner environment and external membrane cladding of the pavilion
© Monica Armani Architects.
Figure 7: Detail of the cross section of the loadbearing steel truss cladded with a timber finish
© Monica Armani Architects .

Basement

The structure of the pavilion is connected to a rigid modular basement made of a primary rigid orthogonal grid of steel hollow sections (90x90mm, 3mm thick) and by a secondary grid made of extruded aluminium profiles (110x80mm, 2,5mm thick). The floor is made of timber panels 40mm thick carried by adjustable supports (Ivica "ETERNO" SE6). The load of the structure is transferred to the ground through adjustable supports designed to spread le vertical load and to accommodate the ballast (steel plates or flexible water bags). It has been estimated that the stability against wind can be achieved with an additional weight equal to 1224daN to be added at the two ends of each portal.

Inflated envelope

The envelope of the pavilion is based on a double layer inflated cushion. The external layer is made of a PVC coated polyester fabric Précontraint 502 Serge Ferrari®, the internal layer is made of VINITEX 9x9, a PVC foil reinforced with polyester yarns. The stability of the cushion is provided by the internal pressure (approx. 220Pa). The cushions are attached to the loadbearing structures through a structural flap along the high points and by means of an aluminium keder rail along the low points. The combination of the two materials creates a peculiar effect in the inner space of the pavilion. The almost transparent VINITEX membrane makes the volume more spacious and airy and provides a nice reflected light from the spotlights oriented towards the roof. The external coated fabric provides protection from the direct solar radiation during the day and creates an eye catching effect for the visitors approaching the pavilion from the square. The colours have been carefully chosen to match the historic context and are inspired by the reddish glow of the alpenglow.

Transportation and installation

The pavilion has been designed to be fully manufactured off site and transported in small components designed to fit the standard sizes of the trucking industry. Each portal is made of 5 components, two pinned joints for the connection to the basement, 2 vertical truss columns and one truss beam connected each other with bespoke joints. Each beam is assembled at ground level and lifted thanks to the movement allowed by the pinned joint. The first portal is connected to the second portal with the purlins becoming a rigid support for the additional modules. Once the structure is complete, the inflated envelope is installed, the cushion connected to the circuit for the pressurized air and inflated by means of a dedicated blower. The pavilion is then completed by adding the basement which includes a rigid structure, the ballasts, the adjustable supports of the timber deck and the final top finish.

Conclusion

This project is an example of how membrane structures are a potential answer to challenging requirements which include a distinctive architectural appeal, reduced installation time and costs, optimized weight of the components, reduced packaging volumes and limited environmental impact of the structure.

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www.macotechnology.com/portfolio/festival-delleconomia-di-trento/
www.monica-armani.com/temporary-architecture/product/pavilion-1/

Name of the project:	Pavilion Trentino
Location address:	Trento
Client:	Provincia Autonoma di Trento
Function of the building:	Exhibition Pavilion
Type of application of the membrane:	Temporary
Year of construction:	2016
Design, project development and management:	Monica Armani Architects
Engineering of the membrane roof:	Maco Technology srl
Material:	Serge Ferrari Précontraint 502, Giovanardi Vinitex 9x9
Covered Surface:	280m^2

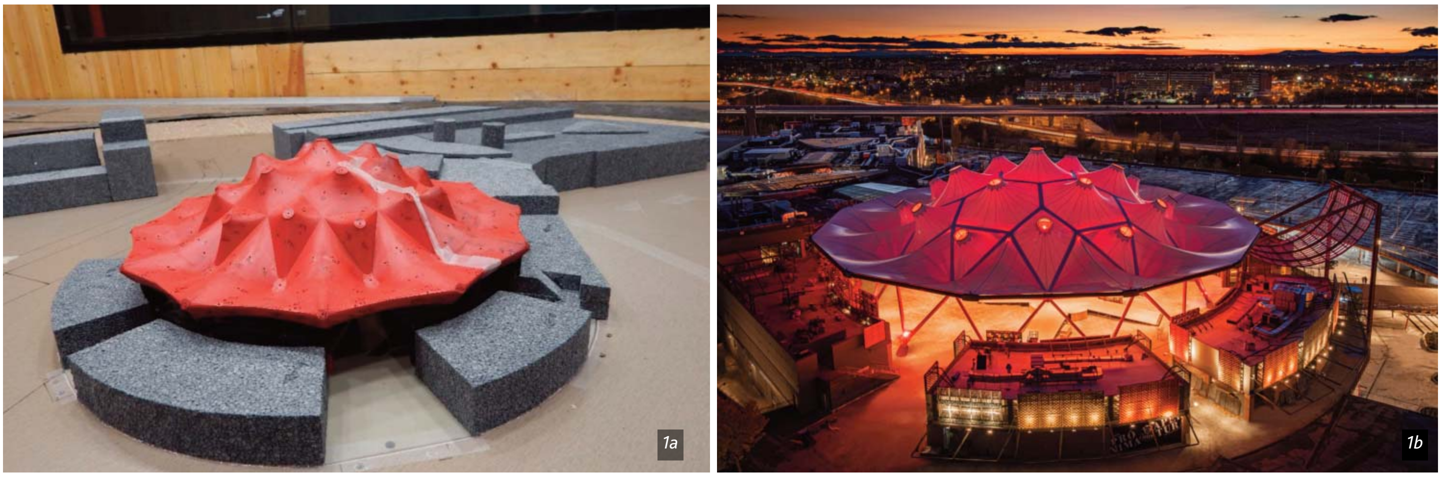


Figure 1. a/ Bird view of the scale model and b/realisation © Héctor Gómez Rioja

X-MADRID SHELL

A metropolitan agora

Madrid, Spain

The X-Madrid dome is a landmark in the Alcorcón metropolitan landscape and the icon of the shopping center refurbishment. For the covering of the main exterior space an explicitly enthusiastic form is designed, collecting the activity of a public square that is designed as diaphanous, permeable to the breeze and sifted light: a metropolitan agora.

This new centrality pole landmark is realised with a polygonal structure of steel beams and covered with a membrane of 75m in diameter and a free height of 25m, offering a leisure oriented technological aesthetic away from the plastic image traditionally associated with shopping malls (Fig. 1).

The continuous surface is a membrane formed by 19 conoids tensioned by flying masts and a continuous sinuous perimeter tensioned by cables. The polygonal structure of beams increases the valence of its nodes as it approaches the supports and globally approaches a spherical cap which includes a cantilever beam that acts like a ring beam and extends the membrane as a shed collecting the visitors from the perimeter buildings (Fig. 2).

The numerical model included both membrane and steel structure, where results from wind tunnel analysis where mapped (Fig. 3).

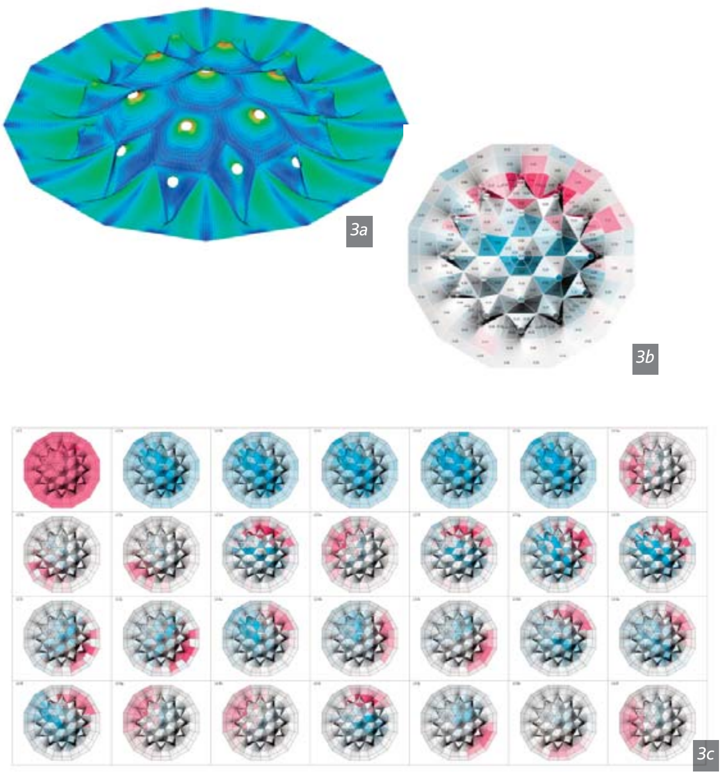


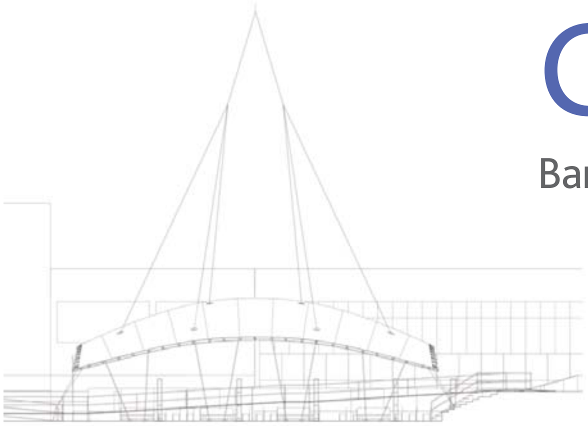
Figure 2 a/b. Canopy made of 19 conoids © Héctor Gómez Rioja
Figure 3 a/b/c. Numerical model of wind tunnel analysis © CODA

Name of the project:	X-Madrid Shell
Location address:	Alcorcón, Madrid, Spain
Client (investor):	Merlin Properties
Function of building:	Shopping center events area
Type of application of the membrane:	
Year of construction:	2018-2019
Architects:	B+R arquitectos, CODA, BEST, Arenas & Asociados
Multi-disciplinary engineering:	CODA, BEST, Arenas & Asociados
Structural engineers:	CODA, BEST, Arenas & Asociados
Consulting engineer for the membrane:	CODA, Arenas & Asociados
Main contractor:	Acieroid
Contractor for the membrane (Tensile membrane contractor):	Moñita
Supplier of the membrane material:	Ferrari
Covered surface (roofed area):	7848m^2

An ephemeral auditorium made of a double curved gridshell

CLOSCA

Barcelona, Spain


1a


1b

The commission was to build an ephemeral auditorium for the FADfest 2017 national architecture prize ceremony, providing the necessary infrastructure to celebrate 4 consecutive days of events with a total seating capacity of 900 people, among the best designers and architects in Spain.

Given the time and budget constraints, the constructive solution adopted was a doubly curved gridshell elastically formed from a flat grid of straight tubes. The location within an emptied lake for this occasion, determined that the structure had to be suspended from the crane used during erection (Fig. 1).

The grid was made with standard tubular GFRP profiles connected with rented free rotating scaffolding system swivel couplers. To lock the skewing, the cross in the middle were non-rotating couplers. Above the grid of tubes, a tailored membrane guarantees the weatherproof and light control required by audio-visual content (Fig. 2).

The main challenge was to find numerically and accurately, the stress state and final form that acquired the structure by self-weight, designing only the lengths of the cables .

The project developed entirely in-house was possible thanks to the integration of the calculation methods in a parametric modelling environment. The simulation was performed comparing two methods of nonlinear analysis: on the one hand dynamic relaxation (Kangaroo2 and K2e) and on the other, the matrix method (Wintess, developed by the partner Ramon Sastre). Both methods were calibrated with laboratory break tests and a full erection test was conducted to guarantee the coupling of numerical model with the physical model (Fig. 3).

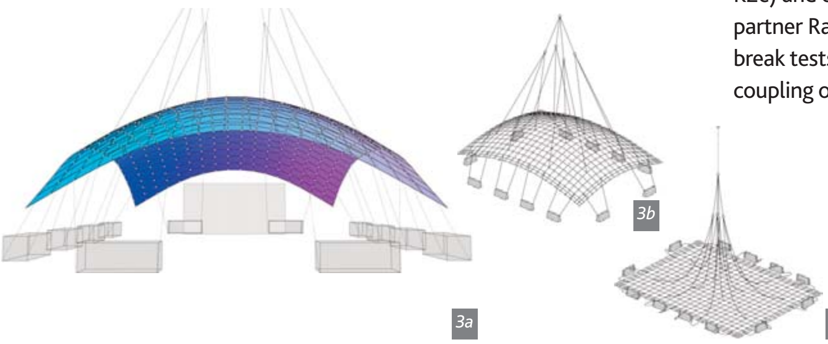

3a 3b 3c

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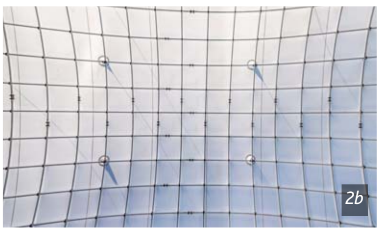
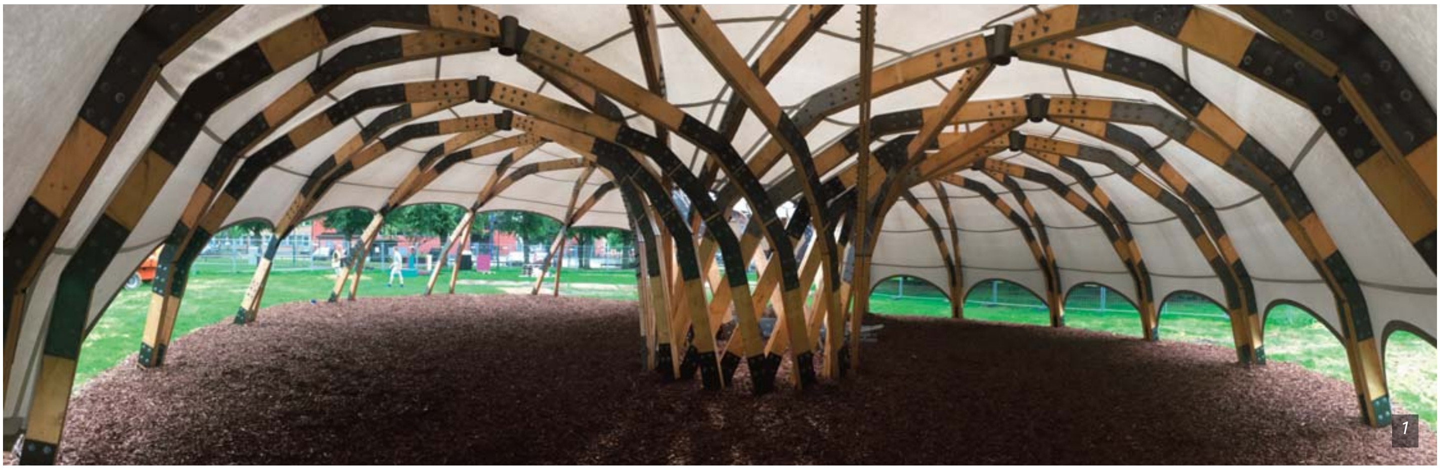
Figure 1 a/b. Drawing and installation of the curved gridshell © Andrés Flajszer
Figure 2 a/b. Underneath the gridshell © Andrés Flajszer
Figure 3 a/b/c. Numerical modelling © CODA
Figure 4. Construction detail © Andrés Flajszer


2a


2b


4

Name of the project:	Closca
Location address:	Barcelona, Spain
Client (investor):	FAD Foment de les Arts i Disseny
Function of building:	Ephemeral Auditorium
Year of construction:	2017
Architects:	CODA
Multi-disciplinary engineering:	CODA
Structural engineers:	CODA
Consulting engineer for the membrane:	CODA
Main contractor:	TP Arquitectura i construcció textil s.l.
Contractor for the membrane (Tensile membrane contractor):	TP Arquitectura i construcció textil s.l.
Supplier of the membrane material:	SIOEN
Manufacture and installation:	TP Arquitectura i construcció textil s.l.
Material:	B8301
Covered surface (roofed area):	432m²



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THE OPPORTUNITY SPACE PAVILION

Malmo, Sweden

An adaptable and inviting space for refugees and longtime residents of Sweden

Context

Launched in 2016, the "Opportunity Space" competition was set up to challenge designers to build a cost-effective yet dramatic temporary structure to house "programs supporting social and economic inclusion" particularly focused on immigration and the integration of refugees. Enticed by both the design challenge and the social plight, a New York based design team led by Rik Ekström of ARExA entered with their tensile fabric clad timber and steel pavilion and were thrilled to be announced as the inaugural winners.

Project team

Once awarded the project, the design team began to assemble a team who shared their vision and having worked previously with Rik Ekström in 2007 on the re-brand of the O2, London, Architen Landrell were the obvious choice to collaborate with on the tensile membrane.

Simplify the design and installation

The design team, including AREXA and engineering company Walter P. More, alongside Main Contractors, Skanska, began to rationalise the scheme as much as possible to ensure that the pavilion could be installed on site by a team of volunteers and to keep the costs down. The structure was carefully modelled and analysed in Rhino; designers worked to limit the number of variations in the timber profiles ad steel plates in order to minimise the number jigs required to produce the structure. The connections and joints were kept as simple as possible, using off the shelf components, basic nuts and bolts, bungee cables and the like.

For Architen Landrell, the complex shape Rik Ekstrom wished to create using the glulam structure proved a challenge for a design team whose goal was to keep costs and installation simplicity to a minimum. "*We had worked on a project for UK TV station Channel 4 several years before where the*

DENKA

The CLT PARK HARUMI Pavilion

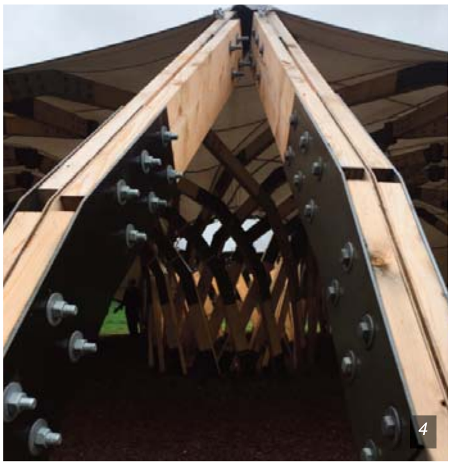
A HIGH PERFORMANCE FLUORIDE FILM TEFKA® ADOPTED FOR ARCHITECTURAL MEMBRANE STRUCTURES.

Tokyo, Japan

Figure 1. General view of the CLT PARK HARUMI Pavilion has adopted TEFKA®

Denka Company Limited adopted their TEFKA® high performance fluoride film to be use in the CLT PARK HARUMI Pavilion, an event facility under the supervision of renowned architect Dr. Kengo Kuma. This pavilion is the symbol of CLT PARK HARUMI that stands at the heart of the facility. It is a relaxation space with an artificial lawn that is usually open to public. In future, it will be leased to tenants organizing a diverse array of events.

So for this project Denka has been working to extend the applications of their film product to architectural membrane structures. TEFKA® is a copolymer film made of ethylene and chloro-trifluoro-ethylene (ECTFE)[1] not only with high transparency and light transmissivity either equivalent to or more than glass but also superior weather resistance, flame retardancy, secondary



membrane was required to 'breathe'" said Amy Richardson, Head of Sales. "A fan was used to inflate the membrane form and then suck it back to its original form like a living organism, and for that we needed to use a material with a good degree of elasticity and the ability to withstand the external environment. Drawing on our experience there, we settled on using a polyurethane coated nylon (most commonly used for hospital bed coverings) which could stretch and adapt to the 3D form of the timber structure".

Using a stretch membrane allowed Architen Landrell to fabricate a single membrane which could be evenly tensioned without the need for specialist trained staff or equipment. Time did not allow for a survey of the timber structure or a test-build but the structure had been modelled in 3D using Rhino, so Architen Landrell were able to accurately pattern the membrane to fit the complex form. Once fabricated, the tensile fabric cover was shipped to Malmo and installed under the watchful eye of Architen Landrell's experienced Project Managers.

The tensile membrane structure at Opportunity Space offers both architectural beauty and a socially progressive space; hosting a range of workshops, programme and activities designed to help both refugees and residents of Sweden to learn new skills, find jobs and make connections. It was important to Rik and the team that the space would be adaptable and inviting. By day it's open sides and bright atmosphere are welcoming and intriguing, and by night the gentle glow of lighting on the membrane turns it into a gathering space where all types of people can mingle.

Figure 1. An hosting space made of a glulam structure covered by one single stretch membrane © Architen Landrell
Figure 2. Bird view © ARExA, Rurik Ekstrom and Associates LLC
Figure 3. Bird view - detail © Architen Landrell
Figure 4. Construction detail © ARExA, Rurik Ekstrom and Associates LLC
Figure 5. 3D modelling with Rhino © Architen Landrell

Amy Richardson, Architen Landrell
Amy.Richardson@architen.com
www.architen.com/

Name of the project:	Opportunity Space Pavilion
Location address:	Enskifteshagen Park, Malmo, Sweden
Function of building:	Temporary pavilion
Year of construction:	2017
Architect:	ARExA
Engineer:	Walter P Moore
Main contractor:	Skanska
Tensile membrane contractor:	Architen Landrell
Supplier of the membrane material:	Dartex Coatings Ltd
Material:	P098S
Covered surface (roofed area):	230m²

processability, developed out of a long-term-accumulated Denka's fluoride film production and processing technologies. It is the first of Denka's products to be adopted for structures using cross-laminated timber (CLT) which is a wood-based material created by laminating and bonding wooden boards in a way in which their grains are orthogonally crossed.

Figure 2. The TEFKA® film is used between CLT wall panels

Architect Dr. Kengo Kuma described this new material as follow: ""TEFKA® is lighter than glass and so pliable as to be rolled to transport it. It is ideal material for relocation and reconstruction. It also has the perfect transparency we have sought."

Takaaki Kino
takaaki-kino@denka.co.jp
www.denka.co.jp/eng/

[1] ECFTE, an ethylene and chlorotrifluoroethylene copolymer, is one of the fluoride resins.

Name of the project:	CLT PARK HARUMI Pavilion
Location address:	3-2-15 Harumi, Chuo-ku, Tokyo, Japan
Client (investor):	Mitsubishi Estate Co., Ltd
Function of building:	Exhibition facility
Type of application of the membrane:	Façade by single layer
Year of construction:	2019
Architects:	Kengo Kuma and Associates
Multi-disciplinary engineering:	Mitsubishi Jisho Sekkei Inc.
Consulting engineer for the membrane:	TRA·K Co., Ltd.
Main contractor:	Mitsubishi Estate Home CO., Ltd.
Contractor for the membrane (Tensile membrane contractor):	TRA·K Co., Ltd.
Supplier of the membrane material:	Denka Co., Ltd.
Manufacture and installation:	TRA·K Co., Ltd.
Material:	ECTFE film
Covered surface (roofed area):	500m²

STRUCTURAL MEMBRANES 2019

IX International Conference on Textile Composites and Inflatable Structures

The "Ninth International Conference on Textile Composites and Inflatable Structures" was held in Barcelona in October 2019 together with the IASS Symposium 2019. It was organized by the International Centre for Numerical Methods in Engineering (CIMNE) and was chaired by E. Oñate (UPC), K. U. Bletzinger (TUM) and C.Lázaro (UPV). It was the ninth of a series of symposiums that originated in Barcelona in 2003. The next session will be held in Munich in 2021.
https://congress.cimne.com/Formandforce2019/frontal/default.asp

At the four-day conference, 15 plenary lectures and 593 presentations in 114 sessions were given to 887 registered participants. The wide range of topics that were covered included from the design to the realization of (almost) all kind of structures and materials with a special concern for environmental aspects. Structural membranes were the subject of a number of dedicated sessions:

- Membrane materials
- Conceptual and parametric design
- Structural morphology
- Form finding
- Analysis. Computational methods. Numerical methods and modelling
- Wind engineering and fluid-structure interaction.
- Optimization
- Manufacture, detailing, installation, realizations
- Inflatable, pressurized membrane structures
- Adaptive, deployable, transformable lightweight structures
- Bending active systems
- Tensegrity systems
- Environmental compatibility and life-Cycle
- Teaching and education

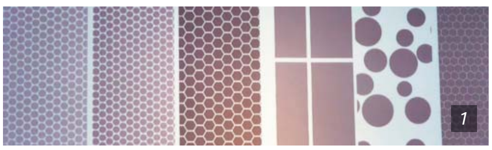
It was not possible to attend all presentations (they were held in 12 rooms at once!). Nevertheless, they can be downloaded at: http://congress.cimne.com/formandforce2019/frontal/doc/Ebook2019.pdf

MATERIALS

Almost all the materials used in membrane architecture were mentioned but, as usual in the last meetings, ETFE was frequently referred to. Sophie Gledhill, from the Fraunhofer Institute for Solar Energy Systems, addressed ETFE coatings to improve its performance. ETFE cushions have low thermal insulation and high solar transmission to which spectrally selective coating solutions can be applied resorting to low emissivity and solar control. Dr. Gledhill explained the challenge of applying this technology and presented the sputter system and lacquered layer that have been developed and tested in realistic conditions with flaws, weld-seams and joints, identifying a suitable lacquer for flaws which occur in cushion construction. She announced a 1x1m demonstrator ETFE coated cushion under development.

Carl Maywald from Vector Foiltec went also into improvements of ETFE by coating including ink, intensity and geometry (Fig. 1). He provided a brief introduction into the development of coating and printing on ETFE in particular, as well as an introduction into different techniques for solar shading of ETFE cladding systems in architectural buildings. He stated that a well-balanced relation between adhesion and cohesion is a fundamental requirement because the pigments have to remain stable on the foil surface even under conditions of multiple cyclic deformation. In order to allow for quality assessment of these coatings taking into account elastic and plastic deformation of the target material, he introduced a new test procedure for coated ETFE.

Katja Bernert from Low and Bonar expanded the concept of smart fabrics beyond sustainability. She highlighted the merits of fabric meshes as lightweight materials because they are apt to wrap buildings at a fraction of the material need for other aesthetical enclosures as stone or aluminum façades. Savings in weight, hence sub construction and material consumption are smart in terms of sustainability. But she also considered that actual smartness is evolving towards a fabric as a matrix for all sorts of applications, ranging from leading electricity through its veins to supply lighting. She gave a brief introduction regarding the interrelation between material science and design of smart fabrics and focused on recent material developments and their input for actual projects. With a variety of today's applications (Fig. 2) she led to the conclusion that future research will deal with smart composite materials.



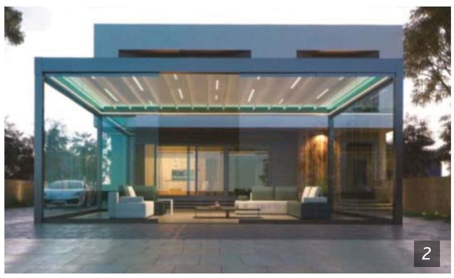


Figure 1. ETFE coatings. different print intensities and geometries (C. Maywald).
Figure 2. Valmex System: a coated fabric integrates tube-like bags to be filled with LED light strips, steel cables, insulation material or heating wires.

Hubertus Pöppinghaus from IF-Group dealt with reinforcement belts for textile structures. They are an important part of retractable/ transportable structures because they can be folded together with the membrane. But two shortcomings limit broader applications to all kind of structures: fixation techniques and appropriate stiffness. That's why a new weldable protected belt has been developed and tested comparing it with a standard pretensioned polyester belt (Fig. 3). The results expanded the knowledge in the field but still did not yet lead to a viable product for the market.

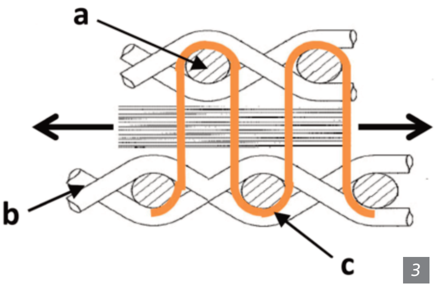


Figure 3. New Dyneema®-stem-thread-belt protected by PVC coated fabric in plain wave. a) PVC coated weft threads. b) PVC coated warp threads. c) Uncoated binder threads.

DESIGN

The bases of structural analysis for membrane structures were addressed by Nick Gibson from Tensys. Tensile structures are complicated 3 dimensional structural systems difficult to simplify into 2 dimensional problems to be solved by simple hand or numerical tools. They suffer large deflections which are outside normal building deflection limits. Their complex shapes require form-finding and detailed load distributions to be considered which might be derived from wind tunnel test or CFD analysis. In addition, they suffer large geometry deflections and reductions of prestress when supporting these loads. That's why the analysis tools must be able to accommodate large scale geometry changes, handle the characteristics of the materials and deal with the detailed review of possible water ponding. As a consequence, he asked for detailed studies before partial factors are set by the forthcoming Eurocode.

Tim Finlay from Buro Happold Engineering showed gravity stressed cable net stadia roofs starting from the transformation of the London Olympic Stadium and the delivery of the Education City stadium for the Qatar World Cup (Fig. 4). He exposed the development of a parametric matrix based design tool for form-finding of the system and its use in the development of design solutions for a Premiere League stadium. The particular challenge of finding the 3D equilibrium geometry for a system where the geometry of the elements is fixed on plan (as might be dictated by the stadia bowl geometry or architectural requirement) was described along with the non-iterative matrix based solution. The solution was implemented within Grasshopper for Rhino, a parametric visual scripting environment.

Dieter Ströble from technet compared and discussed a radial cutting pattern with the results of a parallel cutting pattern (Fig. 5) dealing with the two membrane envelopes of a double membrane system of biogas containers. Different scenarios, e.g. the situation under internal operating pressure and the situation under a gust of wind, were simulated. In the case of 'fast' loads (wind), the gas law applies and, in the case of rapidly occurring loads, it must be investigated whether the outer shell and the gas membrane touch each other. He also took into account the wind loads and the deformations in the iterations. The material properties were defined by warp and weft stiffness, including the so-called transverse and shear stiffness in order to simulate a realistic behavior in the radial or parallel directions. It turned out that the differences between the radial and parallel cutting patterns in relation to the size of the maximum membrane stresses were very small. This means that the parallel cutting patterns, which are much easier to produce, can be used in the future.

An optimum cutting pattern generation of membrane structures considering welded seams was the topic of Professor Yan Yang from the Shanghai Jiao Tong University. Using 2D displacements of the membrane elements as key variables, the proposed iterative method utilizes a geometrically nonlinear finite element analysis, based on the initial cutting patterns. The simulation of welded seams is integrated in the full cutting analysis and the deviations of stress and shape from the target values are minimized simultaneously. The numerical results show that the method achieves high accuracy of patterning and assembly.

In the closing session, Kai-Uwe Bletzinger from the Technische Universität München set out the role of simulation in design, noting the progress in the availability of numerical analysis. He dared to mention hot topics, most treated and pending aspects of the numerical simulation technologies. Parametric and interactive design, graphic statics, CAD/FEM/BIM integration, digital processes, optimization, form finding, reliability, sustainability, adaptability, material modeling, active bending, fluid-structure interaction, large deflections and complex modeling were mentioned among many others. He distinguished the requirements of low fidelity approaches for preliminary design options from those of high fidelity approaches for final design solutions.

TESTS and STANDARDS

Carl Maywald from Vector Foiltec drew attention to the need to characterize the structural behaviour of ETFE foil through biaxial tests. To date, the commonly used method for determining the ULS and SLS of ETFE foils in roof and façade structures is based upon mono-axial tensile strain and creeping tests, which only reflects one-dimensional properties of the ETFE material. However, in all roof structures, where inflatable ETFE-cushions have been used so far, membranes are exposed to biaxial stress. That's why he presented the results of biaxial tests to get the elastic and viscoelastic properties including the time constants for creeping (Fig. 6). He could conclude that biaxial hysteresis measurements show an enhanced elastic modulus after exposure to the first load cycle, saturation of plastic deformation for each stress level up

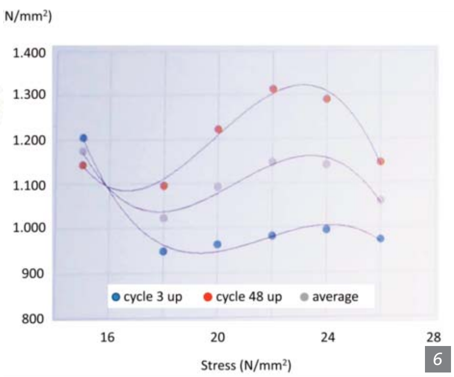
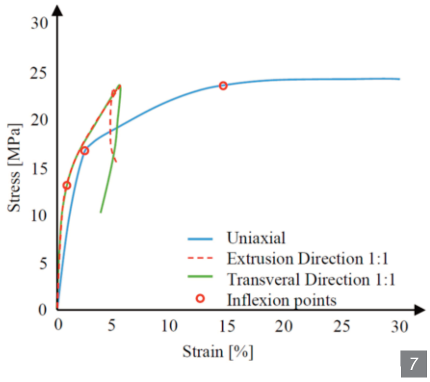


Figure 4. Fenwick-Iribarren Architects, 2019: Education City Stadium, Al Rayyan.
Figure 5. Radial (left) and parallel (right) cutting patterns.
Figure 6. Variation of biaxial E-modulus for 6 different foil stress levels.



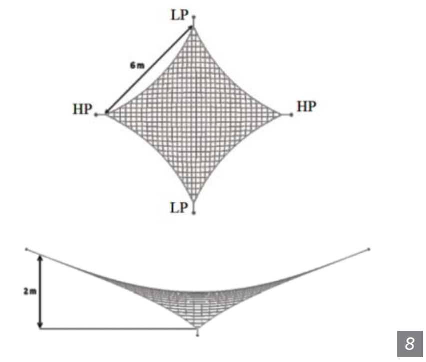


Figure 7. Comparison between uni- (1:0) and biaxial (1:1) material behaviour of ETFE foil (T=23°C, vT=100mm/min).
Figure 8. Top view and side view of the hypar membrane structure.
Figure 9. Richter Dahl Rocha & Associés, 2014: Swiss Tech Convention Centre, Lausanne.

to 24MPa, higher load capacity of cushions due to plastic deformation and the relaxation of foil after 1.000sec.

Testing ETFE foil was also the topic of Natalie Stranghöner from the University of Duisburg-Essen. She stated that uniaxial tensile tests are performed to determine the mechanical characteristics of ETFE. However, ETFE-foils show a different mechanical behaviour in uni- and biaxial tensile tests (Fig. 7). For this reason, she claimed that mechanical properties of ETFE-foils used in biaxial tensioned structures should be consequently determined in tensile tests under biaxial loading. That's why experimental investigations into the uni- and biaxial tensile behaviour of ETFE foils have been carried out applying certain load levels, unloading and measuring the resulting residual strains. The achieved knowledge will contribute to the current development of the Technical Specification for Membrane Structures.

Marijke Mollaert in "The calibration of the partial factors for the design of a typical hypar membrane structure" investigated an existing calibration method to obtain the partial factors to be used for the design of a typical hypar membrane structure (Fig. 8). The reliability analysis was performed using a First Order Second Moment method in combination with Latin Hypercube Sampling. The study was performed for the load cases snow load and wind uplift load. The conclusions state that the proposed method to perform the reliability analysis is applicable to other membrane shapes besides the studied hypar membrane structure, but further research is needed to find partial factors that can be used for a wider scope of membrane structures and more reference cases should be investigated.

Bernd Stimpfle formulated the obvious question: "Do we need technical specifications for membrane structures?". The affirmative answer is based on different reasons:

- it helps to increase the market
- it helps to minimize approval processes
- to have a technology as an established building technology and not only a niche market with high risk
- with harmonized safety levels, and commonly agreed quality standards, the quality of the industry is improved and doubts of clients are avoided
- all players respecting the same high quality standards will result in a fair competition
- to favour the integrated design of the membranes, avoiding their consideration as add-on cladding, neglecting their contribution. Two significant examples of the increase of costs involved in the independent treatment of the ETFE foil façades were the Allianz Arena and the Unilever Building.

"Monitoring forces in tension structural members of lightweight architecture" was the contribution of Martin Jenni from Pfeifer. He showed the Loadscan measuring system to enable simple, permanent and accurate check of tension forces in structural members such as cables or tension rods by the means of ultrasound technology for the detection of structural anomalies during the use of the structure and the management of proper maintenance. He illustrated it with the Swiss Tech Convention Centre of Lausanne (Fig. 9), where the shed roof is pulled into its correct position by two monitorized cables. If the tension in the cables were too low due to the snow load, an alarm would sound at the security office. In other cases, the installation could be closed or, in pneumatic structures, the pressure increased.

INSTALLATION

Under the general topic "Innovative solutions to practical problems", Thomas Hermeking from Pfeifer addressed the refurbishment of stadia that age and experience changes in regulations or rising requirements such as the sheltering of the spectators. He demonstrated that summer breaks in between the season schedules of professional sport clubs provide a tight but sufficient building period for refurbishment or even a new roof structure. He illustrated it with two examples: the 80 additional ETFE cushions (4.700m²) of the San Mamés Stadium roof extension (www.youtube.com/watch?v=xmiUA2mZkzA and Fig.10) and the Mercedes Benz Stadium 38.000m² roof replacement (www.youtube.com/watch?time_continue=2&v=bqmXfxQDR9k and Fig.11).

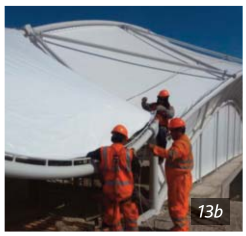
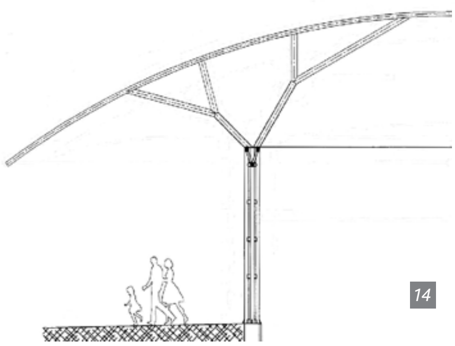


Figure 10. San Mamés Stadium roof extension process.
Figure 11. Mercedes Benz Stadium roof replacement
Figure 12. Jackson Architecture with Tensys, 2006: Royal Melbourne Showground's Grand Pavilion under construction.
Figure 13 a/b/c. "Polideportivo I.E.República Argentina", Chicote 2017. Installation of the central and side modules.

Peter Lim from Tensys showed the Royal Melbourne Showground's Grand Pavilion for agricultural show days, exhibitions, concerts, and other events, one of the largest tensile fabric membrane structures in the Southern Hemisphere (Fig. 12).
Its roof structure consists of a 13.250m^2 of high tensile PVC fabric subdivided into eight segments to enclose 98x84m^2 of indoor exhibition space. It is tensioned over six central conic masts topped with pinnacles that provide anchorages for internal rigging and access to high areas for lighting, sound systems and other services. The installation was based on the erection of the completed masts and pinnacles, which allowed to reduce the assembly time. The pavilion construction timetable allowed four months for steel fabrication and fabric procurement and four weeks on-site for support installation and erection of the fabric roof. Cost and deadline were substantially lower than those of a conventional building of the same covered area.

Another interesting contribution concerning the assembly process was that presented by Miguel Cárdenas from CIDELSA. It was the installation of the "Polideportivo I.E.República Argentina", Chicote 2017, conceived by Aurora Pérez (†), head of the CIDELSA Architecture Department. The design consists of a series of arches which define 2 main areas linked by a central space. For the manufacturing process of the membrane the entire area was divided into 3 blankets: 2 of approximately 1.500m^2 and a 200m^2 central blanket, in addition to the vertical side enclosures (Fig. 13). For the assembly process it is important to establish a step-by-step installation procedure, coded parts and a detailed planning. It is even more important for large projects since installation can involve damaging a well-fabricated membrane. Not forgetting the climatic factor, because a blanket of more than 1.200m^2 under the wind could be easily be spoiled according to the lifting procedure.



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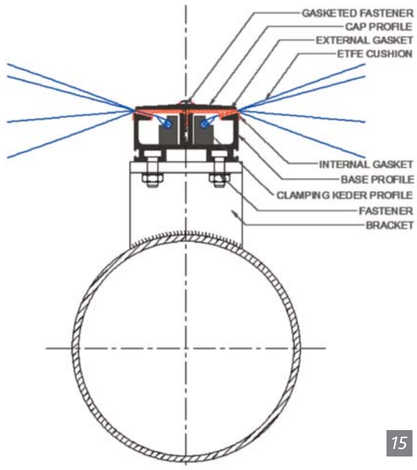

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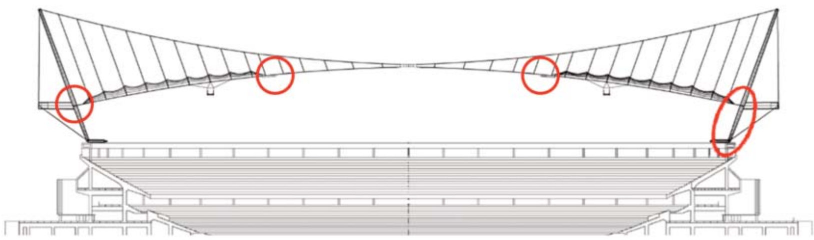
Figure 14. Branched mast. Arquintegral with J.Llorens, 2007: Almuñécar Aquarium.
Figure 15. Aluminum section for ETFE cushions.
Figure 16. Large deformation locations, BC Place, Vancouver, 2011.



16

DETAILING

Three papers (at least) delved into detailing, which is not much discussed at symposia despite requiring a lot of research. One was "Detailing masts" by the Professor Josep Llorens, from the Technical University of Catalonia. As the efficiency and appropriateness of structural membranes depends to a large extent on the supports, a research has been launched on the current design and the possibilities of optimizing the sections and the detailing. Three types were identified: boundary, internal and external masts. The three types accept different strategies to cope with over-dimensioning imposed by buckling on such long elements. They include the use of circular hollow steel sections improved by tapering, trussing, tying, branching (Fig. 14) or coupling. Apart from the section of the shaft, the ends also have a considerable impact on cost, appearance and ease of installation.

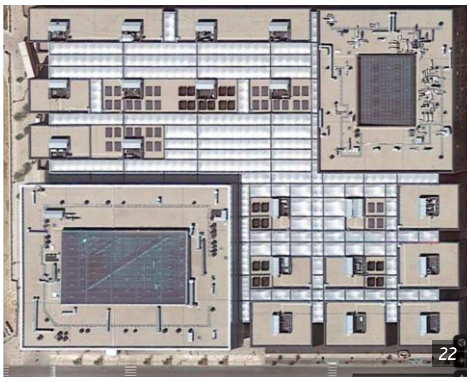
Regarding ETFE foil, Jaume Saló focussed on the detailing and connections between ETFE systems and the other parts of the building that are essential for fulfilling the watertightness, airtightness, and thermal insulation requirements of construction. The most common connections between an ETFE roof and the other parts of the building such as gutters, walls, roof ventilation devices and standard waterproof roofs were discussed (Fig. 15).

"Details of design of large deflection structure building enclosures" by David Campbell from Geiger Engineers dealt with the joints of flexible structural systems that are employed for roofs, facades, atria and other building envelopes. These flexible envelopes must frequently be sealed at the boundaries between large and small deformation elements. That's why innovative connections and closure details are required. Three examples were mentioned. The Capital Center Arena, Landover 1973, was a cable net supported by a compression ring of 122m in diameter roofed by a metal deck (demolished 2002). The Cumberland County Crown Complex, Fayetteville 1997, is a cable dome roofed with rigid panels because they wanted an opaque roof. And the BC Place Stadium, Vancouver (renovated 2011), has to deal with deformations due to snow (Fig. 16).

REALIZATIONS

The most presented topic of the symposium was that of recent projects. Marijke Mollaert from the Vrije Universiteit Brussel was in charge of the tendencies and challenges of contemporary tensile structures in Europe. She alluded to architecture, creativity, lightness, softness, acoustic comfort, adaptability and natural day lightning illustrating them with some of the examples presented in the Symposium. She also referred to the technical specifications that are being drafted by the CEN/TC 250 technical committee. Her summary of challenges was condensed in: "Take care of the planet. Lightweight architecture should not only stand for a physical low weight, but also support well being in the broadest possible sense".

Josep Llorens, from the Technical University of Catalonia focused on the second decade of the 21st century considering that membrane structures have been characterized by the diversification of applications, the increase of the structural efficiency together with new developments and the improvement of the environmental behaviour. Progress is being made in the understanding of the appropriateness of membrane structures. Although bending is expensive, as it was already clear in the 50s pioneering experiences of Frei Otto and his team, many contemporary designs do not take it into account to the point that membrane structures frequently end up being conventional steel structures. Some recent realizations are not yet rid of this drawback but others have assumed it to the point of improving the be-



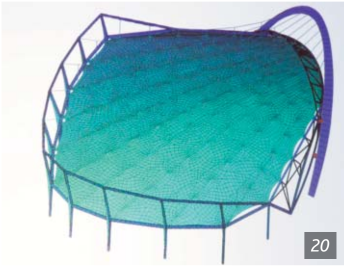


Figure 17. Two approaches to structural membrane design. Left: relying on bending. Right: taking advantage of the benefits of membranes.
Figure 18. Combination of ETFE foil with cables at the SoFi Stadium, LA.
Figure 19. Al Bayt Stadium © Qatar2022 (https://www.youtube.com/watch?v=QOlMrHMPIew)
Figure 20. Retractable roof for the Munjung Cultural Valley, Seoul.
Figure 21. Airport City Belgrade membrane structure.
Figure 22. OMA with IASO: École Centrale, Paris-Saclay University, 2017.
Figure 23. Passage Projects: the roof of the 50 m span "free-form" roof under construction, Bangkok, 2018.

haviour of the structure even more. It is the case of the spooked-wheels, the Tensairity system, cable-beams, active-bending and flying masts, among others (Fig. 17).

Kais Al-Rawi unveiled digital workflows to process and visualize large amounts of structural analysis data to understand and detail the interface between the structure and enclosure. They are especially relevant in lightweight structures, where the geometric non-linearity and long-span tensile elements result in small stiffness with large displacements. Such displacements may not govern the stability of the structure but they can have significant impact on the enclosure systems and detailing. It was illustrated by the combination of ETFE foil and cables of the SoFi Stadium at Hollywood Park, Los Angeles (Fig. 18).

Christoph Paech from sbp showed the Al Bayt Stadium, one of the five new football stadiums being constructed in Qatar, the future host of FIFA 2022 Football World Cup. Its current capacity stands at 60.000 to allow for one semi-final game in 2022. It is supposedly inspired by the Bayt Al Sha'ar tent used traditionally by nomadic people in Qatar, but it is neither a tensile structure nor an active form. It has become an 18.000T cantilevered steel structure that implements membranes (Fig. 19). It has been necessary to transfer the manual pattern of the drawings based on natural fibres to the mechanical loom. And, in addition, it will be necessary to resort to air conditioning to achieve bearable environmental conditions, that were resolved without energy input in the original model. The impressive installation of the stadium can be viewed at: https://www.youtube.com/watch?v=QOlMrHMPIew

The Korean joint research project which has the task to develop the basics for an economical and light retractable roof solution was presented by Alexander Hub from Alfred Rein Ingenieure GmbH. Different project teams from the field of research and economy have developed new approaches to this topic in the former two years. At the symposium, Alexander Hub introduced an application to enable the validation of the results by control and analysis of the operation of the construction. It is a retractable roof for the Munjung Cultural Valley, Seoul. The final completion is scheduled for spring 2020. Currently, a testbed has been carried out containing both a rail and a rope based moving concept, considering that the different driving axes have strong varying total lengths (Fig. 20), which have to be controlled by a sophisticated control system.

Aleksandar Vučur from ArTech inženjering showed a covered space between two contemporary office buildings with curtain wall glass façades in Belgrade in order to protect a pedestrian area and create a plaza (Fig. 21). The membrane is an hypar that covers 487m^2 with a span of 28m with PVC-PES type III. Steel has been adopted for the other structural members and novel solutions have been developed for the corner details and boundary edges that asked for new advanced solutions to introduce pretension at the corners by the elastic deformation of the curved trusses, that's to say relying on active bending. The detailed description of the design, production and installation allowed to get a comprehensive idea of the full process.

Feike Reitsma from IASO showed the construction of Ferrari Flexlight stretch membrane canopies coupled with ETFE cushions on the underside to improve the thermal and acoustic comfort of the "Centrale Supélec", Paris (Fig. 22). The totality of the covers of the hall occupies an area of 4.700m^2 divided into 103 modules of rectangular shape and variable dimensions. The roof of the hall consists of tensile membrane elements that make up the tight outer skin of the cover, ETFE cushions that make up the inner skin of the blanket (powered by an air supply system) and a plenum. This airtight space is slightly over-pressurized with dry air and dehumidified to avoid the risk of condensation and deposition of dust. Each ETFE cushion is formed by 3 films of varying thickness: a printed top film of 200micron, a transparent intermediate film of 100microns and a transparent lower film of 200microns.

Catherine Poirriez from Passage Projects described in detail the design of a 50m span "free-form" steel roof covered with ETFE foil in Bangkok. Several shapes and structural systems were explored at early stage to best integrate the roof in its environment. The resulting shape is a quiet and smooth surface providing shade, natural light and ventilation to the spaces below. Although complex, the geometry was generated to fully take into account the buildability. All the steel members were translated in a language of plates and single radii understandable for the manufacturer. Initially made of conical surfaces, the edge beams section geometry was rationalized through parametric modelling in order to be only made of cylindrical surfaces which are developable and therefore easy to fabricate (Fig.23).

REFURBISHMENT

The timber membrane roof of a small soccer Stadium in Böblingen had to be renovated after a storm ripped off parts of the drastically aged Polyester PVC membrane from the 1970's (Fig. 24). Following the wish of the client to maintain as much of the existing timber structure as possible, the original documents were reviewed. The original analytical calculations and load conditions were compared with the results of a FEM analysis giving insight into the developments of membrane engineering over the last 40 years (Table 1). The new design and formfinding process were discussed to show how ridge cables were used to guide the forces towards the parts of the structure were the highest load reserves were detected (Julian Lienhard from str.ucture GmbH).

Thomas Moschner from sbp was in charge of presenting the new roof structure for the Camp Nou Stadium, Barcelona, the biggest soccer stadium in Europe and number 4 worldwide (Fig. 25). It is going to be renovated from 2020 to 2023. The Japanese architects from Nikken Sekkei won the design competition in 2015 and sbp is one of the General Planners team members and responsible for the roof design. In addition to extending the grandstands to 105.000 seats and upgrading the business areas, the renovation includes a complete roofing of the stadium which sums up to 50.000m². Sbp designed a special kind of cable net structure, considering various demands such as limitations coming from the historical building, time constrains, functional constraints (the entire stadium has to be renovated under full operation, providing min. 80.000 seats during the whole construction phase) and limited access, among others. The presentation explained the roof structure itself and gave an overview about how the various challenges will be handled.


24

Figure 24. str.ucture GmbH: re-design of the Dagersheim Stadium roof.
Table 1. Re-designing of the Dagersheim Stadium. Original calculations compared with the results of a FEM analysis.
Figure 25a/b. The new roof for the Camp Nou Stadium, Barcelona.

Tabel 1	Max. compression (masts)		Max. cable forces	
	Mid span (kN)	Side span (kN)	Mid span (kN)	Side span (kN)
Original design (hand calculation)	-179	-180	56	98
Original design and loading (FEM)	-219	-182	88	112
Original design. New EC loading (FEM)	-256	-188	112	135
New design. New EC loading (FEM)	-283	-219	68	82


25a

25b

RESEARCH

Replacing Rainer Blum from DEKRA, Robert Roithmayr from formfinder GmbH referred to the research opportunities for membrane structures starting with the properties of materials and test methods. The role of the elastic modules and their determination was mentioned. Microscopic pictures of the coating of materials after 20 years of use illustrate the importance of the coating and its behaviour under the influence of the ambient. Thus the improvement of material starts with the improvement of the coating. The building physics of membrane materials and membrane structures, especially the energy saving properties, were also discussed. A new development is the air bubble film used for a new sports hall in Bavaria (Fig. 26).


26


27

Figure 26. The new air bubble film used for a new sport hall in Bavaria.
Figure 27. Modified textiles mounted on the frame under the wind.

"Could the shape and internal structure of the fabric be worked to design architectural structures which become kinetic under the wind? Could the wind be seen as a positive parameter for architectural textiles?" was the challenge assumed by Erica Hörteborn, from the Chalmers University. Smart textiles, whose structure can be changed using heat, were employed to explore how the geometrical expressions of textiles under wind load can be affected through internal property changes. She found that a combination of the digital and the physical design tools enables the creation of an unique workflow to generate architectural design typologies (Fig. 27).

Rosemarie Wagner from the Karlsruhe Institute of Technology presented the research and development of a fabric made of straight monofilaments in warp and weft directions. She included the material properties such as ultimate tensile strength and elastic constants under uniaxial and biaxial loads (Fig. 28). The material showed a different behaviour in warp and weft, translucency, high UV-resistance, water tightness (to a certain amount), high sensitivity to clamping and very little load transfer between single yarns that broke distributed in the whole test sample. The development of seams was difficult because of the sliding of the yarns in the welded seam. A shading structure placed at the location of the producer is planned to demonstrate these specific properties.

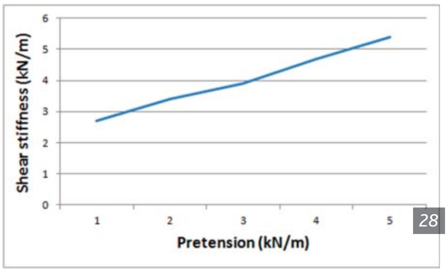


Figure 28. Prestress increases the shear stiffness of fabric with straight yarns.

EDUCATION

Robert Roithmayr from formfinder exposed the bases of his Master's Program for "Tensile Membrane Structures" taught at the Danube University in Krems: https://www.formfinder.at/masters-program/. A collaborative researching and learning method is applied together with a massive amount of content provided by world-class experts including Rainer Blum. The huge amount of information is growing constantly but it is possible to keep the access simple and effective because the content is integrated in a semantic database, including existing building projects, typology, details, products, experts, companies, glossary, details and literature: https://membrane.online/

EXPO PAVILIONS

The IASS WG21 "Advanced manufacturing and materials" invited artists, designers, engineers, researchers and students to submit innovative lightweight pavilions of maximum external dimensions of 4x4x4m. The call was a great success and the jury awarded four winners: the "Elastic rod deployable pavilion, EPFL" for its innovative optimized deployment mechanism (Fig. 29), the "Knit tensegrity shell, Singapore University" for its constructability and artistic expression (Fig. 30), the "Push puppet, Graz University" for its performative character, originality and constructability (Fig. 31) and the "Flexmaps pavilion, CNR-ISTI" for its structural innovation of bending-twisting system, connection constructability and exquisite craftsmanship (Fig. 32). It also deserves to be highlighted the "Quipustructure, Palma University" for its low tech use of local materials like bamboo and reed rope combined with the building techniques developed by the Incas (Fig. 33).

Josep Llorens
ETSAB/UPC
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Figure 29. Elastic rod deployable pavilion, EPFL.
Figure 30. Knit tensegrity shell, Singapore University.
Figure 31 a/b. Push puppet, Graz University.
Figure 32. Flexmaps pavilion, CNR-ISTI.
Figure 33. Quipustructure, Palma University.

NEXT CONFERENCE

The next international Structural Membranes conference will be held in Munich in 2021 at the Technical University. Further information will be made available at: http://congress.cimne.com/membranes2021/frontal/default.asp

ASHFORD DESIGNER OUTLET

Adapting and changing fabric structures

Kent, United Kingdom

Just like any piece of architecture, tensile fabric structures are built to meet a need at the time of construction, but what happens if the use of the building changes? Or an extension is built? Or a new owner wants to update the design?

Adapting and changing existing fabric structures is becoming more common as the lifespan of technical fabrics increases but it is a complicated process. Often integral to the stability of the canopy, fabric panels cannot be cut out or changed without an experienced team carrying out a full assessment of the impact on the wider membrane structure. So when the chance to modify one of our largest tensile fabric canopies arose, we jumped at the chance to be involved.

Originally built in the late 1990s and designed by Richard Rogers Partnership, the canopy at Ashford Designer Outlet is a true tensile canopy. The original teardrop shape is created by a series of tensile fabric panels, large and small steel masts and a network of boundary, tie back and hanger cables which all work together to ensure a stable structure. The removal of any one area would have huge implications for the rest of the membrane canopy. In 2017 owners McArthur Glen embarked on the construction of a brand new extension. However, the new mall buildings clashed with the existing food court and it was clear that the area of canopy over the food court would need to be removed.

A challenging procedure

Using computer modelling software to analyse the existing canopy and the new form proposed by the project design team, various scenarios could be virtually played out to see how the membrane would behave. But once settled on an achievable design, the reality of removing a large portion of the canopy, whilst keeping the retained fabric membrane roof both intact and structurally stable through installation and beyond, was a challenge. As we had built the original canopy 18 years before, McArthur Glen and contractors McLaren Construction returned to Architen Landrell to draw on our extensive experience and long history with the site. With design and installation teams working hand in hand, significant analysis was carried out during the design stage to establish the safest way to stabilise the structure, dismantle the old canopy and install the new one. Working to the highest safety standards, our highly experienced installation team used temporary rigging to hold the canopy in position whilst the food court area was dismantled. Continuous testing was carried out on site during the installation period to ensure that the temporary works were performing and that the remaining portion of the canopy was behaving as anticipated.

Once the food court canopy was removed, temporary rigging remained in place until the new canopy section was attached to the existing membrane and to the newly installed support structure. Only when the newly configured structure was determined to be performing was the temporary rigging removed.

Figure 1. Bird view on the shopping center canopy © Chapman Taylor

The modifications have breathed new life into the tensile fabric canopy and integrated it into the current shopping centre design seamlessly showing that fabric architecture can successfully evolve and grow with the surrounding buildings!

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Name of the project:	Modifications to the Tensile Membrane Canopy at the Ashford Designer Outlet
Location address:	Ashford, Kent, United Kingdom
Client (investor):	The Ashford Investor
Function of building:	Retail Outlet Centre
Type of application of the membrane:	Roof over retail units
Year of construction:	Original installation 1999, Replacement of Membrane 2013/14, Modification works 2018
Architects:	Richard Rogers Partnership (original works), Chapman Taylor (modification works)
Multi-disciplinary engineering:	Buro Happold (original works)
Structural engineers:	Buro Happold (original works), Tensys (modification works)
Consulting engineer for the membrane:	Tensys
Main contractor:	McLaren Construction (modification works)
Contractor for the membrane (Tensile membrane contractor):	Architen Landrell
Supplier of the membrane material:	Mehler Texnologies
Manufacture and installation:	Architen Landrell
Material:	VALMEX MEHATOP F1 FR 1000
Covered surface (roofed area):	35.000m^2

Figure 2 a/b/c/d. Installation of the new membrane © Architen Landrell

Figure 7. Solar radiation control

FASCINATION AND FUNCTION OF *TEXTILE RIBBON FAÇADES*

Baku, Azerbaijan

NATIONAL GYMNASTICS ARENA

The use of tensile surface structures as an additional building envelope has reached an ever growing acceptance in architectural and engineering offices in recent years. They are used as visual, thermal or acoustic filters and create fluid spaces that mediate between the interior and exterior. Creative planners are thus able to apply membranes not just as temporary or permanent gigantic billboards, which is the most common use of textile fabrics in modern architecture.

The history of textile ribbons starts with the long tradition of textile canopies as independent elements that offer shade and rain protection. It is the combination of this old idea with the modern technology of textile envelopes that introduces new options to the field of architectural creation. Once the structural challenge has been solved, it becomes possible to combine shade and transparency in a fascinating new way. The building can be partly revealed and partly covered; sunrays can be deflected, reflected, diffused or filtered with the help of undulating textile ribbons; and last but not least, the building´s appearance at night can be highlighted through sophisticated led illumination systems either from within or from behind the ribbon´s structure.

The National Gymnastics Arena in Baku is a key part of Azerbaijan´s bid for the 2024 Summer Olympic Games and Broadway Malyan, an international architectural firm, has been selected to design the competition level center for rhythmic and artistic gymnastics. IF-Group, a well known German engineering company whose roots lie in the design and calculation of tensile surface structures, participated from the beginning in the elaboration of workshop drawings and the structural calculation of the inclined curtain wall of the new center. In a second phase, for the approved final design, IF-Group designed the supporting steel ladder of the textile ribbon structure and the bracketry fixed to the inclined concrete pillars behind the glazed façade. Its contribution to the new building also included form finding of the textile membrane, cutting pattern generation and the method statement of the complete structure.

Textile Ribbon Façade

The first design of the Textile Ribbon Façade consisted of three horizontal ribbons in the colour of the Azerbaijan flag. As well as the functional task of controlling solar radiation gains, the idea was inspired by the ribbons used in rhythmic gymnastics exercises. However, the chosen coloured bands would have been nearly opaque because of the reduced translucency of coloured PVC coated polyester. In order to achieve a powerful nocturnal lighting together with a diffused solar radiation, therefore it was decided to use a plain white membrane Type II with a relatively high translucency of about 10%.

The steel structure of the Textile Ribbon Façade had to be suspended from the roof top. For this purpose, inclined struts with their tie-down rods were located above the primary steel mullions of the glazed façade.

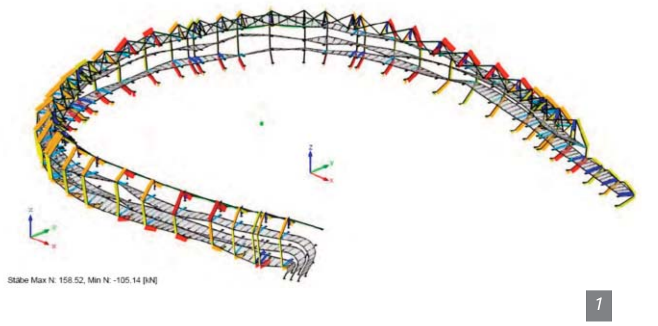

Figure 1. Analysis model © If-group

Figure 2 a/b. Wind-tunnel testing done by the Building Research Establishment Group, UK (2011)

Once the pre-fabricated ladder sections of the textile ribbons were in place the membranes could be fixed and tensioned from either side. The result is a continuous band of textile that completely covers the undulating steel structure. The process of fabrication of this complex three-dimensional form, made of circular hollow sections, was a challenge and required IF-group to send an engineer to the Turkish steel contractor in order to oversee the bending and welding process. Before transporting the elements to Baku, the final assembly process also had to be monitored. The building, including illumination, was finished in 2014.

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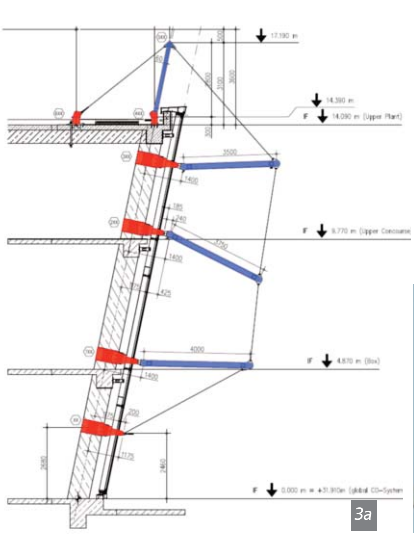
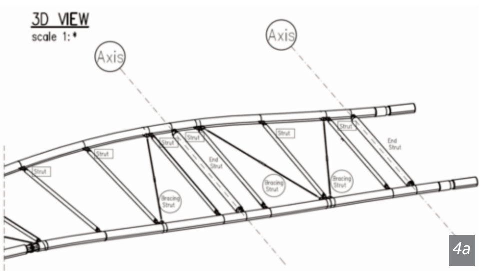
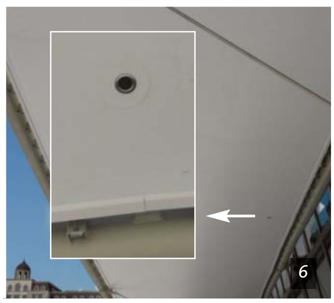
https://www.if-group.de/

Name of the project:	National Gymnastics Arena of Baku, Azerbaijan
Client:	Pasha Insaat, Baku, Azerbaijan
Architecture firm:	Broadway Malyan Limited, London, Great Britain
Structural engineering firm:	if-group, Ingenieure für Flächentragwerke GmbH, Reichenau Germany
Contractor:	Mace International Limited, Baku, Azerbaijan
Membrane engineering firm:	if-group, Ingenieure für Flächentragwerke GmbH, Reichenau Germany
Assembly and design of membrane:	Fabric Art, Istanbul Turkey
Textile manufacturer:	Serge Ferrari S.A.S., La Tour de Pin, France
Trade name of fabric:	1002 S2
m^2 textile used:	$7700m^2$
Light design:	Francis Krahe & Associates Inc., Los Angeles USA







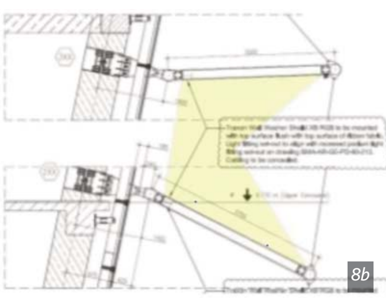


Figure 3 a/b. Anchoring the ribbon structure on the roof © If-group
Figure 4 a/b. Steel ladder: bended circular hollow sections with bracing struts © If-group
Figure 5 a/b. Construction phase © If-group
Figure 6. Emergency drainage © If-group
Figure 7. Solar radiation control © If-group
Figure 8 a/b. Lighting concept by the architects of Broadway Malyan and Francis Krahe & Associates

Kumanovo, North Macedonia

RESTAURANT FACILITY

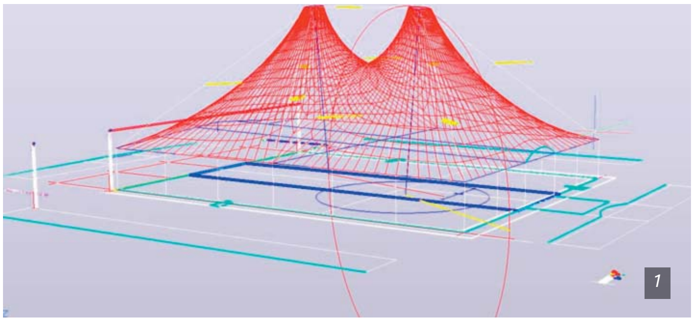


Figure 1. 3D modeling of the cone shaped membrane

The membrane structure in Kumanovo, North Macedonia, is the first ever project with applied material of a completely new ``Atlas`` technology. ArTech inzenjering responsible for design and production, with Membraning as general contractor, decided to try something new. As such this project is unique, bringing completely new experience in textile architecture industry. The client came with the idea of making a different, unique space, which will be used for various party occasions such as weddings, corporative celebrations… etc.

Design

The final design is a light, attractive free space, defined by an asymmetric double cone membrane structure. This unusual building is situated at top of the hill, nearby city of Kumanovo. The exposed position provides a wonderful view of 270º for all users, but also a fantastic appearance visible from very far. The functional organization is separated in two main parts. One is the technical block. This part contains kitchen, storage rooms, toilettes and rest rooms, and additional spaces for stuff and technical installation. The technical block is a simple cubic shape, well insulated and ``not exposed``. The other part is main celebration area, with a central positioned entrance. This huge, 600m² free space is covered with an attractive curved white membrane. The space is enclosed by transparent foil side walls. Two asymmetric masts, besides supporting the membrane roof, offer the possibility to organize this free space in many different ways, defining dancing podium, sitting area, music or performance area, etc. The ''Crown element'' is the two cone shaped membrane that defines the whole structure. The membrane provides a perfect diffuse daylight

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3

4

NEW HIGH-TECH MEMBRANE FOR TEXTILE ARCHITECTURE

SATTLER PRO-TEX

„Brighter. Stronger. For Longer." is the slogan of the new product for textile architecture launched by Sattler PRO-TEX GmbH.

The new product "ATLAS Architecture" stands for aesthetic design, strength, protection and longevity. The ATLAS membranes are revolutionary and unique fabrics, based on a better PVC-coating and an innovative ATLAS weave structure applied to architecture membranes. These fabrics open a wide range of new and interesting possibilities. The specific characteristics are listed alongside.

New base fabric for more durability and sheen: the distinctive mark of the ATLAS membranes is the extra smooth surface of the fabric. The flat and even structure of the base fabric results in a coated membrane with a fantastic sheen and a very smooth surface.

Quality without compromise: the PET yarns are covered with a thicker PVC-coating which protects the fabric even better. The result is an extremely strong membrane with a particularly long service life.

Extremely homogeneous elastic behavior of warp and weft: the elastic behavior in warp and weft of the ATLAS membranes is much more homogenous than that of conventional fabrics. ATLAS membranes have less elongation difference between warp and weft, and stretch in both directions in a more uniform way, without constriction to a desirable flexibility and elasticity in textile architecture.

New lacquers for a longer service life: the fabrics of the ATLAS product line are finished with a TFL lacquer (a multilayer finish with a UV-shield and a weldable PVDF lacquer) or with a TFX lacquer (a multilayer finish with a UV-shield, a new hyper-PVDF lacquer on the top and a weldable PVDF lacquer on the bottom of the fabric). They have a warranty of 15 years for products with TFL-lacquers and 20 years for TFX-lacquers.

Tensile strength higher by up to 16%: thanks to the higher yarn density of the base cloth, these


6

throw-out all the inner space, and a shiny, reflective, glamorous surface for outside impression.

Membrane

Beside technical improvements, verified by lab-testing, this material showed surprising characteristics, during the production and installation process as well as in one year exploitation period so far. Dirt behavior, scratch and crack resistance and the visual appearance are some of the fantastic characteristics that have to be emphasized.

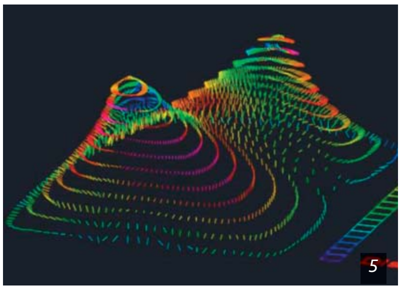
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Figure 2 : Interior view with the two asymmetric supporting masts with a 600m² free space
Figure 3 : Restaurant seen from the entrance side
Figure 4: The visual appearance of the restaurant at night
Figure 5: Form finding, static analysis and patterning the double cone shaped membrane with software MPanel
Figure 6 : Side view of the two cones made of the new "ATLAS Architecture" membrane

✎ Aleksandar Vučur
ArTech inzenjering d.o.o. ,
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Name of the project:	Kumanovo 2019
Location address:	Kumanovo, North Macedonia
Client (investor):	Mr Predrag Pecoski
Function of building:	Restaurant facility
Year of construction:	2019
Architects:	Aleksandar Vučur, ArTech Inženjering
Multi-disciplinary engineering:	M.C.E Andreja Gjureski
Structural engineers:	M.C.E Marko Petrović, B.C.E Ivana Stojanović
Consulting engineer for the membrane:	Aleksandar Vučur, ArTech Inženjering
Engineering of the controlling mechanism:	M.C.E Andreja Gjureski
Main contractor:	Membraning
Contractor for the membrane (Tensile membrane contractor):	ArTech Inženjering
Supplier of the membrane material:	Sattler PRO-TEX Gmbh
Manufacture and installation:	ArTech Inženjering
Material:	Sattler ATLAS 739, 900gr
Covered surface (roofed area):	625m²

fabrics have a higher tensile strength, by up to 16% compared to a panama fabric.
Better resistance to the UV-rays thanks to the new lacquers: the new lacquers for the ATLAS membranes offer better protection from the UV-rays, which has a major positive impact on the durability of the fabric.

Beautiful surface: the ATLAS membranes are whiter than conventional fabrics and have a beautiful shiny surface. The even surface of these high-quality fabrics ensures their elegant look and a homogeneous light transmission. The smooth surface hinders soiling, thus these fabrics are cleaner than conventional membranes.

Anti-wick-treatment: the anti-wick system is a yarn treatment which prevents the penetration of microorganisms into the base fabric of the coated membrane. Thanks to this water and dirt repellent treatment, it is possible to avoid negative influences on functionality and optics on the long term.

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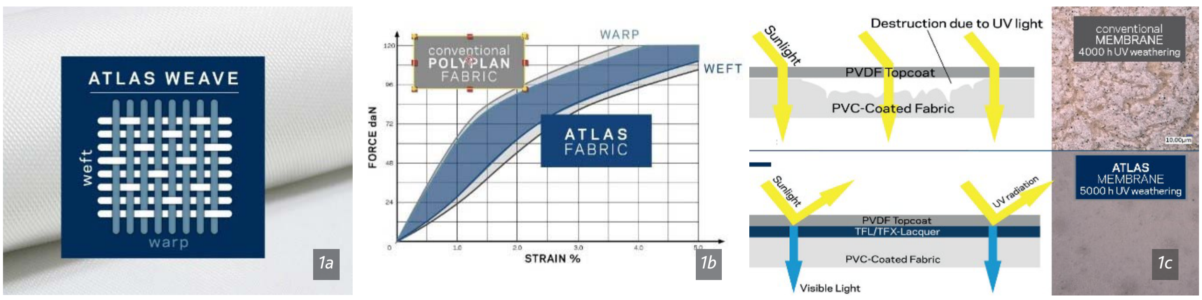


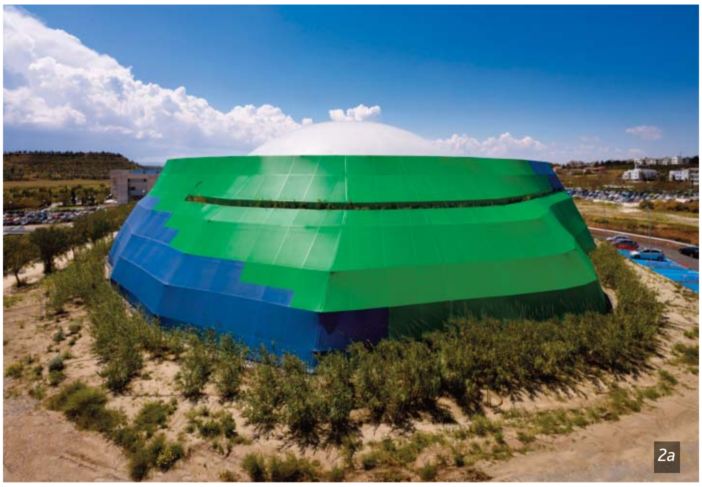
Figure 1 a-c:
a. weaving;
b. extremely homogeneous elastic behavior;
c. New lacquers – for a longer service life.

Figure 1. The building as "an earthwork" © Yiorgis Yerolymbos

ANTHROPIC HILL

An "earth-work" building

Nicosia, Cyprus



Project Description

The Stelios Ioannou Learning Resource Center is located at the Northeast end of the namesake Campus. Named after Cypriot industrialist Stelios Ioannou, the library is a complex of more than 15000m² in the form of a hill with a white glass dome, divided into five levels.
This Learning Resource Center (shortened LCR) occupies the North-East area of the Athalassa University Campus. This building houses approximately 620.000 printed volumes, over 190.000 subscriptions to electronic book titles, 12.000 subscriptions to electronic and printed journals and 180 databases.

The Pritzker-prized Architect Jean Nouvel envisioned the building as an "earth-work" rather than a mere building, replicating the hills in the close surroundings of the Campus (Fig. 1). On the other hand, the vivid colours of the membrane highlight the artificial nature of a man-built construction. The landscape where the building is located creates a hybrid effect of prominence and merging with the surroundings, where building seems to grow from the ground itself. The green membrane embraces concrete gutters that host greenish plants and shrubs, implicating the transfer from natural to artificial green (Figs. 2 – 3).
The PVC membrane has not only the purpose to cover the hill soil underneath, but provides also shading to some parts of the building, where a transparent glass envelope is adopted.
Even though the building itself seems to be encapsulated in a PVC mesh shell, all the daylight comes in through the glass dome located at the very top of the Learning Resource Center. Concrete slabs show wide circular holes that allow daylight to shine all the way down, while a conical opaque column reflects horizontally incoming light accessing from the top.
This arrangement (soil insulated perimeter walls + glass dome) is the result of the architect's intention to provide a fresh and comfortable indoor environment that lets building end-users to experience a naturally cool space and reduce energy consumptions, especially during hot Cypriot summer seasons.

Figure 2. General view of the Stelios Ioannou Learning Resource Center © dezeen.com
Figure 3. Bird view © Ateliers Jean Nouvel

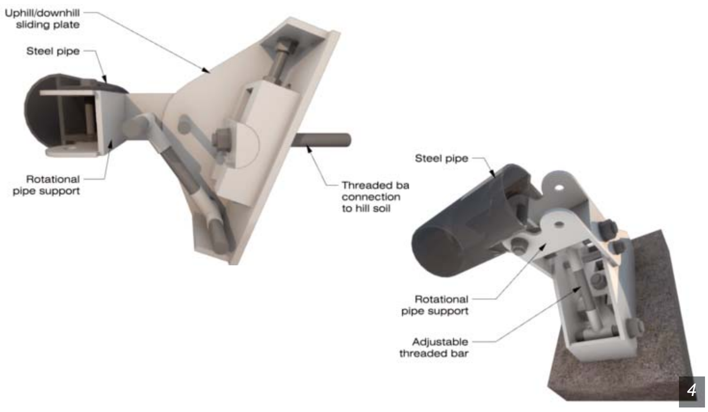


Figure 4. Detailing the connections and supporting structures © Maffeis Engineering

Hill Façade: design and installation

External concrete main structure is covered with soil (like a natural hill) and a steel substructure holds the PVC mesh approximately half a meter above. Membrane is clamped on a rail on the very top and tensioned downward and sideways through PVC belts, supported by median steel pipes that replicate the hill kinks and curves. Suited closure flaps guarantee the PVC envelope continuum leaving no visible gap between each panel. Considering the particular appearance of the building, a membrane façade was the best choice to reproduce natural and soft hill shape.

Considering the irregular soil surface where steel supports are placed and architect´s intention to keep glass and membrane façades' alignment, it was necessary to design adjustable elements that could modify their own base plate inclination without changing final pipes position. Therefore, thanks to the joint efforts between Maffeis Engineering and Taiyo Europe, rotational elements have been designed to ensure a wide adjustment angle between steel supports and hill slope. Stability against suction loads has been achieved through fastening steel plates to threaded bars inserted in the soil and sprayed with filling grouting to improve pull-out resistance.

Supports are made of three parts, one main part directly connected to the threaded bars and one sliding plate that allows up/down adjustments (following hill slope), supporting a third part which is the one holding pipes in final position. Pipes extremities show a pinned constraint on one side and a sliding connection on the other side to facilitate installation due to construction site tolerances and allow steel deformations due to temperature loads (Fig. 4).

Conclusion

This project shows wide membrane potentialities to realize free-form shapes for uncommon projects. Under the technical point of view, most important aspect was to design a system that not only fulfils architect´s intention to give birth to a pseudo-hill building, but also gives installers the chance to adjust supporting structure on a very complicated soil substratum.

Proximity of the façade to walking level and the architectural integration between envelope and walkways successfully accomplished the challenging result to let the end-users experience the translucency and permeability of the PVC mesh façade from very close (Fig. 5).

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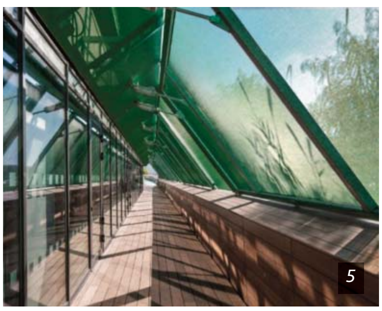
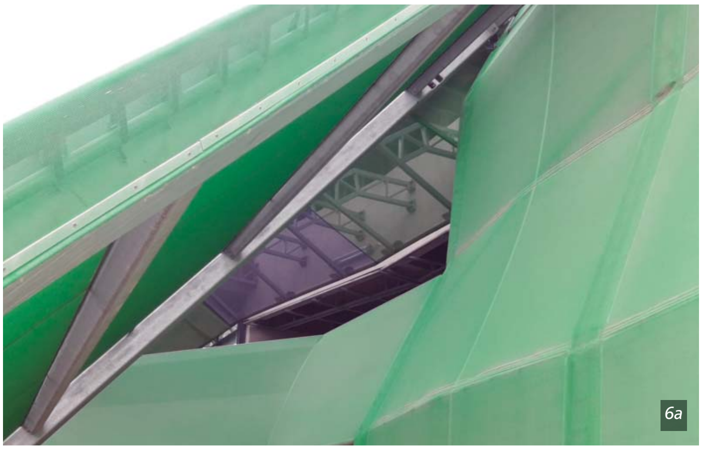




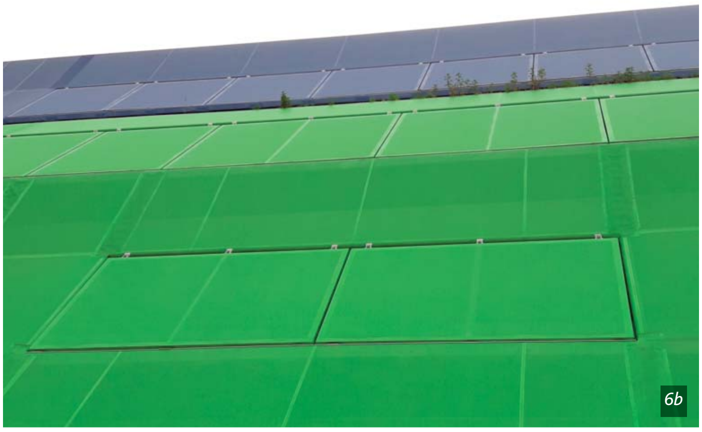


Figure 5. Translucency and permeability of the PVC mesh façade © Maffeis Engineering
Figure 6a Detailing the second skin of the Hill façade ;
b/c. Detailing the second skin of the Central façade © Marijke Mollaert

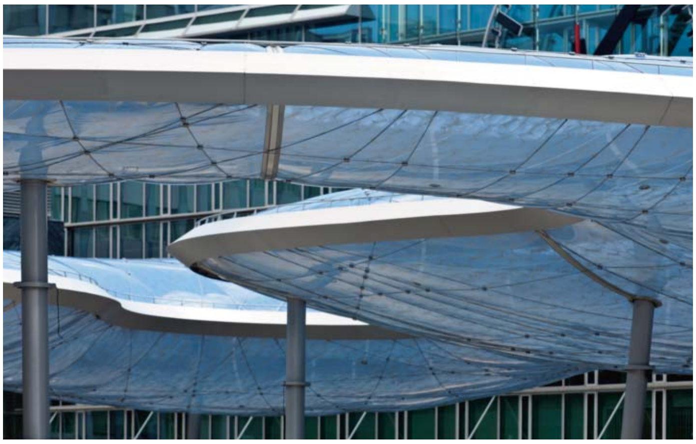
Name of the project:	'Stelios Ioannou' Learning Resource Center
Location address:	Panepistimiou 1, Aglantzia 2109, Cyprus
Client (investor):	University of Cyprus – Dakis Joannou
Function of building:	Information center and library of the University of Cyprus in Nicosia
Architect:	Ateliers Jean Nouvel
Local Architect:	J+A Philippou
General Contractor:	J&P-AVAX S.A. Cyprus Branch
Year of construction:	2017-2018
Contractor of the membrane façade (Hill facade), installation:	Taiyo Europe GmbH
Contractor of the membrane façade (Central facade), installation:	Arka Synthesis
Type of application of the membrane:	Façade
Membrane Engineering Consultant:	Maffeis Engineering SpA
Supplier of the membrane material:	Serge Ferrari S.A.S.
Materials:	Steel S275; Membrane: Frontside View 381
Covered Surface:	5500m^2

ADVANCED BUILDING SKINS

15th Conference on Advanced Building Skins
26-27 October 2020, Bern, Switzerland

International platform for architects, engineers, scientists and the building industry

Architects, engineers and representatives of the worldwide building industry are meeting at the annual International Conference on Advanced Building Skins in Bern to discuss the latest trends and new developments in sustainable building design. The conference is Europe's leading event on building envelopes and combines top-class presentations with active networking in the construction industry. Every year, over 150 speakers present new projects and developments in the design of building skins.
TensiNet will be represented at the 15th Conference on Advanced Building Skins with two TensiNet sessions on Membrane Architecture and with a TensiNet booth designed by our associate partner POLIMI. Lastly we will organise the TensiNet Meeting "TensiNet and friends".



Bus Terminal Aarau, formTL © Niklaus Spoerri

Session 1 - Skins from fabrics and foils

Chair: Dipl.-Ing. Architect Katja Bernert

In the session **Skins from fabrics and foils** *Marijke Mollaert* will give an introduction on tensioned skins and the work of TensiNet. *Carol Monticelli* will deepen the insight by showing the focal points of TensiNet's working group Sustainability and Comfort. From there we'll start an itinerary from raw material to current and future applications. *Sebastian Zehentmaier* shows one of the commonly used raw materials for foil applications. *Katja Bernert* gives an overview on state of the art fabric façade architecture, evaluate the industry's advances in sustainability and give a brief insight on what future building skins might look like. More case studies are presented by *Fevzi Dansik, Roberto Canobbio* and *Gerd Schmid* along examples from Turkey, Italy and Europe. *Claudia Lüling* finishes the session by showing results from research about textile based, lightweight construction at Frankfurt University of Applied Sciences.

Session 2 – Building Membrane Cladding Systems

Chair: Dr. Carl Maywald

The session **Building Membrane Cladding Systems** starts with an input from *Bernd Stimpfle* questioning if technical specifications are needed for building with foils and fabrics. *Carl Maywald* shows ETFE applications along with an outlook on the durability of foils commonly used in tensile architecture. One of today's major functions of tensile building envelopes is highlighted in the presentation of *Monika Rychtáriková* from Leuven University. She talks about researches in the acoustical effects of fabric façades.
The insight in engineering ETFE façades is deepened by a presentation of *Felix Surholt*. *Maxime Durka* shows how foils and fabrics can be combined in one material and *Jürgen Holl* gives an insight in calculating and form finding of tensile structures. Current façade projects in the US are highlighted by *Michael Lussier*.

Interested to have your firm booth at ABS 2020?

As Membrane Architecture will be one of the main topics at ABS 2020 you may be interested to have your own booth or sponsor the event. See link exhibition and sponsorship packages: https://abs.green/files/user_upload/Sponsors_Exhibitors/Sponsorship_opportunities.pdf

Register as TensiNet member TensiNet members receive a reduction up to 30% if you register as early-bird until 31st May.

More info: https://abs.green/home/