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

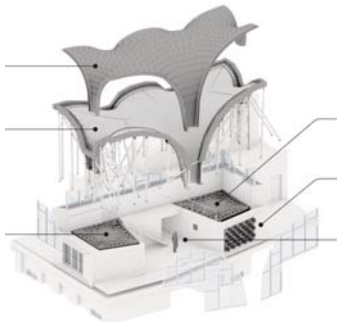
ARTICLE
JOSÉ MIGUEL DE PRADA POOLE

REPORT
STRUCTURAL MEMBRANES 2021

PROJECTS
AN IMPRESSIVE CIRCULAR AND TRANSPARANT CLADDING

AERIAL VIEW OF THE ETFE ROOF RYNEK ŁAZARSKI © TEMME// OBERMEIER GMBH

contents



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Editorial Board
Paolo Beccarelli, Evi Corne,
Maxime Durka, Josep Llorens,
Marijke Mollaert & Carol Monticelli

Coordination
Marijke Mollaert,
marijke.mollaert@tensinet.com

Address
Lombeekweg 26, B1740 Ternat,
Belgium

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Edito

Dear Reader

I hope this finds you well. We had just the feeling that we are leaving the crisis behind, when we stumbled in the next crisis. Beside any impact on our daily business, it is moreover a humanitarian crisis, acting against humans, against friends, and against tolerance and democracy.

Please enjoy anyhow this issue of TensiNews, where you find once more interesting contributions from our network. Two ETFE projects are presented, the largest one chamber ETFE cushion today, in the city of Posen and a wall like roof of an entertainment park in Denmark, and a double skin membrane for a mobile exhibition. A tribute to the Spanish architect Jose Miguel de Prada, a pioneer of pneumatic structures and textile architecture, who passed away last year, has been written by Josep Llorens, as well the summary of Structural Membranes 2021.

A research and innovation unit in Switzerland is presented, demonstrating how digital concrete construction together with flexible formwork can lead to reduced embodied energy. Four temporary structures have been evaluated with respect to their environmental impact.

Initiated by our working group Sustainability and Comfort, we will now become member of IBU, with the target to get a grouped EPD for our members. Furthermore, we applied as Partner of the New European Bauhaus, an initiative that connects the European Green Deal to our living spaces and experiences.

Mid of the year, with the contribution of our working group Specification and Eurocode, the draft of prCEN/TS 19102 will be submitted to CEN for final approval and to be released as a Technical Specification for membrane structures.

After two years pandemic we are glad that many events restart this year in presence, or hybrid. Very soon the 25th edition of Textile Roofs 2022 will take place in Berlin, followed by the Techtextil fair in Frankfurt in June, where we will have also our general assembly.

In autumn the Essener Membranbau Symposium will be held, and the Advanced Building Skins Conference in Bern. TensiNet will again chair two sessions there and will have a booth.

I hope to meet many of you again in real. Please enjoy this issue of TensiNews and stay healthy and safe.

Yours sincerely,
Bernd Stimpfle

Forthcoming Events

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

Textile Roofs 2022 | *9-11/05/2022* | Berlin, Germany | **https://www.textile-roofs.com/**

Techtextil & Texprocess 2022 Beyond innovation Performance. Function. Future. | *21-24/06/2022* | Frankfurt am Main, Germany | **https://techtextil.messefrankfurt.com/frankfurt/en.html**

IASS Annual Symposium and Asia-Pacific Conference on Spatial Structures (APCS) 2022 Innovation, Sustainability and Legacy | *19-23/09/2022* | Beijing, China | **http://www.iass2022.org.cn/**

Essener Membranbau Symposium 2022 | *23/09/2022* | Essen, Germany | **https://www.uni-due.de/iml/07veranstaltungen.php**

International Conference on Advanced Building Skins 2022 | *20–21/10/2022* | Bern, Switzerland | **www.abs.green**

TensiNet Activities

TensiNet at Techtextil & Texprocess 2022

Wednesday 22 June 2022
(hybrid meeting)
14.00 – 15.00
Annual General Assembly

CORRECTION
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"The Hulasol parasol": Lin Bertels and Peter Mortel-mans of Solspiration have dedicated five years of research and development to make the Hulasol parasol. **Amandus VanQuaille (The Nomad Concept) is co-author and designer of this remarkable object.**

In memory of Jose Miguel de Prada

At the end of 1971, two architecture students from Barcelona organised the "Instant City" in Ibiza via the FAD (El Foment de les Arts i del Disseny). After the events in France of May '68, Woodstock in '69 and the Isle of Wight in '70, we issued a manifesto to summon students from all over the world to Cala Sant Miquel for a month. There, we built a temporary city based on work, leisure and counterculture. We asked José Miguel de Prada for his help after learning about his inflatable site huts in Madrid. Obtaining sponsorship from Aiscondel after making a test inflatable in its factory, we travelled to Ibiza to build a city that would fade away with its last inhabitants – what Prada called "a city of seagull's footsteps" – reflecting impermanence, and the rejection of cities that mark out the behaviour of their inhabitants. *Carlos Ferrater, Barcelona, December 2021*

José Miguel de Prada and Carlos Ferrater in the test inflatable at Aiscondel.

ETFE roof Rynek Łazarski An impressive circular and transparant cladding

Poznań, Poland

The rearranged Rynek Łazarski in Poznań is covered by a circular cushion roof. Thanks to the transparent cladding a bright space is created, protected from the weather conditions, inviting to shop at the market stalls underneath, or just to stay.

The cushion roof covers an area of approximately 2400m². A structure like a steel table is formed by an outer ring, an intermediate ring and an inner ring. These rings are connected with an orthogonal grid, supported by columns underneath. Two large cushions are attached to these rings, to form the pneumatic roof.

The outer cushion has a constant span of approximately 13.5m, while the inner cushion has a maximum span of 17m, which is reduced to less than 1m at the opposite side. To allow these spans, arrays made of 12mm stainless steel cables form the structural cushion. The inner pressure applies the tension to these cables through the ETFE foil in-between.

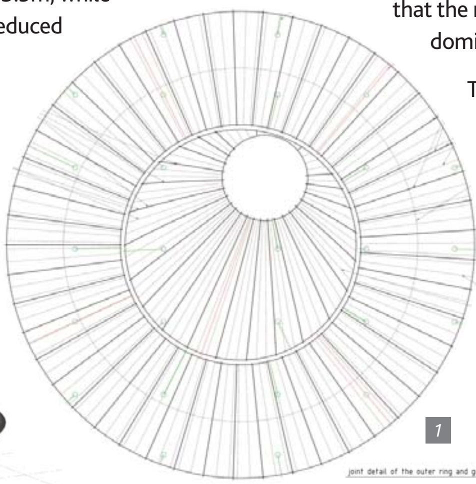
The lower foil is penetrated by the steel columns. Around these columns the cushion has flying clamping joints. The upper and the lower foil are separate layers.

The total volume of the two cushions is approximately 5150m³. Three blower units provide the cushions with supporting air pressure. The blowers are located on two pavilions under the roof structure. The regular cushion pressure is 300Pa. In case of snow this is increased up to a maximum of 800Pa, controlled by a snow sensor.

The single panels have more than 400m² surface area. To minimise the handling of the panels a suitable confection site has been chosen. Prior to fabrication a mock-up has been installed with different printing to shade the place underneath. After a visit of the mock-up the client chose the print pattern. The printing was applied to the lower foil, so that the rather linear steel structure is not too dominant, seen form below.

The installation started with the inner cushion, which allowed to put it under pressure immediately after closing the cushion. Then the outer cushion has been installed starting from the top. This outer cushion forms the biggest one-chamber cushion worldwide today.

Bernd Stimpfle, formTL
info@form-TL.de
www.form-tl.de



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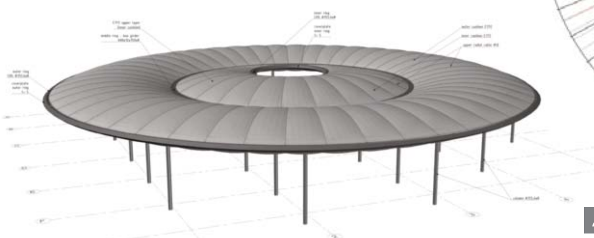

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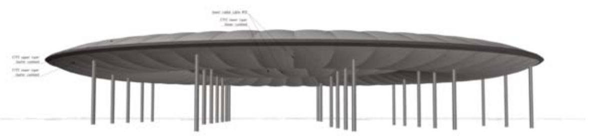

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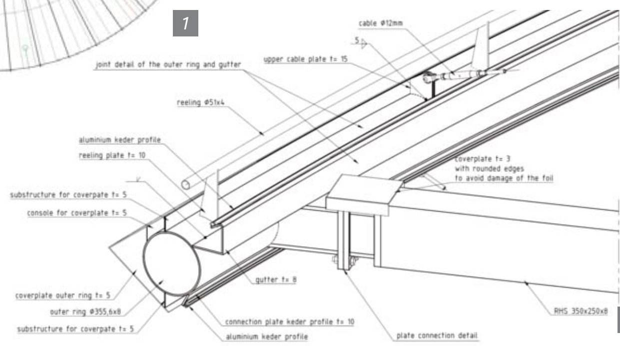

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Figure 1. Cutting pattern layout and location of the joints © formTL
Figure 2. Perspective view from above © formTL
Figure 3. Perspective view from underneath © formTL
Figure 4. Connection detail outer ring © formTL
Figure 5. Inner cushion after completion © Temme // Obermeier GmbH

Project:	ETFE roof Rynek Łazarski in Poznań, Poland
Architect:	Jacek Bułat, Posen, Poland
Conceptual design:	Andrzej Kowal, Breslau, Poland
Foil cushion engineering:	formTL, Radolfzell, Germany
Execution foil cushion:	Temme // Obermeier, Rosenheim, Germany
Confection:	Flontex, Bytom, Poland
Cables:	Top-line, Wüstenrot, Germany
Air supply:	Elnic, Rosenheim, Germany
Material:	Clear and printed ETFE foil 300µ
Cables:	stainless steel spiral strand
Surface area foil:	4600m²
Cushion volume:	5150m³
Dimensions:	55m diameter, 7m above ground

Showing Styria, Austria

Mobile Exhibition Glows with a double-skin made of Sattler Fabric

From its forests to its flag, the state of Styria fulfills its reputation as the "green heart of Austria." A glowing green pavilion helped to tell the region's story. Examining the past, present and future of Styria, the "Showing Styria" exhibition was presented in three museums in the city of Graz and a mobile pavilion, traveled in 2021 to five different locations in Styria.

The pavilion, by architects Kada Design and Bettina Zepp, is designed as a double-skin membrane facade. The exterior facade surface consists of green translucent POLYPLAN Candy material from SATTLER PRO-TEX, the global coated technical textile supplier based in Austria. Parts of the pavilion include printing with the Styria logo. The second membrane layer is used as a projection surface on the inside. It turns white in the space between it and the outer facade to enable the desired effects of the backlighting. Besides allowing amazing effects in transmitted light, the POLYPLAN Candy fabric was chosen because of its anti-wicking properties, fungicide treatment and for being highly UV resistant as well as flame retardant.

Alexander Kada and Astrid Kury, designers and curators for the "Showing Styria" mobile pavilion, explain that as a traveling branch of the Universalmuseum Joanneum, the pavilion "redefines the format of provincial exhibitions. Covering the various regions of the province, using a large-format panorama of films and moving images, it shows Styria as a province of art, which manifests itself as an essential component in all areas of life."

The 800m² pavilion houses a 50m panorama screen that features projected large-format images of Styria, creating a unique spatial experience through the generation of images through light.

"It's a very modern and dynamic approach to design and mediation that takes new ways of seeing into account and goes far beyond conservative, static museum presentations," says Günther Gradnig, managing director of SATTLER PRO-TEX.

protex-int@sattler.com
www.sattler.com/en/home
www.kadadesign.com/project/steiermark-schau

Name of the project:	Showing Styria
Location address:	Vienna, Hartberg, Spielberg, Schladming and Bad Radkersburg (Austria)
Client (investor):	Universalmuseum Joanneum GmbH
Function of building:	Mobile pavilion for exhibition
Type of application of the membrane:	Pavilion
Year of construction:	2021
Structural engineers:	Kada Design, Zepp Architekturbüro, Raunjak
Main contractor:	Raunjak
Tensile membrane contractor:	Raunjak
Membrane supplier:	Sattler PRO-TEX GmbH
Manufacture and installation:	Raunjak
Material: Outer membrane:	POLYPLAN Candy Art. 684,
Inner membrane:	POLYPLAN Tent Opaque Art. 787
Covered surface (roofed area):	800m²

Figure 1. The exhibition pavilion in front of the Hofburg, Vienna © Bettina Zepp
Figure 2. 3D visualization of the pavilion, exterior and interior view © Paul Frick (Bildermehr)
Figure 3. Interior with impressive panorama screen © Paul Frick (Bildermehr)
Figure 4. Easy mountable and dismountable frame © Bettina Zepp

1938-2021
José Miguel de Prada Poole
A pioneer

Spanish architect José Miguel de Prada Poole (Fig. 1), pioneer of pneumatic structures and textile architecture has died at the age of 83. He was part of the visionary underground culture of the sixties of the last century around the "Whole Earth Catalogue", "Ant Farm", May 68, Woodstock and the Isle of Wight Festivals, among others. In tune with Buckminster Fuller, Frei Otto and other pioneers of the time, he was concerned about the need to build with less material, energy and money obtaining better results with fewer resources. Relying on air, the cheapest available material, he used pneumatic structures in building when the only ones that had been built before were those of Walter Bird. In this way he addressed sustainability and minimal impact "avant la lettre". The works exposed below reveal the significance of his contributions.

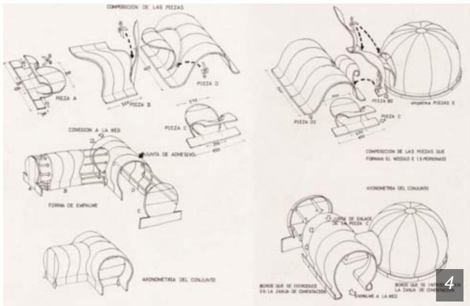
Expoplástica Pavilion 1968/69

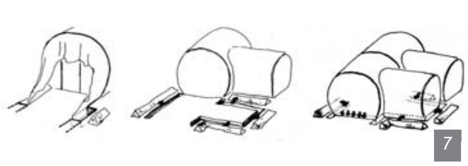
For the Expoplástica Pavilion (Fig. 2) a geodesic Fuller's scheme was chosen but discretized with hexagonal and pentagonal inflated cushions instead of bars, that is without supporting structure. They were assembled with zippers, so that they could be removed easily. The material was polythene 0,2mm thick, resisting 250gr/cm and heat welded. Each cushion was provided with a valve to inflate and regulate the air low pressure (150mm H_2O). The dome was also intended to be adaptable to the environmental conditions, "a pneumatic structure of variable response", anticipating what much later has been called "smart" structures. It withstood gusts of 60 to 70km/h and was dismantled after the exhibition.

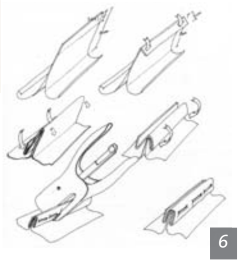
Figure 1. José Miguel de Prada Poole, 1969.
Figure 2. Expoplástica Pavilion, Madrid 1969.
Figure 3. Instant City, Eivissa 1971.

Instant City, Eivissa 1971

For the VII International Congress of Design, that took place in Eivissa in 1971, the students were also called to attend, but they couldn't afford hotel expenses. To solve this problem of temporary accommodation in three months, without budget, some of them invited J.M. de Prada to apply his previous experiences and ideas. The answer was the "Instant City", a colourful expandable temporary city-camp made of strips of the cheapest plastic available at that time on the market, which was donated by the manufacturer (Fig. 3). It was a combination of cylinders and domes that followed a rigorous morphological system based on a set of instructions that was given to the self-builder participants as a "grammar of use" (Fig. 4). All installation procedures were indicated starting with a repertoire of shapes for the corridors and modules (Fig. 5), the marking and cutting of the panels and their subsequent joining by means of staples, for which only markers, measuring tapes, scissors and office staplers were used. The stapled joins are somewhat less resistant (around 15%) than the welded ones, but they only need staplers and also allow amendments without replacement of the affected parts (Fig. 6). The anchoring was carried out in trenches, 30x30cm in cross section, in which the membrane skirts were buried by filling in with the excavated soil, that was manually tamped, so that only shovels were needed (Fig. 7). And finally, the whole was inflated by blowers. Economy of materials and auxiliary means, lightness and self-construction (Fig. 8) in a short time (two weeks) were achieved. It is remarkable in addition that the whole complex disappeared in two days after the event, hence the nickname of "city without trace" that was given to it, fulfilling the maximum aspiration of ephemeral or "perishable" architecture (as J.M. de Prada liked to call it). The reciprocal influence between users and architecture that happened was also greatly appreciated.







INSTANT CITY:
Figure 4. Grammar of use (extract).
Figure 5. Corridors and modules.
Figure 6. Stapled joint instructions.
Figure 7. Anchoring without footprint.
Figure 8. The Instant City was built by its users.

Eleven domed pavilion for the Pamplona Encounters, 1972

The 1972 Pamplona Encounters were an art festival with concerts, exhibitions, performances and installations of all kinds. To house them, eleven large domes, (25m in diameter and 12m in height), covering 5.000m^2 were built close to the Pamplona Citadel (Fig. 9). The colours chosen for the 8.500m^2 welded PVC membranes (white, yellow, and red) filtered the light and spread it across the space, creating an enlightened interior atmosphere (Fig. 10). There were also slight variations in pressure and temperature and the air was perfumed to conceal the smell of plastic. As a result, the effects of sound, tactility, and olfaction were emphasized to address a "sensorial sensitive" experience in line with some of the artistic interventions that took place during the Pamplona Encounters.

Hielotrón, Sevilla 1976

The oil crisis of 1973 launched the need for energy savings. At that time J.M. de Prada received the commission of an ice-skating ring under a hot climate (Figs. 11 -12). A large rink (56x26m) was built, surrounded by 820 tiered seats with complementary service facilities: cloakrooms, sauna, gymnasium, first aid room, restaurant-café, dressing rooms, etc (Fig. 13). There were also, two narrow tracks or "skating routes" 3,70m wide and 120 and 38m long respectively which left the main ice-rink and, after following a winding course, re-entered it. All parts of the complex were placed under an inflated membrane of PVC coated polyester subjected to 62/65mm H_2O) pressure and reinforced by a cable network, which absorbed part of the stresses and diverting the loads to the peripheral concrete rings that rounded the building at a height of 1,20m. A considerable challenge was to maintain a huge thermal difference produced by the variations of outside and inside temperatures, resulting from the weather conditions and the varying flows of the public. The challenge was addressed embedding the mechanical systems into the peripheral rings of concrete intended for anchoring the membranes. In this way, the cool air circulated through the perimeter of the domes and flowed into the rinks. The result was a pool of dense cold air that settled just above the ice, while the height of the domes, equivalent to a five-story building, kept the less dense warm air high up enough to create a thermal gradient. In this way it was possible, even in the warmer months of the year, to skate on ice in short sleeves, with a minimal energy expenditure. So that the project was successful in its aims, achieving the lowest energy consumption of any ice-skating rink. In fact, it was commercially known as Hielotrón (Icetron), connoting a machine or device more than a building.

Figure 9. Pamplona Encounters, 1972.
Figure 10. Pamplona Encounters: interior atmosphere of the domes.

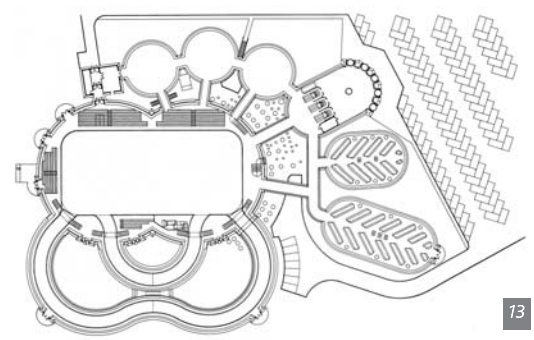
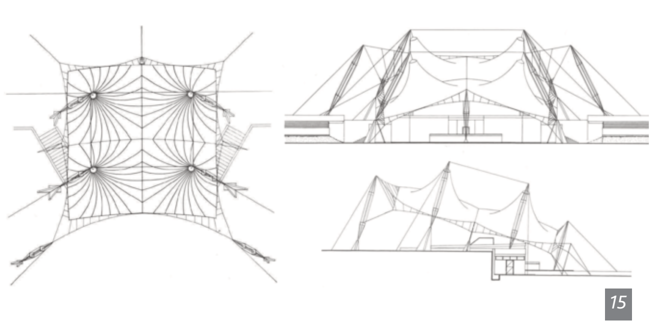


Figure 11. Hielotrón, Sevilla 1973.
Figure 12. Hielotrón: rink.
Figure 13. Hielotrón: plan.



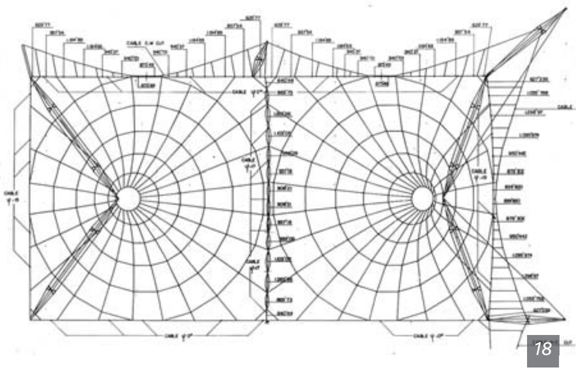


Figure 14. Killian Court, MIT 1981.
Figure 15. Pinar del Rey Auditorium: plan, rear and side views.
Figure 16. Pinar del Rey Auditorium: tied mast.
Figure 17. El Palenque, Sevilla 1992. Front and side views. Under construction and completed.
Figure 18. El Palenque: a corner module in plan.

Open-air foldable roof, Killian Court, MIT 1981

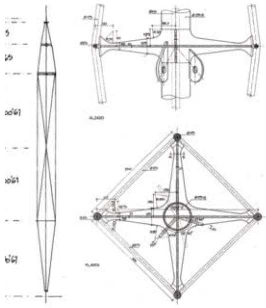
An easily removable open-air roof was designed to shelter academic events held in the university courtyard (Fig. 14). It happens to be one of the first applications of computer assisted design to tensile structures. The students made the patterns with the software provided by J.M. de Prada. They checked it by building the physical model that served some years later as a starting point to design the "Palenque" in Sevilla 1992.

Auditorio Pinar del Rey, Madrid 1986

Starting from the antecedent of the roof designed for the MIT Killian Court, a 625m^2 roof for an open air theatre was designed based on four modules pre-stressed by external cables and supported by tied masts (Fig. 15). Taking the cables outside the edges prevents the sag (needed to ensure low cable forces) from reducing the covered surface. On the other hand, tying the masts is a procedure to reduce buckling and therefore to lighten them. It is achieved with crosstrees and tied rods (Fig. 16). In this way, the cross section of the mast is reduced to 80x3mm, enough so that they are not perceived as oversized, as it is often the case. The resulting ratio of weight of steel to surface was 3kp/m^2 showing the advantage of avoiding bending as it happens with structural membranes.

El Palenque, Sevilla 1992

A further development of previous experiences was the "Palenque" roof for the Sevilla Expo in 1992. It was about covering a large public space (8.125m^2) to meet for shows, formal acts or simply to rest. The roof is subdivided into 25 modules of 13x25m (Fig. 17) and each module consists of two inclined conoids (Fig. 18) that hang from tied masts. The whole is pre-stressed by cables placed in a radial position, following the valleys between modules and running outside the edges according to the solution experienced in Pinar del Rey (Fig. 19). The structure is completed with masts that support the membrane. Of the procedures to lighten the masts and poles such as tapering, branching, coupling or trussing, the "Palenque" opted for tying them. Cross-trees 10mm thick and ties Ø25mm lighten the mast by reducing the buckling length from 7,60m to 4m so that a CHS of 115x7mm is enough (Fig. 20). It is a way to save steel and to prevent the mast from looking oversized. To improve the thermal performance so that the environment was bioclimatically pleasant, a sprayed water cloud above the roof was planned, but unfortunately it was not executed (Fig. 21). However, the roof continued to be used after the exhibition, until its demolition in 2006.



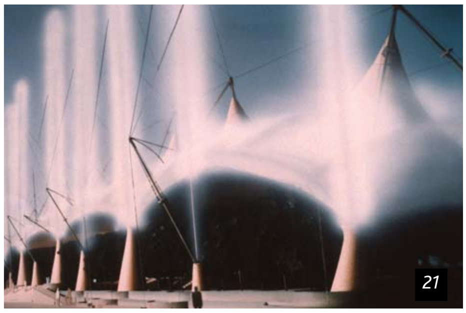


Figure 19. El Palenque: side view. Note the radial, valley and edge cables.
Figure 20. El Palenque: tied mast.
Figure 21. Water spray jets would have greatly improved the climate.

Other works and concerns

J.M. de Prada was very concerned about temporality and mobility of structures, which led him to utopian ideas and the development of several experimental prototypes.

The "Ellipsoid, 1969", (Fig. 22) built in the School of Architecture of Madrid, was an introduction to pneumatic structures. Despite the fact that the plan was circular, the section was elliptical to reduce the volume and to come close to the drop of water resting on a surface which maintains surface stresses uniform. This experience contributed to the development of the knowledge, details and installation procedure that became part of the author's baggage for the realization of his works (Fig. 23).

With the mobile worm "Jonás" (Fig 24) a structure adaptable to variable needs was tested. It could move and was able to group into colonies by changing the pressure of its cushions. Its name came from the first man that lived in an intelligent structure, because the whale swallowed and moved him.

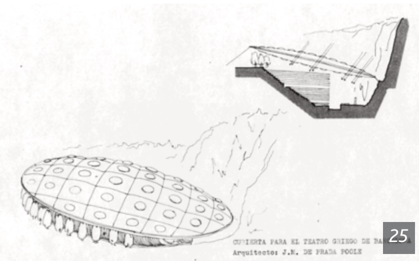
The design of a lentil cover for the Greek Theatre in Barcelona 1973, is a low profile inflatable structure reinforced by a net of cables surrounded by a circular trussed beam (Fig. 25). It is an application of a prototype conceived for temporary roofs such as bullfight rings, an antecedent of the movable roof of the Vista Alegre bullfight ring, 2000 (Fig. 26).

In 1974 another visionary design, related with Archigram proposals of the sixties, was a flying roof, 220x180m, that pushed pneumatic architecture to the limit of airships (Fig. 27). It was about transporting tourists and merchandise and eventually covering stadiums, carrying its own spectators.

More information about other projects, tests, utopias and the philosophical thinking of J.M. de Prada can be found in the bibliography.

- T.Herzog, 1977: "Pneumatic structures. A handbook for the architect and engineer". Crosby Lockwood Staples, London.
- J.M. de Prada et al. 2019: "La arquitectura perecedera de las pompas de jabón". Editorial Recolectores Urbanos, Málaga.
- N.Prieto, 2013: "La arquitectura de José Miguel de Prada Poole. Teoría y obra". Universidade da Coruña. Available at: https://ruc.udc.es/dspace/handle/2183/11917 *(visited 11/12/2021)*

Josep Llorens, Dr. Architect
ignasi.llorens@upc.edu
ETSAB/UPC



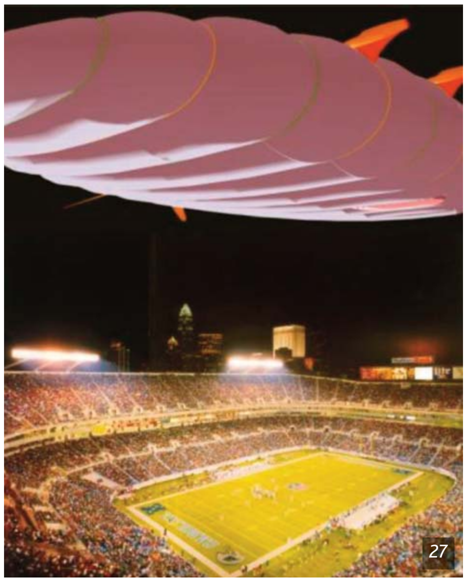


Figure 22. The Ellipsoid, 1969.
Figure 23a/b. Factory buildings, 1983 – 1984.
Figure 24. Jonah, the mobile worm, 1970.
Figure 25. Proposal for the Greek Theatre, Barcelona 1973.
Figure 26. Vista Alegre bullfight ring movable roof, Madrid 2000 (sbp with Skyspan and Pfeifer)
Figure 27. Flying roof, 1974.

THE SUSTAINABILITY

OF TENSILE SURFACE STRUCTURES

For every project, the designer must think about the efficiency of production and use phase, and about the valorisation at the end of life of components and materials. These concerns should be considered from the very start of the design. Tensile surface structures are considered temporary, as the life expectancy of coated fabrics is 20 to 40 years, for ETFE foils it is more (100 years).
When reusable and/or recyclable materials are chosen, a building's environmental performance improves. But, to what extend is this applicable for membrane structures?

Analysing 4 case studies

By means of analysing case studies, 'circularity' in use and current options at the end-of-life phase have been evaluated. Three case studies were made from PVC-coated polyester fabric, one used an ETFE-cushion system (Fig. 1). Environmental Product Declarations are used to estimate environmental data like the Global Warming Potential (GWP) and the Primary Energy Demand (PED) (Table 1).

From the 15th till the 21st of August 2005, the World Youth Day event took place in Cologne. **Wolke Marienfeld** (Fig. 1) was a pneumatic structure that served as the Pope's stage roof. At the end of the event, after only a few days, the construction was dismantled. The modular truss components were reused, while the membrane fabric was unfortunately thrown away (landfill). The client did not want that this iconic construction should be reused for another purpose.

Figure 1. Wolke Marienfeld, © form TL
Figure 2. The Finmeccanica Pavilion, © Canobbio
Figure 3. The new Elspe Grandstand Roof, © Koch Membranen
Figure 4. Dismantling the ETFE-cushions, Vodafone project, © Vector Foiltec

Table 1. Case studies: General information and end-of life	Elspe Grand-stand canopy (3)	Wolke Marienfeld (1)	Finmeccanica Pavilion (2)	Vodafone Project (4)
Year of construction	1978	2005	2006	2001
Covered Area	2600 m^2	960 m^2	1695 m^2	278 m^2
Material	PES-PVC	PES-PVC	PES-PVC	ETFE-cushion 8system
Self-weight membrane	1600 g/m^2	900 g/m^2	750-900 g/m^2	1000 g/m^2
Overall weight	13,5 kg/m^2	260,5 kg/m^2	50 kg/m^2	**4,59 kg/m^2**
Use	**37 years**	2 weeks	every 2 years 4 w	20 years
Year of dismantling/ renovation	Membrane replaced in 2015	Dismantled in 2005	Reused in 2008, 2010, 2013	Dismantled in 2020
End of life	couldn't be recycled/reused	landfill	stored, Incinerated?	**downcycled**
GWP per m^2	**9.8 kg CO_2-eqv**	**4.54 kg CO_2-eqv**	**5.55 kg CO_2-eqv**	58.2 kg CO_2-eqv
PED per m^2	**135 MJ**	**142 MJ**	**78.1 MJ**	747 MJ

The **Finmeccanica Pavilion** (Fig. 2) was built in 2006 for the International Air Show (Farnborough, UK). After four weeks, the construction was dismantled and stored. The pavilion was reused in 2008, in 2010, and in a different set-up in 2013 in Le Bourget (Paris, FR). The steel frame could be reused. What happened afterwards with the membrane and foils is unknown.

The **Elspe Grandstand cover** (Fig. 3) is an open canopy, hanging on 2 main cables. The structure was built in 1978 and the membrane replaced in 2014. The primary structure was reused, without major modifications, and supports the new roof for another 40 years. The old membrane was thrown away.

At the **Vadofone project** (Fig. 4) the ETFE cushions in the roof, installed in 2001, have been replaced in 2020, with the primary structure being reused (Newbury, UK). Vector Foiltec takes back all old material to recycle it, and purchases flexible pipes and valves made from recycled ETFE.

Generally spoken, the self-weight of all these structures, considering skin and supporting structure, is low, especially for the ETFE-cushion system (4,59 kg/m^2).
The PVC-coated polyester fabric was in all cases either landfilled or incinerated, which is not at all an eco-friendly option. Only the ETFE foils were cleanly dismantled and downcycled. The GWP as well as the PED for the structures covered with PVC-coated polyester fabric is low compared to the ETFE-cushion system, as in the cushion system the aluminium frame is included.

Sustainable approach

Membrane structures are conceived to be temporary: they appear and disappear depending on their function. It is hard to find data about their environmental impact, or to draw general conclusions. More research effort is needed.

Although it is perceived that worn-out membranes have no value, their production represents a large part in the environmental indicators. Hence, it is important to find alternatives for the landfill and incineration, currently applied after a mostly short lifespan. The technology and knowledge to recycle exist, the whole membrane structures industry must take its responsibility.

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Marijke Mollaert, Lars De Laet, Zehra Eryuruk, Vrije Universiteit Brussel
Marijke.Mollaert@vub.be

Naturkraft
Architecture and Nature
Inspiring Interaction
Ringkøbing, Denmark

"People learn best with practical learning experiences." According to this motto, the Naturkraft theme park on the west coast of Denmark impresses with its unique architecture that makes nature tangible.

Futuristic Building with Texlon® ETFE Building Envelope
A 628m long wall surrounds the entertainment park. Following the form of the wall, there stands a futuristic building at the west side. With a height of about 15m, the Texlon® ETFE cladding allows visitors a great view over the whole area. This is where it helped to create an unforgettable learning environment for all visitors with the Texlon® ETFE building envelope.

The building houses a museum that introduces the public to the forces and power of nature. It provides an inspiring space for learning and reflection. Further, visitors will find a little shop, a restaurant and restrooms in the Texlon® ETFE cladded building.

Elaborate Architecture
Feeling nature is the common theme that is felt as you navigate through Naturkraft. Whether it is an impressive storm simulator, or the real patter of rain on the museum roof – you can hear and feel nature everywhere. This is all a huge bonus, which brings more attention to our environment. The park, and especially the building, give a great sensation of light and sound. The enclosed arena-like area of Naturkraft is not only interesting for families, but for all nature enthusiasts.

An elaborate architecture of a building and landscape awaits. Created by architects Hune & Elkjær with design leading of Thøgersen & Stouby, they deliver recognizable experiences. They bring people back to the park time and again. The Texlon® ETFE building envelope plays a part in contributing to visitors' comfort and satisfaction as well.

Texlon® ETFE Considers Isolation and Sunlight Reflection
Vector Foiltec engineered the Texlon® ETFE system for the facade. The U-value and g-value were important calculations while designing. They were necessary performance criteria that the client requested. At first glance these calculations seemed challenging but were easily executed with our ETFE system.

Our cushion system, combined with a dedicated printing technology on the upper ETFE layer, an ideal combination was created. This allows visitors to feel comfortable inside the building. This also affects the aesthetic and thermal performance of the Texlon® system for the building. Further, the silver print is only located on the outer layer of the system. This was done to ensure the overall transparency of the roof, in an effort to keep the views from the inside, thus enhancing visitors' satisfaction.

An interplay of artificial and natural light creates unforgettable impressions
Particularly impressive is the interplay from the automated artificial light system, with the light that the Texlon® ETFE system lets through. A very high amount of natural light comes through, allowing for a low amount of artificial light – which creates a comfortable atmosphere, plus it saves electricity. At the same time, this helps to blur the transition from indoor and outdoor experiences for visitors with the right amount of light.

1

2

Figure 1. Outside view © Vector Foiltec
Figure 2. Interior view overlooking the clouds © Vector Foiltec

Withstand Wind Forces
The innate toughness, high tear resistance and unique elastic properties of Texlon® ETFE, mean that this technology is particularly suited for applications where large deflections may be anticipated. Therefore, the design and engineering of the building envelope are designed to withstand the wind forces of the Danish west coast.

Build a Building like a Wall? Just Do it with a Texlon® ETFE System.
Is your entire building supposed to have the appearance and act like a wall? The properties and engineering opportunities of Texlon® ETFE and Vector Foiltec's expertise make it possible.

Heidrun Brandes
Heidrun.Brandes@vector-foiltec.com
www.vector-foiltec.com

Name of the project	Naturkraft
Client	Fonden Naturkraft
Function of the Building	Theme Park, Museum
Date	2020
Location	Ringkøbing, Denmark
Sector	Cultural/Exhibition
Structure	Steel
Type	Facades
Architects	Hune & Elkjær, Design
	Thøgersen & Stouby, Design leading
Landscape architect	SLA
Engineering	NIRAS, Fuldendt
Main contractor	Hansen & Larsen
Contractor for the membrane	Vector Foiltec
Manufacture and installation	Vector Foiltec
Material	Texlon® ETFE
Size (Covered surface)	2660m²

STRUCTURAL MEMBRANES 2021

X INTERNATIONAL CONFERENCE ON TEXTILE COMPOSITES AND INFLATABLE STRUCTURES

The "Tenth International Conference on Textile Composites and Inflatable Structures" was held online in September 2021, organized by the International Centre for Numerical Methods in Engineering (CIMNE) and chaired by K. U. Bletzinger (TUM), E. Oñate (UPC), R. Wüchner (TUM) and C. Lázaro (UPV). It was the tenth of a series of symposiums that originated in Barcelona in 2003, but unfortunately the event was not face-to-face, thus without meetings, contacts, coffee-breaks, gala dinner and technical visits. Hopefully, in the next edition, to be held in Valencia in 2023, normality will be restored.

At the two-day conference, 6 plenary lectures and 73 presentations in 14 sessions were given to 99 participants.
https://congress.cimne.com/membranes2021/frontal/Objectives.asp

PLENARY LECTURES

Katja Bernert from Mehler Texnologies started the conference with her plenary lecture: "Transforming textiles to testimonies". She talked about the problem of recycling the materials used in the manufacture of membranes. In recent years, there has been a short success when it comes to solutions for recycling vinyl coated polyester fabrics. The separation of glass fibres from PTFE coatings is not yet solved sufficiently and, on the other hand, clients and industry are not willing to spend money on recycling or reusing material. At the same time the weaving and coating industry developed material with extended durability weakening the need to find immediate recycling solutions. Other approaches could be the use of recycled raw materials (not necessarily from used membranes), specific actions such as urban healing skins (Fig. 1), maintenance, inspection, cleaning or to find regulations that prescribe the use of a certain ratio of recycled material. As in other areas too, a binding commitment might be the only solution to bring forward recycling processes.

Improving the efficiency of membranes was also the topic of Josep Llorens from the Technical University of Catalonia. In his lecture "Appropriate design of structural membranes" he found that although design tools have progressed considerably, some membrane structures are still designed without taking advantage of their structural characteristics.

The result is usually a disproportionate steel structure that is cladded to generate an (arbitrary) projected shape. In order to achieve a good result, he (highly) recommended to respect the principles of only tension, funicularity, curvature and pre-stressing, as well as to take advantage of the available design methods to properly determine the form (in equilibrium), the loads and the hybrid behaviour of the structure. The most significant variables can also be parameterized, just as bending avoided in the supporting structure and compression optimized (Fig. 2). Several improvements have been introduced that can be investigated further and best practices could be looked up.

In the third plenary lecture, Helmut Pottman from the Centre for Geometry and Computational Design KAUST, Saudi Arabia, gave a master class on geometry applied to grid shells for the design of architectural surfaces from flat quadrilateral panels (Fig. 3). The design process of so called "free" form surfaces includes a feasible segmentation (discretization) into panels. A basic, convenient and structurally stable way of representing a smooth shape in a discrete way is the use of quadrilateral meshes with planar faces, that tends to have less weight than triangular meshes [1]. It should be noted that all the treatment was only geometric. The structural behaviour was not analyzed, so there is the possibility that the surface obtained is not feasible with a tensioned membrane.

Figure 1. A second skin façade reduces nitrogen oxide pollution. Aachen Central Bus Station.

Figure 2a/b. Two different approaches to design the support of a membrane.

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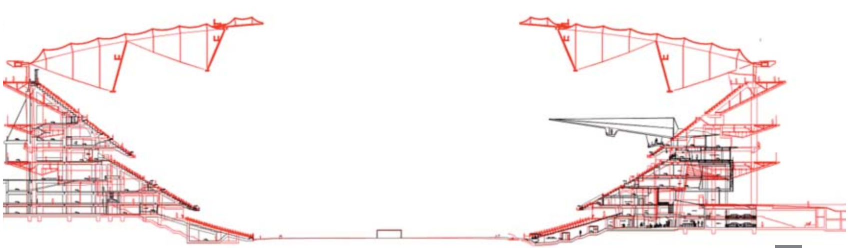

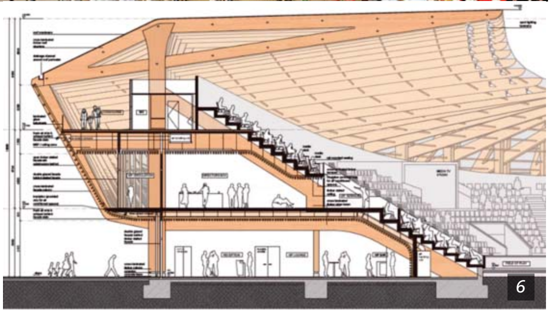

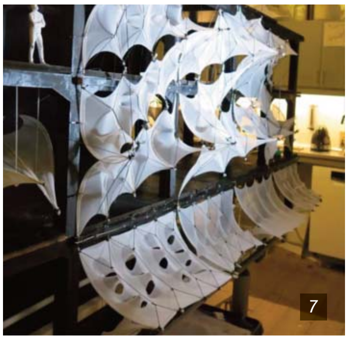

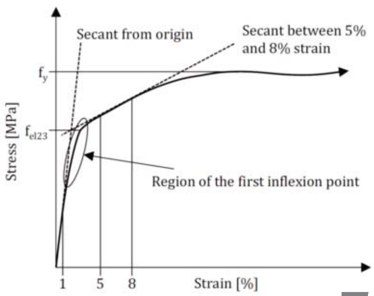

Figure 3. Architectural surfaces from flat panels (Helmut Pottman).

Figure 4. Nou Camp Nou, Barcelona, sbp. (black=existing, red=new).

Figure 5. Demountable and transportable Stadium Ras Abu Aboud, Qatar, sbp together with Fenwick Iribarren Architects and Hilson Moran.

Figure 6. Zaha Hadid Architects with sbp: Forest Green Rover Stadium entirely built of wood and other environmentally friendly materials.

Figure 7. Model study for the installation of knitted membranes, CITA, Denmark.

Figure 8. Simplified method to determine the elastic limit in a uniaxial stress-strain path.

In his presentation: "The lightweight principle - An important key for embodied carbon reduction in construction", Knut Göppert from sbp referred to 5 strategies to improve the sustainability of large span structures. The first strategy is lightness to save material as the top priority, with special mention to the spoke wheel system. For the new stadium of the Tottenham Hotspurs FC, the cable roof provided a 12% weight reduction versus the solution based on trusses and cantilevers. The second strategy is to resort to modernization rather than demolition, as demonstrated in the Mercedes Benz Arena, the Kiev National Stadium and the Berlin Olympic Stadium, among others (Fig. 4). Multifunctional use is the third strategy enhanced by the retractability of the roof, and the fourth is to give stadiums more than one life. It is the case of demountable stadiums, very suitable in cases where smaller venues are needed (Fig. 5). And the use of timber provides the fifth strategy (Fig. 6). He concluded that membranes will be the perfect material for roofs and façades.

Mette Ramsgaard Thomsen from the Centre for Information, Technology and Architecture (CITA), Denmark, explored the possibilities of knitted membranes in architecture. She discussed emerging methods for predicting the material behaviour of functionally graded membranes using knit as a method of locally tuning the performance. Starting from the textile systems and hybrid structures examined by CITA across the last 10 years, she addressed the form finding, simulation and fabrication to create highly bespoke membranes that incorporate detailing and change knit structure detailing to shape the performance. Prominent examples were the hybrid tower installed in Guimaraes, the Isoropia pavilion in Venice and the installation in a large hall of an old factory (Fig. 7).

The last plenary lecture was given by Natalie Stranghöner from the Institute for Metal and Lightweight Structures, Essen: "European ETFE-design. New findings and concepts". She aimed to give an insight into the ongoing development of standardization and research activities for foil structures. With the publication of the Technical Specification prCEN/TS 19102, the European Committee for Standardization (CEN) will provide a European standard for the design, analysis and execution of buildings and structural works made with structural membrane materials. This includes many kinds of tensioned membrane structures, including fabrics as well as foils in general and ETFE foils in particular. The safe and economic design involves an understanding of the material and seam behaviour. For this purpose, she gave an overview on different research projects which examine the short and long-term behaviour of ETFE-foils and their welding. Subjects of these projects are the tensile, creep and relaxation behaviour of the base material under uniaxial and biaxial stress ratios as well as the tensile behaviour of the weld seams and the optimization of the welding and testing procedures (Fig. 8).

9

Figure 9. Sequence of the modeling with combined pneumatic and mechanical stressed structures.

NUMERICAL METHODS AND MODELING

This session is the one that received more contributions. Jürgen Holl from Technet participated with: "Fast model generation and static calculation of combined pneumatic and mechanically stressed structures". The generation of models and static calculation of combined structures are often a challenge because mechanically stressed membranes need form finding calculation. The geometry cannot be fixed arbitrarily because internal forces or stresses and the surface geometry are not independent of each other. It is not the case of pneumatic structures whose shapes can be created sometimes by geometric functions such as spheres, cylinders and torus. When combining mechanically and pneumatically stressed structures, a particular difficulty in model generation is the intersection of individual volume elements. To avoid the intersection problems in the case of discrete meshes, Nurbs surfaces can be used and intersected. The newly created partial surfaces as objects are combined and then discretised. This results in topologically correct mechanical models that are suitable for a static calculation (Fig. 9).

DETAILING - CASE STUDIES - INSTALLATION

Katja Bernert from Mehler Texnologies started this session with "A travel guide to textile architecture" showing recent textile architecture projects highlighting a school and a resort. The Green School campus in New Zealand is described [2] as a "collaborative design based on organic materials in order to function sustainably and provide students with a shelter nestled amongst nature. Curved shapes are predominant to create an atmosphere that supports alternative thinking. The learning pods are built with light materials and surrounded by native plants in an inspirational environment for the students to think openly and creatively, while enjoying all aspects of the exquisite outdoor setting" (Fig. 10). In a more playful way, she also mentioned the Thorntree River Lodge, Zambia (Fig. 11).

Nicolas Pauli from the Laboratoire Innovation Forme Architecture Milieux (LIFAM), School of Architecture of Montpellier described the design, fabrication and erection of the permanent circus tent with rock wool isolated tensile roof of the National Circus Centre "SIRQUE" installed in the heritage site of the castle of Nexon (Fig. 12). The size of the circus tent is 40x18x11m. The surface in plan is 650m^2, the surface of the membrane is 1.100m^2 and its form is "cylindrical" with an end in a quarter of "sphere". Its structure is composed of 7 arches and 5 half arches made of steel. The envelop is based on the use of 2 textiles skins with a distance of 300mm, including a 140mm rock wool insulation layer (U=0.2 W/m^2K) in between, naturally laying on the internal membrane, and just maintained in place by straps. To avoid condensation venting areas have been designed. The membranes are laced all along their peripheral edges on upper and lower tensioning beams upon a Ø33mm CHS. Notably, in order to avoid moisture pass through from the inside of the building into the rock wool, the internal skin has been waterproofed manufacturing it in only 1 piece of 1.100m^2 creating a watertight barrier between in and out.

Gerd Schmid from formTL exposed: "Infrastructure buildings – New design language for urban architecture: Bus stations, tram stations, transfer hubs". He introduced the problems of the roofs in public spaces that are rarely cleaned. The glazing and the colour-coated metal roofs become dirty. Pigeon defence spikes are stuck to lattice girders in which paper cups, bird feathers and gray cobwebs collect. The buildings fulfil their intended task inadequately because lack of care provokes negligent behaviour and the public places become more and more inhospitable. In addition, construction is often carried out with open profiles on which a lot of dirt is deposited. As a result, these roofs often look neglected. As a solution, materials that have less adhesion can be used. For example anodized aluminium, ETFE foil, circular hollow sections with no landing places for pigeons and corrosion protection (Table 1).

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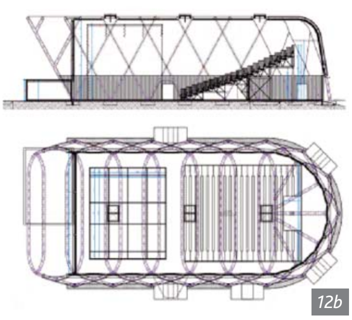

12b

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form TL design compared with common design	Common designed High maintenance needed Short term visual quality	Enhanced form TL design Little maintenance. Long term visual quality
Profile	Open profile	Hollow section
Girder	Girder truss. Space frame	Single beam
Envelope	PVC coated polyester Membrane with acrylic finish Glass sheets	ETFE or PTFE Anodized aluminium
Combination	Exposed structure	Covered structure
Corrosion protection (profiles)	C3-C5 M (5-15 years)	C3-C5 VH (>25 years)
Corrosion protection (ropes)	Hot dip coated steel wire	Stainless steel Galfan coated wire Aluminium coated wire

Figure 10. Boon Architects, 2020 Green School, New Zealand.

Figure 11. Thorntree River Lodge, Zambia (courtesy of Mehler Texnologies).

Figure 12a/b. ADH Architects with Abaca, VSO and SIRC, 2021: "SIRQUE" National Circus Centre tent, Exon.

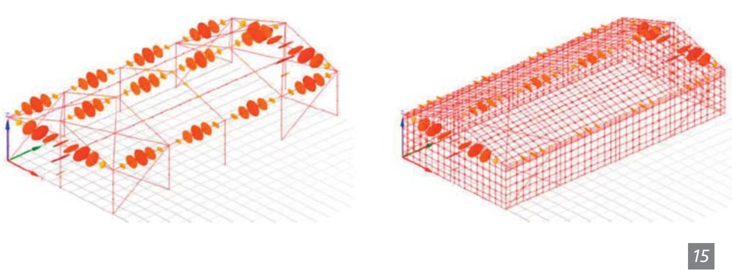
Table 1. formTL design compared with common design of bus stations

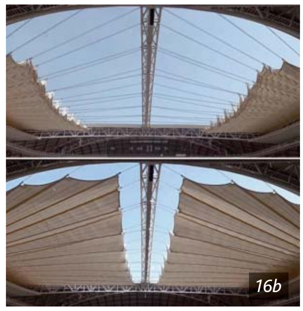
Figure 13. formTL: Bus Terminal, Sursee.

Figure 14. Seam test carried out with foil exit angle of 15º.

Figure 15. The flexibilities of the ridge and eave purlins are far bigger in the conventional calculation (left). The membrane stiffens the steel structure (right).

Figure 16a/b. Zaha Hadid with Maffeis and Pfeifer, 2019: Al Janoub Stadium, Al Wakrah.





On the other hand, table shapes can be adopted to be freely adapted to floor plans. Together with the visual lightness, the interaction between artificial, natural light and the colour of the sky creates a good and friendly atmosphere on site supported by the cleanliness and quality of the materials (Fig. 13). This design language is not only suitable for mobility buildings but basically for all types of buildings in public spaces, where it is important that architecture creates identity and where the town administration often forget to look after their buildings.

Andreas Kunze from the Deutsche Institute für Textil und Faserforschung, Denkendorf, introduced the "Integration of ETFE foil cushions into conventional glass facade systems by means of adapted, space-saving joining methods". The current technology for producing a translucent facade is dominated by glazing, facade construction kits and a high degree of prefabrication. A new technology was discussed, that allow the integration of ETFE foil cushions into conventional, customary, modular glass facade systems on the market. A new facade element was presented, which consists of a rigid profile frame with integrated thermal separation, covered on both sides with ETFE foil. New edge formations have been developed and tested with regard to the industrial prefabrication of rectangular ETFE facade cushion elements. In particular three space-saving joining methods for joining ETFE foils with aluminium profiles were presented and discussed: gluing with cyanoacrylate adhesive, welding onto an ETFE coating and clamping in a mini keder, as well as the associated, necessary pre-treatment methods. An assessment of the joints was made through tensile tests (Fig. 14) and long-time outdoor weathering tests. All methods were applied in demonstrators. He concluded that all methods represent technical solutions and, with regard to recycling and reuse, the clamping process offers easy material separation. The glued foils can also simply be peeled off and the profiles cleaned by sandblasting. So far, the ETFE coated surfaces can only be welded over. The welding technology is particularly interesting for the automatic covering of frames in a production line.

Dieter Ströbel from technet addressed the calculation of textile halls. He stated that the calculation of textile membranes should never be carried out independently of the primary support structure. The separation of the membrane and the primary structure, with the reaction forces applied as external loads, results in significantly higher steel consumption and is therefore uneconomical. The idea that the savings from the hybrid calculation (i.e. the calculation of the membrane and the primary construction together) are only given for double-curved membrane surfaces was refuted because even with straight membrane surfaces, as they are usually present in textile halls in general, smaller cross-sections are obtained for the primary construction through the coupled or hybrid calculation. Nevertheless, these more accurate models are little used in practice because their generation is time-consuming and not all requirements can be represented in usual software packages. In particular, membrane panels that are not firmly attached to the steel or aluminium elements, but rather membrane surfaces that slide over them, are a problem. He showed that a fast modelling under consideration of sliding conditions yields results that are below the usual deformations and metal quantities (Fig. 15).

"Structural membranes in motion" was the contribution of Thomas Hermeking from Pfeifer. He started listing the elements of retractable structural membranes that are cables, sliding trolleys, winches, membranes and operation and control systems. He mentioned several examples, highlighting the main characteristics of the Al Janoub FIFA World Cup Stadium retractable roof. It is a unique combination of structural cables and membranes in motion, with a surface of 12.000m^2. It consists of two halves that close on a central girder with a combination of cables and membranes reinforced with belts in a widening geometry that created new challenges for the driving system never faced before. The lines have been arranged in a “V” shape by means of non parallel valley and ridge Ø55mm cables connected to the central girder (Fig. 16). The trolleys of the driving system travel on rails that are not straight, but slightly arched with different lengths, different levels, different slopes and changing distances between the grid lines. 50 Winches have to be synchronized for moving and tensioning the panels up to 200kN. An advanced driving system with maximum control flexibility to move the membrane smoothly and tension it correctly has been needed. Additional requirements were the extreme environmental conditions (high corrosion, high temperatures and sandstorms) and minimized visual impact of the mechanical system, meaning a reduced number of catwalks and grating, together with tensioning the membrane with winches instead of hydraulics.

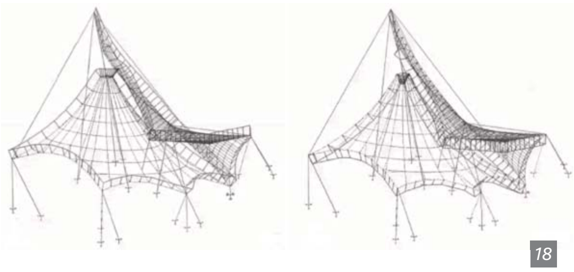


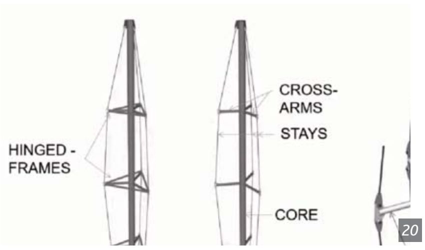
Figure 17. G. Capellán with Arenas & Asociados and Lastra & Zorrilla, 2003: Alicante Cruise Terminal.
Figure 18. Uniform wind load: pressure (left), suction (right).
Figure 19. A. de Palacio & F. Arnodin, 1893: Bizkaia Bridge, Getxo.

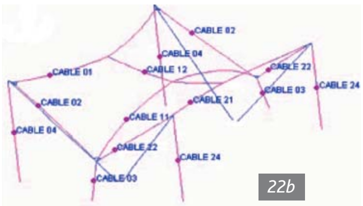
MASTS

Structural membranes rely on tension, but their supports are structures under bending or compression that are much less effective. Bending may be avoided as much as possible, but there is almost no choice but to grapple with compression. That's why it is of greater interest to deal with masts which are the compressed members par excellence.

Santiago Guerra from Arenas Asociados drew attention to the design of masts with the example of those that support the textile roof of the Alicante Cruise Terminal (Fig. 17). It consists of a hyperbolic paraboloid overlapping a conoid around a main mast (33m high, Ø619x16mm) tensioned by 6 secondary masts (5 to 11m high, Ø170x10 to 219x10mm) and anchor points through Ø22mm cables. The footings receive the masts and act as counterweights to tension anchors. They are braced by beams to resist seismic actions. The simulated wind load (pressure and suction) was uniform, independent of the deformations, with values from 1kN/m^2 up to 30m high to 1,25kN/m^2 beyond (Fig. 18). Covered surface: 460m^2; Material cost (2003) 315.000€; Bidding cost 450.000€ = 975 €/m^2 (VAT included).

Bruce Danziger in his lecture: "Elegant Mast Structures" explored the creative structural engineering design process for elegant mast structures. He was amazed by some achievements of the past such as the Shukov tower in Moscow 1922 and the transporter bridge in Marseille 1905 similar to the first one in Getxo (Fig. 19). He mentioned the Travel and Transport Building of the Century of Progress Exposition in Chicago 1933, the Trylon, Perisphere and Helicline of the World of Tomorrow in New York 1939, the Skylon of the Festival of Britain 1951, Miguel Fisac, Robert le Ricolais, the Yoyogi National Olympic Stadiums 1964 and the Batcolumn in Chicago 1977 among others. He also mentioned more recent examples in which he participated including the Pavilion of the Future at the EXPO '92 in Sevilla, the Sony Center Forum Roof in Berlin and the Tropical Rainforest Greenhouse of the Taichung Botanical Gardens.





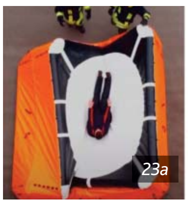


Figure 20. Stayed masts.
Figure 21. HOK Sport, 2003: Algarve Stadium, Faro.
Figure 22a/b. Stage canopy, Barrie.
A redundant cable (nº 12) would hold the masts in the event of failure of the membrane and would create a ridge under snow load to prevent ponding.
Figure 23. Rescue cushion: at work (a), simulation (b).

Large cable-stayed masts were the topic of Sudarshan Krishnan from the University of Illinois at Urbana-Champaign. Their structural merits lie in the reduced core size and high compression strength derived from the use of prestressed stays attached to crosstrees (Fig. 20). They have been used in iconic stadia structures such as the Algarve stadium in Portugal designed by HOK (Fig. 21). Its roof is suspended above the seating to allow for uninterrupted spans and views for the spectators by means of four majestic steel stayed masts that support the roof structure. Steel trussed-arches connect the base of the stayed columns along the long directions. Two additional tubular arches reduce the overhang of the roof framing. The PVC fabric membrane roof is suspended from cable trusses and supported by the arch system below. Each roof is supported by two mega stayed columns that rise 72m high and help to anchor the high-tension forces from the 210m long catenary cables holding the fabric membrane. The stayed masts are anchored by means of four 32mm diameter cables. The column core dimensions and weight are optimized by a system of three-tier cross-arms that provide lateral restraint to the 660mm diameter core tube. More examples illustrated the advantages of improving the masts by staying.

David Campbell from Geiger, Lynch, MacBain & Campbell Engineers worried about "Mast Stability and Prevention of Disproportionate Collapse in the Event of Membrane Failure". He stressed the need for the structure to be redundant in order to prevent a local failure from becoming a total collapse. Tension membranes have low tear strength in relation to their tensile strength. This results in the membrane being vulnerable to tear propagation due to imperfections. That is why the ASCE/SEI 55-10 Standard [3] states: "Tension membrane structures shall be designed so that failure of the membrane or of a single supporting element, does not result in progressive collapse of the structure". Masts are elements that require special consideration in the event of a membrane failure as they are often components of considerable size and mass. Issues concerning the stability of masts in post failure modes were reviewed. Various design solutions were shown together with several examples of built mast supported structures illustrating design strategies, philosophies, and solutions (Fig. 22).
A surprising presentation was that of Rami Faraj from de Institute of Fundamental Technological Research, Polish Academy of Sciences. It was about "Development of a new type of inflatable structure – the adaptive rescue cushion". It concerned a special type of inflatable structure, which can be classified

within the group of airbag systems. An application of airbags is the evacuation of people from heights. In such application airbags are used as so-called rescue cushions, which are operated by fire brigades in case the conventional evacuation is unavailable (Fig. 23). Although relatively high number of patents can be found, the scientific literature in this field is very limited. Nevertheless, importance of the problem and appearing accidents motivated the authors to start the research on development of a new, safer type of rescue cushion system, which will guarantee high performance and adaptive capabilities. A preliminary study revealed the possibility of significant improvements. That is why further research was conducted in order to provide a solution ensuring successful adaptation of the rescue cushion to the evacuation height, as well as the mass of the landing person. The general design methodology and objectives of the optimization have been presented within a case study. Constraints resulting from legal, functional and economic requirements were also discussed indicating the main challenges and directions of further research.

HYBRID AND ADAPTIVE STRUCTURES

Arno Pronk from the Eindhoven University of Technology and being a fan of ice keeps building and experimenting with it. He dealt with: "Fabric formwork with ice in Canada". In his workshop at the University of Alberta, the students tested V shaped beams, little over 6cm thick, made of a mixture of frozen water and paper, reinforced with a pre-stressed foil, fixed on a wooden frame, and smoothed as it froze (Fig. 24). As a result, the reinforced ice resistance can be estimated as three times stronger than the regular frozen water and greatly improving the ductility. The fibre also acts as an insulator and ensures the ice does not melt as fast. The materials are cheap and natural. Therefore, they do not harm the environment.

The lecturer considered the future of building with ice in projects that need to be strong but can be hard to clean up, such as temporary foundations for drilling rigs. He also said that it might have future applications, such as research on Mars, where the environment is very cold. This project with Canadian engineering students might inspire them to new possibilities in cold climates.

Andrey Chesnokov from the Lipetsk State Technical University in: "Adjustment of stresses in the top chord of the dome-like hybrid roof structure" showed the optimization of a hybrid structure described in figure 25. It consists of 8 ridge radial cable beams (1, 2, 3, 5 and 8), 8 valley cables (7). 2 hoop cables (4) and the pre-stressed membrane cladding (6). He distinguished between passive and active strategies to reduce material consumption under various external influences. Passive optimizations could be for example triangulating the top chords for stability enhancement and adding spatial ribs and flexible ties to mitigate bending moments. They are effective (reducing the peak beam stress from 508MPa to 219MPa) but not very efficient because they complicate the structural framework. Instead, the active strategy implies real-time stress adjustments by actuators driven by load cells. In case of sudden external impacts (e.g. earthquake, displacements of supports or soil deformations), the parameters of the construction are dynamically adjusted with jacks embedded in the construction. There is no need to add members or material to the structure to get a similar result. However, this active adaptive concept needs appropriate equipment for controlling the stresses and for implementing the adjustment in real time. It is currently used in solar energy harvesting, dynamic façade modules and damping of vibrations in cable-stayed bridges.

Andrey Chesnokov also presented: "Development and analysis of a pre-stressed cable roof with stiffening girder and polymer membrane cladding". In this case the hybrid structure is another combination of membrane, cables, stiffening girders and struts (Fig. 26). The membrane is attached to the top chord of the cable beams and pre-stressed by valley cables. In order to enhance the efficiency, the girder and the struts are linked together by means of limited design clearances (Fig. 27). The limited clearance is a gap between the girder and the strut that allows the strut to move freely up to a limited value in the vertical direction. In this way overstressing of the girder under uniformly distributed loads is prevented. But under non-uniform impacts, if the clearance run has been consumed, the retainer at the end of the clearance do not preclude levelling the loads and reducing the deformations of the roof. A section of the roof highlighted in figure 26 was analyzed with a computational technique based on static analysis. The polymer membrane cladding was included into the structural model. Deformations of the roof at the pre-stressing and operational stages were provided together with the stiffness properties of the cables and the girder, the required pre-tensioning of the bottom chord and the size of the design clearance. The favourable effect of the girder and the design clearances is remarkable. The deformation of the non-uniformly loaded roof without the girder is 1.45 times as large as the deformation of the roof with the girder installed and skipping the design clearances leads to overstressing the girder by the uniform load.

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[2] https://www.mehler-texnologies.com/wp-content/uploads/2020/08/Green-School-in-New-Zealand-2.pdf (visited 23/10/2021)
[3] ASCE/SEI 55-10, 2010: "Tensile Membrane Structures", Reston.

Josep Llorens, Dr. Architect
ignasi.llorens@upc.edu
ETSAB/UPC


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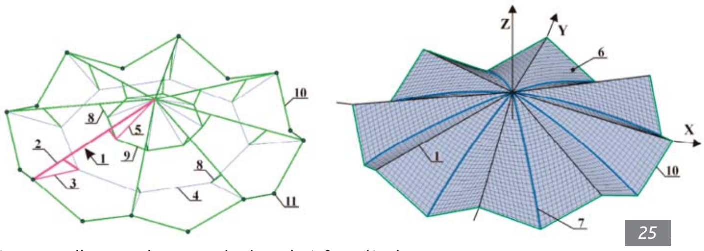
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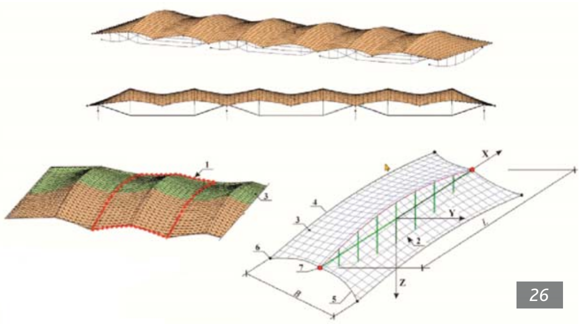
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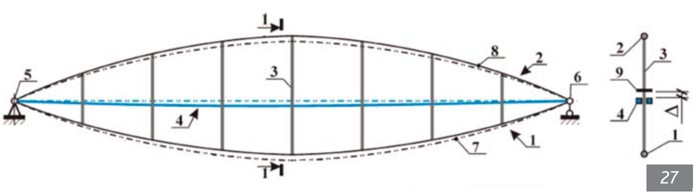
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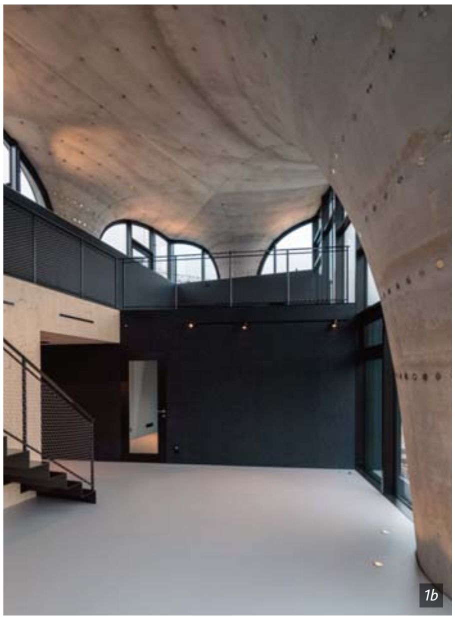
Figure 24. Alberta students tested V shaped reinforced ice beams.
Figure 25. Hybrid roof structure. Left: framework. Right: membrane
Figure 26. Cable roof structure
Figure 27. Structural model of the roof

HiLo Research & innovation unit for NEST

Dübendorf, Switzerland



The HiLo unit of the Next Evolution Sustainable Building Technologies (NEST) platform in Dübendorf, Switzerland, demonstrates the potential of digital concrete construction to lower embodied emissions and energy in the structure of buildings, reduce construction waste and minimize resource consumption. It also shows how the integration of advanced building systems in lightweight structures allows for energy efficient operation and high user comfort. HiLo stands for High Performance with Low Emissions. The unit is designed as a two-storey collaborative and flexible workspace with two closed offices and multiple shared, open office areas.

HiLo's key innovations include: (1) a doubly curved, two-layered concrete shell, (2) a flexible formwork with on-site active control, (3) a rib-stiffened funicular floor system, (4) the integration of Ventilation, Heating and Cooling, (5) an adaptive solar façade, and (6) intelligent and learning-based operation.

In HiLo, the Block Research Group at ETH Zurich shows three innovations in digital concrete construction that set new benchmarks for lowering embodied emissions, reducing construction waste and minimising resource consumption.

Doubly curved two-layered concrete shell (1)

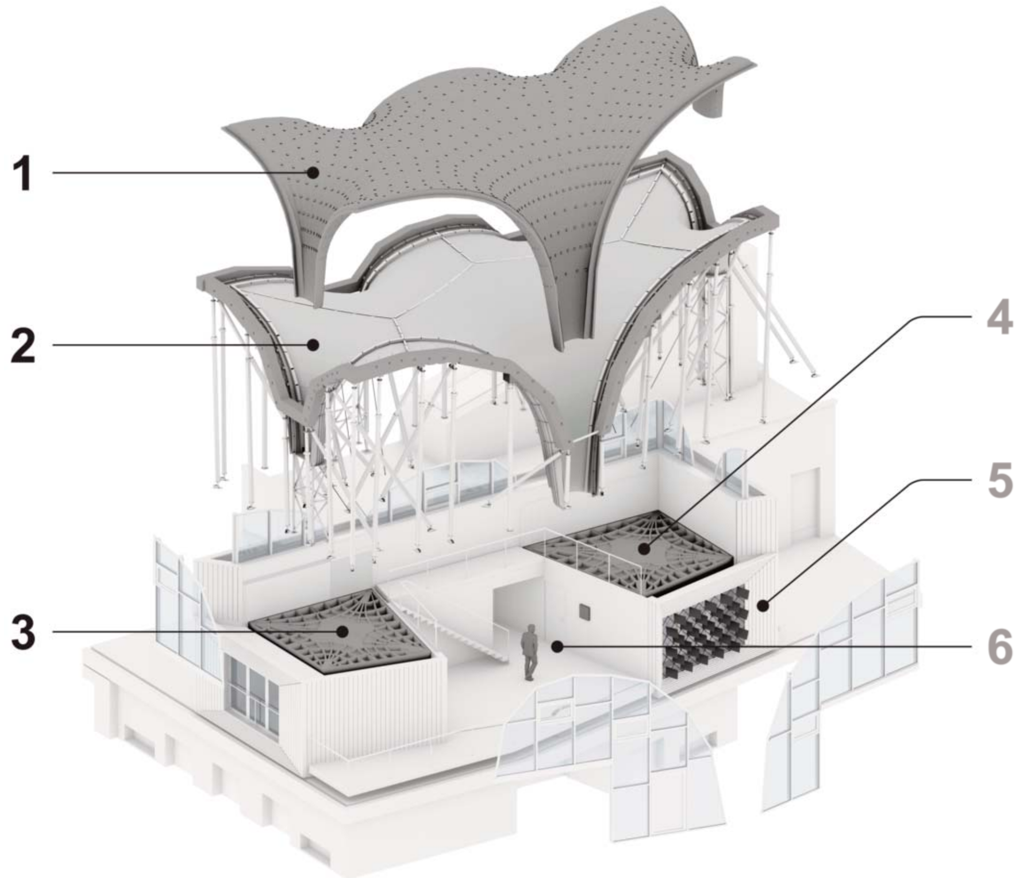
HiLo's roof is a doubly curved "sandwich" shell, containing a layer of insulation blocks between two sheets of reinforced concrete of only 5 and 3cm thick. The concrete layers are connected by thin compressive stiffening ribs and vertical tension rods to activate the entire depth of the section. Combining this lightweight, two-layered structure with the strength derived from the roof's highly curved geometry, the self-supporting facade structure of the unit can be integrated without creating thermal bridges, while allowing the exposed concrete surface of the shell to flow across the boundaries of the building envelope.

Flexible formwork with on-site active control (2)

Non-standard structures in concrete require complex, custom formworks that are costly and wasteful. Instead, the HiLo roof structure was built using a flexible formwork, consisting of a tensioned cable-net covered with a thin fabric membrane onto which the concrete was sprayed. Since a flexible formwork is not rigid like a traditional formwork, deformations occur under the weight of wet concrete. To compensate, the prestress in the cable-net and the corresponding shape of the formwork are adjusted such that the first layer of the concrete sandwich structure of the roof deforms the formwork exactly into the desired shape of the final shell. All key details of the roof structure and its formwork system were worked out through prototyping in collaboration with experts and partners from industry. The principles of the developed solutions were integrated into a flexible design-to-fabrication workflow implemented with COMPAS, the open-source computational framework for research and collaboration in Architecture Engineering and Construction. This workflow served as a central hub for the computational development, coordination and planning of the key innovations and provided an effective research-to-practice transfer mechanism.

Rib-stiffened funicular floor system (3)

Traditional concrete floor slabs typically consist of a solid section of concrete reinforced with large amounts of steel. In contrast, the HiLo floors use a thin, doubly curved funicular shell with vertical stiffeners to transfer loads to the supports through compression only. The resulting forces are accumulated in the corners, where their outward thrust is absorbed in post-tensioned ties. By placing material only where it is structurally needed (following the flow of forces in compression and tension) the HiLo floor system developed by the Block Research Group saves 70% of con-



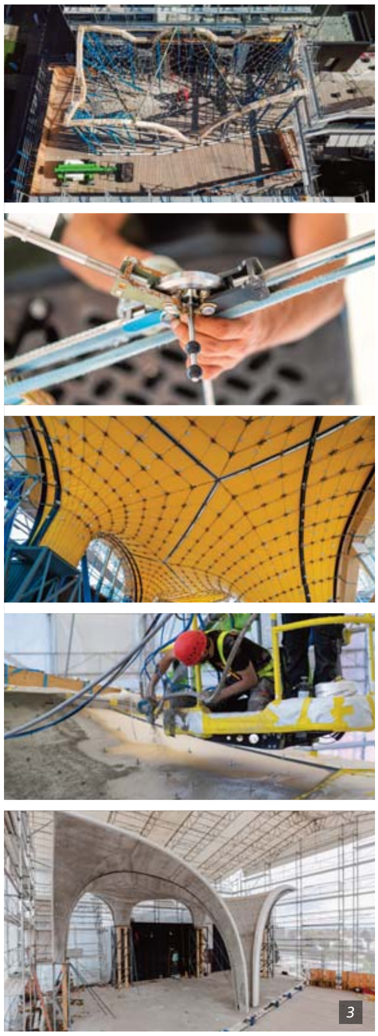


Figure 1a-b. Exterior and interior view of the HiLo roof top unit.
Figure 2. Axonometry, 1/a doubly curved, two-layered concrete shell, 2/a flexible formwork with on-site active control, 3/a rib-stiffened funicular floor system
Figure 3. Constructing the double curved two-layered concrete shell.

2

3

crete and 90% of reinforcement steel compared to the standard reinforced concrete slab, and, by keeping all materials separate, allows for easy recycling at end of life. Furthermore, the funicular geometry of the floors results in low stresses in the structure allowing low-strength materials, which typically have a low carbon footprint, to be used as well as high percentages of construction demolition waste instead of our scarce natural resources. It is estimated that over 200 billion square metres (more than 2 trillion square feet) of floor area are to be constructed within the next three decades, mostly in urban areas where medium high-rises of 10 to 30 storeys are a common typology. On average, 40% of the mass of these buildings is found in their reinforced concrete floor slabs. Introducing the funicular floor system would result in savings of one-third of the total volume of concrete for the entire building and therefore have a significant impact on the embodied carbon-dioxide emissions of newly constructed buildings worldwide.

Tom Van Mele, Block Research Group
Institute of Technology in Architecture
van.mele@arch.ethz.ch
https://block.arch.ethz.ch

Name of the project:	HiLo
Location address:	Ueberlandstrasse 129, 8600 Dübendorf, Switzerland
Client (investor):	Empa - eawag
Function of building:	The HiLo unit is a two-storey collaborative and flexible workspace with two closed offices and multiple shared, open office areas.
Type of application of the membrane:	Shuttering layer of a flexible cablenet-and-fabric formwork for the construction of a doubly curved, two-layered concrete sandwich shell.
Year of construction:	2019-2021
Architects:	ROK Architects & Block Research Group, ETH Zurich
Multi-disciplinary engineering:	Block Research Group, ETH Zurich
Structural engineers:	Dr. Schwartz Consulting AG & Block Research Group, ETH Zurich
Consulting engineer for the membrane:	Block Research Group, ETH Zurich
Engineering of the controlling mechanism:	Block Research Group, ETH Zurich
Main contractor:	Marti AG & Bürgin Creations
Contractor for the membrane	Block Research Group
Installation:	ETH Zurich
Supplier of the membrane material:	Bieri Tenta AG
Manufacture:	Bieri Tenta AG & Jakob AG
Installation:	Block Research Group, ETH Zurich & Marti AG
Covered surface (roofed area):	170m^2

The TensiNet association applied as Partner of the New European Bauhaus (NEB).

The NEB is a creative and interdisciplinary initiative that connects the **European Green Deal** to our living spaces and experiences. The NEB initiative calls on all of us to imagine and build together a beautiful, sustainable and inclusive future. One of the goals is **no more emissions of greenhouse gases by 2050**. The NEB turns the European Deal into something that can be approached and shaped. It is the goal to build a sustainable and inclusive future in Europe. The general shared objective across all calls is to support projects that bring aesthetic, sustainable and inclusive elements of transformation. See link https://europa.eu/new-european-bauhaus/index_en

As **sustainability** is one of the main goals, it was proposed to establish a sub-group NEB within the Working Group sustainability & Comfort. Alena Behrmann (Vector Foiltec) is the driving force behind this partnership with NEB.

TENSINANTES 2023

TENSINET SYMPOSIUM 2023 at Nantes University

The TensiNet Symposium 2023 **"Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment"** will be held at Nantes University (France) from **Wednesday 7th till Friday 9th June 2023** with 3 main topics:

Structural membrane: contemporary, innovative, adaptive daring and impactful solutions

In Jules Verne's hometown, with its focus on innovation and futuristic issues, membrane architecture can provide answers to current problems, especially for ever denser cities and for a world that is always on the move.

Tensioned membrane structures: the seventh building material

Recent advances in the design of membrane structures, development of a Eurocode dedicated to structural membranes: the word membrane must now be part of the daily vocabulary of architects, designers and decision-makers, and the specificities of membrane design must be part of the knowledge of all structural engineers.

Structural membrane: an answer to issues of the 21st century

Lightweight design, well-being, environmental impact, energy and acoustic performance, life cycle of materials and structures, end of life of membrane structures: these keywords are part of the current and future construction challenges and are an important message for the younger generations.

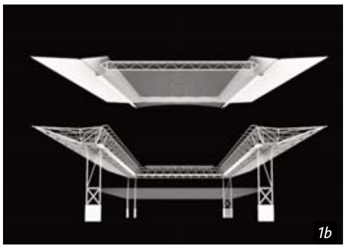
We are in contact with several keynote speakers. **Dominique Perrault Architecture** confirmed his lecture on the new foldable roof of the Suzanne Lenglen Court, on the site of the Roland Garros tournament, Paris. Enjoy the appetizer!

Figure 1a. Visualisation showing the foldable roof in "action" © Dominque Perrault Architecte_RSI_FFT_Adagp

Figure 1b. Visualisation showing the structural elements © Dominque Perrault Architecte_TESS_Adagp

The "pleating" of the Suzanne Lenglen Court

In haute couture, pleating refers to the art of folding a piece of fabric. For a garment, this technique allows great freedom of movement with style and elegance.



Positioned above the existing stands, with a sufficient overhang, it comprises a mobile part, made of PTFE fabric, and a fixed part that provides support for the mobile part and integrates all the equipment necessary for its deployment and folding. The mobile cover consisting of SEFAR® Architecture TENARA® 4T40HFT stretched by cables attached to the structure will fold up on the south side by the movement of a mobile button in a horizontal movement. The simplicity of the elements used, and their repetitions create a new balance that assumes the addition of a new element without presenting anything superfluous.
www.youtube.com/watch?v=pUvPBw5cVCQ

CALL FOR ABSTRACTS SYMPOSIUM 2023

Interested to participate than choose one of the three main topics and upload your abstract!
For more information see:
https://tensinantes2023.sciencesconf.org

Abstract submission 30th May 2022
Abstract acceptance 30th June 2022
Paper submission 31st October 2022
Paper acceptance or feedback 5th January 2023
Revised paper submission 16th February 2023

Scientific Committee The following members have confirmed their commitment to review abstracts and papers: *Prof Adriana Angelotti (Politecnico di Milano), Ass Prof Paolo Beccarelli (University of Nottingham), Dipl Ing Arch Katja Bernert (Low and Bonar), Dr Alexis Bloch (Méca), Prof Heidrun Bögner-Balz (Hochschule für Technik Stuttgart), Dr Rabah Bouzidi (Université de Nantes), Roberto Canobbio (Canobbio Textile Engineering), Prof John Chilton (University of Nottingham), Prof Jan Cremers (H,ochschule für Technik Stuttgart), Prof Lars De Laet (Vrije Universiteit Brussel), Dr Olivier Flamand (Centre Scientifique et Technique du Bâtiment), Prof Gunther Filz (Aalto University), Dr Laurent Gornet (École Centrale de Nantes), Prof Peter Gosling (Newcastle University, School of Engineering), Prof Josep Llorens (Universitat Politecnica de Catalunya), Prof Marijke Mollaert (Vrije Universiteit Brussel), Prof Arch Carol Monticelli (Politecnico di Milano), Prof Nicolas Pauli (Ecole Nationale Supérieure d'Architecture de Montpellier), Ass Prof Arno Pronk (Eindhoven University of Technology), Dr Monica Rychtáriková (KU Leuven, Belgium / STU Bratislava), Prof Franck Schoefs (Université de Nantes), Dipl Ing Bernd Stimpfle (formTL), Prof Natalie Stranghöner (Universität Duisburg-Essen), Ass Prof Martin Tamke (Royal Danish Academy), Prof Patrick Teuffel (Teuffel Engineering Consultants), Dr Jean-Christophe Thomas (Université de Nantes), Dr Ing Jörg Uhlemann, (Universität Duisburg-Essen), Adjunct Prof Salvatore Viscuso (Politecnico di Milano) and Prof Alessandra Zanelli (Politecnico di Milano).*