TensiNews

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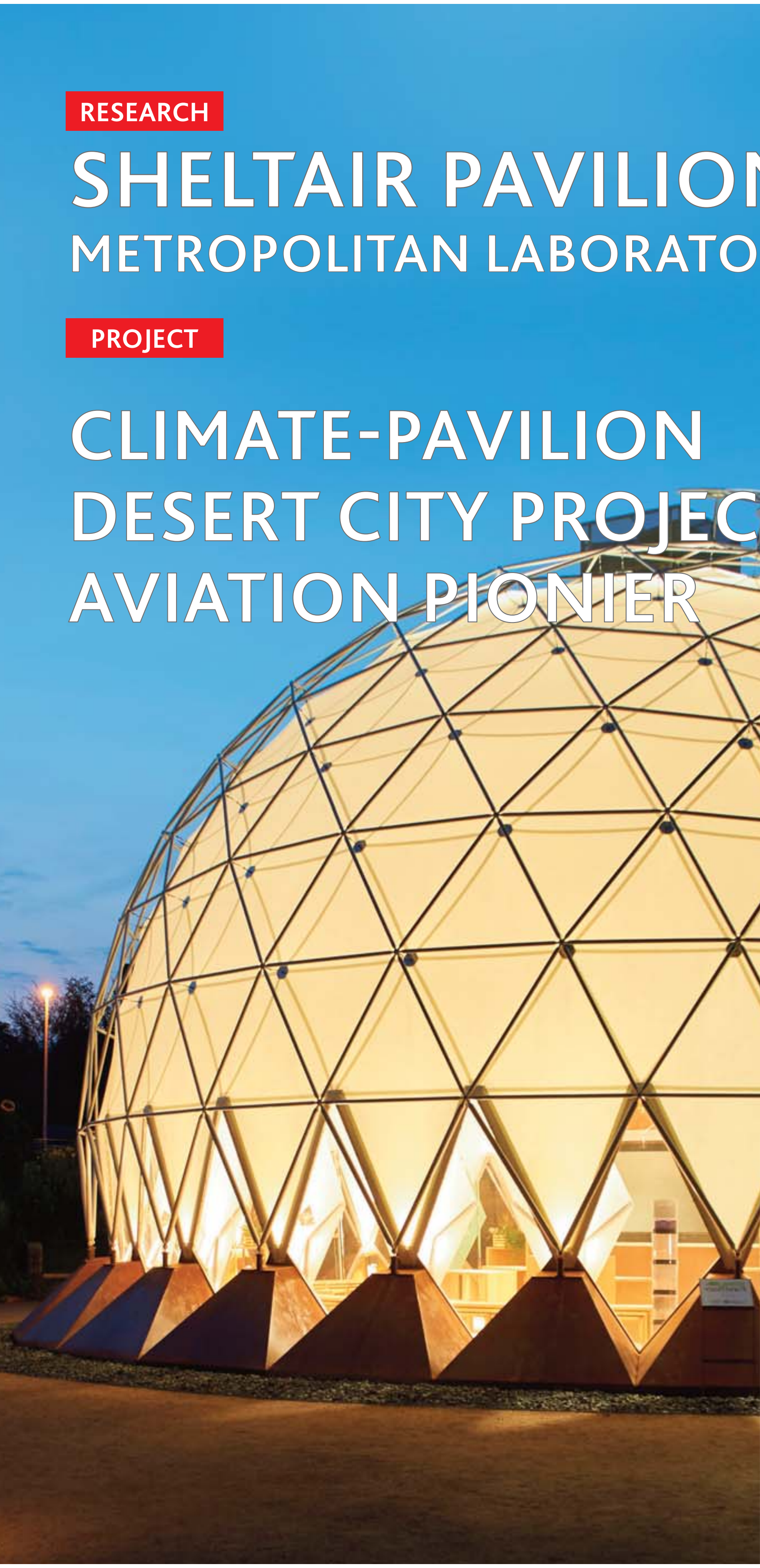
RESEARCH

SHELTAIR PAVILION
METROPOLITAN LABORATORY

PROJECT

CLIMATE-PAVILION
DESERT CITY PROJECT
AVIATION PIONIER



The climate-pavilion referring to the domes of Buckminster Fuller © reich.architekten BBD ▲
Desert City Project, view of the exhibition courtyard © Desert City ►

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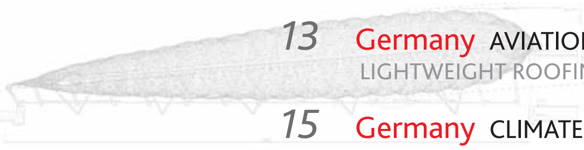
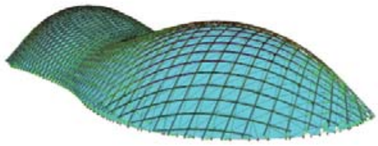
PROJECTS





RESEARCH

MISC

SOFTENING THE HABITATS

Edito

Dear Reader,

In not much more than a year our next TensiNet Symposium "Softening the Habitats" will take place in Milan. The organizing committee is working on the program. You find herein the call for abstracts, and more details on the variety of topics.

This issue of TensiNews is full of inspiring projects for permanent and for temporary use, and a large variety of cladding materials. We are glad to announce that the LCA working group has been reactivated. You are invited to participate.

Many new ETFE projects are shown. One pneumatic roof structure using the thin ETFE foil is covering an exhibition space for thorny cactuses. Under the name of the aviation pioneer Lilienthal a triangular ETFE cushion is covering an atrium. The new stadium in Chicago is covered with an ETFE roof, the first one hosting the super bowl. In England one of the oldest railway stations has been extended by a bus station with ETFE canopies.

Covered with translucent material, the roof for the new Volgograd stadium is presented. In the south of France large inverted cones are covering a High-Tech campus. A geodesic dome resembling to Buckminster Fuller has been built for an exhibition. An inflatable pavilion combining the principle of an air hall with an air beam is installed every year near Stuttgart. Also for temporary application a pavilion has been built in Italy, covered with PVC foil.

The University of Arts in Berlin presents the research project of a bending active grid shells in combination with air-inflated cushions, to be used as temporary shelters for events and for humanitarian missions.

I hope you enjoy this issue of TensiNews, and will be glad to meet you soon.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

7th IMS international textile architecture seminar 1st edition in Miami, USA | *17-19/05/2018*
http://www.membrane-symposium.org/symposium-miami-2018.html

23rd International workshop Textile Roofs 2018
1st edition in Moscow, Russia | *24-26/05/2018*
www.textile-roofs.de

IASS 2018 - Creativity in Structural Design
16-20/07/2018 | MIT Campus Cambridge, Massachusetts
www.iass2018.org

SLTE 2018 - VII Latin American symposium of textile structures | *12-14/09/2018* | Universidad Ricardo Palma, Lima, Peru | **www.slte2018.com**

13th International Conference on Advanced Building Skins | *1–2/10/2018* | Bern, Switzerland
https://abs.green/callforpapers/

Aachen-Dresden-Denkendorf International Textile Conference 2018 | *Turning Fibers into Value* | *29-30/102018* | Aachen, Germany
www.aachen-dresden-denkendorf.de/en/itc/

6th International TensiNet Symposium |
"Softening the Habitats: Sustainable Innovations in Minimal Mass Structures and Lightweight Architectures"
3-5/06/2019 | Politecnico di Milano, in Milan, Italy
www.tensinet2019.polimi.it

in memorandum Mike Barnes

With great sadness we announce the death of Mike Barnes. Mike died this February at the age of 75.
Mike was member of the EU-funded TensiNet thematic network from 2001 to 2004 and he was the first chairperson of the TensiNet Association from 2005 to 2006.
Mike was Professor Emeritus at Bath University and visiting professor at Bauhaus University in Dessau. He was teaching tensile structures. The video-based learning pack he developed in '90 is still a reference for contemporary architecture.
Mike was a passionate engineer with very valuable expertise in the domain of tensile surface structures. He was a leader in numerical modelling in dynamic relaxation for analysis and design of tensioned membrane structures and cable structures.
He was involved in many important projects worldwide, including the German Pavilion in Seville and the Shading Tents for the Expo 88 in Brisbane. He was in the team for the assessment of the Montreal Olympic Stadium Roof and performed checking analysis for the Millennium Dome.
Mike we will miss you.

Aix-en-Provence, France

THE CAMP

HIGH-TECHNOLOGY CAMPUS AND BUSINESS INCUBATOR

SERGE FERRARI SUPPLIES ITS FLEXLIGHT XTREM TX30 FOR THE AMAZING TENSILE CANOPY ROOF

Serge Ferrari was chosen to supply some 8.500m² of innovative material, Flexlight Xtrem TX30, for the tensile canopy roof of The Camp, located in Aix-en-Provence. Serge Ferrari, a specialist of flexible composite materials since 1973, has lent its expertise to a project named The Camp: a brand new campus entirely dedicated to the development of digital technologies and research on new habits. A long-time purveyor of solutions for large-scale architectural projects around the world, the Group, based near Lyon, France, has once again been chosen for its flexibility and innovative technical materials, all 100% recyclable.

Figure 2a/b. Views underneath the canopy © Fred Bruneau
Figure 3a/b/c/d. Detailing: Connecting membrane to the metal structure © Fred Bruneau

A High-Technology campus to house start-up businesses

The largest digital innovation campus of its kind in Europe was inaugurated on 28 September, in Aix-en-Provence, Southern France. With a total surface area of 11.000m² it houses up to 40 hand-picked start-up businesses, providing them with a sustainable environment where they can grow and imagine tomorrow's digital innovations. The Camp consists of five units, including two learning centres for students, business owners and managers, an incubator for start-up businesses and SMEs, a testing laboratory, as well as a conference hall to hold events for the general public (Fig. 1 & 2).

An architectural prowess

Designed as an open-air environment, The Camp is a celebration of modernism and new technologies, with its decidedly futuristic look. Corinne Vezzoni et Associés, the architecture firm in charge of the project, chose a canopy roof provided by ACS Production, which used Serge Ferrari's high-technology composite membranes. As Corinne Vezzoni commented, "this solution was the best option available to create the giant 'parasol' structure we had envisioned, designed to shelter the whole complex from the sun's glare."

ACS Production, in charge of designing and installing the canopy roof, spent eight months working hand-in-hand with Serge Ferrari on the feasibility studies to guarantee the solution would be resistant to harsh weather (wind, snow, rain) and would meet requirements in terms of comfort and design. CEO of ACS Production Yannick Faurant explained: "As a leader in metal-textile structures, we have been working with Serge Ferrari for over 27 years. Over time, the Group has become one of our

Figure 1 © Fred Bruneau

most trusted partners. We introduced Serge Ferrari to the project developers and main contractors, so they could argue the case for composite, rather than PTFE membrane – the project developer's original intent. The Lyon Stadium, whose roof structure was also covered with Flexlight Xtrem TX30 , was the best example to demonstrate the material's immense qualities to the architect and project developers. The Camp's canopy roof is undoubtedly one of the most ambitious projects of the kind we have seen during the past 10 years, because it is a testament to the amazing level of understanding and expertise it required. The structure is reduced to its bare minimal: a peripheral frame that appears to be floating in mid-air. To achieve this impressive result, of course we had to go through a complex process: designing the structure, researching membrane options, exploring technical constraints, etc. The various entities involved in this project collaborated together and all strove to achieve the architect's vision." (Fig. 3)
The material that was eventually chosen for this ambitious project is Flexlight Xtrem TX30, a durable, lightweight solution, that delivers homogeneous light flow, creating the illusion that the canopy is suspended, blending elegantly into the surrounding natural environment.

Serge Ferrari: Responsible Business

Serge Ferrari is the only industrial group to set up its own plant to recycle the Group's products: Texyloop, based in Italy. As a result, Serge Ferrari has become a leader on the market for tensile architectural solutions. And it is this unique competitive advantage that has earned the Group the opportunity to collaborate on so many high-profile projects with challenging architectural needs. The company's deep commitment to sustainable development is led by Managing Director Romain Ferrari.

Name:	The Camp
Location:	Aix-en-Provence
Year of completion:	2017
Surface area:	11.000m²
Architect:	Corinne Vezzoni & Associés
Design & installation:	ACS Production
Applications:	Roofing structures for permanent and long-term buildings
Material:	Flexlight Xtrem TX 30 Product Profile PVC-coated polyester
Lifespan:	30+ years
Weight:	1,500g/m²
Width:	178cm
Tensile strength:	1000/800daN/5cm
Standard:	ISO 9001 compliant

Project Timeline	
September 2013:	first contact with Serge Ferrari.
Autumn 2013 – spring 2014:	technical studies for the structure.
August 2015:	ACS Production wins bid.
Winter 2016:	Production begins at Maine Bâches manufacturing plant.
Late March 2017 – mid-July 2017:	First elements of the canopy are installed.

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LOW & BONAR GMBH

VOLGOGRAD ARENA
RUSSIA

Bird view of membrane roof
© Low & Bonar

Context

The Stadium was built at the foot of the Mamayev Kurgan memorial complex, near the Volga River. The previous stadium from 1958 was demolished to make room for the new arena. Originally the Stadium was meant to be part of a whole sports complex. The plans for the swimming pool and other facilities were postponed because of budget reasons. Apart from being venue of several group games Volgograd Arena will host FC Rotor Volgograd in the future. Project Institute ARENA, an architects' office that was founded in 2011, did the design and engineering part of the planning. PI Arena is general designer for public venues in different regions of Russia with a focus on developing sport facilities and stadiums.

The roof

Low & Bonar worked in partnership with Russian engineering contractors Stroytransgaz and Kurganstalmost to deliver a hard-wearing architecture membrane which can withstand extreme weather conditions, incorporating a challenging design. The upper cover is composed of blue and white rhombi. The blue diamonds accumulate at the outer fringe of the roof. The Russian branch of Maffeis Engineering worked on the fabric part of the roof. Kurganstalmost, a company originated in bridge building, integrated the fabric into the roof's steel construction.

Katja Bernert
Katja.Bernert@lowandbonar.com
lowandbonar.com

Name of the project:	Volgograd Arena
Location address:	Volgograd, prospekt Lenina 76
Client (investor):	Sportengineering
Function of building:	FIFA Worldcup 2018 football stadium
Type of application of the membrane:	roof
Year of construction:	2018
Architects:	PI Arena
Multi-disciplinary engineering:	PI Arena
Structural engineers:	PG Maximum
Consulting engineer for the membrane:	Maffeis Engineering
Main contractor:	Stroytransgaz
Contractor for the membrane (Tensile membrane contractor):	Kurganstalmost
Supplier of the membrane material:	Low & Bonar GmbH
Manufacture and installation:	Dovleti/Kubantent
Material: VALMEX MEHATOP F1 TYPE IV (37.000m² white ; 44.000m² blue color)	
Covered surface (roofed area):	73.462m²

OFF THE CUFF PAVILION

Palazzo Litta, Milan, Italy

FOR THE 'A MATTER OF PERCEPTION' EXHIBITION

The pavilion "Off the Cuff" is the main installation of the third edition of the 'A Matter of Perception' exhibition which explored the theme of LINKING MINDS. The exhibition, organized by Mosca Partners and DAMN°, was hosted by Palazzo Litta which is itself a fascinating example of Lombard Baroque architecture in the city and an expression of the connection between Milanese culture and the French and English Enlightenment.

Concept

The pavilion was designed by Diller Scofidio + Renfro, an interdisciplinary design studio based in New York City that integrates architecture, visual arts, and performing arts. According to Liz Diller, the initial concept was based on the idea of "using ready-made modules – actually misusing them – for architectural purposes. In the back of our minds – and this might sound very peculiar – we have always wanted to use actual trousers as a module".

Maco Technology and the University of Nottingham were contacted in January 2017 in order to provide the support for the final engineering, manufacturing and installation of the pavilion by the 3rd of April 2017. The project has been challenging under several aspects such as the extremely tight time schedule, the constraints imposed by the Monuments and Fine Arts Department, the building materials used and the complex 3D modelling of the structure.

Structure & Materiality

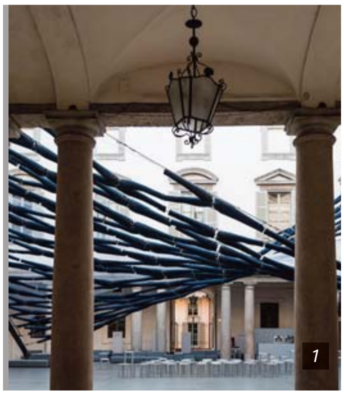
The canopy is a jean fabric grid stretched between cable-stay posts. Structural stability was ensured through a balance of form-finding and the base structure which resolves the system without the need for heavy ballast under the ties. Material testing was performed to verify the structural integrity of the denim and connections with transmitted forces of up to 2kN. Thin Kevlar rope was introduced as an erection aid and remains to provide supplementary support to the system. A PVC foil sits above the denim and kevlar mesh (Fig. 1-3).

The main challenge was to optimize the shape of the pairs of trousers which had to fit the mesh selected by the architect and the size of the inflatable mannequins available on the market. Thanks to a form finding algorithm it has been possible to adjust the geometry of the surface in order to have only one module and, consequently, only one size of trousers to be produced. The required strength of the trousers has been achieved by increasing the number and size of the belt loops and by inserting a metal ring in correspondence of the cuffs.

The elongation of the denim under load and in presence of different levels of humidity has been addressed through adjustable connections (cable ties) in correspondence of the cuffs and the waist of each unit and adding a set of adjustable Kevlar ropes between the steel frame and the mesh in order to introduce the required level of pretension into the tensile structure. The length of the Kevlar rope was controlled by means of a GI-GI plate, a multiuse belay plate commonly used for climbing.

The mesh was supported by a rigid steel structure designed to avoid the transfer of additional loads to the existing building apart from the gravity loads. The final structural solutions did not require permanent foundations, anchoring points or heavy ballasts. The vertical loads have been distributed on the ground through thick timber boards.

In order to facilitate the installation of the steel structure, the two main posts have been designed with pinned joints able to allow the rotation from the initial horizontal plane, used for the connection of the components at ground level, to the vertical plane required by the final geometry of the pavilion. Each post was stabilized by two cables (Full Locked Coil by Redaelli Tecna) connected to the basement.



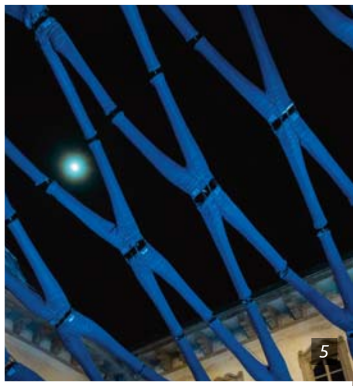


Figure 1. A jean fabric grid as canopy © Salone-del-Mobile
Figure 2. PVC foil above the denim and kevlar mesh © Ruy Teixeira
Figure 3. Connection detail © Laurian Ghinitoiu
Figure 4. Installation © Maco Technology
Figure 5. Night view © Ruy Teixeira

Installation

The installation of the pavilion was mainly driven by the limited access to the site which was located in one of the busiest areas of the historic centre of Milan. Due to the small size of the main gate and because of the reduced space available inside the courtyard, which was almost entirely occupied by the pavilion, the pavilion had to be subdivided in small

Name of the project:	Off the Cuff Pavilion
Location address:	Palazzo Litta, Corso Magenta, 24, Milan
Client (investor):	Mosca Partners
Function of building:	Artistic Installation
Year of construction:	2017
Architects:	Diller Scofidio + Renfro
Structural engineers:	Thornton Tomasetti
Consulting engineer for the membrane:	Paolo Beccarelli
Main contractor:	Maco Technology srl
Contractor for the membrane (Tensile membrane contractor):	Maco Technology srl
Supplier of the membrane material:	Trussardi
Manufacture and installation:	Maco Technology srl
Material:	Denim, Trussardi; PVC Cristal, F.lli Giovanardi
Cables:	Redaelli Tecna
Covered surface (roofed area):	400m^2

components which could be easily moved and assembled by a team of 6 people with the support of the hydraulic crane installed on the truck used to deliver the components onsite (Fig. 4).
In addition, the courtyard of the palace was available only for eight working days with a very tight programme that limited to a maximum of five days the time available for the erection of the structure of the pavilion.
The installation started with the assembly of the basement made by a rigid steel frame obtained by welding and bolting a set of hollow square sections 400x200x5mm (diagonals) and 260x260x4mm (perimeter). Timber beams were used to level the steel basement and to spread the load in order to reduce the risk of damages to the ancient floor made of pebbles stones.
Once completed the basement, the team of workers installed the lateral beams and posts which, thanks to the special pinned joints, were initially installed in the horizontal plane and then lifted by means of the hydraulic crane installed on the truck. A set of two cables were designed to stop the rotation of the steel structure once reached the correct position. The task was extremely challenging due to the limited space available and the risk of damaging the columns and the facades of the building.
The following step was the assembly of the mesh of safety Kevlar ropes designed to support the mesh of trousers during the installation and to provide an emergency support in case of failure of one, or more, of the units.
Finally, the surface was completed with the installation of 304 pairs of trousers which were partially covered by a strip of PVC Crystal designed to protect the central part of the pavilion from the rain.

The installation included a bespoke lighting provided by Zumtobel (Fig. 5) and a timber floor used to cover the grid of beams used for the foundations.

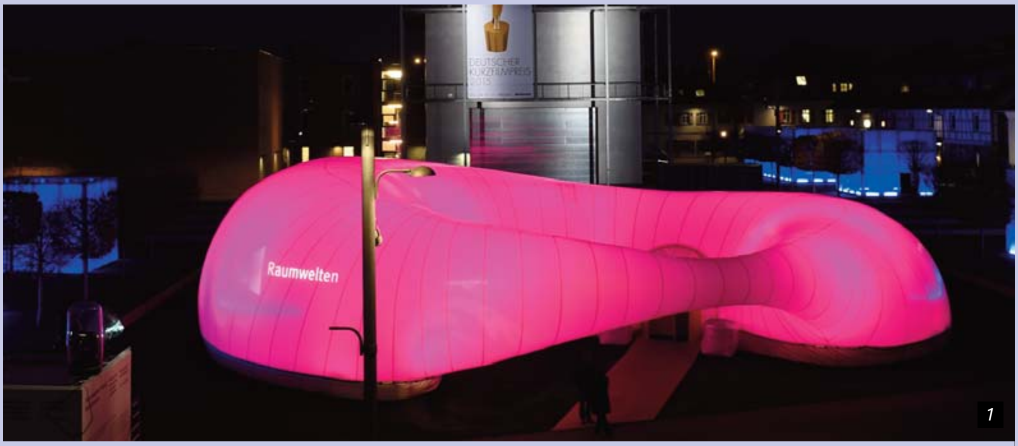
Paolo Beccarelli
info@macotechnology.com
www.macotechnology.com
www.youtube.com/watch?v=s93C17S6i1g

formTL

Ludwigsburg, Germany

RAUMWELTEN PAVILION ‘LICHTWOLKE’

RAUMWELTEN is an established event for scenography, architecture and media. In 2015 the event took place in an air-supported pavilion for the first time. It shall be used the next three years.



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Figures 1 - 2. ‘Lichtwolke’ in Multicolored appearances © Rainer Pfisterer

3

Figure 3. Interior view © Daniel Fuchs

The form of the pneumatic pavilion reminds of a donut – with a size of more than 200m² and a height of 6m. It was designed by students of the Hochschule für Technik (class Prof. Thomas Hundt) and by students of the Staatlichen Akademie der Bildenden Künste Stuttgart supervised by Prof. Tobias Wallisser and Sebastian Schott. formTL converted the design to an air-supported membrane structure. Special is, beside the individual form of the membrane structure, the foundation with internal gravel bags. To avoid damage to the car park sealing under the lawn, the ballast bags are not embedded into the ground.

formTL
info@form-TL.de
www.form-TL.de

Air volume:	1.600m³
Material: Membrane:	Hiraoka, 102T-IIE
Steel grids:	S235
Cables:	VA 1.4401, round strand ropes Ø 10mm
Execution: General contractor:	ADUNIC AG
Membrane supplier:	Koch Membranen
Compressor:	Gustav Nolting GmbH
Structural design, detailed design & specialized design membrane:	formTL

DESERT CITY PROJECT

BUBBLE ROOF FOR THE CACTUS EXHIBITION COURTYARD

San Sebastián de los Reyes, Madrid, Spain

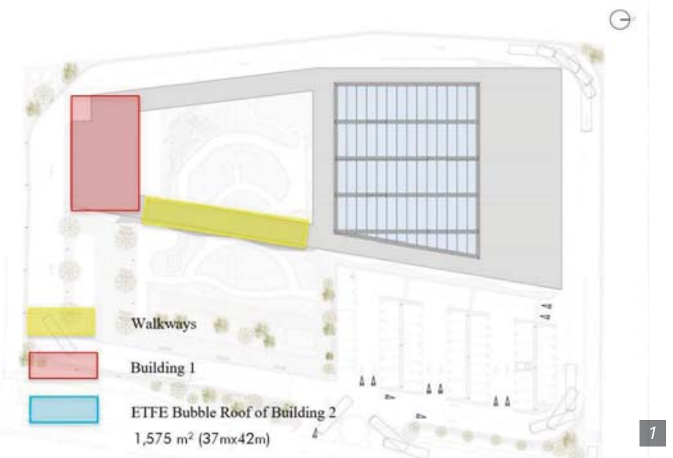
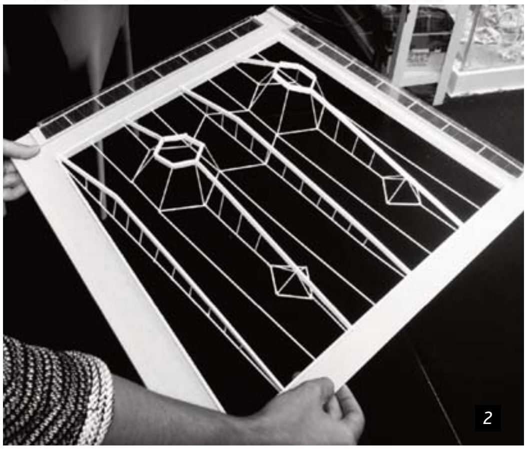
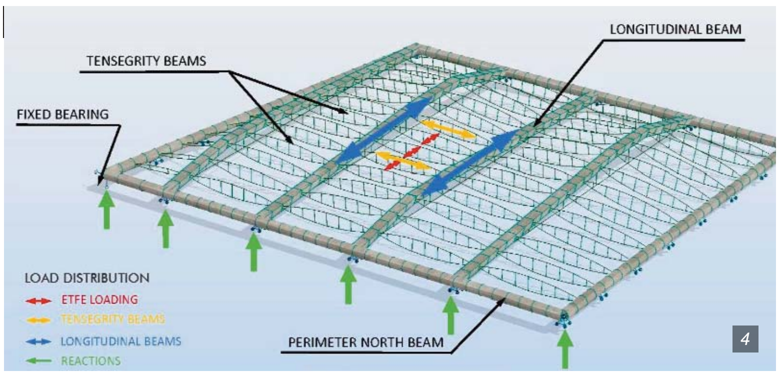


Figure 1: Plan view of Desert City - Architectural Drawing © García-Germán Architects
Figure 2: Conceptual Mock-up of primary structure © García-Germán Architects
Figure 3: Visualisation © García-Germán Architects
Figure 4: Roof structural concept - Analysis model © Arenas&Asociados





Introduction

Desert City LTd, the Spanish pioneer xeriscaping company, entrusted to García-Germán Architects Studio the design of their Headquarters in San Sebastián de los Reyes. The building is composed by volumes connected by means of peripheral walkways, freeing the in-between space existing after having built such volumes and generating a first cactus open-air showroom. The main volume has got an inner courtyard, intended to be the principal cactus exhibition and wished to be covered by a light and permeable roof. The dimensions of this courtyard are 37m x 42m which gives a surface of 1.575m^2.

What better solution than an ETFE foil roof to provide a perfect showroom inside a bubbling greenhouse? So, this was the seed of the covering design.

The Desert City Headquarters was built by Spanish Contractor Isolux-Corsán, who outsourced the roof erection to the specialist tensile-structure Contractor Lastra&Zorrilla, who contacted us, Arenas&Asociados Bridge Designers, as their Structural Engineers, as both companies have collaborated in several tensile-structure projects such as PVC membranes and ETFE cushions.

Based on the conceptual sketches made by the architectural team (Fig. 1), Arenas&Asociados provided the architectural, structural design and erection sequence that fitted the most to such conceptual sketches, with a feeling of being open air but being sheltered from weather by an almost transparent layer.

The roof consists in a rigid steel frame with four longitudinal steel beams as primary structure. This primary structure generates a void between the longitudinal beams which is filled with ETFE cushions reinforced internally with transverse tensegrity beams, made-up by cables and steel strut-masts due to the span, 9m, that those ETFE cushions must cover between the longitudinal beams and they should be as flat as it could be possible (Fig. 2). These masts, observed from the courtyard will provide a sensation in the spectators of a sea of scattered cactus spikes floating inside cumulus clouds (Fig. 3).

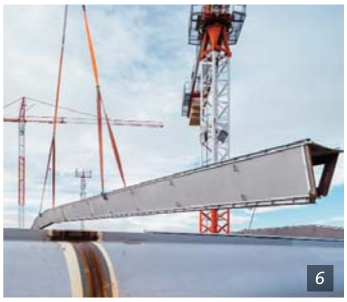
Structural concept

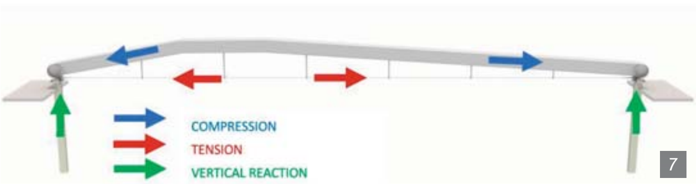
The Desert City Bubble Roof structure is arranged in three levels, the main steel frame, composed by four longitudinal sloped beams fixed to a peripheral pipe steel shaped frame; a second level, composed by the tensegrity transversal girders and the ETFE cushions as the third level (Fig. 4). It must to be said that the roof had to be designed once the building supporting structure was already built and this conditioned the roof structural concept, being the project more challenging, from the point of the view of the designer and at the same time more enjoyable for this reason.

1.Primary structure: steel frame

The primary structure, framing support of the bubbles, bears in the existing building supporting structure, and this conditioned the design of the whole roof, and specially the steel frame, as it was the linking element between the covering and the building. Thus, this primary structure is composed by a peripheral Ø900mm steel tube which receives the four longitudinal beams and provides the bearings that makes rest the roof on the existing steel structure (Fig. 5). The main four longitudinal girders have been designed with a triangular cross section shape, allowing in this way, from the below point of view of the spectator in the cactus courtyard, as if all the roof was made only by ETFE cushions, thanks to the sharp profile of the bottom girder (Fig. 6).

These bearings had to be designed in a way that the horizontal forces transferred to the existing building supporting structure were neglectable, as the columns hadn't enough capacity to resist horizontal forces on their top. Our experience in the design of bridge lead us to provide PTFE sheets to elastomeric pads, and a low friction contact PTFE-steel was successfully achieved, being in the correct way to avoid the transmission of horizontal forces. But, due to the lightness of the roof and to avoid undesired uplifts, all the bearings were clamped, being this connection designed by Arenas&Asociados, as no commercial bearings were available for our design conditions. The use of PTFE sheets required another step further to avoid the transmission of horizontal force on top of the columns of the existing structure so the bow-string concept applied by Arenas&Asociados in some of their most well-known bridges, as Barqueta in Seville and Third Millennium Bridge in Zaragoza, is also used here, allowing a rational use of materials and spanning 37m with 840mm depth steel slender beams (ratio height-span 1/44). That means that a posttensioned (P0=200kN) high-grade steel cable was introduced in the main girders tiding their bearings, so the horizontal force component of the main girders is compensated internally and only vertical loads flow through the building columns to the foundation (Fig. 7-8).





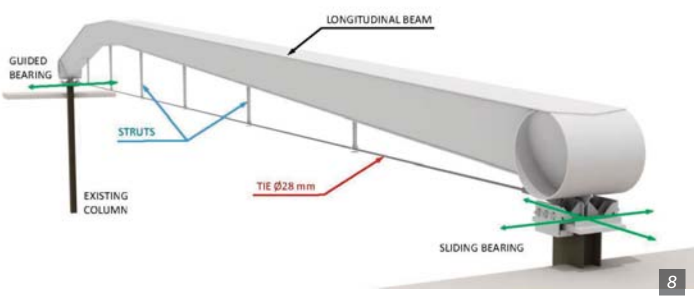


Figure 5. Assembling of main girder in the peripherical steel frame © García-Germán Architects
Figure 6. Triangular shape section of one of the main girders © García-Germán Architects
Figure 7: Bow-string longitudinal beam concept © Arenas&Asociados
Figure 8: Bearing arrangement © Arenas&Asociados

2.Secondary structure: tensegrity girders

The four longitudinal main girders that conform together with the peripherical pipe shaped beams the steel frame of the primary structure, divide the roof in 5 sectors. These sectors are covered by ETFE cushions, spanning 9m, it is to say, the distance between consecutive girders. The tensegrity girders are spaced 2.6m between them.

Due to the external loads, climatic loads mainly, as wind and snow, it makes necessary the reinforcement of the ETFE bubbles by means of cables girders, which we have named tensegrity girders due to its configuration. As the bubbles span 9m, with a sag of 0.9m, common sag vs length of 0.1L; and as per ETFE it is recommended to behave under a tensile strength of 21MPa (3.0ksi) in ETFE to avoid plastic deformations in the material, cable girders are used as bubbles reinforcement. As a quick check, as 250mm thickness ETFE sheet were used, if no reinforcement should have been provided, the tensile stresses in the cushion layers should have been, as explained in the next numbers.

As a clear transverse flow of forces happens, and considering the geometrical conditions presented above, results a Radius=11.7m. Using the relation, T=p·R, being T, the tensile force; p, the external loads, and R, the Radius; the tensile force can be obtained.

The demanding load is the sum of the internal pressure of 30kg/m^2 and 100kg/m^2 due to the snow load, so p=130kg/m^2 (p=0.189lbf/in2), leads to a T=130kg/m^2·11.7m =15.2kN/m (T=1.042kip/ft), giving a tensile stress of Σ=60.8MPa (8.8ksi). Thus, the stress level is out of the working tensile range for ETFE, so the introduction of an auxiliary structure was necessary.

The tensegrity girder structural concept is based on the sketches shown in the figure 9 and figure 10. Each girder has got two main cables that are used, one for snow and wind pressure (bottom one) and the other one for wind suction (top one), having been stressed both cables to avoid the

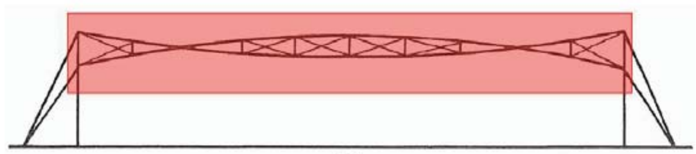
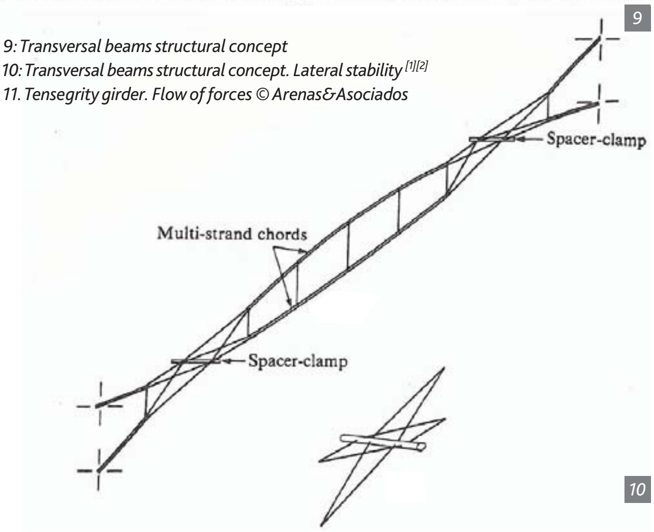
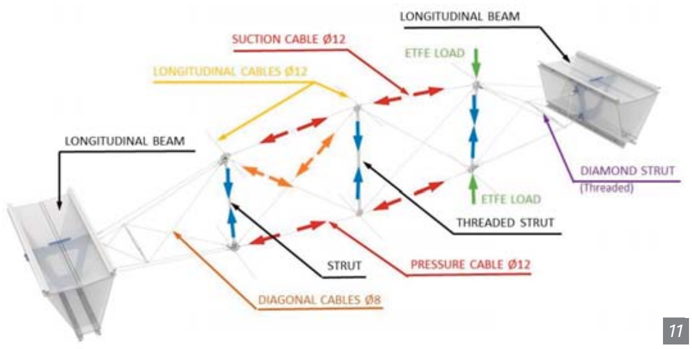


Figure 9: Transversal beams structural concept
Figure 10: Transversal beams structural concept. Lateral stability [1][2]
Figure 11. Tensegrity girder. Flow of forces © Arenas&Asociados





slackening in Ultimate Limit Strength, so the cables will be always under tensile forces. The pretension force introduced in the cables was of 30kN (6.7kip), and it was induced by the actuation in the horizontal strut as it will be shown lately. The tensegrity girder cables were dimensioned to the 45% of its maximum breaking load capacity for service loads to consider the fatigue effect. No risk of buckling was detected in the strut elements, as compressive force demand was low.

The main cables, top and bottom (ø12mm) resist together the bending forces in the bubble beam to transmit the loads to the longitudinal steel frame girders, which unload the external actions through the bearing devices in the existing supporting structure of the building. But these main cables require embracements, diagonals, to improve the structural behavior, resisting the shear forces and overall, providing lateral stability during the transversal beam erection and during its lifetime. These embracements, shear resistant elements are composed by rigid steel struts and cable diagonals (ø8mm), with spacer-clamps, which provide the above-mentioned lateral stability.
It must be added that the pretension (Fig. 11) in the tensegrity girder was introduced by the spacer clamps, threaded bars that with its enlargement tension all the cables (Fig. 10).

The erection sequence of the tensegrity girders was done is two stages (Figs. 12 -15). In the first state, only the in-plane elements were installed, and in the second one, the diamond strut element with its out of plane cables. Furthermore, the tensioning of the tensegrity girders was developed sequentially, to provide a balance with the contiguous modules as the longitudinal girders weren't designed to resist unbalanced out of plane forces. The longitudinal steel girders were designed to resist the 40% of that out of plane forces during the global erection sequence in order to save steel material and provide the maximum slenderness in such out of plane direction. The transverse slenderness was pointed out with the sharped shape of the longitudinal girder cross section, as it can be seen in figure 12a.

Figure 16. View of ETFE cushions reinforced by the tensegrity girders © García-Germán Architects

The conjunction of struts and cables became these girders in tensegrity beams, and oneiric spikes floating in the air, a cactus deconstruction was achieved, idea made real.

3.Tertiary Structure: ETFE Cushions

The last element that constitutes the Desert City roof are the ETFE cushions, which are reinforced by mean of the tensegrity girders due to the lack of structural capacity shown in the previous clause. Although they are in the third structural level, they can be considered on the top of the architectural concept, as they are the greenhouse cactus roof and the element that provides the open space (Fig. 16).

Two layers cushions were used with transparent sheet in the top layer and a white translucent sheet in the bottom layer. Both layers have got a thickness of 250microns, with a ratio of sag vs length of 1/10, usual value for ETFE cushions, providing a good balance between shape and tension to be resisted under external loading.

Previously to the adoption of the layer colors, mockups were developed in the Lastra&Zorrilla Workshop, the ETFE Manufacturer, and delivered to site in order to check the transparency desired to be provided inside the cactus exhibition courtyard, checking directly with the light present in Madrid.
The cushions are by default inflated under a pressure of 30kg/m^2, enough to avoid slackening of the layers under the usual external loads. Additionally, it was provided also a system to regulate the internal pressure to

Figure 12. Tensegrity girders erection sequence. In-plane girder (left), diamond strut (centre), Tensegrity girders connected to longitudinal steel girders (right) © Germán-Architects
Figure 13. Tensioning of the tensegrity girders acting on the diamond struts © García-Germán Architects
Figure 14. View of the tensegrity girder elements. Spike effect © García-Germán Architects
Figure 15. Cactus Spike effect © García-Germán Architects

Figure 17. View of the roof in the Inauguration of the Desert City © García-Germán Architects
Figure 18. View of the exhibition courtyard © Desert City

counterweight the effects of snow and wind when they could be in risk of induce slackening in the ETFE cushions. This system is ruled by a climatic station installed in the building roof. Structurally, the ETFE cushions are intended now to resist the external loads between the 2.60m that is the spacing between tensegrity girders, being now in the range of tensile stresses of the ETFE.

Conclusion

In our humble opinion, all the members of the team involved in the design, development of the project and the erection of the roof could succeed in achieving the goal of providing the best roof for the Desert City exhibition courtyard.

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www.archdaily.com/876678/desert-city-garciagerman-arquitectos/597aa8d4b22e385d4c000184-desert-city-garciagerman-arquitectos-axonometric

[1][2] *References: Buchholdt H.A., Introduction to Cable Roof Structures. Cambridge Company. University Press, 1985.*

Name of the project:	Desert City Project
Location address:	San Sebastián de los Reyes, Madrid (Spain)
Client (investor):	Desert City LTd
Function of building:	showroom, greenhouse
Year of construction:	2017
Architect:	Jacobo García-Germán (García-Germán Architects Studio)
Structural Engineer:	Guillermo Capellán Miguel, Julio González Zalduondo, Santiago Guerra Soto (Arenas&Asociados)
Constructor:	Alberto J. Charlez (Isolux-Corsán
Manufacture and installation:	José María Lastra (Lastra&Zorrilla)
Material:	ETFE foil
Covered surface:	1.575m^2

CLOSING THE LOOP

The Dyneon Up-Cycling plant at the Burgkirchen site has been selected as winner of the "Responsible Care Competition 2017". The award was presented at the meeting of the members of the Chemical Industry Association (Verband der Chemischen Industrie, VCI) on 29th of September 2017 in Frankfurt.

DYNEON WINS RESPONSIBLE-CARE COMPETITION 2017

Up-Cycling plant in Burgkirchen wins VCI national award

After having already won the VCI Bavarian State Competition in July 2017, the materials specialist Dyneon has now won a national award with its project. Dyneon is thus one of this year's three national winners of the Responsible Care Competition. In keeping with the motto "We have good ideas for recycling management", projects were sought from companies that promote recycling opportunities, the intelligent and sustainable use of resources and the reduction of their consumption.

World's first fluoropolymer Up-Cycling plant

The award-winning plant was put into operation by Dyneon in 2015 as the world's first fluoropolymer up-cycling plant. Up to 500 tons of fluoropolymer waste can be up-cycled annually with this plant. This allows for the return of valuable raw materials into the manufacturing process of new fluoropolymers thereby completing the material cycle. The Dyneon Up-Cycling process has a high yield and corresponding purity, with no loss of material quality.

Focus on sustainability

"Naturally we are delighted by this important industry award from the VCI. Our pilot plant in Burgkirchen shows the size of the savings that can be achieved with low consumption of resources", explains Burkhard Anders, Managing Director of Dyneon GmbH, a 100% subsidiary of 3M. The fluoropolymer Up-Cycling process is important with regard to genuine sustainability for these valuable materials, which have become indispensable in so many applications: for example corrosion prohibiting linings in the chemical industry and chemically inert automotive components.

www.dyneon.eu/up-cycling

Ina Vrancken and Burkhard Anders from 3M received the first price of the VCI Responsible Care competition © 2017 Verband Der Chemischen Industrie

REACTIVATION

WG LCA ENLARGES ITS BOUNDARIES AND CHANGES THE NAME

Call for participation to the TensiNet Working Group Sustainability and Comfort

The main objectives of the WG S&C are:

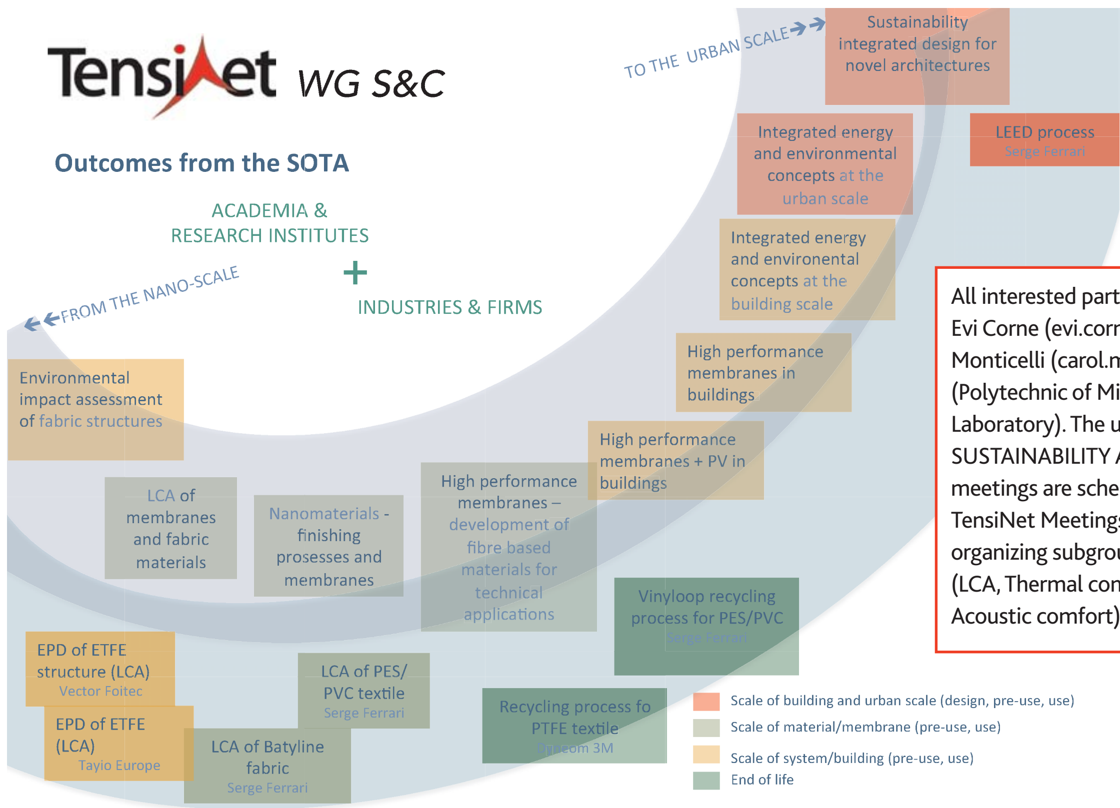
- Measuring the quality of current and future lightweight constructions in terms of environmental efficiency, user's comfort, materials and building products' durability and end-life scenarios.
- Introducing the themes, and the related rules, of eco-efficiency, thermal comfort, optical comfort, acoustic comfort in a process of European standardization;
- Adding a set of sustainable design principles to the membrane structure design guide;
- Harmonizing the LCA data of the membranes and foils, defining average values (between the materials' producers) to be added to the existing LCA databases.

Membrane and foil structural skins exploit minimal amounts of material to cover a space, compared to common envelope materials, thanks also to the ability to be tensioned, by shaping themselves to the forces ways, with a few additional components. Their environmental compatibility together with the thermal, optical, and acoustic performances are crucial factors during the designing phase.
Many studies are converging to the necessity of increasing the designers' awareness of both lightweight and flexible materials and their performances, in a life cycle thinking perspective, achieving membrane architectures with a smaller environmental footprint.
Inside the lightweight technology development perspective, the Working Group Sustainability and Comfort aims to keep alive and updated the discussion on the searching of the most effective life-cycle-based design methodology, which will support designers during their daily work, and not as a mere theoretical analysis for scientists and environment specialists. This research need actually comes up from the networking between researchers and firms - both manufacturers tensile/pneumatic structures and membrane/foil producers - as well as engineers and architects, which are all asking to find a easier way to compare the eco-profile of lightweight material alternatives nowadays available on the global market.

From this scenario, the original WG Life Cycle Assessment, established in 2012, focused principally on the Life Cycle Assessment methodology for the membrane eco-efficiency, has been redefined changing the name; it has meant enlarging the boundaries and focusing to sustainability and comfort issues: the first comprehend LCA, durability aspects, recyclability, social acceptability, the second one involves thermal, optical, acoustic comforts.

The discussion has been reinforced in the past four years by the networking activity during the COST ACTION TU 1303 – Novel Structural Skins: the Working Group Sustainability and life cycle analysis of structural skins worked to update the state of the art in literature, by researches and good practices, and to share the priorities and urgencies in this field.

The first "reactivation" meeting was held during the last TensiNet Partner meeting in Stuttgart at Dekra and the discussion was on:
- The needs for the material and membrane producers, for the membrane systems manufacturers and for the architectural and engineering companies, in terms of eco-efficiency and comfort aspects; specific questions will be send to the TensiNet partners to have contributes and opinions;
- The understanding of the priorities between the validation of friendly eco-design principles for membranes or the setup of an LCA tool, easy (but not simplistic) and efficient, for comparisons and verifications during the membrane design process, together with the harmonization of the LCA data on materials and find out an average.



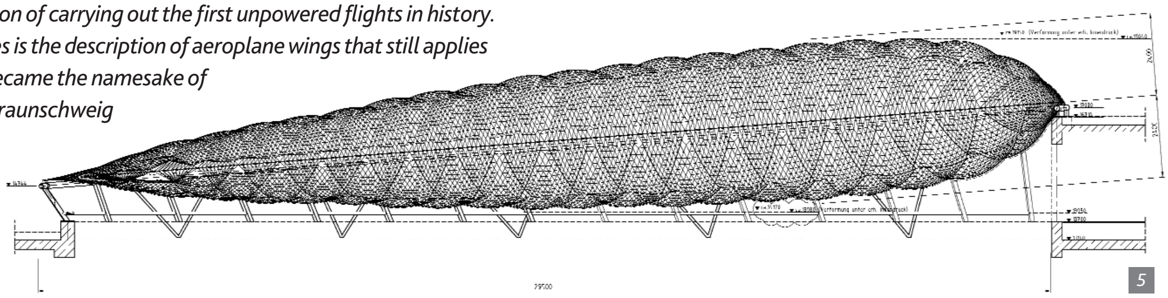
State of the art of the sustainability and comfort themes in the field of membrane structures (@ Monticelli - Zanelli)

All interested parties are invited to contact Evi Corne (evi.corne@vub.be) and Carol Monticelli (carol.monticelli@polimi.it) (Polytechnic of Milan, Textiles Hub Laboratory). The upcoming WG SUSTAINABILITY AND COMFORT meetings are scheduled during the next TensiNet Meetings with the intention of organizing subgroups on different topics (LCA, Thermal comfort, Optical comfort, Acoustic comfort).

AVIATION PIONIER

Braunschweig, Germany

Otto Lilienthal has the distinction of carrying out the first unpowered flights in history. Also based on these experiences is the description of aeroplane wings that still applies to this day. He consequently became the namesake of the new Lilienthalhaus at the Braunschweig Research Airport – the first building on the nascent Lilienthal Quarter at Braunschweig Airport.



formTL developed the lightweight roofing for the atrium in the new Lilienthalhaus

Project

The new four-storey building shows itself to be just as idiosyncratic and innovative as its namesake. Its shaping is based on a building plot with a triangular ground plan. The architect Hartmut Rüdiger bulged the three sides out, creating in this way a friendly, well-lit atrium in the middle of the building that forms the centrepiece of the Lilienthalhaus. It is open to the public and provides a space for events, exhibitions and lectures. A free-standing spiral staircase constructed from white-lacquered steel is located in the middle of the foyer as an eye-catching feature that provides access to the office spaces occupying the four upper storeys. Thanks to their alignment towards the atrium, these areas benefit from the bright atmosphere of the interior courtyard. The sky lounge and roof terrace in front of it are located on the blunt side of the triangle, directly beneath the ETFE roof.

Atrium

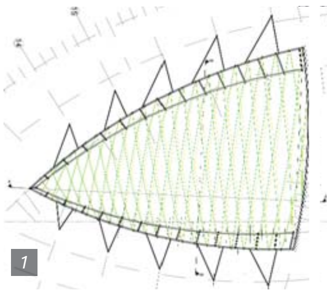
In order to provide a bright and friendly ambience in the atrium, the roofing was to be translucent. Due to fire safety requirements, however, a glass roof was ruled out. Using glass would also have required a correspondingly heavy substructure because of its high dead weight. Rüdiger Architekten therefore consulted the membrane experts at formTL in Radolfzell. The engineers found a light alternative for the roof that met the set requirements – transparent ETFE foils. Like glass, this innovative material not only offers a high level of UV permeability and translucence, but at the same time it also guarantees the fire protection required by making the substructure considerably lighter (Figs. 1– 4).

ETFE cushions

The formTL engineers designed a triangular ETFE cushion over 400m^2 to cover over the Lilienthalhaus. This solution has one particular feature: Due to tensile forces only, it was possible for the roof to be built with an extremely light substructure. Steel cables arranged in a rhombic shape and fixed to the perimeter tube around the building form the cushion and carry the loads. The supporting structure is thus almost invisible, giving the roofing the necessary lightness on the one hand and a great degree of elegance on the other. The triple-layer ETFE roof, which inclines towards the tip of the triangle, was elevated and anchored on top of the concrete structure. The inclination has given rise to further façade surfaces between the roof and the edge of the building which have likewise been realized using ETFE foil and integrated smoke and heat exhausting. The low structural weight of this lightweight structure is absolutely convincing, amounting to less than 20kg/m^2 for the entire roofing of the atrium from the upper edge of the concrete structure.

Sun control

In order to reduce heat gain due to sunlight, the outer layer of the cushtion was printed with an even pattern. The roofed atrium thus ensures that users of the Lilienthalhaus will have a space in which to spend high-quality time throughout the year.




Bernd Stimple
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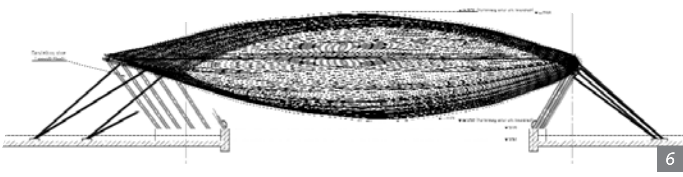
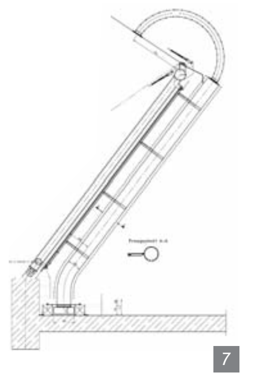
Figure 1. Top view atrium roof © formTL
Figure 2. View from within the atrium © hannokeppel.de
Figure 3 - 4. View into the atrium with transparent ETFE-roofing © hannokeppel.de
Figure 5. Longitudinal section ETFE-roof © formTL
Figure 6. Cross section ETFE-roof © formTL
Figure 7. Vertical section roof border detail with cushion air support © formTL

Client :
Volksbank BraWo Projekt GmbH, Braunschweig/GER
Architect:
Hartmut Rüdiger, Braunschweig/GER
Structural and foil planning atrium roofing:
formTL ingenieure für tragwerk und leichtbau, Radolfzell/GER

7TH IMS INTERNATIONAL TENSILE ARCHITECTURE SYMPOSIUM MIAMI

17TH TO 19TH MAY 2018
SCHOOL OF ARCHITECTURE AT THE UNIVERSITY OF MIAMI

The IMS e.V. Archineer® Institute (Institute at Anhalt University Dessau-Rosslau), Germany, is organizing the first IMS Symposium in Miami. It is the first IMS Symposium in the US and will take place from May 17 to May 19, 2018 at the prestigious School of Architecture at the University of Miami.

The IMS Symposium 2018, is a didactic and academic event. In a short period of three days experienced professionals will give master lectures on Tensile Architecture. Keynote speakers like Nicholas Goldsmith, Prof. Dr. Günther Filz, David M. Campbell and many other specialists will share their expertise with the participants. The main topic consists of planning, design and increasingly frequent inclusion of high-tech membrane structures within the modern architecture. Likewise, the rising importance and popularity of this global industry.

At the same time, the symposium will be a unique opportunity to interact and to meet a large number of professionals, students and craftsmen currently involved in the industry and in the world of membrane or tensile structures. Consequently, this offers a special chance to network both on a personal and on a company scale and this way improving professional and commercial relationship within the industry. Therefore, the symposium addresses to all people interested in the dynamics and the development of the textile architecture and building. As the symposium takes place at one of the most prestigious universities in South Florida, in the city of Miami, it is an invitation especially for North American and Latin American participants.

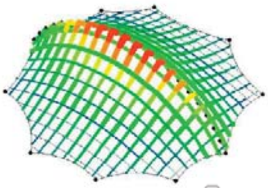
usa@ims-instiute.org
www.membrane-symposium.org/symposium-miami-2018.html

23RD TEXTILE ROOFS 2018 RUSSIA

24TH TO 26TH MAY 2018
MOSCOW ARCHITECTURAL INSTITUTE (STATE ACADEMY)

The well-established series of Textile Roofs workshops takes on another challenge. After many years of holding the event in Berlin, for the first time Textile Roofs will go to Russia. Between May 24th and 26th this year the 23rd edition of the "International Workshop on the Design and Practical Realization of Architectural Membrane Structures" will take place in Moscow.

The rising interest in membrane architecture in Russia, a developing market in this field, as well as future plans in modern city views, make Moscow be a desired destination for the next edition of Textile Roofs. Together with our partners we will welcome the international community of Membrane Architecture at the Moscow Architectural Institute (State Academy). The event is hosted by Prof. Vladimir Ermolov (CEO & Founder of Verteco Co. Ltd.) and will have the same structure as in the previous years. Presentations in the mornings, followed by various workshop activities in the afternoons will guide you through the whole process of making architectural membrane structures real. Starting



ACADEMUS ACADEMY SERVICES

from the basic idea up to the final mantling, every single manufacturing step will be explained and discussed.
Therefore the key component of the Textile Roofs workshop activities will be the traditional joint project, where the participants work together on the design, the calculation, the definition of details - such as cables and anchors - and the mantling of a structure that will be built in the courtyard of the Institute during the three days of Textile Roofs.
Outstanding experts from Europe and Russia will share with you their knowledge and the insight view on both: general market opportunities and the best approaches to build with textiles, based on specific projects. A special guest lecture and an exciting evening dinner at the Informational-Analytical Centre of Moscow Urban Construction Policy Department complete the program.
Please save the date and discover your opportunity to be part of Textile Roofs 2018, as a participant, expert or sponsor.

mail@textile-roofs.com
www.textile-roofs.com

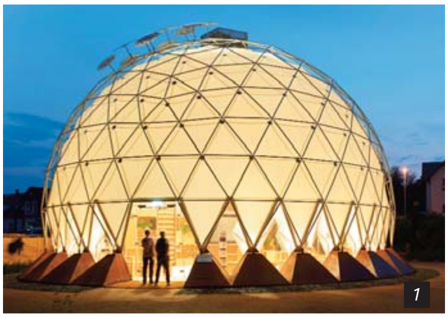
Textile Roofs 2017 - Berlin, Germany

CLIMATE-PAVILION

COUNTY GARDEN EXHIBITION 2017

Resembling one of Richard Buckminster Fuller's "Domes", the Climate-Pavilion initially installed at the County Garden Exhibition 2017 in Apolda, Germany, has been one of the attractions during the exhibition.

AN EXCITING MATERIAL, CUSTOM TAILORED MEMBRANE MADE OF ATEX 5000 AND INSTALLED BY HIGHTEX.



Apolda, Germany

Context

The project was planned on behalf of the Thüringen Ministry for Environment, Energy and Nature Conservation and realized by Thüringen's Energy and Greentech Agency. At the County Garden Exhibition Apolda, the Pavilion is powered through renewable energy. With specially designed "Solar Flowers" and "Solar Umbrellas" installed directly onto the supporting structure, the building produced its own energy for lighting and air conditioning. Consequently, Reich Architects BDA and Professor Jürgen Ruth from Bauhaus University Weimar chose a silicone coated glass fabric by Hightex for their spherical climate-pavilion.

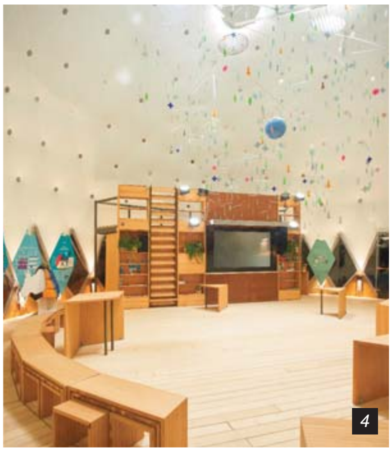


Figure 1. The climate-pavilion referring to the domes of Buckminster Fuller © reich.architekten BBD
Figure 2. Connection detail basement – structure – membrane © reich.architekten BBD
Figure 3. Detail of the photovoltaic elements © reich.architekten BBD
Figure 4. Interior view - space for exhibitions, seminars and presentation events © reich.architekten BBD

Design conditions

Pavilions require little space, are often installed temporarily and are subject to less complex legal conditions than permanent structures. For these reasons, pavilions can be planned and installed in a much more experimental, even playful manner. For such projects, what would be better suited than a material matching the following criteria: light and economical, translucent and UV-stable, hardly inflammable and extremely resistant to temperature while at the same time applicable multiple times due to its flexibility and resistance to bending and finally completely recyclable (Figs. 1-2).

Photovoltaic plant

This poses an extra challenge for the material that has to be highly flexible and resistant to bending. The silicone coating is harmless to the environment and meets all security regulations. The highlight of the structure is an organic photovoltaic plant that is installed over the membrane, complementing the translucent, futuristic look. With this feature, all requirements for energy efficiency are met through least possible material use (Fig. 3).

Lightweight

Despite its impressive size (diameter 15m), the Pavilion weighs less than a middle-class automobile. Its small weight stems from the silicone-glass-membrane, confectioned and installed by Hightex. Including some specially developed details, it is attached to the steel-construction from the inside. The material's high translucency of 21% creates warm and comfortable light inside of the Pavilion. On an area of 170m² and a height of 9m, the Pavilion offers space for exhibitions, seminars and presentation events (Fig. 4).

On the move!

Apart from Apolda, over the next years it will be set up at various other locations in Thüringen and provide citizens with information regarding climate change, environmental protection and responsible use of natural resources. The unique steel-membrane envelope, that resembles our atmosphere, has proven its sustainability: in a virtual model it outperformed an equivalent concrete structure in all environmental indicators and only produced a tenth of the greenhouse gas emission. The climate pavilion will be reinstalled in 2018 at the County Garden Exhibition 2018 in Weimar.

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www. hightexworld.com

Name of the project:	Climate-Pavilion
Location address:	Future County Garden Exhibitions Thüringen
Client (investor):	THEGA Thüringer Ministerium für Umwelt, Energie und Naturschutz
Function of building:	Pavilion for the County Garden Exhibition Apolda
Type of application of the membrane:	Temporary
Material:	silicon coated glass fabric
Year of construction:	2017 (and 5 following)
Architects:	Prof. Dr.-Ing. Jürgen Ruth, blueKon, reich.architekten BDA

SHELTAIR PAVILION

AEDES METROPOLITAN LABORATORY IN BERLIN, GERMANY

This pavilion investigates the use of air-filled cushions to rapidly, safely and cheaply erect beautiful and structurally efficient elastic gridshells for events and humanitarian causes. Scientifically developed by Gregory Quinn as part of his doctoral thesis at the Berlin University of the Arts at the department of Structural Design and Technology KET (Prof. Christoph Gengnagel) and exhibited in the summer of 2017 at ANCB The Aedes Metropolitan Laboratory in Berlin.

Figures 1 - 2. Inside and outside view of the SheltAir pavilion

Introduction

The importance of large shelters for medical treatment, social convalescence and religious gatherings in refugee or disaster stricken areas remains underserviced due to the necessary focus on smaller family dwellings but also due to the cost, time, complexity and energy demands associated with their construction.
Based on rigorous research, this holistic solution facilitates the fast, safe and low-energy erection of elastic gridshells by means of pneumatic falsework i.e. air-filled cushions. Benefits are found in the ability to generate large, stiff and beautiful doubly curved shells from slender and straight beams with very little material or embedded energy. This 13m pavilion in the garden of the Aedes Metropolitan Laboratory Berlin was built to test and validate the researched method but also to demonstrate its architectural potential. The biomimicry of the shell curvature and repeating patterns of the grid complement the sustainability aspects of the solution and offer a refreshing contrast to typical planar shelter systems (Figs. 1 - 2).

A novel method

Elastic gridshells such as Frei Otto's Multihalle in Mannheim are highly efficient structures, able to cover large spans with very little material or embedded energy. The simplicity of these structures lies in their ability to generate beautiful doubly-curved shell surfaces from slender and initially straight beams. While elastic gridshells are efficient in their built-state, the existing methods with which to erect them are usually associated with significant complexity, cost and time. This novel method, which makes use of pneumatic falsework (i.e air-filled cushions), has the potential to greatly increase the speed of construction for large-span shells (i.e. up to 100m in a matter of days), which would have groundbreaking implications on construction costs and efficiency with promising potential for application in rapidly deployable event covers and shelters (Fig. 3).

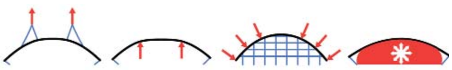

Figure 3. Schematic representation of erection methods for elastic gridshells:, left to right "lift up", "push up", "ease down" and "inflate".

The erection methods for elastic gridshells can be grouped into the following four categories: "lift up", "push up", "ease down" and now also "inflate". Various technological methods for pneumatic falsework and formwork are well established in the context of continuum shells made from reinforced concrete (e.g. Wallace Neff's bubble houses and Dante Bini's work). Using pneumatic falsework to erect concrete shells presents technical challenges relating to large dead-loads, maintaining pressure during curing and minimisation of displacements.
The pneumatic erection of elastic gridshells presents its own set of unique challenges. A key advantage of elastic gridshells is their ability to be assembled as a flat grid on the ground however this means that a vertical repositioning of the kinematic grid into its final shape is necessary. In this intermediate state of erection, the grid is extremely soft and flexible due to the slenderness of the rods and the single degree of rotational freedom at every node making the system highly susceptible to overstressing from bending and tricky to restrain effectively. Furthermore, the erection process of elastic gridshells is hindered by modern health and safety legislations which forbid working underneath a partially-restrained structure. Also, scaffolding platforms and safety measures are usually necessary when adding grid stabilisation elements (such as struts or cables). As such, this puts into question the claim of rapid deployability often associated with elastic gridshells. The use of pneumatic falsework offers an interesting answer to this question, particularly for large elastic gridshells with spans over 30m. Further benefits include: the distributed support of the soft gridshell during forming, the support and restraint of the shell during the addition of shell stabilisation elements and the provision of a safe walk-on working surface during construction and finally the reuse of the cushion membrane as an architectural envelope. The reuse of the erection membrane can also be considered for the stabilisation of the grid shell.

The SheltAir pavilion

For the SheltAir pavilion, the target shape or base geometry for the shell was a digitally form-found funicular surface. This surface is then re-meshed using a Chebyschev discretisation which defines the geometry of the gridshell. Funicular shell surfaces are inherently well suited to resisting evenly distributed compression forces and as such were deemed a highly suitable target geometry for the gridshell. A surface with plenty of double curvature and curvature changes (from convex to concave) was selected due to the aesthetic appeal from such curvature changes but also due to its stiffening effect on the shell.
The method proposed here sees the cushion being removed before the gridshell is stabilised (in this case by means of bracing cables); as such the resultant shape of the gridshell in the end-state is in fact the relaxed elastica despite the target shape being defined as a funicular. For this to work the gridshell must be stiff enough to support its own self-weight without stabilisation once the beam-ends have been secured in place and the cushion is no longer supporting the gridshell.
The cushion design proposed here is a passive (no shape compensating) cushion which is

identical to the target shape of the gridshell. It comprises an upper doubly-curved part and a flat ground sheet which, when clamped together at the perimeter edge, form a closed volume which is fully restrained. This perimeter restraint ensures that the cushion stays in the correct position during and after erection. Once the gridshell has been erected, demounting the perimeter clamps results in immediate deflation of the cushion. Further shape manipulation could be achieved with internal tethering cables.

The presence of only one small opening was conscious and intended to minimise the shell-weakening effects of large and multiple openings.

Figures 4 - 5. Construction details - connections

Figures 6 - 7. Interior impressions

Erection sequence

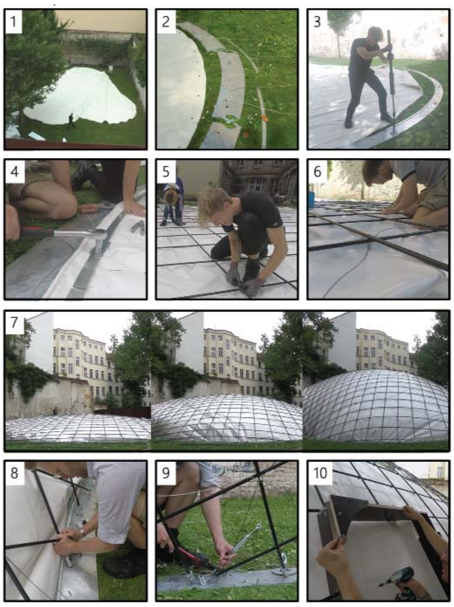

Figure 8. Erection sequence

1. *Flat ground sheet is positioned in desired shelter location. No measuring or marking of site required.*
2. *Steel anchor plates are positioned and interlocked with one another as well as the membrane ground sheet. Ground sheet acts as template. No measuring or marking required.*
3. *Anchors are driven into the ground, securing the steel plates.*
4. *The upper cushion membrane is added and the clamping plate is secured.*
5. *The grid is assembled on top of the deflated cushion.*
6. *Bracing cables are fed through the appropriate nodes with a generous amount of slack.*
7. *Cushion is inflated.*
8. *Beam ends are positioned into their corresponding support sockets in the base plate.*
9. *Bracing cables are pretensioned.*
10. *Doors and details are added.*

Low-tech implementation: high-tech simulation

The implementation & construction for the proposed solution is purposefully and necessarily low-tech. However the physical interaction between the elastica curves of the beams with residual stresses and the pneumatic form of the cushion in relation to the architectural target shape is particularly complex. Bespoke simulation methods have been developed based on a novel dynamic relaxation solver which is insensitive to the system's transience between dynamic (inflating) and static (inflated) states. Simulations and physical prototypes have produced a breadth of results which determine, for example, which spans, curvatures and pressures are feasible and suitable with this method. The amount of design freedom permitted within the constraints of the solution is considerable.

In order to simulate the proposed erection method, bespoke simulation pipelines were developed in the Rhinoceros 3D / Grasshopper software environment making use of the Kangaroo Dynamic Relaxation (DR) solver alongside substantial customisations using Python and C# programming scripts. A series of 2D and 3D mechanically calibrated case studies were conducted which simulate the incremental inflation of a membrane cushion of high tensile stiffness but zero bending stiffness in combination (colliding) with a grid featuring significant bending stiffness and relatively low self-weight. The method features low membrane utilisation stresses and bending stresses climb gradually such that overstressing of the beams is avoided entirely, demonstrating the effectiveness of the method. The importance of external and internal tethering cables for restraint and the significance of an initial 'trigger' pressure were also investigated.

Computation

In structural engineering implicit integration methods are more common, typically featuring a full six degrees of freedom (DOF) at each node which can accurately describe mechanical stresses and displacements in a discretized continuum under the assumption of small deflections. If equilibrium is being sought in a system where deflections are large, the stiffness matrix must be updated over multiple iterations in a non-linear analysis which can be computationally demanding and often unstable. Generally, a prerequisite for implicitly integrated methods is that the systems must be statically determinate or indeterminate. Mechanisms cause numerical instability and are harder to solve. Initial simulations were carried out into the pneumatic erection of elastic gridshells using implicit global stiffness based solver simulation methods in SOFiSTiK (Fig. 9).

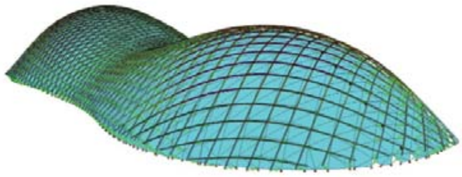

Figure 9. Initial FE simulations using implicit global stiffness-based solver with SOFiSTiK. Contact between the grid and cushion was simulated by means of compression-only springs but the method has significant limitations relating to the particular computational challenges presented by this erection method (i.e. large deformations, sliding contact, mechanisms).

Dynamic relaxation (DR) on the other hand, does not require the computation and inversion of a global stiffness matrix, but instead seeks equilibrium in each node explicitly and simultaneously by assigning mass, acceleration and a method of damping to the nodes. This means that DR methods are insensitive to the static determinacy of the structural system such that mechanisms and large deformations are not an issue, provided the solver is able to remain stable (as is the case with Kangaroo). Furthermore, collisions can be quite easily achieved using Kangaroo.

In order to be able to use the DR solver in Kangaroo for the simulation of structural systems with accurate stiffness properties, development and calibration of Kangaroo was carried out by the Kangaroo's creator Daniel Piker together with Gregory Quinn and a team of experts (Anders Holden Deleuran, Cecilie Brandt-Olsen, Will Pearson). The latest release of Kangaroo and its ability to model mechanically accurate systems has implications and application potential that reach far beyond the scope of the studies presented here.

At the time of writing, the Kangaroo solver is based on the manipulation of vertices with three degrees of freedom and a 6DOF version is in BETA stages. This has certain implications on which mathematical models can and can't be used for the simulation of structural behaviour. For the modelling of beams in Kangaroo, axial and bending stiffness are defined by goals based on Hooke's Law and the Barnes / Adriaenssens model respectively. The bending model defines bending radii on a plane of three sequential nodes and does not account for orientation or anisotropy of cross sections. Nor is beam torsion accounted for. As such the beam model is simple and fast to compute. While more accurate 4 and 6 DOF solutions exist to describe beam behaviour using DR their increased computational demands significantly reduce their speed and hence suitability for this method. The graphical display of internal forces was scripted using native Grasshopper components as well as custom Python scripts.

A great strength of the latest Kangaroo (2) is the ability to script custom 'goals' in C# or

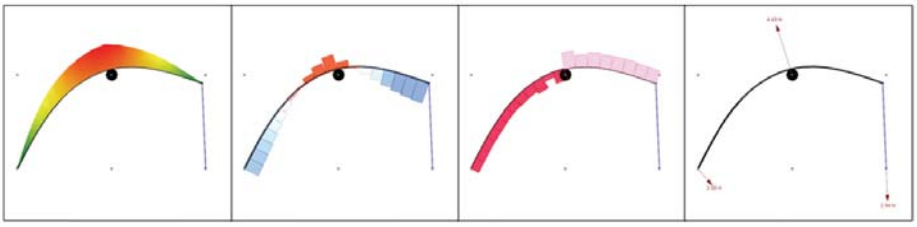

Figure 10. Custom GUI and visualisation of internal and external forces. From left to right: bending moments, axial force, shear force and reactions.

Python which define move vectors and weightings for particles in the system to be solved.

The methods here make use of predominantly native Kangaroo goals in combination with some custom goals scripted by the author.
The DR solver in Kangaroo seeks equilibrium for a user-defined threshold of the root mean square of particle velocities or 'VSum' in Kangaroo terminology. For the 2D simulations, the default value of 1e-15m/s was increased to 1e-10m/s since during inflation the semi-inflated cushion, by its very nature, struggles to find equilibrium as the membrane folds and slides. These low-resolution convergence steps are essentially snapshots of an instable system during inflation. Only when the cushion is fully inflated, and the structure sufficiently restrained, can precise equilibrium be found. More suitable convergence criteria could be the particles' acceleration or residual energy, which are likely to be available in later Kangaroo releases.
Custom GHPython scripts monitor the VSum output and flag when the solver has converged. Convergence then triggers logging of result data (such as bending stresses and screenshots) and then the Grasshopper slider for the internal air pressure is signalled to progress to the next increment. Manipulating sliders is made possible by accessing the Grasshopper software developer kit (using GH-Python). Sending data upstream (i.e. disrupting GH's directed acyclic data-flow) is made possible by accessing the RhinoPython "sticky" variable (a dictionary hash-table data structure) which can be accessed from anywhere in the current Rhino session using either of the Python editors (Edit- PythonScript or GH-Python). For easy access to a basic and custom GUI, the GH remote panel was used extensively. The stored result data (.csv format) is finally loaded into a second GH file which automates the drawing of graphs.

Funicular Pneumatic Elastica

The funicular, pneumatic and elastica forms lie at the very heart of this thesis. Gaining a robust understanding of these individual shapes and, when combined, their influence on one another is central to developing solutions for the proposed method.

For the gridshell geometry, the SheltAir prototype make use of a funicular target shape or base geometry. Digital studies have shown that the deviation between the funicular, pneumatic and elastica forms is minimal for shells with a span-to-height ration less than 3:1 but more significant as the height increases. Funicular shell surfaces are inherently well suited to resisting evenly distributed compression forces and as such were deemed a highly suitable target geometry for the gridshell (Fig. 11).

The funicular target surface for the ANCB pavilion was generated by means of a digital hanging model. This surface was then re-meshed with a Chebyshev subdivision such that all mesh edges are the same length: a key requirement for the functionality of an elastic gridshell. For the funicular form-finding step, the initial mesh and method of loading has an influence on the shape of the funicular surface. The starting mesh for a funicular surface can be either quadrilateral or triangular.
While regular quadrilateral chains are a perfectly valid means of surface form-finding for elastic gridshells, they are subject to directional bias along their orthogonal axes particularly for irregular or asymmetric shapes. A regular quadrilateral chain lattice hanging chain can be simulated digitally by applying a length-dependent vertical load at the beginning and end of each element. The elements may be given an arbitrary spring stiffness (albeit proportional to their lengths) allowing them to extend under applied load. This results in an approximate catenary surface which is very much subject to directional bias relative to the mesh orientation. By using a triangulated configuration for the initial form finding mesh, it is possible to apply barycentric loads to the corner nodes which, if

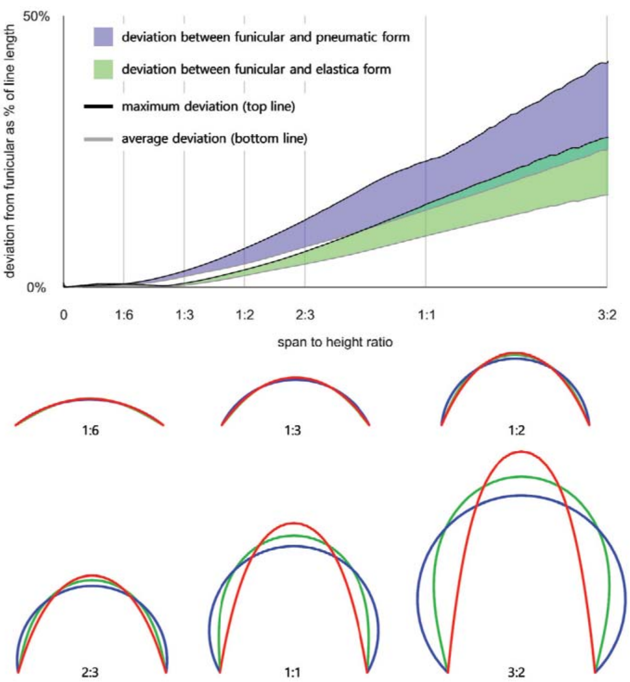

Figure 11. Deviation in 2D for different span-to-height ratios between the three forms central to this method: funicular, pneumatic, elastica

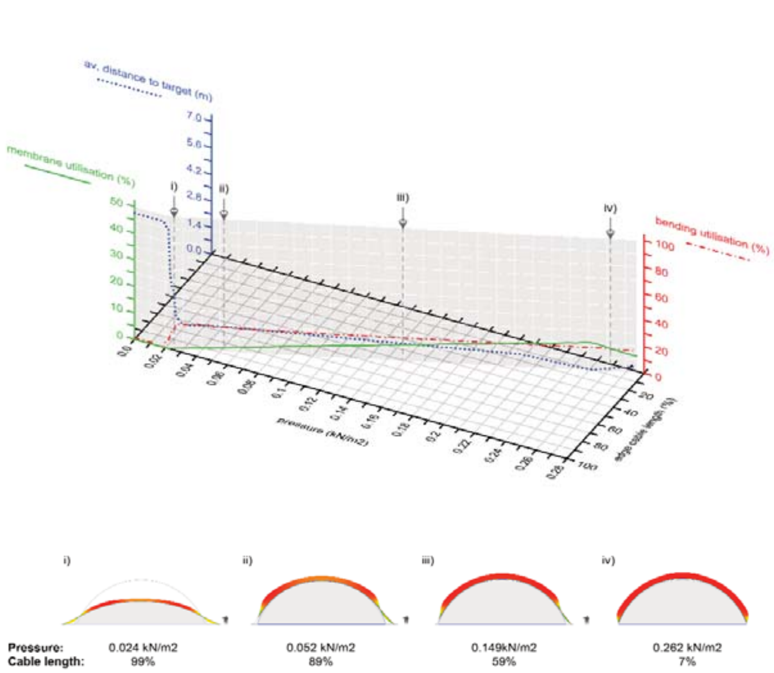

Figure 13. Sample of 2D erection analysis results. Erection of 30m dome with edge cable length initially at full length and then progressively shortened at a constant rate after the trigger pressure has been reached.

the elements are given stiffness proportional to their length, will result in a uniform funicular shape without directional bias. A custom Kangaroo goal (based on existing goals from Daniel Piker) was written for the barycentric vertical loading of triangulated meshes.

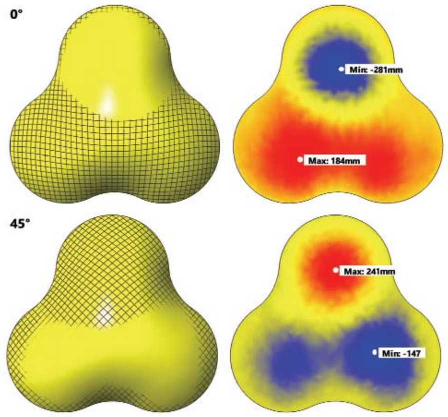

Figure 12. Directional bias of digital hanging chain model using a mesh quadrilateral subdivision (black) compared with a triangular mesh (yellow). Deviation shown right.

Experimental results

Generally, it was proven that the erection method is very gentle to the rods in terms of bending stresses. The results help to quantify with precision which curvatures, spans, shapes and material choices are feasible and sensible for the proposed method which, in light of the successful prototype, is proven to offer a viable solution for rapidly-deployable, structurally efficient and architecturally elegant dwellings ideal for application in event or disaster shelters.

During inflation bending stresses in the beams remain null until the trigger pressure is reached, after which a rapid increase can be observed. Crucially however, the bending stresses climb gradually and overstressing, as can occur with other erection methods such as 'lift up' and 'push up', is avoided entirely demonstrating the effectiveness of the method.
The membrane stress is also very low throughout the inflation process. Larger spans result in lower curvature and subsequently higher membrane strain for a given pressure. However even for the weakest type (I) of PVC coated polyester membrane, the membrane stresses are uncritical. Overall, exhibited membrane stresses are even low enough to satisfy typical safety factors accounting for long term effects, temperature and environmental degradation, however due to the very temporary demands on structural performance, membrane utilisation stresses up to 90% are deemed acceptable for the proposed erection method.
The need for external tethering cables is twofold. Firstly, external tethering cables can prevent excessive lateral sliding of the beam/grid on the cushion. Secondly, when the cushion is fully inflated, the beam/grid ends cantilever out and must be pulled towards their support points before the grid shell can support itself independently of the cushion. The external tethering cables can be shortened (by hand or winches) in order to pull the beam ends to their target support points. The shortening of these edge cables can occur at different stages during (or after) the inflation process. The strategic value and structural impact of when to shorten the edge cables has been investigated in detail revealing that it is most sensible to shorten the external tethering cables after full inflation (Fig. 13).

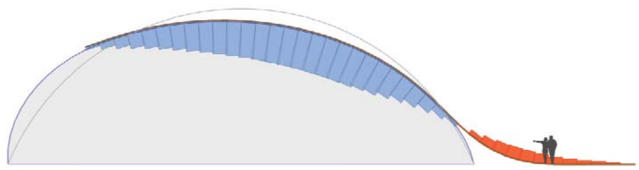

Figure 14. Demonstration of lateral sliding of beam along membrane surface highlighting the need for external tethering cables. Notice the change in axial forces from predominantly tension (blue) to compression (red).

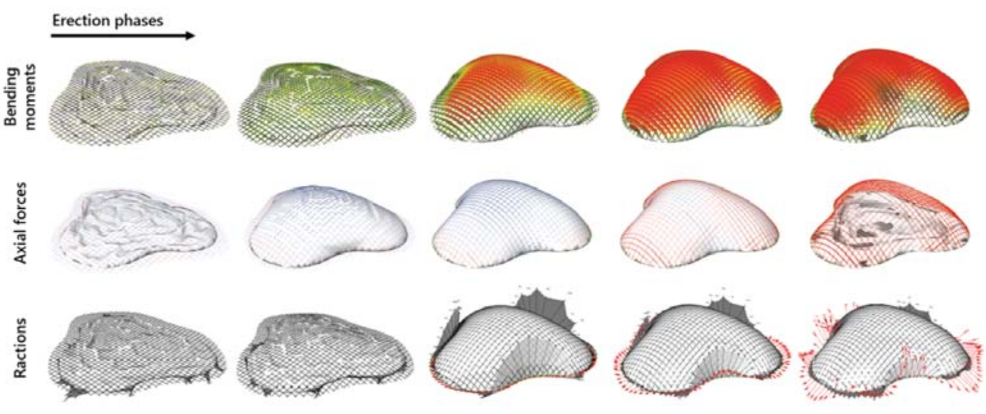

Figure 15. Sample of 3D erection analysis results.

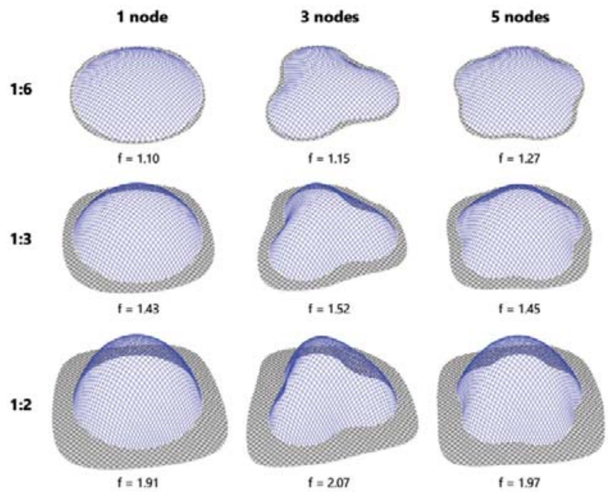

Figure 16. Influence of span-to-height ratio and shell shape on area compensation factor in calculating the trigger pressure required to initiate pneumatic erection of an elastic gridshell. Shown in blue is the end-state gridshell and in black the initial and flat configuration.

Trigger Pressure

An important aspect of being able to pneumatically erect elastic gridshells is knowing how much pressure is required to do so. Low pressures are desirable because they are easy to supply (with low-cost blowers) and because they have simpler and more affordable demands on detailing for the membrane. The pressure required to inflate a gridshell (trigger pressure) can be defined as:

$$\text{trigger pressure} = g_{\text{membrane}} + f_{\text{Area}} \cdot g_{\text{gridshell}}$$

Where g_{membrane} is the distributed self-weight of the membrane, $g_{\text{gridshell}}$ is the distributed self-weight of the gridshell and f_{Area} is a factor for area compensation between the footprint of the gridshell in its end-state and the gridshell footprint in its initial and flat state. This area factor will increase for higher height to span ratios and is also dependent on the shape of the gridshell (Fig. 16).

Physical Mock-up

In parallel with FE simulations, a scaled physical model was used to perform a first ever erection of an elastic gridshell by means of pneumatic falsework. The scaled model makes use of acrylic beams with an 8mm square cross section. The scale of the physical model is one tenth (1:10) of a full-scale 30m span equivalent structure, subsequently it had a span of 3m.

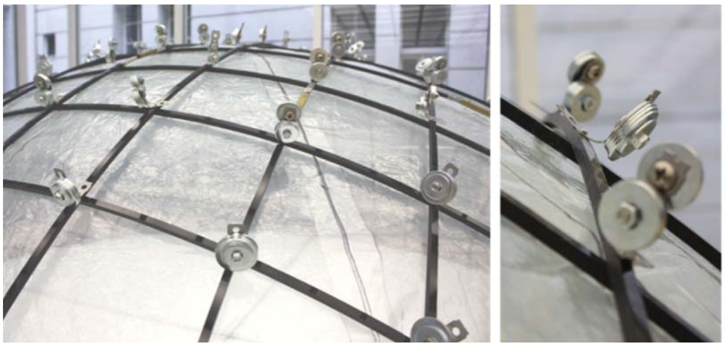

Figure 17. Increased self-weight of the grid shell by means of an additional 104g at each node to account for scaled physical properties according to dimensional analysis.

Dimensional Analysis which makes use of the Buckingham Pi theorem is a method for establishing dimensionless variable groups in order to reproduce physical behaviour in scaled models and was used here (Figs 17-18).

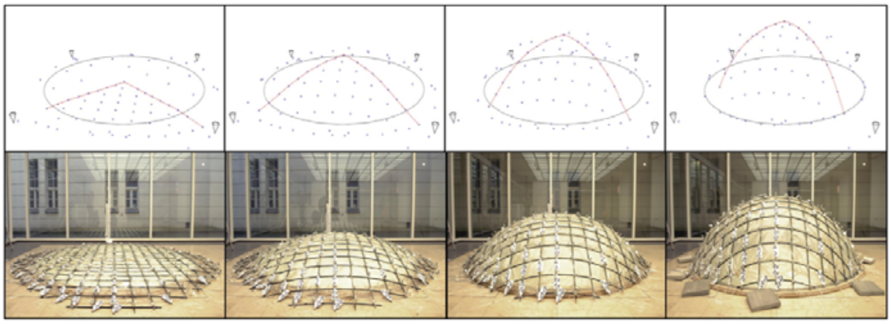

Figure 18. Four snapshots from the inflation process with elevation photos (below) and photogrammetric 3D point cloud data (above).

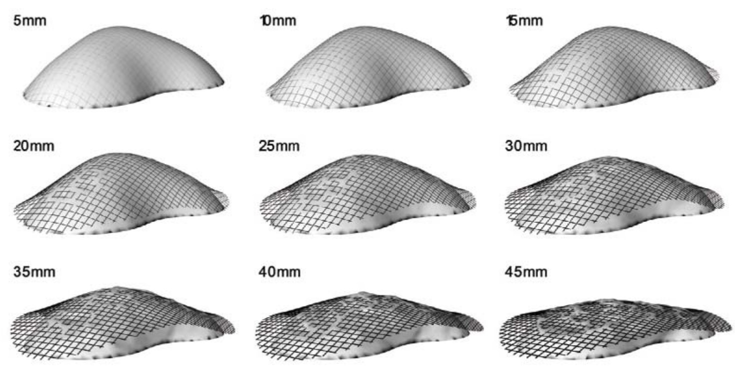

Figure 19. For GFRP rod diameters ranging from 5mm to 45mm, the interaction between the grid and cushion, under its respective trigger pressure, is shown.

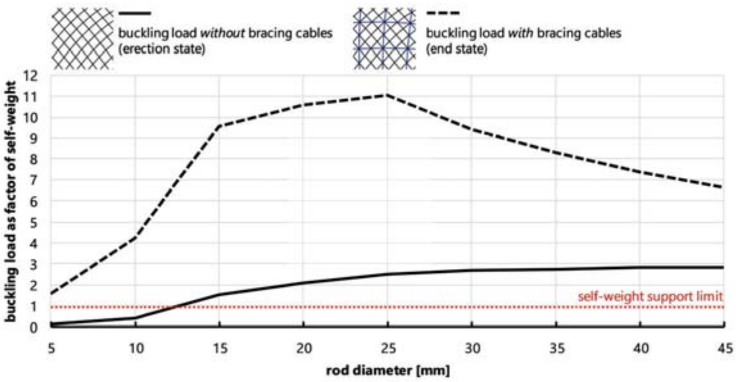

Figure 20. Here the buckling load of elastic gridshells without bracing cables (erection-state) and with bracing cables (end-state) is shown for a variety of rod diameters. This shows how smaller rod sections are not stiff enough to support the gridshell's self-weight while large diameters are too stiff and inefficient.

rod diameter	5	10	15	20	25	30	35	40	45	mm
gridshell UDL	1,9	7,6	16,8	29,8	46,6	67,2	91,4	119,4	151,1	N/m2
trigger pressure	0,01	0,02	0,04	0,06	0,08	0,11	0,15	0,19	0,24	kN/m2
deviation from target	13	61	150	307	446	579	711	812	939	mm
manual anchorage load	0	3	8	16	27	42	60	86	114	kg
beam utilisation	5	9	13	18	22	27	31	36	40	%
membrane utilisation	10	16	26	40	58	80	106	137	171	%
buckling load no cables	0,1	0,4	1,5	2,1	2,5	2,7	2,8	2,8	2,9	SW factor
buckling load cables	1,6	4,2	9,6	10,6	11,1	9,4	8,3	7,4	6,6	SW factor

viable

failure | undesirable | desirable

Figure 21. Range of experimental results which show the bandwidth of viable specifications for the SheltAir prototype.

Fitness Criteria

It was found that the range of materials, spans and shapes can and must be selected very specifically in order to ensure the method's success. If the rods are too stiff, the grid mechanism will not deflect sufficiently under its own self-weight and will subsequently reduce its contact area with the cushion, requiring much higher air pressures and membrane detailing in order to achieve successful erection. Conversely if the rods are too soft, the gridshell will not be able to support its own self-weight in the transition phase after erection (including removal of the cushion) and before the gridshell has been stabilized (e.g. with bracing cables) (Fig. 19).

At higher rod diameters, the self-weight component from the membrane (0.0111kN/m^2 in the case of typical PVC coated polyester fabric) to the trigger pressure is dominated by the gridshell self-weight component meaning the cushion must crumple and deflect downwards in order to ensure sufficient contact area between the grid and the volume of air. Gridshells with smaller rod diameters are less stiff and so deflect more under self-weight and in doing so make contact with the cushion which means that the cushion must not deflect to ensure sufficient contact area. Similarly, gridshells with higher rod diameters are stiffer and will deflect less under self-weight meaning that unless the cushion deflects, only a small area of contact would be available between it and the cushion (Figs. 20 - 21).

Simply increasing the air pressure to compensate for this phenomenon is only a feasible solution within strict limitations. Higher pressures result in overstressing of the membrane, adding to the demands of the membrane details (welds in particular) and will be much more difficult to effectively seal at boundaries.

Enabling and sustainable technology

The practical benefits of elastic gridshells, such as low material usage and fabrication simplicity, are undermined by the existing methods for their erection (lift up, push up & ease down) which are time-consuming, costly and can overstress the system. This novel method has extremely low demands on energy, material consumption and construction. Only very simple blowers for low temporary pressures (under 5mbar) are required. Architectural skins and/or insulation can be

erected simultaneously with the gridshell, further reducing construction time and complexity. Repetition and simplicity of predominantly linear construction elements is extremely high and all manual labour is conducted at ground level. The method proposed here has been shown to be effective and viable. The simulation methods developed to validate the method technically have wider reaching implications for the speed and accessibility of engineering simulation tools.
A second prototype, modified for application as a humanitarian disaster relief shelter, is planned for the summer of 2018 in collaboration with the Universities of Bath and Cambridge under the umbrella of the research project *Healthy Housing for the Displaced.*

Acknowledgments & material sponsorship:
Pultrex, Hightex, Serge Ferrari, Spirafix

Gregory Quinn
quinn@udk-berlin.de
Pneumatic erection video: https://youtu.be/OKe14VF03RM
Design & Build Video:https://youtu.be/y56PkC7tpU8

Figure 22. Rendering of a pneumatically erected elastic gridshell for a highly suitable application of the novel method: large-span, rapidly deployable disaster-relief or event shelter.

Name of the project:		SheltAir
Location address:		The garden of ANCB, Christinenstr. 18 - 19, 10119 Berlin
Client (investor):		Berlin University of the Arts, Department of Structural Design and Technology KET (Prof Gengnagel) / Aedes Metropolitan Laboratory Berlin
Type of application of the membrane:		Shelter
Year of construction:		2017
Structural engineers:		Gregory Quinn
Contractor for the membrane:		Hightex
Manufacture and installation:		Gregory Quinn / KET
Material:	Rods:	nylon-sheathed glass fibre reinforced plastic (pultruded)
	Membrane:	PVC-coated polyester fabric
	Foundation plate:	Hot-dip galvanized and laser cut steel (6, 8&10mm)
	Cables:	7x19 strand steel wire 3mm
	Cable-Rod connectors:	thread-tapped trellis wire connectors /
	Ground anchors:	ram-driven steel screws
	Membrane-tensioning:	Nylon rope 8mm

U.S. BANK STADIUM

THE FIRST SUPER BOWL UNDER AN ETFE ROOF!

Figure 1. Bird view © Mark Goodman

Minneapolis, USA

U.S. Bank Stadium is the first professional sports stadium to incorporate ETFE in the United States. Shortly after its inception in 2016, U.S. Bank Stadium was chosen to be the host of Super Bowl LII. The biggest game of the NFL season took place under a Texlon® ETFE roof for the first time in February 2018.

Stadia become multipurpose venues

Exciting and iconic sports events, like the Super Bowl, are not the only events occurring at stadiums. With the ability to gather thousands of people under one roof, stadia are now multi-faceted destinations, that entertain outside of just the professional sports genre. In general, stadium and arena designs have changed over the last 15 years to accommodate more than just professional sports teams. These spaces are used for musical concerts and other exciting special events. No matter the location around the world there are commonalities in overall design results, and they are the comfort and experience of the individuals in these stadiums. Vector Foiltec has been an integral part of the transformation of stadia with their Texlon® ETFE (ethylene tetrafluoroethylene) technology.

New era in stadium construction

The early completion of the new home of the Minnesota Vikings, marked a new era in stadium construction. By utilizing Vector Foiltec's transparent Texlon® ETFE system for 60% of the roof at U.S. Bank Stadium, sunlight comes in, but simultaneously keeps snow, rain, cold and heat out. The superb construction is the largest ETFE roof in North America, spanning 22.000m², and the first stadium to incorporate this technology. The weather conditions in Minnesota were a unique challenge when designing the roof. Vector Foiltec collaborated with a talented team of architects to help engineer a roof that could withstand harsh winter conditions, while maintaining an aesthetically pleasing roof design. Some of the individual Texlon® ETFE panels are over 110m long, resulting in a significant reduction in the weight of the supporting structure.
The new home of the Minnesota Vikings, was designed to resist the potential devastation of a 100-year snow event.

LEED Gold Certification

As with most projects in the United States, U.S. Bank Stadium planned for LEED certification after its completion. In November 2017, it official reached it goal, and received Leadership in Energy and Environmental Design (LEED) Gold certification. Vector Foiltec's Texlon ETFE system is part of the strategy to reduce the ecological footprint. The weight of the steel roof structure is less due to implementation of ETFE, and the adjusted transparency of the technology will allow for less artificial lighting, while helping control solar heat gain.

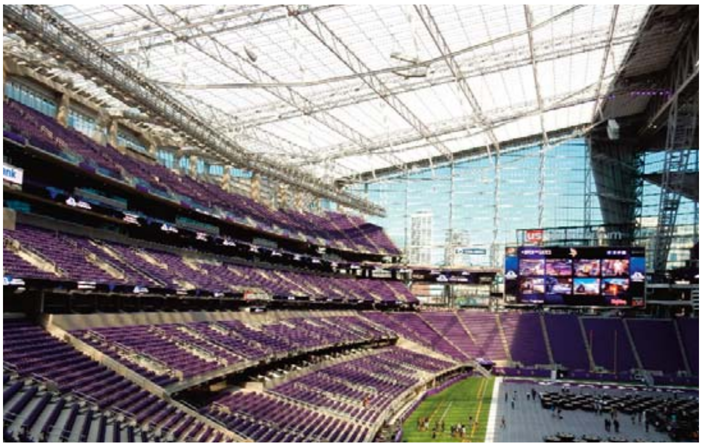

Figure 2. Interior view © Vector-Foiltec

About Vector Foiltec

Vector Foiltec continues to bring more technical innovations to the industry. With the world's only independently verified environmental product declaration (EPD) for this technology, they recognize that sustainability is a priority for designers and owners. Balancing innovation and sustainability is a constant challenge they overcome. Vector Foiltec assisting clients with their building envelopes for projects ranging from small atria enclosures and office skylights to large-scale landmark buildings, shopping malls and stadia. With 18 offices globally, Vector Foiltec is available to help clients with their stadium design needs.

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www.vector-foiltec.com
http://www.mortenson.com/company/news/video-library/videos/clear-is-the-new-retractable

Name of the project:	U.S. Bank Stadium
Location address:	401 Chicago Ave, Minneapolis, MN 55415, USA
Client (investor):	Minnesota Sports Facilities Authority (MSFA)
Function of building:	Stadium, Multipurpose Venue
Type of application of the membrane:	3 layer, Texlon ETFE cushion system
Year of construction:	2016
Architects:	HKS
Structural engineers:	Thornton Tomasetti; Chase Engineering; Palanisami & Associates
Consulting engineer for the membrane:	Thornton Tomasetti
Engineering of the controlling mechanism:	ME Engineers
Civil Engineer:	EVS inc
Main contractor:	Mortenson Construction
Contractor for the membrane (Tensile membrane contractor):	Vector Foiltec
Supplier of the membrane material:	Nowofol
Manufacture and installation:	Vector Foiltec
Material:	Texlon ETFE
Covered surface (roofed area):	22.000m²

Figure 1. General view © David Kemp

Figure 2. Construction detail © Landolt + Brown architects

Tottenham, London, UK

FUNCTIONALITY FOR DECADES

ETFE FILM CANOPY FOR BUS STATION

At over 175 years old, Tottenham Hale Station in London is one of the oldest railway stations in Europe. In an extensive construction project, a bright, friendly bus station has now been built at the traffic junction with a roof comprised of six large umbrellas. The steel structure is designed for a lifetime of at least 60 years. The coverings of the umbrellas with highly transparent films made from the 3M Dyneon Fluoroplastic ETFE also verifiably withstand at least four decades of environmental influences even under the harshest climatic conditions.

Design

The key component of this project was the formation of a consolidated bus interchange, drawing together a plethora of bus stops and stands into a single location with safe, clear walking routes to the major rail interchange at Tottenham Hale. The main architectural challenge was to integrate this substantial piece of bus infrastructure in a characterful, elegant way that enhances, rather than distracts from the quality of public open space. In order to give the bus station a clear sense of place in an area dominated by non-descript, shed retail outlets and heavily traffic roads, Landolt + Brown architects and Mott MacDonald structural engineers developed proposals for a series of distinctive steel canopies which span the main waiting areas of the bus station. The brief for these structures, beyond providing shelter from the worst of the weather, was to minimise their physical impact on the (necessarily) narrow island waiting areas at street level, to ensure that they were of sufficient height to allow the buses to pass beneath them, with sufficient clearance to allow the buses to be jack-lifted in the event of breakdown and to create canopies that would allow daylight to penetrate, but would not be reliant on sheet materials that could collapse in the event of a vehicle fire or explosion. (More information on https://landoltbrownportfolio.wordpress.com/2013/11/15/tottenham-hale-interchange/).

Rows of steel trees support highly transparent film roof

Two rows of umbrellas with a total of around 860m² of film roof protect passengers against rain and snow. The highly transparent films made of Dyneon ETFE allow more than 95% of the light to pass through, but weigh only 5% of a comparable glass construction. The support structures for the film roofs are thus very slender, which further increases the brightness. Each row of umbrellas consists of three steel columns. Six arms radiate from each in a star pattern, ending in a rectangular frame measuring 8mx17m. The construction is deliberately designed to resemble a row of trees. Vector Foiltec GmbH has stretched single-layer ETFE film between the struts. Tensioning wires support the film webs, which are welded to each other. Vector Foiltec covers the entire spectrum from the conception to the support structure planning and from the manufacturing to the installation of the film roofs. Multi-layer pneumatically supported film cushions are often used for closed buildings. They offer good insulation against outside temperatures and sustainably lower air conditioning and heating costs. A single-layer version is sufficient for open-air applications.

Resistant to dirt of all kinds

The films were extruded from 3M Dyneon ETFE by Nowofol Kunststoffprodukte GmbH & Co. KG. The company produces NOWOFLON® ET 6235Z films in thicknesses of between 80 and 400 microns. Transparent films have been used in London, but Nowofol produces them in virtually all RAL colours for other applications.

Resistant to chemicals of all kinds

The steelwork is designed for a lifetime of 60 years and will most probably last well beyond Tottenham Hale's 200th birthday. That also applies to the films made from Dyneon ETFE. They have proven to be extremely robust and durable for over forty years in all climate zones. There are no discolourations whatsoever, even after decades of intense solar irradiation. Dyneon ETFE is chemically resistant to virtually all other compounds – an important prerequisite for use in urban agglomerations with their numerous emissions and types of dirt.
The umbrellas are shaped like upside down pyramids. As a result, the typical English heavy rain is discharged through the hollow central columns into the sewer. The surface of the film is so smooth that the rain showers rinse off virtually all dirt particles. The roof is thus practically maintenance free. ETFE films feature very good values for tensile strength, tear propagation resistance and puncture resistance. They also reliably withstand impact-type loads, such as those caused by hail, and can bear high snow loads. Not only that, they meet the high requirements for fire protection with fire class B1 (according to DIN 4102).

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Name of the project:	ETFE film roof for bus station
Location address:	Tottenham, London, UK
Client (investor):	Transport for London
Function of building:	canopy
Year of construction:	2014
Architect:	Landolt + Brown Architects
Structural Engineer:	Mott MacDonald
Supplier of the membrane material:	Nowofol Kunststoffprodukte GmbH & Co. KG
Manufacture and installation:	Vector Foiltec
Material:	NOWOFLON® ET 6235Z
Covered surface:	720m²

THE 6TH TENSINET SYMPOSIUM 2019
MILAN, 3RD - 5TH JUNE

SAVE THE DATE JUNE 3-5, 2019, MILAN, ITALY
VISIT WWW.TENSINET2019.POLIMI.IT

The 6th International TensiNet Symposium "*Softening the Habitats: Sustainable Innovations in Minimal Mass Structures and Lightweight Architectures*" will take place from the 3th to the 5th of June 2019 at Politecnico di Milano (PoliMi), in Milan, Italy. The 2019 TensiNet Symposium (TS19) is organized and hosted by the TensiNet Association and in particular by PoliMi and Textile Hub, which is an interdepartmental research laboratory on textiles and polymers based in PoliMi.
The 2019 TensiNet edition will open a twofold reflection – by means of both a conference and an exhibition – on current innovations, trends and strategies in the field of lightweight membrane structures and mainly on the future of those technologies, on which the TensiNet Association's interest is focused: tensile and pneumatic structures, textile architecture, membranes and foils, ultra-lightweight constructions and structural skins.

The last few decades have brought numerous significant innovations in terms of materials, design and computation tools, as well as construction detailing and installation methodology. As a consequence of such innovative applications, membrane construction now has an established place in the field of Architecture. It is increasingly pivotal by now an analysis on the existing state of the art and a prefiguration of the scenarios concerning the textile architecture. Can we expect any major innovations in this area? What part of our imagination still remains to be explored today? Will current technical advancements in materials production lead to lighter and more efficient structures and to greater environmentally sustainable enclosures? What is the biggest challenge of the next few decades in the field of tent construction? Can we envision a future where unknown durable and recyclable materials will contribute to decrease the current conflicts between society and nature?
The main theme proposed for the next 2019 symposium edition – *Softening the Habitats* – entails to investigating constraints but also opportunities of textile architecture for dealing with a near softer future in building architecture.
Three mornings of inspiring keynote lectures plus a number of plenary sessions, followed by just as afternoons of parallel sessions will create a very special event where experts in the areas of membrane architecture and engineering, as well as researchers and industry representatives are invited to contribute to constructive debates on soft structures, softening the environment and soft skins.
Thus, on one side, the conference will focus on how building technologies on membranes are being more and more directed towards achieving a smaller environmental footprint and obtaining more resilient cities and landscapes. On the other side, the exhibit will start one week prior to the conference and it will show an exhaustive picture of responsibilities at various levels – academia, industries, practitioners, construction sector and standards – acting on tensile, membrane and foil constructions in Europe and worldwide. The aim of the exposition is first and foremost to support the role of the TensiNet Association as a disseminator of information at the regional level and amplifying it to the global scale, and vice-versa.
To cope with the complexity of the theme, the 6th TensiNet Symposium is structured by:

- 3 Plenary sessions, namely Soft Structures, Softening the Environment, Soft Skins;
- 1 Academia vs Industry Open Talk Session, linked to the Exhibition;
- 5 Parallel sessions which are expected to drive and spread 10 different topics on special technical issues, reviews of State of the Art and case studies and
- 1 Exhibition.

In the **"Soft Structures"** Plenary session, the future frontiers of tensile membrane structures will be explored thanks the involvement of a variety of disciplines and perspectives. The concept of lightness will shift its essence from vision to necessity, from shape to matter, while lightweight structures will have to become fully energy-saving, efficiently load-bearing and, last but not least, carrying on novel concepts of beauty, flexible functions and adaptive structures. The summary of key topics of the "Soft Structures" Plenary session is: Structural Lightness, Structural efficiency, New materials & unpredictable shapes, Metal free structures, hybrid structures, Detailing & installation.

Furthermore, the Plenary session **"Softening the Environment"** will focus on the pivotal role of designing, manufacturing and building architectures, structures and landscapes and their impacts on global sustainability challenges. The main goal of the Plenary session is to draw the attention to measuring the quality of current and future lightweight constructions in terms of environmental efficiency, user's comfort, materials and building products' durability and end-life scenarios. The summary of key topics of the "Softening the Environment" Plenary session is: Weight reduction opportunities in design and manufacturing, Material selection strategies in lightweight industry and in lightweight construction, Standard regulations, sustainability targets for the next textile architecture, Production methods, Environmental product declaration and Life Cycle Assessment Methodology.

Finally, the third Plenary session **"Soft Skins"** will be devoted to the crucial and challenging topic of living structures. We have been long wishing for unwoven, seamless, elastic and durable materials, such as a kind natural fleeces and thin shells. Further basic researches and outstanding practices are leading the development of novel resilient structures and adaptive skins, which will be able to perform a next generation of human constructions. The summary of key topics of the Soft Skins Plenary Session is: Novel aesthetics, Material and light effects, Designing with advanced lightweight materials, Solar design and daylighting optimization, Energy active skins, Energy/thermal management, Sound insulation, Detailing and installation.

Several Parallel sessions will eventually explore the following main sub-topics: the **"Movement in Lightweight Structures"** will unfold the topics: Demountable structures and Kinetic/ Kinematic/ Foldable structures. In parallel, the session **"Recently Built Structures"** will unfold the topics: Pneumatic & air-supported structures and Complex/ hybrid structures. The Parallel session: **"Environmental Compatible Membrane Structures"** (IASS WG18 Environmentally Compatible Structures joined session) will unfold the topics: Design & Simulation and Analysis & Performances assessment.
Lastly, the Parallel sessions "Adaptive of Membrane-based Skins" and "Adaptivity of Transparent Foils-based Skins" will unfold the topics: Design & Simulation and Thermal & Acoustic Comfort.

Scientific Committee: Adriana Angelotti (*Politecnico di Milano)*, Paolo Beccarelli (*University of Nottingham)*, Katja Bernert (*Low & Bonar GmbH)*, Heidrun Bögner-Balz (*Institute for Membrane and Shell Technologies, DEKRA)*, Jean-Marc Bourinet (*SIGMA Clermont)*, Roberto Canobbio *(Canobbio)*, Andrea Campioli (*Politecnico di Milano)*, Valter Carvelli (*Politecnico di Milano)*, John Chilton (*University of Nottingham)*, Jan Cremers (*Hochschule für Technik, Stuttgart)*, Lars De Laet *(Vrije Universiteit Brussel)*, Christoph Gengnagel (*Universität der Künste)*, Peter Gosling (*Newcastle University, School of Engineering)*, Klaus-Michael Koch (*Hightex)*, Sebastian Koch (*Koch membranes)*, Nikolai Kugel (*arch22)*, Benson Lau *(University of Westminster)*, Julian Lienhard *(str.ucture GmbH)*, Josep Llorens *(Universitat Politecnica de Catalunya)*, Claudia Marano *(Politecnico di Milano)*, Marijke Mollaert *(Vrije Universiteit Brussel)*, Carol Monticelli *(Politecnico di Milano)*, Giorgio Novati *(Politecnico di Milano)*, Andrea Ratti *(Politecnico di Milano)*, Monica Rychtáriková *(KU Leuven/ STU Bratislava)*, Franck Schoefs *(Université de Nantes)*, Natalie Stranghöner (Universität Duisburg-Essen), Martin Tamke *(Royal Danish Academy of Fine Arts, School of Architecture)*, Jean-Christophe Thomas *(Université de Nantes)*, Jörg Uhlemann *(Universität Duisburg-Essen)*, Alessandra Zanelli *(Politecnico di Milano)* & Walter Zech *(Eccon)*.