

RESEARCH

## PROJECT **SPEEDKITS** FIELD TEST

**MULTITEXCO** SMART MULTIFUNCTIONAL  
TECHNICAL TEXTILES

REPORT

## STRUCTURAL MEMBRANES 2015

PROJECTS

TRAFFIC HUB IN CALIFORNIA

**BUILDING SHELL MADE OF ETFE CUSHIONS**

*SPEEDKITS: Clever Roof set-up in Senegal © Vincent Virgo / Guy Buyle ▲  
The exterior shell of the three-storey ARTIC building © John Linden ►*







Buro Happold  
www.burohappold.com



Canobbio S.p.A.  
www.canobbio.com



CENO Membrane  
Technology GmbH  
www.ceno-tec.de



Dyneon  
www.dyneon.eu



FabricArt  
Membrane Structures  
www.fabricart.com.tr/



Form TL  
www.Form-tl.de



Mehler Technologies  
www.mehler-technologies.com



Messe Frankfurt  
Techtextil  
www.techtextil.com



Saint-Gobain  
www.sheerfill.com



Sefar  
www.sefar.com



Serge Ferrari sa  
www.sergeferrari.com



Sioen Industries  
www.sioen.com



technet GmbH  
www.technet-gmbh.com



Verseidag  
www.vsinidutex.de

## TensiNewsINFO

### Editorial Board

John Chilton, Evi Corne,  
Peter Gosling, Marijke Mollaert,  
Javier Tejera

### Coordination

Marijke Mollaert,  
phone: +32 2 629 28 45,  
marijke.mollaert@vub.ac.be

### Address

Vrije Universiteit Brussel (VUB),  
Dept. of Architectural Engineering,  
Pleinlaan 2, 1050 Brussels, Belgium

ISSN 1784-5688

All copyrights remain by each  
author  
Price €15  
postage & packing included

# contents



## PROJECTS

PAGE

4 **Austria** BUTTERFLY MEADOW  
"MORE GREEN INTO THE WHITE CITY"

4 **USA** PLATINUM AWARD TRAFFIC HUB IN CALIFORNIA SETS  
NEW STANDARDS FOR SUSTAINABLE BUILDING

9 **USA** SPEARHEADS TENSILE MEMBRANE  
CANOPY DESIGN AND CONSTRUCTION

13 **The Netherlands** A REVEALING COVER  
FOR THE EU PRESIDENCY

17 **Saudi Arabia** TENSILE FABRIC COVERING  
PRINCE MOHAMMED BIN ABDULAZIZ INTERNATIONAL AIRPORT

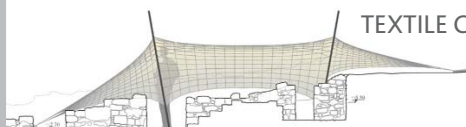


## REPORT

6

## STRUCTURAL MEMBRANES 2015

VII INTERNATIONAL CONFERENCE ON  
TEXTILE COMPOSITES AND INFLATABLE STRUCTURES



## RESEARCH

10

## MULTITEXCO

HIGH PERFORMANCE SMART MULTIFUNCTIONAL  
TECHNICAL TEXTILES FOR THE CONSTRUCTION SECTOR

14

## SPEEDKITS



## 18 ICD/ITKE RESEARCH PAVILION 2014-15

APETISER UPCOMING SYMPOSIUM 2016



## ARTICLE

8

COVERTEX JOINS PFEIFER GROUP

## MISC

19

## BOOKREVIEW

TEXTILE MATERIALS FOR LIGHTWEIGHT CONSTRUCTIONS  
TECHNOLOGIES – METHODS – MATERIALS – PROPERTIES

## ANNOUNCEMENTS

12

ADVANCED COURSE ON FIBRE-BASED MATERIALS  
AND PRODUCTS 13-14-15 JUNE 2016

12

AACHEN-DRESDEN-DENKENDORF INTERNATIONAL  
TEXTILE CONFERENCE 24-25 NOVEMBER 2016

20

NOVEL STRUCTURAL SKINS 26-28 OCTOBER 2016

# E

Dear Reader,

This issue of TensiNews presents recent membrane and foil projects for infrastructure projects, such as the ARTIC Anaheim traffic hub covered with ETFE cushions, and the new passenger terminal of the international airport in Medina with a variety of membrane roofs. Furthermore a single layer ETFE covered public space in Graz, a stand covering for a stadium in Florida and the application of 3D printing for large façade elements are introduced. The research project Multitexco on high performance smart textiles is described, as well as the research project Speedkits on the development of emergency kits for humanitarian organisations.

Last October the Seventh Structural Membranes symposium took place in Barcelona where several TensiNet members gave a lecture. Joseph Llorens wrote a summary of the event for us. During the symposium we held our annual general meeting and a partner meeting.

The Eurocode working group contributed to CEN TC 250 WG5 which has finalized and submitted the science and policy (SaP) report "Prospect for European guidance for the Structural Design of Tensile Membrane Structures", providing background information to the future technical specification and Eurocode. It has now been published by the joint research centre (JRC) and the standardisation bodies are asked for an evaluation. We expect to start with the elaboration of a technical specification by the end of this year.

Together with COST Action TU1303 WG5 'From material to structure and limit states: codes and standardisation' the TensiNet Eurocode working group is already continuing the work towards a technical specification. The groups have confirmed that they want to organise a Round Table session for experts in the domain of tensile surface structures to discuss the importance of this Eurocode and to increase involvement of other experts.

The COST Action TU1303 'Novel structural skins' ([www.novelstructuralskins.eu](http://www.novelstructuralskins.eu)), where TensiNet is very active, held a meeting at the Politecnico in Milan on the 16th and 17th of March. The plenary lectures were held by Maurizio Gaudagnini from the University of Sheffield on composites in construction, Marco Perino from the University of Turin on adaptive façades, Carl Maywald of Vector-Foiltec on ETFE for indoor comfort and Christoph Gengnagel from Universität der Künste in Berlin on hybrid skins.

During the COST Action TU 1303 meeting in Milan we held a partner meeting, and the kick-off meeting of our new working group "good practice" took place, chaired by Heidrun Bögner-Balz.

We are now only a few month away from the TensiNet / COST TU1303 Symposium 2016 (see also <http://conferences.ncl.ac.uk/tensinet2016>), which will take place at Newcastle University, from the 26th till the 28th of October 2016. The symposium has the theme Novel Structural Skins, the same as the COST Action. We have received more than 70 contributions covering a wide spectrum of the five main topics, and several interesting keynote speakers have already confirmed their presence. Wednesday 26th of October 2016 in the afternoon takes place the open session with the focus on built projects. Architects, engineers and professionals are invited to learn more about structural skins and the recent development. You find in this issue of TensiNews an appetiser from Jan Knippers who is one of the keynote speakers.

We look forward to seeing you all in Newcastle or on other tensile structures related events. In the meantime we hope you enjoy this issue of TensiNews.

Yours sincerely, Bernd Stimpfle



## Forthcoming Events

### Textile Roofs 2016

Berlin, Germany • 2-4/05/2016

[www.textile-roofs.com](http://www.textile-roofs.com)

### Advanced course on fibre-based materials and products

University of Minho in Guimarães, Portugal  
13-15/06/2016 • Registrations and more information: [www.fibrenamics.com/en/advancedcourse](http://www.fibrenamics.com/en/advancedcourse)

Email: [fibrenamics@fibrenamics.com](mailto:fibrenamics@fibrenamics.com)

### ICSA 2016

Guimarães, Portugal • 27-29/07/2016

[www.icsa2016.com](http://www.icsa2016.com)

### IASS 2016

Tokyo, Japan • 26-30/09/2016

<http://iass2016.jp/>

### TENSINET - COST ACTION TU1303 SYMPOSIUM 2016 Novel structural skins

Newcastle, UK • 26-29/10/2016

<http://conferences.ncl.ac.uk/tensinet2016/>

### Aachen-Dresden-Denkendorf International Textile Conference,

Dresden, Germany • 24-25/11/2016

[www.aachen-dresden-denkendorf.de/itc/](http://www.aachen-dresden-denkendorf.de/itc/)

## Forthcoming Meetings

### Partner Meeting 2 and Annual General Meeting

Thursday 27 October

Newcastle University

Annual General Meeting 18.00 - 18.30

Partner Meeting 18.30 - 19.30

<http://conferences.ncl.ac.uk/tensinet2016/>

### CORRECTION

TensiNews 28 / page 11

Apology: Figure 8 on page 11 should have been attributed to Sabrina Afrin.

TensiNews 29 / page 4

Additional information: Architect: Ar. Mustapha Khalid Palash / Architect to the contractor: Ar. Golam Morsalin Choudhury Rana

## SaP-Report

### 'Prospect for European guidance for the Structural Design of Tensile Membrane Structures'

As announced in the CEN TC250 meeting of the 20th of November, the Science and Policy Report (SaP-Report)

'Prospect for European guidance for the Structural Design of Tensile Membrane Structures' has been published by JRC (Joint Research Centre).

This version will be made available to the European Standardisation Bodies for evaluation as 'basis' for the Technical Specifications.

Comments can be given during 6 months. After this period of 6 months CEN TC250 will decide if - taking the comments into account - the elaboration of the Technical Specifications can start or not (decision expected by November 2016).

You can download the on-line version from:

<http://eurocodes.jrc.ec.europa.eu/showpublication.php?id=540>

## Graz, Austria Butterfly meadow

The new public open space and important junction in front of the University Hospital in Graz was designed themed to "more green into the white city".



### Introduction

Even the name for the project "butterfly meadow" has been selected and implemented faithfully. The whole open space that was designed new, covers an area of about 6000m<sup>2</sup> and should give a park-like character. The main structure, a single-layer, trussed ETFE foil and

steel roofing is located in the eastern part of the square (Fig. 1).

### Project

In the plan view, the shape is reminiscent of two interlocking eggs - perhaps the earliest development stage of a butterfly? The two ellipses are set to a total of eight,

slightly inward, to each oval centre, inclined columns. In its longest dimension, one oval amounts to about 17m and in its short dimension to about 9m. The covered area of the whole roofing amounts to about 220m<sup>2</sup> (Fig. 2). Each oval consists of a steel sheet and three respectively four also

elliptical cutouts for the ETFE foil, a total of seven ETFE openings. The cutouts are covered with a transparent and printed ETFE foils. The domed shape is obtained by pressing thrust plates by means of trussed cables upwards against the foil. One difficulty was to find a way that allows to transfer the

## TRAFFIC HUB IN CALIFORNIA SETS NEW STANDARDS FOR SUSTAINABLE BUILDING

DYNEON

## Platinum award for building shell made of ETFE cushions

South California, USA

### Introduction

The "Anaheim Regional Transportation Intermodal Center" (ARTIC), a traffic hub in Orange County, South California which opened at the end of 2014, will be used by more than forty million visitors and travellers every year. This transit station links many diverse means of public and private transport and in addition houses restaurants and shops under a building shell made of film cushions. The films extruded from 3M Dyneon Fluoroplastic ETFE are part of the reason why the building is certified to the highest US environmental standard for buildings, LEED Platinum. The development of local and long-distance public transport is right at the top of the political agenda in southern California, which is plagued by traffic jams. The construction of the Anaheim Regional Transportation Intermodal Center (ARTIC) marks an important milestone here. At this hub near the State Route 57 and Interstate 5 highways, travellers can change to the most diverse means of transport. Here, the national railway network meets the regional Metrolink, a large number of bus routes and further means of transport such as airport shuttles, taxis and bicycle hire stations.



### Low G-values and natural air circulation

The architecture of the ARTIC concentrates entirely on a bright, light-flooded ambience. The exterior shell of the three-storey building consists of 160 three-layer inflated film cushions. The Bavarian company Nowofol Kunststoffprodukte GmbH & Co. KG extruded about 19.000m<sup>2</sup> of NOWOFLON® ET 6235Z film from the high-performance material 3M Dyneon Fluoroplastic ET 6235Z. The underside of the upper film is printed in order to reduce the direct incidence of sunlight. The G-value of the cushions is so low that the ARTIC requires no air conditioning, despite the hot climate. At the front ends, 37m high glass facades open up the view into the interior. Hinged segments enable natural air circulation in the three-storey building when necessary.

### Very resistant material with a long lifetime

The high-performance material 3M Dyneon ETFE is extremely resistant to chemical effects of all kinds. Films made from ETFE are very resistant to tearing and to UV radiation. They have proven their worth in lightweight roof constructions in all climatic zones for over forty years. The surface of



right-angled grid of cables to the thrust plates without lose much space between the cables, so that foil and cables run as close as possible to each other. Furthermore, a



concept had to be worked out that the top pressure points are free from creases and will not get a problem with punching (Fig. 3).

On the inside of the ETFE cutouts several spotlights are foreseen, they intensify the harmonious design of steel, ropes and ETFE cushions. Harmonious, structured and elegant appears the construction also through the relatively thin cross sections of the columns with internal drainage, the small cable diameters and the thrust plates which allows an additional possibility of adjustment to tension the foil and the cables (Fig. 4).

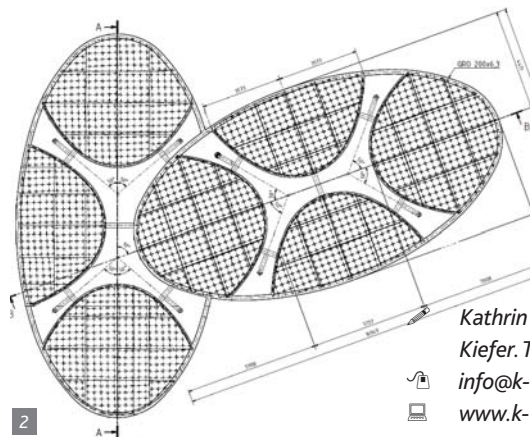
This project was carried out with great attention to detail and the result shows - it is worthwhile!

Figure 1. Covered public space as junction  
© Architekten Kassarnig ZT-GmbH

Figure 2. Plan view

Figure 3. Bottom view

Figure 4. Construction detail



Kathrin Kaltenbrunner,  
Kiefer. Textile Architektur  
info@k-ta.de  
www.k-ta.de

Name of the project:	Butterfly meadow
Location address:	Auenbruggerplatz 1, 8010 Graz, Styria, Austria
Client (investor):	Krankenanstalten Immobiliengesellschaft mbH
Function of construction:	Roofing for park, landscape, artwork
Year of construction:	2015
Architect:	Architekten Kassarnig ZT-GmbH
Main contractor:	Sattler CENO Membrane GmbH
Structural engineer:	Kiefer. Textile Architektur
Manufacturer of steel:	Gänsweider Metalltechnik GmbH
Manufacturer of ETFE:	Sattler CENO Membrane GmbH
Cutting Pattern ETFE:	Kiefer. Textile Architektur
Installation:	Montageservice LB GmbH
Material:	printed ETFE-foil 250µm
Surface area:	ca. 220m <sup>2</sup>



the films is so smooth that a rain shower can effectively clean them. That considerably reduces maintenance costs and simplifies the design, since no professional cleaning is necessary on the outside of the building. The two porches made of film cushions are joined almost seamlessly to the building shell. The steel support structure forms a diamond-shaped network for the film cushions and is three-dimensionally curved. Vector Foiltec was responsible for the construction of the support frames and their connections to the support structure as well as for the assembly and installation of the film cushions. The company's Texlon® ETFE system focuses entirely on structural film construction with ETFE films and has realised a large number of projects worldwide in the past decades. A particular challenge in the case of the ARTIC was the increasingly smaller radii of the support structure from the eaves up to the roof ridge. For that reason, Vector Foiltec had to pre-bend the sail tracks of the frames in some cases while still maintaining their function as film fasteners. The roof ridge cushions are designed for high loads and the cushions of the northern porch, the main wind direction, are additionally reinforced by wind suction ropes.

The exterior shell of the three-storey ARTIC building consists of 160 three-layer inflated film cushions made from 3M Dyneon Fluoroplastic ETFE. © John Linden

### Completely recyclable roof

The building fulfill the LEED Platinum certification. The Leadership in Energy and Environmental Design (LEED) is a classification system defined by the US Green Building Council for environmentally friendly, resource-saving and sustainable construction. The building's energy consumption is about 34% lower than the defined limit. In addition, solar cells on the car parks generate 20% of the required electricity.

Beyond that, the LEED Platinum environmental standard places high demands on the use of recyclable building materials. Films made from Dyneon ETFE can be fully recycled. On top of that, the films are 95% lighter than glass. That allows the support structure to be very slender, thus saving resources in its manufacture, contributing once more to sustainable building!

✍ Helmut Frisch & Judith Seifert

✉ hfrisch@mmm.com

🌐 www.dyneon.eu

Name of the project:	Anaheim Regional Transportation Intermodal Center (ARTIC)
Location address:	Orange County, South California
Client (investor):	City of Anaheim / Orange County Transit Authority (OCTA)
Function of building:	Traffic hub
Type of application of the membrane:	ETFE cushions
Year of construction:	2014
Architects:	HOK and Parsons Brinckerhoff
Structural engineers:	Thornton Tomasetti
Contractor for the membrane:	Vector Foiltec, Texlon® ETFE system
Supplier of the membrane material:	Dyneon
Manufacture and installation:	Vector Foiltec, Texlon® ETFE system
Material:	NOWOFLO® ET 6235Z film from 3M Dyneon Fluoroplastic ET 6235Z

# STRUCTURAL MEMBRANES 2015

## VII INTERNATIONAL CONFERENCE ON TEXTILE COMPOSITES AND INFLATABLE STRUCTURES

The "Seventh International Conference on Textile Composites and Inflatable Structures" was held in Barcelona in October 2015. It was organized by the International Centre for Numerical Methods in Engineering (CIMNE) and was chaired by E. Oñate (UPC) and K. U. Bletzinger (TUM). It was the seventh of a series of symposiums that originated in Barcelona in 2003. The next session will be held in Munich in 2017.

At the three-day conference, 9 plenary lectures and 81 presentations in 13 sessions were given to 118 participants from 25 countries and 4 continents. The main topics that were covered included: building physics, materials, testing, and advanced methods for analysis and simulation. Ongoing research, applications and recent projects were also shown.

<http://congress.cimne.com/membranes2015/frontal/default.asp>

### Main lectures

R. M. Pauletti from the University of Sao Paulo began the plenary lectures exposing some basic ideas on the behaviour and analysis of cable and membrane structures. These structures require their elements to be taut rather than slack or wrinkled, in order to work properly. They are characterized by being lightweight, funicular, and flexible. Dr. Pauletti highlighted the paradox between the formal stiffness required by flexible structures and the wide range of shapes permitted by stiff structures (Fig. 1 and 2).

K. Göppert entertained the audience as he usually does with an impressive collection of works of Schlaich, Bergermann und Partner. He stressed the efficiency of the solutions developed illustrated with the Mercedes Benz (Stuttgart) and Amazonia (Manaus) Arenas, the BC Place (Vancouver), and the stadiums of Kiev, Krasnodar, Caracas, Cape Town, Warsaw, Baku and Abu Dhabi. However, disproportionate investments, whimsical shapes, and abandonment do not meet in some cases, the principles of efficiency and sustainability (Fig. 3).

R. Wüchner, from the Technical University of Munich, considered the computational wind-structure interaction for the analysis and design of flexible, lightweight, and complex-shaped structures. He focused on the ultra-lightweight and flexible Buildair pneumatic arches and evaluated the wind-induced phenomena, local wrinkling, the required consideration of increased air pressure under heavy storms, anchoring forces, and deformations. He explained the difficulties of simulating wrinkles, vibrations, proper wind modelling, dynamic properties, coupling, damping, stiffness, boundary conditions and scaling that require systematic stepwise validation of the results for the simulations be reliable (Fig. 4).

"70 years in 30 minutes" was the presentation of J. Henniecke from the ILEK (Stuttgart). He recalled the principal contributions of Frei Otto to the knowledge and dissemination of structural membranes and looked over his career, including his collaboration with P. Stromeyer, the largest manufacturer of tents in Germany, and the founding of the Institute for Lightweight Structures in Stuttgart in 1964.

Frei Otto based his method of design on the observation of natural processes to obtain the form as it was illustrated by his most significant work. In order to continue Dr. Otto's legacy, J. Henniecke recommended the issue of number 20 of the journal of the Institute, where 400 problems and issues related to the development of lightweight structures that remain unanswered are listed.

M. Majowiecki from the University of Bologna in "Wide membrane enclosures: personal experiences" discussed the particularities of wide span structures. He focused especially on the effects of scaling, mentioning particularly the Montreal Olympic Stadium, where the 1.800m<sup>2</sup> solution of the Boulevard Carnot swimming pool was scaled up to 20.000m<sup>2</sup>. He noted that the Roma Olympic Stadium was the first of the current generation of large membrane roofs based on stretched radial cables that connect the inner tension and outer compression rings (Fig. 5).

J. Marcipar from Buildair explained his experience in the design of inflatable structures. He showed some images of what they have done in the past in order to detect weak points that led to improvements in making very large inflatable and portable structures based on single pressurized tubes. According to this technology, a 45m indoor span hangar for the Lufthansa Service has been erected at the Budapest airport (Fig. 6). Other applications, such as industrial, off-shore activities, remote locations, humanitarian aids, aeronautical applications, and disaster relief were envisaged.

A. Pronk, from the Technical University of Eindhoven, surprised the audience with ice architecture. Specializing in formwork techniques, he recovered the fibre-reinforced ice called "pykrete" and shared various experiences. His version of Antonio Gaudi's "Sagrada Familia" in ice stands out among his works and projects (Fig. 7). He announced upcoming designs based on Felix Candela and Leonardo da Vinci ideas (Fig. 8).

R. Wagner, from the Karlsruhe Institute of Technology, also surprised the audience by showing nets that are accessible to the public, that which recall the trapeze artists of the circus shows. The installation "In Orbit," by Tomas Saraceno in Düsseldorf, is a superposition of three cable networks, separated and stretched

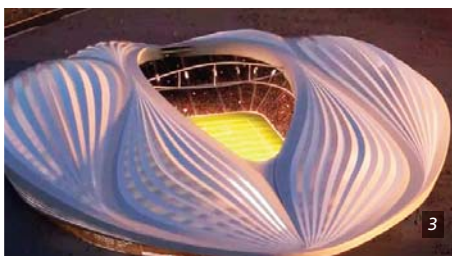


Figure 1. The form of flexible structures is neither arbitrary nor free. It is funicular.

(National Library, Riyadh).

Figure 2. The shapes of rigid structures can be arbitrary. (Louis Vuitton Foundation, Paris).

Figure 3. Al-Wakrah Stadium, Qatar.

Figure 4. Geometrical, non-linear structural simulation of a single tube. Wrinkling is highlighted.





Figure 5. The Roma Olympic Stadium, 1990, was the first of the current generation of large membrane roofs.



Figure 6. Buildair hangar, Budapest airport.



Figure 7. The "Sagrada Familia" in ice.

by six inflated spheres that produce the sensation of floating in the air to those who dare to move in them (Fig. 9). In the pavilion of Brazil at the Milan Expo 2015, the use of the network provided a combination of architecture and scenery as a metaphorical expression of flexibility and fluidity, offering to the visitors unexpected scenarios for leisure and rest (Fig. 10).

#### Technical sessions

17 Technical sessions included 81 papers devoted to topics of greatest interest for structural membranes, such as folding and adaptable structures, design procedures, advanced methods of analysis, ETFE, wind action, active flexion and flexible forms, pneumatic structures, aerospace applications, materials, essays, case studies, details, and installation processes.

#### Accomplishments, recent projects

R. Houtman from Tentech showed the "Inno-wave-tion" portable pavilion based on the "tensairity" principle of combining inflated air beams with compression elements and cables (Fig. 11). In this case, a roof is pushed up by a central sphere and stretched against a compression ring made of CHS, stabilized by an inflated meandering torus around the perimeter. The structural analysis was performed integrating membrane and steel sections, and respecting the gas law, using the Easy-Beam and Easy-Vol modules of the Easy software by Technet GmbH.



Figure 8. Ice bridge inspired by Leonardo da Vinci.



Figure 9. Tomás Saraceno, "In Orbit" installation, Düsseldorf.



Figure 10. Brazil pavilion, Expo Milano, 2015.

M. Barozzi from the Technical University of Milano proposed a solution to cover archaeological excavations that require climate protection, ease of installation, lightweight construction, minimal impact, and flexibility to match the different configurations of the archaeological sites. He developed a prototype for the ruins of Nora in Sardinia, based on the principle of active bending, in which the tension of the membrane is coupled with the bending of the supporting arches (Fig. 12).

Another accomplishment was presented by P. Becarelli, from the University of Nottingham, namely the itinerant Ducati Superbike Pavilion. The main requirements were to represent the commitment of the company to innovation and to the optimization of the transportation and assembly process of the structure. It was therefore decided to use five tensairity pneumatic beams resting on the trucks used for the transport of motorcycles and their equipment (Fig. 13).

C. Armendariz, from Crearquitectura, showed his achievements in Latin America. He highlighted the Mix Mall membrane structure in Guatemala. It is a ridge and valley membrane over a courtyard protecting a restaurant (Fig. 14). He announced the "VII Simposio Latinoamericano de Tensoestructuras" to be held at the Rafael Landívar University of

Guatemala from 7 to 9 September 2016: <https://sites.google.com/site/sltevisimposio-guatemala/home/slte-vii>

N. Pauli described the insulated, ventilated, multiple-layer membrane of the CIRC Auditorium in the town of Auch, in southern France (Fig. 15). It has an elliptic ground plan of 48x32m, and a height of 19m. The structure is composed of 22 trussed arches made of laminated timber. The envelope is multi-layered. The internal skin is opaque, impermeable, and manufactured in one 2.200m<sup>2</sup> piece. The external skin is translucent and the 160mm Rock-wool insulation layer is fastened upon a 400g/m<sup>2</sup> PES/PVC 402 standard, white membrane. All membranes are PVC-coated polyester provided by Ferrari. A ventilated air cavity and water collector complete the design of the roof envelope.

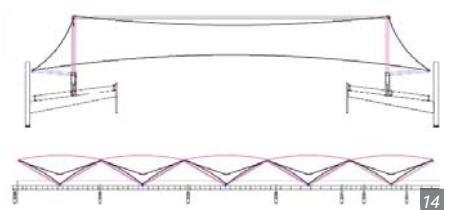
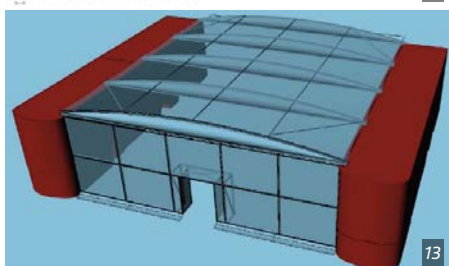
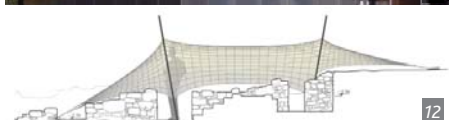


Figure 11. "Inno-wave-tion" pavilion by Silvain Dubuisson, for BNP.

Figure 12. Bending active shelter for the ruins of Nora (Sardinia).

Figure 13. The Ducati Superbike Pavilion.

Figure 14. Mix Mall, Guatemala, made by Crearquitectura.

Figure 15. CIRC Auditorium, Auch.





Figure 16. Autonomous mechanical clamping system.  
Figure 17. Corner detail. Domerplatz structure, Vienna.

### Detailing

A. Hub, from Alfred Rein Ingenieure GmbH, discussed technical solutions for the construction of retractable roofs. The main points he focussed on were minimizing friction on the slide bearings, using central motor units, anchoring, locking, clamping (Fig. 16), pretensioning, and protecting the parking position. These points were illustrated by three case studies: the courtyard roof for the Künstlerhaus München, the Dome roof for the Tree Top Path in Bad Harzburg, and the auditory roof of the Natur Theatre in Bad Elster.



S. Chiu, from the University of Southern California, referred to corner details for tensile membrane structures in order to improve their design. The detailing of the connections and joints is particularly critical, because they essentially affect the entire structure's stability, durability, installation, maintenance, aesthetics, and cost. Firstly, corners involve material property changes among different structural elements. Secondly, through corner details forces are transferred from a large surface area to a supporting structure. And lastly, all these considerations must be resolved in the most concentrated area of the structure. Consequently, research has been initiated on this subject through interviews and case studies (Fig. 17).

### Proceedings, plenary lectures and next conference

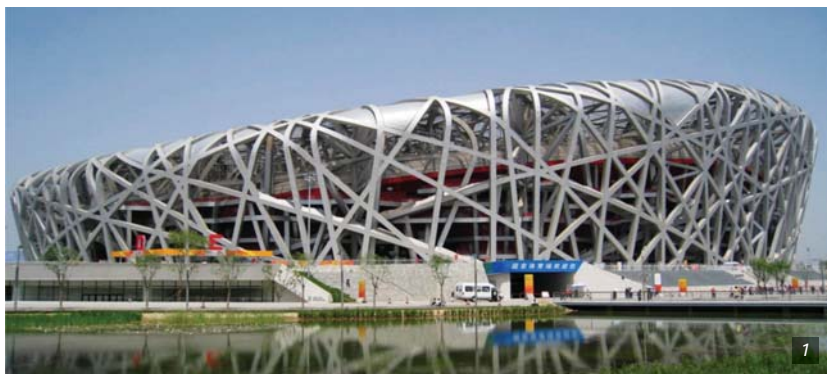
The Proceedings of the Conference are available at: <http://congress.cimne.com/membranes2015/frontal/doc/Ebook2015.pdf>

and the plenary lectures at YouTube: <https://www.youtube.com/playlist?list=PLIyl-VE6-1ou1-0pa8KV456yEtZU6stcU>

The next international Structural Membranes conference will be held in Munich from 9 to 11/10/2017 at the Technical University. Further information will be made available at: <http://congress.cimne.com/membranes2017/frontal/default.asp>

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

# Covertex joins Pfeifer group



Covertex membranes (Shanghai) Co., Ltd. provides advanced design, engineering, manufacturing and construction services in the field of membrane structures. Using materials such as ETFE, PTFE, PVDF/PVC and others, Covertex designs, produces and installs iconic membrane structures for government and private-sector in a wide array of industries, including infrastructure, commercial, sports and entertainment markets.

Since July 2015 it is a German owned business entity, held by PFEIFER Seil- und Hebetechnik GmbH, one of the world's leading company for complex structures. PFEIFER's well known expertise in steel, cable, glass and movable structures is now completed by the integration of Covertex. Thus, this global portfolio starting from design, engineering, fabrication, installation up to maintenance is now provided from a single source – a unique service to the construction business worldwide!

Together with Pfeifer, Covertex will continue to actively improve and develop new membrane technologies in close cooperation with innovative architects, high performance material suppliers and certified research institutes. With its design-, engineering- and manufacturing capacity, they will be a leading company in the field of membrane structures. Covertex is completing Pfeifer expertise by supplementing membrane know-how. It is a competitive alternative to other building materials and best fitting to Pfeifer's cable structures, able to span large distances, flexible to complex shapes.

Examples of these iconic projects erected in China are the National Stadium, Macao Oceanus, Suzhou SIP and Guangzhou South Railway Station (Fig. 1 - 4).






 Dr. Gregor Grunwald,  
Pfeifer Covertex  
 ggrunwald@pfeifer.de  
 Thomas Hermeking,  
Pfeifer Seil- und Hebetechnik  
 thermeking@pfeifer.de  
 www.pfeifer.info

Figure 1. National Stadium (2007)

Area: 36.500m<sup>2</sup> Single layer ETFE

Figure 2. Macao Oceanus (2009)

Area: 6.460m<sup>2</sup> ETFE Cushion

Figure 3. Suzhou SIP (2009)

Area: 9.500m<sup>2</sup> ETFE cushion + 8.500m<sup>2</sup> PTFE

Figure 4. Guangzhou South Railway Station (2010)

Area: 15.2200m<sup>2</sup> ETFE cushion





# SPEARHEADS TENSILE MEMBRANE CANOPY DESIGN AND CONSTRUCTION FOR FLORIDA STATE UNIVERSITY DOAK CAMPBELL STADIUM, USA

## Renovations to Seminoles' South End Zone

### Introduction

FabriTec has been contracted to design, engineer, fabricate, supply and install two identical tensile membrane canopies supported by steel and cables at the Seminoles' south end zone in accordance with the University's plans to build a premium club seating section at the south end of Doak Campbell Stadium. The tension structures will be PTFE Chukoh Skytop 800 architectural membrane and cantilever out over the stadium seats from columns located on a new club level deck. The new deck area will add 6.000 premium seats and hosted services. The total fabric plan area covers a 24.930sq.ft (2.316m<sup>2</sup>).

### Project

The design of the tension structures is to protect football fans from sun and rain, but also ensure that no columns would hinder fans' enjoyment of the game. A notable design element will be the "spearheads," located at the field end of several horizontal





outriggers, which will extend out over the seating and capture the essence of the spear used by the Seminole Indian – Florida State University's mascot. Each one will be lit up with LED lighting to provide a spectacular scene at night.

The fabric canopies are part of an extensive renovation at the south end of Florida State University's Doak Campbell Stadium initiated by FSU administrators and the Seminole Boosters and underscore Coach Jimbo Fisher's commitment to rebuilding the dynasty that lead the football team to an Atlantic Coast Championship in 2014. Other proposed improvements include: raising the height of the exterior of Stadium, installing exposed glass staircases and architectural lighting.

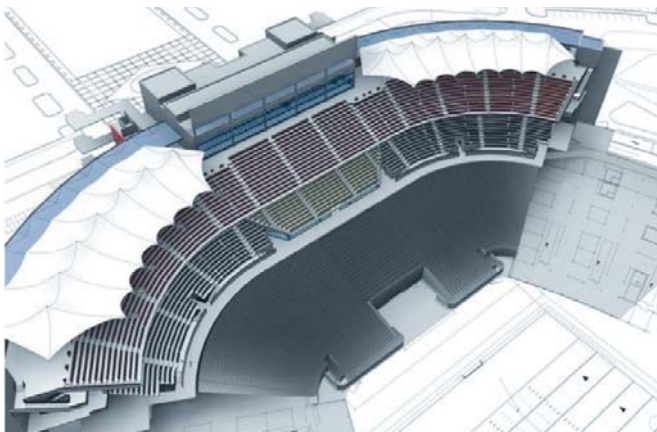
The architectural consultant on the project is Rosser International, one of the leading architectural firms involved with collegiate stadiums and other athletic facilities.



FabriTec expects to start work on site by April of 2016. The entire project will be ready for Florida State's football home opener in September of 2016.

 **Kathy M. Dumalski**  
 [kdumalski@fabritec.com](mailto:kdumalski@fabritec.com)  
 [www.fabritecstructures.com](http://www.fabritecstructures.com)  
 **Seminole Boosters, Inc. -**  
*illustration - EMI Architects.*

Name of the project:	FSU Doak Campbell Stadium South Endzone Canopies
Location address:	1 Champions Way, Tallahassee, FL 32304
Client (investor):	Florida State University
Function of building:	Sports Stadium
Type of application of the membrane:	Mast-supported tensile membrane canopies
Year of construction:	2016
Architects:	EMI Architects
Structural engineers:	FabriTec Structures, LLC
Main contractor:	Childers Construction
Contractor for the membrane:	FabriTec Structures, LLC
Supplier of the membrane material:	FabriTec Structures, LLC
Manufacture and installation:	FabriTec Structures, LLC
Material:	PTFE FGT- 800 as supplied by Chukoh Fabrics.
Covered surface (roofed area):	2.316m <sup>2</sup>



# MULTITEXCO

## HIGH PERFORMANCE SMART MULTIFUNCTIONAL TECHNICAL TEXTILES FOR THE CONSTRUCTION SECTOR

*The MULTITEXCO project aims at characterizing and demonstrating the latest achievements in technical textiles for their applicability in the construction sector. This will support the SMEs involved in the construction sector to fully exploit the new generation of multifunctional technical textiles. The project is focusing on applications of smart textiles in 1/ roadwork and embankments, 2/ structure retrofitting and 3/ fabrics for tensile structures. For each field of application a demonstrator is exemplifying the use and reliability of novel, smart multifunctional fabrics. Especially for this contribution, attention will be paid to the application of such smart fabrics in tensile structures.*

### Introduction

The largest industry in the world is covered by civil infrastructure and has about 10% share in the GDP [1]. As a result, technical textiles for this market may govern an important turnover. Unreinforced masonry walls are particularly vulnerable for earthquakes and landslides. The use of technical textiles as reinforcement in both masonry and ground works is increasing and efficient methods for the retrofitting of existing masonry buildings and earthworks and related monitoring systems make it possible to prevent structural damage. In architecture, technical textiles are used in large-span and temporary structures, such as air domes, stadiums, airport terminals, sport halls, hangars or stations. Fabrics are particularly suited for lightweight façades for new and existing buildings. In addition, due to the intrinsic efficiency of tensioned membrane structures, technical textiles are successfully used in several indus-

trial applications such as biogas plants, floating dams, inflatable flood barriers and flexible tanks.

Sensor embedded textiles for structural health monitoring (SHM) of constructions have been demonstrated though many building practitioners are unfamiliar with the behavior and the characteristics of these materials. The lack of information about the use and the properties of these materials limit their implementation and thus prevent achieving the highest possible standards in quality assurance and control for construction projects.

### Hampered breakthrough of textiles for construction

Building materials are strictly regulated by the Eurocode building practices and materials. However, despite the fact that technical textile materials are available today for use in a variety of building and construction applications,

textiles are not mentioned by the eurocodes [2]. As a consequence, their use is limited to small temporary pavilions or iconic structures and buildings where *ad-hoc* authorization can be obtained. The future Eurocode 12 on membrane structures is currently under development by the European Committee for Standardization - CEN TC250 and it is supported by one of the working groups of the EU funded COST action TU1303 on Novel Structural Skins [3].

### A new generation of architectural fabrics

The use of sensible and adaptable envelopes is increasing in recent years and building industry is looking for means to interact with the surroundings via temperature, humidity or solar irradiation monitoring [4,5]. For structures designed for extreme applications (e.g. large span structures prone to fluttering and

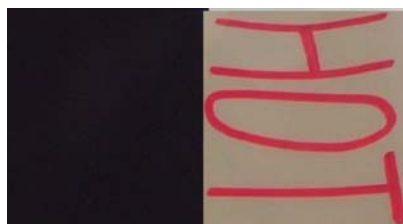
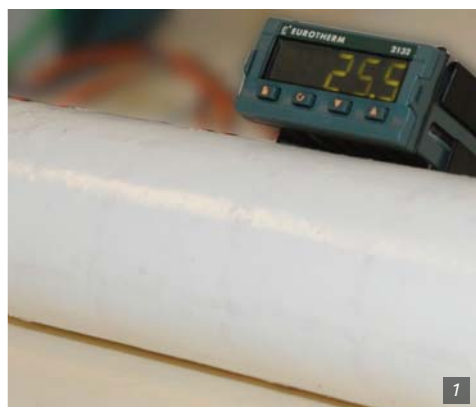
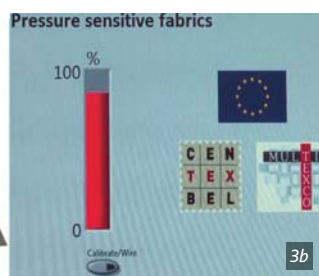


Fig. 1. Temperature responsive fabric using an electronic sensor integrated inside the fabric.

Fig. 2. Textile coating with thermochromic pigments. The coating becomes transparent at temperatures above 70°C (right) and returns black when cooling down (left).

Fig. 3. Pressure responsive sensor integrated in PVC coated polyester fabric (left), response on acquisition software (right).

Fig. 4. Fabrics responsive to corrosive or toxic gases. Left: ammonia sensitive (a. no  $\text{NH}_3$ ; b. in presence of  $\text{NH}_3$ ). Right: hydrogen sulfide sensitive (c. no  $\text{H}_2\text{S}$ ; d. exposed to  $\text{H}_2\text{S}$ ). Samples are 1cm high.





ponding, industrial applications characterized by high working temperatures, biogas reactors with corrosive gases) there is the need of a continuous monitoring in order to highlight anomalies and avoid the progressive propagation of the initial damage. A new generation of sensible technical fabrics equipped with sensors has now become available due to miniaturization of electronic components and new manufacturing techniques for technical textiles. Within the MULTITEXCO project, research on this topic is focusing on temperature monitoring, pressure monitoring and chemical sensing of noxious gasses.

Temperature monitoring of tensile structures is of particular interest for PVC coated fabrics. PVC coated fabric for tensile structures have a glass transition temperature roughly between 70°C and 90°C<sup>[6,7]</sup>. At these temperatures, the polymer will become weaker and welded seams will slowly extend or even detach while being under tension<sup>[8]</sup>. In order to signal a pending failure, temperature sensors can be mounted on the construction after erection. However, most exposed locations are often difficult to reach and attaching several sensors is laborious. In addition, wiring compromises the aesthetics of the often admired organic shapes that can be achieved in textile architecture. To overcome these issues, miniature temperature sensors are integrated in hybrid fabrics with integrated electric leads. In a second step, the sensor loaded fabric is combined with the traditional fabric and coated with PVC. In this way, the sensors are well protected, no wiring is visible and all leads end up at the fabric side (Fig. 1). After confection, these leads are available for connecting monitoring devices at the edge of the construction.

While electronic sensors are well known for their accuracy and ease of data acquisition, connecting and wiring the sensor fabric remains an issue of intense research<sup>[9]</sup>. Alternative to electronics, thermochromic pigments also respond to variations in temperature. Although temperature resolution of these materials is limited<sup>[10]</sup>, the spatial resolution of a coated material is considerably higher than the point wise electronic sensors. This allows for a quick visual inspection and real time monitoring of potential 'hot spots'. Such thermochromic coatings may not be suitable for larger structures, they can be advantageous for quality control during welding of the seams where high enough temperatures have to be reached to insure proper connection of the fabric parts (Fig. 2).

Defining a form for a tensile structure is a crucial step in designing new structures. The form finding methods and finite element modeling tools are key to predict the forces and tension distribution along the fabrics ensuring a stable structure<sup>[11]</sup>. However, the transformation of a digital geometry into a real structure is a process characterized by several intermediate steps such as textile production, confection and build-up. In all of these, minor inaccuracies may influence the result and add up to unforeseen instabilities. This is particular of interest for wind loads causing fluttering, water ponding and snow pile-up on the fabrics<sup>[8]</sup>. These dynamic loads endured by the fabric, can result in extreme tension or unpredicted forces on rigid restraining devices.

An early warning system may be advantageous for signaling increased loads endured by the fabric, but it may also act as a feedback loop between modeling and real life conditions. This would allow the architect to refine the design and the computational processes. In order to achieve such warning system, thin, flexible pressure sensors were integrated in a PVC coated fabric. By connecting the sensor to integrated electric leads in the fabric and subsequent coating, the sensor is well protected while the leads allow for easy connection of the sensor to the readout at the fabric brim (Fig. 3).

While pressure and temperature can clearly contribute to safer or better designed tensile structures, stability is a combined effort of the designer, developer and end user. It is unfortunately not uncommon that fabrics for tensile structures are used in a way they were not designed for. The user then easily points to the manufacturer in case of a defect, while misuse is sometimes the real cause of failure<sup>[12,13]</sup>. Corrosive gases emitted by for example cattle or biological waste may compromise the materials integrity and cause hazardous situations when inadequate materials have been used. For two of such gases, an irreversible indicator patch has been developed. Color will change irreversibly upon

exposure to ammonia or hydrogen sulfide, indicating that the fabric properties can no longer be guaranteed (Fig. 4).






## Conclusion




Technical fabrics for construction offer a wide range of new possibilities in building applications. However, exploitation is hampered by the lack of clear standardization and harmonized legislation. In addition, building practitioners may feel reluctant to use novel materials they have limited experience with. By integrating sensing, monitoring and early warning systems in technical textiles for construction, confidence in textiles as building material may be increased. Moreover, the sensing tools highlighted here may also offer solutions to improve design and modeling of tensile structures and aid to a better understanding between architects, developers and end users.

## Acknowledgements

The research leading to these results has received funding from the European Union's Seventh Framework Program managed by REA-Research Executive Agency <http://ec.europa.eu/research/rea> (FP7/2007-2013) under grant agreement n° 606411.

 [www.multitexco.eu](http://www.multitexco.eu)

 Pieter Heyse (Centexbel)  
 [pieter.heyse@centexbel.be](mailto:pieter.heyse@centexbel.be)  
 Guy Buyle (Centexbel)  
 [guy.buyle@centexbel.be](mailto:guy.buyle@centexbel.be)  
 [www.Centexbel.be](http://www.Centexbel.be)

 Paolo Beccarelli (Maco Technology srl)  
 [info@macotechnology.com](mailto:info@macotechnology.com)  
 [www.macotechnology.com](http://www.macotechnology.com)

## REFERENCES

- [1] J. Bijen, Durability of engineering structures: Design, repair and maintenance. 2003, Woodhead Publishing Limited.
- [2] The eurocodes. What are they?, DG Enterprise and Industry Joint Research Centre.
- [3] <http://www.novelstructuralskins.eu/>.
- [4] D. Clements-Croome, Intelligent buildings: Design, management and operation, ICE Publishing, 2013.
- [5] M. Crisinel and E.C. C13, Glass & interactive building envelopes, IOS Press, 2007.
- [6] A.K. Sen, Coated textiles: Principles and applications, second edition, CRC Press, 2007.
- [7] G. Wypych, Pvc degradation & stabilization, ChemTec Publishing, 2008.
- [8] J. Llorens, Fabric structures in architecture, Elsevier Science, 2015.
- [9] R. Chapman, Smart textiles for protection, Elsevier Science, 2012.
- [10] A. Seeboth and D. Löttsch, Thermochromic and thermotropic materials, Pan Stanford, 2013.
- [11] P. Beccarelli, Biaxial testing for fabrics and foils: Optimizing devices and procedures, Springer International Publishing, 2015.
- [12] S.E. Craig G. Huntington, The tensioned fabric roof, ASCE Press 2004.
- [13] M. Seidel and D.S. Sturge, Tensile surface structures: A practical guide to cable and membrane construction, John Wiley & Sons, 2009.

## ADVANCED COURSE ON FIBER-BASED MATERIALS AND PRODUCTS

13 . 14 . 15  
June, 2016

University of Minho  
Guimarães, Portugal

Organization



Co-organization



The **Advanced Course on Fibre-based Materials and Products** offers a unique chance to learn about the most important topics related to fibrous materials from the pioneering scientists in the field. Specially organized for the young researchers and scientists, this course aims at providing advanced scientific knowledge and understanding on fibre based materials as well as discussing the key issues related to product development and marketing. The scientific lecture sessions will cover various timely topics including production and application of functional nanofibres, renewable and bio-nanofibres, smart fibrous systems, advanced fibrous structures, multi-functional composite materials and innovative fiber based products. In-depth scientific discussions on the fundamental and basic concepts as well as on the most recent scientific and technological advancements in the field of fibre science and technology will be addressed in these sessions. The processes and strategies to

transform the scientific knowledge and understanding in to value added market products will also be discussed. The participants will get the opportunity to interact with these experts to discuss their quarries and thoughts. Besides, representatives from leading organizations and companies producing or using fibre-based products such as RILEM (civil construction), TENSINET (architecture), 3B's (medical), LABIOMEPP (sports), CEiiA (transports) and AITEX (protection) will deliver talks on the product development and market perspectives, based on their long experience in this field. This course will also include exhibition and demonstration of high value and innovative products developed or used by these organizations.

Registrations and more information:

[www.fibrenamics.com/en/advancedcourse](http://www.fibrenamics.com/en/advancedcourse)  
 [fibrenamics@fibrenamics.com](mailto:fibrenamics@fibrenamics.com)

## AACHEN DRESDEN DENKENDORF INTERNATIONAL TEXTILE CONFERENCE 24-25 NOVEMBER 2016, DRESDEN, GERMANY

The Aachen-Dresden-Denkendorf International Textile Conference will be organized by the Institute of Textile Machinery and High Performance Material Technology (ITM) of TU Dresden along with its Circle of Friends and Supporters. It will take place on Thursday 24 and Friday 25 November 2016 in Dresden, Germany. Since 2007 the textile research institutes of the regions of Aachen and Dresden have jointly organized the Aachen-Dresden International Textile Conference. Boasting over 700 participants most recently, this conference counts as one of the most important textile conference in Europe. Starting in 2016, the German Institutes of Textile and Fiber Research, Denkendorf (DITF) will also be a co-organizer. The third co-organizer is the DWI - Leibniz Institute for Interactive Materials from Aachen. The Aachen-Dresden-Denkendorf International Textile Conference will take place on a yearly alternating basis at one of the three sites. Various plenary sessions and special symposia are planned in the 2016 conference in Dresden. Those include: fiber-reinforced composite materials, protective and functional textiles, membranes, polymer materials, and functionalization of textile structures. Topics that will be covered are, among others: new materials, textile 2D and 3D constructions, textile machine modifications, textile production technologies, modeling and simulation, sensors and actuators, personal

and property protection, testing, standardization, certification, recycling, modeling and simulation. Global megatrends, such as electromobility, industry 4.0, health, architecture, and environment will be covered in lectures and discussed by the audience. In addition, ADD-ITC and Forschungskuratorium Textil e. V. organize an industry transfer session where achievements within recent R&D-projects funded by the German government will be summarized.

In 2016 Switzerland and Austria are the official partner countries for the outline of the program, which comprises plenary lectures, invited keynote lectures and contributed talks. Furthermore, we expect more than 100 poster contributions. Three prizes for the best posters will be awarded.

On behalf of the textile research institutions of the Aachen, Dresden, and Denkendorf areas, we would like to invite all interested companies, research institutes, associations and students from around the world for a lively scientific exchange of experiences and information. Submitting of papers for oral and poster presentations is very welcome.

Annett Dörfel  
 [annett.doerfel@tu-dresden.de](mailto:annett.doerfel@tu-dresden.de)  
 <http://www.aachen-dresden-denkendorf.de/en/itc/>



# A Revealing Cover for the EU Presidency

Amsterdam, The Netherlands

## Context

The EU Presidency will be hosted in the Netherlands from January until June 2016. A temporary convention center has been installed at a former navy base in Amsterdam. DUS Architects designed the façade for the main entrance.

A sail-like design which refers to the history of the location as well as revealing the future showing large 3D-printed elements (Fig. 1).

## Concept

The façade gives image to the complex. The white screen is lifted up by invisible strings to open the building visually and physically to the public. This creates overhang, covering the entrance of the complex and creating alcoves for people to meet informal. The white screen is gradually lit at night by pulsating lights (Fig. 2). The sail elements have been carefully detailed to appear as clean and sharp as possible, no connections or tensioning devices are in sight. Along the overhang, the fabric is folded around the edge and clamped onto the steel frame. Side and top edges of the fabric fold around the steel frame and is tensioned to the back of the

frame using springs. The structure of the façade is temporary and re-usable. It consists of eight different steel frames, easily installed and placed in front of the aluminium structure behind.

The benches show a pattern varying in shape and size, depicting the variety and community of the EU countries. They are designed parametrically and are fitted in precisely inside the alcoves. They are a commercial spin-off of the 3D Print Canal House project, a project of DUS architects, Tentech and other collaborators. For this project Tentech advises and validates the structural components produced by DUS' "Kamermaker"; a life-size printer which can print elements up to 2x2x3,5m. The prints are made of a specially developed linseed oil-based bioplastic. The area is open to public and will be installed from January 1, to June 30, 2016.

*Daan Rietbergen & Rogier Houtman,  
Tentech bv*

*info@tentech.nl*

*www.tentech.nl*

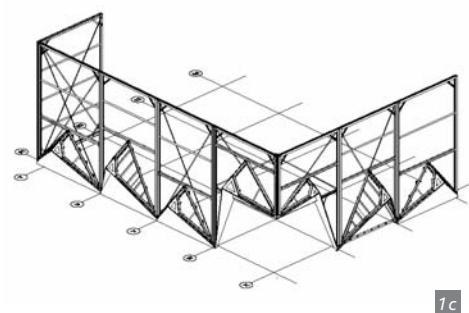
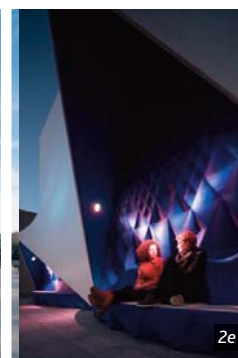
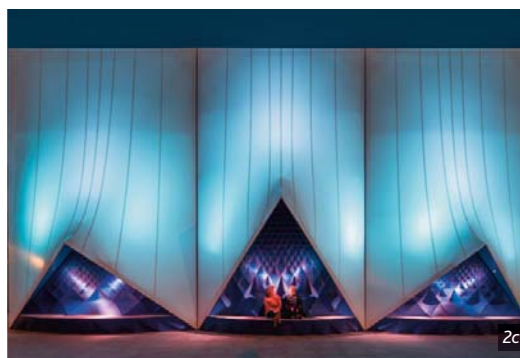


Figure 1. The façade: 3D model of the aluminium frame and final version (day and night view) © Ossip van Duivenbode



Name of the project:	Europe Building 2016
Year of construction:	2015
Architect:	DUS Architects
Client:	Neptunus Structures
Structural Engineering & membrane consultancy:	Tentech
Manufacturer membrane:	Indu-Con
Fabric Roof:	Ferrari 502
Covered Area:	300m <sup>2</sup>

Figure 2. The revealing façade (day and night view) © Ossip van Duivenbode

# PROJECT SPEEDKITS

## Context

Humanitarian organizations use a large variety of emergency kits to support an affected population after a disaster. These kits should be able to be deployed immediately after a disaster has stricken and provide all basic needs such as medical care, clean and sufficient drinking water, proper sanitation, energy supply, shelters, etc. The European project S(P)EEDKITS, which started in 2012, developed several emergency kits which emphasises the SPEED of the kit solutions and the possibility to act as a SEED to rebuild the affected environment, to allow fast and early reconstruction and to reduce as much as possible the temporary or transitional phase. The project started by investigating the Red Cross's Emergency Items Catalogue and obtaining the feedback from field experts from different humanitarian organizations. This will highlighted the strength and shortcomings of currently used solutions and allowed to define the field of possible research. Secondly, complementary features and new concepts were developed to drastically reduce the volume and weight for transportation, and to improve their performance. All European partners (Italy, Belgium, Netherlands, Luxembourg, Norway and Germany) worked on the following topics:

- Improving the supply chain in terms of logistic - and transport parameters and dedicating sufficient research on standardized packaging systems with 3 harmonized scales (bag-europallet-20ft container)
- The development of 4 adequate shelter types which can cover the 4 elementary needs based on family and community requirements
- The cleaning and purification of water which provides sustainable access to safe drinking water and basic sanitation
- Developing new infrastructure systems which includes medical, energy and re-building solutions
- Improving supporting tools which are able to assess, monitor and evaluate future deployments

The S(P)EEDKITS designs are to be deployed in an affected city, a spontaneous or planned camp or a scattered rural region, in order to support the transformation of the 'temporary' post-disaster situation towards the rebuilding of economic and social life.

## The Clever roof + Cocoon

This article will solely focus on one novel shelter solution developed in the framework of the S(P)EEDKITS project: the Clever roof + Cocoon. The Architectural Engineering Department of the Vrije Universiteit Brussel (VUB), the Architecture - Built environment and Construction Engineering Department of the Politecnico di Milano (POLIMI), the Belgian Textile Research Centre Centexbel, the membrane manufacturer Sioen Industries and the International Federation of Red Cross and Red Crescent Societies (Shelter Research Unit) worked together to develop this innovative shelter solution. The kit composes of a 'Clever Roof' which is a mechanically stressed membrane and a 'Cocoon' which is a perfectly waterproof, insulated chamber. The Clever roof shelter kit provides a shelter solution which consists of a PVC coated polyester fabric, structural elements, connectors, pegs, belts, a hammer and a clear manual. The basic function of this Clever Roof kit is to provide cover (24m<sup>2</sup>) against heat and rain. It is not only a fast solution able to meet the basic needs during an emergency phase but also a cover having a longer lifetime than the existing products to ensure a long use or even better be part of a reconstruction process as a first element. This ensuring that reconstruction phase after disaster begins at day 0 just after distribution. Because of its straightforward design, the shelter can be deployed by the affected population themselves. The total package of the Clever roof only weights 30kg and is provided in an easy to carry bag to facilitate the transportation on site (Fig. 1). The total volume and weight of the package is minimized to reduce the cost needed for transportation. The shelter itself can be erected by two persons in a time span of 15min. The

T3 - COCOON  
an insulated room to be hung to  
the structure of the T1 - Clever Roof

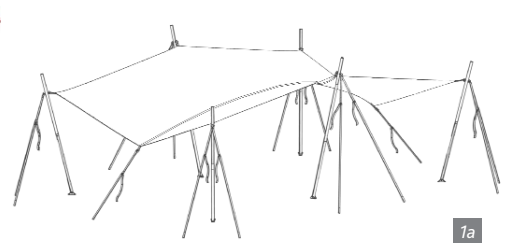
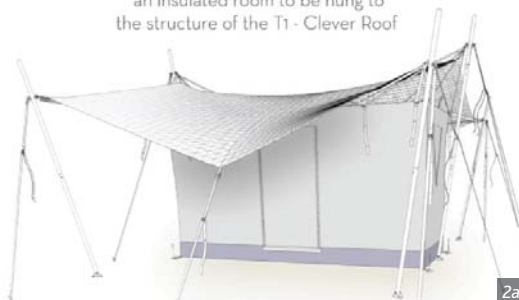


Figure 1. a: Slightly double curved 'Clever Roof'  
b and c: Different configurations

clear manual ensures that non-experts are able to correctly set-up the shelter solution. The main research question for these shelter solutions was to properly tension a flat piece of membrane. The classic use of cutting patterns for tensioned textile surfaces has been neglected for this particular case to reduce the fabrication cost of the product. The membrane is manually tensioned between a set of high and low boundary points in order to create a cover with a slight double curvature and a basic pretension (Fig. 1a).

Most currently used shelter solutions lack versatility in shape (tent solutions) or do not provide sufficient materials or knowledge on site to built a safe shelter. The Clever roof shelter kit is a new shelter solution not existing on the current humanitarian market, which provides a versatile product that can be used for several functions. Different shapes are



Figure 2: Insulated Cocoon



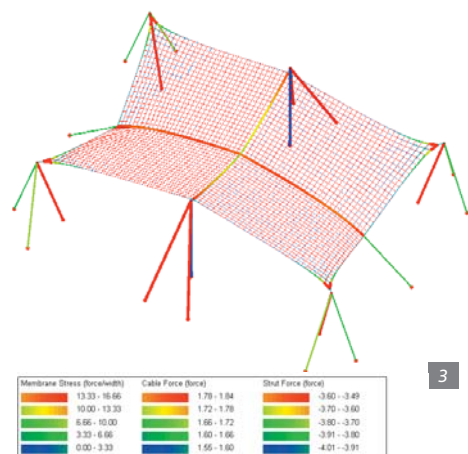
obtainable with the same set of components to provide an adequate solution for different cultural needs and to guarantee a good rain/sun protection (Fig. 1b and 1c).

In a first stage, the 'Clever Roof' has no walls and solely provides protection against heat and rain. In a second stage, walls can be added to make a closed family shelter. These walls can be made by connecting standard tarps to the structural Clever Roof or by using an insulated Cocoon (Fig. 2).

The cocoon is an insulated room which can be hung underneath the Clever roof using the same structure. All walls, roof and floor of the cocoon are fabricated from a nonwoven material which insulates the closed box. The walls and roof of the cocoon consists of the now woven material with a layer of PVC coated polyester at one side to assure decent water tightness. The ground sheet of the cocoon consists of a non woven material which has a layer of PVC coated polyester at both sides. Two windows guarantee a decent cross-ventilation of the inner volume. The cocoon can also be used separately without the Clever roof as partitioning element in a temporary settlement inside large public buildings. The total weight of the cocoon is also 30kg which facilitates the transportation on site. The placement of the Cocoon underneath the Clever roof still provides a covered outside area which can be used for cooking and daily social activities.

### Clever roof analysis

The researchers at the Architectural Engineering Department of the Vrije Universiteit Brussel (VUB) investigated experimentally and numerically the structural behaviour of the Clever Roof (Fig. 3). The analysis had to verify that tensioning a flat piece of membrane provides enough curvature and tension to create a structurally safe cover. In a first step the material properties of membrane, struts and belts were defined.



The next step was the form finding of the Clever Roof. This means that a flat tarp of 4m by 6m was tensioned in a slightly anticlastic configuration by elevating the corner points and pre-tensioning the tie-down cables. Further improvement of the numerical model was needed as the stress concentrations at the membrane connections were very high and did not represent the real situation. In reality, the connection is a belt loop stitched onto the membrane, transmitting the force more smoothly into the membrane. Therefore, the numerical model is adapted by adding 2 links at the connections which represents these belt loops (Fig. 4).

Step 3 defines the load cases and the load combinations: self-weight and wind load (longitudinal direction versus transversal, uplift versus pressure, symmetrical versus asymmetrical). The analysis has shown that the two symmetric load cases, with wind in the longitudinal direction, are most critical for this form-active membrane shelter. Therefore, these two load cases were considered in the Limit State Designs (SLS and ULS). The last step demonstrates the Service Limit State and Ultimate Limit State (Longitudinal wind down and wind up, symmetric loading). The real dynamic behaviour of the membrane structure will not be as dramatic as shown by this static calculation (Fig. 5). However, as a result of the limited pre-tension in the membrane, the structure will deform significantly under the dynamic wind actions. For these highly flexible membrane structures the deformations under extensive wind load calculations (with a detailed distribution pattern of wind loads) are about 30% larger compared to the simplified uniform wind load distribution.

The Clever Roof is adequately dimensioned to withstand the Ultimate Limit State design:

- Membrane: taking into account the simplifications in the design model (approximation by a cable net) lower values



Figure 3. Isometry of the basis configuration of the Clever Roof  
Figure 5. Deflection under longitudinal upward wind loading

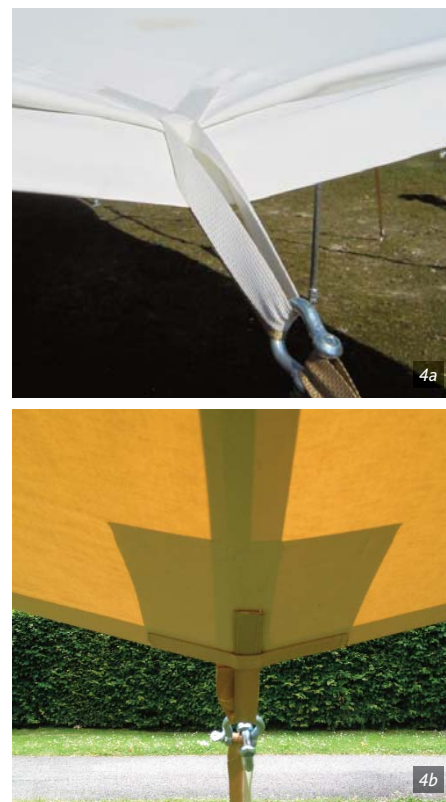


Figure 4: Connection in the test set-up

and a better distribution of the stresses at the connections are expected. To provide resistance to the stress concentrations, it is proposed to apply multiple layers of membrane at the connection zones, or to implement a high strength membrane locally.

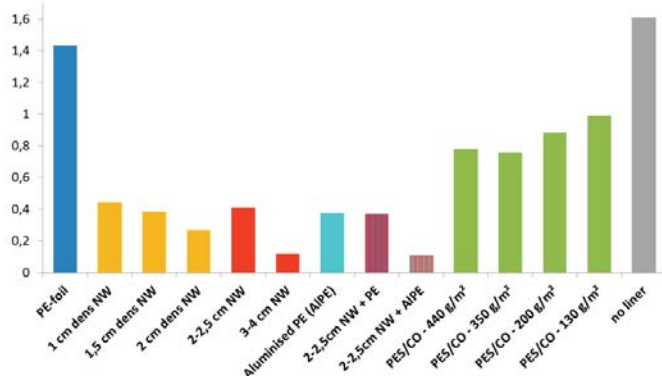
- Struts: the buckling resistance is never reached.
- Tie-down belts: the tensile strength of the belts is almost twice the maximum occurring force.

### Membrane material development

To optimise comfort and life span, the materials of the innovative shelter were very precisely chosen and developed. The Clever Roof is made of a coated textile which is 100% waterproof. Ordinary tarps lose their water repellent quality due to UV deterioration. The selected advanced materials are already used for technical applications but were until now never used for emergency housing. Compared with the ordinary tarps (which have a lifespan of about 1 year) these coated fabrics have a life span which is more than 10 times higher. The Cocoon is made of a special developed layered fabric combining coated textiles and a nonwoven layer. The nonwoven material is already used as thermal insulation in the traditional housing industry.

At Centexbel several types of nonwovens (different thicknesses and densities) were evaluated for their thermal behaviour, and

Temp Rise [°C/s]



Graph 1.  
Evaluation of the  
insulating  
performance of  
the cladding  
materials (radiant  
panel test)

compared with the currently used polyester/cotton tent fabrics. This laminate really outperforms the currently used cladding materials as can be seen in graph 1.

## Prototypes

Several prototypes were manufactured, tested, evaluated and further optimised. All membrane materials were produced and developed by SIOEN Industries in collaboration with the Belgian Textile Research Centre CENTEXBEL. The Architectural Engineering Department of the Vrije Universiteit Brussel together with the Architecture, Built environment and

Construction Engineering Department of the Politecnico di Milano performed the design and the structural calculation for both 'Clever roof' and 'Cocoon'. The field experience of the Shelter Research Unit was crucial in the whole process to assure the practical relevance of the designed shelters. The latest prototype of the innovative shelter (Fig. 6) was demonstrated at the Médecins Sans Frontières site in Belgium during the AidEx fair (November 2015) and is tested on site in Senegal since December 2015. The first results after 2 months are extremely good and the beneficiary feedbacks are really promising.

## Senegal field test

To demonstrate the relevance and the efficiency of the designed product, there has been decided in close collaboration with Luxembourgish Red Cross, to ship mockups to a small fisherman's village near the Mauritanian border in Senegal (Fig. 7). The beneficiaries (20 families) evaluated and tested the sent products on their usability, set-up time and effectiveness. In total 20 'Clever roofs' and 10 'Cocoons' have been sent to the site. The beneficiaries are frequently affected by floods where they lose their homes (due to erosion of the walls). This background provides the ideal circumstances to test our newly developed product. Packaging, ease of transport, assembling time and satisfaction level have been measured through means of questionnaires. In parallel the internal climate of the shelter solutions have been measured with temperature/humidity loggers. The first feedbacks are excessively positive and the Red Cross delegates are really glad to daily observe the efficiency of the intervention.

## Acknowledgement

S(P)EEDKITS received funding from the European Commission's Seventh Framework Programme for research, technological development and demonstration under grant agreement no 284931.

Read more about the project at

□ <http://www.speedkits.eu/>.

Guy Buyle (guy.buyle@centexbel.be)

Ine De Vilder (Ine.DeVilder@centexbel.be)

Pieter Heyse (Pieter.Heyse@centexbel.be)

□ [www.centexbel.be](http://www.centexbel.be)

Marijke Mollaert (Marijke.Mollaert@vub.ac.be)

Jan Roekens (jroekens@vub.ac.be)

Jimmy Colliers (jimmy.colliers@vub.ac.be)

Lars De Laet (lars.de.laet@vub.ac.be)

Evi Corne (Evi.Corne@vub.ac.be)

□ [www.vub.ac.be/ARCH/ae-lab/lightweight](http://www.vub.ac.be/ARCH/ae-lab/lightweight)

Alessandra Zanelli

(alessandra.zanelli@polimi.it)

Salvatore Viscuso (salvatore.viscuso@polimi.it)

Marta Barozzi (marta.barozzi@mail.polimi.it)

□ [www.polimi.it](http://www.polimi.it)

Vincent Virgo (Vincent.Virgo@croix-rouge.lu)

□ [www.croix-rouge.lu/presentation-du-sru/](http://www.croix-rouge.lu/presentation-du-sru/)

Bert Groenendaal

(Bert.Groenendaal@sioen.be)

□ [www.sioen.com/technical-textiles/eu-calls](http://www.sioen.com/technical-textiles/eu-calls)

## REFERENCE

[1] <http://procurement.ifrc.org/catalogue/detail.aspx?volume=1&groupcode=111&familycode=111001&categorycode=SHEK&productcode=KRELSH EK02>

Figure 6. Prototype of the Clever roof installed during the AidEx fair

Figure 7. The Clever Roof set-up in Senegal (© Vincent Virgo / Guy Buyle)





Madinah, Saudi Arabia

## Tensile Fabric Covering

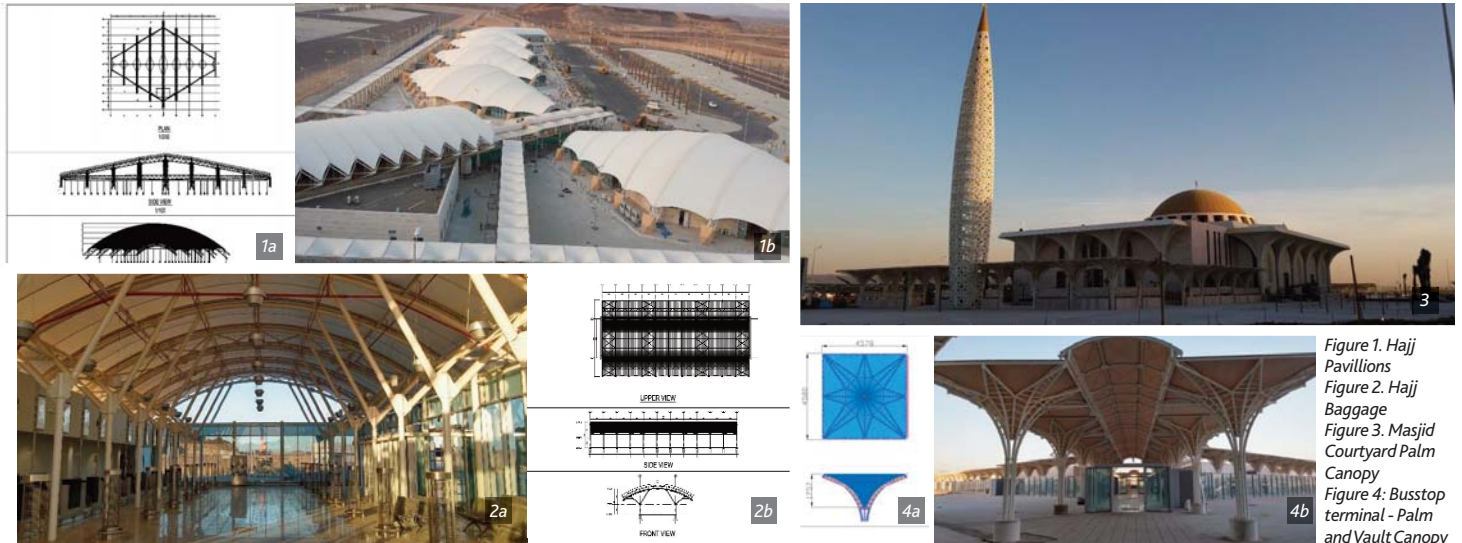


Figure 1. Hajj Pavillions  
Figure 2. Hajj Baggage  
Figure 3. Masjid Courtyard Palm Canopy  
Figure 4. Busstop terminal - Palm and Vault Canopy

## Introduction

Madinah is located in Western Saudi Arabia. It is the second holiest city in Islam after Mecca and the first capital of Islam. The city, hosting the tomb of Prophet Muhammad, is an important destination for religious tourism and attracts each year a large number of pilgrims. The passenger traffic at the airport increased by approximately 21% to 5,7 million passengers in 2014, compared with 2013. The increasing number of passengers led to a phased expansion and rehabilitation of the airport.

## Design

The first phase of the expansion includes the construction of a new passenger terminal building. The architecture is well integrated into the existing infrastructure of the airport. The design of airport's expansion over three phases was made by the GMW Architecture. Their design concept was inspired by the airport's role as a gateway for millions of Islamic pilgrims and the palm tree, symbol for peace and welcome, has become emblematic in the terminal building. This palm frond was the main source of inspiration for the architectural form and it provides an efficient structural support.

The geometry of the grand canopy refers to the structure of an octagonal family of radiating, intersecting and concentric line-work in resonance

with the symbolic working of Islamic geometries and focuses on elegant, modular and spacious interiors. The new terminal and airport is built to the highest international standards and allows an initial operating capacity of 8 million passengers per year.

## Textile roofs

Tensaform was involved in the engineering, manufacturing and installation of different textile roofs: Ministry of Hajj Roof, 6 units of Hajj Pavillion Building Roofs (Fig. 1), Hajj Baggage Roof (Fig. 2), Masjid Courtyard Palm Canopy (Fig. 3), Hajj Area Walkway Shading Vault Shade, Hajj Area Walkway Shading Palm Canopy, Bus Stops Palm and Vault Canopy (Fig. 4), Carpark Single and Double Module Shade Types (Fig. 5).

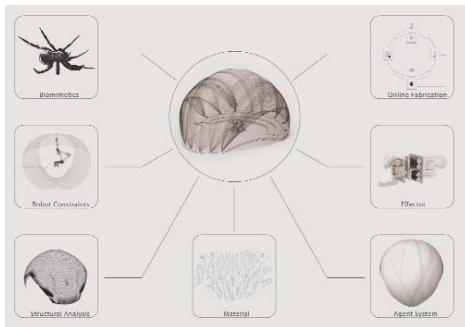
Tensaform has chosen for these roof coverings the membrane PTFE Type III B 18089, manufactured by Verseidag – Indutex. A membrane surface of approximately 57.318m<sup>2</sup> was manufactured by Tensaform at its manufacturing factory, located at Malkara.

 Mehmet YILMAZ  
 Mehmet.yilmaz@tensaform.com  
 www.tensaform.com



Figure 5. Carpark - Single and double modules shading

Name of the project:	The Construction of Prince Bin Abdulaziz International Airport Tensile Fabric Covering for Sheds
Location address:	Medinah, Saudi Arabia
Client (investor):	TAV Construction and Al- Arrab Contracting Co.
Function of building:	Commercial and Industrial Structure
Type of application of the membrane:	Hajj Pavillions Roof Covering and Carparking Lots
Year of construction:	2015
Architects:	GMW
Consulting engineer for the membrane:	Tensaform Membrane Structures Industry & Trade INC.
Main contractor:	Al Arrab Contracting Co.
Contractor for the membrane:	Tensaform Membrane Structures Industry & Trade INC.
Supplier of the membrane material:	VERSEIDAG-INDUTEX
Manufacture and installation:	Tensaform Membrane Structures Industry & Trade INC.
Material:	Verseidag PTFE Type III B18089 membrane
Covered surface (roofed area & carparking lots):	57.318m <sup>2</sup>



1 Figure 1. Diagram of integrated design criteria

*The ICD/ITKE Research Pavilion 2014-2015 demonstrates the architectural potential of a novel building method inspired by the underwater nest construction of the water spider. Through a novel robotic fabrication process an initially flexible pneumatic formwork is gradually stiffened by reinforcing it with carbon fibers from the inside. The resulting lightweight fiber composite shell forms a pavilion with unique architectural qualities, while at the same time being a highly material-efficient structure.*

### Introduction

The Institute for Computational Design (ICD) and the Institute of Building Structures and Structural Design (ITKE) continue their series of research pavilions with the new ICD/ITKE Research Pavilion 2014-15 at the University of Stuttgart. These building prototypes explore application potentials of novel computational design, simulation and fabrication processes in architecture. The pavilion was developed at the intersection of the two institute's research fields and their collaborative teaching in the context of the interdisciplinary and international ITECH MSC program. This prototypical project is the result of one and a half years of development by researchers and students of architecture, engineering and natural sciences.

### Concept

The design concept is based on the study of biological construction processes for fiber-reinforced structures. These processes are relevant for applications in architecture, as they do not require complex formwork and are capable of adapting to the varying demands of the individual constructions. The biological processes form customized fiber-reinforced structures in a highly material-effective and functionally integrated way. In this respect the web building

process of the diving bell water spider, (*Agyroneda Aquatica*) proved to be of particular interest. Thus the web construction process of water spiders was examined and the underlying behavioral patterns and design rules were analyzed, abstracted and transferred into a technological fabrication process (Fig. 1).

### Water spider

The water spider spends most of its life under water, for which it constructs a reinforced air bubble to survive. First, the spider builds a horizontal sheet web, under which the air bubble is placed. In a further step the air bubble is sequentially reinforced by laying a hierarchical arrangement of fibers from within. The result is a stable construct that can withstand mechanical stresses, such as changing water currents, to provide a safe and stable habitat for the spider. This natural production process shows how adaptive fabrication strategies can be utilized to create efficient fiber-reinforced structures (Fig. 2).

### Application

For the transfer of this biological formation sequence into a building construction application, a process was developed in which an industrial robot is placed within an air supported membrane envelope made of ETFE. This inflated soft shell is initially supported by

air pressure, though, by robotically reinforcing the inside with carbon fiber, it is gradually stiffened into a self-supporting monocoque structure. The carbon fibers are only selectively applied where they are required for structural reinforcement, and the pneumatic formwork is simultaneously used as a functionally integrated building skin. This results in a resource efficient construction process.

### Methodology

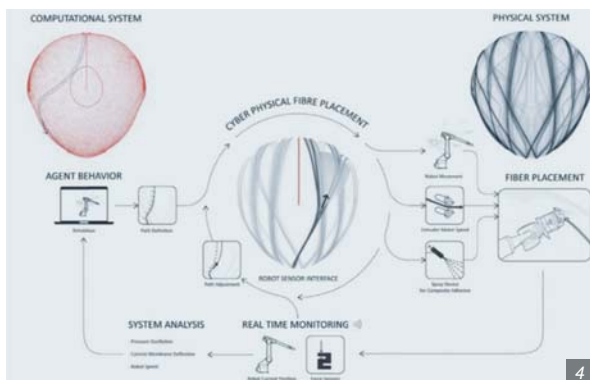
At the beginning of the design and construction process, the shell geometry and main fiber bundle locations are generated by a computational form finding method, which integrates fabrication constraints and structural simulation. In order to determine and adjust the fiber layouts a computational agent-based design method has been developed (Fig. 3). Similar to the spider, a digital agent navigates the surface shell geometry generating a proposed robot path for the fiber placement. The agent behavior is derived from a variety of interrelated design parameters. This computational design process enables the designer to navigate and simultaneously integrate these design parameters into various performative fiber orientations and densities. Corresponding to the adaptive computational design strategy, a prototypical robotic fabrication process was developed for carbon fiber reinforcement on the inside of a flexible membrane. The changing stiffness of the pneumatic formwork and the resulting fluctuations in deformation during the fiber placement process pose a particular challenge to the robot control. In order to adapt to these parameters during the production process the current position and contact



Figure 2. Diving Bell Water Spider (*Agyroneda aquatica*) reinforcing an air bubble from the inside for the ICD/ITKE Research Pavilion 2014-15

Figure 3. Comparison of various fiber reinforcement strategies

Figure 4. Cyber-physical fibre placement process





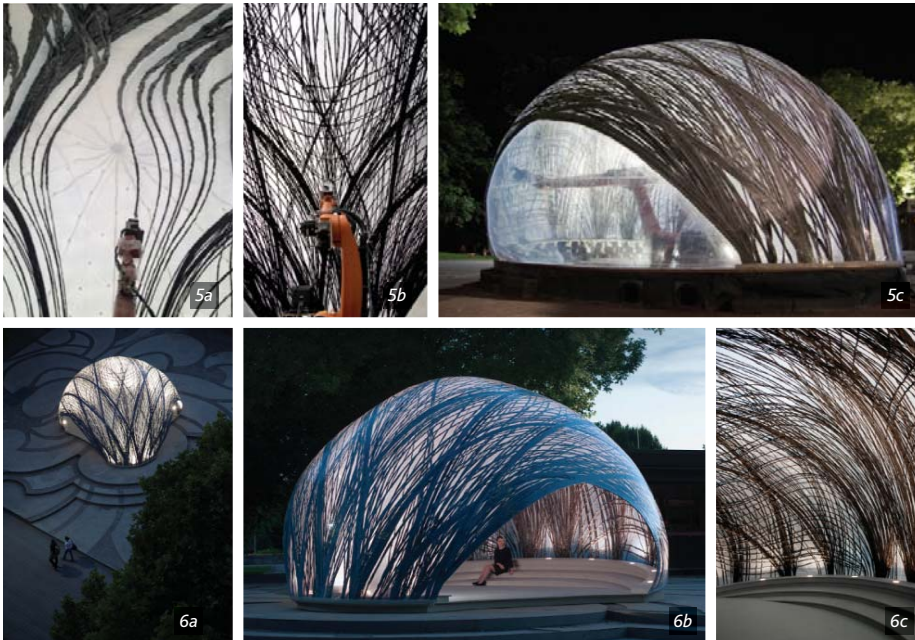


Figure 5. On-site robotic fiber placement of reinforcement fibers with parallel distribution / Robotic placement of carbon fiber reinforcement layers / Reinforced membrane with hierarchical fiber arrangement

Figure 6. ICD / ITKE Research Pavilion 2014-15, an innovative and expressive architectural demonstrator

force is recorded via an embedded sensor system and integrated into the robot control in real time. The development of such a cyber-physical system allows constant feedback between the actual production conditions and the digital generation of robot control codes. This represents not only an important development in the context of this project, but more generally provides new opportunities for adaptive robotic construction processes (Fig. 4)

### Fabrication

The prototypical character of the fabrication process required the development of a custom made robot tool that allows placement of carbon fibers based on integrated sensor data (Fig. 5). The technical development of this tool became an integral part of the architectural design process. This process also posed special challenges for the material system. ETFE was identified as a suitable material for the pneumatic formwork and integrated building envelope, since it is a durable façade material and its mechanical properties minimize plastic deformation during the fiber placement. A high degree of functional integration is achieved through the use of the ETFE film as pneumatic formwork and building envelope. This saves the material consumption of conventional formwork techniques as well as an additional façade installation. A composite adhesive provided a proper bond between the ETFE film and the carbon fibers. During manufacture, nine preimpregnated carbon fiber rovings with a total length of 45 km were applied along a 5 km robot path at an average velocity of 0.6 m/min. This additive process not only allows stress-oriented placement of the fiber composite mate-

rial, but it also minimizes the construction waste associated with typically subtractive construction processes. The ICD / ITKE Research Pavilion 2014-15 covers an area of about 40m<sup>2</sup> and an internal volume of approximately 130m<sup>3</sup> with a span of 7.5m and a height of 4.1m. The total construction weight is just 260kg, which corresponds to a weight of 6.5kg/m<sup>2</sup>.

### Demonstrator

The ICD / ITKE Research Pavilion 2014-15 serves as a demonstrator for advanced computational design, simulation and manufacturing techniques and shows the innovative potential of interdisciplinary research and teaching. The prototypical building articulates the anisotropic character of the fiber composite material as an architectural quality and reflects the underlying processes in a novel texture and structure. The result is not only a particularly material-effective construction, but also an innovative and expressive architectural demonstrator (Fig. 6).

✍ Prof. Achim Menges,  
Institute for Computational Design (ICD)  
✍ Prof. Dr.-Ing. Jan Knippers, Institute of Building Structures and Structural Design (ITKE)  
University of Stuttgart, Scientific Development: Moritz Dörstelmann, Valentin Koslowski, Marshall Prado, Gundula Schieber, Lauren Vasey

### More Information:

🌐 <http://icd.uni-stuttgart.de/?tag=RP14>  
🌐 <http://www.itke.uni-stuttgart.de/entwicklung.php?id=69>  
© ICD / ITKE Roland Halbe

## BOOKREVUE

### Textile materials for lightweight constructions

Technologies – Methods – Materials – Properties



Publisher: Springer

Edited by Chokri Cherif

ISBN: 978-3-662-46340-6

Language: English | Published: 2016

This textbook is the work of scientists of the Institute of Textile Machinery and High Performance Material Technology (ITM) at the Technische Universität Dresden as well as other experts from research and teaching. Textile materials and semi-finished products have an extremely diverse property potential and are often carriers and drivers for innovative, resource-efficient lightweight construction and high-tech applications. In this book, experts on textile technologies convey both general and specific information on various aspects of textile engineering, ready-made technologies, and textile chemistry. They describe the entire process chain from fiber materials to various yarn constructions, 2D and 3D textile constructions, preforming, and interface layer design. In addition, the authors introduce testing methods, modeling and simulation techniques for the characterization and structural mechanics calculations of anisotropic, pliable high-performance textiles, including specific examples from the fields of fiber-reinforced polymers, textile-reinforced concrete and textile membranes. Readers will also be familiarized with the potential offered by increasingly employed textile structures, for instance in the fields of composite technology, construction technology, security technology and membrane technology.

## Improving Sustainability and Efficiency through new Structural Textile Materials and Design Tensinet - COST Action TU1303 Symposium 2016

Novel structural skins - The urban built environment is being transformed by building skins derived from textile architecture. Working from a basis of tensioned membranes, these highly efficient structural forms are now being integrated with multi-disciplinary technologies to form new multi-functional systems that address the needs and global challenges of the urban built environment. The rapid emergence of lightweight building skins is in response to factors associated with climate change, energy, and workplace health and well-being, and is directly linked to advances in material development, analysis tools, and skills in design.

The three day symposium is divided into five main topics, to be introduced by keynote speakers:

- New applications of structural skins and new concepts
- Sustainability and Life Cycle Analysis of structural skins
- Building physics and energy performance of structural skins
- Materials and analysis
- From material to structure and limit states: codes and standardization

**Jan Knippers:** Institut für Tragkonstruktionen und Konstruktives Entwerfen, University of Stuttgart  
Fibres Rethought - Towards Novel Constructional Articulation

**Carl Maywald:** Vector Foiltec GmbH, Bremen  
Sustainability - The Art of Modern Architecture

**Raul Fangueiro:** University of Minho, **Martin Tamke:** School of Architecture, Royal Danish Academy of Fine Art  
Bespoke Materials for Bespoke Textile Architecture

**Gordon Mungall:** Arup, Newcastle upon Tyne  
Unlocking the Potential of Insulated Fabric

**Jürgen Wacker:** Wacker Ingenieure, Birkenfeld  
Wind Impact on Textile Structures

### An Open Session:

'Built Projects' is scheduled for the afternoon and evening of Wednesday 26 October 2016 when prominent experts in the membrane architecture and engineering world will present their inspiring built projects to demonstrate to a wider audience the potential of lightweight structures.

**Patrik Schumacher:** Zaha Hadid Office, London  
Formfinding and Tectonic Articulation - Making Performative Logics Speak

**Julian Lienhard:** str.ucture GmbH, Stuttgart  
Pushing the Boundaries of Textiles in Architecture

**Tim Lucas:** Price & Myers, London  
Full Metal Jacket

**Al Fisher:** BuroHappold Engineering, London  
How to Build Lightweight - Advances in Computational Engineering

Attendees will also have the opportunity to visit the University's building, known as The Key, the first fabric structure to be used as a heated work space in the UK.

Full details at <http://conferences.ncl.ac.uk/tensinet2016/programme/>  
or email [tensinet2016@ncl.ac.uk](mailto:tensinet2016@ncl.ac.uk)

Sponsored by:



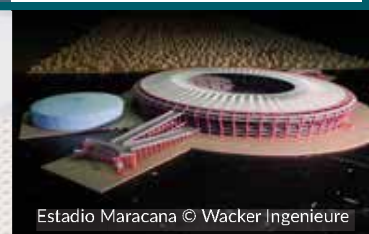
**3M** Science. Applied to Life.

**VERSEIDAG**  
COATING AND COMPOSITE

**Serge Ferrari**

**Redaelli**  
**MEHLER**  
TECHNOLOGIES

Endorsed by:



Estadio Maracana © Wacker Ingenieure



Manchester Victoria Station © Sam Peach



The Key



Research Pavilion



US Ananheim - ARTIC © John Linden



Hybrid Tower



© Ahlquist