

REPORT

## TEXTILE ROOFS 2014

### STUDENT'S PROJECT WEEK

RESEARCH

## FROM MEMBRANE FORM TO RIGID SHELL

PROJECTS

KING FAHAD NATIONAL LIBRARY

FIFA WORLD CUP BRASIL

INNOVATIVE MEMBRANE ARCHITECTURE  
FOR CARPORT





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



Heytex Bramsche GmbH  
www.heytex.com



Hightex GmbH  
www.hightexworld.com



Mehler Technologies  
www.mehler-  
technologies.com



Messe Frankfurt  
Techtextil  
www.techtextil.com



Naizil S.P.A.  
www.naizil.com



Saint-Gobain  
www.sheerfill.com



Sefar  
www.sefar.com



Serge Ferrari sa  
www.sergeferrari.com



Sioen Industries  
www.sioen.com



Taiyo Europe  
www.taiyo-europe.com



technet GmbH  
www.technet-gmbh.com



Verseidag  
www.vsinutex.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  
fax: +32 2 629 28 41

ISSN 1784-5688

All copyrights remain by each

author

Price €15

postage & packing included

# contents



## PROJECTS

PAGE

4

**Germany** LORDS GARDEN OF RELIGIONS  
A PLACE OF WORSHIP FOR THREE RELIGIONS



4 **Greece** PASSENGERS TERMINAL COVER

5 **India** TENSILE ARCHITECTURE  
FOR RESIDENTIAL APPLICATION

6 **Germany** CARPORT  
INNOVATIVE MEMBRANE ARCHITECTURE

9

**Brasil** FAÇADE CONSTRUCTION  
AMAZING TEXTILE ROOF

10

**Brasil** FIFA WORLD CUP  
FLEXIBLE COMPOSITE MATERIALS FOR EACH PURPOSE

12

**Saudi Arabia** KING FAHAD NATIONAL LIBRARY  
A SECOND SKIN FOR FACADE AND CEILING



17

**Thailand** SHOPPING MALL OUTDOOR ROOF COVER

PAGE

## REPORT

18

**TEXTILE Hybrid Softhouse**  
HAMBURG, GERMANY



## 19 TEXTILE ROOFS 2014 REPORT

*The Nineteenth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 26-28 May at the Deutsches Technikmuseum Berlin. It was attended by 90 participants from 27 countries from four continents.*

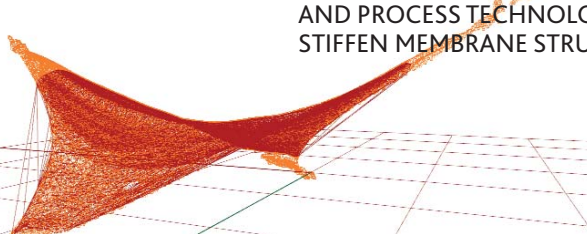
24

**24 STUDENT'S PROJECT WEEK** TEXTLE ROOFS 2014

## RESEARCH

14

**FROM MEMBRANE FORM TO RIGID SHELL**  
APPLIED RESEARCH ON MATERIAL  
AND PROCESS TECHNOLOGY TO APPLY AND  
STIFFEN MEMBRANE STRUCTURES WITH SHOTCRETE



**E**dito  
Dear Reader,

Years with important sport events lead to many new or renovated sports facilities. Large span together with translucency are the main advantages of structural membranes, that's why many new membrane projects are built for these events. This year for the FIFA world cup 2014 most of the 12 stadiums have been realised with structural membranes. For one of them you find a project article in this new issue of TensiNews.

Since the last TensiNews many activities were going on within the Eurocode working group and in the COST Action on 'Novel structural skins'.

The Eurocode working group is preparing the scientific and policy (SaP) report "Guideline for a European Structural Design of Tensile Membrane Structures made from Fabrics and Foils". This report is summarizing the actual code of practice in different European countries, and gives an outlook for a future Eurocode. It will be finished and submitted by the end of this year. It is supposed to be published by the joint research center (JRC) as background information to the future technical specification and Eurocode. The ETFE working group has contributed to the Eurocode working group a chapter on the limit states for ETFE foil, and is supposed to contribute also further general information based on the ETFE Design Guide.

After a first meeting in March, the COST Action on 'Novel structural skins - Improving sustainability and efficiency through new structural textile materials and designs' is meeting this September in Brussels. TensiNet members are involved in the different working groups.

TensiNet was present at Textile Roofs 2014 in Berlin, with many interesting lectures about projects, research and student work. Josep Llorens has prepared a report about this nineteenth international workshop held in Berlin this May.

Actual research on rigid shells, photovoltaic integrated in ETFE cushions and natural ventilation to avoid air-conditioning are beside many interesting projects subjects of this issue. Please enjoy it. I hope to meet you at our activities and events.

Yours sincerely,  
Bernd Stimpfle



**TensiNet**

## Invitation and conditions for participation in the 13<sup>th</sup> Techtextil Competition **TEXTILE STRUCTURES FOR NEW BUILDING 2015**

### Areas of textile building

- Structural engineering – from construction using textile-reinforced concrete or plastics to construction using membranes for permanent and temporary, adaptable and mobile buildings;
- Interior construction – including such developments as the use of polymer fibre-optic cables for light transmission, textile air-channel systems for draught-free air conditioning in rooms, movable sound-insulation walls in production facilities, etc.;
- Product design for architecture;
- An additional focal theme has also been included: 'Suitability for re-use and recycling';
- Civil and industrial engineering.

The subject of the project submitted is a free choice. Work will be accepted, which has been produced either under a supervisor or without a supervisor.

The deadline for uploading your summary and your contact data online at [www.techtextil-student.com](http://www.techtextil-student.com) is **27 February 2015**.

The award winning projects will be exhibited and win one of the cash prizes from the total pay-out of € 8.000.

ORGANISED BY TECHTEXTIL / SPONSORED BY TENSINET

## Forthcoming Events

### CLADDING and FIXINGS for humanitarian sheltering

Luxemburg, Luxembourg | 3-4/09/2014  
[lfrs-sru@croix-rouge.lu](mailto:lfrs-sru@croix-rouge.lu)

### IASS-SLTE 2014 symposium

Brasilia, Brazil | 15-19/09/2014  
[www.iass2014.org](http://www.iass2014.org)

### Essener Membranbau Symposium 2014

Essen, Germany | 26/09/2014  
[www.uni-due.de/iml](http://www.uni-due.de/iml)

### Aachen - Dresden International Textil Conference

Dresden, Germany | 27-28/11/2014  
<http://www.aachen-dresden-itc.de/>

### TECHTEXTIL 2015

Frankfurt, Germany | 4-7/05/2015  
[www.techtextil.messefrankfurt.com](http://www.techtextil.messefrankfurt.com)

## Forthcoming Meetings

### TensiNet Meetings

Espace Vinci, 25 rue des Jeuneurs, 75002 Paris | 23/09/2014  
10.00 - 16.00 CEN/TC250 WG5 core group meeting

VUB, Building D, Pleinlaan 2, 1050 Brussels, Belgium | 30/09/2014

13:30 - 14:00 Annual General TensiNet meeting - welcome

14:00 - 15:00 Annual General TensiNet meeting - Presentation and summary of the activities  
WGs of both TensiNet and the COST action TU1303 - Novel structural skins

15:00 - 16:00 Partner meeting

### COST Action TU1303 Meetings

TensiNet members can also attend the COST Action TU1303 meetings

VUB, Brussels, Belgium | 29-30/09/2014

29/09 morning plenary session, afternoon parallel Working Group sessions

30/09 morning parallel Working Group sessions, afternoon joined COST TU1303  
+ TensiNet meeting

Additional information can be found at <http://www.novelstructuralskins.eu/events/meetings/>





## Bamberg, Germany

# Lords Garden of Religions



*The National Garden Show 2012 in Bamberg allows for the first time, even if only temporarily, to build a place of worship for three religions. During the State Garden Show 2012, the house of prayer of religions, invited Christians, Jews and Muslims "to touch the paradise".*

The project had a lifetime of about six months, from 26 April 2012 to 7 October 2012. The diameter of the base plate was about 10m, the usable floor area was 60m<sup>2</sup> and the total height of the structure was about 6,10m. A dome of three, in the same direction curved, printed

surfaces embodies the three monotheistic religions that revolve around a common center. The supporting structure of the dome is divided into a main structure and three shell structures, which supports on the base plate, and the high point of the main structure

## Patrasso Port, Greece

# PASSENGERS TERMINAL cover

The structure covers a surface of 68m x 34m. The bearing frame consists of 4 calendered hot dipped galvanised arches, placed in a longitudinal way, having a width of 34m supported by 2 hot dipped galvanised steel pillars. The height is 6,70m, reaching a height of 3,70m at the perimeter (Fig. 1).

Each arch is braced by means of cables anchored to the top of the pillars and the membrane is stretched on the perimeter on top of 3,70m high stands.

The structure has been calculated according to EUROCODE 1 standards. Accidental loads taken into consideration were the following: snow:  $q_s = 60 \text{ kg/m}^2$ ; wind:  $q_w = 80 \text{ kg/m}^2$

Due to the shape and the involved loads, the covering membrane was manufactured using a

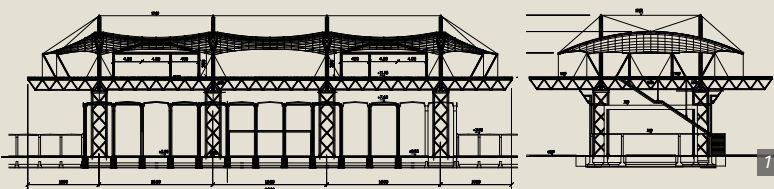
Précontraint 1002 Fluotop T- with a Polyester reinforcement 2x1100dtex – surface treatment 100% PVDF, with tensile strength of 420/400daN/5cm; tearing strength of 55/50daN and weight of 1050gr/m<sup>2</sup>.

The shape of the single layer membrane has a double negative curvature, which is stabilized by pre-stressing (Fig. 2).

Antonella Fedeli  
[texarch@plastecomilano.com](mailto:texarch@plastecomilano.com)  
[www.plastecomilano.com](http://www.plastecomilano.com)  
[www.pmtexarch.com](http://www.pmtexarch.com)

Figure 1. Front view - side view

Figure 2. Passengers terminal cover



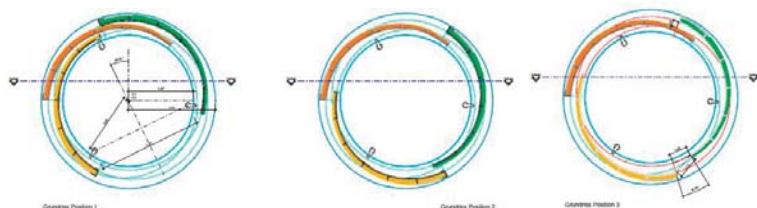
## PM ENGINEERING



Name of the project:	Passengers Terminal cover
Location address:	Patrasso Port, Greece
Client (investor):	Mekaterattiki Diodos SA
Function of building:	Passengers Terminal cover
Year of construction:	2004
Architects:	PM Engineering SRL
Consulting engineer for the membrane:	Eng. Dario Ravasi, Varese Italy
Main contractor:	Arka Synthesis LTD
Supplier of the membrane material:	Ferrari SA
Manufacture and installation:	PM Engineering SRL - Plasteco Milano - Arka Synthesis LTD
Material:	PRECONTRAIN 1002 FLUOTOP T
Covered surface (roofed area):	2312m <sup>2</sup>

(Fig. 1). The main structure consists of three curved, point-symmetrical-ly arranged steel tubes which meet at the highest point on a circular ring. The three bowls are biaxial curved in the same direction, geometrically identical lattice structures and also arranged point-symmetrically around the center. Two of the dishes are executed mobile and thus provide a setting for the entrance to the place of prayer (Fig. 2). To stiffen the shells and as bearing system for the membrane lattice

structures were provided with a network of bent steel tubes with very small diameters. This supporting structure is followed by the clamping of a printed translucent tissue consisting of extremely high tensile strength polyester fibers and a PVC coating to protect for UV radiation and other environmental influences. Due to the translucency of the fabric, the printing can also be performed inside the structure while also ensuring adequate illumination without additional light sources (Fig. 3).



Name of the project:	Lords Garden of Religions
Location address:	National Garden Show 2012, Bamberg
Client (investor):	Erzbistum Bamberg
Function of building:	Temporary pavilion
Type of application of the membrane:	Roof and facade
Year of construction:	2012
Architects:	Michael Kiefer (K.TA)
Concept design and print layout:	Bernhard Kümmelmann
Structural engineers:	Tobias Lüdeke & Manfred Schieber (K.TA)
Engineer for the membrane:	Tobias Lüdeke (K.TA)
Main contractor:	Prebeck Bauunternehmung GmbH
Contractor for the membrane:	Koch Membrane GmbH
Supplier of the membrane material:	Mehler Technologies GmbH
Installation of membrane:	Membran Service Wilfing
Material:	Mehler Valmex Cristal FR
Covered surface:	160m <sup>2</sup>

Figure 1. Axonometric of the dome structure  
Figure 2. 3 different positions of the shell structures  
Figure 3. Outside and inside views of the printed membrane







 Kathrin Kaltenbrunner  
 info@k-ta.de  
 www.k-ta.de

## NOVEL PRODUCTS

## Tensile Gazebo, Sangli, India

# TENSILE ARCHITECTURE for residential application

The concept of the project was realized with the idea of promoting the use of tensile architecture. Presently the tensile architecture projects in India are mainly confined to metropolis. However, the presence of tensile structures in the interior parts is relatively low or nonexistent. The gazebo on the terrace of a private residence is a tensile membrane canopy supported by two vertical poles & two inclined needle masts supported by stays. This greatly adds to the beauty of the entire ambience. Additional tilting flaps operated by gas springs are provided on three sides of the tensile canopy to further protect the sitting area from sun and rain. This is optional and the flaps can be tilted as and when required. The roof also got heavily exposed and sustained to the hailstorm recently experienced by several districts of the state of Maharashtra. The sole objective of this project is to depict how tensile architecture can enhance the beauty of outdoor spaces, retaining its practical utility with its unique feature of relocatability. This was further developed specifically keeping in mind the boom in the construction industry in the urban and semi urban parts of India. The project is located at Sangli a small city located in the southwestern part of the central Indian state of Maharashtra around 300km from Mumbai, the state capital.

 Suhas Kunte  
 productsnovel@gmail.com  
 www.novelproducts.co.in  
 www.pmtexarch.com



Name of the project:	Roof top Tensile Gazebo
Location Address:	'CHINTAMANI'
Client: (Investor):	145 South Shivajinagar Near Ram Mandir Sangli 416416 (Maharashtra) India.
Function of the building:	Mr. Kunte
Type of Membrane:	Outdoor leisure
Year of Construction:	Pvc coated 502 Precontraint- Ferrari
Architects:	2013
Consulting engineer for the membrane:	Novel design studio
Main Contractor:	Novel products
Supplier of membrane material:	MechTech
Covered Area : (Roofed Area)	Serge Ferrari
	28m <sup>2</sup>



## München, Germany

ROOF COVER MADE OF THREE-LAYERED ETFE FILM CUSHIONS WITH INTEGRATED FLEXIBLE PHOTOVOLTAIC CELLS



# Innovative membrane architecture for carport

## Introduction

It's not always easy being green, that's what we discovered when attempting to build the AWM (Abfallwirtschaftsbetrieb München) carport roof in Munich. The project, which involved an ETFE film roof with photovoltaic cells, came under close and critical scrutiny of city officials, engineering specialists and the general public. It was for the team a long and hard way, because every step was controlled. The city and public had good reason for its skepticism. The new roof was meant to replace one that had partially collapsed in 2006 after a heavy snowfall - an event that gave the city and architect a lot of bad publicity.

The same architect, Munich-based Ackermann and Partner, was hired for the re-construction.

## Process

In the summer months in 2011, Taiyo Europe GmbH erected the new roof structure for the carport used for under-cover parking of the trucks belonging to Munich's waste disposal companies. This structure comprises a steel construction with a roof cover made of three-layered ETFE film cushions (3M Dyneon ETFE 6235Z) with integrated flexible photovoltaic cells (Fig. 1). This innovative project, located near to the famous Olympic Park here in Munich, is also used for all-year electricity generation at the main headquarters of the waste disposal companies in Munich (AWM). The new carport roof was planned by the architects, in close cooperation with the city's Building Department and AWM. AWM short-listed two versions from the series of possible solutions presented. The roof variant with integrated photovoltaic system favoured by AWM was then approved by the Municipal Committee and thus resolved. For AWM, the reconstruction work presented the opportunity of designing the large roof area as an innovative photovoltaic structure. The new roof concept thus makes a significant contribution to sustainability, particularly to climate and resource protection, which AWM has declared as one of its major maxims alongside efficiency. We are very glad and proud, that we completed this new technology project in October 2011. Since then we follow up this project and since today we are very sufficient with the result.

## Description of the concept

One basic pre-condition for the new roofing was the use of existing points of support for the hinged columns made of tubular steel with integrated roof drainage. The column grid is 10mx12m in size. The primary load-bearing structure comprises multi-bay frames comprising columns and 3-corded tie bars which are fanned out at

the edges using tensioned braces. The trussing meant that the curved tubes could be kept slim. The total steel weight is 480T, or 48 kg/m<sup>2</sup> covered area. Unlike the earlier design, the primary load-bearing structure has been designed to be stable irrespective of the roof covering (Fig. 2 - 4). The steel structure is coated with the classic Deutsche Bundesbahn colour DB 703 high-gloss paint.

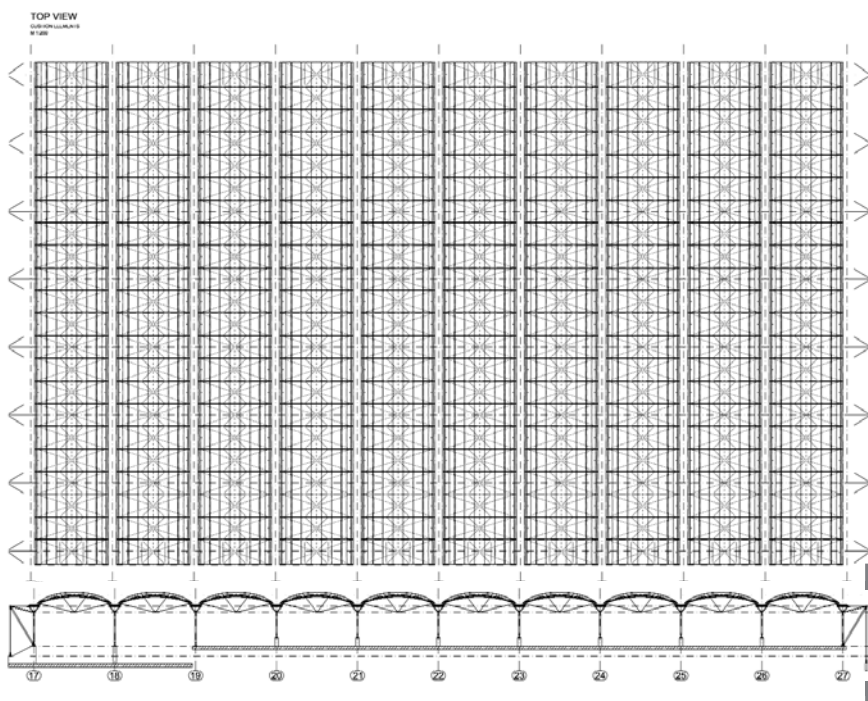
The roof area is made from 220 air-supported cushions. The 220 air cushions covering the roof elements are made of ETFE film. This material is very translucent and resistant to the influences of the weather. Each cushion is made of three layers of ETFE film. As is customary in membrane constructions, the layers are termed upper layer UL, middle layer ML and inner layer IL (Fig. 5).

The lower film layer is printed to reduce the light transmitted through the film cushions onto the carport deck. There are 12 photovoltaic modules fixed to the middle layer of each cushion by means of mechanical connectors, some of which can be moved, so that the modules are not subjected to any bending, tensile or shearing forces, even not in the event of heavy snow loads. As with bridge supports, for example, one of the PV module attachments is always without a longitudinal hole, in other words it is in a permanently fixed position, preventing the PV module from "floating freely". The middle layer is mechanically pre-stressed to prevent creasing and is without load in the operating state, since the large ventilation openings in it lead to the same inner pressure above and below the middle layer. To allow any faulty modules to be able to be replaced easily even in the long term, the upper film layer was fixed separately from the other two heat-sealed film layers in the double-welt clamping profile (Fig. 6). This layer can be opened separately and basically works like a service cover.

The load cases of the pre-tensioned ETFE films, intrinsic weight, snow, wind and change in temperature were considered in the calculation of the roof structure. Whereas the static calculation of the primary load-bearing structure was carried out using a standard calculation program for space bar frames, the calculation software using the force-density method, which has been especially developed for architecture membranes, was

used for the final design, static calculation and cutting pattern layout specification of the ETFE film. Pneumatic systems become tensioned, pre-stressed structures due to the air overpressure at the inside. The pre-stress in the upper and lower membrane is the result of the difference in pressure between the inside of the cushions and atmospheric pressure. It also depends on the radius of the





**TABEL 1 - Technical data**

**Dimensions:**

Length x Width	120,00m x 70,00m
Column grid	10,00m x 12,00m
Eaves height	+8,45m
Ridge height	+10,03m
Covered area	8.400m <sup>2</sup>

**Steel structure S355J2H/ E355+AR/St.52.0 S**

Total coating 280μ: (base pre-treatment, primer coat, intermediate coat in the factory and finishing coat on site) with Icosit EG Phosphat Rapid and Icosit Eg 5 and 2K-PUR, DB 703 high-gloss paint

**ETFE film cushions 10 x 22 cushions, 220 in total**

Dimensions 3,33mx10,40m

Thickness of upper and lower layer: 250μ

Thickness of middle layer: 100μ

Edge clamping profiles made of anodised aluminium

**Solar system 12 photovoltaic modules per cushion  
2.640 modules in total**

Power: 145,73kWp

Specific power yield: 889 kWh/kWp

Average power yield: 129 kWh/a

corresponding membrane layer. The overpressure in the cushion is maintained using blowers. The membrane layers are always tensioned under load and are thus kept stable. Cushions are usually designed with two or three layers, depending on the structural-physical requirements. The design of the air supply to the film cushions through blower units primarily depends on the magnitude of the defined inner pressure, the number of cushions and the size of the total area. An air dryer is included upstream of the blower. The supply air is dried to prevent condensation forming in the film cushions.

The air supply is connected to the lower cushion chamber. Air is exchanged between the upper and lower cushion chambers via overflow openings in the middle film layer (two rows of 12 circular holes with a diameter of 90mm at the edge of the middle layer of the cushion and one row of 12 holes at the peak of the middle layer). The air escapes via the air outlet. The flushing rate of the cushion volume (air exchange of the cushion volume was estimated at 3.000m<sup>3</sup>/24h at planning) was specified by the building engineer to 4.500m<sup>3</sup>/24h, in other words 1,5 times per day. The prescribed flushing rate is set using the cross-section area of the air outlet. In the nominal case, the support air pressure inside the cushion is 300 Pascal compared with the atmosphere. In the event of snowfall, this pressure can be increased to 600 Pascal. If the snow load exceeds 0.6 kN/m<sup>2</sup>, the cushion is compressed in a controlled way. In this case, the upper and lower film layers bear the load together. The geometric form of the film cushions chosen means that no water pockets will occur even if the blower fails during a period of rainfall. Pockets of snow can form towards the lower edge in the event of drifting snow. However, the local additional loads do not endanger the structural safety and do not lead to any significant deformation.

The stability of the cushion roof structure is not dependent on support air supply. Nevertheless, it was decided to make this supply particularly reliable (Fig. 7). Three blower units supply one third of the roof area each. Each station has two redundantly wired blower motors which alternate on a weekly basis and automatically replace each other if one of the blowers should fail. The air supply is connected to an emergency power supply and a remote warning system. Each cushion assembly with corresponding blower is integrated in a separate ring air pipe. All three ring air systems are separated from each another by valves which enable the area affected by blower station failure to be supplied by a neighbouring station. In addition, an air pipe system with high density class and non-return valves was chosen for the blower stations, making the whole system extremely airtight.

**Assembly procedure**

The static system chosen by the structural planner required assembly to be carried out in several stages. Following erection of the statically stable primary load-bearing structure, the film cushions could be fitted. The film cushions were clamped in all-round aluminium profiles which were then screwed to the sub-structure. The photovoltaic thin-layer modules fastened mechanically to the middle film layer 100μ thick were fixed in place on site on a special pre-assembly table before installation of the cushions. So-called welts were heat-sealed at the edge for the linear edge attachment of the film layers. These welts were clamped into the attachment profiles.



Figure 1. Roof cover made of three-layered ETFE film cushions

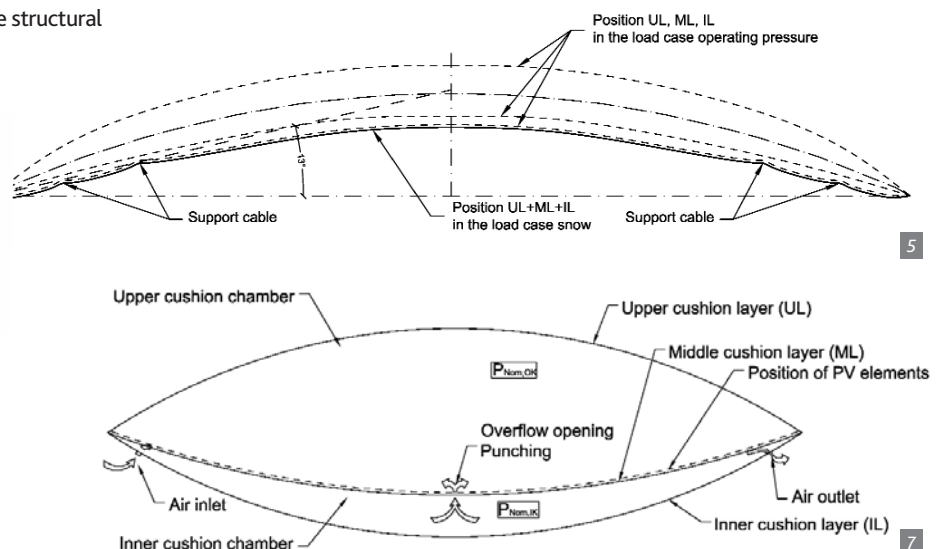
Figure 2. Top view

Figure 3. Longitudinal cross section

Figure 4. Steel bearing structure – 3D visualisation

Figure 5. Cushion design

Figure 7. Diagram showing the air supply in the cushions





## Properties of ETFE films

The cushion membranes are made of ETFE film (Ethylene TetraFluoro-Ethylene) – a fluorine-based plastic with outstanding physical properties. The load-bearing films were dimensioned and selected with a thickness of 250µ due to the loads to be expected. The main reasons why the client and architect decided in favour of the version with ETFE cushion roof were as follows:

- > High transparency from UV to IR range and a translucency of 90%.
- > Flame-resistant and without burning droplets, construction material class B1, additive-free
- > Very good separating properties or self-cleaning on the basis of the non-stick surface
- > Long service life of at least 30 years

In addition to the standard acceptance test certificates for the material designated to be used, a comprehensive range of tests were carried out on typical details to meet the requirements set in this individual case by the Supreme Building Authorities. There is no generally valid building approval available for Germany for the membrane material ETFE film. For this reason, a new application must be made for every project. In this individual case, approval was granted 4 months after the complete technical documentation had been submitted. The physical properties of ETFE films are comparatively complex compared to other materials such as steel or concrete. The load-bearing behaviour is non-linear and non-elastic, and the material is anisotropic. The stress-deformation behaviour of the films differs in machine and cross direction, and can vary from one production batch to the next. This means the usual procedure is to determine the specific material properties by means of tests before specifying the cutting layout. In the biaxial test, the load-bearing and deformation behaviour and the compensation values for the pre-stress are determined on the basis of the load to be expected. In the case of the carport project, a mean compensation value of 5% was determined for the cross direction. The machine direction was not compensated.

The ETFE films are manufactured using the slit die extrusion method. The rolls of film used are 1,55m wide and 250µ thick in the case of the upper and inner layer, and 100µ in the case of the middle layer. The density of ETFE is approx. 1,75g/cm³. Due to the limited film width, individual lengths of film are cut and then heat-sealed together to form a film cushion layer (part-surface connection). At the edge of the cushion the middle layer and the inner cushion layer were heat-sealed to form so-called edge welt pockets using the same method. The upper film layer was also given an edge welt pocket. All three layers or the two edge welts were then fixed in the double-welt clamping profile (Fig. 6).

ETFE film sealing seams are homogeneous i.e. the sealing seam is made of the same thermoplastic (repeatedly meltable) material ETFE as the part-surfaces it connects. The load transmission thus takes place from film part-surface to film part-surface without an intermediate layer as sealing aid. Quality assurance for the construction products and their production is carried out from film production through to installation through the following measures:

- > Acceptance test certificates from the film manufacturer according to DIN 10204-3.1
- > Incoming goods checks at the manufacturing company
- > Internal quality control accompanying production by the manufacturing company
- > External quality control of production by the membrane expert
- > Compliance certificate from the inspection, monitoring and certification office

## Description of pneumatically supported film cushions

Film cushions become load-transferring, pre-stressed membrane structures due to overpressure at the inside. During normal operation, the films are tensioned under load and stable even under outer loads such as wind and snow. Depending on the structural-physical requirements, air-supported film cushions are designed as two- or three-layer cushions.

TABLE 2 - Properties of ETFE films

Properties	ETFE NOWOFLON ET 6235, 250µ, clear
Printing on the lower layer	Negative dot, silver standard, décor no. 920201, Reisewitz printing
Resistance to high temperatures	Permanently from max. +150°C to a temperature range of up to 230°C for short periods (6-8h)
Melting point	approx. 270°C
Tear-growth resistance N/mm	470
Mass per unit area (g/m²)	350
Fire behaviour DIN 4102	B1, flame-resistant
Transparency	90%
Anti-soiling properties	excellent
Fungal development	Not possible
Service life	30 years

ETFE fluoropolymer film is mainly used as the cushion material. In this project, a solution with three-layer film cushions was chosen for the roofing, which is open at the side, whereby in this case the purpose of the middle layer was not to improve heat insulation but rather to serve as a carrier for the flexible photovoltaic modules integrated in the cushion. The middle layer can contribute to load transfer in the case of a snow load, but it is not necessary here since the upper film layer and the inner film layer are sufficiently dimensioned. The film cushions (secondary system) are clamped between the steel arch supports (primary system). The primary system is stable without the secondary system. The secondary system is not required for stabilisation, deformation limitation or load transfer. The film cushions are connected to the primary system all the way round by means of aluminium clamping profiles. The film cushions are interlocked into the clamping profiles and connected by pressure transfer through contact pressure between the welt and welt profile as well as between the welt profile and the basic profile. The interlocking connection between basic profile and steel structure is made using a screw connection. The air supply to the film cushions was designed and dimensioned by the applicant in cooperation with the blower manufacturer.

The advantages of ETFE air cushions as space-enclosing components lie in their transparency and low weight, which also affects the efficient and aesthetic quality of the primary structure, for example. The successful result of this unique project finally depends on the cooperation of all who are involved in that project. For this reason Taiyo likes to thank his subcontractors for the excellent team work and the power of endurance during the hard times. Without them it would have been never such a good result since now. This project is a milestone in the development for further applications of photovoltaic in combination with architectural membranes for roof and facade structures. Taiyo Europe GmbH and the Taiyo Kogyo Group will continue further developments to combine this technology with other membrane materials offering owners the possibility of combining the superior esthetic properties of architectural membrane structures and unique energy earnings.



Dipl.-Ing. (FH) Hubert Reiter  
h.reiter@taiyo-europe.com  
www.taiyo-europe.com

Figure 6. Diagram of the clamping profile

Location address:	Munich, Germany
Client:	City of Munich-Building Division and Abfallwirtschaftsbetrieb® AWM München
Function of the building:	Carport Roof
Year of construction:	2011
Architects:	Ackermann und Partner Architekten BDA, Munich
Structural planner:	Ackermann Ingenieure, Prof. Dipl.-Ing. Christoph Ackermann
Steel structure production and assembly:	Steel Concept, Chemnitz
Contractor for the complete structure:	Taiyo Europe GmbH, Sauerlach, in cooperation with Konstrukt AG, Rosenheim and the assembly service LB, Hallbergmoos
Material (ETFE foil):	ETFE NOWOFLON ET 6235, 250µ, clear
Raw material supplier:	3M Dyneon ETFE 6235Z
Supplier (ETFE foil):	Nowofol Kunststoffprodukte GmbH & Co. KG
Covered surface area:	8.000m²



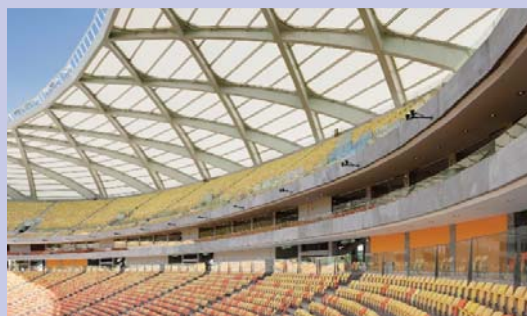
# FAÇADE CONSTRUCTION FOR THE WORLD CUP STADIUM AMAZING TEXTILE ROOF Arena da Amazônia

CENO-TEC

DYNEON

Manaus, Brasil  
*Jungle as inspiration*

The final stage of the FIFA World Cup™ has never before been held as close to the equator as it was in 2014. The latitude of the venue in Manaus is a mere 3 degrees south. Making use of lightweight textile architecture, the newly constructed Arena da Amazônia provides the best possible protection from the sun and optimum ventilation. The 240m x 200m arena is located directly on the central corridor connecting the airport with the city centre. Integrated into a sport park, which also contains a Sambadrome, a track-and-field-sport complex, multi-purpose halls and a swimming centre, the arena is ideally suited to hold professional and local sports meetings and events.



Ceno Tec took only four months to erect the textile roof-façade construction covering a total area of 32.000m<sup>2</sup>. The spectacular supporting structure for the 35m high textile roof took the jungle for its inspiration, while also evoking the veins on leaves. Huge cantilever beams made of steel hollow-box girders, which mutually brace each other, serve simultaneously as large roof drains, to absorb the enormous deluge of water generated by the tropical rainfall. In view of the hot and moist climate on the Amazon, the roof merges into a façade, which provided shade for the spectator passages and vertical developments. The natural ventilation resulting from the interaction with the façade openings should provide a pleasant micro-climate for roughly 45.000 spectators.

The membranes, manufactured and coated by **Verseidag Indutex GmbH**, are made from glass cloth with a tensile strength of up to 10kN/5cm. Coating the membranes with the high tech plastics **3M Dyneon PTFE** achieves an elongation at break of up to 600% and protects the cloth

against UV rays, humidity and other environmental effects. This high-performance material has been used in textile architecture for several decades and has proven to be extremely durable. One key advantage of the coating, particularly relevant in a tropical climate, is its almost universal resistance to environmental effects and to chemicals of all types. PTFE belongs to the fluoropolymer family and needs no plasticisers or stabilisers, which can evaporate over time leading to brittleness of the coating. This means that, even after decades of use in a tropical environment, there are no cracks in which bacteria and fungi can lodge. At the same time, the surface is so smooth that it virtually cleans itself during a rainstorm.

The overall roof-façade supporting structure consists of 252 membrane elements. The translucent membranes protect the spectators against direct solar radiation, while also pleasantly spreading out the light. Because of the complex nature of the details involved, approximately 52.000m<sup>2</sup> of material were used. A huge challenge faced by this project was

the low dimensional tolerances for the 252 membrane fields. These had to be prefabricated with extremely high dimensional accuracy at the plant, because the construction site itself was no longer able to accommodate any major adjustment operations. On top of all this, the huge hauling distances into the region posed an enormous challenge in terms of logistics, while the tropical rainy season greatly hampered the assembly process.

 Anne Bosse  
 anne.bosse@ceno-tec.de  
 www.ceno-tec.de  
  
 Helmut Frisch  
 Michael Dadalas  
 h.frisch@mmm.com  
 www.dyneon.eu

Figures Interior and exterior views

© Michael Bredt, Germany /

Ceno Membrane Technology GmbH

Name of the project:	Arena da Amazonia
Client:	Companhia de Desenvolvimento do Estado do Amazonas, Manaus
Location address:	Manaus, Brasil
Year of construction:	2014
General contractor:	Andrade Gutierrez, Brazil
Architect:	gmp - Architekten Gerkan, Marg & Partner, Germany
Engineering:	Schlaich, Bergermann & Partner, Germany
Steel structure:	Martifer Steel Construction, Portugal
Membrane structure:	Ceno Membrane Technology GmbH, Germany
Membrane:	Verseidag premium-quality glass-fibre fabric
Coating membrane:	3M Dyneon PTFE Dispersion coating
Covered surface (roof and façade):	52.000m <sup>2</sup>

The Arena da Amazônia is one of the first stadiums to have been certified under the criteria of the US Green Building Council's LEED programme (Leadership in Energy and Environmental Design). This holistic ecological approach takes into account the entire life cycle of buildings, including the structural materials. 3M Dyneon PTFE fits well into this philosophy as the coating is fully recyclable, therefore making a contribution to sustainability.

# FIFA WORLD CUP, BRAZIL

## Choosing FLEXIBLE COMPOSITE MATERIALS for each purpose

*Zooming in on Serge Ferrari's architecturally inspirational flexible composite membranes, ensuring sports facility aesthetics and guaranteeing spectator visual and thermal comfort for the Arena Pantanal (Cuiabá), Arena das Dunas (Natal) and Arena Corinthians (São Paulo).*



Figure 1. View of the microclimatic façades of the Pantanal stadium

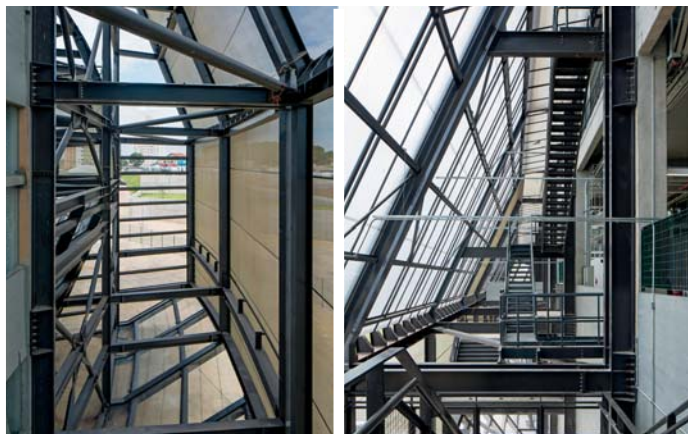


Figure 2. Detail of the envelope with metal louvers and a microclimatic façade made of Soltis FT 381 composite material © GCP Arquitetos

### ARENA PANTANAL CUIABÁ

#### Introduction

Cuiabá, with its 570.000 inhabitants, is situated in the Brazilian State of Mato Grosso and is known as the "capital of Southern Amazonia". It is considered the hottest city in Brazil with a climate that is humid in the summer and dry in the winter. Football fans therefore anticipated a stadium that takes into account the climatic criterion. Right from design stage, the project evolved around three main guidelines established by Serge Coelho, the GCP Arquitetos associate architect: "Sustainable development to ensure a stadium with the lightest possible environmental footprint, secondly, the "legacy" aspect with its stands composed of four independent modular units, of which two could be dismantled for re-use in an identical configuration or for shows, exhibitions, etc., and thirdly, urban redevelopment of an initially disadvantaged neighbourhood and conversion into a leisure and cultural area". Nicknamed "Verdão", as much for the environmental commitments embodied by it as for its cactus green shell by Serge Ferrari, this stadium projects a strong architectural identity and will play host to both Mixto and Operario football clubs. The stadium has a capacity of 39.900 spectators.

A microclimatic facade made of Soltis FT 381 composite material. This highly graphic, cactus green façade integrates totally into its environment. Installed on a steel structure, the microclimatic façade provides visual and thermal protection for spectators. The North stands are exposed all day, the West stand late in the afternoon, while offering pleasant outward visibility and ensuring the structure's natural ventilation. To counter the stifling heat that afflicts this region, the microclimatic façade allows water from basins located right next to the stands to pass through it and evaporate. The system's ingenuity contributed to spectator refreshment and comfort.

Total material area:	15.000m <sup>2</sup>
Maximum size of the 28 panels:	40,6mx17,2m

#### Portals framing the terraces made of Précontraint 902 S2 composite material

Specified requirements for these shells to be illuminated at night by LEDs were of three orders: to offer an aesthetic aspect through membrane dimensional stability and a lightweight aspect to the huge steel structures and to guarantee ease and speed of installation.

Total material area:	11.400m <sup>2</sup>
Maximum size of the 72 panels:	47,90x8,2m

*Composite material recyclability through the Texyloop® process was one of the determining factors since LEED (Leadership in Energy and Environmental Design) certification of this stadium is now underway.*

✍ Françoise Fournier  
✉ [francoise.fournier@sergeferrari.com](mailto:francoise.fournier@sergeferrari.com)  
🌐 [www.sergeferrari.com](http://www.sergeferrari.com)  
🌐 [www.texyloop.com](http://www.texyloop.com)  
✍ Christine Marchand, Ad'hoc Presse  
✉ [contact.adhoc@free.fr](mailto:contact.adhoc@free.fr)



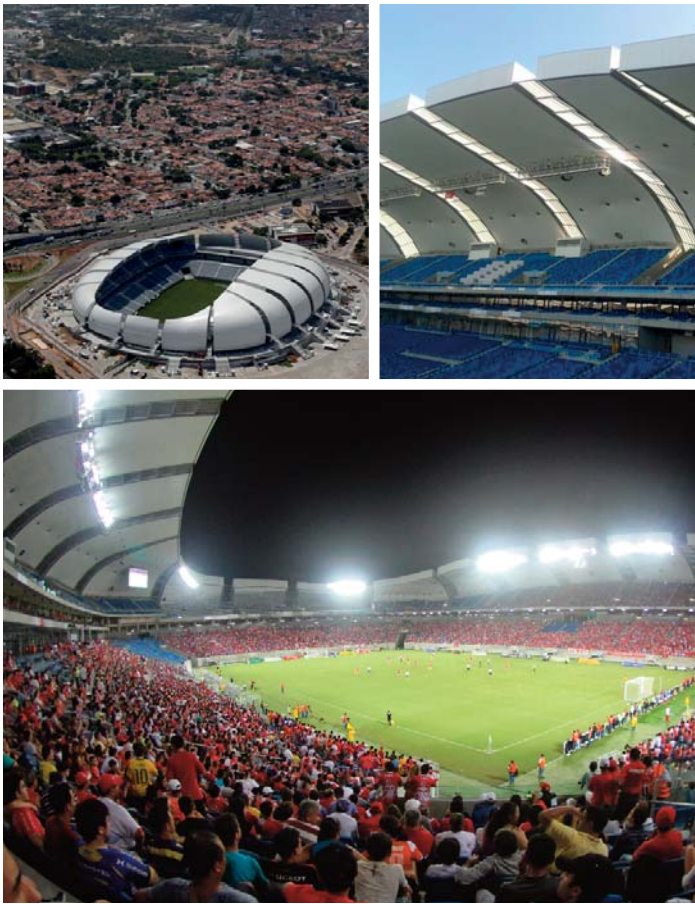


Figure 4. Interior view of the shell made up of petal-shaped modules © Canindé Soares

## ARENA DAS DUNAS NATAL

### Introduction

Built in 1972, this stadium was demolished and rebuilt within the scope of a global urban redevelopment project. It was officially inaugurated in January 2014. The spectacular sand dunes in the Rio Grande Do Norte region - one of Brazil's 27 states - inspired the design and construction of this new undulating sports infrastructure. Its architectural shell made up of 20 petal-shaped modules allows perfect thermal and acoustic insulation, while offering better ventilation and facilitating the natural light contribution. The stadium has a capacity of 42.600 spectators. Due to the resizable structure 10.600 seats will be removed after the World Cup. Architects Ben Vickery and François Clément have banked on the installation versatility through implementation of a custom, flexible, lightweight structure. More than a stadium hosting an international competition, the Arena das Dunas is a real endowment for the Rio Grande Do Norte region. The multi-functional nature of the stadium ensures its hosting of many socio-cultural, sports, leisure or business events.

Tensioned ceilings made of Précontraint 1002 T2 composite material installed under 20 asymmetrical petals forming the stadium roof.

A veritable engineering challenge since none of the 20 modules is of the same size or has the same curvature. In addition to its thermal and acoustic insulation performance, the visual comfort offered to the spectators, the design "in movement", hugging the steelwork outlines, the structural strength and dimensional stability of the Serge Ferrari composite membrane makes all the difference here!

Total material area:	20.000m <sup>2</sup>
Panel sizes:	400m <sup>2</sup> to 1.500m <sup>2</sup>

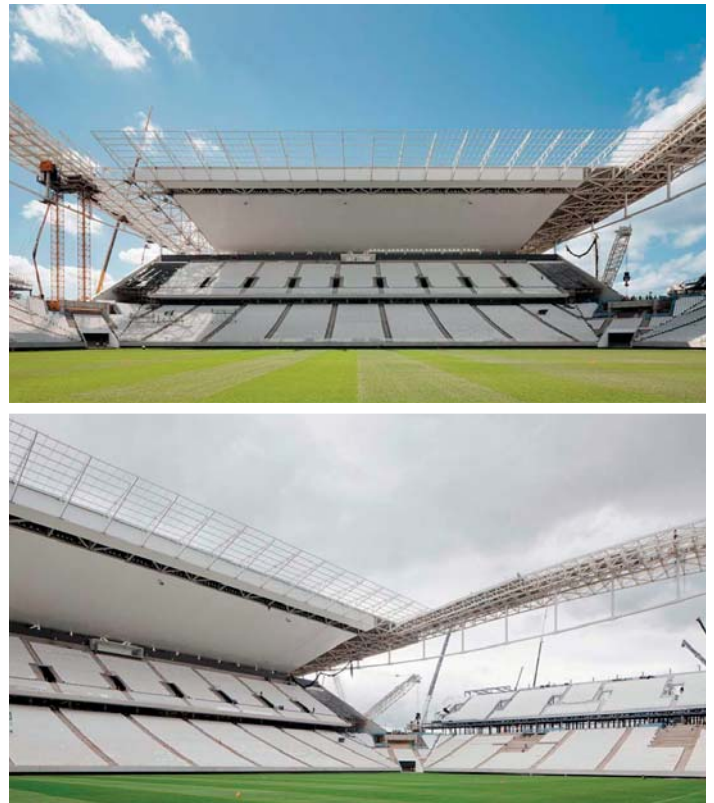


Figure 5. Membrane panels used as video screen © Marcus Bredt

## ARENA CORINTHIANS SÃO PAULO

### Introduction

Largest football club in the State of São Paulo in terms of the number of supporters - 30 million - and second largest on a national level (after Regatas do Flamengo in Rio de Janeiro), the Corinthians club, which celebrated its centenary in 2010, didn't have its own sports facility and played its matches at the Pacaembu municipal stadium. Located in the working class neighbourhood of Itaquera, this newly built emblem is a forerunner of sporting facilities of the future: it incorporates an auditorium, a museum, multiple boxes for club sponsors, restaurants and... the largest video screen in the world! The Arena is an embodiment of the region's economic dynamics which, in the long term, should ensure development of transport infrastructures, educational facilities and setting up of private companies. The stadium has a capacity of 61.600 spectators. Due to the modular system on long term, the stadium will offer 48.000 seats. Together with Coutinho Diegues Cordeiro Arquitetos, Populous Architects (preliminary design) and Grupo Stadia (detailed design) Werner Sobek Engineering & Design was involved with the design of the roof construction with a span of 200m x 245m and covered with an opaque membrane.

Tensioned ceilings made of Précontraint 1002 S2 opaque composite material

A special production of 30.000m<sup>2</sup> of material for screening event images was fabricated. The membrane was installed beneath the four stands sheltering the spectator terraces. The panels - whose flatness and dimensional stability are essential since they are used as video screens, conceal the structural steelwork and effectively black out all light sources. Aesthetic, lightweight, durable and 100% recyclable through the Taxyloop® process, these composite membranes also ensure optimum visual, thermal and acoustic comfort for spectators.

Total material area:	28.000m <sup>2</sup>
Maximum panel size:	7,5mx60m

## Riyadh, Saudi Arabia King Fahad National Library

SEFAR

### Introduction

The way in which tried and tested building materials and new elements clearly complement one another symbiotically can be seen at the King Fahad National Library in Riyadh, Saudi Arabia. Here in the national capital, already rich in contemporary architecture, the application of modern materials has turned a building dating back to the 1970s into an urban landmark which skillfully blends into the Arabic city skyline.

Tradition and progress in equal measure characterize modern life in Saudi Arabia. Architects from Gerber International Berlin realized the existing building complex was worth preserving and so retained its monumental precision whilst providing the exhibits with a lot more space and light. A new square building now encases the library in a seemingly floating, but at the same time geometrical form. Just as the graceful building appears to be embroidered into the spacious Olaya City Park, so after nearly three years of construction it now appears open and transparent. In searching for the most suitable fabric for the ceiling solution, a final decision was made to use Sefar. By employing SEFAR® Architecture IL-80-OP Fabric together with a Sefar Lightceiling System specially developed for this project, the entire area is now illuminated by a translucent, seemingly floating light ceiling.



### Reading the traces of the past

The new solution supplements the old with a cubic ring, meeting historical conservation criteria and resulting in an optically successful entity in which the existing flat roof of the original structure has been transformed into a reading room. Here in the interior – like a treasure trove – the books can be found. The main entrance hall, exhibition area, restaurant, and a book store can be found on the ground floor, arranged around the existing building. Visitors from the reading room reach the open-access section on the third floor of the new building via bridges. The library for women, separated from other functions and independently accessible, is on the first floor of the new south-west wing. An existing dome was converted to a steel-glass construction which towers above the entire inner courtyards and reading room with an integrated roof.

### Restful under the translucent light ceiling

The recommendation of project director and leading on-site architect, Thomas Lücking, was for a spatial interior effect which reflected typical urban life. Below the roof is a tensioned white membrane of Sefar fabric totaling around 16.000m<sup>2</sup> which filters powerful sunlight shining through the long, narrow skylights, providing all areas with an even

and non-blinding light source.

Acousticians involved in the project recognized an ideal noise insulator in a material chosen principally for its optical properties. The fabric forms a closed skin comparable to an eardrum; very little reverberation is directed downwards – and the echo above the membrane is absorbed by the mineral wool and perforated trapezoidal metal sheets of the insulated ceiling. Installing the membrane presented a particular challenge since working in a dust-free environment, as is customary, was simply impossible in a city such as Riyadh, surrounded by the desert. For this reason, the membrane construction had to be installed before the building was airtight and cleaned only at the very end.

### Architecture lightceiling system

The SEFAR® Architecture Lightceiling System was developed as part of the King Fahad National Library (KFNL) project in Riyadh, Saudi Arabia. The obvious task facing Sefar and ArtEngineering was to invent a system capable of supporting the 16.000m<sup>2</sup> fabric ceiling within the library building.

### Performance / area of application:

The SEFAR® Architecture Lightceiling System is ideal for covering surfaces with unit membranes up to 10m×25m.

Ideally, the geometry of the membrane boundaries should be polygonal. The system is characterized in particular by having very short assembly times for the individual membrane panels. As was seen in the case of the KFNL project, the system technology is also straightforward enough for contractors not immediately familiar with fabric or ceiling assembly to use without difficulty.

### System description and system components:

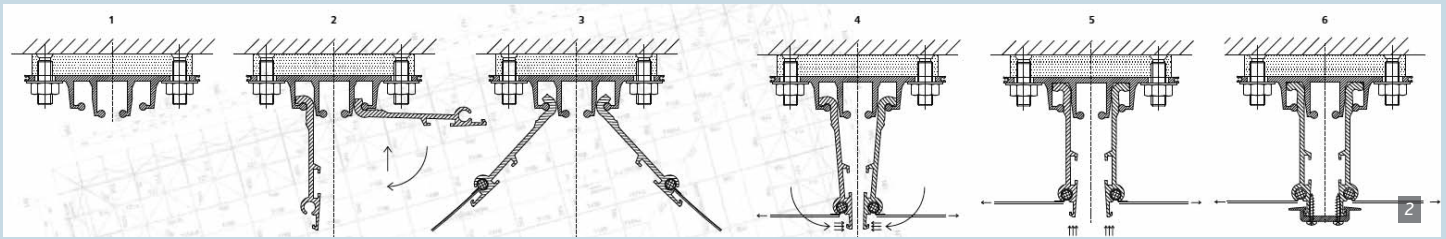
The essential parts of the system consist of light-technical fabric, attachment components and assembly tools, as well as planning and maintenance documentation. The light-technical fabric forms the visible surface and with the help of attachment components it is firmly fixed to the main structure (steel or concrete supports etc.), tensioned and crease-free. The attachment component consists of a three-part extrusion profile – the supporting rail, the tensioning rail, and covering rail.

### Basic functioning principles

Fast and safe assembly is made possible by the use of a continuous, pivoted tensioning rail which is threaded into the fabric. A special tool permits the rolled-up membrane panels to be inserted into the tensioning rail directly from the ground.







## Planning, production and assembly

**Planning:** The fabric tailor receives cutting plans and detail plans for the stitching design and for the manufacture of handling aids. The assembly company receives the layout for the attachment components as well as detailed solutions for corners, open edges, ceiling breaches, etc.

**Membrane panels:** Membrane panel manufacture is carried out by a tailor and these are sewn together from individual sections of fabric. At the factory, the fabric is cut into exact parallel widths. These preset widths, together with specially developed stitching details and a predefined sewing procedure, make it possible to align two neighboring membrane panels exactly at a later date if required. Despite the stitching having a very discreet width of only 10mm, there is still a visible outline within a membrane panel. Once the individual fabric sections have been sewn together to form a membrane panel, the edges are seamed with piping. Following a final quality control check, the membrane panel is rolled onto a cardboard tube and prepared for shipping to the construction site.

**Fixing elements:** Just like the membrane panels, the fixing elements are precisely defined during the planning phase, cut to right length, and if used for connections

predrilled or prepunched. In the KFNL project, the supporting rails were attached to the main structure by means of M10 welding studs. With the help of a template, the position of the bolts on the main structure is marked in advance and afterwards the bolts are set. Although the work took place overhead, the technology proved to be consistently robust with a uniform and visually verifiable result. As soon as the bolts are welded, the supporting rail is inserted, positioned, and then fixed using slotted holes and spacers. Guide bolts at the points where the two supporting rails meet ensure an exact alignment. In the next stage of construction, tensioning rails are mounted along the membrane panel. Here too, guide plates ensure a precise and friction-locked connection at the junction points. Special retention clamps prevent the tensioning rail from accidentally falling out of the supporting profile groove during the threading of the fabric. Once these preparations are complete, the fabric is fed into the groove of the tensioning rail and final adjustments made. As soon as the desired position is reached, both open edges are overlaid with tensioning rails, tensioning always taking place in both directions (warp and weft). In one final stage, a delicate covering rail similar to a zipper is "unrolled." The rail ensures that not only the gap between the two membrane panels is covered, but also the preload force on the two

Name of the project:	King Fahad National Library
Location address:	Riyadh, Saudi Arabia
Client (investor):	Saud Bin Ladin Group, Saudi Arabia
Function of building:	Library
Year of construction:	2013
Architects:	Gerber Architekten International GmbH, Germany
Lightceiling	
Engineering and system development:	ArtEngineering GmbH & Pollux GmbH, Germany
Tailoring:	ALI TAMIMI SONS CO
Supplier of the membrane material:	Sefar
Material:	SEFAR® Architecture IL-80-OP
Covered surface (ceiling):	16.000m²
Light-technical fabric / Fabric-technical specifications:	
Fabric material	PVDF (polyvinylidene fluoride)
Material coating	100% fluoropolymer
Fabric width (cm)	160
Weave	Plain weave 1/1
Surface weight (g/m²)	250
Highest tensile strength warp/weft (N/5cm)	1,050/1,050 according to EN ISO 13934-1
Highest tensile elongation warp/weft (%)	40/25 according to EN ISO 13934-1
Tear propagation force warp/weft (N)	35/50 according to DIN 53859-5
Water column (mm)	> 500
Fire performance	B1 according to DIN 4102; B-s1, d0 according to DIN EN 13501-1
Light-technical specifications Grade of transmission (%)	> 80 according to ASTM D1003
Degree of reflection (%)	19
Absorption (%)	1



neighboring panels is short-circuited and the bending load on the arms of the tensioning rail is minimized.

 Sarah Dupont  
 sarah.dupont@sefar.ch  
 www.sefar.com

Figure 1. Tensioned white membrane ceiling for the interior. © Christian Richters

Figure 2. Membrane panels assembly details

Figure 3. The erection of the membrane panels

Information on the façade concept see <http://www.archdaily.com/469088/king-fahad-national-library-gerber-architekten/>



# FROM MEMBRANE FORM TO RIGID SHELL

The topic of how to stiffen fabric structures respectively converting flexible curved structures into rigid shells is not a new one. As early as the 1950s and 60s, Heinz Isler amongst others, experimented with new form finding methods to freeze wet, hanging and draped textiles (Fig. 1). He developed a unique, detailed and very practical approach to generate uncommon structures. Likewise his pneumatic experiments and the resulting "Buckelschalen" show his elaborate technique of utilizing soft forms to build concrete shells. Another example is the Philips Pavilion for the Brussels Expo in 1958 which was designed by Le Corbusier and Yannis Xenakis (Fig. 2). The geometry was built up from conjoining hyperbolic paraboloids. The surface which started as sand hills divided into quadrangles by a grid of casing planks and consequently placing reinforcement meshes into the mould, were casted with concrete. The 1.5m<sup>2</sup> large and 50mm thick prefabricated panels were numbered, transported to site and re-assembled. The primary loadbearing structure was made from a set of beams that defined the borders and ridges of the structure and a combination of steel rods and a cable net structure upon which the panels were mounted. In contrary to the ephemeral icing approach of Isler, Frei Otto solved the conversion problem from flexible to rigid with his IL-Institute building in a more enduring way (Fig. 3). The flexible cable net structure initially designed to hang a fabric underneath (for the Expo Montreal 1967) was converted to carry a rigid multilayer roof construction made up of wooden slats and slate shingles that followed the initial tensile form. This method was very labour intensive and required sophisticated and skilled craftsmanship. Another technique of conversion was used at the Multihalle Mannheim ("Bundesgartenschau" 1975). The conversion and inversion of a hanging form into a compressive grid-shell structure was achieved by lifting up a wooden lattice construction to a given position, fixing the borderlines and locking the lattice joints. A PES-PVC fabric was cut, connected to the structure and welded on site (Fig. 4).

## APPLIED RESEARCH ON MATERIAL AND PROCESS TECHNOLOGY TO APPLY AND STIFFEN MEMBRANE STRUCTURES WITH SHOTCRETE.

### Institute for Membrane and Shell Technology - IMS

The comprehensive interest for membrane and shell structure was the reason that Prof. Robert Off, Director of the IMS e.V. Dessau, initiated a research project with the research objective to „develop a method to harden mechanically pre-stressed membrane structures by spraying them with concrete – fabric used as reinforcement and as dead formwork“. Our overall goal was to use mechanically pre-stressed fabric structures, on behalf of formal approach and structural behaviour and spray them with concrete. Beside the research of the material technology, an important structural question was how to activate the pretension within the membrane to optimize the load bearing behaviour of the overall composite structure.

The IMS, which is an associated Institute of the Anhalt University of Applied Sciences in Dessau, has been teaching and researching in the field of membrane structures since 1999. Among others innovative approaches with foam/hardened composite fabric structures were elaborated.

Together with a partner for the membrane fabrication tasks (Stegmaier Zelte) and a partner for concrete restoration respectively expertise for shotcrete (Lenz&Mundt), an interdisciplinary team was formed and a foresightful research was conducted. The funding came from the Federal Ministry for Economic Affairs and Energy respectively from the AiF (German Federation of Industrial Research Associations). "As an industry-driven organization, the AiF aims at initiating applied research and devel-

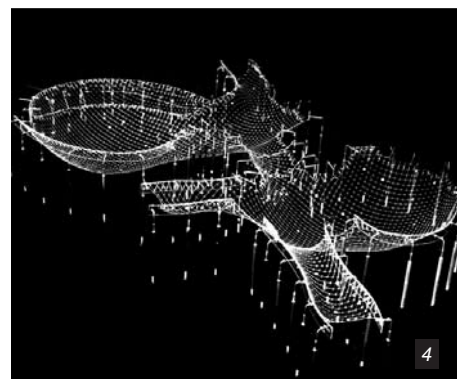


Figure 1. Ice structure by Heinz Isler

Figure 2. Philips Pavilion in Brussels by Le Corbusier © wikimedia commons / Wouter Hagens

Figure 3. Inside view of the IL-Pavilion by Frei Otto © ILEK/Universität Stuttgart

Figure 4. Hanging model for the Multihalle Mannheim

opment for small and medium-sized enterprises, as well as qualifying the new generation of academics in innovative fields and organizing the distribution of scientific knowledge. Furthermore it is intended to turn ideas into successful products, processes or services in the market."

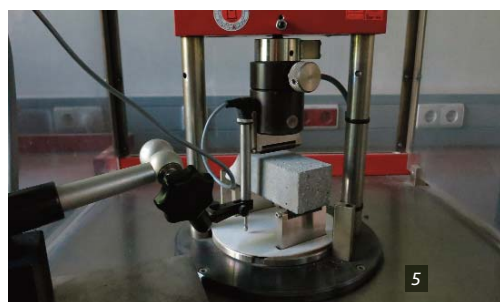


## Material testing and composite development

Starting point was the evaluation of the material properties to get an in-depth understanding of each material component. Different cements and strength classes, additives and maximum grain size categories were evaluated. With compression tests on cubical specimen, splitting tensile strength on cylindrical specimen and three-point-flexural-tension tests on prismatic specimen, we surveyed the compressive stresses and ductility of the concrete. Second step was the evaluation of the fabric material. Beside the physical parameters, the main focus was on the chemical resistances (NaOH,  $H_2SO_4$ , Paraffin, NaCl,  $MgSO_4$  and  $K_2CO_3$ ). The applicability of the different yarn materials, coating material as well as the size of the mesh openings and the weaving styles had to be assessed. Beside the technical values the properties concerning the processing and workability of the materials were of high interest.

With the same testing program as for the individual materials we surveyed the composite behaviour. In this stage of the research we took the influence of the level of pre-stress in the membrane layer (uniaxial as well as biaxial) into consideration. Special specimens were developed and the testing rigs had to be modified. With the three-point-flexural-tension testing we succeeded to record the characteristic material curve which was used to setup a model in a FEM Software (Fig. 5).

Simultaneously to the investigation of the laboratory specimen, we executed spraying trials within "real" conditions to adjust the parameters (type of spraying, pressure, water-cement-ratio, distance and angle of the gun nozzle to the membrane) of the spraying process. From these trials we retrieved numerous samples and identified a big difference in the values between the "handmade" laboratory specimen and the sprayed specimen. Due to the parameters of the spraying process and the so called "Rückprall" (the bouncing back of particles when they hit a surface) the applied concrete mixture differs from the initial mixture that is provided by the producer and was used for the lab-specimen.



## Prototyping and evaluation

With a sail setup we started the evaluation of the findings from the material testing. The elaboration of the spraying process, the construction details and the overall structural behaviour was the focus in this stage of the research. For simplification reason our first structure was a 4 point sail with cable edges (3m x 3m). 3d scans of the upper and lower side of the sail structure revealed the structure's property to move and the insufficient level of pre-stress in the membrane caused a kind of ponding, hence a very uneven thickness of the sprayed concrete layer could be noticed. In close collaboration with the Institute of Geoinformation and Surveying a very detailed deformation analysis was executed. Results and the applicability of the photogrammetric versus the 3d scanning survey during static and dynamic load tests were evaluated (Fig. 6). This first large scale attempt was very fruitful in detecting the real problems of the spraying process and helped to improve the design of the structural details.

With the realization of the final prototype we wanted to gather more detailed knowledge while getting as close as possible to a real building situation. Curvature, usability, cost, testing facilities (also for the long-term behaviour) were taken into account for the design task. The geometry of the prototype is described by an anticlastic surface between 3 high points and three low points with rigid edges and ridgelines in the surface. It is 4.5m in height and 6.2m (at the highpoints) in diameter, and consists of the following building components:

- three steel A-frames (plus foundations) from HEA beams,
- three stay cables (plus foundations) with tensioning fittings,
- three ridge cables meeting in the central point of the surface.

The steel frames were connected to the foundations with hinged supports to allow movement for mounting and pre-stressing and for measuring the cable forces. In the axis of each stay cable we implemented two units for tensioning as well as a load cell to control, define and monitor the cable forces. From the preliminary large scale tests and the material survey we could develop a catalogue of specifications and hence decided for a steel fibre reinforced shotcrete and an open mesh fabric (Fig. 7a - b).

For a future application we decided to apply the concrete in more than one step. For large scale projects a first thin layer should give the structure enough stiffness to allow craftsmen walking on the structure for the following application steps. The second layer should guarantee the end rigidity of the concrete shell. The third and last layer was intended only for the final surface appearance. A smoothing treatment by hand was executed to seal the surface and prevent water and dirt from sticking on the surface. For an optimal bonding and adhesion of the shotcrete layers each layer was sandblasted before the next spraying application. Loose grain material was removed and cracks were "opened". During the building process we executed various 3d scans to evaluate the geometry and

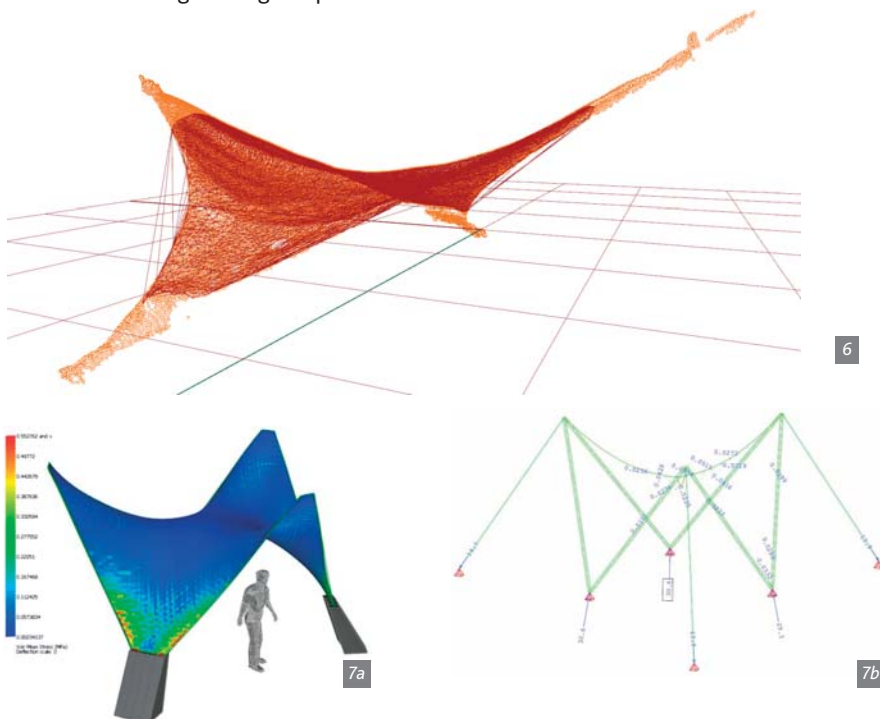


Figure 5: 3 point flexural tension testing rig with external displacement transducer

Figure 6: Evaluation of the geometry of the 4 point sail structure from a 3d scanning survey

Figure 7a - b: Digital model (Mises Stresses) and reaction forces

tested how well the digital model and realised structure matched. Specimen from the onsite spraying were taken to the lab and compared to the assumed values. Cable forces were constantly monitored and adjusted according to the specifications.

The structural behaviour was observed during mounting of the fabric structure, spraying and hardening process of the concrete (Fig. 8). The verification of the various results and the merging of all parameters was challenging but also very promising. The comparison between the digital model and the real prototype gave various surprising findings and a holistic knowledge of the structures properties and behaviour (Fig. 9 - 10).

One key issue when applying the shotcrete was to guarantee an even distribution of the sprayed concrete. The geometry of the edge beams helped to define the layer thickness at least close to the edges. The thickness in the inner surface areas had to be monitored and manually adjusted by the skilled craftsman.

By matching scans from the upper and the lower surfaces and processing them, we could evaluate the variation of the layer thickness (Fig. 11). Even though the specifications were held, a perspective for future structures could be to adapt and optimize the control of the layer thickness.

IMS e.V. (Institute for Membrane and Shell Technologies, Building and Real Estate)  
Institute at Anhalt University of Applied Sciences

✍ Henning Duerr

✉ he.duerr@ims-institute.org

✉ robert.off@ims-institute.org

🌐 www.ims-institute.org

### Conclusion - call to cooperate

Even though not all of the intended findings are fully evaluated yet, the outcome of the research project is satisfying and gives a perspective towards further research objectives.

- From large scale load tests as well as the simple material tests with specimen extracted from the shell, we expect a comprehensive knowledge of the structural behaviour of the prototype.
- The long term behaviour of the composite (durability of bonding and the membrane material) will be evaluated.
- Questions regarding the design, the scale and economic matters of the shell structure are going to be investigated.

Therefore we are very much interested in cooperating with new partners to proceed and extend this research. Aside from this topic, further research in the field of textile and polymer façade structures are just about to be launched at the IMS. However we are also open for your research proposals. For further interest or discussion please do not hesitate to contact us via [www.ims-institute.org](http://www.ims-institute.org).

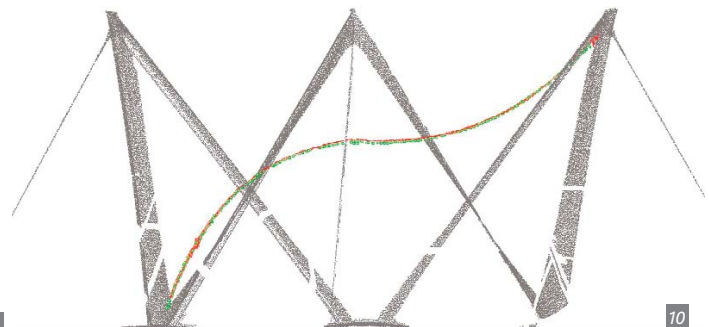
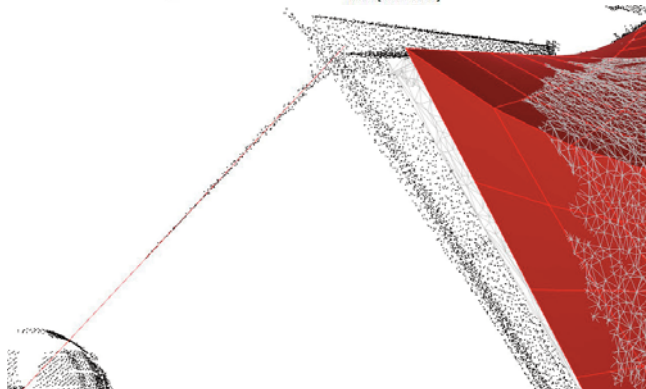
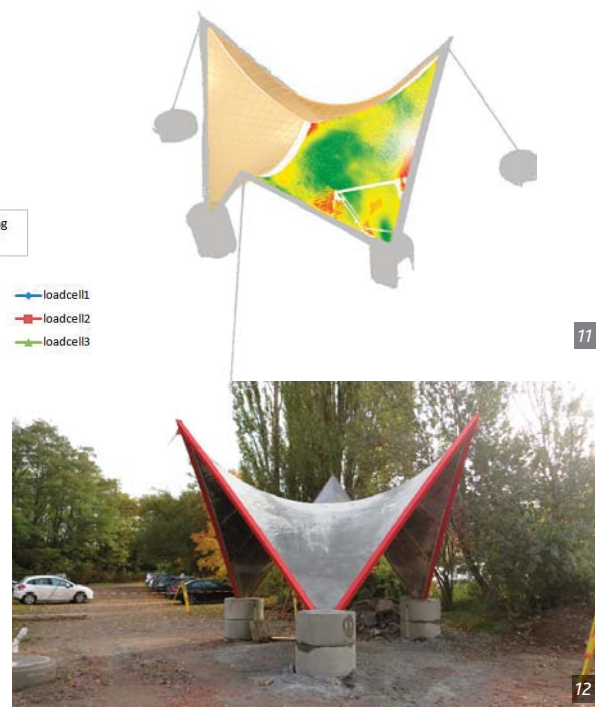
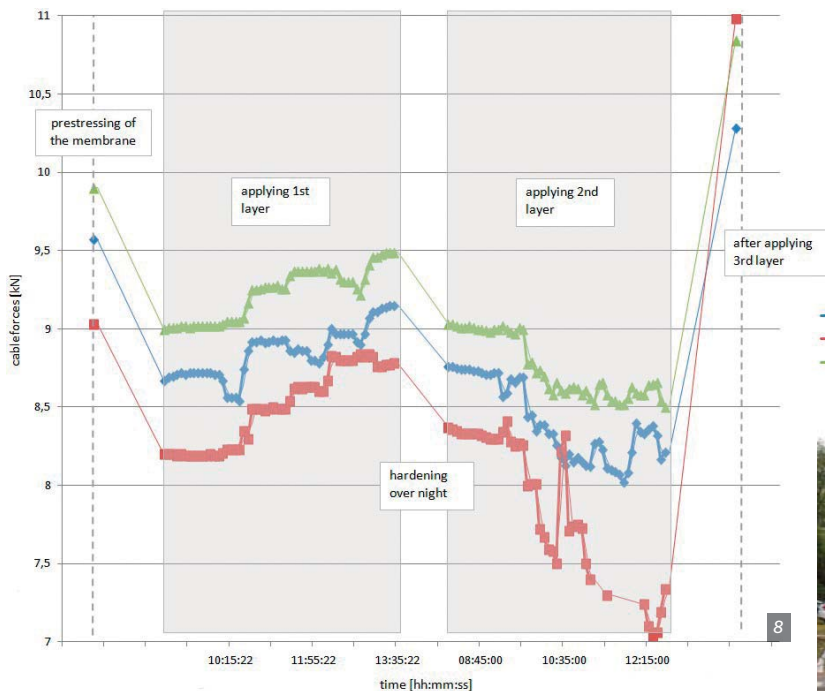


Figure 8. Monitoring of the cable forces during spraying and hardening process

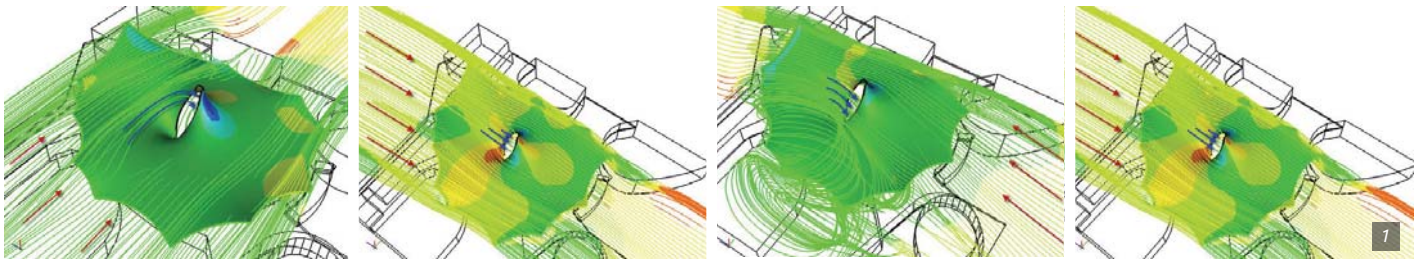
Figure 9. Matching of the digital "formfinding" model (red) and the 3d scan (grey)

Figure 10. Deflection of the lower shell surface after spraying (green) compared to the plain prestressed membrane structure (red)

Figure 11. Evaluation and supervision of shell thickness from 3d scanning survey Range of thickness from 30mm (green) up to 70mm (red).

Figure 12. Final Prototype





FASTECH

Porto Chino Rama II, Samutsakorn province, Thailand

# SHOPPING MALL OUTDOOR ROOF COVER

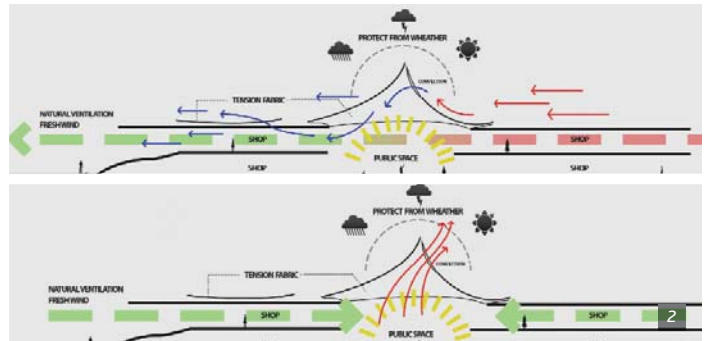
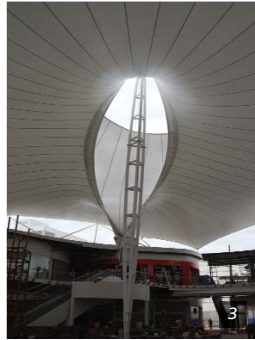


Figure 1. CFD Wind simulation to calculate the pressure coefficient and direction of winds (seasonal depending)  
Figure 2. Convection  
Figure 3. Interior view  
Figure 4. Connection details

## Context

As the climate change has more and more impact on our lives, architects need to develop well thoughtout solutions for this issue. The outdoor roof cover for the shopping mall Porto Chino was based on a "green thinking" design. Architects get rid of air-conditioned shopping mall types and when constructing in a tropical area they want to keep the most valuable natural ventilation. Each block of the building is placed in such a way that it does not obstruct the others from the main direction of wind, which is seasonal depending (Fig. 1). All interesting landscape and eye-catching membranes are placed in the front to welcome the clients at the first sign while they cross the Rama II road.

## Project

As the shopping mall consists of separate stores the overall air-con-

ditioning can be reduced. Thus, having separated energy is easier to manage and it can minimize the budget. The challenge is how to connect all small stores to become one unique mall without putting all within four walls, so the introduction of a tension fabric cover becomes the best choice at the time. The design allows cool wind to flow downward and hot air to rise so the tensile structure can function as a natural air-conditioning system (Fig. 2).

With a large span of nearly 40m the membrane structure gives a tremendous free space to the public area. The structure refers to an inverse flower blooming in spring with a transparent layer at the center to make a lighting effect, which serves as a landmark for the shopping mall. With this lightweight structure, Fastech tried to create a contrast among the crowded space below and the cover on top. People

have lots of activities to do while they are walking and shopping and whenever they look up, a big simple soft white membrane make them feel relax and comfortable (Fig. 3). The result of this lighting effect does not only take advance during the day as less artificial lights save more energy but it also becomes a beautiful landmark at night with a diffuse lighting illuminating the dark sky.

Yimm Somrutai  
 somrutai@fastech.co.th  
 www.fastech.co.th

*The project Porto Chino received from the Lightweight Structures Association Australasia the 2013 DESIGN AWARD High Commendation.*

Name of the project:	Porto Chino Rama II
Location address:	Samutsakorn province, Thailand
Client (investor):	D-Land Property Co., Ltd.
Function of building:	Outdoor roof cover
Type of application of the membrane:	Life Style Shopping Mall
Year of construction:	2012
Architects:	CONTOUR CO., LTD.
Multi disciplinary engineering:	ENPLUS CO., LTD.
Structural engineers:	EDMA CO., LTD.
Consulting engineer for the membrane:	GEOMETAL LIMITED (New Zealand)
Main contractor:	Cho. Runglert Co., Ltd.
Contractor for the membrane	FASTECH CO., LTD.
Supplier of the membrane material:	FERRARI
Manufacture and installation:	FASTECH CO., LTD.
Material:	Fabric 1202s2 for Roof Membrane
Covered surface (roofed area):	2.700m <sup>2</sup>

## Hamburg, Germany



# TEXTILE Hybrid Softhouse

### Introduction

As part of the international exhibition 'Bauausstellung' IBA 2013 in Hamburg Germany, architects from KVA MATx team and engineers from Knippers Helbig Advanced Engineering have developed an integral energy harvesting façade shading system for their 'Softhouse' project. Its overall energy concept includes an energy harvesting hybrid textile roof featuring flexible photovoltaic, which contributes to create a micro-climate for the building as well as a shading second skin for the terrace and glass façade. This responsive façade is based on a textile hybrid system, using textile membranes and glass fibre reinforced plastics (GFRP) in an intricate form- and bending-active structure.

### Concept

The textile façade of the 'Softhouse' undergoes two modes of shape adaptation. The form-finding and simulation of the initial system as well as its shape adaptations and the performance of all positions under wind and combined snow loads set a particular challenge to the engineering of the project (Fig. 1).

The adaptive façade shading system consists of a parallel arrangement of 32 individual strips which are combined in sets of 8 per housing unit. Each strip is a textile hybrid system with a 4m x 0.6m pre-stress form-active membrane attached to a bending-active 6m pultruded GFRP Board (500mm x 10mm). Flexible photovoltaic cells are attached to the upper third of the membrane,

continuing to the apex of the shape-adaptive GFRP board. In a yearly cycle, the GFRP boards on the roof top change their bending curvature and therefore adjust the PV cells to the vertical angle of the sun, while the daily east-west sun tracking and daylight harvesting is achieved by a twisting of the vertical membrane strips in front of the façade in a range of  $\pm 90^\circ$ . The membrane strips are attached to cantilevering GFRP boards which work as compound springs compensating the change in length of the membrane strip through twisting (Fig. 2).

The two modes of shape adaption described above necessitate a system which is able to compensate the nonlinear change in length of the membrane strip from twisting. An intricate system was developed,

in which a cantilevering GFRP board works as a compound spring to the attached membrane strips and thereby freely compensates the nonlinear change in strip length during twisting. On top of the roof, the cantilevering board

continuously evolves into a bending-active arch system which offers a change in rise and curvature due to the kinematics of the underlying steel structure. In order to maintain constant pre-stress in both directions of the membrane, cross bars are introduced at 60cm distance in the strips. In order to control shear deformation of the fabric during twisting an open mesh glass fibre membrane was chosen.

Some early pictures of this project show vertical wrinkles in the membrane, this is due to the fact, that the expanding ends of the cross bars where not yet tensioned during the opening of the project.

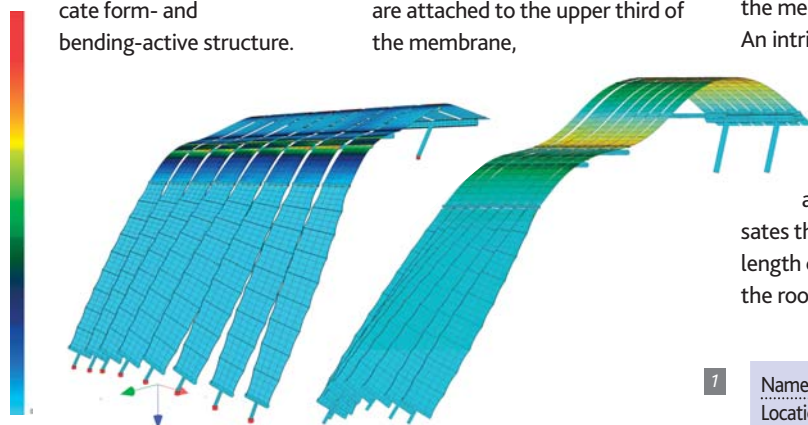
Figure 3 shows the final pre-stress state without wrinkles.

Julian Lienhard  
 lienhard@str-ucture.com

Figure 1. FEM analysis of storm and winter position in a coupled system including the steel kinematics

Figure 2. Testing the various modes of shape adaptation on the finished structure

Figure 3. Finished 'Softhouse' at IBA Hamburg April 2013



Name of the project:	IBA Softhouse
Location address:	Hamburg, Germany
Client (investor):	Patricia
Function of building:	Residential
Year of construction:	2013
Architects:	KVA MATx
Structural engineers:	Knippers Helbig Advances Engineering
Consulting engineer for the membrane and GFRP:	Dr. Ing. Julian Lienhard
Contractor for the membrane (Tensile membrane contractor):	Textilbau GmbH
Supplier of the membrane material:	Versaidag
Manufacture and installation:	Textilbau GmbH
Material:	Versaidag duraskin B 18656
Covered surface (roofed area):	200m <sup>2</sup> including GFRP Boards



# TEXTILE ROOFS 2014 REPORT

*Textile Roofs 2014, the Nineteenth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 26–28 May at the Deutsches Technikmuseum Berlin, and was chaired by Prof. Dr.-Ing. Rosemarie Wagner (Karlsruhe Institute of Technology, KIT) and Dr.-Ing. Bernd Stary (Berlin Academy of Architectural Membrane Structures, AcaMem). It was attended by 90 participants from 27 countries from four continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.*

## Introduction to the topic and overview

Prof. Dr. Arch. Josep Llorens from the School of Architecture of Barcelona introduced the topic of textile roofs and structural membranes, pointing out their main characteristics. He started with tents and awnings for shading, and mentioned the crucial contributions of Frei Otto and other pioneers who established the fundamentals. He formulated a typology based on the pretension mechanisms and shapes (Fig. 1). Deployable, movable, adaptable, and transformable roofs were also included, as well as structural supports, cables, arches, masts, beams, and frames. Reference was made to the three basic principles of textile roofs and structural membranes (only tension, double curvature and prestress) and to the characteristic values of the most commonly-used materials (PVC-coated polyester, PTFE-coated fibre glass, and ETFE).

The main membrane requirements (other than structural) were listed, with special reference to light, thermal performance, acoustics, fire resistance, environmental impacts, site location, visual expression, geometry, installation considerations, and economy. The need to consider all of these requirements at an early stage of the design process was shown. The design process was also described, and it was stressed that this does not only include form-finding, structural analysis and patterning. It also comprises initial information, preliminary design, detailing, specifications,

bills of quantities, cost estimation, and culminates with manufacturing, handling, transportation, installation, and maintenance. Details cannot be transplanted from a standard repertoire, since they have to be adapted to the requirements of each case. Solutions are successful when they meet the specific requirements of the entire structure. Any time requirements are changed, the design must also be altered.

To conclude, future trends were identified such as the parametric design, multi-layering, façades as envelopes, energy harvesting, glass substitution, refurbishment, large span roofing of existing buildings, archaeological areas, translucent insulation, new materials, or the Tensairity system for optimizing inflated beams.

## The design of tensile architecture

DI. Dr. Techn. Robert Roithmayr from the Vienna University of Technology described the philosophy involved in "Formfinder", a software developed to assist architects in the design, planning, and cost-effective assessment for the implementation of tensile membrane structures: <http://www.formfinder.at>. The design process is based on a dialog between clients, architects, structural engineers, manufacturers, and builders, and begins with a hand-sketched spatial model. Forces, form finding, typology, proportion, components, appearance, and proper detailing are considered.



Figure 2. A.Korren & I.Shani: Palma de Mallorca Aquarium

The design can be compared with the projects of the database provided in the software in order to know what has already been built (Fig. 2). The result goes to the "Technet" related software, in order to proceed with the analysis and patterning.

He also called attention to the postgraduate MEng program "Membrane Lightweight Structures," launched for the first time in November 2010 at the Vienna University of Technology. This program prepares postgraduate students to work in the field of membrane construction, providing profound knowledge for qualified participation in architects' and engineers' offices, in implementing companies in the private sector, as well as in the public sector.

## Computational modelling of lightweight structures

After presenting the company "Technet", its partners and academic institutions, Dr.-Ing. Dieter Ströbel went over the main restrictions of physical models, (namely the lack of post-processing, time, and scale), to emphasize the need for computational modelling:

<http://www.technet-gmbh.com>.

He defined the form finding process as a procedure for the determination of the geometry of a balanced structural system where "form follows force." The material is flexible, and only tensile forces can be borne, leading to anticlastic forms prestressed mechanically, or synclastic forms, where prestress is introduced pneumatically. Regarding the analytical procedure, Dr. Ströbel summarized the linear force density method that begins with the boundaries and mesh, and provides the shape, support forces, force and stress distribution (Fig. 3), contour lines, slope arrows, and slope lines for drainage. Automatic generation of primary structure is also implemented, and different net types are made possible in combination with rigid members and enslaved points.

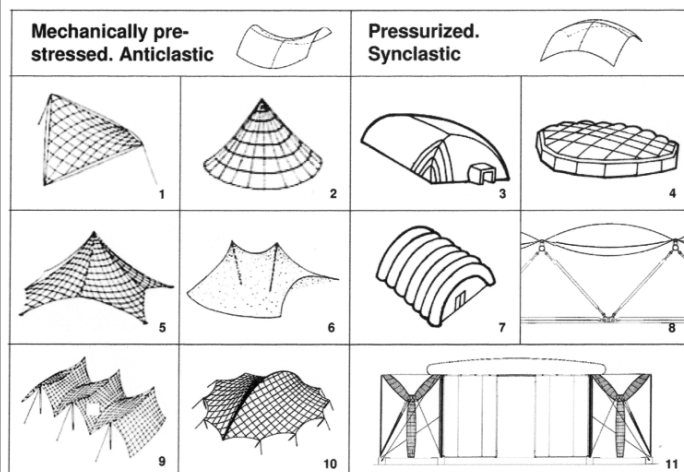


Figure 1. Typology.

*Mechanically pre-stressed, anticlastic.*

(1) Saddles and (2) conoids in units or (5-6) compositions. (9) Wave forms (ridges and valleys and (10) arch supported.

*Pressurized, synclastic.*

*Air supported:* (3) single or two layered and (4) reinforced.

*Air inflated:* (7) arches, (8) cushions and (11) beams (FESTO Airtecture Pavilion, 1996).

*At the moment, cushions (8) are particularly relevant due to recent ETFE application.*

The subsequent static analysis includes - shear stiffness, prestress, external loads, cables, bending elements, and struts. It connects to RStab for the stress analysis of the steel members and provides for cross section optimisation. In pneumatic membranes, the gas law  $p_1 \cdot V_1 = p_2 \cdot V_2$  is satisfied so that the volume and interior pressure are inversely related, and hence the membrane stresses are relaxed. "Add-ons" to the system are the silo, car shades, and cushion automatic patterning creators. In the description of the cutting pattern generation, Dr. Ströbel noted the convenience of following geodesic lines and shortening the dimensions, in order to obtain the prestressed surface that minimizes the distortion. He covered additional aspects, such as checking the lengths and marking the seams. He concluded by stating that computer models use information from many different experts, and need to be accurate, fast, and usable for mass production.

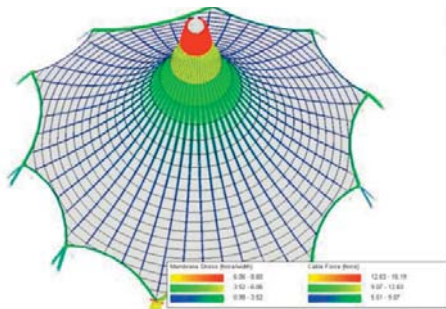


Figure 3. Easy-Form (Technet). Analytical formfinding: stress distribution

### On shapes, forms and structures

As usual, Dipl.-Ing. Jürgen Hennicke recounted the principles of lightweight structures, starting with the generating processes of objects in nature and their ability to bear and transmit forces. Key aspects of his presentation were the similarities between form, structure, material, loading, bearing capacity, mass, and energy expense. These principles can be used for design and optimization processes in architecture, as well as a model of thinking, and as a way of proceeding in design, construction, and in life in general. Sir D'Arcy Wentworth Thompson (1860-1948) developed these approaches from the viewpoint of bio-sciences, and introduced them into the general scientific discussion.



Figure 4. T-shaped hypostyle hall, temple of Chephren's pyramid complex (2520 BC)



Figure 5. A. Gaudi, 1878: "La obrera matoronense" textile cooperative shed, Mataró

There are two ways of building: 1) with columns and beams (forces follow form) still commonly used nowadays (Fig. 4), or 2) funicular shapes (forms follow forces) (Fig. 5). Mr. Hennicke stated that, by taking care of the influences of sun, air, water and earth, lightweight structures can provide everyday architectural solutions, and can fulfil common objectives and demands of people by upgrading the built environment, improving architectural quality by avoiding a conflict with nature, and ensuring our survival through sustainability.

### Integrated analysis and experimental verification of kinematic form active structures.

"Can fabrics be tensioned in different configurations for similar applications?" was the key issue formulated by Prof. Marijke Mollaert from the Vrije Universiteit Brussels, responding to the growing interest in foldable protections. She presented a typology of adaptable membrane structures based on the movement of the membrane or supporting structure. Three tests and numerical simulations have been conducted with a deployable dome (based on a rotating supporting structure (Fig. 6), a full-scale single panel (Fig. 7), and a full-scale single foldable unit (Fig. 8). As a conclusion, Prof. Mollaert indicated that the initial question remains unanswered, because the folding of a structure is not an unsurmountable problem. Nevertheless, the tension of the membrane requires adjustments and control in each configuration. The numerical values of stresses are similar, but reinforcements and wrinkling do not fit the experimental values. It seems to be a long way before experiments and simulations match up

with each other. A supplementary question arose in this discussion: can a retractable membrane system be stable in intermediate configurations and thus bear snow and wind loads without wrinkling? Finally, Prof. Mollaert showed the "Soft House" designed by Kennedy & Violich Architecture in Hamburg, an example of dynamic textile façade that moves and turns towards the sunlight, similarly to a sunflower, with photovoltaic cells incorporated into the membrane that make the best use of the sunlight for producing energy. Parts of the façade also cast shade in summer, while in winter they minimise energy loss and allow light to penetrate deeper into the interior. The view can also be adjusted by residents. For more information: <http://www.iba-hamburg.de/en/projects/the-building-exhibition-within-the-building-exhibition/smart-material-houses/soft-house/projekt/soft-house.html> (see also page 18)

### MORE WITH LESS.

#### Multiperformative surfaces in architectural design

The most astonishing contribution to Textile Roofs 2014 was presented by LAVA, the Laboratory for Visionary Architecture (T. Wallisser, Ch. Bosse, & A. Rieck). Incredible projects were paraded under the slogan "Man - Nature - Technology." These projects are based on complex surfaces developed by computer for different functions: <http://www.l-a-v-a.net>. Four milestones by LAVA are: Watercube Stadium, Mercedes Benz Museum, Snowflake Tower and Green Void (Fig. 9). "Learning from nature and advanced computing enables us to conceive structures of incredible lightness, efficiency, and elegance."



Figure 6. Full-scale deployable dome / Figure 7. Full-scale single panel / Figure 8. Full-scale single foldable unit / Figure 9. LAVA Mexico Monde d'Eau Hotel Resort



## World Cup Membrane Structures.

Dipl.-Ing. Arch. Ms. Lena Brögger and Mr. Martin Glass.

Lena and Martin have continued to develop spectacular textile stadiums, recently for the 2014 Brasil World Cup: Mineirao Stadium, Belo Horizonte (Fig. 10), Manaus, and Brasilia: [www.gmp-architekten.com/projects.html](http://www.gmp-architekten.com/projects.html).



Figure 10. gmp Architekten, 2014: Mineirao Stadium under construction, Belo Horizonte

## Comparative life cycle assessment: Texlon ETFE and glass cladding

Dr. Carl Maywald from Vector Foiltec GmbH began his presentation mentioning relevant ETFE applications.

In addition to having transparency, Texlon®ETFE is resistant, aseptic, non-metabolizable, acid-resistant, alkali-resistant, UV stable, self-cleaning, flexible (elongation at break > 300%), and lightweight (1 kp/m<sup>2</sup> for 3 layers).

To compare the characteristics of glass with ETFE, a life cycle assessment has been made of two existing roofs: DomAquarée Complex, Berlin and Kapuzinergraben, Aachen (Fig. 11). The Texlon cladding system is more environmentally friendly than glass for transparent roofs because the production of ETFE cushions is much more ecological, and the amount of steel and aluminium required is less. Improvements could be made by using renewable energies and less energy-demanding air supply and drying systems.

[www.vector-foiltec.com](http://www.vector-foiltec.com)

## Light structures with and without air: Bus terminal Aarau

Dipl.-Ing. Gerd Schmid from "form TL" showed in detail the development and construction of the bus terminal of Aarau, designed by Mateja Vehovar & Stefan Jauslin Architektur, which was given a 83,8% approval by the citizens of the city.

[www.archdaily.com/473610/aarau-bus-station-canopy-vehovar-and-jauslin-architektur/](http://www.archdaily.com/473610/aarau-bus-station-canopy-vehovar-and-jauslin-architektur/) The reflective semi-transparent canopy, qualified as a "functional sculpture," or "blue amoeba cloud," provides protection from rain and snow. The organically-shaped opening in the middle of the inflated cushion intensifies the impression of lightness (Fig. 12).



Figure 12. M. Vehovar & S. Jauslin Architektur, 2014: Aarau bus terminal

## Précontraint TX 30 a new generation of Précontraint flexible composite materials

Mme. Françoise Fournier from Serge Ferrari S.A.S. presented the Précontraint TX 30 new range with a design life of 30+ years -for tensile structures. This durability is possible thanks to a new top coat technology (CROSSLINK), and a 30 YEAR PVC formulation. Specific accelerated weathering protocols have been designed for this polymer, in order to quantify the photo oxidation rate and the remaining tensile strength after 30 years. She also showed recent applications of the Serge Ferrari products in architecture. The Arena das Dunas (see also page 11) is a football stadium designed by Christopher Lee, Australian architect of Populous, and

responsible for the master plan of the London Olympic Games, 2012 (Fig. 13). The stadium was built in 2014 in Natal, the capital of Rio Grande do Norte Brazilian state, to host football matches for the 2014 FIFA World Cup held in Brazil:

<http://populous.com/project/arena-das-dunas/> The Arena Corinthians in Sao Paulo, Brazil, is the stadium of Sport Club Corinthians Paulista, also built to host the 2014 FIFA World Cup. It was designed by Aníbal Coutinho, and engineered by Werner Sobek: <http://www.ice.org.uk/topics/structuresandbuildings/Case-Studies---Information/World-Cup-2014-Stadiums/Arena-Corinthians>



Figure 13. Christopher Lee, Populous, 2014: Arenas das Dunas Stadium, Natal.

## ETFE in China. An overview

Dipl.-Ing. Björn Beckert from "Seele Covertex Membranes Shanghai Co" presented a report on the development of ETFE for architectural applications in China over the last ten years, with attention to commercial and institutional achievements (Fig. 14).

From 2007 until now, the main ETFE applications are distributed as follows: 58.3% sport, 18.6% commercial, 10.6% transport, 9.3% exhibition and 3.2% leisure, offices, green-houses, industrial facilities, etc. He finally concluded that after 10 years, the ETFE market in China can be seen as fully developed. Private investors are increasingly taking advantage of ETFE, while government funds still play a major role in infrastructure projects. The complexity of ETFE projects is increasing.



Figure 14. ETFE in China: Sun Island membrane structure, Heilongjiang (Seele Covertex Membranes Shanghai Co.)

	Domaquarée Office Atrium: 1.600 m <sup>2</sup>				Kapuzinergraben			
	Texlon roof		Glass roof		Texlon roof		Glass roof	
	14 three-layer (1 printed and 2 transparent foils) cushions 3 x 40 m. Same structure as glass. No secondary aluminium network		2,7 x 1,33 m panes of laminated glass with low emissivity coating. Steel structure + secondary aluminium network		10 three-layer cushions 2,5 x 16 m with transparent foils.. Light network of steel beams and cables.		2,02 x 1,5 m panes of laminated glass with low emissivity coating. Steel structure with several columns and beams.	
Weight	Kp	%	Kp	%	Kp	%	Kp	%
Steel	95.466	94,7	103.066	55,7	12.250	91,1	78.270	80,7
Aluminium	3.719	3,7	22.103	12	801	6	1.000	1
ETFE	1.323	1,3	-	-	352	2,6	-	-
Glass	-	-	59.113	32,1	-	-	17.601	18,2
EPDM	216	0,2	420	0,2	38	0,3	103	0,1
PP	33	0,03	-	-	9,2	0,1	-	-
<b>Total</b>	<b>100.756</b>	<b>100</b>	<b>184.900</b>	<b>100</b>	<b>13.456</b>	<b>100</b>	<b>96.974</b>	<b>100</b>

Figure 11. Texlon®ETFE compared to glass: two case studies

## Theory and design of cable-net structures

Dipl.-Ing. Kai Heinlein revealed the project MemNet, conducted with Prof. Dr.-Ing. Rosemarie Wagner from Karlsruhe Institute of Technology, which was developed to simulate the behaviour of cable nets used for security, design, zoos, and façades. Individual cables were tested in tension to determine the E modulus, which was not constant. Bending tests were also performed, and the relationship between loads and sags were measured. From the comparison of these values based on various simulations, it followed that the moment of inertia under different bending moments is not constant. Biaxial testing was performed on a single element of mesh (spreading it out), as well as on the whole net (Fig. 15 and 16). Due to bending moments, a lower level of stress in the centre and a higher level in the border of the net were observed. On the other hand, a mock-up simulation revealed the interdependency between the bending moments on the knot points and the spreading out of the cable net. Finally, the cutting pattern of the textile covering of the net was also explored.

The conclusions were formulated as follows:

- For correct analysis and simulation of cable structures, it is necessary to use beam elements to represent correct results.
- Associated to beam analysis with large deformation, the correct curvature has to be integrated.
- It is possible to simulate with virtual moments of inertia.
- For structural load analysis of cable net structures, it is necessary to know the initial condition of the net or the inner energy.

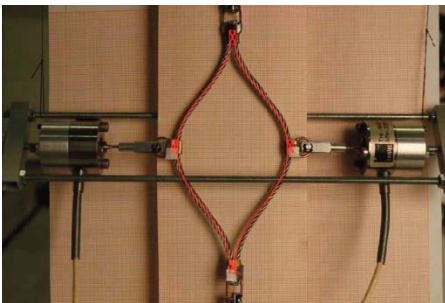


Figure 15. Biaxial testing on a single element of the mesh

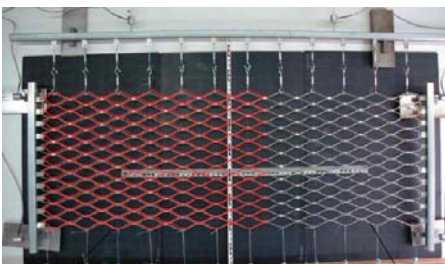


Figure 16. Biaxial testing on the whole net

## Fastening details. Ropes and fittings

Dipl.-Ing. Thomas Krieger from Carl Stahl GmbH recounted the main features of cables and fittings, and gave some tips on their use in structural membranes.

Because there are more than 9.000 different types of ropes, a selective criteria is needed that can be based on function (running or standing), the required end fittings, tensile strength, breaking load, or environmental conditions. Typical tensile strength of wires is 1.370 to 2.400 N/mm<sup>2</sup>, with higher values corresponding to smaller diameters. The breaking load of the rope and its metallic cross section depend on the diameter of the cable and its composition. In saddles, if the radius  $r_1$  is not less than the greater of  $30d$  or  $400\varnothing$ , the breaking resistance of the strand and rope is reduced by not more than 3% ( $d$  is the diameter of the cable and  $\varnothing$  is the diameter of the wire, according to EN 1991-1-11: Eurocode 3. Design of steel structures. Part 1-11). For running cable pulleys, the diameter of the pulley is related to the diameter of the rope.

When assembling cable ends, care should be taken with the weakest point because it determines the load capacity. Weakest points tend to be at welded forks, bolt contacts or eccentric connections. With the special TENNECT Carl Stahl universal connecting element, most weak points can be avoided: [www.tennect.com](http://www.tennect.com).

Regarding expansion:

- for temperature, the thermal coefficient is  $16 \cdot 10^{-6}$ , which has to be multiplied by the length and the difference in temperature
- for construction, no proper values can be calculated
- the increase of length due to tension is (rope length x force) / (metallic section x E modulus).

Handling, assembly, protection, and maintenance were the subject of practical advice that also apply to stainless steel.

Finally, Dipl.-Ing. Thomas Krieger referred to X-TEND, the stainless steel wire mesh for zoos, façades, railings and falling protections (Fig. 17): <http://www.carlstahl-architektur.com/en/products/x-tend.html>

Figure 17.  
X-TEN mesh as  
exterior  
scaffolding



## Installation of membrane structures

### Requirements and accomplishments.

The installation was the subject of Architect/Project Manager Claudius Dangel from 3dtex. He exposed some case studies that illustrated different particularities of the process:

<http://3dtex.net/>.

The Venezuela Pavilion was first erected in Hanover 2000, and was re-built in Barquisimeto in 2007. An auxiliary temporary structure was used for pre-assembling the petals. The tensioning of the membrane in Hanover was difficult due to the size of the corners. For this reason, they designed a special tool for Barquisimeto.

The installation concept is influenced by:

- Choice of materials (PTFE-coated glass fabric, or PVC-coated polyester)
- Local conditions on building site regarding the possibilities of delivering, material storage, points of anchoring, other craftsmen, and installation of barriers
- Installation model or simulation
- Installation team: skills, experience in membrane installations, industrial climbers, and number of workers
- Tools: development of special tensioning tools, tool list, cranes, and lifting ramps
- Consultation with the person who will be in charge of the installation
- Wind, rain, snow, and ice make the installation more complicated or even impossible. Weather forecasts have to be checked before and during the duration of the entire installation
- Safety concepts, as well as an emergency plan have to be worked out
- After the completion of the installation, there should be a debriefing between planners and workers to optimize future installations.

Other cases mentioned were the ponding on the Berlin Gasometer, 2011, the accumulation of snow on the PTFE-coated fibreglass "Schoolyard canopy" in Aarau 2012, and the compensation factor for the membrane "Acapture Sail" in Eckernförde, 2014, not considered in the cable length (Fig. 18). Mr. Dangel concluded by highlighting the need to consider the installation process during the design and detailed planning work.



Figure 18. Sculpture  
sail, Eckernförde



## Wind loads on fabric roofs and corresponding dynamic response.

Dipl.-Ing. Michael Buselmeier introduced Wacker Ingenieure – Wind Engineering consultants. Since 1992, they offer services within the scope of applied building aerodynamics and indoor airflow. They provide expert opinions, analysis, prognoses, calculations, measurements, and worked-out solutions which are based on literature searches, simulations, and wind tunnel experiments:

<http://www.wacker-ingenieure.de/>.

Wind tunnel experiments are useful in cases where simple approaches and numerical models cannot be applied. For numerical air flow, pressure and temperature simulations, they use different computer models, including finite element approaches, computational fluid dynamics (CFD), as well as zone/node models.

They combine traditional with modern rapid prototyping manufacturing methods to investigate special structures not covered under the standards.

For the structural design of a fabric roof, realistic dynamic wind loads are required. These loads, together with the variability and complexity of shapes make it often necessary to do wind tunnel testing. Moreover, membrane structures are often attached to larger structures, which complicate wind factors, and enhance turbulences and dynamic excitation, which are situations not addressed by codes or past experience.

The main characteristics of wind tunnel testing are the modelling laws (geometric similarity, similarity of the approaching flow, the flow around the structure), and rigidity. Rigid models are usually used, assuming that deflections are small enough to not influence the pressure distribution. When deformations are significant (Fig. 19), additional tests may determine the deflected shape, or theoretical estimations, and numerical calculations may be performed, because aerolastic modelling is extremely complex, inexact, and expensive. Two case studies were presented: large scale 53m x 53m umbrellas and 180m x 90m flat fabric roof exposed to strongly turbulent wind. In conclusion, Dipl.-Ing. Michael Buselmeier summarized his presentation concluding that:

- Wind may affect membrane roof design in various ways.
- Wind effects on membrane roofs can be investigated by means of appropriate wind tunnel tests in a boundary layer wind tunnel.
- The appropriateness of these tests is especially evident with regard to the assessment of structural and local design wind loads and the corresponding dynamic wind loading effects.

- The benefit of wind tunnel tests is demonstrable, especially if the wind engineer is involved in an early stage of planning.

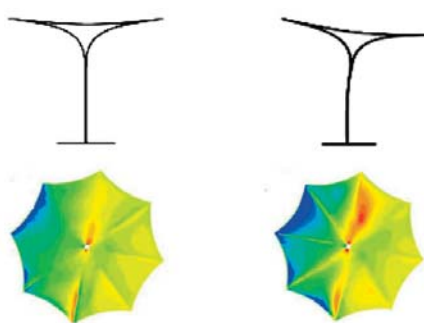


Figure 19. The deflections influence the pressure distribution

## Gino Park Besenová membrane

Dipl. Ing. Arch. Ján Dolejší showed in detail the installation of a double-layer membrane for a thermal swimming pool in Slovenia.

Particularly outstanding features were, among others, the deep foundation made of piles, the central tripod supporting the high point (Fig.



20), and all the ducts hanging from the upper membrane which ran into the cavity.

Figure 20. The high "point" of the Gino Park membrane before erection

## Textile façade for tower on Velaa private island, Maldives

Ing. Arch. Zdenek Hirnsal presented Archtex/ Kontis, a joint venture that offers complete turnkey projects from architecture design, manufacturing of textile membranes, ropes and supporting structures. Projects include the installation, and are executed around the world. They designed the textile façade of a tower for a restaurant on Velaa Island, the northern atoll of Maldives Islands (Fig. 21). The façade was based on irregular elliptical rings with different inclinations. Total height: 25m, and diameter: 11m. A special feature of the form finding and cutting patterns of the membrane (assisted by D. Ströbel), was the cable net inside the windows to transfer the loads through the surface. All the parts were manufactured in the Czech

Republic and in Germany, and were transported by ship to the worksite. Materials for the textile façade included 800m<sup>2</sup> of Serge Ferrari Stamisol FT381, 380m<sup>2</sup> of Carl Stahl cable mesh and ropes, 5T of stainless steel for the façade and 4,5T of stainless steel for the handrails. Installation was done floor by floor with scaffolding, and was completed in 24 days by 9 workers: [www.archtex.cz/en/projekty.html](http://www.archtex.cz/en/projekty.html)



Figure 21. Textile façade of the Velaa Island restaurant

## Students' Project Week "Cloud of shading"

The students' project week ran parallel to Textile Roofs 2014. The subject was "cloud of shading", a flying roof that defies gravity, disregards supports, and hangs from the sky on the Earth instead of standing on the ground, and is easy to install. The final presentation and discussion took place at the closing of the Workshop.

The following six proposals were presented and discussed by the students, the audience, and the teaching team composed by R. Wagner, L. Brügger, M. Glass and S. Bringmann:

- 1 Redesigning the logo as a chain of holes.
- 2 Not only a roof for the entrance of the hall.
- 3 Red flag: a hyperbolic paraboloid for the entrance of the museum.
- 4 Weather balloons.
- 5 Drops connected by a net or by Velcro.
- 6 An inflated torus surface used as a canopy (Fig. 22).



Figure 22. Student's Project Week: an inflated torus surface

✍️ Josep I. de Llorens  
 📄 ETSAB/UPC  
 📧 [ignasi.llorens@upc.edu](mailto:ignasi.llorens@upc.edu)

*The Twentieth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures will be held on 11-13 May 2015. In celebration of its 20th anniversary, TR 2015 will invite lecturers of the past 20 years. The format will be similar to that of TR 2014, with seminar-style lectures and hands-on activities. It will be preceded by the student seminar and sponsored by AcaMem, gmp, Serge Ferrari, KIT, Carl Stahl, Technet and TensiNet: <http://www.textile-roofs.de>.*

# STUDENT'S PROJECT WEEK TEXTILE ROOFS 2014 BERLIN

The location of the textile Roofs Workshop 2014 was the Deutsche Technikmuseum Berlin and the student's project within the Textile Roofs Workshop is designing an extreme lightweight cover as a sign for the two entrances of the museum. The museum was founded in 1983, the location is the old freight area of the Anhalter Bahnhof and the exhibitions are showing old and new technical developments of mankind within an area of more than 25 000m<sup>2</sup>. The entrance building of the museum is made of brick in 1908 and was the headquarter of the Markt- und Kühlhallengesellschaft founded by Carl Linde. The second entrance is into the former freight terminal called Spectrum. The distance is app. 300m between the two buildings and both entrances are unspectacular doors of the two old buildings. The target of the students' project week is to design and to build a cover defining the entrances of the museum visible from the Tempelhofer Ufer, the street of the north side of the museum area. The 11 students of the master course in architecture of the KIT are accompanied by the following professionals: Martin Glass and Lena Brögger, both employee of von Gerkan, Marg und Partners Architects and Stev Bringmann, working as freelance designer of lightweight structures in Berlin.

The project started with a visit of the museum by the director of the museum, Professor Hoppe organized by Dr. Bernd Stary, coordinator of the Textile Roofs Workshop. Developing a canopy for the two entrances of the Museum the target is to design a pneumatic structure lighter than air and filled with helium. The requirements of the design are less material as possible, shapes of inflated membranes without any rigid bending or compression elements and high gas tightness of the manufactured hulls. During the two hour tour through the museum the task is increased by possible signs and installations within the museum and the inner courtyard of the museum.

The next days the students are guests of the Sabine Raible, a Berlin Architect and head of the platform Elemente Material Forum Berlin, located close the museum. The showroom of Sabine Raible has space enough to host the students and the equipment such as foils, textiles, welding and sewing machines for building physical models. Using modern design tools such as CAD software the development of free shaped inflated membrane structures is easy and the students start with these techniques. They tried afterwards to build small scale models of welded PE-foil, filled with helium and testing their shapes. The



experience of welding and testing the flying structures gives an impression of the difference between CAD designed models and reality. The students learned in the two following days to respect the material behavior of the foils, the influence of the manufacturing gastight seams with the required strength and the physical relation between shape, tension stresses and internal pressure creating an interesting appearance of the inflated structures. The students developed six different proposals with different locations and use in the museum. One of the designs used the inner courtyard of the Museum as a playroom for demonstrating gravity by water and helium filled balloons. A second design are hexagonal cubes as symbol of the steam of the old steam engines, coming out of the entrance doors, openings in the roof of the old railway depot and used as sign through the museum (Fig. 1 and 2). The sign of the museum itself gives two groups of the students the idea to their design. One group designed 4 cones with spheres at the end, put together to a flying roof in front of the entrance building (Fig. 3). The other design is an inflated ring with different scaled spheres; the ring is rotation around a center mast and shows the sign of the Museum for different views. One of the students develops an inflated four point sail as entrance canopy in front of the Spectrum (Fig. 4) and the last design is a hyperbolic shaped inflated ring as well in front of the same building.

On the third day of the project week the students present their proposals to Lena Brögger and Stev Bringmann and one of the proposals is chosen to be built in the scale of M 1:1 within the next three days. It seems to be possible to build the hyperbolic ring as inflated and helium filled structure using a hull made of fabric and internal gas chambers of 50µm PE-Foil. The whole students group is divided into three subgroups, one responsible for the cutting pattern of membranes, the second for welding the gas chambers (Fig. 5) and the third for sewing the hull (Fig. 6). The proposals with the small scale models and the final design are presented on the afternoon of the last day of the experts of Textile Roof Workshop (Fig. 7).

Rosemarie Wagner  
 Rosemarie.Wagner@kit.edu  
<http://fjb.ieb.kit.edu>

Figure 1 and 2. Hexagonal cubes as symbol and sign through the museum  
 Figure 3 and 4. cones with spheres as a flying roof in front of the entrance building  
 Figure 4. Inflated four point sail as entrance canopy  
 Figure 5. Hyperbolic ring - welding gas chambers  
 Figure 6. Hyperbolic ring - sewing the hull  
 Figure 7. Hyperbolic ring - final design