TensiNews

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NEWSLETTER OF THE EUROPEAN BASED NETWORK FOR THE DESIGN AND REALISATION OF TENSILE STRUCTURES

REPORT

2. ESSENER MEMBRANBAU SYMPOSIUM

SLTE 2014

NEW CALL

ROUND ROBIN

INTERPRETATION OF BIAXIAL AND SHEAR TEST DATA
& COLLATING WIND TUNNEL DATA FOR THE BASIC SHAPES OF TENSIONED SURFACE STRUCTURES

PROJECTS

MEMBRANE SCULPTURE "HARBOUR POINT"
REPLACING TENSILE ROOF FABRIC
INNO-WAVE-TION
HOSPITALITY BASED ON TENSAIRITY®

Membrane Sculpture "Harbour Point", Eckernförde, Germany © 3DTEX▲
Deployable structure © C. Morales, Facultad de Arquitectura de Poza Rica, Universidad Veracruzana ▸

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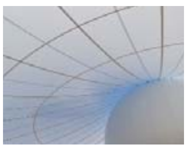
NEW CALL



MISC

Edito

Dear Reader,

Activities within the Eurocode working group and in the COST Action on 'Novel structural skin's dominated the TensiNet work beginning of this year. The Eurocode working group is finalizing the last steps to submit the scientific and policy (SaP) report "Guideline for a European Structural Design of Tensile Membrane Structures made from Fabrics and Foils", summarizing the actual code of practice in different countries, and giving a first outlook for the future Eurocode. It will be submitted mid of this year and will be published by the joint research center (JRC) and provides background information to the future technical specification and Eurocode. The COST Action on 'Novel structural skin's met this March in Denkendorf in different working groups. The COST working groups contribute with their work to TensiNet working groups. Many TensiNet members are involved in these different working groups.

In March we had a fruitful TensiNet Partner meeting where we discussed our mission. As a common sense we all agreed that textile architecture is a state of the art building technology. It needs special care to be taken on quality issues to ensure this reliable technology. We agreed to establish a TensiNet Best Practice Guidance for textile architecture, which can be developed into a seal of quality in the future. I am glad to announce that we have re-elected the board and the secretary, and that all have confirmed their availability to continue their work.

We look forward to many interesting events. Techtextil in Frankfurt takes place this year, where TensiNet is again sponsor of the Techtextil Student Competition. TensiNet will be present at the 20th Textile Roof in Berlin, and you will find many of us in Barcelona on Structural Membranes or in Amsterdam on the IASS symposium.

The next TensiNet Symposium will take place in October 2016 at Newcastle University. It will be held in collaboration with the COST action under the title "novel structural skins". You will find more information in this issue, beside many Interesting projects like for example the first ETFE project in Mexico and two Tensairity projects. Josep Llorens has prepared a report about the 6th Latin American symposium in Brasilia, and Jörg Uhlemann is reporting on the second Essener Leichtbau Symposium.

I look forward to see you at one of these events. Please enjoy meanwhile this issue of TensiNews.

Yours sincerely,

Bernd Stimpfle

TensiNet

Forthcoming Events

TECHTEXTIL 2015
Frankfurt, Germany | *4-7/05/2015*
www.techtextil.messefrankfurt.com

Textile Roofs 2015
Berlin, Germany | *11-13/05/2015*
http://www.textile-roofs.com/

IASS 2015 _ Future visions
Amsterdam, The Netherlands |
17-20/08/2015 **http://www.iass2015.org/**

Structural Membranes 2015
Barcelona, Spain | *19-21/10/ 2015*
http://congress.cimne.com/membranes2015/frontal/default.asp

9th Aachen-Dresden International Textile Conference 2015
Aachen, Germany | *26-27/11/2015*
www.aachen-dresden-itc.de

TENSINET - COST ACTION TU1303 SYMPOSIUM 2016
Novel structural skins | Newcastle, UK |
26-29 Oct 2016 | **see back cover**

Forthcoming Meetings

COST Action TU1303 Meetings

TensiNet members can also attend the COST Action TU1303 meetings
8-9/09/2015 Guimarães, Portugal
Additional information can be found at
http://www.novelstructuralskins.eu/events/meetings/

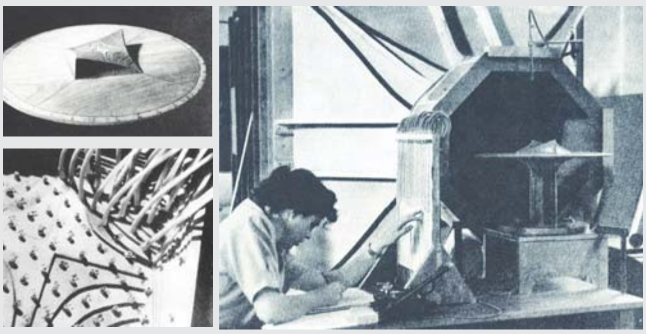
Frei Otto IN MEMORANDUM 1925 - 2015

Thank you for being an inspiration to so many past and future generations!

All of us involved in Textile Architecture are grateful for the enormous contribution of Frei Otto to the technical progress as well as to the beauty of tensile surface structures.
To honor him we quote him on two still relevant topics.

"There are no published measurements of the wind conditions for roof designs that match, or that are even remotely similar to, those of suspended membranes. The simplified wind load distributions on roof surfaces in accordance with DIN 1055, part 4, figures 3 to 5, are not reliable as they would be used for suspended membranes."

FREI OTTO, DAS HÄNGENDE DACH, BERLIN, 1954 (REISSUED STUTTGART, 1990)



Nowadays, we are still dealing with similar problems. Standards for the calculation and dimensioning of lightweight structures subjected to wind loading do currently not exist. To continue the work of Frei Otto, Round Robin exercise 3 is launched in order to evolve to a Eurocode section on designing membrane structures and especially on wind loading.

Especially in an era where advanced design tools are commonly used, it is worthwhile to recall what Frei Otto wrote in the preface of IL21.

"Objects which transmit large forces with relatively low mass are considered as "lightweight". But when we state: "That form of many structures, such as towers, bridges and roofs, which uses the construction material optimally, is unknown", the layman and even many engineers are astounded. … A structure is designed more or less "by inspiration" and then calculated. Where it is too weak, it is reinforced, where there is too much material, some is removed. This kind of method cannot break out of the limits set by the design, cannot produce the unknown forms.… The connections of FORM-FORCE-MASS answer the question of "Shape and Structure". A key to the aesthetic qualities of material objects can obviously be found there. … We think it [IL21] provides the bases for improving a little our understanding of the link between architecture and construction and also between nature and technology."

EDA SHAUR, IL21 BASICS FORM – FORCE – MASS 1, STUTTGART, 1979

Figure 1: The experiment for a hypar roof of an exhibition hall was carried out in the Föttinger Institut of the Technischen Universität, made possible and supported by Prof. Dr.-Ing. Rudolf Wille.






3DTEX

AN EYE-CATCHING ARCHITECTURAL LANDMARK

Membrane Sculpture "Harbour Point"

Eckernförde, Germany

Context

As part of the redevelopment of the old harbour in Eckernförde, the architectural firm Rimpf designed and built a new apartment block on the "Hafenspitze" (Harbour Point). The city administration also wanted to erect a new landmark for Eckernförde in this prominent spot. The maritime atmosphere of the new "Hafenspitze" quarter – with views of the Baltic Sea, the yacht harbour and the beach – made a textile membrane sail an obvious choice for an eye-catching architectural landmark.

Project

Because 3dtex became involved in the project at an early stage, it was possible to work together with the architects in developing the shape of the sail. The design is based on two mirror-symmetrical four-point sails that appear to take on changing forms as one approaches the harbour by water or on land. The shape of the sail was subject to many different criteria in terms of its visual effect from a distance and the views it enabled from the individual balconies of the apartment block. Particular attention was given to the dynamic lines and design details that serve to accentuate the sail's overall form and objective. The fabric used was a PTFE-based fibreglass from Verseidag (type III), which as expected, faded within approx. 5 weeks from its original brown colour to a brilliant white. All steel elements were hot-dip galvanized and painted, which required the nearly 24m-long supporting pole to be segmented. The joints have been left visible and are not cladded, which is why they also needed to be designed with aesthetic considerations in mind.

Erection

The construction was erected in two stages: the supporting pole was already erected in January 2014, but it was necessary to wait for warmer weather to install the membranes, in order to avoid damage caused by wrinkles in cold weather. It took five days to add the membrane with additional re-tensioning procedures. A specially built tensioning tool enabled the 12-t tensioning force to be applied at the upper attachment point by means of two hydraulic cylinders. With this, the tensioning force could be precisely applied and controlled according to the specifications.

The building developer, the architect and as well the majority of the citizens of Eckernförde are fully satisfied with the result. With its expressive form, the membrane sail is not only representative for the new "Hafenspitze" (Harbour Point) area, but is also a new landmark for Eckernförde.

Stev Bringman
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www.3dtex.de

Name of the project:	"Harbour Point" Eckernförde
Location address:	Jungfernsteg 2, 24340 Eckernförde, Germany
Client (investor):	Penta Nord Immobilien GmbH & Co, Germany
Function of building:	Apartment House with Membrane Sculpture
Type of application of the membrane:	outside freeform sculpture
Year of construction:	2014
Architects:	Rimpf Architekten, Eckernförde, Germany
Consulting engineer for the membrane:	IB Zapf, Straußberg, Germany
Main contractor:	3dtex GmbH, Berlin, Germany
Contractor for the membrane:	3dtex GmbH, Berlin, Germany
Supplier of the membrane material:	Verseidag, Germany
Manufacture membrane:	Flontex Europe, Poland
Manufacture steel:	Stahlbau Hartleb, Germany
Installation:	3dtex GmbH, Berlin, Germany
Material:	PTFE-coated glassfabric Type III
Covered surface (roofed area):	237m^2

Replacing tensile roof fabric

Telluride Town Park, Telluride, CO (USA)

ATTENTION TO NEW REQUIREMENTS ON SNOW LOADS

Context

The town of Telluride required the tensile fabric at the Telluride Town Park to be replaced . The structure provides approximately 23m x 12m of coverage and is used as shelter during events, as their main concert & event arena and as rest area for ice rink participants and other users of the park year-round. The original structural drawings were not available. Signature Structures LLC, of Bethlehem, PA, won the contract and followed the tensile fabric replacement process they have refined through multiple similar projects. The town requested that the steel structure, foundations, and cables be re-used to the maximum extent possible.

Project

A complete survey was conducted and the tensile roof was modeled using standard tensile software. Engineering documents were submitted to obtain a building permit. As is typical for membrane replacements projects in snow load areas in the USA, some compromises were required in regards to snow loads that are currently required versus what was originally used in the design. The existing roof of PVC coated fabric was 29 years old and code requirements have evolved substantially in that time.

When the roof was initially analyzed with current snow load requirements, using the engineer's interpretation of potential drift, the resulting cable sizes and sizes of fittings exceeded the sizes of existing hardware in certain areas. The Town accepted a modified design as presented based on a full engineering report listing all assumptions and interpretations. This resulted in a design that was consistent with a defined set of load assumptions versus just copying what was existing and not really understanding if differences in fabric properties, prestress and exact shape had altered the internal forces. The initial code-based snow load was 75 psf (3.6 kN/m²). Compared with the initial snow load and the initial drifting assumptions, a reduction of 25% was applied to make the design consistent with the existing parts. (Fig. 1)

The town requested minimal changes to the tensioning hardware to retain the rustic look that they favor. Although tensile technology has evolved greatly over the last 29 years, and options to update the technology were reviewed, the original tensioning methods were retained, both to keep the original aesthetics and to ensure that load distributions in existing frame parts and cable attachments would not change substantially. The original design used catenary cables in fabric pockets, with the ends of the fabric pockets tensioned using webbing straps and turnbuckles. This results in busy assemblies with multiple turnbuckles and D-shackles at each tension point. The rustic look of the existing design was preferred over a proposed change to membrane plates with a more crisp modern looking finish.

The install took only one week, thanks to meticulous preparation and excellent cooperation with township personnel, and left the town very pleased with the result.

Figure 1: Drawing of the new design.

Name of the project:	Telluride tensile roof replacement
Location address:	Telluride Town Park, Telluride, CO (USA)
Client (investor):	Town of Telluride
Function of building:	weather protection during events and protected rest area for park users
Type of application of the membrane:	tensile roof
Year of construction:	2014 (original structure 1985)
Structural engineers:	Lightweight Design Inc.
Consulting engineer for the membrane:	Lightweight Design Inc.
Main contractor:	Signature Structures LLC
Contractor for the membrane : (Tensile membrane contractor)	Signature Structures LLC
Supplier of the membrane material:	Serge Ferrari
Manufacture:	Lightweight Manufacturing Inc.
Installation:	Signature Structures LLC
Material:	Precontraint 1202 T2
Covered surface (roofed area):	500m²

Dirk Cos, Lightweight Manufacturing, Lightweight Design
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www.lightweightmanufacturing.com

The Institute for Metal and Lightweight Structures (Institut für Metall- und Leichtbau) together with the Essen Laboratory for Lightweight Structures (Essener Labor für Leichte Flächentragwerke, ELLF) organised the "2. Essener Membranbau Symposium" in Essen on September the 26th. The organizers were delighted to welcome a large professional audience of 130 guests containing of experts from industry and research in the field of membrane construction. Representatives from the membrane material producers, manufacturers, test facilities and building control authority appeared as well. They enjoyed the multifaceted and detailed presentations on engineering membrane structures and used the possibilities for vital discussions.

The speakers at the 2. Essener Membranbau Symposium (from left to right): Prof. Natalie Stranghöner, Jörg Uhlemann, Thomas Kierner, Klaus Saxe, Sebastian Gerhold, Dr. Alexander Michalski, Prof. Daniel Balzani and Dr. Martin Synold.

LARGE AUDIENCE AT THE 2. ESSENER MEMBRANBAU SYMPOSIUM

130 guests from membrane research and practice have found the way to Essen for a multifaceted program

Professor Daniel Balzani (Technische Universität Dresden, Institut für Mechanik und Flächentragwerke) presented current research results on mechanical modelling of fabric materials utilizing shell elements and a hyperelastic constitutive law. With this model the material behaviour can be described by only four parameters which can be determined from a biaxial tensile test. A special feature of the presented method was its allowance for the simulation of wrinkles by using a polyconvex energy function.

Dr. Alexander Michalski (SL-Rasch GmbH, Stuttgart) commented on the challenges of wind load determination on flexible, doubly curved membrane structures. He illustrated different methods: the simplified application of standardized wind pressure coefficients, the utilization of wind tunnel tests and the application of Computational Fluid Dynamics which may be used additionally to wind tunnel tests for major projects. Aiming at a future expansion of standardized wind pressure coefficients he developed a classification of typical membrane structure geometries.

Klaus Saxe (Universität Duisburg-Essen, Essener Labor für Leichte Flächentragwerke) addressed the relationship between structural demands and the choice of material. He clarified which materials are appropriate for specific structural demands. In particular, he relativized some statements that are even spread among the professionals. For instance, in opposite to a common assumption Polyester/PVC fabrics can be produced with the same tensile strength or even a higher tensile strength than Glass/PTFE fabrics. Furthermore, higher costs for the raw Glass/PTFE material can appear to compensate when the readymade structure is assessed over a long life time.

Jörg Uhlemann (Universität Duisburg-Essen, Institut für Metall- und Leichtbau) introduced current design approaches for membrane structures on the one hand and presented results on an analysis of anonymized statical verifications of realized structures on the other hand. The analysis revealed a great variety of design approaches attended by a great variation of safety levels for the different structures. Envisaging the development of a European design standard he recommended to distinguish between "safety factors" and "strength reduction factors". The first are to consider uncertainties in the design process, the least take into account the real strength reduction of typical membrane materials due to loading or environmental aspects. This would enable to assess the actual safety level of a structure.

The current work on a European harmonization of the design of membrane structures aiming at the establishment of a new Eurocode was presented by Professor Natalie Stranghöner (Universität Duisburg-Essen, Institut für Metall- und Leichtbau). At present, a background document on structural design and the standard development is prepared which shall be the basis for the evolution of the new standard. She gave the audience an understanding of the planned structure and content of the standard as well as the time schedule for its preparation.

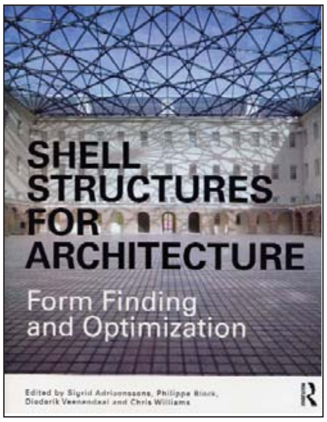
A detailed discussion on judicial subjects associated with the engineering and installation of membrane structures was held by the specialist solicitor Thomas Kierner (Althoff Kierner & Partner, Dresden). A main topic was the clarification of typical misunderstandings between lawyers and technicians. Moreover, he emphasized the importance of the technical

specifications and how crucial it is to precisely prepare it. This message was condensed in the concise sentence: “You build something very particular, so specify it in particular.”
ETFE foil structures enable failsafe running functions of a complete structure: This was the main message of Sebastian Gerhold (Vector Foiltec GmbH, Bremen). He reported on long lasting experiences in engineering, installing and operating ETFE structures. From his point of view a consideration of a building in its entire scope is important. In this way ETFE foils can be included in the structural safety concept, e.g. regarding fire or detonation safety.
Furthermore, he showed exemplary in how far high safety factors for single structural components do not necessarily lead to a high safety level of the entire structure.
At the end of the symposium Dr. Martin Synold presented innovative project ideas considering the use of tensile materials which are currently developed at his domains at the Institut für Leichtbau Entwerfen und Konstruieren (ILEK) of the University of Stuttgart and the engineering office Werner Sobek. In addition to currently realized projects he gave an outlook on future constructions with innovative materials which may include sensors or textile actuators.
The day ended with a visitation of the ELLF laboratory and with more possibilities for discussion.

The proceedings are available under:
Natalie Stranghöner,
Klaus Saxe, Jörg Uhlemann (Ed.):
Essener Membranbau Symposium 2014,
Shaker Verlag, Aachen, 2014
(ISBN 978-3-8440-3066-2).

In the light of the good feedback the organisers look forward to the next Essener Membranbau Symposium to be held in 2016.

Shell structures for architecture.
Form finding and optimization.



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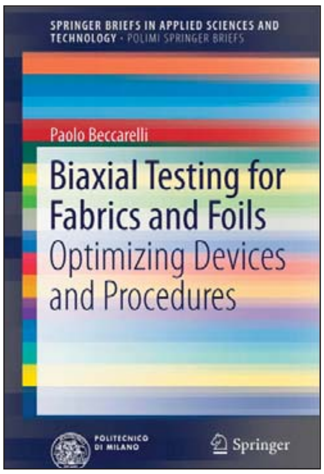
ISBN: 978-1-315-84927-0 (ebk)
Pages: 340 | Language: English | Published: 2014

This collective work uses contributions from the fields of research and practice to present current methods for designing shells and gridshells, including form finding and structural optimization. In addition to presenting the structures, the book also deals with analytical methods, computer algorithms and examples of development of complex surfaces, which have been misnamed “free surfaces”.
In the Prologue, Jörg Schlaich and Shigeru Ban explain that these structures require a symbiosis between architecture and engineering.
Part I introduces sheets and membranes, highlighting the relationship between form and structural behaviour. It also outlines how form finding methods and optimization techniques have evolved.
Part II familiarizes the reader with current form finding techniques, i.e. the force density method, thrust network analysis, dynamic relaxation and particle-spring systems. The section ends with a comparison and discussion of the advantages of each one.
Part III deals with optimization methods and Part IV presents the roofs of the Mannheim Garden Pavilion and the courtyard of the British Museum in London, the work of Félix Candela and Heinz Isler, and the reinforced concrete shells of the 21st century.

✎ José I. de Llorens , ETSAB/UPC

Biaxial Testing for Fabrics and Foils



Publisher: Springer
Edited by Paolo Beccarelli
ISBN: 978 - 319 - 02227 - 7
Pages: 138 | Language: English | Published: 2015

This book offers a well-structured, critical review of current design practice for tensioned membrane structures, including a detailed analysis of the experimental data required and critical issues relating to the lack of a set of design codes and testing procedures. The technical requirements for biaxial testing equipment are analyzed in detail, and aspects that need to be considered when developing biaxial testing procedures are emphasized. The analysis is supported by the results of a round-robin exercise comparing biaxial testing machines that involved four of the main research laboratories in the field. The biaxial testing devices and procedures presently used in Europe are extensively discussed, and information is provided on the design and implementation of a biaxial testing rig for architectural fabrics at Politecnico di Milano, which represents a benchmark in the field. The significance of the most recent developments in biaxial testing is also explored.

ETFE roof Cubierta Voronoi

Monterrey, Mexico

FORM-TL

Z3RCH

3DTEX

A KEY PROJECT FOR THE ETFE TECHNOLOGY IN MEXICO

Figure 1: Overview of the ETFE roof ©3dtex

Context

Cubierta Voronoi is the first ETFE roof in Mexico. It is located in the city of Monterrey. The concept of the project was to form a meeting point for the new shopping mall in the neighbourhood of San Pedro Garza Garcia.

Project

The structure consist of six tree-like main columns supporting a honeycomb shaped steel structure. The roof structure has a height of 21m and a steel weight of 120 tonnes. The combs are covered with hexagonal ETFE cushions. The cushions have a transparent foil on the bottom and a white foil on the top (Fig. 1).

The project started as a Voronoi structure. The roof surface was divided into panels with the algorithm developed by the mathematician Woronoi (see http://en.wikipedia.org/wiki/Voronoi_diagram). The result was a very nice and aesthetic structure, but far away to be built within the budget and time schedule propose by the client.

Even though the project kept this name, it was necessary to rethink and redesign the project to fit into the time schedule and the clients budget. It was then designed as a free form steel roof structure which kept the overall curvature of the initial design, but subdivided in honeycomb cells. The big advantage was the possibility to build this free form roof with 5 different modules (Fig. 2 and 3). This accelerated the production process and reduced obviously the cost. Also the assembly process could be standardised so that the whole 100 cushions could be installed in 12 days only (Fig. 4).

In Mexico is no local ETFE fabrication, therefore the ETFE cushions were designed and produced in Germany and the installation was under German supervision. The extrusion profiles came from the United States and the steel was produced in Mexico.

The roof is in operation since 6 month now, and has got a very good resonance from the Mexican people. It is a key project for the ETFE technology in Mexico, and new projects are already planned with this technology.

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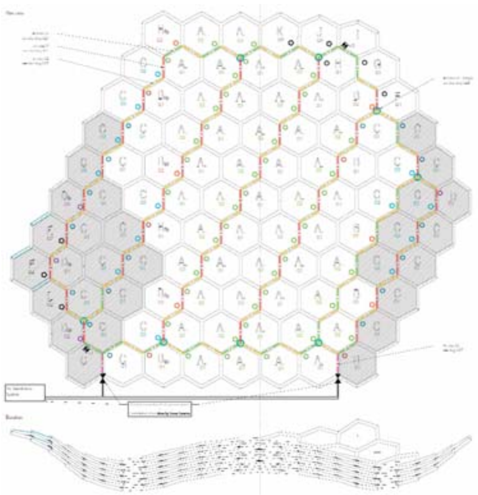


Figure 2: Cushion layout ©z3rch

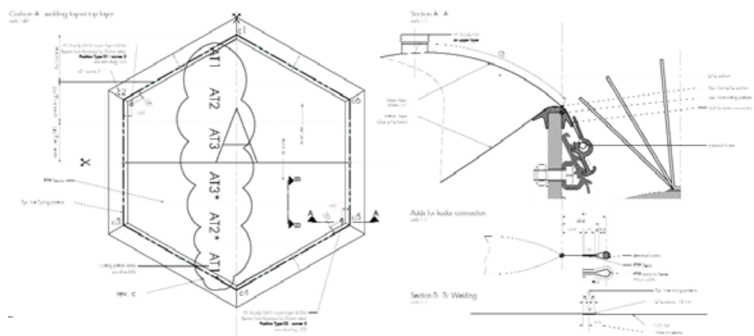


Figure 3: Cushion detail ©z3rch

Figure 4: Installation of the steel structure © z3rch

Name of the project:	Cubierta Voronoi
Location address:	Monterrey, Mexico
Function of building:	Shelter, Eye Catcher
Year of construction:	2014
Main contractor and Installation:	Lonas Lorenzo SA
Foil cushion contractor and Supervisor:	3dtex GmbH
Engineer for the foil:	z3rch
Cutting Pattern:	formTL ingenieure für tragwerk und leichtbau gmbh
Confection:	Novum Membranes GmbH
Supplier of the foil material:	Nowofol GmbH & Co. KG
Material:	ETFE foil 250µm and 300µm, clear bottom and white top
Structure:	Coated steel structure
Dimensions:	Hexagons approx. 16m² each
Covered area:	1600m²

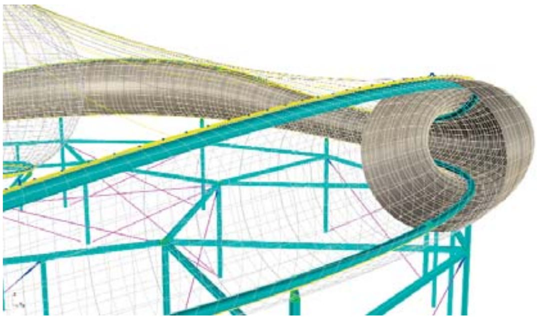
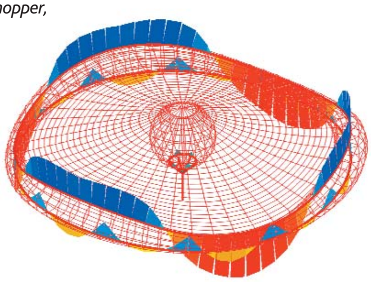


Figure 1: Developing the waving shape in Grasshopper, a parametric plug-in of Rhino3d and structural calculation



Inno-WAVE-tion

TENSAIRITY PRINCIPLE FOR AROUND-THE-WORLD TRAVELING PAVILION

Figure 2. Outside and interior views

Context

For an around-the-world traveling pavilion, designed by Silvain Dubuisson Architecte, Tentech engineered a light weight roof structure based on the so-called Tensairity principle. The project was commissioned by High Point Structures (from France) and Buitink Technology (from the Netherlands). The roof structure is part of the main pavilion for exposition WAVE, organized by BNP Paris-Bas, starting in Parc de la Villette, Paris, and now traveling through France and the world.
In this exposition the collective ingenuity and innovation of men is highlighted, showing examples of economic movements that occur worldwide, such as sharing-economy, co-creation and the creator-movement. In his design and materialization, architect Silvain Dubuission, aimed to reflect the enthusiasm, experimentally and fluidity of these movements.

Concept

The design was presented as sketches so the first task for the engineers was to digitally rebuild the shape. Using Rhino's Grasshopper the initially arbitrary shape could be rationalized in such extend that structural engineering became straightforward.
The roof structure has a UFO-like appearance. It consists of a 24m torus-shaped outer ring, a 4m sphere dominating the central area in the pavilion and a roof membrane stretched between the outer ring and levitated by the central sphere creating the distinctive design. The torus' centerline is divided in six parts and given two different inclinations. Next, a varying minor diameter creates a wave around the perimeter.
The waving shape of the torus is constructed in Grasshopper, a parametric plug-in of Rhino3d. This gave the opportunity to change and optimize the shape during design and engineering. Meshes created in Grasshopper were directly linked to engineering and patterning software, hence greatly organized the process (Fig. 1).

Structure

The structural system works as a combination of a tensile compression ring with Tensairity. The donut spreads the roof membrane and the central sphere's pressure controls its tension. The tension forces of the membrane are transferred into a steel ring inside the torus. A second steel ring transfers the forces to the columns below. The air pressure in the inflated tube is structurally twofold; it doesn't only support the upper steel ring, it also increases its buckling resistance. The combination of pressure elements and inflated elements are considered Tensairity.
The earlier rationalization of the design eased the production of the pavilion. For example, both steel tubes inside the donuts have, unlike their appearance, only one radius.

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Name of the project:	WAVE
Year of construction:	2014
Architect:	Silvain Dubuisson Architecte
Structural Engineering & membrane consultancy:	Tentech
Contractor:	High Point Structures & Buitink Technology
Fabric Roof:	Ferrari 402
Fabric Sphere & Torus:	Ferrari 1202
Covered Area:	490m^2

SLTE 2014

SIXTH LATIN AMERICAN SYMPOSIUM OF TENSILE STRUCTURES

The Sixth Latin American Symposium of Tensile Structures was held in Brasilia in September 2014. It was organized by the Polytechnic School of the University of Sao Paulo and chaired by Ruy Marcelo de Oliveira Pauletti. It was the sixth in a series of symposiums that began in São Paulo in 2002, followed by one in Caracas in 2005, in Acapulco in 2008, in Montevideo in 2011 and in Santiago de Chile in 2012. This edition has been held in conjunction with the annual Symposium of the International Association for Shell and Spatial Structures, which provided the opportunity to enlarge the scope of the conference. The main topics focused on recently-executed projects, as well as typology, design, materials, testing, current research, and education.

OVERVIEW

In his presentation, A. Capasso summarised his book: "Atopic architecture and membrane structures" (ISBN 978-88-8497-242-2), which focused on the use of tensile membrane structures in construction. The book aims to illustrate the contemporary place of these structures in architecture as a new structural archetype of the twentieth century. This approach involves textiles and fabrics, which define a contemporary architecture of lightness, brightness, and versatility, amounting to a new language with its own repertoire. Invited contributors to the book enrich the volume, and the blue sketches made by the author are delightful (Fig. 1).

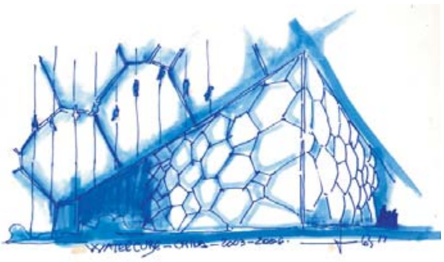


Figure 1. A. Capasso: Water Cube, Beijing 2008.

TYPOLOGY

K. Morishita introduced a classification of tension structures made of cables based on the tensile force level and on prestress application methods. According to this classification, recent designs and interesting installation examples were shown, with the pergola in the Marunochi Park Building standing out: an oval bicycle wheel around a column (Fig. 2 and 3).

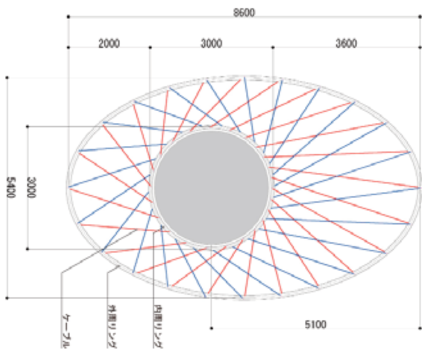


Figure 2. Pergola in the Marunouchi Park Building. Plan. M. Miyashita, I. Ogawa, T. Yoshihara, A. Okada & N. Miyasato, 2009. (Courtesy of K. Morishita).

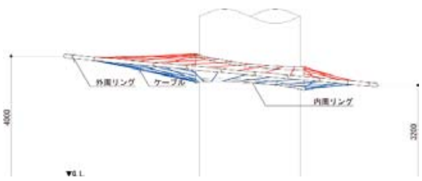


Figure 3. Pergola in the Marunouchi Park Building. Elevation. (Courtesy of K.Morishita).

J. Jimenez presented the "String Tens" system to stabilize regular and semi-regular polyhedral frames, with emphasis on formal and functional optimization through the use of tensile structures. An application was submitted to the student competition (Fig. 4).

Figure 4. A playground in a cube stabilized with halyards. Universidad Privada del Norte, Perú.

Figure 5. The form of the Wuhan Greenland Centre optimizes the wind effect.

DESIGN

According to N. Goldsmith, shape finding and form finding are different approaches to design. By shape, he meant an arbitrary formal geometry or algorithm that suits aesthetic requirements, whereas form implies organization and purpose, such as efficiency and appropriateness (Fig. 5).

J. Llorens referred to several types of recoverable lightweight foundations in tension for structural membranes with different materials, geometries, manufacturing, installations, efficiencies, and depths. A better understanding of their uplift behaviour and mode of failure allows for the pull-out capacity of anchors to be estimated confidently, encompassing the complex relationship between various modes of failure, anchor geometry, and soil properties.

MATERIALS - TESTING - MONITORING

F. Sahnoune presented the Serge Ferrari Group's new product Précontraint TX30, which focuses on innovation, durability, and recycling based on its new top coat technology and PVC formulation. Recycling has been a concern that has led to the Texyloop procedure, because

80% of the material output is generated by raw materials. Prominent examples of recycling PVC-coated polyester fabric are the Mound Stand Lord's Cricket Ground, the German Pavilion at the 2010 Shanghai Exhibition, and the 2012 London Olympic Aquatic Centre (Fig. 6): http://en.sergeferrari.com/lightweight-architecture/recycling-a-promise-is-kept

Figure 6. The London Olympic Aquatic Centre has been partly dismantled and the PVC-coated polyester has been recycled.

H. Li monitored a 1.5x1.5m monolayer cable net that supports a 60.05x21m glass curtain of the Shanghai Lujiazui Diamond Tower (Fig. 7) to investigate the wind environment and the wind-induced vibration characteristics. He showed that the spectrum of measured fluctuation of wind velocity was basically in agreement with the Davenport wind spectrum, and the probability distribution characteristics of wind-induced response did not correspond to a Gaussian distribution due to the structure's nonlinear stiffness.

Figure 7. Glass curtain wall, supported by a monitored cable net.

J. Chilton presented on-site monitoring results of the thermal behaviour of an atrium enclosed by an ETFE foil-cushion roof, including the distribution of air, mean radiant and foil surface temperatures, and incident solar radiation. The study showed heat gain on the upper level under warm sunny conditions, and convection heat transfer during the absence of solar radiation on overcast days (Fig. 8).

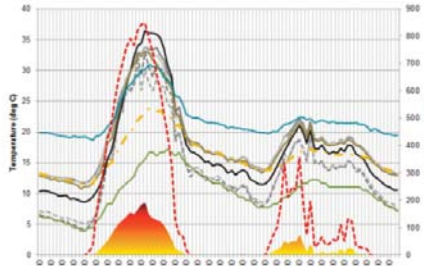


Figure 8. Typical thermal behaviour of the ETFE cushion during consecutive warm sunny and cloudy days in April 2014 (Nottingham).

ETFE

A novel form-finding method called the visco-plastic-forming process has been studied by M. Wu, using the unrecoverable deformation of ETFE foil to form the designed structural shape. This process makes the form-finding process of the ETFE cushion simpler. He performed uniaxial viscoplastic-forming tests, and found that strain contributes more to the creep process leading to the final unrecoverable deformation than does time.

Y. Li focused on biaxial creep tests of cruciform and bubble specimens of ETFE foil and their numerical simulation. He established coefficients of relation with uniaxial tests and simulated the bubble test by FEM with good agreement (Fig. 9 and 10).

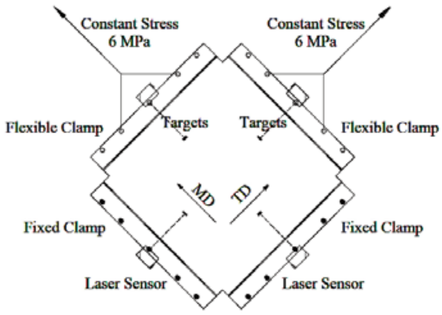


Figure 9. Cruciform creep test.

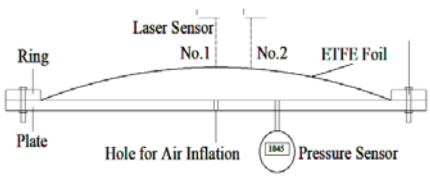


Figure 10. Bubble creep test.

E. Jeong reviewed the applicability of stretch fabrication using ETFE film. By manufacturing a study model (Fig. 11) and by performing tests, he was able to verify that stretch fabrication can be applied to films with various shapes and that it is an effective method for using the film under high stress.

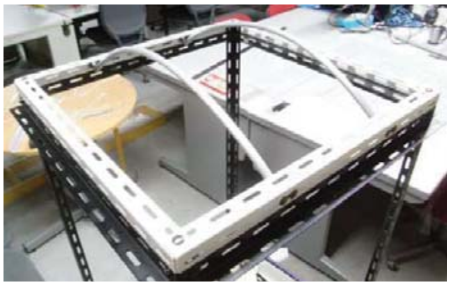


Figure 11. Parallel arch model to verify stretch fabrication.

W. Chen insisted on the flat-patterning way to determine the form of ETFE cushions. He developed an experimental set-up system of 2.5m triangular cushions, including photogrammetry and laser displacement measurements. Three phases were observed: form developing, creep, and creep-recovery (Fig. 12). The results demonstrated the applicability of the flat-patterning method and they unveiled more ETFE properties.

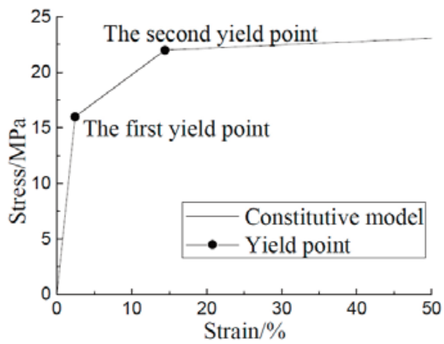


Figure 12. Simplified nonlinear constitutive model of ETFE foil.

CURRENT RESEARCH

The research of G. Filz & S. Schiefer provides a general framework for the creation of structurally-efficient forms composed of one or more intersecting anticlastic shapes assembled from planar modules, which can consist of planar elements. Due to planarity and material cuts, little data is necessary for the fabrication of the modules, which are easy to store, transport, and quickly assemble. In addition, changes of the sidewall angles generate architecturally-interesting patterns that can be rotated in space, while maintaining their structural performance and interlocking qualities (Fig. 13).

Figure 13. One full catenoid rotated in space. A compression-only form and a self-interlocking produce a simple joining through stacking.

Following the steps of E. Pérez Piñero and F. Escrig, C. Morales from the Universidad Veracruzana showed a lightweight, deployable, and flexible structure, based on the scissors mechanism. The design of the nodes was specially highlighted, because they need to be simultaneously adaptable to the different positions during the installation and dismantling processes, adjustable, and hinged. This allows for convergence of the bars in order to avoid additional eccentricities (Fig. 14).

Figure 14. Deployable structure developed experimentally by C. Morales, Facultad de Arquitectura de Poza Rica, Universidad Veracruzana.

A. Bloch proposed a new analytical formulation to predict the collapse of an inflatable beam, which agrees with experimental results. He applied the Virtual Image Correlation (VIC) method, which finds an analytical contour that best fits the physical boundary. This contour allows the identification of the mechanical properties of the inflatable beam, and it validates the model.

EDUCATION

Professor E. Cortés of the Faculty of Architecture and Design at the "Pontificia Universidad Javeriana" in Bogotá, reported on the module "Architecture in Concrete," that includes the application of fabric flexible formwork with the aim of obtaining different textures, complex curves, and geometric forms (Fig. 15).

Figure 15. Different textures obtained with fabric formwork.

J. G. Oliva demonstrated teaching procedures practiced for several years at the Faculty of Architecture at the "Universidad Nacional Autónoma de México" applied in the teaching of design and construction of tensile structures to architecture and civil engineering students. The results obtained were demonstrated with projects carried out by the students (Fig. 16). From the fusion of mechanics and geometry, a new term emerged called MECHAMETRY, which could be defined as the application of Mechanics and Geometry to the architectural and structural design of lightweight structures.

Figure 16. The "Trajinera" designed by a student of the UNAM won the IFAI International Achievement Award competition in 2007.

O. F. Avellaneda in turn exposed his experience with the "Deployable and tree-like structures workshop" of the School of Architecture in Sant Cugat del Vallès, Spain. Its practical and theoretical approaches are aimed at learning the design of non-conventional structures in architecture, using physical and digital tools (Fig. 17). The students submitted the winner entry to the IASS-SLTE 2014 competition.

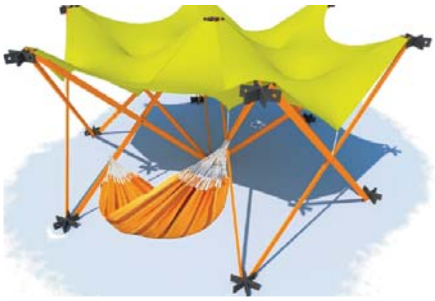


Figure 17. Itinerant book house for outdoor reading:
http://smia-experimental.com/2014/03/06/itinerant-book-house/

RECENT PROJECTS

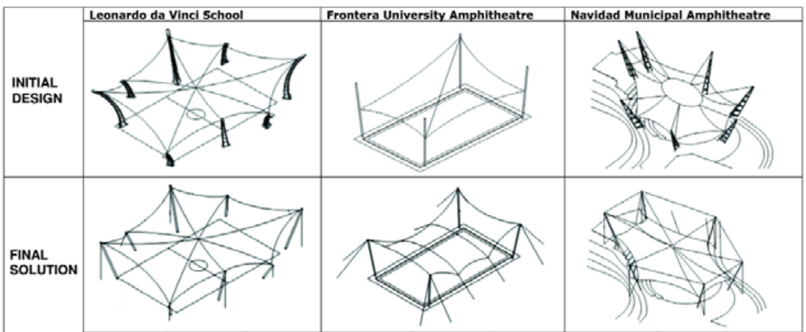
In addition to the Brazil 2014 World Cup Arenas, which are well-documented in the literature, some interesting works were presented at the Symposium. A selection is shown below.

N. Fiedler, who is a pioneer on the use of structural membranes in Brazil, - exposed some of his works. After manufacturing tents in his garage, developing software, and meeting Frei Otto, he produced more than 18.000 projects-, 1.760 of which have been built (Fig. 18). A selection of them is available at: http://www.fiedler.eng.br

Figure 18. Nelson Fiedler: 14.000m² temporary roof for Petrobras, 30m high in Itaborai.

F. Alvarado, from "Espacio Cubierto, SA" Chile, presented three cases of design optimization: the Leonardo da Vinci School, the Frontera University Amphitheatre and the Navidad Municipal Amphitheatre. Three criteria were adopted in the comparison: sections, unit weight, and reactions. Differences between starting designs and final solutions were considerable (Fig. 19).

Ch. Garcia-Diego & H. Pöppinghaus, from IF Group, described the envelope of the National Gymnastics Arena in Baku. It is a lightweight textile ribbon structure that wraps around the curved perimeter of the building on three different levels, suspended from the roof-top, and supported on an undulating steel structure made of circular, hollow sections (Fig. 20).



	Leonardo da Vinci School			Frontera University Amphitheatre			Navidad Municipal Amphitheatre		
	Initial (up)	Final	%	Initial (up)	Final	%	Initial (up)	Final	%
$Ø_{MAX}$	813x10,31	168,3x7,11	-79%	168,3x10,97	101,6x8,08	-40%	323,9x25,4	273x10	-16%
Kp/m²	15,9	3,08	-81%	15,47	2,95	-81%	57,27	7,92	-86%
Reactions	204 kN 1598 mkN	213 kN 0 mkN	+4% Supressed	61 kN 31 mkN	204 kN 0 mkN	+293% Supressed	292 kN 54 mkN	330 kN 0 mkN	+13% Supressed

Figure 19. Comparative values of three initial and final optimized designs by "Espacio Cubierto," Chile.

Figure 20. Baku National Gymnastics Arena, IF Group.

R. Santomauro presented some relevant examples of membranes developed in Uruguay during the last 15 years. He discussed the interaction between technological and constructive learning, market requirements, architectural programs, specific uses, collaborative teamwork, resolution problems, and choice of appropriate materials. He emphasized what can be accomplished with light-weight non-traditional methods, highlighting the new expressions that are attained (Fig. 21). He finally referred to the current teaching practices at the Faculty of Architecture of the "Universidad de la República," Montevideo.

Figure 21. Olimar River Amphitheatre, P. Pinto & R. Santomauro, Uruguay.

G. Carella, Senior Architect of CIDELSA, Peru, introduced his personal opinion about membrane architectural design, and how it has evolved over time. He mentioned four basic concepts to be considered and managed properly in order to develop a good project:

- geometrize the idea into a shape that can be drawn, measured and built,
- configure the structure for stability
- modulate, vary, and repeat
- relate the environment, structure, and membrane

All concepts were illustrated with a wealth of examples built by CIDELSA, Perú (Fig. 22).

Figure 22. CIDELSA: Central Square, Paseo Quilín Mall, La Florida, Santiago de Chile.

The projects presented at the Symposium that were best adapted to the environment, most sustainable, and most ecological were the "Ecogalpoes," (ecopavilions) developed by Bambutec, a company formed by researchers and former students of the Catholic University of Rio de Janeiro (Fig. 23). The "Ecogalpoes" employ a prefabricated structural system of spatial trusses made of bamboo treated with raw clay, natural fibres, and castor oil polymers that ensure durability and protection from weathering. The connections employ ropes and textile craft moorings, and the roof is covered and stabilized by tensioned, textile canvas. The lightness and mobility of structural components, manufacturing techniques, and materials employed favour the design of new forms for construction, the clean application of local installation, and the formation of a new profile of skilled builders, resulting in agile execution, little waste & noise, low power consumption and low environmental impact.

Figure 23. "Ecogalpoe" Bambutec: http://www.bambutec.com.br

From the same University, a low-tech prototype was presented to reconcile tensile structures technology with tradition. It is a prestressed frame and cable net supporting the

Fig. 24. Low-tech prototype. Universidad Pontificia Católica de Sao Paulo

membrane (Fig. 24). Since the prototype is still under development, we hope to see the results in the next Latin American Symposium.

STUDENT COMPETITION

The competition for design projects that make use of textile, cable, or tensegrity structures was open to architecture, engineering, and design students. The jury was made up by Débora Frazatto, Architect IAB SP, Brazil, professor Reyolando M.L.R.F. Brasil, Universidade Federal do ABC, Brazil, professor Juan Gerardo Oliva Salinas, UNAM, México, and professor Roxana Garrido Sánchez, Universidad Ricardo Palma, Perú. The jury gave the award to Omar Avellaneda and Natalia Torres (Fig. 25) supervised by professor Ramón Sastre, Sant Cugat School of Architecture, Universitat Politècnica de Catalunya.

Fig. 25. O. Avellaneda & N. Torres, 2014: Temporary deployable school. Winning entry to the SLTE student's contest.

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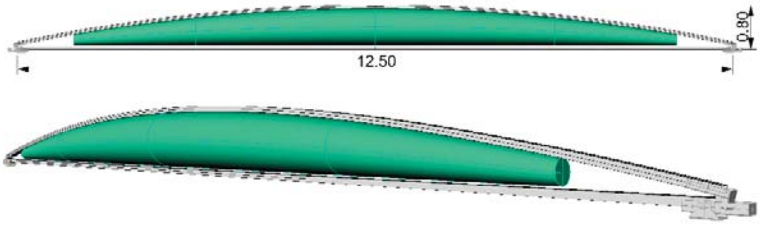
LA TENSORED.
The Latin American Network of Tensile Structures

The Sixth Symposium was also an occasion to meet the members of the Latin American Network of Tensile Structures. This group consolidated their association, approving the statutes and defining the registration. The VII Symposium 2016 in Guatemala was announced, and representatives of Peru and Argentina showed an interest in organizing the VIII and IX editions in 2018 and 2020, respectively. More information and the full text of the proceedings are available at: http://www.latensored.org

MACO TECHNOLOGY SRL

DESIGN COMBINED WITH EFFICIENCY

Hospitality based on Tensairity®



The world of temporary events is always looking for new forms, shapes and products able to offer something different from standard solutions. Velocity of assembling, durability when stockpiled and minimum volume of transportation are the key features for effective solutions. In the motorsport sector, these characteristics are stressed even more: structures should be set up as fast as possible (maximum 5 hours) by an unskilled crew of people and should be packed to travel for thousands of kilometres in two semi-trailer. The use of a crane or any other lifting devices for the assembling process is considered a disadvantage.

Tensairity®

Any inflatable technology would be perfect for this kind of applications but standard inflatable systems based on bulky and unstable elements often do not match with the quality standard of the clients involved. On the contrary, the Tensairity® principle fulfils the majority of the demands listed above. It combines the beauty of aerodynamic girders with lightness and reduced volume when packed. A very promising application pops up when the area between two trucks or containers should be sheltered with a roof. In the paddock area, semi-trailers are parked at a distance which varies from a minimum of 4m to a maximum of 12m according to the category of the race and the budget of the team involved.
Two different examples are presented in the next paragraphs.

Ducati SBK hospitality

The roof consist of a series of 5 tensairity® asymmetric spindle-shaped girders of 12m span inflated at low pressure (150 millibar) able to withstand load generated from winds at 28m/s. Standard aluminium keder profiles are used as tension and compression elements. The inflated hull is made of a 300gr/m^2 PU coated polyester fabric which combines good structural properties and high translucency. The beams, once deflated, can be stored in one piece, on the top of one of the semi-trailer without detaching the hull from the aluminium part. Within 6 hours, the 156m^2 roof together with the front and back facade is installed by a crew of 5 people.

Audi sailing hospitality

Audi is the main sponsor of the Audi Tron sailing series and has set up the hospitality based on 2 containers which are arranged at a distance of 12m. The containers are 8m long. Therefore, the beams are disassembled and split in shorter elements (the longest is 6m) which can be stored in the containers. The roof consists of 3 beams for a total surface covered of 100m^2.
The area between the beams is covered by a double layer system which slides into the keder rails of the Tensairity® girders. Within 8 hours and with 4 people, the full hospitality is positioned and assembled completely including floor and furniture.

Name of the project:	Ducati SBK Hospitality
Client (investor):	Ducati
Covered surface (roofed area):	156m^2
Name of the project:	Audi sailing series hospitality
Client (investor):	Audi sailing series
Covered surface (roofed area):	96m^2
Location address:	(temporary)
Function of building:	Hospitality (temporary)
Type of application of the membrane:	Inflatable/tensairity®
Year of construction:	2014
Architects:	Maco technology srl
Structural engineers:	Maco technology srl
Consulting engineer for the membrane:	Maco technology srl
Engineering of the controlling mechanism:	Maco technology srl
Main contractor:	3B fabbrica tende
Contractor for the membrane (Tensile membrane contractor):	3B fabbrica tende
Supplier of the membrane material:	Contender sailcloth
Manufacture and installation:	3B fabbrica tende
Material:	PU coated polyester

Controls

All Tensairity girders incorporate a RGB-LED lighting system to enlighten the area underneath the roof but also to light up the beams. The system is controlled by an app which allows users to modify the lights through a smartphone.

The blower, which compensates the loss of air due to temperature shift, is programmed to keep the pressure of the beam in the design pressure range. In addition, it is also remotely controlled: the hospitality is equipped with a sim card connected to the 3g internet network. It is possible to connect to the control panel from anywhere and modify the pressure of the beams, check the operative time of the blower and the last inflation ramp too. The blower can be remotely programmed in “Standard”, “Strong wind” or “Deflation mode”.

The application of Tensairity® to temporary structures opens new scenarios which look promising and exploit the advantage of the Tensairity principle deeply.

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Out of this work with Tensairity for the hospitalities, the startup Tensairity Solutions srl was founded in December 2014. Based in Brescia, Italy, the company owns the rights on the Tensairity technology. The goal of Tensairity Solutions srl is to develop, produce and market structures based on the Tensairity principle. Temporary and permanent products such as hospitalities, tents, roofs and bridges are developed for the civil and other sectors.

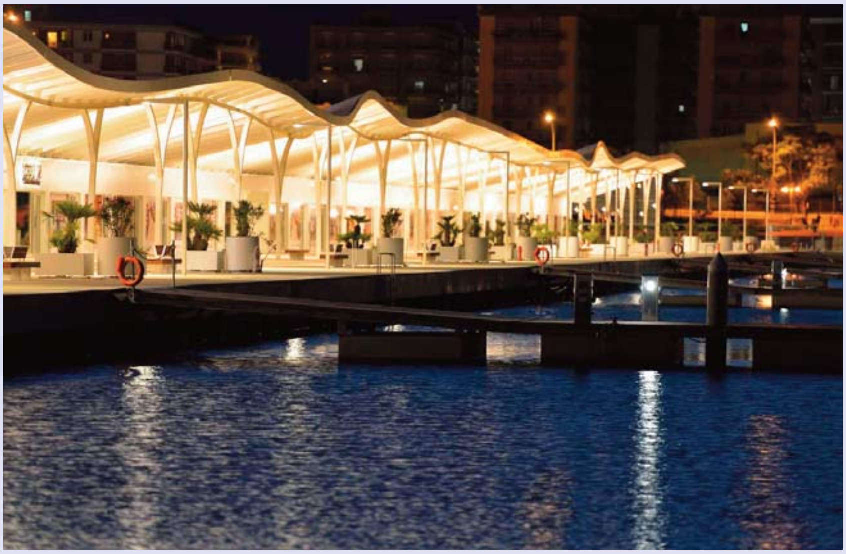
For more information:
Tensairity Solutions srl
Via Ugo la Malfa 86/88
25050 Provaglio d’Iseo Brescia IT
Info@tensairitysolutions.com
www.tensairitysolutions.com

PM ENGINEERING S.R.L.

Cover "under-wave" at the tourist port

Manfredonia, Foggia, Italy

A PROMENADE CANTILEVER



Context

The construction consists of a number of cantilevers covering the entrances of the shops at the tourist port of Manfredonia. The covering named “under-wave” covers a surface of 8,50m x 300m. It is supported by a steel frame having a linear shape on the back side, while the front side has a shape referring to the sea waves.

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Name of the project:	Manfredonia tourist port cantilever
Location address:	Manfredonia, Foggia, ITALY
Client (investor):	Impresa Taddei
Function of building:	Promenade cantilever
Year of construction:	2013
Architects:	PM Engineering SRL
Consulting engineer for the membrane:	Eng. Massimiliano Scaburri, Senago Italy
Supplier of the membrane material:	Naizil SPA
Manufacture and installation:	PM Engineering SRL - Plasteco Milano
Material:	Naizil BIG COVER PVDF TITAN W
Covered surface (roofed area):	4600m²

Project

The covering name “under-wave” consists of 16 inclined galvanised steel structures with the dimensions approximately 11mx12m. The single layer covering membrane, which shape has been stabilized by pre-tensioning, has been manufactured in PVC coated Polyester fabric type 2 – weight 900grs/m² – tensile strength 400 daN/5cm – tearing strength 50 daN with TITAN W surface finishing.

It is a fluoridised resin to which a special degree of titanium dioxide is added – both are conveyed in an acrylic resin. The known characteristics of fluoridised polymers (PVDF) in terms of resistance to ageing and to UV rays have been further improved. The different sheets have been welded by high frequency welding. The outer edges of the membrane have been anchored by aluminium profiles and self piercing screws.

The structure has been calculated according to EUROCODE 1 standards. Accidental loads taken into consideration were the following:

Snow: qs 0,90 kN/m²
Wind: qw 1,137 kN/m²

ROUND ROBIN EXERCISE 2: INTERPRETATION OF BIAXIAL AND SHEAR TEST DATA

This is the second round robin exercise to be run by the TensiNet Analysis & Material Working Group (AMWG). The first exercise was a comparative study of analysis methods and results for a set of well-defined membrane structures. The results were published in 'Engineering Structures' and the full paper is available here: http://eprint.ncl.ac.uk/pub_details2.aspx?pub_id=184881 (click on link to 'Full text file 1' - no journal subscription required)
Round robin 2 will follow a similar format – a comparative exercise carried out by practitioners and Universities worldwide, with the anonymized results presented at conferences, in TensiNews and in academic journals. Contributors will be acknowledged in all disseminations.
The exercise is being organised by Dr Ben Bridgens and Prof Peter Gosling. The email address for correspondence, including return of completed submissions, is: tensinet.amwg@ncl.ac.uk.

1. What is a "round robin"?

A **"round robin"** exercise refers to an activity (e.g. measurement of properties, structural analysis, or physical experiment) performed independently by different groups, institutions, or companies. Each participant will provide an independent solution to a particular problem. Once the exercise is complete the solutions are reviewed and analysed. The collective outcomes are then used to produce a number of key conclusions and recommendations.

2. The purpose of the round robin exercises

Firstly, and most importantly, it should be noted that the round robin exercise is not a competition. The round robin exercise aims to determine the current state of activity in a particular field and to assist in the development of that field.
It is well known that coated woven fabrics exhibit complex, non-linear biaxial and shear behaviour. Variations in biaxial and shear test methods and interpretation of the results from these tests introduces considerable uncertainty in material properties for use in analysis. **This exercise will focus on the interpretation of biaxial and shear test data, i.e. the assessment of the stiffness of architectural fabrics and how these properties are represented in the analysis of a structure.**
The work of drafting a Eurocode for Membrane Structures by CEN/TC 250 Working Group 5 is underway. It is important that the EN standard accurately reflects the methodologies and practices used in the analysis and design of membrane structures. Interpretation of test data and the method of incorporating this information in membrane analysis is an important part of this. This is clearly important at the European level, and also for international practice for which the EN standard for Membrane Structures may be adopted. This is particularly relevant given the link between the CEN and ISO organisations through which CEN standards may be adopted worldwide.

3. Principles

The round robin exercise is proposed as a non-commercial activity. It is intended to serve the purpose of advancing scientific knowledge and engineering practice in the analysis and design of membrane structures. Participation in the round robin exercise is further based on the following principles:

- Involvement in the round robin exercise is voluntary,
- Completion of the round robin tasks is undertaken without fee and liability,
- The completed tasks will not be used outside the remit of the round robin exercise and will not be made available in a format that could be used for design purposes by a third party,
- The round robin outputs will be made anonymous in two ways: (I) participants will be acknowledged in all dissemination, but all results will be reported anonymously, (II) manufacturers who provide materials for the exercise will be acknowledged in all dissemination, but fabric materials will be described generically (e.g. Type III PVC-polyester) such that the results cannot be associated with a particular material.

4. Overview

Round robin 2 will operate in two distinct ways depending on the type of participant:
Route A: interpretation of 'typical' biaxial and shear test data provided by Newcastle University. Route A is for consultants, analysts, designers and fabricators who interpret biaxial test results provided by others. Newcastle University will provide data from 'typical' biaxial and shear tests. Participants will be provided with biaxial and shear test data for a selection of fabrics, in both graphical form and tables of stress and strain values (.csv and .xls formats). Full details of the Newcastle University biaxial and shear test equipment will be provided. In addition, participants will be provided with a description of the structure that the fabric is being used for, including stress plots, in case this information is required to inform their interpretation of the test data. Participants will report how the test data is analysed and incorporated in their analysis (see Section 4 below for details).
Route B: carry out biaxial and/or shear test and interpret results. Route B is primarily for test houses, but may also apply to consultants and analysts, whose method of interpretation relies on results from a particular test protocol. Participants will be provided with fabric samples, and a description of the structure that the fabric is being used in, including stress plots, in case this information is required to inform their testing and interpretation of the test data. Participants will carry out fabric testing and then provide details of how the test results are interpreted (see Section 4 below for details).
Participants may take part in both routes – providing interpretation of typical test data, and carrying out their own tests and interpreting those results. Alternatively it may be the case that an organisation follows one route for interpretation of shear results, and the other route for interpretation of biaxial results. The guiding principle is that participants should carry out whatever methodology they would usually use on a commercial project.

> Note that Round robin 2 is **NOT** a comparative material testing exercise. We do not expect different organisations to repeat the tests detailed below (Section 6). Further testing (Route B) is only required if a particular method of interpretation relies on data from a particular test protocol.

5. Reporting of results

A standard form will be provided to report the results of the exercise, which will ask for the following information:
5.1 Route A: interpretation of 'typical' biaxial and shear test data provided by Newcastle University

A1. Describe how the biaxial stiffness of the fabric is incorporated in your analysis. A typical response may be specification of elastic moduli and Poisson's ratio, but we are also interested in other methods.

A2. Describe how you determined the biaxial stiffness parameters described in A1. For example, methods include the MSAJ strain minimisation approach or calculating gradients from stress-strain plots. Provide as much detail as possible – attach additional sheets as required. Report if and how the details of the proposed structure (see Section 4) were incorporated in your interpretation of the test results.

A3. Describe how the shear stiffness of the fabric is incorporated in your analysis. A typical response may be: specification of shear modulus, but we are also interested in other methods.

A4. Describe how you determine the shear stiffness parameters described in A3. For example, methods include calculating gradients from stress-strain plots or using typical values based on biaxial stiffness. Provide as much detail as possible – attach additional sheets as required. Report if and how the details of the proposed structure (see Section 4) were incorporated in your interpretation of the test results.

A5. For each set of test results (PVC-polyester, PTFE-glass, and so on) provide the values that would be used to represent the biaxial and shear behaviour in the analysis. A typical response may be values of elastic moduli, Poisson's ratio and shear stiffness for each material, or other values as described in A1 and A3.

5.2 Route B: carry out biaxial and/or shear test and interpret results

B1. Describe the principles of operation of the biaxial test equipment that you have been used for this exercise.

B2. Provide details of the biaxial test protocol that has been used. This would typically take the form of a series of times and force values in warp and fill directions. Report if and how the details of the proposed structure (see Section 4) informed the details of the test protocol.

B3. Describe the principles of operation of the shear test equipment that you have used for this exercise.

B4. Provide details of the shear test protocol that you have used. This would typically take the form of a series of times and force values in warp and fill directions. Report if and how the details of the proposed structure (see Section 4) informed the details of the test protocol.

B5. Provide your biaxial and shear test results, in both graphical form and tables of stress and strain values (.csv and .xls formats).

B6. Complete A1 – A6 (above) to describe how the test results are interpreted.

6. Proposed biaxial and shear test protocols for Route A – for comment

The following test protocols are proposed as they are widely used in industry, but we welcome any comments or suggestions for modifications.

6.1 Proposed biaxial test protocol

Cycles	Description	Warp load (percentage of warp UTS)	Fill load (percentage of fill UTS)
1-3	1:1 conditioning	25%	25%
4-6	1:1	25%	25%
7-9	2:1	25%	12.5%
10-12	1:1 conditioning	25%	25%
13-15	1:2	12.5%	25%
16-18	1:1 conditioning	25%	25%
19-21	1:0	25%	Prestress
22-24	1:1 conditioning	25%	25%
27-29	0:1	Prestress	25%

Notes: UTS = strip ultimate tensile strength (kN/m), Values given are peak values, loads return to prestress between cycles, Each cycle takes 10 minutes (5 minutes increasing load + 5 minutes decreasing load).

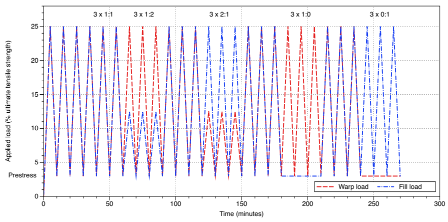

Figure 1. Proposed biaxial test protocol

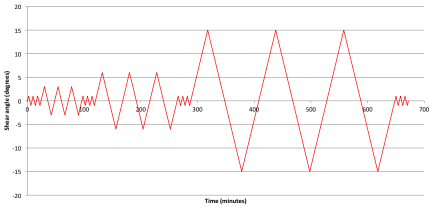

Figure 2. Proposed shear test profile.

6.2 Proposed shear test protocol

Cycles	Shear angle
1-3	+/- 1 degree
4-6	+/- 3 degrees
7-9	+/- 1 degree
10-12	+/- 6 degrees
13-15	+/- 1 degree
16-18	+/- 15 degrees
19-21	+/- 1 degree

Note: The shear test is displacement controlled – a shear angle is imposed and the shear force required to achieve this deformation is recorded.

7. Timeline

March 2015	**Round robin 2 is launched.** **Proposed test protocols are provided for comment.** **Manufacturers are invited to volunteer to provide fabric samples for testing.** We are looking for one medium weight example of each material – e.g. 1 x Type III PVC-polyester, 1 x PTFE-glass, 1 x silicone-glass, 1 x Tenara?, 1 x other interesting materials…? It is anticipated that no more than 10 linear metres of each fabric will be required, and the amount will be minimised once we know how many participants are taking Route B. **Participants are asked to register their interest in the exercise by emailing Dr Ben Bridgens at tensinet.amwg@ncl.ac.uk and to specify whether they want to take Route A or Route B** (in which case they will require fabric samples).
June 2015	Test protocols for Route A are finalised.
	samples are delivered to Newcastle University for testing and distribution to participants taking Route B.
August 2015	Full details of round robin 2 are circulated to participants including all test data and reporting forms.
October 2015	Deadline for return of results to tensinet.amwg@ncl.ac.uk
Nov 2015 – March 2016	Analysis and dissemination of results

Dr Ben Bridgens
Deputy Chairman of the TensiNet Analysis and Materials Working Group, Newcastle University, School of Civil Engineering and Geosciences
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NEW CALL

ROUND ROBIN EXERCISE 3: COLLATING WIND TUNNEL DATA FOR THE BASIC SHAPES OF TENSIONED SURFACE STRUCTURES

The first Round Robin Exercise, launched by the TensiNet Working Group Materials & Analysis, was a comparative study of analysis methods and results for a set of well-defined membrane structures. The results were published in 'Engineering Structures' and the full paper is available at http://eprint.ncl.ac.uk/pub_details2.aspx?pub_id=184881.
The second Round Robin Exercise, just launched by the TensiNet Working Group Materials & Analysis and WG4 of the COST Action TU1303 Novel Structural skins, follows a similar format. A comparative exercise will be carried out by practitioners and Universities worldwide on the interpretation of biaxial and shear test data, i.e. the assessment of the stiffness of architectural fabrics and how these properties are represented in the analysis of a structure.
The third Round Robin Exercise is launched by the TensiNet Working Group Specifications and WG5 of the COST Action TU1303 Novel Structural skins and aims at collating wind tunnel data for the basic shapes of tensioned surface structures.

Membrane structures are typically applied in outdoor applications as sheltering or facade element. Therefore, they are subject to the natural elements and must be designed to resist these external loads. Especially in the field of wind analysis accurate wind load determination on these pre-tensioned lightweight structures has to be investigated, as stipulated in the European Design Guide for Tensile Surface Structures (Forster et al., 2004). The need for accurate wind-load Standards on these structures has also been stressed in several international publications (Gorlin 2009), stating the lack of the current Standards (ASCE) in governing the wind-resisting strength for these structures and the need for an industry-wide set of Standards.

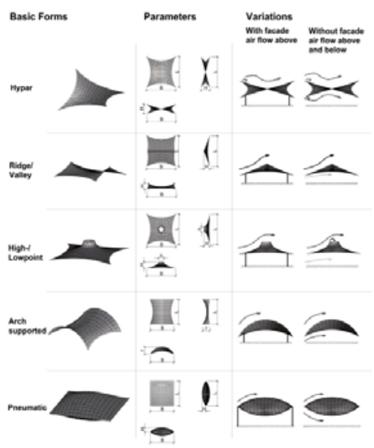
In general, conventional Codes on wind design give upper bound values for the majority of structures (conventional building typologies), but the level of uncertainties increases as the building configuration deviates from the codified Norms. The structural analysis of membrane structures can only benefit from improved and more accurate wind load estimations and analysis methods. Currently, wind loading on tensioned surface structures is often based on rough approximations referring to flat or spherical shapes of EN 1991-1-4, while the special nature of the textile covers are not taken into account (EN 1991-1-4 and EN 13782, which refers to EN 1991-1-4 for wind loading, is insufficient for tensile surface structures, dynamics actions, flexible deformations etc.). Extrapolation from the Standard may be acceptable for static structures, but for flexible membrane structures, with a non-uniform curvature, additional wind investigation has to be performed. Appropriate wind pressure data is essential to provide confidence in the analysis and design process, and to ensure the development of the Eurocode that will facilitate the safe and efficient design of membrane structures.

Therefore in a first stage, research institutes, universities, specialized laboratories and engineering offices are asked to provide the available experimental data for basic forms in a uniform way to allow comparing and interpolating the information. Further, where crucial data is missing new experimental campaigns should be launched. In a second stage, engineers and research institutes experienced in performing wind tunnel tests are invited to perform standardized **wind tunnel test** on the **basic membrane forms**. The standardized results could be used for a prospective Eurocode on wind loading for tensile surface and shell structures.

The Round Robin exercise is proposed as a non-commercial activity. It is intended to serve the purpose of advancing the scientific and engineering practice in the analysis and design of membrane structures. Participation in the Round Robin exercise is voluntary and undertaken without fee. Contributors to the exercise will be acknowledged in all disseminations (journal papers, reports etc.), while the ownership of the data will remain with the participants.

Timeline

January 2015	**Round Robin Exercise 3 is launched.** Research institutes, universities, specialized laboratories and engineering offices are invited to volunteer to provide available experimental or analytical data for wind analysis of basic membrane shapes. Participants are asked to register their interest in the exercise by emailing Eng.-Arch. Jimmy Colliers at jimmy.colliers@vub.ac.be.
June 2015	Full details of Round Robin Exercise 3 are circulated to participants.
September 2015	Deadline for return of results by emailing to jimmy.colliers@vub.ac.be.
Oct 2015 - Jan 2016	Analysis and dissemination of results.



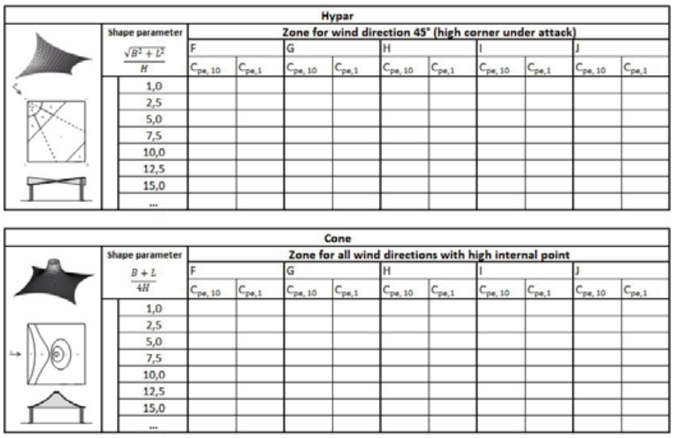


Figure 1.
Left: Overview of basic shapes, established by Alex Michalski
Right: Example of a simplified data template (hypar, cone)

cost EUROPEAN COOPERATION IN SCIENCE AND TECHNOLOGY

NOVEL STRUCTURAL SKINS COST ACTION TU1303

Specifications Working Group TensiNet

GROUPE ALTO

Removable reception hall
CONTEMPORARY MOROCCO EXHIBITION
Arabic World Institute in Paris, France



Introduction

19th of August 2014: Shake hand with Jack Lang in his office in the Arabic World Institute for a challenge to deliver a presentation hall for the Moroccan Contemporary Exhibition due to last four months after delivery date.
14th of October 2014: Inauguration by Morocco representative and our French President François Hollande.
Between those two dates a tough race arose to design and deliver a 600 m^2 foundation-free tensile hall on schedule.

Concept

As for the technical design, it was very early decided to undertake a parametric three dimensional model for it was obvious that our architectural partnership would lead to many different sketches.
Amongst them occurred two main options regarding sides and access to the tent: the first one emphasizes a free access all around the peripheral outskirt leading to several little posts as in traditional Berber tent whilst it was finally preferred during the development process to let the overall shape reach down the ground. In this last option, at least two accesses had to be provided on one long side and another facing it on the other one. This was operated by just adding over the height randomly distributed inner masts, two small ones to smoothly and discreetly lift the membrane on its sides, which of course disturbed once again, among several other trials, the whole form-finding process.

Design

Thanks to our early thorough scripting, we were able to operate these ultimate changes before choosing the best patterning.
To be noticed, a young architecture student trainee at Groupe Alto, blended three applications together, the first being the renowned Rhino CAD application, merged with two dedicated plugins which are Grasshopper for parametric sake and the second Kangaroo for relaxation method of form finding. The custom made process enabled several potential parameters to be adjusted in whatever order, amongst which:

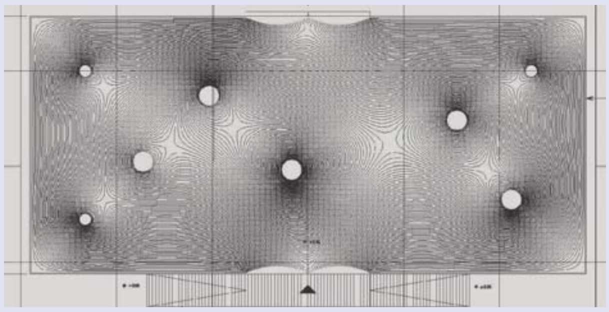
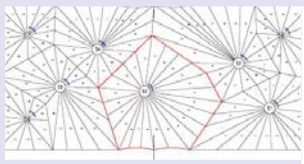
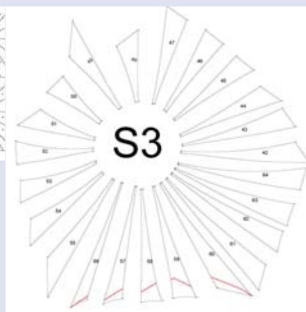
- Height of mast,
- X, Y position of top and bottom,
- Circular hollow section diameter of each mast,
- Suspension top ring tube diameter and overall radius,
- Height of conical top cap.

Intermediate step to be undertaken was the welding lines choice. With unequal sub-areas arising from the height randomly distributed Chinese hats; the task was a rather aesthetic approach…but nevertheless taking into account the wish of coordinated fits through two adjacent sub-areas. Another design topic laid on how to stabilize this 600m² tensile surface reaching 9m at upmost mast, avoiding hard foundation plus a site over a car park.
The clue was obviously a ballast solution, but with minimal volume and moreover minimal height because or the necessary 4% slope ramp length to be developed for disabled visitors.
As membrane tension are largely slanted over mere vertical uplift, a more efficient rubbing coefficient than classical 0,4 between steel and stone had to be found. The project being ephemeral, an issue was to stick a neoprene foam band under each steel box in such a way to enhance the coefficient to a rather unexpected 1,1 ratio even during rain fall… !
Thus the overall ballast weight consisting of 10mm thick steel plates reduced from 88tons to merely 29tons for 10cm thickness, allowing a relative small gap to step inside the tent.

Installation

At last, the worst was still yet to come; how to manage covering the modern PES/PVC tent with camel hair woven canvas. The idea we cope with consisted in sewing in shop a small fabric PVC coated strip under each roll of camel canvas, and then welding them, on site dot after dot, with a hot air gun. It worked perfectly except for a forgotten side effect which arose when rain drenched the canvas and shrinked it at a dramatic rate… Fortunately, the rigging team could tame the damage on time by pragmatic, yet efficient cuts on the camel strips and the project was delivered on the very day of opening. Allah Akbar

Name of the project: Contemporary Morocco Exhibition removable reception hall	
Location address:	IMA (Arabic World Institute), Paris, France
Client (investor):	IMA and Contemporary Morocco Crafts
Function of building:	Removable provisory reception 600m² hall
Type of application of the membrane: Tensile on several non-symmetrical Chinese hats	
Year of construction:	2014
Architects for general concept and interior exhibition:	Tarik Oualalou Kilo
Technical conception, stabilization and development for the all structure +(steelwork shop drawings and cutting pattern):	Groupe Alto
Structural engineer:	Marc Malinowsky (Manager & engineer of Groupe Alto)
Main contractor and installation:	Normandie- Structures
Supplier of the membrane material:	Serge Ferrari
Manufacture Sub-contractor :	ACS
Material:	PES / PVC Type I
Covered surface (roofed area):	600m²

Marc Malinowsky, Group Alto
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www.groupealto.fr

TENSINET - COST ACTION TU1303 SYMPOSIUM 2016

NOVEL STRUCTURAL SKINS 26-28 OCTOBER 2016

The TENSINET - COST ACTION TU1303 SYMPOSIUM 2016 will be organised by the Tensinet association, Cost Action TU 1303 Novel structural skins and Newcastle University as hosting university. The symposium will be held at the old Science Museum located at the University site.

The upcoming symposium will be the fifth of a series of symposiums that began in Brussels in 2003: *Designing Tensile Architecture and continued in Milano in 2007: Ephemeral Architecture: Time and Textiles, Sofia in 2010: Tensile Architecture: Connecting Past and Future and in Istanbul in 2013: [RE]THINKING Lightweight Structures.*

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

The focus of the symposium **Novel structural skins** is divided into 5 main topics (& an extra topic "Others").

1. New applications of structural skins and new concepts
2. Sustainability and Life Cycle Analysis of structural skins
3. Building physics and energy performance of structural skins
4. Materials and analysis
5. From material to structure and limit states: codes and standardization
6. Others

These research topics are well related to the built environment. During the three days symposium, an 'open session' is programmed on Wednesday afternoon and evening. Prominent experts in the membrane architecture and engineering world will present their inspiring built projects to demonstrate the audience the multitude of possibilities lightweight structures have.

The scientific committee welcomes besides the 5 main topics also abstracts and papers on built projects (from small to extra-large scale), especially if they illustrate advancements related to these topics.

Local Committee

Newcastle University (hosting): Peter Gosling (chair) & Ben Bridgens
University of Nottingham: John Chilton & Paolo Beccarelli
Tony Hogg Design: Benedict Whybrow

Scientific Committee

New applications of structural skins and new concepts

- Prof. Lars De Laet (Vrije Universiteit Brussel, Belgium)
- Prof. Tim Ibell (University of Bath, UK)
- Prof. Philippe Block (ETH Zurich, Switzerland)
- Prof. Christoph Gengnagel (Universität der Künste Berlin, Germany)
- Dr. Julian Lienhard (str.ucture GmbH, Germany)

Sustainability and Life Cycle Analysis of structural skins

- Prof. Alessandra Zanelli (Politecnico di Milano, Italy)
- Prof. Jan Cremers (Hochschule für Technik Stuttgart, Germany)
- Prof. Joost Hartwig (Frankfurt University of Applied Sciences, Germany)
- Prof. Eija Nieminen (Tampere University of Technology, Finland)

Building physics and energy performance of structural skins

- Prof. John Chilton (University of Nottingham, UK)
- Dr. Monika Rychtáriková (KU Leuven, Belgium)
- Prof. Heidrun Bögner-Balz (Institute for Membrane and Shell Technologies; DEKRA, Germany)
- Prof. Jan Cremers (Hochschule für Technik Stuttgart, Germany)
- Arch. Benson Lau RIBA (University of Nottingham, UK)

Materials and analysis

- Prof. Peter Gosling (Newcastle University, UK)
- Prof. Natalie Stranghöner (Universität Duisburg-Essen, Germany)
- Dr. Ben Bridgens (Newcastle University, UK)
- Prof. Heidrun Bögner-Balz (Institute for Membrane and Shell Technologies, Germany)
- Prof. Kai-Uwe Bletzinger (Technische Universität München, Germany)

From material to structure and limit states: codes and standardisation

- Prof. Marijke Mollaert (Vrije Universiteit Brussel, Belgium)
- Dr. Jean-Christophe Thomas (Université de Nantes, France)
- Dr. Jean-Marc Bourinet (Institut Français de Mécanique Avancée, France)
- Prof. Peter Gosling (Newcastle University, UK)
- Prof. Franck Schoefs (Université de Nantes, France)
- Prof. Natalie Stranghöner (Universität Duisburg-Essen, Germany)
- Dipl.-Ing. Jörg Uhlemann (Universität Duisburg-Essen, Germany)

Fully Funded PhD Research Studentship

The Architecture and Tectonics Research Group – University of Nottingham
Applications (UK/EU students only) are invited for a fully funded PhD studentship in Architecture/Building Technology.
The Architecture and Tectonics Research Group has a long research experience in tensioned membrane structures and lightweight building systems. This PhD will explore the new opportunities in this field provided by parametric software (e.g. Rhino Grasshopper), innovative concepts (e.g. active-bending) and single-board microcontrollers (e.g. Arduino and Raspberry PI).
Students should have a minimum of 2:1 honours degree level (or equivalent) in civil engineering, building engineering or architecture.
Students should be able to demonstrate a proven background and strong interest in the design of membrane structures; should have good written and oral presentation skills as well as strong analytical and problem solving skills.
The studentship will cover PhD tuition fees for UK/EU students and a tax free stipend for three years (£13,863 for the 2014-15 academic year).
The studentship is expected to start as soon as possible.
For informal enquiries or formal applications, please contact and send a CV to Dr. Paolo Beccarelli, email: paolo.beccarelli@nottingham.ac.uk.