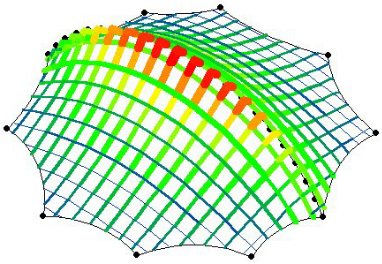


Textile Roofs 2017

May 15th - 17th 2017

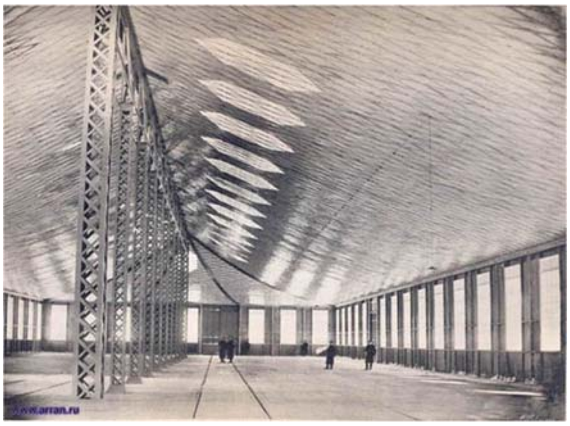
Prof. Dr.-Ing. Rosemarie Wagner

Dr.-Ing. Bernd Stary

Archenhold Observatory Berlin

Report

Prof.Dr.-Architect Josep Llorens
School of Architecture - Technical University of Catalunya (UPC)
Barcelona, Spain - *ignasi.llorens@upc.edu*

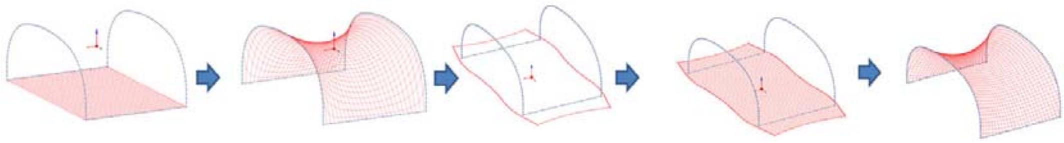


Introduction

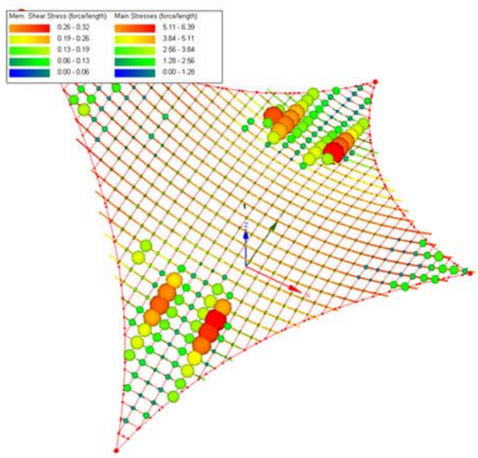
Textile Roofs 2017, the twenty-second International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 15–17 May, 2017 at the Archenhold Observatory Berlin, and was chaired by Prof. Dr.-Ing. Rosemarie Wagner (Karlsruhe Institute of Technology, KIT) and Dr.-Ing. Bernd Stary (Berlin Academy of Architectural Membrane Structures, AcaMem). It was attended by 83 participants from 13 countries covering two continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.

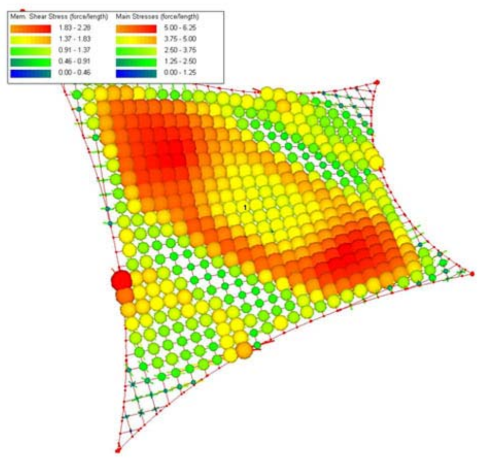
Computational modelling of lightweight structures, Dieter Ströbel, technet GmbH

A complete overview of the technet software was presented including the company profile, modelling, membrane construction, analytical form finding, statical analysis and cutting pattern generation.



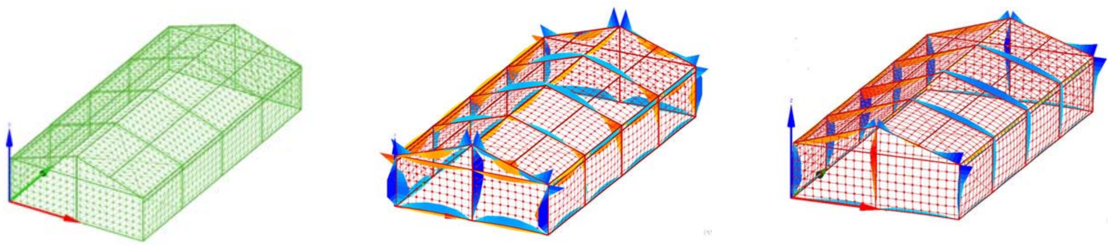
An outstanding feature is the boundary mapping in the form finding procedure that leads to optimal stressed membrane structures, useful for equidistant cable meshes.





Case A: Materialdirection parallel to main curvature:	Case B: Materialdirection under 45° to main curvature:
Small shear-stresses under snow-loading.	Big shear-stresses under snow-loading.

It is also noticeable the possibility of analyzing different behaviours under loads with different material directions of warp and weft.

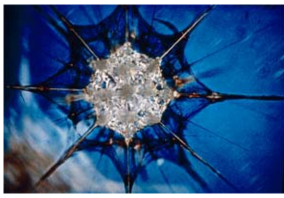


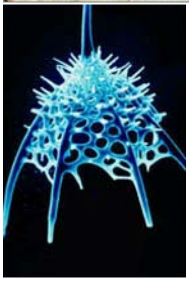
And an interesting application is the optimization of textile halls with precise 3D models, considering the interaction between the steel or aluminium frame and the membrane.

In summary, D.Ströbel formulated that computer models have to be correct, precise and complete, generated in a fast way, used for mass production if necessary and collect information from many experts. Finally, he announced the "PreDesigner" free software for modelling.

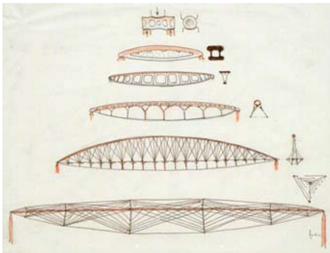
The lightweight design approach, Jürgen Hennicke, ILEK Sttutgart








Jürgen Hennicke began his lecture emphasizing that lightweight structures are not new. Slides included the Bedouin tent, the retractable roof of the Pompeii amphitheatre, radiolarian, grid shells and bubbles. They satisfy the same physical and natural laws as our designs that are much more rough and primitive.


He provided different examples of simple structural concepts. In Stonehenge (3.000 ~ 2.000 BC) the bases of the conventional building system were established (left). Trussed constructions aimed to the minimization of the flexural-resistant structure, F.Otto 1980 (middle). Trees collecting forces and bringing them down at the Sagrada Familia basilica, Barcelona 2008 (right).



The possibilities of grid shells (left) and inflated tubes (right) were also illustrated, mentioning particularly the Mannheim Multipurpose Hall and Restaurant at the Federal Garden Exhibition 1975 designed by C.Mutschler with F.Otto and O.Arup (middle), in danger of extinction. Believe it or not the city council of Mannheim decided in June 2016 by a large majority the demolition of the multi-hall, if it should not be possible to collect a significant amount by end of 2017.

The conclusion referred to lightweight and membrane structures as everyday architecture which can satisfy all our needs as living beings in a built environment, increasing our physical, mental and social quality of life in harmony with the natural environment as a reconciliation between man and nature and with himself.

Ageing behaviour of ETFE foils, Carl Maywald, vector foiltec

Stability of ETFE was the main topic and conclusion of Carl Maywald's lecture. First application was the 1982 Burger's Zoo in Arnhem (left) enlarged by the Mangrove Hall 35 years later (right).

Left: Desert Hall (Burger's Zoo, Arnheim 1982). The size of the cushions was limited because of road transportation limitations. Middle: Chelsea Hospital. (London 1990). ETFE was adopted because it was cheaper than glass. Right: Aachen Kapuzinergraben 2002. The historic façade has been protected without need of columns and saving steel compared to the glazed solution.

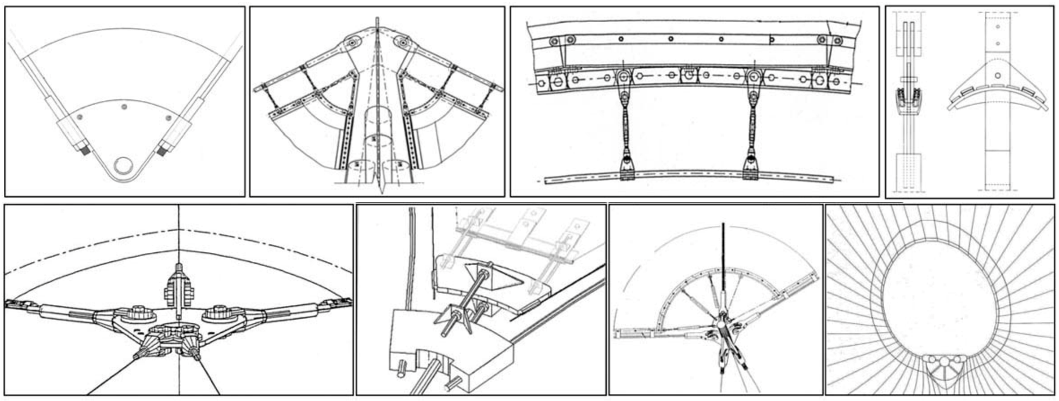
Structure	**Designed by**	**Year**	**Location**	**Cladding**	**Comments**
Biosphere Dome	B.Fuller	1967	Montreal	Acrylic cells	Burned in 1976
Olympic Hall	G.Behnisch & F.Otto	1972	Munich	Acrylic glass	Refurbished
Eden Project	N.Grimshaw with A.Hunt	2001	Cornwall	ETFE	Still in use

He also mentioned a series of applications, including three outstanding cladded structures and listed ETFE main characteristics as high transparency, UV stability, flexibility, low weight, long lifetime, self cleaning, outstanding fire performance, recyclable, high chemical resistant and provides acoustic comfort. Regarding longevity, he showed several tests that reveal extraordinary stability and no chemical degradation under environmental conditions.

He finally left a couple of lapidary sentences for posterity: "Innovation comes from the industry" and "Let's turn innovation into education!"

Detaling, Josep Llorens - School of Architecture, Barcelona.

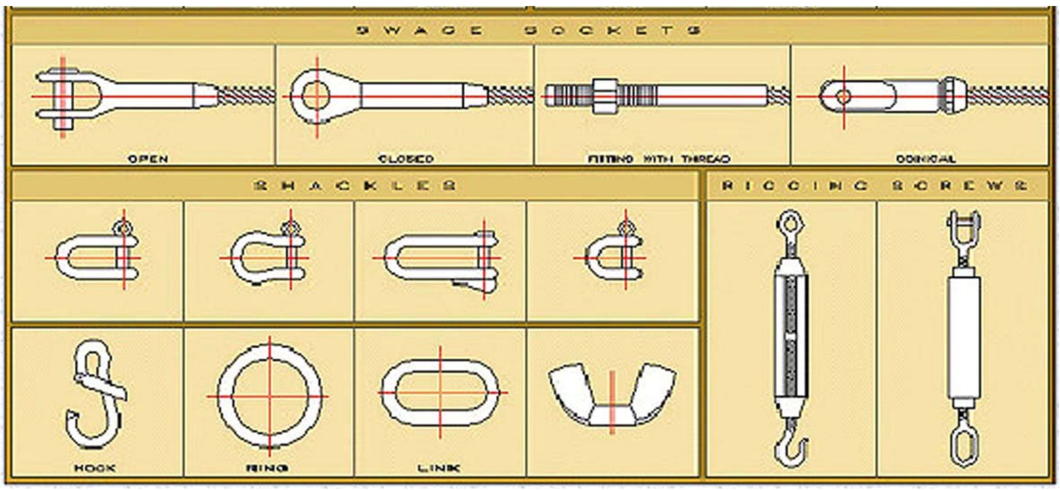
J. Llorens' presentation was a kind of academic master class about detailing textile roofs and structural membranes emphasizing that detailing is a significant part of the design process. It is critical to the overall conceptualization and the resulting structure, because details are not only derived from the general idea, but end up defining the result. They are essential to the requirements of the entire structure, including behaviour, materials, geometry, installation, durability, maintenance and visual expression.



A typology of details for fabric structures in architecture was presented. It included seams, edges, corners, high and low points, ridges and valleys, cables, fittings, and anchors. Many examples were shown and discussed keeping in mind that:

a) Details cannot be directly transplanted from a repertoire, since they have to be adapted to the requirements of each case. Solutions are successful when they meet the specific requirements of every application. *Changing the requirements means that the design must be changed*.

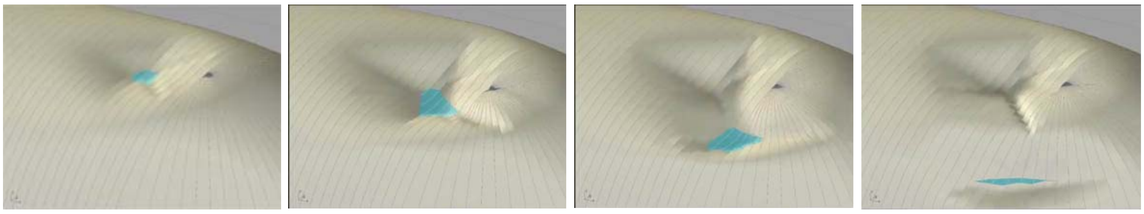
b) Detailing has to be taken into account from the beginning of the design process. It is not an independent step, because it is also essential to the general requirements of the whole structure. *Details are not an afterthought*.



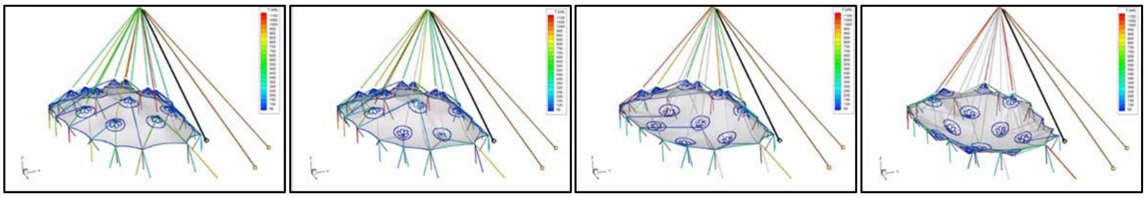
In addition, the professor presented a data base to facilitate the coordination between the fittings that converge usually in most connections, which can be visited at: *http://sites.upc.es/~www-ca1/cat/recerca/tensilestruc/portada.html*

Fifty years of relaxation, David Wakefield - Tensys Limited, Bath.

David Wakefield. another veteran rider, summarized his extensive experience in membrane engineering including form finding, load analysis, patterning, dynamic fluid flow simulation, hydrostatic loading, ponding assessment, installation, failure propagation analysis, and supervision. Fields of applications are not limited to mechanically prestressed membranes. They also include pneumatic cells, kites, lighter than air systems and balloons illustrated by a wealth of examples.

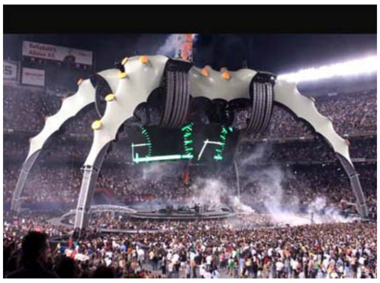


Modelling of pond water loading on top of air inflated structures

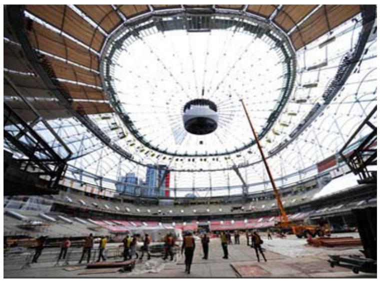


Time stepping analysis to assess the ability to withstand local failures

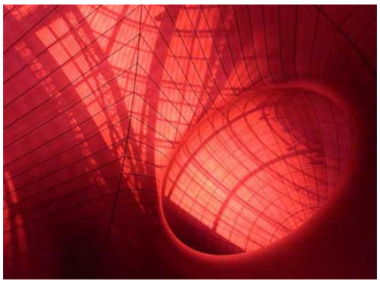
Wimbledon Central Court



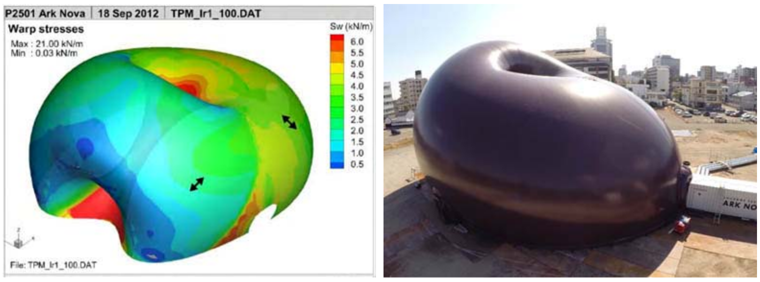
U2 Stage



BC Place roof replacement



Leviathan, A.Kapoor, Paris 2011



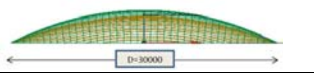
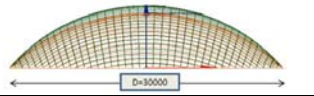
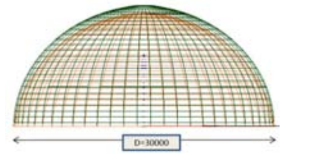
Ark Nova, A.Kapoor, Japan 2013

Ultra long duration balloon

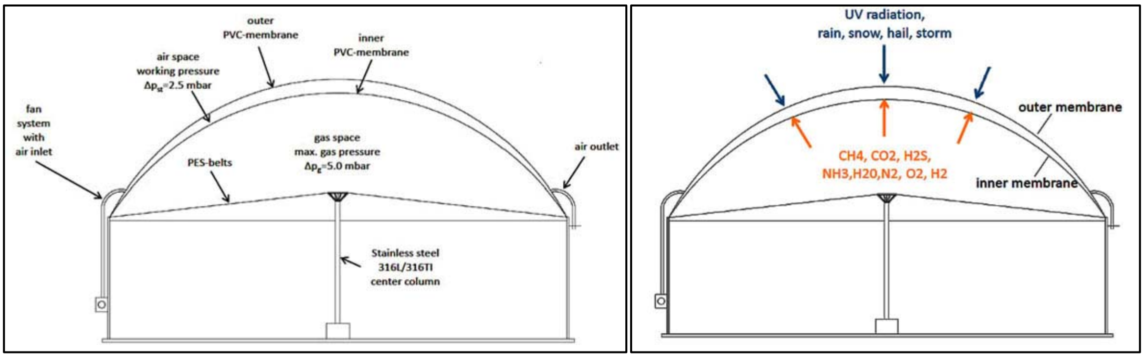
Lockheed Martin P791 HAV Demonstrator

Membrane biogas storage systems, Christopher Seybold, H.Seybold GmbH & Co. KG, Düren.

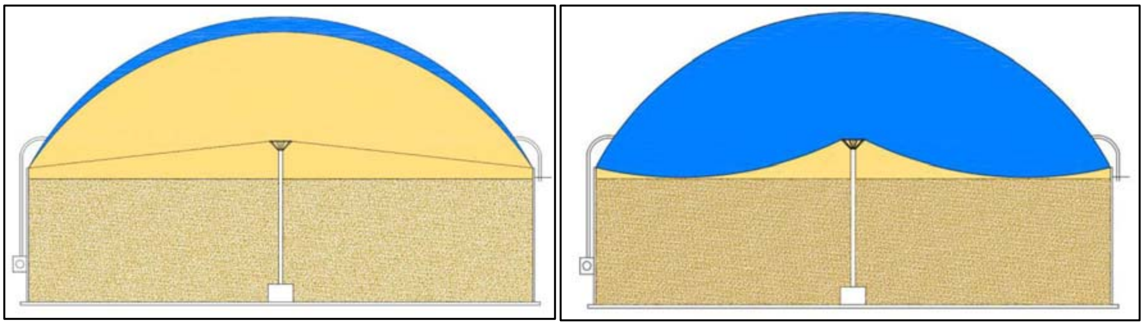
The number of biogas plants in Germany has grown from 3.711 in 2007 to 8.075 in 2016 and the installed electrical power from 1,3 to 4,1 GW. The biogas is stored in cylindrical enclosures roofed by pneumatically or mechanically tensioned structures.

Shapes		Height inner mem.	Height outer mem.	Cut	Air pressure (mbar)	Gas pressure (mbar)	m^3 gas storage volume
flat		10%	13%	Parallel	2,5	5	1.000
quarter ball		21%	24%	Parallel	2,5	5	2.300
Hemi-sphere		45%	48%	Radial	4,5	7	5.800

Different shapes and storage volumes of the spherical roof starting from Ø = 30



Membrane biogas storage system pneumatically tensioned, double layered

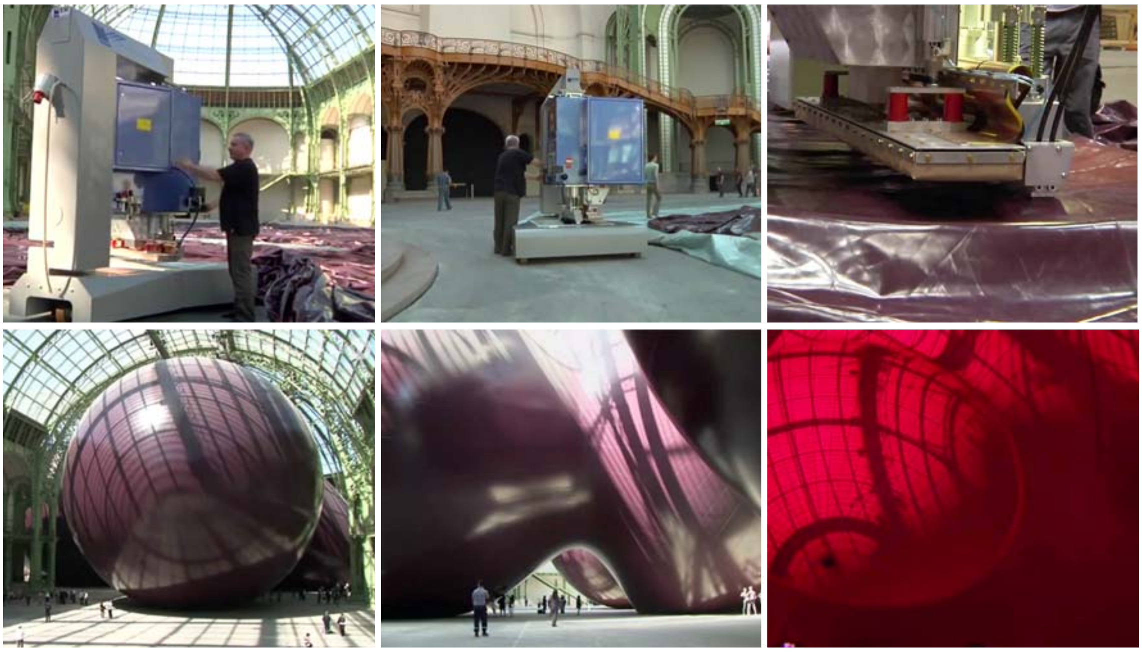


Maximum gas volume (left). Minimum gas volume, gas storage empty (right)

Mechanically tensioned structure(left), pneumatically tensioned structure (right)

Tensile Structures: welding and structural integrity, Wojciech Staniszewski, FIAB, Sp.z o.o.Sp.k.

Professional building machines were presented together with a live demonstration by Wojciech Staniszewski in the garden and auditorium of the Archenhold Observatory, Berlin.

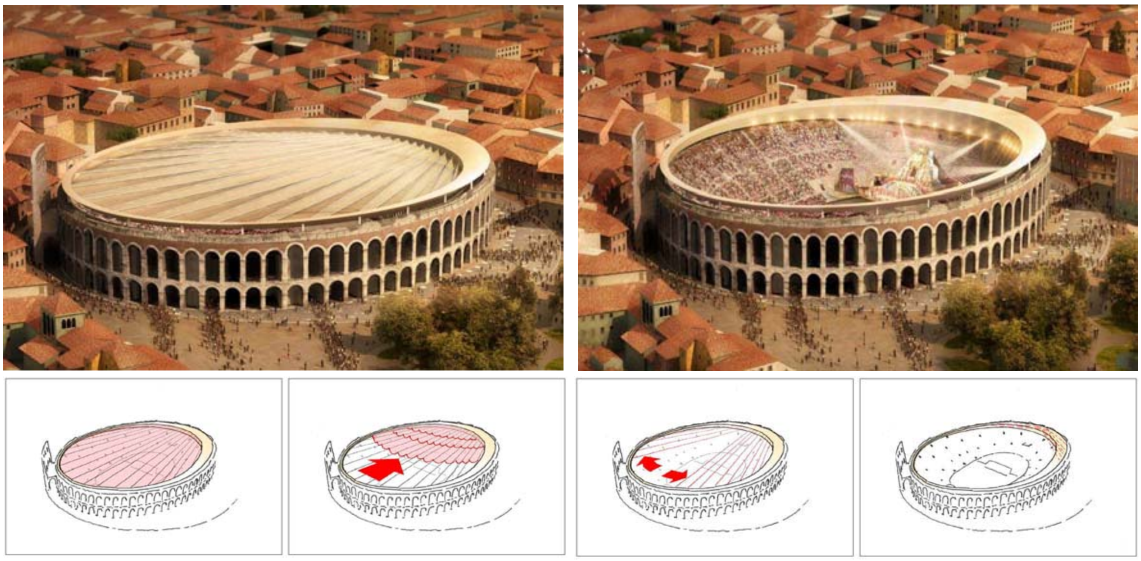


One of the most outstanding works welded with the machinery presented during this session was Leviathan, an inflated sculpture by Anish Kapoor at Grand Palais, Paris. More information at: http://www.FIABmachines.com

World Cup Membrane Structures. Martin Glass, gmp Architekten: *http://www.gmp-architekten.de*

Martin Glass began by recalling the general philosophy of gmp Architekten designs summarized by simplicity, clear solutions, variety, uniformity, distinctiveness and structural order avoiding monotony. He profusely illustrated these principles and highlighted two outstanding examples: the Al Bayt Stadium in Al Khor City, Qatar and the new retractable roof for the Verona's Roman arena.

The Al Bayt Stadium in Al Khor City, Qatar design is based on the Bayt Al Sha'ar, a black and white tent used traditionally by nomadic people in Qatar as a welcome symbol of hospitality for desert travelers. Changes of scale, materials and building solutions are noticeable, particularly the trussed steel structure and air conditioning.

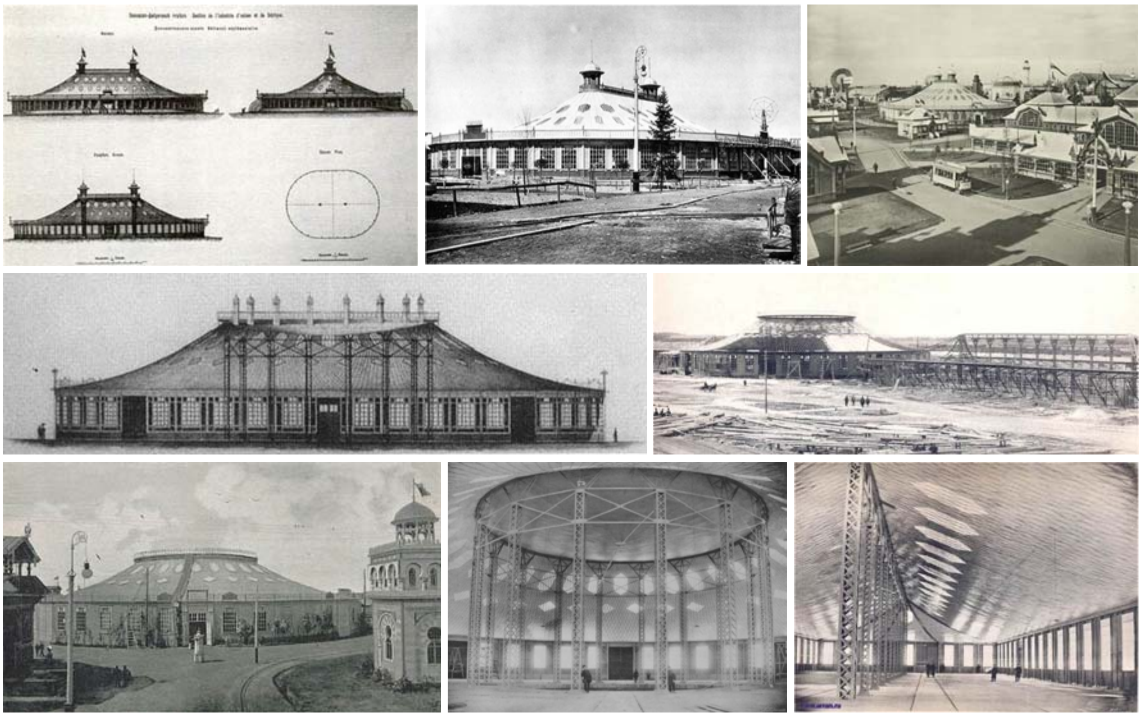


The other example is a risky intervention on a historic building, the Verona Roman amphitheatre. An international competition was launched with demanding requirements. The controversial winner scheme is a 12.000 m^2 foldable membrane sliding through a radial set of cables, hidden and stored beneath the compression ring, when not in use. The solution claims to be "a subtle intervention that will not take focus away from the architecture of the historical arena". But main unknowns are the compatibility between the structure required by such a roof and how its foundations should be executed without substantially affecting the existing building.

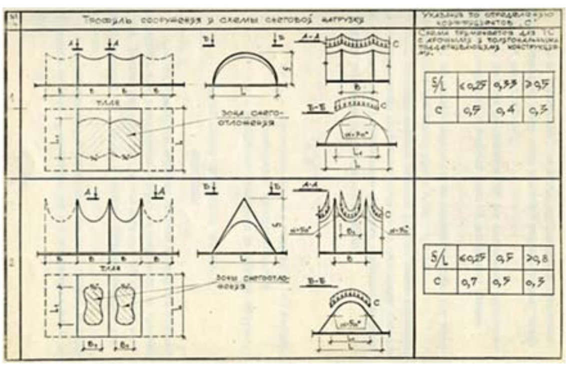
More information: *http://www.gmp-architekten.com/news/2172gmp-and-sbp-win-international-ideas-competition.html* (visited 17/06/2017)

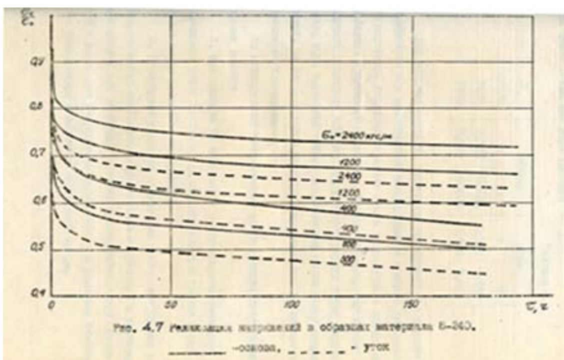
Membrane structures in Russia, Vladimir Ermolov, Moscow Institute of Architecture & Verteco.

A universe of membrane structures was shown by Vladimir Ermolov, starting from the antecedents found in ancient Russia icons and drawings.

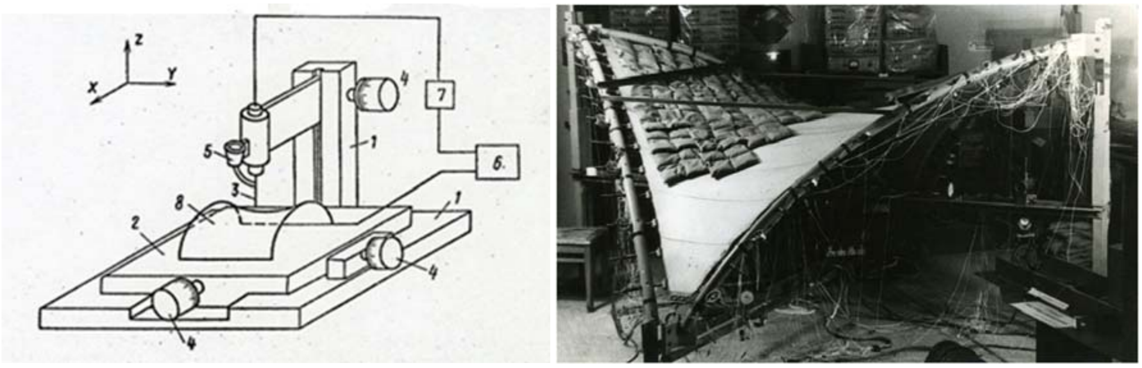


In the case of Russia, the outstanding case of early tensile structure engineer and architect is Vladimir Shukhov (1853-1939) for his steel tents at the 1896 All-Russian Exhibition in Nizhny Novgorod.





1981-1989 Attempts to quantify snow loads, stress relaxation and shear modulus.



Form finding measuring physical models and testing.

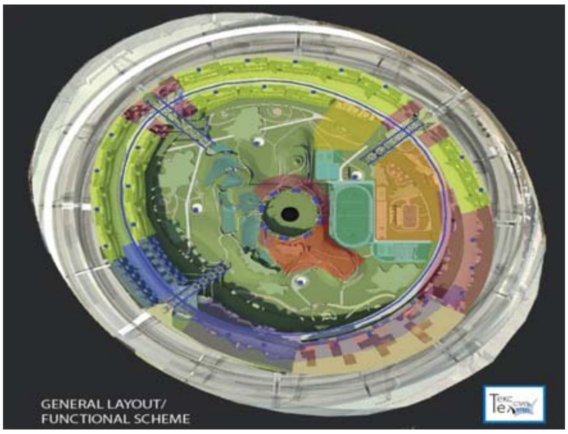
From 1991, with the Perestroika, everybody founded their own firm.

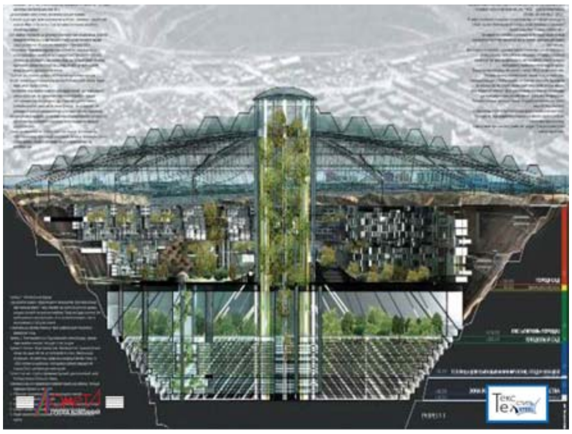
Finally the speaker showed some of his realizations by Verteco Co Ltd, Balashikha.

Large-sized dome-shaped constructions, Andrej Moroz, Lommeta, Novosibirsk.

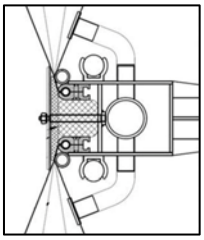
Lommeta presents itself as a company devoted to unique challenges and innovative solutions that disregards the possibility of using the word "impossible": www.lommeta.ru. The presentation of Andrej Moroz was about to confirm such a daring assertion.







Large-sized domes are designed to cover neither more nor less than open pit mines to turn them into conditioned cities, recovering the 1960 idea of Buckminster Fuller for a two-mile-wide dome over Manhattan to save energy and make a better city.

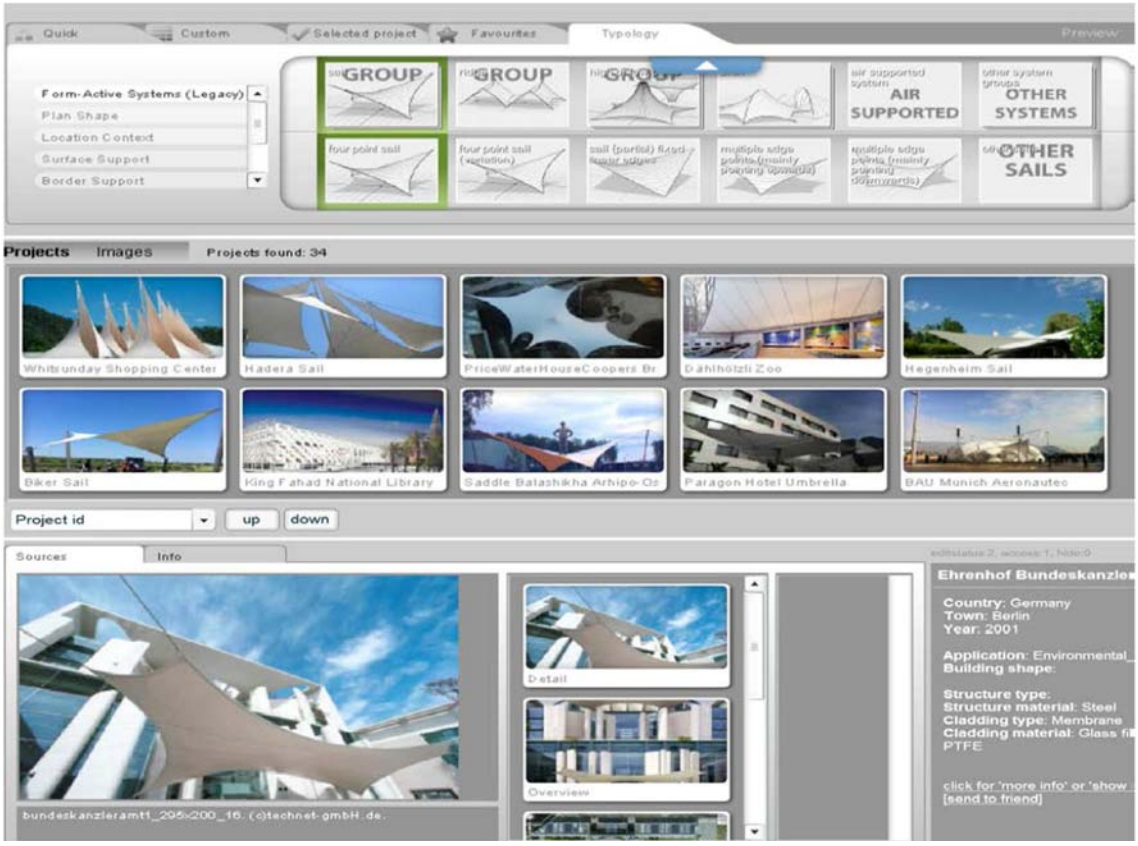
More realistic was the "Allianz Arena" style façade made of multilayered ETFE cushions framed by tubular sections.

And even more realistic was the automated solution for storage of equipment, vehicles and aircraft: a lightweight and robust aluminum frame lined with a high-strength architectural PVC material.

Lightweight Membrane Structures postgraduate MEng programme, Robert Roithmayr, formfinder GmbH.



Robert Roithmayr presented the "Lightweight Membrane Structures" postgraduate MEng programme 2017 to be held at the Donau University Krems, for individuals working in the field of lightweight membrane structures and related fields, ranging from design and architecture, engineering, business administration, manufacturing, installation, textile industry and related sciences.



The curriculum of the course includes guiding principles, architecture and engineering, tools for design, materials, details, management, manufacturing, installation and master's thesis. It is supported by "formfinder", the computer assisted design of Lightweight Membrane Structures, and its data bases: SDA Database by Prof. Vincenz Sedlak, Stromeyer Archive by Jörg Wagner, Dürr Database by Horst Dürr and Formfinder Project Database.

For the reasonable amount of 16.900€, participants will join the professional team of experts and practitioners led by R.Blum, J.Hennicke, H.Dürr, S.K.Chiu, V.Sedlak, D.Ströbel. J.Holl, J.Lienhard, M.Bechthold, A.Heslop, B.Imhof, P.Kneen, A.Korren, P.Resch, M.Schultes, M.Seidel and R.Roithmayr himself. They will be prepared for a rapidly changing and challenging future with new skills and experience.

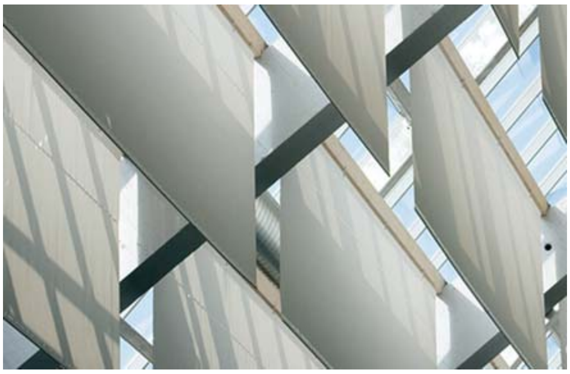
More information at: www.donau-uni.ac.at/dbu/membrane and https://www.formfinder.at/

Natural light, acoustic and thermal comfort in membrane structures, Farid Sahnoune, Serge Ferrari S.A.S.

Farid Sahnoune addressed four challenges for membranes in architecture: durability, acoustics, thermal insulation and natural light.

Regarding the durability, he presented the performance of the highly durable and recyclable "Précontraint TX30", a new generation of composite materials to match the requirements of the most demanding projects. This technology combines a Crosslink PVDF surface treatment highly resistant to photo-oxidation, a 30 year PVC coating formula engineered to resist erosion for more than 30 years and an outstanding dimensional stability thanks to the Précontraint technology. Accelerated ageing has been measured and correlated with monitored natural ageing.

Project references Products	Installation date	Usage duration	Residual tensile strengths
AIRBUS HANGAR - BREMEN – GERMANY Précontraint 1302	1982	22 years	Warp : 97% Weft : 84%
STORAGE STRUCTURE – FRANCE Précontraint 832	1989	20 years	Warp : 91% Weft : 95%
EXHIBITION HALL - PORT GENTIL - GABON Précontraint 1302	1982	18 years	Warp : 78% Weft : 76%
AIRPORT TERMINAL - LYON - FRANCE Précontraint 1202	1989	16 years	Warp : 78% Weft : 98%
RIVERVIEW SCHOOL - KERI KERI – NEW ZEELAND Précontraint 702	1994	14 years	Warp : 95% Weft : 87%
LES HALLES CARPARK FACADE - AVIGNON - FRANCE Précontraint 392	1994	12 years	Warp : 90% Weft : 80%
WALKWAY COVER - PARIS - FRANCE Précontraint 1002	1989	11 years	Warp : 97% Weft : 86%
RADISSON HOTEL - CAPE TOWN - SOUTH AFRICA Précontraint 1002	1996	10 years	Warp : 99% Weft : 100%
LADIES PAVILION - ABU DHABI - U.A.E. Précontraint 1202 Fluotop	1996	10 years	Warp : 89% Weft : 98%
UNITED AIRLINES HANGAR - MIAMI - USA Précontraint 1002 Fluotop	1999	6 years	Warp : 97% Weft : 100%



Concerning the acoustic comfort, he introduced Batyline Aw with its calibrated micro-texture that ensures sound absorption, highly uniform acoustic behaviour and significant reduction in reverberation time. It can be adapted to slopes, curves, and complex shapes fulfilling the comfort requirements of buildings receiving the public. Its most outstanding application is the acoustic improvement of swimming pools, restaurants, sport halls, ice rings and the like absorbing, on average, 65% of the noise without the need for other absorbent materials such as mineral wool or plastic foam.

Testing, Rosemarie Wagner. Karlsruhe Institute of Technology.

Professor Rosemarie Wagner started her lecture commenting on fundamental equations for numerical simulations:

Equation of force equilibrium

$$\mathbf{m}\cdot\ddot{\mathbf{x}}(t)+\mathbf{d}\cdot\dot{\mathbf{x}}(t)+\mathbf{k}\cdot\mathbf{x}(t)=\mathbf{p}(\mathbf{x})$$

dynamics

$\mathbf{m} = mass$

$\ddot{\mathbf{x}} = \text{increase of velocity}$

$\mathbf{d} = damping\ \text{factor}$

$\dot{\mathbf{x}} = velocity$

statics

$\mathbf{k} = stiffness$

$\mathbf{x} = defomation$

Statically analysis

$$\mathbf{K}_f\cdot\mathbf{u}_f=\left(\mathbf{K}_{G,f}+\mathbf{K}_{E,f}\right)\cdot\mathbf{u}_f=\mathbf{F}_f$$

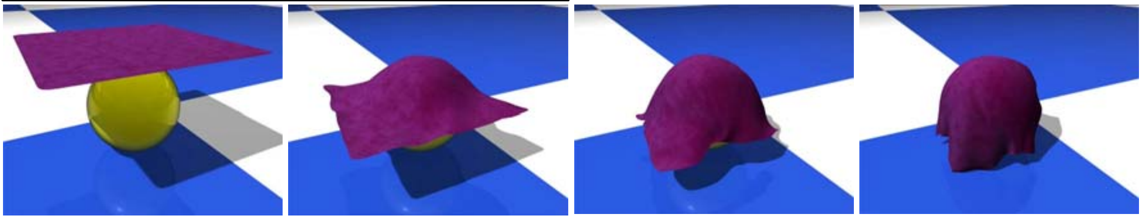
Stiffnessmatrix of the structure $\mathbf{K}_f$,

Geometric Stittness matrix $\mathbf{K}_{G,f}$

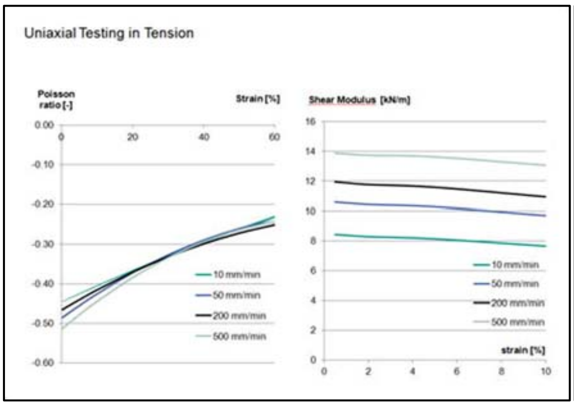
Elastic Stittness matrix $\mathbf{K}_{E,f}$

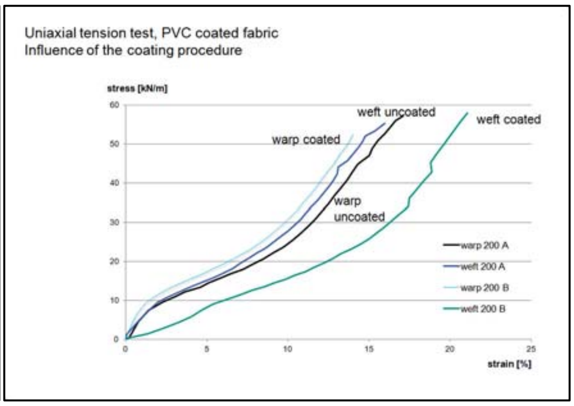
vector of displacements of the nodes $\mathbf{u}_f$

Vector of External laod $\mathbf{F}_f$

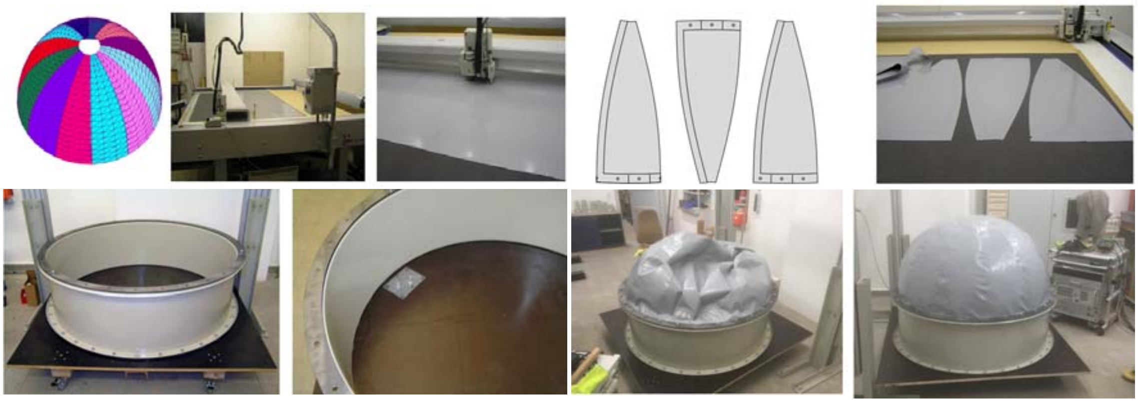


Dynamic simulation by J.Bender, Karlsruhe Institute of Technology





She addressed then the uniaxial and biaxial testing of textile membranes exploring the effects of coating, directions of warp and weft, load speed, load ratios, cyclic loading, compensation values, creep, material constants, damping and fatigue to obtain estimations applicable to the numerical analysis.

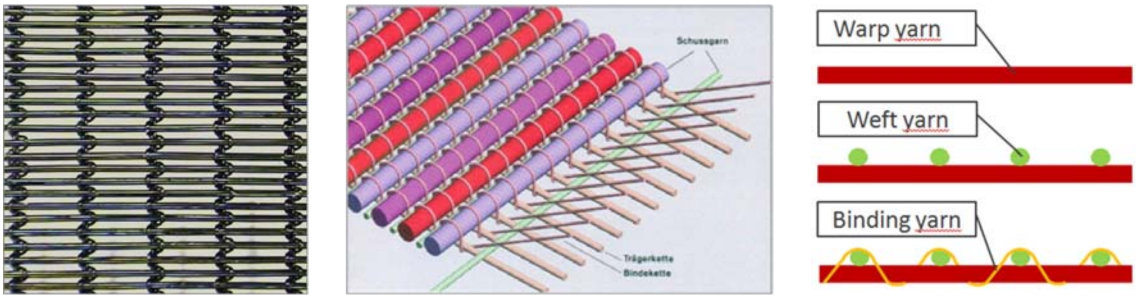


She finally presented the current research on folding and inflating membranes for tanks.

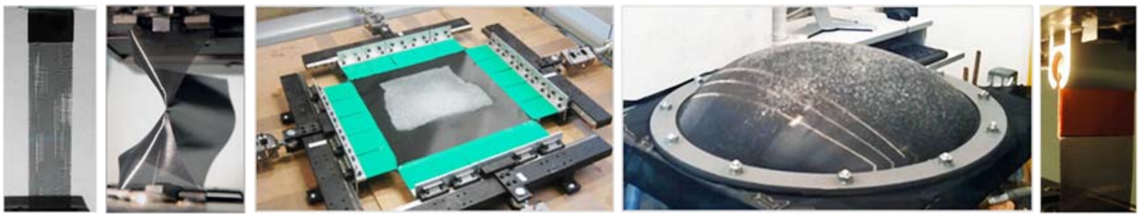
TransProof. New opportunities for weather protection, Tobias Raithel, ETTLIN, Ettlingen.

Since 2008 ETTLIN produces innovation products for application areas with a high change potential such as smart materials for lighting, electronics and architecture. The lecture was dedicated to the new development TransProof, a special fabric for outdoor shading presented by R.Wagner at textile Roofs 2016.

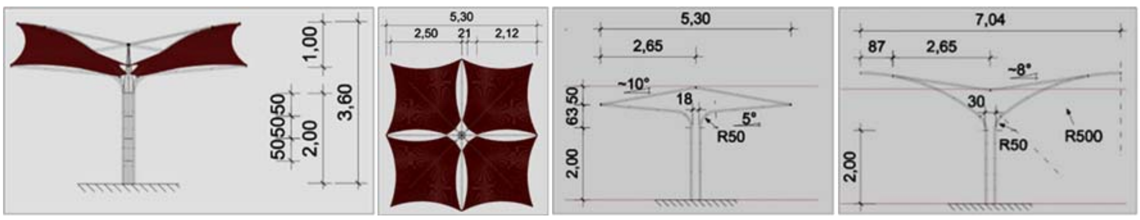
T.Raithel introduced the advisable properties of textile shading systems as: good shading, low or no air permeability, no transparency, weather protection and water-repellence. The new material TransProof adds to them protection against moisture and rain, good sight and cooling shadow without heat accumulation.



The structure of TransProof is characterized by the grid of the fabric with narrow and elongated adjustable openings, black colour (or customized from 2.000 m^2), water-repellent, good transparency and air permeable. There are three independent thread systems with strength and strain properties adjustable in warp and weft directions with low deformations due to the straight yarns.



Its suitability as a prestressed and curved textile membrane for outdoor shading has been thoroughly tested at the Karlsruhe Institute of Technology. The parameters for the load capacity, use, assembly and fixing have also been determined concluding that the fabric is quite suitable for the textile membrane construction. However, in designing the construction, the properties of the fabric must be considered and the assembly and fixing technology of the textile fabric may be performed with the classical procedures such as melting and sewing.



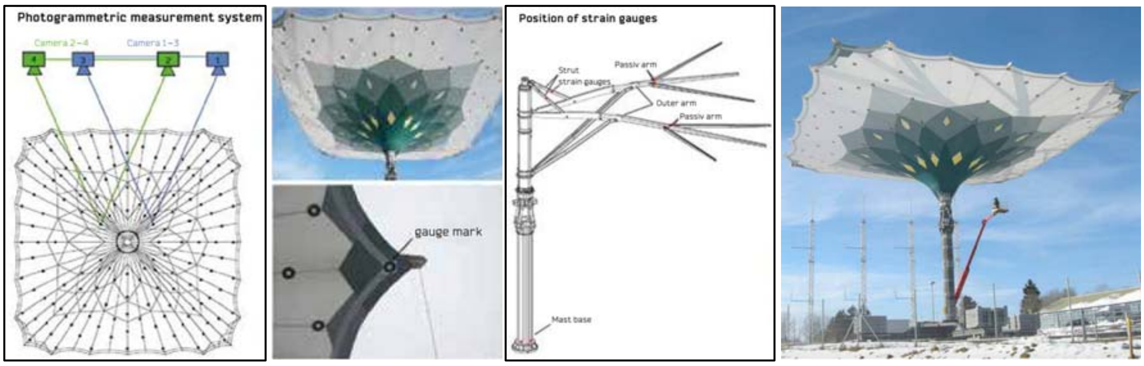
A construction of a sunshade was shown as an example.

Finally, further development of TransProof was envisaged consisting of customizing the tightness and porosity by means of an adjustable special water-repellent finish. Thus, the respective properties such as shading, air permeability, transparency and water-repellence can be adjusted in each direction.

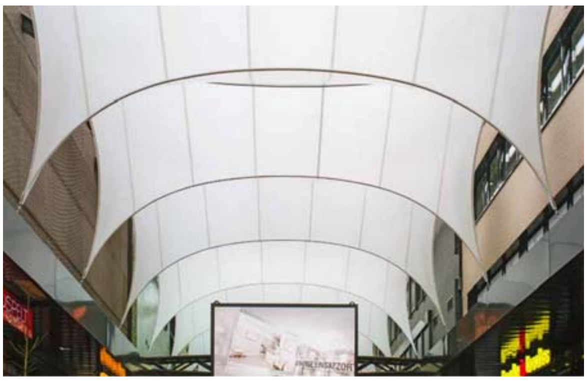
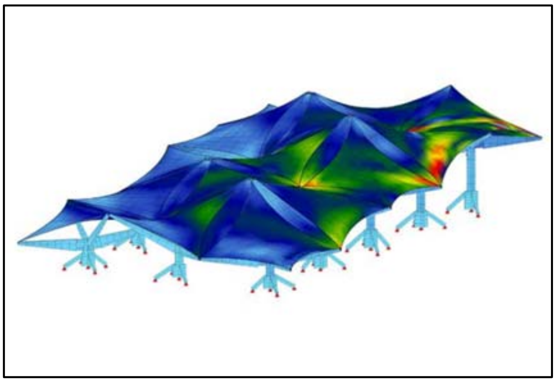
Wind membrane interaction, Alexander Michalski, str.ucture GmbH, Stuttgart.

Alexander Michalski introduced his lecture with a philosophical approach. "Lightweight design is more than a generic term for structural optimization and material efficiency. Complex architecture leads to new challenges regarding building technology and physics that go beyond mere structural considerations in a functional design. Today, the potential in lightweight design may be seen in functional integration. Here, two aspects must be focused upon:

- the development of new materials
- the continuous enhancement of simulation techniques to step closer to physical reality, which permits to reduce conservative assumptions".



He presented a fluid-structure-interaction simulation suitable for highly elastic membrane structures, such as applications where the structural response of wide-span membrane structures is affected by added mass and added damping effects of the surrounding air. This methodology, incorporating all kinds of physical effects, has been developed by str.ucture especially for lightweight structures and validated at a real-scale test of a 29 m umbrella prototype in cooperation with SL.Rasch.

Among other examples, he commented on the Buchs convertible roof (left) and the Norway pavilion for the Shanghai Expo (right). The convertible roof in Buchs (Switzerland) spans over a 50 m long pedestrian road. When deployed, the membrane takes on an undulating shape, pronounced by sharp ridges and valleys. When retracted, it is collected under a parking bridge. During the deployment process, the roof is pre-stressed in both directions to generate its final wind stable state. Wind tunnel tests were used as part of the structural analysis.

The Norway pavilion for expo 2010 Shanghai is supported by 15 tree elements made of laminated timber spanned by a PTFE membrane. The membrane covers an area of 2,500 m² with a maximum span of 11 m.

More information at: http://www.str-ucture.com

Tensile structures in India, Abdul Sathar, Technospan Structures Pvt Ltd. Bangalore.

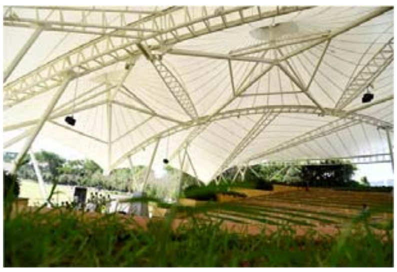
Before entering the membrane structures in India, Abdul Sathar introduced a short history of roofing systems in India with straws (left), coconut leaves (middle) and clay tiles (right).

Membrane structures were first implemented in India in automobiles and tents. Textile roofs started being executed in 2004. There were less than 2 or 3 companies until 2008. Today there are more than 150 companies but only 5 in grade A fully integrated.

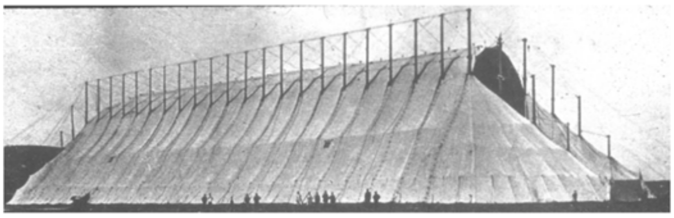
Most of the structures are designed without any engineering with prices that start from 30 - 100 € for the complete structure (?). Failures are common due to poor engineering and bad detailing aggravated by the stormy weather.

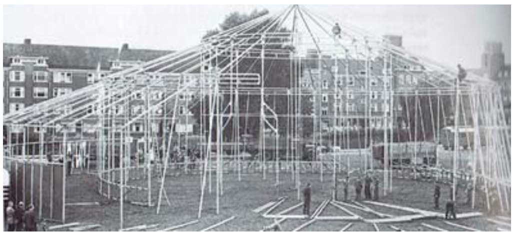
Fortunately, the company Technospan, with a history of 18 years in the field of roofing structures in India, bought in 2007 the "Easy" suite of programmes and met Matti Orpana.

More information at: www.technospan.co.in

Temporary structures / Circus tents, Rogier Houtman, Tentech BV, Utrecht.




Left: Luftschiffhangar, Behrens & Kühne, Stahlkonstruktion 1911. Right: Ringling Bros. and Barnum & Bailey Circus 1956

Frans Mikkenie, introduction of Aluminum 1948. Aluminium frame structures are noe widely used.

Rogier Houtman started showing some historic temporary structures, particularly hangars and circus tents as an introduction to his own works as a leader of Tentech, an innovative design and engineering consultancy founded in 1997 as a spin-off from the Faculty of Civil Engineering at Delft University of Technology specialized in lightweight structures. Their architects and engineers focus on membrane structures, temporary structures, complex geometries and the use of distinctive materials. In addition to fabric, steel, wood and aluminum, Tentech explores the implementation of cardboard, synthetic materials and bamboo.


Left: 60 m yent "Texas" with separated patterns for different colours and reinforced with belts. There are not queen poles. Right: Courtyard of the "Carré des Arts", Mons.


Rose Garden. Tomorrow land 2016, Belgium. Printed fabric reproducing the veins of the monster's wings.

More information at http://tentech.nl

The "**Joint participants' project**" was led by Stev Bringmann, 3dtex GmbH. A four point sail was designed and erected by the participants led by Stev Bringmann and Jürgen Hennicke with the collaboration of Serge Ferrari, Karsten Daedler e.K., FIAB, Pfeifer Seil und Hebetechnik GmbH and technet GmbH.

Different views of the joint participants' project led by S.Bringmann & J.Hennicke

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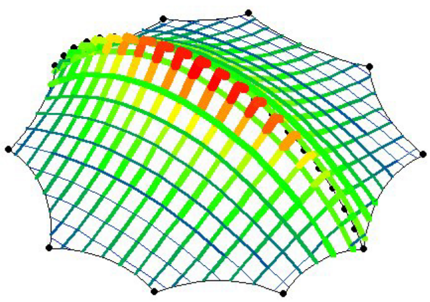

Textile Roofs 2018

May 28TH - 30th 2018

Prof. Dr.-Ing. Rosemarie Wagner

Dr.-Ing. Bernd Stary

Archenhold Observatory Berlin

The Twenty-third International Workshop on the Design and Practical Realisation of Architectural Membrane Structures will be held on 28-30 May 2018. Its format will be similar to that of TR 2017, with seminar-style lectures and hands-on activities. It will be preceded by the student seminar and sponsored by Serge Ferrari, Pfeifer and technet, and supported by TensiNet, KIT and gmp. http://www.textile-roofs.de.