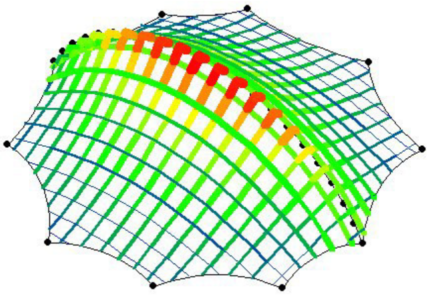

Textile Roofs 2013

June 17th - 19th 2013

Prof. Dr.-Ing. Dr. h.c. Lothar Gründig
Dr.-Ing. Bernd Stary
Berlin Institute of Technology
Technische Universität Berlin

Report

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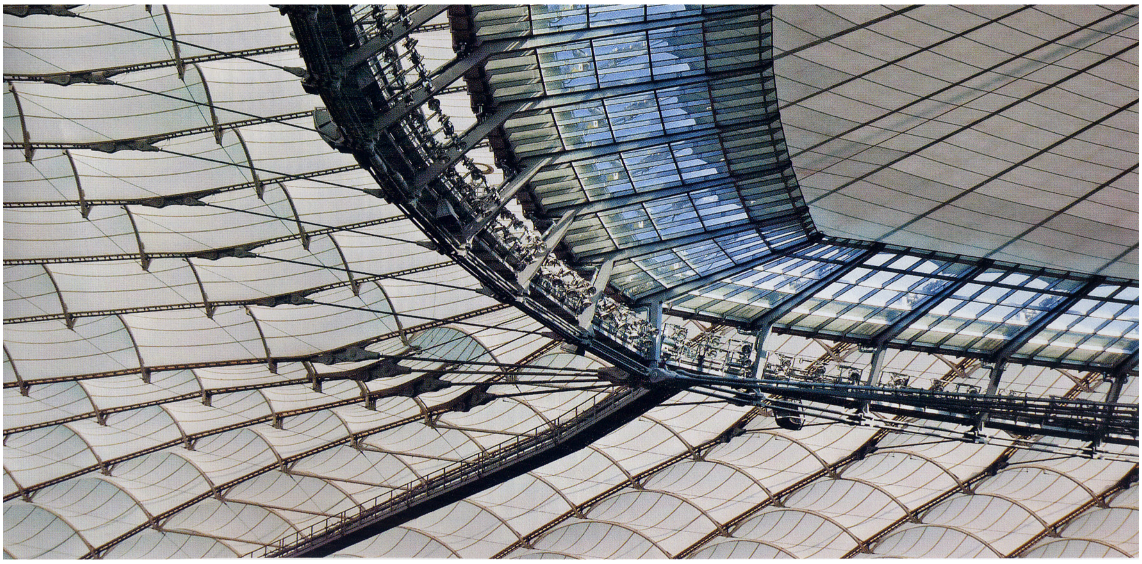


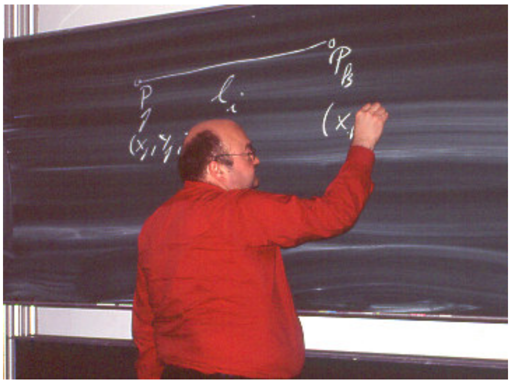
Fixed textile roof, polycarbonate and mobile roof of the "Warsaw National Stadium", **gmp** Architekten.

Introduction

Textile Roofs 2013, the Eighteenth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 17–19 June at the Technische Universität Berlin, and was chaired by Prof. Dr.-Ing .Dr.h.c. Lothar Gründig and Dr.-Ing. Bernd Stary. It was attended by 63 participants from 18 countries from four continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.

Welcome session in honour of Prof. Joachim Bahndorf

Dr.-Ing. Bernd Stary, of the Organizing Committee, welcomed the participants to TR 2013 by summarising the antecedents of the event and by introducing its activities, which included main lectures, specialist presentations, hands-on physical and computer modelling workshops, a special guest lecture, a students' project, technical visits and a banquet.

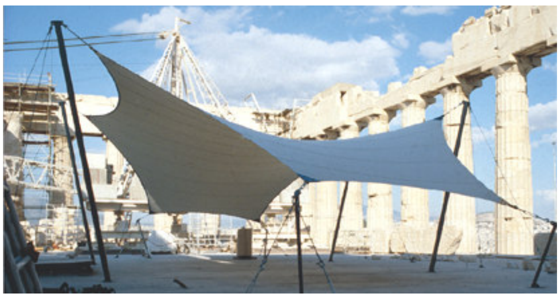


He honoured Professor Joachim Bahndorf, from the FH Bielefeld University of Applied Sciences, who has always been involved in Textile Roofs, and who unexpectedly passed away. "His sudden death came as a shock to all of us, especially to those who were fortunate enough to work with him. His balanced -advice and his visions about future success will be missed forever. Bahni: Thank you so much! We will always remember you" were the touching words that Bernd dedicated to his colleague.

On shapes, forms and structures. Jürgen Hennicke, ILEK (Stuttgart) & Vienna University of Technology.

"Lightweight structures can help us to increase quality of life" summarises the flood of ideas and concepts exposed by Jürgen Hennicke in the opening session. He referred to light and natural construction as an attempt to turn away from anti-nature, contamination and waste. Much motivation and ideas could be gathered and ranked, such as tents, pneumatics, cable nets, branching columns, grid shells and their various hybrids. These ideas offer an abundance of creative, constructive and functional possibilities which cannot be accomplished through conventional structures and buildings.



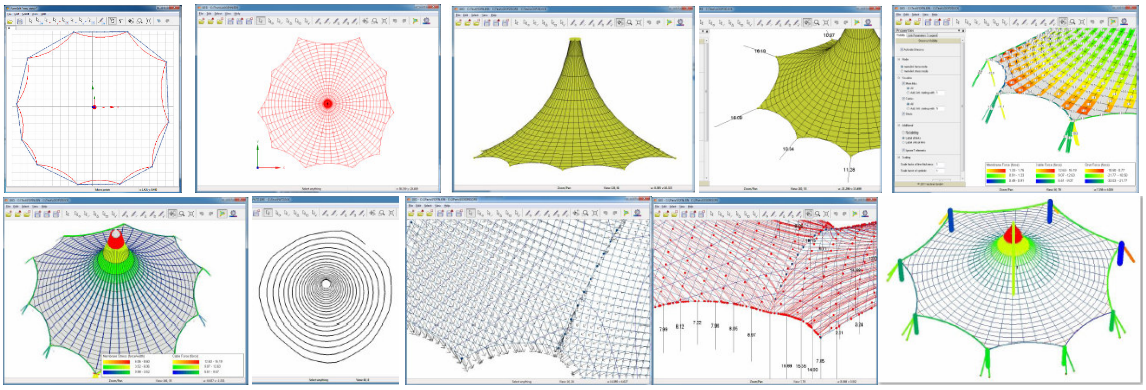



He emphasized the need for rethinking the traditional procedures and methods to improve the aesthetical quality and create visual and functional appeal through the diversity of forms and structures, saving material and energy, taking care of the resources, achieving recycling capacity and sustainability. All these ideas were thoroughly illustrated with stimulating images from the research carried out at the IL Institute.

Computational modelling of lightweight structures

Dr.-Ing. Dieter Ströbel, after introducing the Technet company profile, alluded to the need for computational modelling due to the limitations of physical modelling and difficulties that arise from double curvature and pretension requirements.

He presented the analytical form finding of structural membranes as a procedure for determining the geometry of a balanced structural system, where "form follows force" since geometry and forces interact with each other. The membrane is a flexible material that can only carry tensile forces. That's why double curvature and pretension are needed and need to be dealt with in the form finding process.



The force density method is an analytical theory that can be applied to deal with such difficulties, whose fundamentals were presented next. The process determines the form in practice after defining the boundaries and the net. The reactions, force and stress distributions, contour lines, slope arrows and slope lines are also obtained.

The static analysis is based on a non-linear system, the material properties and external loads. It provides a solution derived from energy methods that obtain equilibrium by satisfying material laws and geometrical compatibility. Two important features were added to the process: the inclusion of cables, struts, beams and sections and the satisfaction of the gas law (for pneumatic structures). A significant case study was presented, which showed the relevance of the method.

	No external loads	**Wind - Gas law not satisfied**	**Wind - Gas law satisfied**
Inner pressure (kN/m^2)	0,55	0,55	0,18
Volume (m^3)	77036	77036	77321
Max. stress (kN/m)	25	60	29

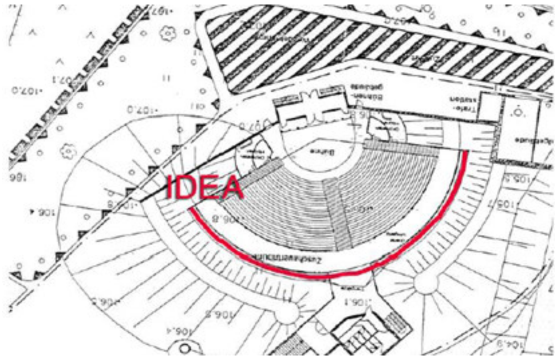
Concerning cutting patterning, the main aspects were exposed. The membrane surface cannot be represented on a plane without distortion because it is prestressed and doubly curved to resist external loading. The planar strips have to be as straight as possible in order to limit the cutting out waste as little as possible. The width of the 2D strips should be as wide as possible in order to minimize the amount of labour. The maximum strip width depends on the roll width. Additionally the geometrically developed surface has to be corrected (compensated) in order to establish the prestressed surface. Moreover, the cutting drawings have to be transferred on to the fabric and the results must be evaluated.

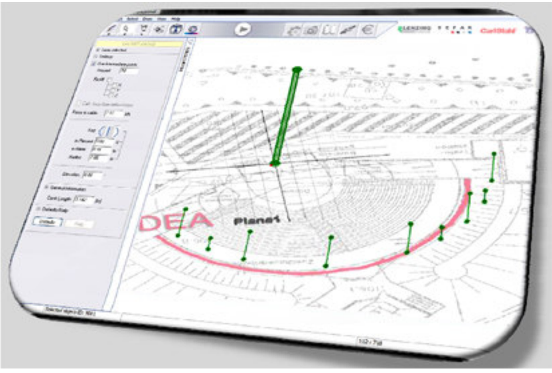
Automated patterning procedures were also mentioned, which minimize the amount of material and achieve high quality in a short time. They are available for cones, saddles, air halls and other repetitive designs.

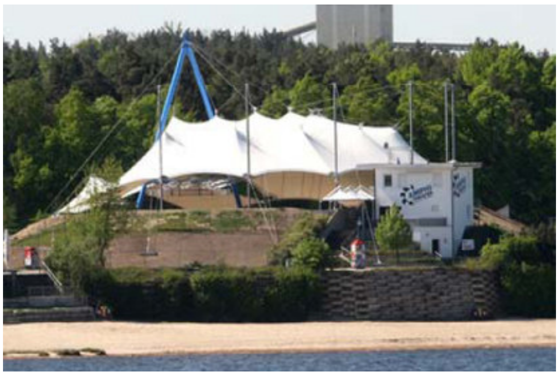
Design: membrane and architecture

Robert Wehdorn-Roithmayr, from the Institute of Interdisciplinary Construction Management (Vienna University of Technology), examined the process of designing membranes. He began by discussing sketches and drawings as means to communicate the design and identify the people involved, namely the owner, the architect, the engineer and the manufacturer.

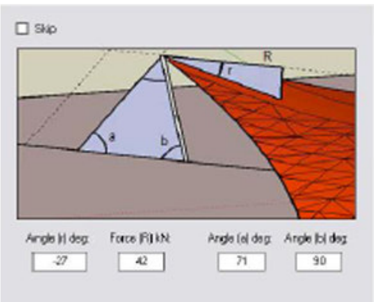
He considered the basic parameters related to forces and components, particularly curvature, proportion, number of corners, joints, edges, high and low points.

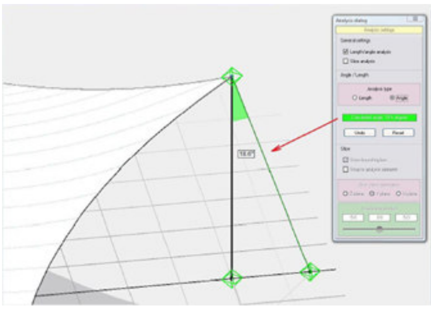


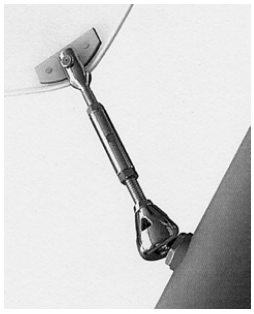




The application of the “formfinder”, a dedicated software for membrane structures, was illustrated with the design of the Senftenberg Theatre roof by Horst Dürr/IF Group.





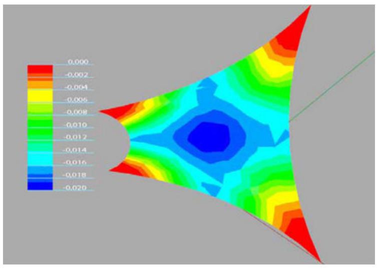


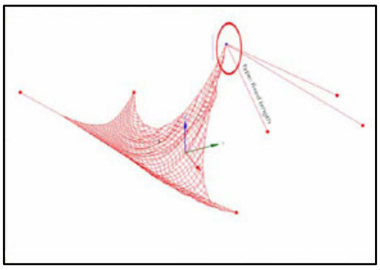
Special attention was devoted to connections, their geometry, forces and realization, with consideration for allowances, regulation and eccentricity. The 3D adjustable Tennect/Carl Stahl ball head was recommended as a universal connecting cable end suitable for 80% of all applications, because it adjusts automatically the acting forces in the direction of the pull.

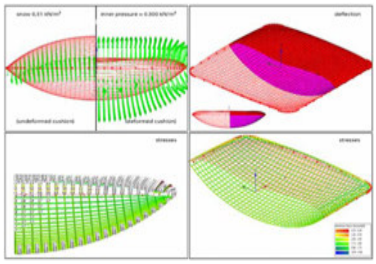
At the end of the lecture, we were reminded of the Master of Engineering Program: “Membrane Lightweight Structures” of the Vienna University of Technology.

Digital tools in architectural education

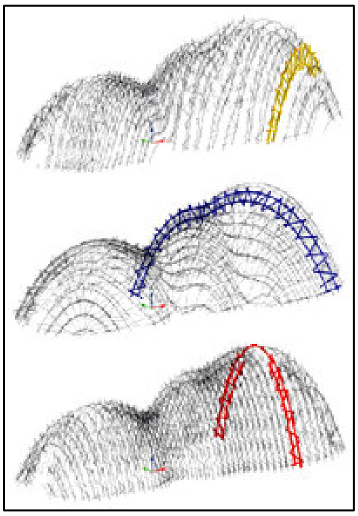
Prof. Dr.-Ing. Manfred Feyerabend from the Koblenz University of Applied Sciences exposed his experience in teaching lightweight structure design with digital tools such as Easy, Formfinder, Rstab, Rhino and Photoshop in the context of bachelor and master courses.

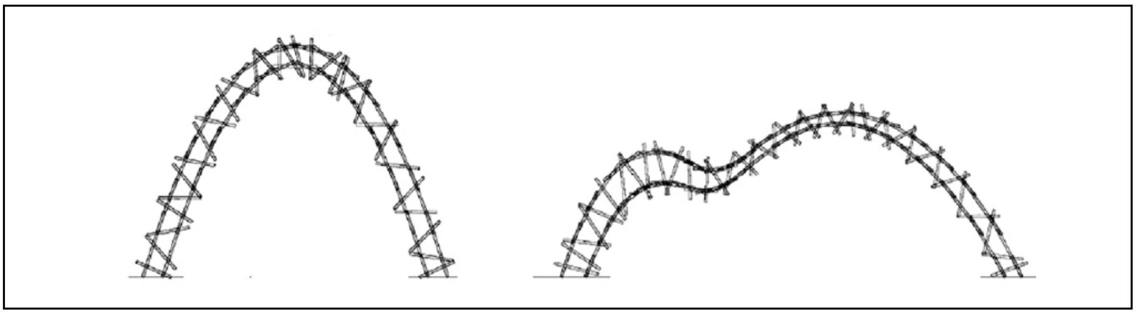






He illustrated the use of Rhino and Photoshop in lecturing on surface analysis, visualisation of curvatures, assembling states and cushion behaviour under wind and snow loads. At the end of the design process, the final shape can be controlled by plaster modelling with a 3D plotter and the seams are determined by using the laser fabric cutter.

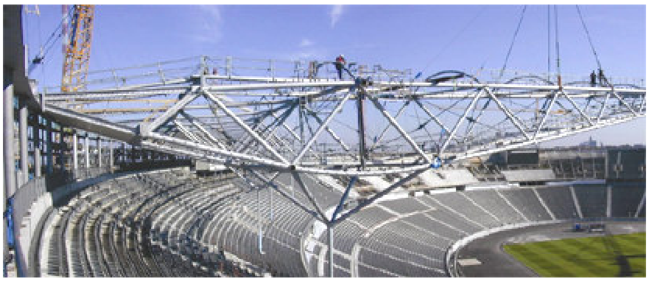
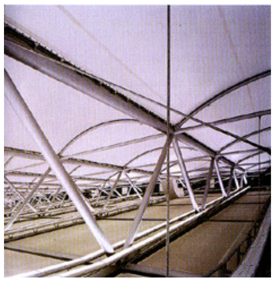




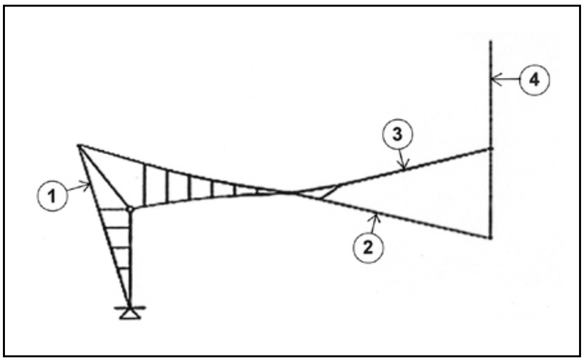
A remarking example of a student's work was shown. The in-house designed wooden experimental “Echolot” pavilion for BUGA (Federal Horticultural Show) 2011 in Koblenz succeeded in materializing with complexity a simple design. In order to be “bionic,” the ground plan was derived from the oscillogram curve of the sonar of a local bat, the so-called ”evening sailor.’ From the plan, the shape was explored by blowing-up the surface and suspending little chains. A double layered suspension form was also conceived for stiffness and finally, the shape was modelled with a framework of multiple bars. After the BUGA event, the pavilion was dismantled in 11 pieces and transported to the campus site, where it was re-assembled.

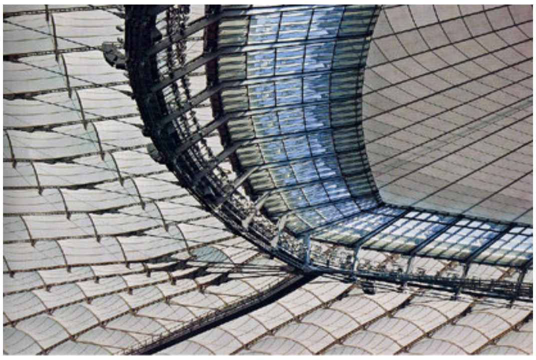
Current gmp membrane projects

Dipl.-Ing. Arch. Lena Brögger & Martin Glass (**gmp**, Gerkan, Marg und Partner, Berlin) presented an impressive array of non standard buildings, including airports, railway stations, trade fairs, exhibition halls, cultural venues, urban planning and stadiums. They proposed an ambitious philosophy of design based on simplicity, variety, uniformity, distinctiveness and structural order. Four projects were explained in some detail: the Olympic stadiums of Berlin, Warsaw and Manaus and the Berlin Brandenburg Willy Brandt Airport.

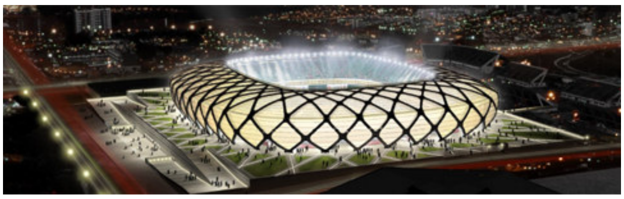
The Berlin Olympic Stadium is a monument that required conservation and modernisation. Several operations were undertaken. Among them, four basements were excavated under the building for underground facilities, access and garage. A lightweight cantilevered roof steel truss was chosen which required the insertion of 20 columns in the upper tier of the seating. Its upper and lower surfaces were covered by 0.7 mm PTFE coated glass fibre fabric membrane (1,200 g/m^2 on top) and 0.7 mm PTFE coated open wave glass fibre fabric (150 g/m^2 at the bottom) to hide the structure in such a way that the roof has a smooth, closed appearance from the underside.





In Warsaw, the stadium roof is based on the principle of a spoked wheel, distinguishable by the cantilevered polycarbonate from the fixed part that protects the joint. 1: tension element; 2: steel cables penetrating the membrane; 3: convertible part of the roof (as in Frankfurt); 4: flying mast.



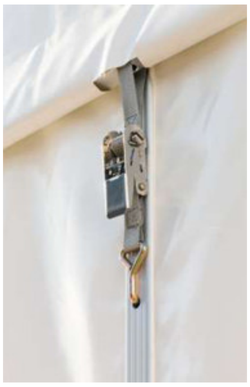
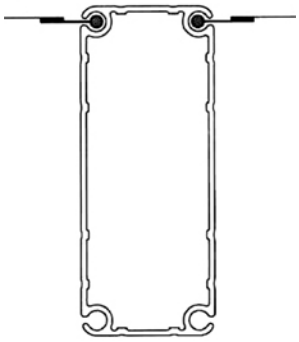
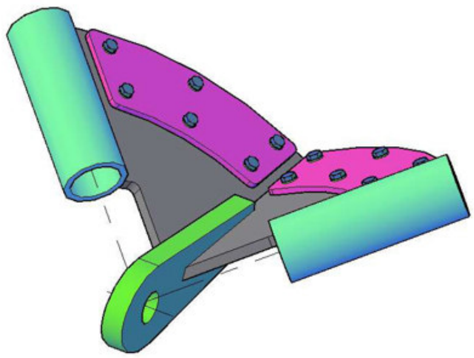


For Manaus, the identity of the design inspired by the specific conditions of the site culminated in rhombus shaped openings cladded with a double layered membrane.

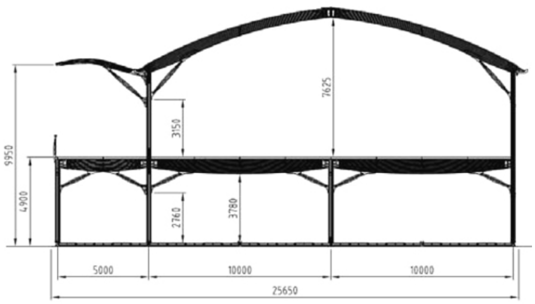
The Berlin Brandenburg Willy Brandt Airport was visited by the audience the following day.

From tent to textile architecture

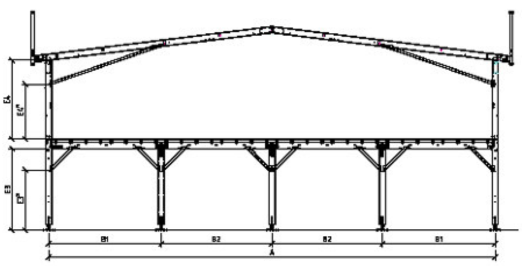
Dipl.-Ing. Jochen Groz, from Losberger GmbH, Bad Rappenau, introduced his company as a leader in temporary space solutions for events, industry, military, emergency services, pool covers and other applications worldwide.

He noted the differences between tents and textile architecture, focusing in design, materials, structure, detailing and foundations. (Typical details: left and middle for tents; right for textile architecture).

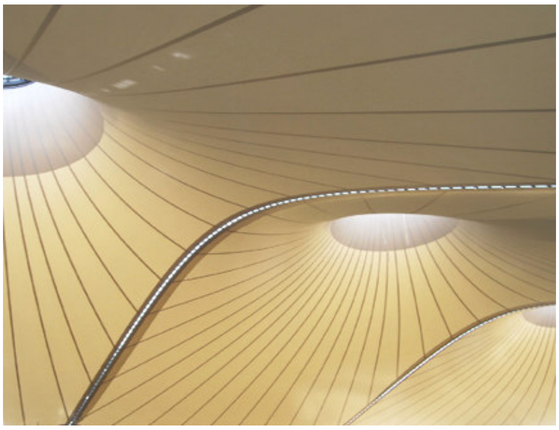


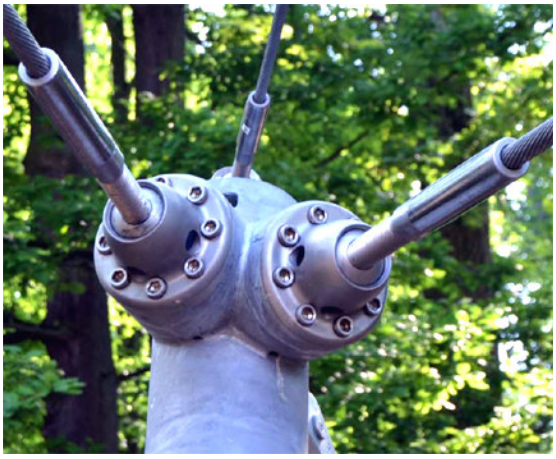
He acknowledged that the market is demanding more and more architectural designs in the fashion of the De Boer Emperor system designed by Rogier Houtman/tentech, which doesn't look like a tent.



He also showed the new large volume event and trade fair tent structure: Palas Emporium/Losberger, which is visually appealing and amply dimensioned. Straight line architecture, cubic shapes and generously proportioned glass façades allow for multiple design possibilities, and they meet the requirements of the aforementioned tendency towards textile architecture and design.



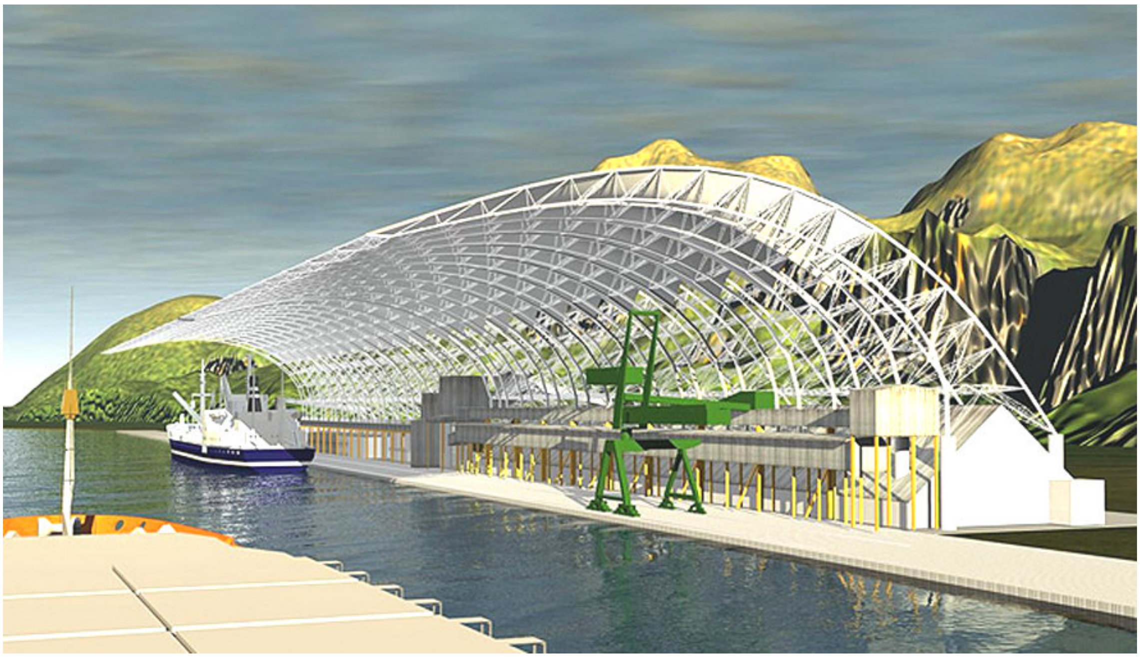
Dipl.-Ing. arch. Michael Kiefer showed different projects illustrating the integration of all parts and the interdependence between shape, position and pretension.

The 3D adjustable Tennect/Carl Stahl ball head was used in many connections because it automatically adjusts the acting forces in the direction of the pull. A doubt was raised concerning the system’s ability to maintain the adjustability in the long term due to its lack of lubricant.

Recent Brazilian Projects.

Nelson Fiedler, from SEPA, Sao Paulo, protagonised the most spectacular presentation of TR 2013. Factories, warehouses, sports arenas, stadiums, gymnasiums, auditoriums, race tracks, cultural and social event enclosures, entertainment venues, funnels, emergency buoys, temporary housing, mines, oil refineries, building work protections, water tanks and many other applications were shown. Most of them were enormous, fancily coloured, spectacular, incredible and astonishing.

His background is equally impressive. He decided to gain experience by executing the design, manufacture and installation of more than 1000 (one thousand) unique works (each design was executed only once) between 1979 and 2013. He used ANSIS for "checking the results", as he replied to the objection of RW by reminding him of the non linearity of membrane structures. Regarding wind loads, he relies on computer simulations due to the limitations of the codes, as well as the difficulties arising from cost and time to execute wind tunnel tests. For the installation, he employs many workers, in the same way circus troupes do, and he prefers to weld and paint the steel on site to reduce transport costs. (It was inferred that labour is cheaper than transport).



His current practice concerns the port cover prototype for ship loading/unloading to operate 100% of the time, regardless of bad weather conditions. This prototype may be visited during the "VI Simposio Latinomericano de Tensoestructuras", Brasilia 2014.

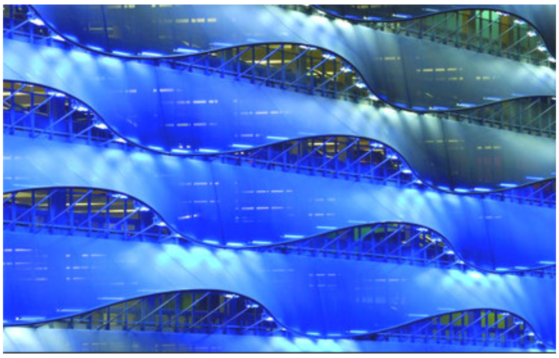
New developments in façade and acoustics.

Mr. Farid Sahnoune, from Serge Ferrari, La Tour du Pin, took on the challenge to address the acoustics of textile roofs for the first time in Textile Roofs. He began by explaining the basic concepts of sound, sound level, frequency, octaves, sound absorption, sound insulation, reflective materials and absorbent materials.

He emphasized the importance of using absorbent materials to reduce echoes and reverberation time, in order to improve intelligibility and to reduce sound levels. For this purpose, he presented Batyline Aw, a micro perforated mesh, 1mm thick, that is resistant to humidity and micro organisms, translucent and absorbent. Applications for this product include ceilings, baffles, curtains, walls, creative designs or acoustic sails and panels.

A comparison study showed values of α_w = 0.65 for Batyline Aw (with a 40 mm gap), whereas α_w = 0.80 for rockwool, (which requires a support - fabric or mesh - and takes humidity. Other values of sound absorption (as a reference) are: concrete, marble and terrazzo: 0; concrete blocks, bricks and gypsum: 0.05; wood: 0.10; velour: 0.60; seated people: up to 0.80.

An Aquatic Centre in Zurich was conditioned with Batyline Aw to reduce the reverberation time from 4.2 s (before treatment) down to 1.5 s (after treatment), which compares well with the requirement of 1.55 s.



Multi-storey car park – Cardiff

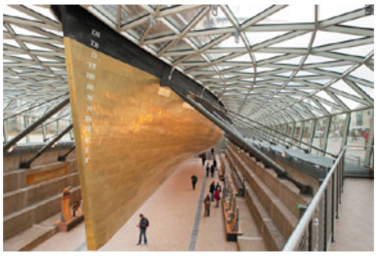
German Pavilion - Shanghai

Santa Lucia Hospital - Cartagena

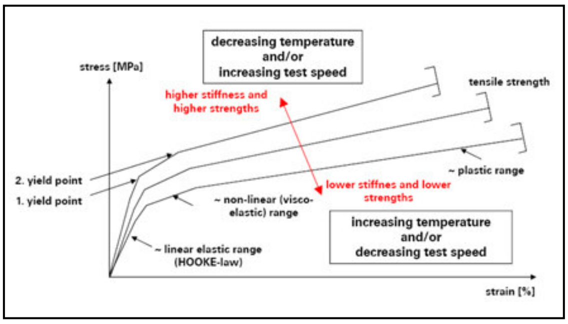
In the second part, Mr. Sahnoune discussed textile façades based on Stamisol FT précontraint, a Serge Ferrari fabric with dimensional stability, high UV resistance, negligible elongation and prolonged life in harsh environments. He insisted on the mechanical resistance needed for flat surfaces, impacts, hailstorms, weathering and fire, and mentioned other advantages the product offers, such as thermal comfort, translucency and visibility (from the inside). Application possibilities were illustrated by recent applications for car parks, offices, exhibition halls, hospitals, hotel renovations and aquatic centres among many others. The presentation covered 3D shapes, printing and light projections.

Structural design and membrane analysis of ETFE film cushions.

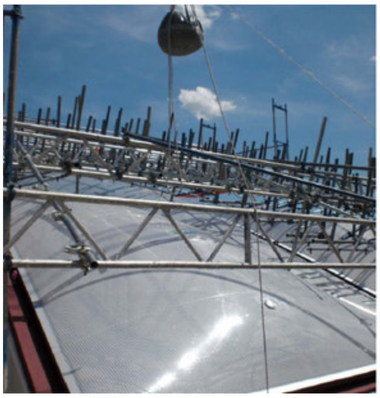
Prof. Dr.-Ing. Karsten Moritz introduced the **seele** group and their three areas of expertise (structure, faces and covers), which he illustrated with outstanding examples.



He focussed on ETFE foil characteristics and applications. Regarding these characteristics, he showed the results of several tests on materials and mock-ups. The influence of temperature revealed that stiffness and strength increase with decreasing temperature or test speed. Performance tests included resistance to wind loads, air tightness, water tightness to wind driven rain, impact with soft bodies and non standardized bursting, water pond and illumination tests.




He also referred to reduction factors for different load cases and building situations, including separate factors of safety for biaxial effect, long term and permanent loading, influences of UV light and moisture, temperature, production inaccuracies and welding.

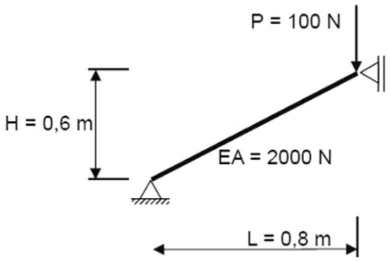





He finally showed recent realizations in France: the indoor swimming pool and climbing hall in Neydens and the “Pôle de loisirs et de commerces Lyon Confluence”

Membrane structures, some comments and further applications.

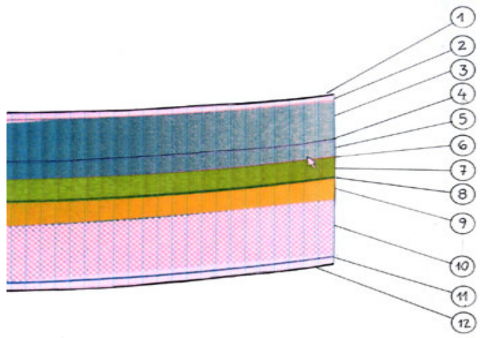
Prof. Dr.-Ing. Rosemarie Wagner, from the Karlsruhe Institute of Technology, began her dissertation discussing two ways of describing the orthotropic behaviour. Based on the values of Poisson's ratio derived from biaxial tests, four equations for four unknowns are derived for a linear stress-strain relation. On the other hand, defining the stiffness matrix and nodal forces of the elements, assembling them and introducing the boundary conditions, a linear or non-linear equation system is deduced, that can be solved in different ways to obtain the displacements and to calculate the support reactions, inner forces and stresses.



Example single strut	
Linear theory	0,139 m
Geometrical non linear (ABAQUS)	0,180 m
Geometrical non linear with Green-Lagrange strain	1,308 m
Easy	0,236 m
Exact compatibility	0,236 m

Through the example of a simple strut, she proved that Easy provides the exact solution, unlike other finite element procedures that are not very accurate.

In the second part, she showed the research conducted at the Institute of Textile Technology and Process Engineering, Dekendorf to develop thermal energy efficient materials. A solution was adopted to collect energy with a 12 layer skin fabric made of materials available in the market.

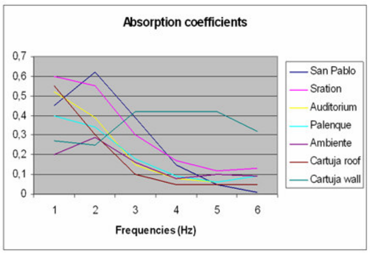


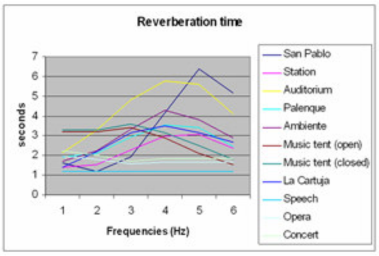
From top to bottom, a transparent envelope of ETFE admits 99% of visible light and ultraviolet rays (layer nº 1). It is reinforced by cables every meter (layer nº 2) and it closes a 10 cm air cavity (layer nº 3) to drain condensation water and to prevent transfer of loads. The air cavity is limited below by a 1.5 cm closed air ETFE cushion (layers nº 4, 5, 6) to avoid heat radiation from the spacer fabric below and to capture as much solar energy as possible. Under the cushion, a 1.5 cm black fabric spacer (layer nº 7) separates the cushion from the black membrane, allowing air to move as a thermal energy collection mechanism. The thermal energy is absorbed by black silicon- coated glass fabric (layer nº 8), which is able to carry its own weight and the dead load of the fabric spacer. As the temperature raises to more than 100º, the collector part of the roof needs to be insulated (layers nº 9, 10) to prevent from heating the interior. A PE foil (layer nº 11) is a water vapour barrier that protects the thermal insulation and lastly, a cable net (layer nº 12) bears the thermal insulation. In summary: the heat is absorbed by the silicon- coated glass fabric, transported by the air and stored in containers of silica gel.

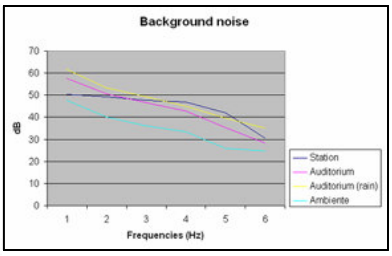
The effectiveness of the system will be known by the end of 2013.

Acoustic performance of textile roofs.

Prof. Dr.Arch. Josep Llorens from the School of Architecture of Barcelona also dealt with acoustics. He presented a method of in situ measurements as a basis for design recommendations and he offered advice for acoustic conditioning and improvement of existing spaces. Seven case studies were presented.







The results reveal inappropriate absorption of the surfaces exposed to sound because the values are low at medium and high frequencies. Reverberation time is too long at high frequencies, intelligibility is poor. Sound distribution is also poor because of the difference in absorption at the different frequencies. In addition, the curved shapes of reflecting surfaces cause sound concentration and reflection delays and disturbing background noise, which are all signs of poor soundproofing.

From these measurements, a set of design recommendations was formulated:

1 The acoustic performance of textile roofs should be considered during the design process.

2 Attention has to be paid to material properties and geometry in order to control noise levels, reverberation time, intelligibility and sound distribution.

3 Lack of attention to these factors will require acoustic conditioning, because the lightness in weight and the geometry of structural membranes are not favourable to good sound conditioning.

Some partially or totally successful designs were shown.

Acoustic conditioning of existing spaces was also discussed. Starting from relevant examples, some guidelines were formulated:

1 Provide absorption, as for example, double layering with a cavity or insulation in between. Alternatively, hanging devices or lining with porous fabrics may be used.

2 Control curvatures: convex surfaces are diffusers and concave surfaces focus the sound.

3 Avoid loud environments and sound immissions.

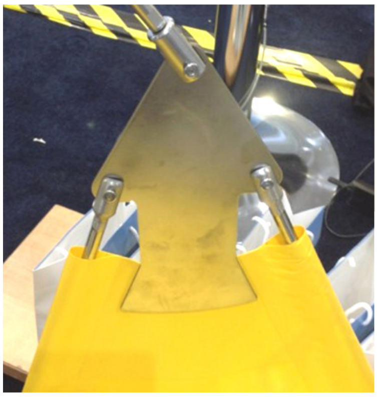
4 Use sound barriers.

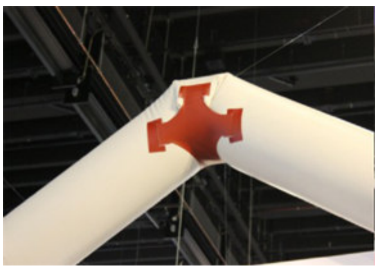
	125 Hz	250 Hz	500 Hz	1000 Hz	2000 Hz	4000 Hz
Before treatment	1,6	2,2	3,2	4,4	3,7	2,8
After treatment	1,1	1,6	1,4	1,5	1,4	1,3

A pertinent example was provided by courtesy of Farid Sahnoune (Serge Ferrari) concerning the conditioning of the "Ambiente" exhibition hall, a continuous vaulted membrane roof. Its values of reverberation time were high at medium to high frequencies; background noise was also high and intelligibility was poor. A treatment with Batyline Aw on the ceiling is proposed, and the results should be satisfactory.

Innovations in HF welding.

Mr. Mikhail Wallin, representing Forsstrom High Frequency AB, Lysekil, displayed innovative welding machines for PVC and PU installed in more than 56 countries worldwide. Applications included not only roofs, but also trucks, boats, tarpaulins, tents, sun shades, pool liners, billboards, pneumatic products, liquid tanks, stretch ceilings, valves, linings, tubes, oil booms, etc.





He mentioned four major innovations:

1 The new machine TH-Flex with travelling gantry, 1,200 mm lateral movement, 360º rotation of machine head, automatic welding of complex products, remote control and unique functions such as angular welding, 360º turning capability, radius, circular and lateral/cross welding and RAM.

2 The new method Forflexx of joining coated metal with PVC/PU for a great range of products such as keders, patches, tents, doors and corners.

3 The Tubeflexx technology for arched tubes based on welded patches to control the angle with no need for cutting. It provides a tight seal and minimizes the possibility of leaking.

4 Software applications EMP and IQ to streamline the welding process:

EMP sets the parameters of the machine automatically to the values optimised for each material. It is less dependent on operator skills, allows simple changes and improves the weld quality. A weld sample database based on EMP is available in the Internet for the main material manufacturers: Serge Ferrari, Mehler Texnologies, Dickson Coatings, Dickson Sun, Verseidag and Sioen.

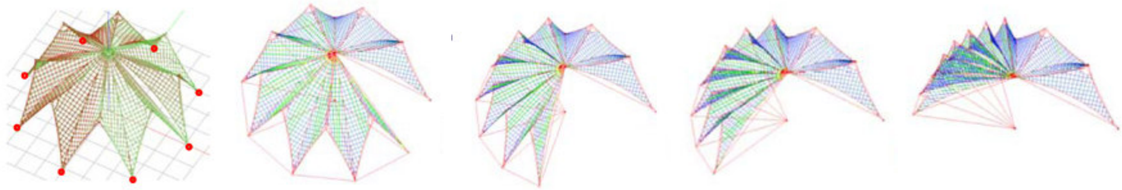
The **IQ** software monitors and reports the machine performance and provides online problem solving by the Forsstrom service team.

In addition, Forsstrom's customers and partners are welcome to the demonstration and training centre in Lysekil, a full range production facility, with different types of welding machines, eyelet press, cutting machine(s) and tensile tester.

Integrated analysis and experimental verification of kinematic form active structures.

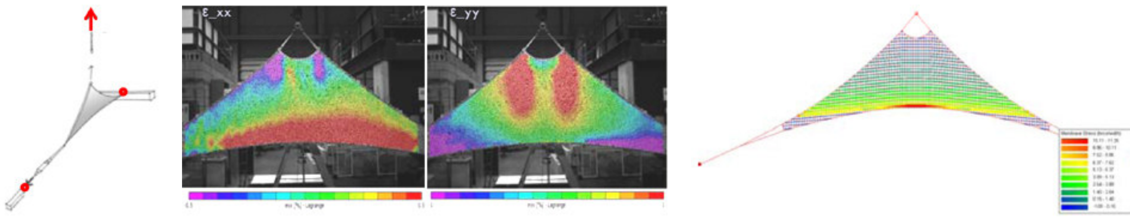
Prof. Marijke Mollaert, from the Vrije Universiteit Brussel attempted to answer to the following question: Could fabrics be tensioned in different configurations?

After examining the typology and existing adaptable membrane structures, he expounded the initial concept: a deployable dome structure with a foldable membrane skin.



In the computer model, the membrane remains tensioned in the different configurations, although the force densities of the belts controlling the tension in the membrane are not optimised.

In the actual size deployable demonstrator, folding the frame was not a problem, but the questions that remained were how to increase or to adjust the pretension after folding and the force in the boundary belts, as well as the possibility and magnitude of changing the lengths of the links.

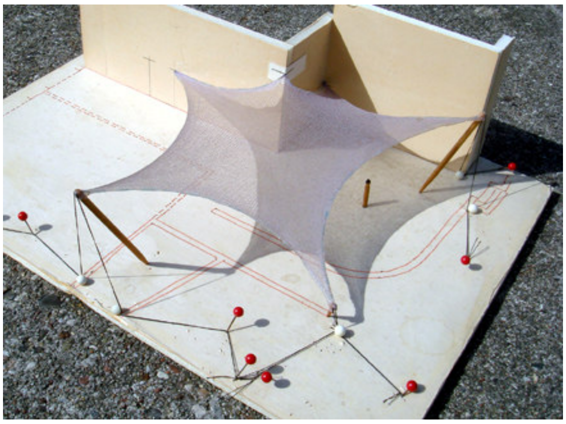


Test results and numerical analyses are difficult to compare because they do not start from the same configuration, the strain values do not correspond, the material properties are not properly defined and reinforcement and wrinkling are not correctly simulated.

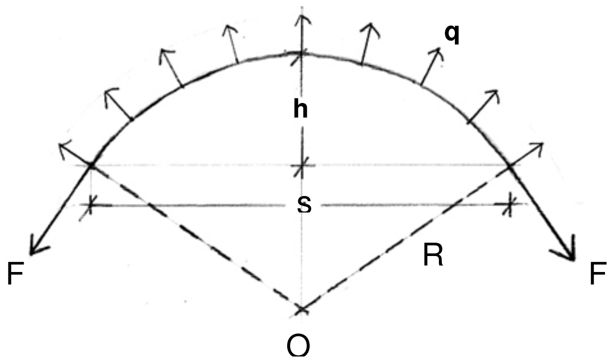
A question arose while testing a single foldable unit made of two triangles joined along the base: How is it possible to adapt the length of the links in order to obtain uniform pre-stress? She concluded that the initial question has been amplified: Can a retractable membrane be stable in intermediate configurations and still carry snow and wind loads without wrinkling? And how can the pre-tension be adjusted for different opening angles?

Afternoon sessions.

Afternoons were devoted to four parallel workshops: physical modelling (conducted by J. Hennicke & J. Llorens), "Easy" modelling (U. Gründig & TechNet), "Formifinder" (R. Wehdorn) and "RStab 3D" (W. Rustler).



Professors Jürgen Hennicke & Josep Llorens introduced and conducted the physical modelling workshop. They began by explaining the basics related to materials, elements, shapes and procedures and they formulated several recommendations.



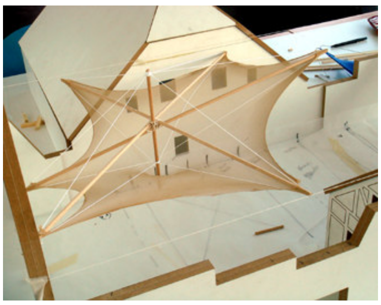
Geometry: $\mathbf{R} = \dfrac{\mathbf{s}^2 + 4 \cdot \mathbf{h}^2}{8 \cdot \mathbf{h}}$

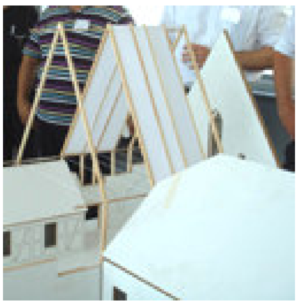
Load: $\mathbf{q} \approx 1$ kN/m

Tension: $\mathbf{F} = \mathbf{q} \cdot \mathbf{R}$

R: radius; **s**: span; **h**: sag

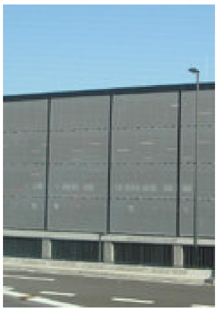
They also emphasized that physical modelling is much more than determining the form. It identifies the critical points and provides the primary structural values from simple measurements such as lengths, sags, angles and spans. This means that it is also useful for pre-dimensioning and for checking the results. With experience and judgement, physical models can replace the use of computers (in small and medium sized structures, except for patterning).

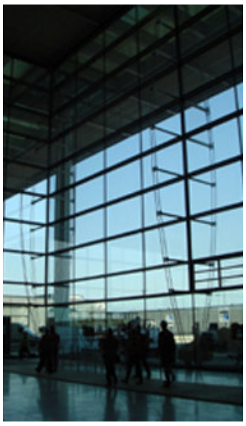




The presentation of the 2013 Students' Project evidenced the utility of physical modelling for exploring shapes, approaching the design, visualization and presentation to interested parties.

Visit to the Berlin Brandenburg Airport and Schöneberg gasometer.





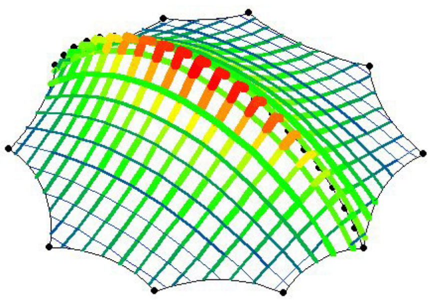
The participants enjoyed an excursion to the new Berlin Brandenburg Airport,
and encountered a propylaea receiving them as a monumental gateway, evoking a combined memory of Berlin Neues and Altes Museums.

Membranes are used extensively in the airport for the ceiling of the main building and the envelope of the contiguous parking lots.

Another tensile-related feature is the vertical- oriented cable trusses supporting the glass façade, in memory of Peter Rice at La Villette, Paris.

Astonishingly, all works are finished and ready, but the airport is not in use. This readiness, combined with the emptiness of the spaces configured a strange perception of a science fiction scene.

Next visit was the gasometer of Schöneberg, interestingly preserved by refurbishing it with an inflated textile roof.



Textile Roofs 2014

May 26th - 28th 2014

Prof. Dr.-Ing. Dr. h.c. Lothar Gründig
Dr.-Ing. Bernd Stary
Berlin Institute of Technology
Technische Universität Berlin

The Nineteenth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures will be held on 26-28 May 2014. Its format will be similar to that of TR 2013, with seminar-style lectures and hands-on activities. It will be preceded by the student seminar and sponsored by TU, TensiNet, Ferrari and Technet.