

Textile Roofs 2009

June 11^h - 13th 2009

Prof. Dr.-Ing. Lothar Gründig
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Report

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B.Stary	W.Rustler	M.Kroeger	N.Kim	F.Rodríguez	G.Grunwald	J.Hennicke	J.Llorens

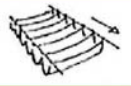







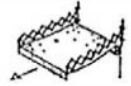



Introduction

Textile Roofs 2009, the Fourteenth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 11-13 June at the Technische Universität Berlin and was chaired by Prof. Dr. Ing. Lothar Gründig. It was attended by 72 participants from 16 countries in three continents, once again demonstrating the success of the event, which has become firmly established since it was first held in 1995.



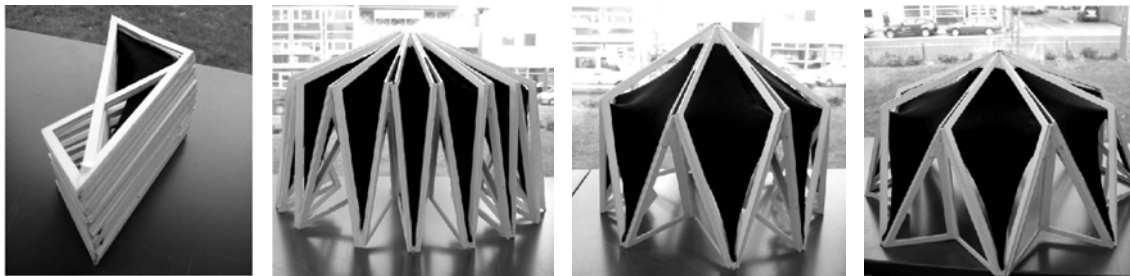
Transformable Tensile Structures by Prof. Marijke Mollaert & Niels De Temmerman, Vrije Universiteit, Brussels

After a brief description of TensiNet (an international professional network for tensile fabric structures) and Contex-T (an EU-funded integrated project on textile architecture, explained in more detail during the afternoon session), the main characteristics of tensile surface structures were presented as an introduction to foldable objects and structures.

Construction system	Type of movement	Parallel	Central	Circular	Peripheral
Stationary supporting structure	Membrane				
	Sliding				
Moveable supporting structure	Supporting structure				
	Folding				
	Rotating				

A typology of transformable roofs.

To study transformable tensile structures, the kinematic behaviour of a circular foldable frame with a membrane connected at the nodes was examined, taking into account form finding, unfolding analysis, pre-tension and loading.



The membrane folds together with the frame. The intermediate configurations modify the opening angle. Adjustability of the pretension is needed

Two potential solutions for the textile faces of the model were proposed:

- adding two triangles (flat polygons) to allow easy folding, which is a simpler solution but produces greater deformations.
- patterning a hypar.

Further research will focus on the material, the connections (what should be connected, how this should be done, and how the connections should be adjusted), the method for introducing pretension, the kinematics and adaptability, and the angle to which the system can be folded. All of these factors are influenced by the scale of the model (small, medium or large span).

Computational modelling of lightweight structures by Dr. Eng. D. Ströbel,
technet GmbH, Stuttgart

Computational modelling is used in membrane engineering for form finding, structural analysis and cutting pattern calculation. All of these functions are provided by Easy, a suite of software modules for the complete design of lightweight structures.

Form finding, based on the force density method, is the procedure by which the shape of a surface is determined from the interaction between geometry and forces. Contour and slope lines can also be determined, and different nets, enslaved points and cables introduced. Mechanically stressed and pneumatic systems are possible.

Static analysis is based on a nonlinear system into which starting values are entered after the form finding process. The material properties are introduced and load cases generated. Beam elements may be included, and information can be transferred to DLUBAL software for steel elements, also provided. The static analysis module also offers force-finding tools for optimal pre-stress, flexibility ellipsoids and sensitivity investigation.

The cutting pattern is obtained by small flattening distortion using geodesic lines that optimise the use of material and minimise deformation energy.

The following applications were presented:

- Re-formulation of the Abuja Velodrome roof with the total system in equilibrium, starting from the existing cables and masts.
- Fast mass production of the patterns for the Allianz Arena, a 32 GByte stiffness matrix.
- Efficient patterning for car shades and silos, starting from basic data.
- Exact computer modelling of the Matti Orpana pneumatic structure in Finland with $P \cdot V = \text{constant}$.
- Precise boundary cable calculation.
- Complete model of the chambered pneumatic structures for the Swiss Expo.



Abuja Velodrome



Allianz Arena



Matti Orpana Pneumatic
exact computer modelling

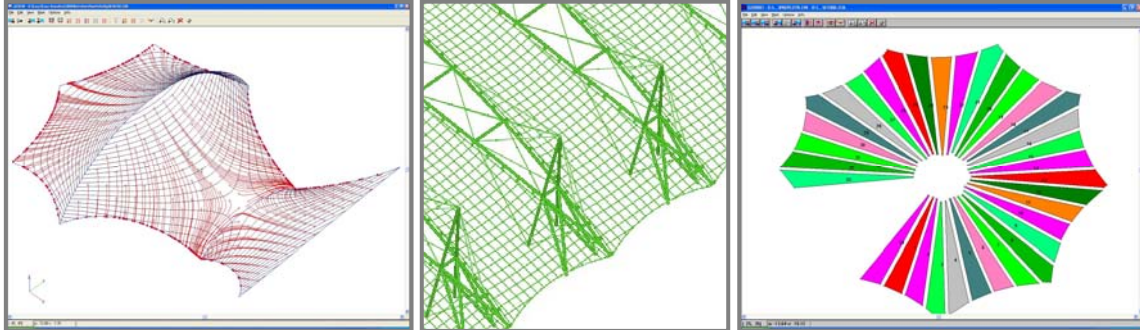


Chambered pneumatic
structures, Swiss Expo

This presentation was completed during the afternoon session by J. Holl and U. Gründig.

Introduction to Easy by J. Holl & U. Gründig, technet GmbH, Berlin

The main features and procedures of the Easy suite of software modules for the complete design of lightweight structures were introduced through a series of short demonstrations.



Easy form, which is based on the force density method, uses a linear equation system to find the only tensile surface in equilibrium with forces. The result is obtained in a single calculation step.

Easy stat is used for static nonlinear analysis. External loads are generated and precise or simplified material laws are accepted. Membrane stresses and forces are visualised and the results are presented in reports. Additional tools provide contour lines, slope lines for drainage dimensioning, and force-finding for pre-stress optimisation.

Easy cut minimises cut-off by calculating the maximum pattern width and geodesic lines. Other features of this module include export to cutting machines, fully automated optimisation for standard cases, and the use of map projection theories to reduce flattening distortion.

Easy beam imports the model from Easy stat and produces hybrid structures until a balance is reached by increasing the number of iterations or changing cross sections or materials. It can be linked to Rstab for steel analysis.

The benefits of computing the complete structure were illustrated by a complete model of the pneumatic structures for the Swiss Expo. Separation of nonlinear lightweight systems is only a preliminary, very imprecise and expensive estimation.

	2 Separated subsystems: pneumatic membrane + steel ring, struts and cables	One hybrid integrated system
Max. deflection	0,50 m	0,25 m
Max. bending moment	30.000 kNm	18.000 kNm

More information can be found at www.technet-gmbh.com

Design: Membrane and Architecture by DI. Dr. R. Wehdorn, Vienna University of Technology

Formfinder, a software package used in membrane structure design, was presented in five steps:

1. Design with forces (form finding): as introduced in the previous presentation.
2. Geometry (typology, dimension, proportion): synclastic surfaces need pressurisation; flat surfaces deform in excess; anticlastic surfaces depend on the overall proportions, pre-tensioning, curvatures, edges and joints.
3. Element catalogue (gestalt, appearance): every detail must be considered, but a catalogue of elements may be useful as a reference.
4. Building physics (climate, acoustics, fire protection): thermal, ventilation and acoustic concerns are frequently needed to complete the design.
5. Manufacture (installation process, maintenance): manufacture is also considered from the initial sketch to the construction phase.



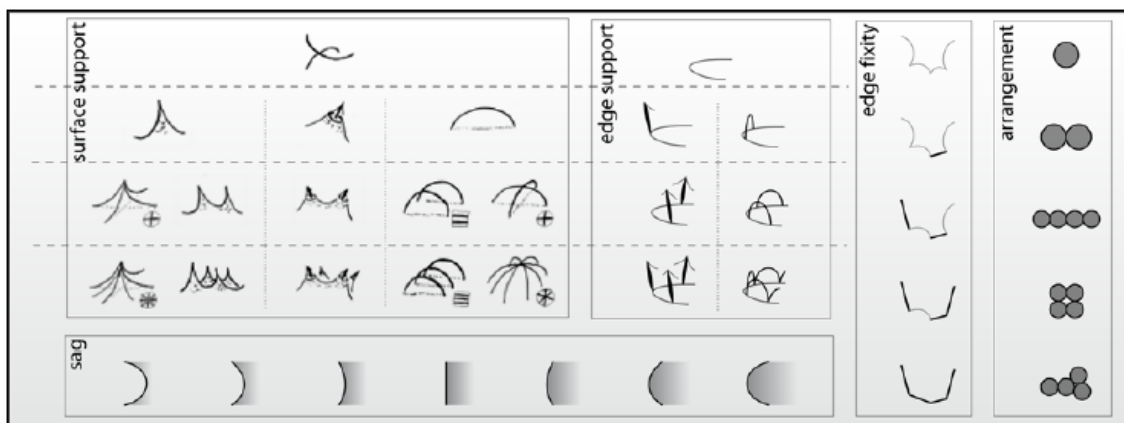
The Schönbrunn lion cage in Vienna, a cable net subjected to a dynamic load of 250 kp, was presented as an example.

The morning session ended with a short demonstration of the Formfinder software as applied to different material, projects and detail databases. The demonstration was completed during the afternoon session of the following day.

“One click” cost estimation tool for the design of form-active structures by Prof. N. Kim, Formfinder GmbH, Vienna

Unrealistic cost decisions often have severe consequences for the partners involved in the project planning/building process. Many projects – most of them considered novel, ambitious and promising – failed simply because of the “cost explosion” caused by the fact that the costs were not estimated properly at each design stage. The speaker described an approach to prevent this problem and presented a tool for making accurate cost estimations, which applies the following criteria:

- Closer collaboration between the main partners in the project is essential. The team is often multi-disciplinary and comprises a wide range of specialists. Agreements are reached through estimation of the total costs.
- Continuous monitoring during the design process is preferable to producing an estimate at the end of the process and obtaining a value that does not reflect any specific steps. Real-time information makes it possible to identify and correct errors as early as possible. Various analysis tools guide the user through the design. Length and angle analyses ensure that specific elements such as posts, edges and corner points are correctly dimensioned and oriented. A slice analyser inspects the shape of the whole structure and provides important information on the load produced by wind, snow or rain. A proportion measuring tool is provided to produce clearer visualisations of spatial parameters of the modelled structure such as height, area and volume.

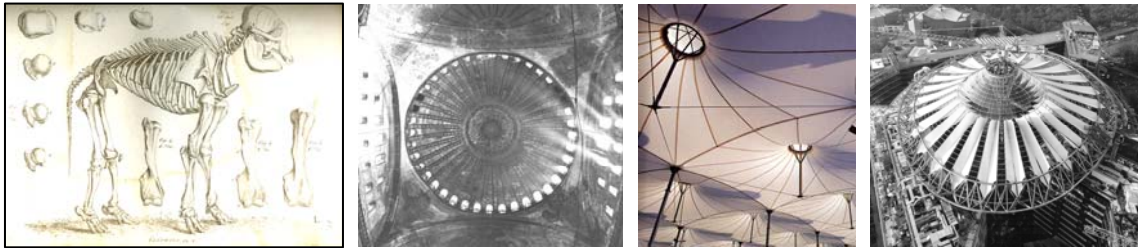


- The tool must be simple but powerful enough to produce sufficiently accurate estimations. The estimation process is simplified for the benefit of designers, and the user-friendly operation of the tool means that architects no longer need to analyse every detail and struggle with complex formulas that take time to understand and verify.
- The “intelligence” of the cost estimation tool derives from two main components: the first extracts data from the structure being modelled, and the second retrieves experience data by extracting information on a small subset of similar projects according to the data produced by the first component.

The speaker did not actually press the “one click” estimation key, but assured us that it would be available soon. We hope that this is the case.

Detailing by Prof. J. Llorens, School of Architecture, Barcelona

Choosing, designing and evaluating connections and joints are integral to the overall concept of the structure and its results. As the “correlation between parts” principle states, every part is related to the whole system in such a way that changing the part entails changing the system. From one separated part, many characteristics of the whole system can be derived. A detail provides information about many characteristics of the overall system, such as size, magnitude of stresses, direction of loads, skill of the designer, materials, budget style and complexity.



From a molar to the complete skeleton.

“Lightness is not only lightweight or low weight. It is an architectural approach”.
Jürgen W.Hennicke

The first part of the presentation focused on detailing principles and requirements, including visual expression (coherence, homogeneity, lightness, simplicity, balance, proportion, smoothness and style), structure (strength, stability and flexibility), geometry (load path, space, scale and coordination), weather exposure (impermeability, ventilation, day lighting and durability), installation (hinges, auxiliaries, adjustability, accessibility and security), sustainability and cost.

The following statements were made:

“Visual expression factors are not only visual”

“Lightness is not only lightweight or low weight. It is an architectural approach”

“Details do not express only technology”

“A local failure can easily cause a general collapse”

“Free movements release stresses”

“Space is needed”

“Changing the scale entails much more than changing the size”

“Nature never changes the scale. Different sizes mean different shapes, proportions or materials. Nature does not zoom”

“Adjustability and rotation are the most common temporary demands”

In the second part, the typology of details for membrane structures was reviewed: seams, edges, ridges and valleys, corners, high and low points, base plates for masts, and cables and anchors.

Finally, the Joints, Connections, Fittings and Anchors Data Bank was presented: <http://sites.upc.es/ca1/cat/recerca/tensilestruc/portada.html>. Textile construction and tensile structure require a wide variety of joints, connections, fittings and anchors. To design these types of components it is necessary to know the dimensions and resistance of every part involved. The database provides data from manufacturers and professionals and data extracted from the bibliography.

Recent publications and events were announced at the end of the session, including the Fifteenth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures, University of Technology Berlin, 3-5 June 2010.

Textile Architecture. Context T. Textile Structures and Buildings for the Future by Prof. Dr. Ing. R. Wagner, Munich University of Applied Science

Contex-T is an EU-funded integrated project for SMEs that brings together a consortium of 30 partners from 10 countries over a four-year period (August 2006 - August 2010). Each partner was carefully selected on the basis of expertise and knowledge in the field. The work of the resulting multi-disciplinary group integrates the activities of high-tech SMEs, research institutes and universities to develop a new generation of multifunctional textile materials that will reshape the entire value chain of textile architecture.

The Contex-T project is aimed at transforming the traditionally resource-driven textile sector into a sustainable and competitive knowledge-based industry by creating breakthrough innovation in the high-technology area of technical textiles for construction. Because this area is a driving force behind innovation, it will create significant spill-over into other important technological textile areas such as protective clothing, automotive textiles, textiles for transportation & packaging, fibre-reinforced structural elements and upholstery materials.

Context-T addresses the development of radically new concepts and new knowledge in multi-functional technical textile materials using nanotechnology and nano-structured materials. Following a holistic approach, this project aims to achieve a breakthrough in textile architecture, lightweight textile-reinforced structures and tension fabric structures. The approach consists not only in developing new materials but also in making intelligent use of these materials in novel applications. The technology developed under this project will form the basis of the textile buildings of the future, which will combine creativity and aesthetics with multi-functional, resource-conserving use of materials, shorter construction periods, long life and low costs. Innovative construction technology will ensure that these buildings are safe, healthy and comfortable.

The three main objectives of the Contex-T project are as follows:

1. To develop new, lightweight buildings using textile structures with a lifetime of up to 60 years and which meet the strictest requirements on noise reduction, acoustic absorption, thermal insulation, light transmission and reflection.
2. To create safe, healthy and economic buildings offering comfort and safety to their inhabitants.
3. To produce customised structures and buildings quickly and easily.

Research & development activities include:

- Optimised acoustic properties
- Improved thermal insulation and moisture management
- Transparency control for different types of radiation
- Easy cleaning properties
- Optimised fire safety properties
- Integrated power harvesting via solar cells
- On-site membrane stiffening
- Joining problems
- Reducing degradation due to corrosion by replacing steel cables with textile cables
- Lightweight and fireproof textile reinforced composites
- Stability of structural systems
- Optimised flexible and integrated design
- Design of intelligent kinetic structures

Fabric formwork concrete shells by PhD student L. Guldentops, Vrije Universiteit, Brussels

There is increasing demand for “organic” shapes that raise questions about buildability and affordability. Recent designs by Toyo Ito were mentioned as examples.



Organic shapes in concrete require complex formwork that could be produced in textiles, which are inexpensive and provide a cleaner finish and texture.



The state of the art is focused on the work of Prof. Mark West (barrel vaults and shotcreted panels), which is based on the physical laws concerning membrane tension, concrete compression and the inversion procedure for generating arches from hanging chains. Membrane pretension, shotcreting and reinforcement are the main challenges in producing textile formwork. The force density method is also applied to generate anticlastic in tension surfaces designed to be inverted as formwork for concrete shells.

Case studies were presented, including a hypar made of 5 cm-thick GFRC (no gravel).

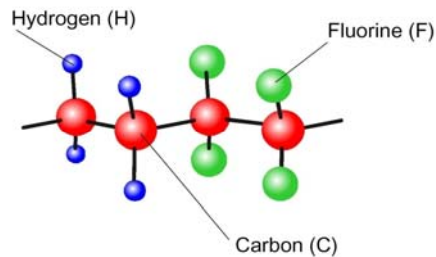
Two objections to the form-finding procedure and analysis were raised: that in tension there are large (nonlinear) deformations, and that the thickness implies dead load and, by extension, bending.

The website

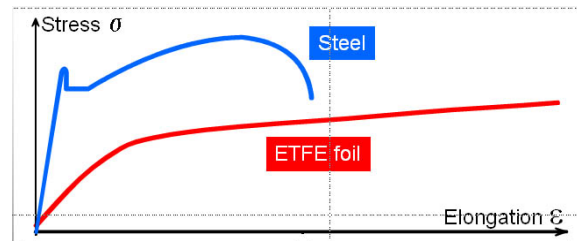
http://www.umanitoba.ca/cast_building/research/fabric_formwork/index.html was recommended as a source of further information.

ETFE foils under extreme conditions by Mr. D. P. Emmer

ETFE foil characteristics and applications were introduced in the Afternoon Special Guest Lecture. Dirk Emmer made clear that ETFE foil architecture is a competitive technology and a feasible alternative to glass architecture but NOT a viable substitute for fabric architecture.



Ethylene Tetra Fluor Ethylene



Mechanical behaviour

The laudatory presentation highlighted several important characteristics of ETFE foils, including the following: load bearing 15 N/mm^2 (including safety) and high tear resistances, a useful life of more than 30 years, self-extinguishing properties, minimal cleaning requirements thanks to the smooth, anti-adhesive surface, high resistance to environmental and chemical influences, resistance to hail and hurricane-strength wind, low weight, high strength, thermal insulation, fixed and variable sun shading, high transparency, noise absorption, and UV and earthquake resistance.

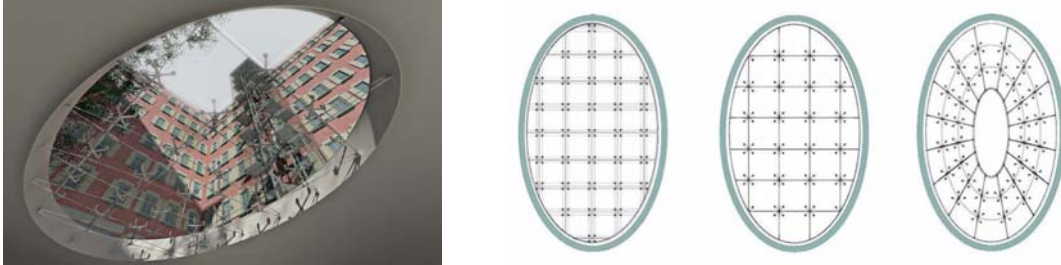
The following system components were also discussed: air supply stations, air inlet valves, air pressure sensors, aluminium profile frames and corners, cable nets, bird deterrents, welded joints and opening elements. Calculations were presented for wind suction of up to 4.0 kN/m^2 , wind pressure of up to 4 kN/m^2 and a standard snow load of 4.0 kN/m^2 . The speaker also highlighted the measurability, experimental revisability, high strength, toughness and low weight of ETFE foils and discussed the feasibility of various "organic" and "free" forms.



At the end of the talk, Mr. Emmer presented some of the leading examples of the application of ETFE foils, including the National Aquatics Centre (Water Cube) in Beijing, the Foster and Partners Khan Shatry Entertainment Centre in Astana, a Mars Station and, most importantly, the extrapolation of the Eden Project in Cornwall: the $2,100,000 \text{ m}^2$ ETFE Houston TX Mega Dome, which measures 500 m in height and 5.9 km in circumference and is designed to protect the inner city against environmental impacts.

Metallic tent surfaces by Dr-Ing. W. Laufs, Vice President Thornton Tomasetti, NY

The company Thornton Tomasetti has a lightweight structures group. Three recent projects were presented: a tensegrity-glazed skylight ellipse, the Hippy Teepee and a suspended ceiling for an art gallery.



A tensegrity-glazed skylight was chosen to cover the courtyard of a historic building in Soho, NYC, following consideration of two initial designs: steel I purlins or pre-stressed rods converging at the centre in a “bicycle wheel” pattern. Finally, the tennis racket tensegrity support system was adopted: strings (rods) in tension and struts in compression, the whole encircled by the concrete slab of the roof. Asymmetric live load was considered and construction details presented.



The “Hippy Teepee” for external shading was designed by the artist Benjamin Ball. It consists of a tripod with a ring on top and a mesh of riveted stainless steel triangles. Form-finding and static analysis were carried out considering a membrane-based surface in which the theoretical fabric stresses were converted into rivet forces and the stainless steel triangles were dimensioned.

Two objections were raised: that the triangles cannot be flat, and that the overall structure is not tensile, but a shell.



Art Gallery suspended ceiling under the High Line, Chelsea, NYC

Textile constructions in the interior and outside skirts by H. J. Koch, Koch Membranen, Rimsting am Chiemsee

As far as 1962, Koch Membranen began its way to structural membranes with special highlights in 1969/72 (Olympic Games) and 2002 (introduction of acoustic membrane technology). Main products are conventional structural membranes, textile developments and interior applications shown by a multitude of examples, many of them transformed in icons of the field.



Skating Ring, Munich Olympia Park



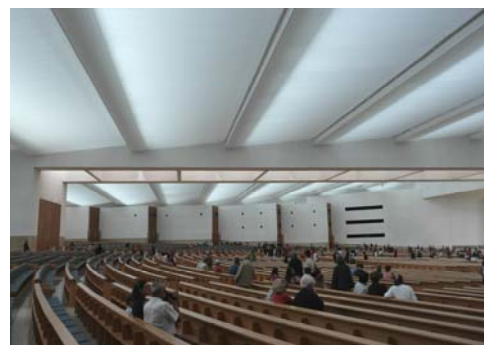
Lords Cricket Ground, London



Walls and partitions. Gläserne Manufaktur Dresden. Material: Helioflon® Lichtgewebe



Fátima Sanctuary skylights, Portugal



Sustainable development strategy in composite textiles by F. Fournier,
Ferrari SA, La Tour du Pin

After a brief presentation of Précontraint-coated technology, the Marsyas sculpture by Anish Kapoor was shown as an example of predictable dimensional stability and consistency.

The application of textiles to façades was illustrated by the example of the giant wrapping of the Vienna Airport car park and Texo Frame technology for office buildings and similar premises.



Abu Dhabi Ladies Pavillion: residual strength after 10 years of exposure: warp 89% and weft 98%

Durability was also emphasised as an important factor in long-term structural integrity, aesthetics, thermal performance and reuse. Mrs Fournier stated that “The best material is the one you do not have to produce”, pointing to the differences between short-term second life, long-term second life and recycling.

Indicators	Unit	Recycled	Incinerated	Dumped
Energy	MJ – Eq.	31,44	54,063	54,055
Water	Litres	47,05	81,30	80,75
Natural resources	Kg Sb	0,01079	0,01968	0,01967
Global warming	Kg CO ₂	1,21	2,51	2,31
Toxicity	kG 1,4DB eq	0,4306	1,4807	1,4531
Ordinary waste	Kg	0,1914	0,3373	0,6850
Dangerous waste	Kg	-0,0002	0,0007556	0,0007557
Values given for 1 m ² of white, non fire retarding Batyline 500 g/m ² without hemp, excluding steps 6, 7, 8				

Mrs Fournier presented a life cycle assessment of PVC-coated polyester membranes, which determines the total environmental impact of products throughout their life cycle. She explained that impacts can be measured by considering the following ten stages: 1) resource extraction; 2) transport; 3) raw material production; 4) transport; 5) textile manufacture; 6) transport; 7) textile manufacture; 8) product life; 9) end of product life; and 10) transport.

The key impact factors in recycling, incineration and dumping are energy, water, natural resources, global warming, ordinary waste and dangerous waste. The positive effects of recycling are shown in the table of values. In addition, most impacts derive from the extraction and production of raw materials and can therefore be minimised by recycling.

Membranes and cable nets. Some projects in detail. Arena canopy and outdoor chimpanzee enclosure by Dipl Ing. G. Zapf, IBZ Ingenieurbüro, Berlin



A canopy supported by two masts was designed for the Sangerhausen Rosarium. Its main characteristics are the valley cable against flattening and ponding and the double-layer reinforcement around the high points.



Outdoor chimpanzee enclosure, Berlin Zoological Garden.

The enclosure is rectangular. The masts are outside the enclosure. The main loads considered are ice and wind. The design was constrained by the limited space available and an interior tree (a view of the intersection is shown on the left).

The tension of the cables was measured.

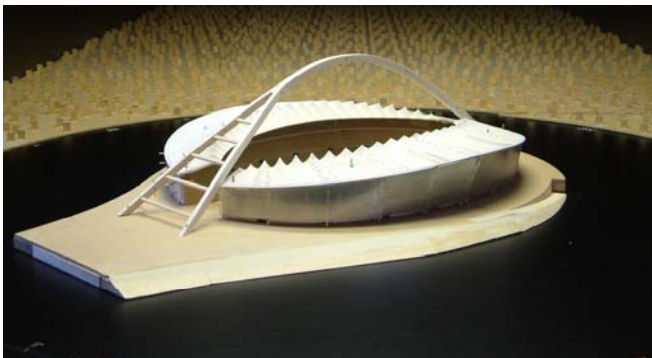
Wind and snow loads on membrane roofs by Dipl. Ing. M. Buselmeier, Wacker Ingenieure, Wind Engineering Consultants, Birkenfeld

Realistic wind and snow loads must be taken into account in the design of a membrane roof. The wind loads are classified as: exterior wind loads, interior wind loads, overall wind loads on the main supporting structure, wind loads on tributary areas (membrane design, substructure), local wind loads on cladding, quasi-steady wind loads and dynamic wind loads.

Information on wind loads can be obtained from standards (for example Eurocode, or ASCE, which is only valid for simple structures), theoretical estimations, data from previous projects with similar geometry, numeric simulations and wind tunnel tests of rigid or elastic models.

Wacker Ingenieure carries out wind tunnel tests of rigid models, which are feasible when deflections do not influence the pressure distribution (i.e. when deflections are small relative to the dimensions of the building and the outer edges of the structures are in almost fixed positions). If these conditions are not met, additional tests could be performed, taking into account the deflected shape and incorporating theoretical estimations and numerical calculations. Elastic models are not used because they are complex and expensive.

A series of examples was used to illustrate the benefits of wind tunnel model testing.



1 Recommendations for temporary bracing during the installation of the new Durban Stadium. 2 Reduction of local suction wind load at the windward roof edge by means of a spoiler, Masoala Hall Zurich, Switzerland. 3 For the Olympic Stadium in Berlin, a reduction of net wind loads on lower membrane was obtained by means of partitions between lower and upper membrane and optimization of their position. 4 Snow load distribution on the Fröttmaning (Allianz Arena) train station.

Other factors that must be considered include wind-induced vibrations, local wind loads, wind load impact on neighbouring buildings, dispersion of exhaust air, natural ventilation, indoor airflow, smoke extraction in case of fire, pedestrian comfort at the base of the building, the impact on the ventilation of neighbouring city districts, and wind-induced noise.

DLUBAL Engineering Software for Structural Analysis and Design by Dipl. Ing. W. Rustler, Engineering Software Dlubal GmbH, Germany

DLUBAL Engineering Software, based in Tiefenbach, Germany and with development facilities in Prague, has over 20 years of experience in developing structural analysis software. The company currently employs ~100 staff. Its software is used in over 40 countries by more than over 7000 users.

Dlubal solutions:

RSTAB Beam Elements, the framework program and additional modules:

- Stress-Analysis
- Stability Analysis
- Connection Design
- Dynamic Design
- CAD Interfaces
- Concrete and Timber Design
- Composite Beam Design

RFEM Beams, Plates, Shells, Solids, the FEM program and additional modules:

- Stress-Analysis
- Stability Analysis
- Dynamic Design
- CAD Interfaces
- Concrete and Timber Design



Dlubal solutions were used in the development of the following constructions, among others: fairgrounds in Milan (Italy), the Olympic Stadium in Berlin (above, top left), Graz Airport, the Eden Project (UK), the Scottish Parliament building (above, top right), the Expo 2000 roof in Hannover (above, bottom left), the Allianz Arena football stadium in Munich (above, bottom right), the Hotel Marina (Lake Constance), and a steel bridge over the River Danube.

A demo version can be downloaded from www.dlubal.com

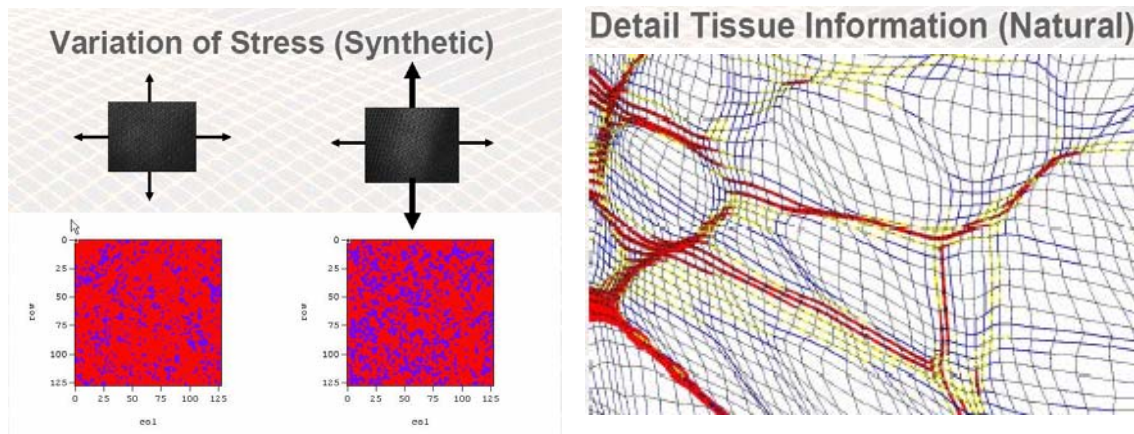
Contactless Measurement of Microstructure of Synthetic and Natural Two-Phase Material by Dr. Ing. M. Kroeger, technet GmbH, Stuttgart

The principles and potential use of contactless image analysis for measuring the properties of two-phase synthetic and natural heterogeneous materials were presented.

Synthetic and natural materials are classified on the basis of the formalism of random heterogeneous material.

Image processing and pattern recognition are used as an experimental approach for contactless measurement of material properties.

Microstructure and cross-property relationships provide a link between pattern parameters from images and material properties.



Results were presented for volume fraction, variation of stress, fraction of fibre, strain, variations with temperature or storage time, and detailed tissue information.

References were suggested, for those interested in learning more about contactless measurements:

Aguilera, J.M., Stanley, D.W. 1999, *Microstructural Principles of Food Processing and Engineering*, All Aspen Publications, Gaithersburg

Garboczi, E.J., Bentz, D. P., Martys, N.S. 1999, *Digital Images and Computer Modeling*, in: Po-zen Wong (Ed.), *Methods in the Physics of Porous Media*, Academic Press, San Diego

Jähne, B. 1997. *Digital Image Processing*, Springer, Berlin

Kroeger, M. 2003. *Image analysis for monitoring the quality of fish*, In: Luten, J.B., Oehlenschläger, J., Olafsdottir, G.(Eds.), *Quality of Fish from Catch to Consumer*, Wageningen Academic Publishers, Wageningen

Russ, C.R 2004. *Image Analysis of Food Microstructure*, CRC Press, Boca Raton

Ströbel, D., Singer, P. 2005. *Computational Modelling of Lightweight Structures; Formfinding, Load Analysis and Pattern Cutting Generation*, Textile Roofs 2005, Berlin, Germany

Lightweight Structures in South America (Peru) by F. Rodríguez Faverón, Cidelsa, Lima

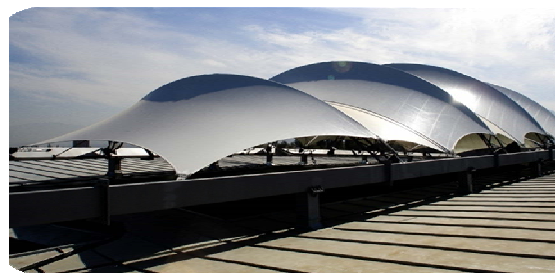
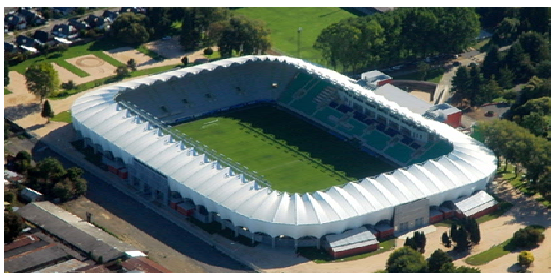
F. Rodríguez presented a wide variety of textile roofs designed or built in South America. Cidelsa has offices in Peru, Colombia, Chile and Mexico, and carries out projects in Peru, Ecuador, Bolivia, Colombia, Venezuela, Central America, Chile, Argentina, Mexico and the USA.



Cidelsa factory: 4.000 m² of steel structure + fabric

Cidelsa are experts in architectural design and engineering, membrane transformation, high-frequency welding, manufacturing of steel structures and accessories, and assembly.

A collection of projects was presented, which included “Muelle Uno” (1991), mentioned as the first lightweight structure in Peru, the Estadio Temuco in Chile (2008), and several shopping centres, stadiums, museums, convention centres, beer gardens, squares, sports halls and stations.



Cidelsa originally used physical modelling software such as MPanel and SAP 2000, but two years ago they changed to the Easy suite of software modules for the complete design of lightweight structures. This software can be used for form-finding, to determine material properties, to calculate pre-stress, to study load cases, and for the static analysis of hybrid models using the Easy Beam module, completed with the Rstab Dlubal solution, which was presented in a previous session.

Future projects and international awards created a feeling of optimism in an area seriously affected by the financial crisis.

Modular constructions by Dr. Ing. G. Grunwald, Hightex GmbH, Rimsting

A foil façade, composed of equal frame modules covered with mechanically pre-stressed foil, was installed at the Training Centre of the Bavarian Mountain Rescue Division in Bad Tölz, Germany.



A simple rectangular building was erected to provide a covered space for rescue training. The simple box-shape is accented by the arch-supported frame modules of the façade, where the spatially curved and tensioned foil produces an unusual pattern of reflections that alternately show the interior of the structure and the exterior landscape. The modules were developed, tested and optimised for use as a single layer façade, which protects the inside of the building from wind and rain. Heating and acoustic protection were not required, since the building was designed to reflect realistic outdoor conditions as far as possible.



More than 70 tons of ETFE foil were assembled in the Dolce Vita Tejo shopping mall in Lisbon. The roof cushions (more than 350 pieces with an average size of 10 m x 10 m) are activated by an intelligent thermal concept. The diagonal printing on the upper and lower layers of the cushions optimises the shading properties of the roof and prevents direct sunlight from entering the building. A special coating on the transparent parts of the cushion reflects the light. In addition, the three air chamber system strengthens the thermal behaviour of the construction. This combination of standardised cushion modules and innovative thermal behaviour is a highly promising concept for future developments.

Hightex GmbH now aims to extend the capacity of this technology to multilayered, insulating and wide-span structures for extended roof and façade applications and to standardise foil constructions for future uses.

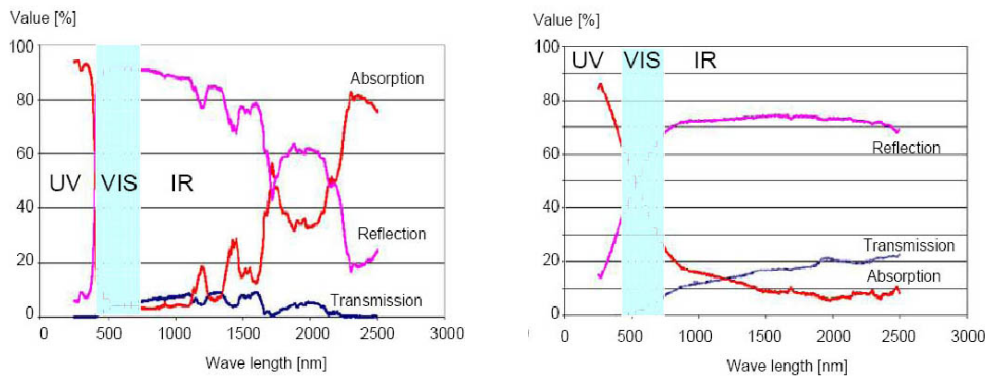
Membrane structures today and tomorrow, by Dr. Ing. R. Wagner, Hochschule für Angewandte Wissenschaften- FH, München

Discussion on existing membrane structures led to a series of remarks on a range of aspects, including the diversity of materials, aging, self cleaning (depending on the material, location and drainage), changes of stress, cutting pattern detailing, compatibility along seams and compensation values.



Cutting patterning of the protected parking facilities, Office for Waste Management, Munich

Future developments were presented, including the impact of less or no curvature in façades, greater translucency and strength, three-dimensional fabric for sound absorption and thermal insulation, light reflection and light diffusion, belts in membranes instead of cables, cable nets with no cutting pattern, coating of cable nets with sprayed flexible textiles, and environmental applications such as oil booms and flood protection, water harvesting, flexible thermal insulation and integration of systems for converting solar radiation into energy.



Thermal properties. Left: coated PES fabric. Right: PTFE coated glass fibre fabric

What did she see at TR 2009? At the beginning of her presentation, R. Wagner summarised some of the main points raised during the workshop:

- Easy differs from other software developments for tensile membranes by applying the theory of equilibrium of the deformed shape.
- Considering the equilibrium of the deformed geometry, tension and compression are not reversible.
- Shapes of equilibrium vary according to whether vertical or tangential equilibrium, triangular or square nets, and shear stiffness and flattening process are considered, which suggests that the cutting pattern can be incorporated into the design process.

Wagner reminded the reporter that, when the finite element analysis of brick vaults was (well?) established, one participant noted the lack of rigidity of the edges and the discontinuity of the joints.

Hands-on physical modelling workshop

Hands-on physical modelling workshops were held in the afternoons. Participants worked on their own models before (or after) entering them into computers. The practical work was used to illustrate several fundamental aspects of tensile membranes, grouped below according to type:

Physical modelling evaluation criteria, by Prof. J. Bahndorf, J. Llorens, M. Mollaert & R. Wagner:

PRINCIPLES

1. Only tension
2. Funicular shape (form active)
3. Double curvature (anticlastic)
4. Pre tension

SHAPE

5. Flatness (sag/span)
6. Ponding

RATIOS

7. Height/width or height/length
8. Surface of membrane/covered area
9. Shaded area
10. Rain protected area

PRIMARY STRUCTURE

11. Internal supports
12. Boundaries: pin connections, curvature
13. Angles between boundaries, cables

DETAILS

14. Edges
15. Corners
16. High/low points
17. Ridge and valleys
18. Anchoring forces



Bettina Heinz shifted from a one-direction-rain-protected roof to an imaginative open ended spiral corridor.

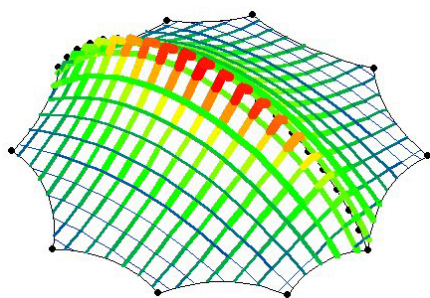


D. Veenendaal minimized the number of vertical supports under compression



Sightseeing cruise

The 2009 sightseeing cruise followed a new route through the docks of Berlin, which took participants past heavy industrial installations and the Central Station before rejoining the traditional route under the Kronprinzen, Marschall, Weidendammer, Eberts, Monbijou, Friedrichs, Liebknecht and Rathaus bridges.



Textile Roofs 2010

June 3rd - 5th 2010

Prof. Dr.-Ing. Lothar Gründig
Technical University of Berlin (TUB)
Berlin, Germany

The Fifteenth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures will be held on 3-5 June 2010. Its format will be similar to that of TR 2009, with seminar-style lectures and hands-on activities. It will be preceded by the student seminar and sponsored by TU, TensiNet, Ferrari and Technet