Forthcoming Events

FUTUROTEXTIEL 08
International Journal of Space Structures

Transparent inflatable globe and giant lightweight mirrors, Belgium
Amphitheatre OLIMAR, Uruguay

Visiting the Bigo, Italy

Membrane structures in India

Designing, detailing and building with textiles.
Projects realised with different fabric.

Rhino-Membrane

Integrated design of tensile structures

Open Learning Centre, Belgium
Dalian Seals Show Hall, China
Canopies for Hospital, Canada
Municipal Sport Pavilion, Spain

Techtextil 10th Student Competition 2009

TensiNet is becoming stronger: the ‘team’ supporting the Association is consolidating and the dissemination and networking activities are increasing. The whole group working in the field of tensile surface structures is growing. Since the beginning of August Evi Corne has been working part-time for the TensiNet Association. We were able to finalise this issue before the Annual General Meeting (10th of November in Stuttgart) thanks to her help! We had a meeting with the graphic designers T.M.&C. (Talent, Marketing & Communication) and from 2009 we will change the ‘style’ to improve the readability of the newsletter and include larger photos.

On the website www.tensinet.com, under Tensinet News, events and contract proposals are announced. TensiNet is supporting the Techtextil Student Competition 2009 and an invitation to participate has been sent to our ‘school’ members. TensiNet is present at the Futurotextiel08 Fair (from 9 October until 7 December, Kortrijk) with a continuous slide show displaying recent projects and in the exhibition with samples of the used materials.

The Special Issue No. 4 of Vol. 23 (last of this year) of the International Journal of Space Structures will be entitled ‘Tensioned membrane construction’. Papers in this Special Edition were selected from those presented at the TensiNet Symposium ‘Ephemeral Architecture: Time and Textiles’ held at the Politecnico di Milano, in 16-18 April 2007. The Working Groups Website&Database, Analysis&Materials and Specifications have started up or continue their activities.

We kindly invite all TensiNet members to participate in the next Annual General Meeting to be held on the 10th of November, in Stuttgart. We hope to meet you in Stuttgart.

Marijke Mollaert
Heidrun Bögner-Balz

Annual General Meeting
Partner Meeting
Monday 10th November 2008 - STUTTGART

Dearest TensiNet members,

We would like to kindly invite you to the next TensiNet Meetings on Monday the 10th November 2008 in Stuttgart. The morning lectures will present research results and new projects. In the afternoon during the Annual General Meeting it will be possible to comment on the current activities of the TensiNet Association. The Partner Meeting will start at 3pm. During the Partner meeting a new Board will be elected.

LOCATION
University of Stuttgart,
Pfaffenwaldring 27, Lesesaal

EXTRA VISIT
1 During the TensiNet Meeting day you are kindly invited to visit Labor Blum.
2 Guided visit to New Architecture in Stuttgart Sunday the 9th November 2008 or subsequently to the meetings like e.g. the new Mercedes-Museum, the new modern arts gallery and the new exposition halls.

Interested? Send a mail to heidrun.boegner@gmx.de before 27th October. Extra information will be sent.

CONFIRMATION
Confirmation of attendance for the morning lectures, the annual general meeting & partner meeting is obligatory. Send an e-mail before the 27th October to heidrun.boegner@gmx.de and a CC to ecorne@irexchange.vub.ac.be.

PROGRAM
9:30 - 12:00 PRESENTATION
1 - Prof. Dr.-Ing. K.-U. Bletzinger
New developments for the analysis of membrane structures.
Stress singularities which are arising from the theoretically based cutting patterns will be analysed.

2 - Labor Blum
New materials and their importance for the environmental performance by simulation and measurement will be presented.

12:00 - 13:30 LUNCH BREAK
13:30 - 15:00 ANNUAL GENERAL MEETING & WORKING GROUPS
15:00 - 17:00 PARTNER MEETING

3 - Dr.-Ing. D. Ballhause
The failure of uni-axially and bi-axially stressed materials analysed on the basis of the Weibull assumptions of probability for the fracture of multi-filament yarns. Extracted results of his thesis will be shown.

4 - Schlaich-Bergermann and Partner
Actual projects will be presented.
Forthcoming Events

Futurotextiel 08
Surprising textile, design & art
International exhibition
Kortrijk, Belgium
9/10 > 7/12/2008

IBERTOLDO 2008
International Biennale
Fira de Cornellà, Barcelona, Spain
29 > 31/10/2008

Roof & Cladding India 2009
International Symposium
Chennai, India
23 > 25/04/2009

Textile Roofs 2009
Workshop
Berlin, Germany
11 > 13/06/2009

Structural Membranes 2009
International Conference
Stuttgart, Germany
05 > 07/10/2009

The “Simposio Latinoamericano de Tenso-Estructuras” (Latin American Symposium on Tensile Structures) was first celebrated at the School of Architecture and Urbanism of The University of Sao Paulo, Brazil in 2003, and it was successfully received by professionals, students and common public. The second edition was celebrated at the Central University of Caracas, Venezuela in 2005, and now, in its third edition, it will be celebrated simultaneously with the IASS 2008 Symposium, Acapulco, Mexico (International Association for Shell and Spatial Structures). This symposium is organized by the Red Latinoamericana de Tensoestructuras (Latin American Working Net of Tensile Structures), whose objective is to promote and stimulate the development, design and construction of tensile structures, by means of creating a discussion forum on these topics for researchers, professionals, enterprises and students.

http://iass2008.unam.mx
Since the dawning of time, woven materials have been used for the construction of all sorts of structures. Whether cosmetic or therapeutic, the fibre or weaving and the stitch to the coating, dressing and micro-encapsulation... they are subjected to different techniques of treatment. Ongoing exploration on the quality and appearance of textile architecture is an important space structures, recently held at the Tri Postal in Lille. More than being an exhibition, it embodies the realisation of the world of textiles. For the reader and visitor, it means the discovery of the world of textiles, as he/she appreciates its incredible diversity, from the fibre or weaving and the stitch to the composites and non-woven materials. The origins of the fibres are sometimes strange: a crab’s carapace, a basalt stone or beetroot give birth to a fibre, thread or tissue. The new fibres seem to have emerged directly from science fiction. Interactive and intelligent, they are subjected to different techniques of coating, dressing and micro-encapsulation... Whether cosmetic or therapeutic, the ‘biosensorial’ textiles alter their physical properties according to environmental conditions, becoming anti-bacterial, thermoregulatory, hydrophilic, therapeutic... In this discovery of the world of textiles, also building and architecture receive particular attention.

Buildtech – Textile Architecture

Since the dawning of time, woven materials have been used for the construction of all sorts of shelter: small ones (tipis), adaptable ones (canvas), transportable ones (circus marquees), large canvas covers (the Velum in the Coloseum of Rome), simple sunscreens (parasols) or even thermally isolated buildings (yurts). Since the middle of the 20th century, several architects (Frei Otto, Bodo Rasch...) and engineers (Horst Berger, Jörg Schlach...) have granted technical textiles a real place as a fully-fledged building material, just like the reference materials of stone, steel, concrete and glass. The main added value provided by technical textiles is their lower weight.

Textiles from natural fibres have a limited lifespan and solidity. The use of new synthetic fibres, coatings and surface coatings, enable the technical textile to respond to the specific demands in the following areas: texture, appearance, colour, flexibility and transparency, differentiated reflection of radiation, self-cleaning, acoustic and thermal insulation, high strength, weld ability and finally, the integration of photovoltaic cells. In terms of lifespan, depending on the material and environmental conditions, a reliable period of 20 to 35 years is predicted, without the appearance of any kind of problems. The textile becomes a multi-functional component, which is adaptable or re-adjustable according to the application to which it is assigned. Ongoing exploration on the quality and performance is triggered by collective research (www.context.eu) and thematic networks (www.tensinet.com).

Evidently, the textile remains a supple support. In order to be inserted into a building it is forced into double curvature. Tension is applied to the whole surface (like in an open umbrella) or by means of internal pressure (like in a balloon). The forms are ‘forms of equilibrium’, in the image of a spider’s web or a soap bubble, capable of adhering to any surface.

The pioneers of architectural textiles emphasise expressive curves and unusual constructions. Thanks to an adapted curvature, it is possible to transfer the loading pressure efficiently to the support points. Nevertheless, the tendency is towards constructions that are barely curved. These are realised, when the material is sufficiently pre-tensed over shorter distances. In addition to progress in the world of technical fibres and their coatings, an improvement has been equally attained in calculation techniques as well as software tools. Architects, engineers, manufacturers, builders and entrepreneurs all have access to specialised computer programmes and systems for analysis and design.

In order to obtain a satisfying result, it is essential that all the players in the project collaborate from the outset. Transport, assembly and anchorage factors must equally be integrated. Tensioned textiles are used for diverse applications in construction. While in the 1930s, architecture concentrated on ephemeral constructions, ever more ‘permanent’ projects are initiated in shopping centres, cultural buildings, stadiums, schools, etc.

In the current tendency, tensioned textiles can fulfill the demand for more curved forms. With their natural shapes, architectural textiles can easily find their place beside the massive volumes, where, thanks to their lightness (both physically and figuratively), they are capable of creating a contrast beside more imposing structures. Textiles can also facilitate reconciliation between newer creations and what already exists.

Marijke Mollaert for futurtextiel08

www.futurotextiel.com

INTERNATIONAL JOURNAL OF SPACE STRUCTURES (IJSS)

The journal includes regular reviews of technical publications, books and trade literature. Also included is information on recently built important space structures, recently held conferences and forthcoming events of interest. The Journal also publishes Special editions.

The journal is published quarterly. ISSN 0266-3511

The aim of the journal is to provide an international forum for the interchange of information on all aspects of design, construction and space structures. The scope of the journal encompasses structures such as single-, double- and multi-layer grids, barrel vaults, domes, towers, folded plates, radar dishes, tensegrity structures, stressed skin assemblies, foldable structures, pneumatic systems and cable arrangements. No limitation on the type of material is imposed and the scope includes structures constructed in steel, aluminium, timber, concrete, plastics, paperboard and fabric. The journal aims at striking a balance between theory and practice and creating a platform for exchange of information between structural engineers, architects, civil engineering contractors, system manufacturers and research workers in academic and non-academic establishments.

One of the forthcoming Special editions will be “Tensioned membrane construction”. Papers in this Special Edition were selected from over 40 presented at the TensiNet Association Symposium “Ephemeral Architecture: Time and Textiles” held at the Politecnico di Milano, in 16-18 April 2007. They cover a wide range of topics, from Campioli, Margiaretto and Zanelli’s historical review of textile architecture in the Italian context, and Hendrick’s inspirational account of relationships between lightweight and natural structures and tensile architecture, to the more mathematically analytical approach in Gosling and Bridgens’ presentation of a new concept for materials testing of architectural fabrics and Wagner’s paper describing simple analytical design/checking tools for single/ double-curved membranes and inflated cushions. To complement these, Adriaenssens examines the feasibility of spliced-spine stressed medium-span membranes and, as a practical case study, Stimpfl describes the redesign and installation of the Velodrome roof in Abuja, Nigeria.

For more info see www.multi-science.co.uk/space.htm
Buitink Technology fabricates and installs transparent inflatable globe and giant lightweight mirrors in the atrium of the Justus Lipsius Building in Brussels (Belgium).

Since July 2008, France has the Presidency of the Council of the European Union. For the design of the interior of the EU building Justus Lipsius in Brussels, the French government contracted the well known French architect agency “Dubuisson Architectes” in Courbevoie (France).

An important part of the design is a huge transparent globe (15m diameter) in the middle of the atrium that is printed with the different flags of the members of the European Union. This globe is hanging in the middle of the atrium, with at both sides a giant mirror with a size of 12m x 10m. The transparent exterior features 28 coloured strips which reflect the flags of the Member States and the European Union. These suspended strips, which twist in spirals around the globe, have been printed in translucent inks (except the white which, for technical purposes, is more opaque) to enhance the globe's transparency and heighten the overlay effects. They not only reflect the individuality of each country, but also create an overall harmony through the combination and juxtaposition of the colours in an upward movement.

The reason for placing the two huge inclining mirrors on either side of the globe becomes apparent at a key point at the very heart of the foyer. Anyone crossing the foyer who stands at this point under the globe, can glance up and see the logo of the French Presidency reflected in the mirrors against the coloured strips. From this focal point, the globe fills the whole space of each mirror. In the top of the globe, a ring with LED lighting is installed, that lights the different flags in different colours.

The globe is made from a strong and transparent ETFE film. The globe is kept under pressure by an automatic air system. The two mirrors of 10m x 12m are made of aluminium frameworks, which are cladded with a lightweight (80g/m²) mirror film.

Rienk de Vries
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Originally there was a metal amphitheatre that was destroyed in a storm wind. The idea was to rebuild it with a more functional roof for the scope. The new construction is a membrane tensioned over 2 longitudinal reticulate arches, with 28m span each one, stabilized by 3 structural lines anchored to the floor and giving stability to the entire roof. The membrane is attached to the structure with ropes.

The objectives of the new roof are the following:
1. The need for a special design that is more suitable for the amphitheatre, that works better acoustically and that achieves best visual effects of the show, either day or night through the lighting of the shows;
2. Low building costs;
3. Rain protection;
4. Easy installation and the need for a demountable structure.

Finally was chosen for a prestressed PVC-membrane on the basis of following two reasons:
1. It strictly complies with all the objectives;
2. When compared to other traditional systems such as metal or concrete construction, these traditional systems do not meet all the requirements, not offering the aesthetic and formal opportunities PVC membranes can offer. The roof has been designed respecting the minimum height to develop shows, and generating a membrane with double curvature to encourage the good diffusion of the sound for the spectators. The structure and the membrane were designed at the same time. The metal structure is made of arches in round pipes 5” and 2” and the anchorage in Platinum in 1”. The membranes are made of polyester fabric (PES HT 1100dtex, 5x5 threads per cm (12 threads per inch) with PVC coating, UV protection on the outside, a weight...
In 1992, on the occasion of an international exposition commemorating the 500th anniversary of the discovery of the Americas by Columbus, the old harbour of Genova and the historical city district (which had long been separated) were rejoined through redevelopment. Old 16th century buildings were restored and an aquarium and the Bigo (bigo is the old Genovese word for a ship’s crane) were newly reconstructed. After the exposition ended, the facilities were turned into a large waterfront park and have since been administered by the city. The tent roof (60m long by 40m) covers a multi-functional space: after the exposition, it has served as a skating rink in winter and a place where miniature soccer games for children or outdoor concerts are held in summer. The Bigo consists of 2 independent sets of cigar-shaped booms forming out from a small island located within the water of the dock. One set of booms supports the membrane roof and the other carries a vertical cable-car passenger lift from the quayside. Both sets are anchored down with tie bars to foundations beneath the harbour water. Radiating out from the tip of each of the booms supporting the canopy are fans of 16 cables which support slender arch ribs from which in turn the membrane canopy (made of PTFE-coated glass fibre) is suspended. The canopy consists of 5 discrete membrane panels each of which has ‘edge cables’. Glass lenses close off the gaps between the membranes while a pantograph mechanism automatically synchronises the position of the glass with that of the membrane roof under changing loads. The Bigo, built 16 years ago with a PTFE-coated glass fibre fabric, is still a nicely tensioned, clean white, impressive free span cover and one can feel that this precisely engineered structure performs well. Roberto Canobbio would just prefer that the steel structure could be painted to ensure an extended life time of the whole structure.

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of 800gr/m² (230oz/sqyd) and a breaking load limit of 30daN/cm. (167lbs/inch). The prestressing of the membrane has being done manually with a rope tied to the structure. Everything was manufactured in the workshop in 30 days and the assembly took place in 10 days.

The objective sought after by the roof was achieved to perfection, accomplishing an enjoyable space for holding shows.

Roberto Santomauro
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Name of the project: Bigo
Location address: Genova, Italy
Function of building: covering multi-functional space (skating rink, miniature soccer games, concerts, etc.)
Year of construction: 1992
Architects: Renzo Piano Building Workshop
Engineers: Ove Arup & Partners; form TL ingenieure für tragwerk und leichtbau gmbh
Tensile membrane contractor: Canobbio S.P.A. (www.canobbio.com), Italy
Supplier of the membrane material: Verseidag-Indutex gmbh
Material membrane: PTFE-coated glass fibre
Covered surface: 40m x 60m

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VISITING THE BIGO

Figure 2. Reflection of the globe in lightweight mirror
MEMBRANE STRUCTURES IN INDIA

IBM Food Court
The food court building for IBM in Bangalore is a unique combination of glass, fabric and steel. The building houses various multi cuisine restaurants, arranged on three levels and connected by stairs. There are large continuous spaces and the connectivity between these spaces enhances the feeling of height and openness.

Pre-fabricated components in structural steel were used to enhance the speed of construction. The roof cover is formed by pre-stressed PVC membrane panels - like the petals of a flower - that have been seamed together and stretched continuously between 2 ring beams. This roof provides an optimized, two dimensional large surface that is readily used for rain water harvesting. Rainwater is collected in the central open space and re-circulated. This offers a unique indoor-outdoor environment. The light transluency of the roof provides for natural lighting during day time, thereby optimizing the running costs of the building.

The façade does not have typical walls and windows but a PVC mesh membrane fabric that is tensioned like the sails of a ship using cables from the top level to the lower level. The mesh blocks the view from the outside but lets the people inside have a view to the outside. This façade in turn reduces the need for artificial ventilation and lighting. The structure displays excellent energy efficiency and eco-sensitivity. The façade and the floor are integrated by using thin roller deck steel floors that are supported by sleek steel columns and extremely lightweight external walls. This structure can be completely dismantled and erected elsewhere!

This building received the INSDAG (Institute for Steel Development & Growth) award for the best steel building in India.

| Name of the project: | IBM Food Court |
| Location address: | Bangalore, India |
| Function of building: | restaurant |
| Year of construction: | 2005 |
| Design and construction: | Construction Catalysers, Pune, India, info@concat.in, www.concat.in |
| Material membrane: | Valmex FR 1400 Mehatop F type IV |
| Covered surface: | 1780m², ø55m |
| Area of building: | 40000m² |

Sahara Sails Sail Sculpture on a Dam Wall
The dam wall at Amby Valley doubles up for a two lane vehicular bridge. On one side of this dam are the serene backwaters of the Lonavala valley and the other side is adorned by a Sail Sculpture.

This unique Sail Sculpture is an array of 24 membrane modules. Each module is 14m high and 9m wide. The arch girders are made from steel plates with the provision for pedestrians to move besides them.

With coordinated light projections at night, and a very proud stance through the day, the large sculpture stands witness to the serenity of the valley and the human activity in the township. The sculpture acts as an aesthetically engineered backdrop to the 10km long developed waterfront and the sculpted beauty of the igneous Sahyadri mountains in Lonavala.

This building received the INSDAG (Institute for Steel Development & Growth) award for the best steel building in India.

| Name of the project: | Sahara Sails |
| Location address: | Amby Valley, 70km east of Mumbai, India |
| Sculpture: | Sahara Sails |
| Year of construction: | 2003 |
| Design and construction: | Construction Catalysers, Pune, India, info@concat.in, www.concat.in |
| Material membrane: | Valmex FR 900 Mehatop F Type II |
| Surface: | 1500m² |
Tensile Rotunda at Unitech Rohini

A unique tensile membrane structure is used as a sunshade for a round symmetric pedestrian staircase and a bridge. The membrane structure is made of a mesh type fabric that renders a free shadow over the space beneath. The entire membrane is stretched at an offset height of 3m above the round bridge at 11 points. A principal hoop cable is provided at the inner side of the membrane that stretches continuously from the top of the clock tower spiraling down to the ground towards the basement. Due to the high edge forces on the main inner cable, secondary cables are used within the fabric edge seam that transmits the forces to the main cable at every 3m.

Sacred World  A Truly Tensile Roof

In a hot tropical country like India tensile membranes are ideal for protection against heat and rain. Membranes can control the transmission and reflection of sun light. The Sacred World tensile roof has an elliptical shape in plan. The entire membrane is suspended on two cables with an eye shaped opening created by the crossing of two structural cables. This shape of the opening that evolved from the form finding process is covered with glass panels giving direct light in the atrium below.

This unique, eye shaped glass opening provides curvature in the continuous large fabric surface, thereby creating an aesthetic value to the eye, as a metaphor opening to the sky.

All components of this roof structure are 100% in pure tension. Each and every member carries tension, thereby making it a truly tensile structure.

Membrane structures are particularly suitable to a developing country like India because they can be applied to a variety of spaces like transport terminals, car parks, shopping malls etc. They are economic structures having an immense potential!

Hadker Deepali  deepalihadker@sterlingengg.com
DESIGNING, DETAILING AND BUILDING WITH TEXTILES.

Projects realised with different fabric.

Special Guest Lecture at Textile Roofs 2008

Design: The architect is required to set up a general layout, to establish the geometry and to choose the materials to be utilized for the construction in order to answer to the requests of the client. The first draft is followed by the design drawings. Often however, the final structure size must fit the layout and the calculations of the structural engineer. The tensioned minimal shaped membrane expresses beauty in the play of shade and light and provides a sheltered space; it is water and wind proof and, at the same time, put up with all structural forces. If well shaped, these membrane structures can cover wide areas and large areas with a minimum effort in terms of materials.

Detailing: The form of a tension equilibrium structure follows the laws of Physics and finds its minimal surface within defined boundaries. The art of ‘designing’ membrane structures is the art of controlling their boundary conditions and controlling their support geometry, based on the knowledge of the physical properties of tensioned equilibrium forms, and the search of the best shape to suite the scope. The architect expresses his ideas and it is the structural engineer together with the manufacturer who chooses the most suitable material. This choice is made bearing in mind how each material reacts and the correct compromise between aesthetics, safety, durability and costs. Luckily, nowadays we are in a position to compare a wide range of materials as from the table hereto:

All the other items required to complete a membrane structure such as masts, cables, arches, foundations, pillars, walls required to complete a membrane tent are made of steel, wood and concrete as in conventional buildings. To obtain a lightweight structure it is necessary to apply high construction standards concerning materials and a very dedicated design process, especially when the lightweight structure is integral part of conventional buildings. The main difficulty is produced by the prefabricated elements to be assembled on site which must be well defined and must agree to the 3D geometry and the forces to which all the items are subjected to in order to grant stability to the structure.

Therefore, fabric and cables are to be made within reduced dimensions in comparison to those finally intended so as to allow the development of appropriate strains during the assembling process.

Manufacturing: Having established that the people involved in the design process must well know the materials and their use, one can say it is not the case of finding a manual describing how to make tensioned equilibrium membranes. The architects must compromise practical, scientific and philosophical concepts. The manufacturer must conciliate with all the above in addition to the requirements of the client, the architects and the structural engineers.

But what does a production process mean in practical terms? Check if the selected material is effectively suitable (according maybe to previous experiences); determine which welding system to adopt and the dimensions of the welding; define the cutting lines; flattening of the stripes; determine the de-compensation factors; dimensioning of the edge details in order to allow for an easy connection with other materials such as cables, section by section or primary structure; cutting; check of the homogeneous characteristics of the material used; welding; insertion of details; check; folding; transport and installation.

The criteria used to check if the selected material is effectively suitable are the following: tensile strength; constructive typology; durability; fire resistance behaviour; warranty; flexibility according to folding and installation requirements and others…

At this point it is necessary to compare the calculated stress values with the strength of the selected material. This is why the strength of the material is required according to this heading: strength of the membrane material, strength of the seams and tear strength.
The cutting shape of the individual stripes is determined geometrically from the surface area and the warp and weft orientation. The warp and weft orientation must be defined taking into account the static analysis. We can divide the patterning generators in two methods i.e. the radial or parallel distribution. Fabrication patterning has to be accounted for explicitly within numerical models for both form-finding and analysis of prestressed membranes. Their doubly curved surfaces are manufactured from flat unstressed panels of coated fabric with seams usually made by high frequency welding or hot bars. For reasons of material economy and accuracy, and to avoid wrinkling in the surface form, the centrelines (and seams) of panels should follow geodesic paths over the surface. These geodesics are the trajectories which a flat tape of material could follow without shearing. The directions of the fabric weave, with warp along the panel and weft transverse, are dictated by the patterning and yet the prestresses specified in these weave directions govern the surface shape. Thus the intended weave directions for patterning must be taken into account during form-finding. The same clearly applies to modelling the stress / strain relations of the weave during load analysis. From this the cutting patterns are calculated. It is always important to consider that the membrane is under prestress which causes its elongation. It is therefore necessary to correct the cutting pattern by this elongation and this step is called compensation. We have now come to another necessary production step: compensation in the cutting pattern. For this we need either the relaxation (under fixed boundary conditions) or creep behaviour (under boundary load conditions) of the membrane material. It is therefore necessary in effect to anticipate the deformation which is likely to occur over the life cycle. For this purpose defined stress histories are established and after working through these the compensation data can be read off. At present there are still no fixed rules for compensation trials. To determine those compensation factors it is necessary to undertake some bi axial tests from which we can find out the compensation required. We also have to take into account by using those reductions in percentage of the material the edge details or the fixing of stiffer elements. In this case the compensation factors will be reduced to a minimal value to allow the joining of different elements. All this is done with appropriate software which generates command files to an automatic cutting table. During the unrolling of the fabric the material has to be checked by means of a light table in order to avoid aesthetical and mechanical defects which have to be avoided by eliminating the defected material. Once the material is laid on the cutting table and the nesting has been fulfilled to avoid waste of material, the automatic cutting starts to cut the boundary lines and to introduce marks necessary to locate the single stripes and the definition of some details and intermediate marks in order to verify during assembling the maximum precision. For the assembling phase we can use different kind of welding machines. It is therefore important to make a few preliminary tests for the seam resistance in order to obtain the same welding efficiency. Those tests are executed by internal labs at 23°C and 70°C. The welding configuration parameters are established by an automatic system which is in the machine itself. During the production phase we make few tests to verify the homogeneity of the resistance values of the seams. During welding together it is also important to take account of the fact that the membrane material shrinks during welding. This can be compensated by either allowing for this welding shrinkage during the cutting out process, or by carrying out the welding under stress and then hold this stress long enough for the material to cool. These two methods are possible by using fixed machines or mobile machines. After the assembling process has been completed and the length of the boundary borders are verified we proceed with the insertion of the membrane details, double layers of membrane, reinforcements, holes and so on in order to complete the manufacturing process. All those insertions must be executed taking into account that the lengths of the edges are different with respect to the lengths of the membrane during its manufacturing.

Installation: During the erection procedure, details and connections must take into account the movements and rotations that will occur during the lifetime of the structure and in many cases must also foresee the particular rotational movements which can happen during erection especially for mobile structures which are continuously erected and dismantled. If this is not taken into account, the details will be damaged or destroyed. So the erection procedure must be investigated carefully to discover the needed rotational capacity of the connections.

The tensioning part also plays a very important role. We must take into account if it is possible to pretension the structure by means of the chosen detailing, or if there are temporary adaptations required, and if there is enough adjustment left for future purposes. It is not enough to realise a correct design, to make a nice and precise structure, to use very good materials; erection is a particular stage of the whole work: you need experience, knowledge of the components, of the site, but above all you need a trained and experienced erection team. Any detail is to be taken into account in order to insure a perfect functionality to the new architectural structure.

Responsibility: Normally the fabric manufacturer is responsible for the seam and its strength. On the other hand the seam strength depends to a great extent on the bonding strength of the coating on the fabric, for which the coating firm is responsible. There is thus split responsibility here. The consequences of this must then be explained as follows: the coating firm shows what can be achieved by optimizing its technology of bonding the coating onto the fabric. Besides all this it must be taken into account the influence of the short term loads, of the temperature and of the permanent loads.

2. PROJECT OPPORTUNITIES AND RECENT EXAMPLES

After Renzo Piano had utilised tensile structures in the 90ies – the Bigo in Genoa (see page 5), the Bari Stadium in Italy – which offered old and unrivalled utilisation of textiles, it seemed to have unjustifiably abandoned this type of materials and technology despite the considerable know-how by the Italian companies operating in this field of manufacturing and almost completely ignored by our architects and engineers.

At last, thanks to the various encounters and exchange of information within Europe regarding the development of technology of the membrane tensile structure – TensiNet Network – we can happily say that the architects and structural engineers experiences in this theme have now produced a significant progress in line with the progress of the technology itself and thus are in a position to be the fore front for design and novelty.

In fact, in 2006 and 2007 we have witnessed a recovery in Italy as well and from two points of view.

In some cases, described in detail below, Italian architects and engineers have opted for textile materials rather than more traditional ones for roofing and/or wrapping. As an example, the grand tensile structure made of steel coils and polyester/pvc membranes at the new Rome Fair, built in 2007, by architect Tommaso Valle and engineer Massimo Majowiecki. And again, to the most recent multifunctional covering of Chianciano Terme, a novelty aerald roof made of tensile structure membrane designed by architect Paolo Bodega.

In other cases, Italian architects have designed membrane structures for works erected abroad the fame of which rebounded in Italy as well. For example the temporary Finmeccanica Stand meant for international exhibitions, designed by Studio Gris of Padova and the 12 000m² roof of the orange textile with which architect Massimiliano Fuksas has wrapped the largest auditorium in Europe: Strasbourg Zenith, recently inaugurated. Provided that the various projects entail different difficulties, it is noteworthy to point out that the know-how as well, can encounter chances for novelty and improvements through various and sometime improbable routes. It is the case of projects apparently simple or almost routinely which entail the use of textiles most commonly utilized and well known as we shall try to illustrate better through the issues that follow.
Open buildings

Right from the beginning, the light weight property of textiles and membranes, have suggested their use in the case of wide span areas (such as the case of Trade Fairs and Exhibitions) for which roofing and not thermal or acoustic isolation entails priority. Some recent works stand to demonstrate that this philosophy is still paramount to other ideas, yet at last, tensile and pressure structures have found new openings, almost a new age, as they are being utilized in non conventional situations, side by side or in place of, or as an essential part of other and more traditional materials and buildings.

The most important example is the covering of the Garage Park in Montreux (Figure 1) which proposes a new skyline for a textile roofing and turns into a gleaming landmark in the night noticeable from distance.

A dismountable closed building: the new Tea House MAK, Frankfurt am Main, 2007

The new Tea House (Figure 2) designed by architect Kengo Kuma is innovative in term of form, but above all in term of materials utilized and solutions adopted. It is the outstanding example of how a project evolves in the hands of the various operators involved during the design process as Arch. Gerd Schmidt from Form TL describes it: "The inflatable Tea Pavilion of the "Museum für angewandte Kunst (MAK)" was as a kind of joint between sculpture and temporary room for ceremonies.

It is a gift by Japanese companies to the city of Frankfurt and especially to the MAK which has very tight connections to Japan because of its far eastern collection. It is unusual that from the beginning Kengo Kuma has chosen modern material. While wood and sliding walls were left out, a hint of diminutive bamboo is found at the base of the pavilion. Tatamis, although made of easy-to-clean synthetic material, the low ceilings and the even lower doors as well as the zoning and the counter-sunk fire-place have been kept by Kengo Kuma during the whole design process.

Even on his first drawings he showed a smoothly shaped double-bowl structure which we modified and specified during monthly meetings. At the end the organic shaped structure with membrane cover became a self-carrying double-wall pneu with minimized assembly and dismantling times – and it fits into the budget of Japanese sponsors and the museum.

Because of its shape the Teahouse got the working title "Peanut": a cover of 80 m² encloses with a distance of 40-100 cm an about 60 m² cover. At the footprint the two covers are air-tightly welded together and 3-4 times per m² joined together with thin synthetic ropes between which the air is blown in, similar to a dinghy or water wings. But instead of membrane stripes like they are used for inflatable mattresses the two covers are only point wisely joined which leads to a golf ball shape and defines the texture of the inner and outer surface. The stability of this flexible bowl is formed by the size of the footprint, the internal pressure and the number of joints. From 1.0 kPa internal pressure the "Peanut" stands up and with 1.5 kPa the flexible bowl is stable enough to face a storm. The blower is dimensioned for 2.2 kPa so that there is enough capacity for the air. We had to take into account that after several times of assembly and dismantling the leakage of the cover will raise therefore the blower got a variable regulation so that the leaked supporting air can always be added. Another big advantage is the soft blower noise which allows a use inside the entrance hall. It is thanks to the properties of the membrane that the light – excellent for readers – can pass through and yet shields them (the readers) that the light – excellent for readers – can pass through and yet shields them (the readers) of expression, is made easy on one side by the use of CAD systems which enables exchange of information among those involved in the realization of intricate works and, on the other side by CAM producing process of industrial apparatus thanks to which different items in terms of dimensions and morphology can be attained. Within these wider technical prospects, the designer seems to enjoy great freedom in matching materials and building items and as such can attempt on new materials, new devices and their interconnections.

A nice example of the utilization of the Tenara® fabric is that concerning internal works: an aspect of construction yet seldom employed, but suitable of interesting future developments. More and more often, public buildings are multi-purpose constructions.

The need to create smaller spaces within their structures becomes therefore necessary: spaces intended for specific purposes. In this instance tensile structures can become a suitable solution. It is the case of the works carried out by architects Giancarlo De Carlo and Monica Mazolani inside Pesaro Palazzo di Giustizia (Figure 3) in 2004.

A single layer of PTFE transpiring fabric was employed as the main purpose of the job was to create an enclosure, lighted by the sun rays passing through a roof window. It is thanks to the properties of the membrane that the light – excellent for readers – can pass through and yet shields them (the readers) from external activities and possible disturbances.

Additional advantages granted by the use of this specific construction choice must be underlined: the tensile structure membrane is apt for the creation of a continuous surface, a peculiarity of the flexibility and easy handling of the textile, allows for a fast and simple installation of the internal metal structure and, due to its light weight, the calculation for the structural stress becomes ludicrous.

Closed buildings

Nowadays a vast range of utilization of the membranes is opening up for architectural projects. It is no longer the case of roofing only, but the application of an integrated system i.e. vertical (walls) and horizontal (roofs) in line with the modern "language" adopted by the designers. This trend, meant to value free forms of expression, is made easy on one side by the use of CAD systems which enables exchange of information among those involved in the realization of intricate works and, on the other side by CAM producing process of industrial apparatus thanks to which different items in terms of dimensions and morphology can be attained. Within these wider technical prospects, the designer seems to enjoy great freedom in matching materials and building items and as such can attempt on new materials, new devices and their interconnections.
A temporary building: Finmeccanica Pavilion Farnborough, 2006

If Tenara® is a fairly new material, polyester/pvc is a more traditional and widespread item. Its utilization however, constitutes an experiment as is the case of the covering of Finmeccanica’s temporary stand (Figure 4).

For the “Finmeccanica Pavilion Farnborough” cushions were made of a transparent PVC foil on the outside and a white PVC-coated polyester fabric on the inside to grant a reflecting effect of sky and clouds during the daytime and light during the night-time. The futuristic architectural design has striking features that communicate in unusual ways. The oval-shaped structure measures 1000 m² with another 300 on the upper level. The shape of the pavilion follows curved lines in plan and section creating a unified and flexible image, smooth and rounded everywhere, intensified by the air-filled internal and external cladding. The smoothly sculptured shape creates a continuously changing appearance which catches your eye every time you look at it. (see also TensiNews 11)


The most recent example of how architects intend to promote new employment of textiles is that of Strasbourg Zenith (Figure 5), designed by Arch. Massimiliano Fuksas and completed in December 2007 described from “Arketipo” magazine by A. Zanelli: “The new Zenith in Strasbourg was opened last January and it has set the record with its 10 000 seats of the largest concert hall in Europe. The musical hall is designed as a dark core protected by a hard shell that is moulded on the lines of different curves’ radii that have been studied to optimise the ratio between maximum capacity and best view; this core has been built in reinforced concrete to better control the acoustic performances.

The envelope is instead quite light, coloured, translucent and textile: with this design decision Fuksas seems to rekindle a connection with the materialism of the first two Zenith projects completed in by the architects Chaix and Morel. The first Zenith was completed in Paris in 1984 and the second one in Montpellier in 1986; they are both composed by a metallic frame with a membrane-like cladding.

This thin skin is of an orange colour, it is sensitive to day light and it can lit up in the nocturnal landscape and through its use Fuksas has re-created in Strasbourg the magical atmosphere of the travelling shows and their transient sensation that can be felt under their characteristic tents; however at the same time the architect has opted for the internal hall for a more permanent construction in reinforced concrete to be able to achieve the best acoustic and visual qualities. The new auditorium Zenith however doesn’t show the compromise between two technical solutions that are so different with regards to their construction methods as well as their weight and light transmission properties: a continuous in-situ reinforced concrete shell completed in 18 months and a tensile structure assembled off site and erected in 10 weeks. The project has the characteristics of a happy union and of a true and proper technical and constructive innovative design. The plastic and static shape of the concrete shell is wrapped by five steel elliptical rings that are vertically spread with different eccentricities. The orange fabric is connected like a tape to the steel rings as well as to thinner tensile cables and shrouts the large hall getting closer and further from the concrete shell creating an intermediate space that is full of dynamism. This whirling fabric entanglement is ruled by 22 steel masts that give the perception of being pushed outwards the concrete shell by the hollow steel tubes that are anchored to the shell itself and that present different lengths; in the same way the inclination of the masts varies with regards to the external perimeter of the tensile structure. The novelty of this architecture consists in having overcome the typical skyline where all the tensile structures seems to be condemned from their initial static concept of “form-resistant”: there is no trace here of the counterpoint between the tall columns (the masts) or of the low fixing point (valley cables) or of the ridges and valley fabric profile.

For this project the inclined masts represent the original connection between the concrete and the fabric and they dictate the rules for the definition of an architectural space that welcomes the audience at the entrance and surprises them for full-height views with multiple depths.

The fabric assumes a double curved strengthened shape created by the overlapping of elliptical steel cables that act as valley cables and by the stiff ellipses of hollow steel tubes effectively replacing the ridge rings. The sinusoidal profiles needed to satisfy the static constraints of the membrane tensile structure have been completely re-interpreted: they present themselves as sudden changes in the direction of the fabric that externally is perceived as a single orange surface chiselled by recesses and projections that are curved on the horizontal surface but sharp on the vertical one. The Zenith is Strasbourg is a clever synthesis of architectural research carried out at multiple levels and supported by equally diversified competencies.

The choices made by the architects Massimiliano and Doria Fuksas have been addressed and turned into a built environment by the contribution of a number of specialists focussing on: the study of the reinforced concrete shell, the design of the steel elements of the tensile structure, the dimensioning and installation of the fabric panels and the acoustic engineering.”

(see also TensiNews 14)
Transforming buildings

This area can also offer some possibilities of development. The transformation of a building is economical if executed within a very short period of time. A recent example is that of the covering of Tenerife Astronomic Observatory (Figure 6), designed by Eng. Pedretti of Airlight, experimentally installed at Castelnuovo Scrivia – CAMEC factory – and recently erected at Tenerife. Sometime it is the well defined purpose of a building which can suggest that no modification can take place and nothing new can be tried; on the contrary, it is because of the simplicity of the theme – in this case an astronomical observatory – that could advocate that the time to acquire new acquaintances, in this case the opening and closing of a structure which is made possible by the power of pressurization, has come. Two great steel arches lift and rotate around a central axis pulling a polyester/pvc fabric which at the same time inflates and pulls up the other smaller arches until it reaches the shape of a big pneumatic shell. The gigantic shell measuring 15m in diameter inflates in 7 minutes and more slowly deflates – pressed by the steel casing – thus causing the return of the two arches to their original position. At the end of the operation, the presence on the ground of a building is hardly noticeable whereas the telescopic equipment is free to turn for 360 degrees and from horizon level to the zenith.

Conclusion

The projects described above were chosen to show that the roads from the original idea to the built project can be many and of different type, but all with a common need: that of the deep knowledge of that specific product of which the membrane architecture is made of: a textile, light and transparent material.

The designer could hold the knowledge or, sometimes the manufacturers can contribute to make it known, but, whatever the case, it must be present and profound. The textile industry embraces a potential innovative power that can make today’s achievements obsolete tomorrow.

Designers, producers, manufacturers and contractors are all looking forward to ensuring that new materials would enable textile constructions overcome some limitations which still exist at present. For example, it is difficult to surmount some climatic problems which are easily solved by traditional constructions.

The utilization of a double layer membrane sandwiching air or isolating materials is a possible option, but due to the 3D shape of the membrane, the negative effect on the manufacturing costs is rather high.

This is why various European Communities backed working groups – such as Contex-T – with a view to improve building performances by trying to discover protection systems, films and chemical coatings in order to overcome today’s restrictions. Once found, these articles shall definitely help in maintaining the today’s restrictions. Once found, these articles shall definitely help in maintaining the today’s restrictions.

Terme di Chianciano, Parco Fucoli, Chianciano, 2007

The modification should not be exclusively intended in connection with the opening and closing operations, but also regarding the suitability of the building (or part of it) to season changes. This is the case of the multi-purpose building designed by Arch. Paolo Bodega and erected at Parco Fucoli. The management of Terme di Chianciano (Figure 7) have applied for a multi-purpose space: a wide cover to grant shade and breeze in summertime allowing the un-obstructive view of the surrounding park, yet a closed building acoustically isolated to be utilized for concerts and/or sport events.

A double layer membrane tensile structure was utilized so as to grant aeration as it is the case of a traditionally ventilated roof built with conservative materials. By utilizing a two layer polyester/pvc textile, with dissimilar mechanical specifications and transparency degree, the project minimizes fuel consumption to produce heat in wintertime (closed building + closed air inner space), takes care of the problem to keep the building cool in summertime (open space and removal of the closing perimeter cushions) and reduces solar overheating (the air is funnelled through grates fitted at the base of the building and polycarbonate windows placed on top of the flying masts). The final result is that of a light structure which though fitted with a double layer cover, does not prevent clearness and in fact emphasizes it thanks to luminous spots placed at the foot of the flying masts. It is dry assembled thanks to the wise association among the various materials: wood and steel for the primary structures, textile membranes for the cover, pressurized textile cushions for vertical walls, transparent polycarbonate for the roof windows.

Architects: Studio Paolo Bodega
Architetto, Lecco

Engineering of the structure: Studio Associato
Arti e Tecnologie, Italy

Engineering membrane: Form TL, Germany

Project management, manufacture and installation membrane: Canobbio, Italy

Material: Double layer Polyester/PVC

Figure 7. Terme di Chianciano, Parco Fucoli, Chianciano, © Studio Bodega

Architects: Studio Paolo Bodega
Architetto, Lecco

Engineering of the structure: Studio Associato
Arti e Tecnologie, Italy

Engineering membrane: Form TL, Germany

Project management, manufacture and installation membrane: Canobbio, Italy

Material: Double layer Polyester/PVC

with a view to improve building performances by trying to discover protection systems, films and chemical coatings in order to overcome today's restrictions. Once found, these articles shall definitely help in maintaining the membrane structure characteristics (lightness) unaltered thus granting a wider scope of utilization in the future.

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Modern state of the art application for tensile structure form finding

Rhino Membrane is one of the most powerful tools for form finding of tensile structures and yet most simple to understand and use. An engineering team integrating research, professional software development and expertise in the field of tensile structure design, has produced a high-tech component with very few limitations. This Rhinoceros plug-in combines the efficiency of a modern finite element approach for shape finding with the comfortable and easy-to-use graphical user interface provided by Rhino. The implemented features amongst others include form finding of membranes with isotropic and anisotropic pre-stress, cable elements for cable nets or edge cables, pressure option for form finding of pneumatic structures and stress plots for evaluating the final stress distribution. Using a direct sparse matrix kernel, huge problems are solved in a fast and reliable way, plotting the intermediate non-linear steps on video makes it possible to choose an intermediate result for a future run.

Theory
The theoretical background of Rhino Membrane is provided by the Updated Reference Strategy (URS) for form finding of membrane structures developed by Prof. Kai-Uwe Bletzinger of the TU München (Germany) [2]. For a given topology of a membrane structure and a given stress state in the structural elements (pre-tension in the membrane and cables), the corresponding equilibrium shape has to be determined. With numerical methods this shape finding problem cannot be determined directly, as an infinite number of valid geometrical discretizations with the same mesh topology can be found for the same equilibrium surface. There is no unique solution: metaphorically speaking, the FE nodes can “float” on the surface while still representing the same equilibrium shape. Figure 1 illustrates these floating meshes for a simple four point membrane with fixed edges. In order to stabilize the originally badly-posed problem, the Updated Reference Strategy aims for solving a series of related well-posed problems and thereby gradually converging to the original solution. In the context of membranes this states that instead of prescribing the pre-stress on the to-be-found final geometry (Cauchy stress \( \sigma \) on the current configuration \( x \)), a stress measure related to a certain given starting geometry for the computation is prescribed \( \sigma^r \) on the reference configuration \( X \). For this modified problem, a unique solution can be obtained. Yet, as generally a deformation occurs when the equilibrium shape is computed the stresses on the deformed shape will differ from the initially prescribed ones. This necessitates an iteration loop, which consists of a reference update (the solution surface of step \( i \) will be the reference surface of step \( i+1 \)) and a following form finding step. For an admissible given stress field (a stress field with a possible physical solution), the displacements within each iteration step are converging to zero very fast and stable, while simultaneously the arising stresses converge to the desired solution.

The URS represents a generalization of the well-known force density method [3]. Due to its continuum-mechanical basis, the method is applicable to both cable and membrane elements without any restrictions: e.g. an arbitrary stress state can be specified for the membrane, which can be isotropic in order to generate real minimal surfaces or orthogonally anisotropic, which is very helpful for form finding of textile structures with warp and weft direction. It is even possible to consistently include pressure forces, which are acting always normal to the surface at every state of the procedure, in the form finding process of pneumatic structures such as air-inflated cushions, etc.

Implementation in Rhino 4.0
Rhino Membrane is a fully integrated plug-in for Rhino 4.0. The graphical capacities of Rhino 4.0 are used as pre- and post-processor in order to generate the initial geometry and later to display the results. Instead of working directly on nurbs surfaces, Rhino Membrane uses the mesh and polyline objects as geometrical description for the form finding, since “meshes can represent much more complex shapes than nurbs surfaces” [4]. In a typical design process, the user models the initial geometry using a nurbs representation. In the next step, the nurbs objects are converted to a polygon meshes (triangles and quadrilaterals are allowed) and input data is assigned to the mesh using the interactive menus. When finished, the form finding procedure can be started. During the iterative solution, the intermediate results are displayed allowing for checking the convergence. Afterwards, a new mesh object containing the final geometry is created. It is even possible to visualize the resulting stress state.

Examples
As Rhino Membrane can work directly with membrane elements instead of approximating those with cable nets, the generation of “real” minimal surfaces is easily possible.
The shape of the membranes is defined by the internal equilibrium of the tension stresses and a possibility for reducing the span of the membranes is to introduce beams and arches. In some applications, the membrane is able to stabilize these curved beams or arches.

State of the art
In the past, different applications for stabilizing compression members by tensioned cables or membranes have been developed and have been used in actual structures. Three different principles can be found in literature: stiffened arches, the Tensairity system and umbrella structures. Until now, umbrella structures have not been used as a permanent structure.

The principle of stiffening arches by means of bracing cables is approximately 100 years old and was invented by the Russian engineer V.G. Suchov [1]. His basic idea was to reduce the bending stiffness of the arch by preventing deformation under loads which are not affine to the geometry of the arch (figure 1a & 1b). The reducing of the bending stiffness is equal of the reduction of mass and material and leads to extremely light structures.

This structural efficiency was reinvented in the 1980’s by Jörg Schlaich [2], adapting the stabilization of the bicycle wheel for application in buildings (figure 2a & 2b).

An application of these structural systems in the field of tensile surface structures is the entrance canopy of the “Flower Island” Mainau, Lake Bodensee, constructed in 2002/2003. The arches have a span of max. 40m and are stabilized by the membrane and bracing cables (figure 3). The diameter of the steel tubes is about 30cm.

Umbrellas can be very efficient: they are deployable, self anchored, lightweight and integrated systems. No stay cables or additional masts are required for tensioning the membrane, only the curved beams. In most cases, the struts are directly connected to the membrane. This serves a double purpose: on the one hand the membrane becomes tensioned, while on the other hand the membrane stabilizes the struts against buckling. Typical for umbrellas is that they cannot be used when snow or high wind speeds.

Conclusion
Rhino-Membrane is an easy-to-use, yet very accurate design tool for form finding of a huge variety of membrane structures ranging from soap film with minimal surface content to pneumatic and anisotropically pre-stressed textile structures. We believe that a modern tool like Rhino-Membrane will help architects and engineers understand the principles behind tensile structure design since there are no barriers between the user input and the final result, like clay in the hands of a sculptor, just a few mouse clicks and the ideas get shaped.
are expected. It is a well-known fact that umbrellas can invert under the influence of high wind pressure.

In Tensairity structures, compression and tension are physically separated. In case of a beam, low pressure compressed air is used for pretensioning the tension element and for stabilizing the compression element against buckling. It can be shown that no buckling problem arises, which allows the material to be used to its yield limit for tension and compression. As a result, Tensairity girders can be many times lighter than conventional beams. This technology is ideally suited for wide span structures and for deployable applications such as temporary bridges, scaffoldings or large tents. Prototypes, finite element analysis as well as experimental studies have proven the feasibility of the concept (figure 4a & 4b).

New Development
The Tensairity principle has been applied to mechanical tensioned structures, which has led to the development of two applications: a lightweight column and a wall system for fair stands.

Proposal I: a new lightweight column
Being lightweight is mostly an attribute of the membranes, while the required compression elements are often heavy, simple steel tubes. For designing lightweight masts two possibilities are often used: truss structures or Vierendeel girders, which reduce weight but increase labour hours. Another possibility is to use high strength composite materials in which case the membranes and cables need to be appropriately connected to the mast, and the mast, in turn, to the foundation.

In this project the first proposal is a mast made of massive bars with a rectangular or round cross section. The bars are connected to a plate at the bottom and the top. In the centre of the plate is a cable which can be tensioned. By tensioning the central cable, the bars become curved and are protected against buckling by a membrane which covers the whole system. In the first design the bars are guided in pockets connected to the membrane. The advantage is that the mast can be brought to the site in its respective parts, be assembled and become tensioned on site (figure 5).

The problems which have to be solved are: defining the buckling load of the mast in relation to the number of bars, the cross section of bars, the length of the mast, the tensioned geometry, the tension force, the stiffness of the fabric and the orientation of the yarns.

Proposal II: New wall and roof structure
The second proposal uses the same principle, but reversed. Starting with a cylindrical membrane and a space truss, the free edges of the truss are pulled outside, thus tensioning the membrane and stabilizing the bars (figure 6).

In case these structures would be used for a fair stand, further investigations need to be carried out, especially regarding the definition of an opening for the entrance without destroying the structural integrity. The flexibility or stiffness of the bended bars has to be examined in terms of external load bearing behaviour and the capability of bending without too much increase of bending moments.

The results of the simulation return the elastic stiffness and ultimate stress for the bars. The tension stress in the membrane has to be calculated in relation to the bending stiffness and stability of the bars. For the roof - built in the manner of umbrellas - the same tasks have to solved, such as defining the bending stiffness of the bars in relation to the tension stresses, external load, buckling behaviour and stability offered by the membrane.

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Figure 4a: Tensairity system, principle
Figure 4b: Prototype in test configuration
Figure 5: Principle of a textile mast
Figure 6: Structure of bended bars and tensioned membrane

V.G. Suchov 1853 - 1939  - Kunst der Konstruktionen, S.136 – 149, editorial Rainer Graefe, DVA, Stuttgart, 1990, figure 1b see page 42, Abb.65
Schlaich, Bergermann und Partner, Transparente Netztragwerke, Stahl und Form, Stahl-Informations-Zentrum Düsseldorf, 1992, figure 2b see page 13
M. Pedretti, Tensairity, ECCOMAS 04, Jyvaskyla, Finnland, figure 4a see figure 1, figure 4b see page 5
The Dalian seals show hall is located near to the estuary of the Dragon River in Lushun port of Dalian, China. You could enjoy the beautiful view of the river and the ocean at the same time. The client engaged us to make the design being a new landmark, being a good building to let the spectators feel comfortable to enjoy the show. In addition the structure must be finished in the spring of 2009, which means we have to finish all the buildings in short time.

So we put forward the following three points to be achieved. The 1st point is the magnificent sight; the 2nd is to have the good architectural functioning for a seals show, such as good internal environment, pure natural sun light and energy saving. The last point is to try to finish the roof in a very short timeframe. All this is a challenge to the design team; fortunately we proposed a wonderful membrane structure. After more than 10 conceptual design adjustments, the client’s architect approved the concept (figure 1).

The building is the 1st specialized space for a sea dog’s show in Dalian. The roof system is a hybrid structure consisting of long span truss beams, suspension cables, edge cables and membrane. The grandstands are reinforced concrete frames. They have a total area of 3000m² and can hold 1000 spectators.

The roof system is a complicated space system which consists of a 76m span main truss, 10 secondary truss beams and 2 arched trusses at the entries. The cover materials are PVC-polyester membrane and glazing. Most of the steel structure components are placed on the top of the concrete columns except the two arched trusses, which are positioned on the ground. The total steel structure has a width of 70m, a span of 76m, and the height is 25.8m.

The membrane is tensioned between adjacent secondary truss beams; creating anti-elastic curved surfaces. A water-proof membrane will cover the connection area. A PVDF coated fabric type 3 FR 1000 made by Mehler in Germany is used.

We use the Chinese program 3D3S to do the form-finding, nonlinear analysis, Chinese standard of steel & membrane structure checking and...
The form-finding is done with a nonlinear finite element method. After the form-finding, the membranes are initial equilibrium and minimal surfaces. We put the entire structure together to perform the non-linear analysis. The beam elements, the cable elements and the membrane surface elements are in one computer model, so it is easier to get a more accurate analysis report.

The load cases:
1. Pre-stress (PL): 2.0 x 2.0kN/m for membrane; 20kN & 40kN for edge cables;
2. Dead load (DL): 0.1 kN/m²;
3. Snow Load (SL): 0.4 kN/m²;
4. Wind Load (WL): 0.65 kN/m²;
5. Seismic Load: Chinese Standard, the first vibration mode is 0.24433s;
6. Temperature Load: ±30ºC.

The pretension is mainly taken in the steel construction itself: the main arches and the secondary arches form a rigid framework. The weight of the membrane construction is transferred by steel columns to the concrete structure of the building.

The choice of using steel and fabric for the covering was made consciously taking into account technical as well as aesthetic considerations. The combination of the specific characteristics of both steel and fabric made it possible to obtain a light, aerial and financially feasible solution.

The whole design including the preliminary design, analysis and making the shop drawings took us about two months. Now, the steel structure is installed on site. Parts of the membranes are being mounted (Figure 2).

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Name of the project: Dalian Seals Show Hall
Location address: Lushun port of Dalian, China
Client: Dalian YiHai Travel Corporation
Year of construction: 2008
General engineering, detailing and shop drawing: Beijing Space frame Consulting Engineers Co., Ltd. (SFC, China)
Engineer for the steel structure: Zhao Yu, Xiang Yang
Engineer for the membrane: Zhao Yu
Steel & Membrane manufacturing: YF Space Membrane Technology Engineering Co. Ltd (China)
Installation: YF Space Membrane Technology Engineering Co. Ltd (China)
Material: PVDF-coated fabric, type 3 FR 1000 by Mehler, Germany
Covered surface: 3000m²

Name of the project: Open Learning Center
Location address: Gent, Belgium
Client: Hogeschool Gent
Function of building: Library, study rooms, auditorium and student restaurant
Year of construction: 2008
Architects: baro cv, Sum Project
Engineers: Fraeye Herman Ingenieursbureau NV
Consulting engineer for the membrane: Marijke Mollaert
Vrije Universiteit Brussel
Contractor for the steel construction: Staalconstructies Rietveld
Supplier of the membrane material: Mehler Tex.nologies
Manufacture and installation of the tensile membrane: Axel Troch bvba
Material: PVC-coated polyester, Valmex FR 1000 MEHATOP F - type III
Covered surface (roofed area): 1880m²

André Bauwens
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Figure 2: Installation of the membrane
The Brampton Civic Hospital was opened in 2007, providing healthcare service to over 400,000 residences in Brampton and the surrounding areas. The new hospital, part of the William Osler Health Centre, is a public-private partnership involving a joint venture between Ellis Don Corporation and Carillion Canada Inc.

The new hospital required a series of protective canopies to define and enhance the main access points. Soper’s provided a total of seven engineered tensile membrane canopies, all manufactured of PTFE Sheerfill V fabric as well as architectural grade columns and stainless steel cables and fittings. Columns are all painted with 2-part epoxy paint for tough, UV-resistant durability.

Main Entrance Canopy: The main entrance canopy wraps around the front entrance of the hospital, boasting a signature showpiece to the outside world. Altogether, the 3-sided canopy measures over 60m in length. (Figure 1)

Radial Drop-off Canopy: This angulated radial-shaped canopy protects patients and visitors at the drop-off area beside the main entrance. This canopy, 90m in length, attaches to the main entrance canopy to provide a seamless transition along the front of the hospital. (Figure 2)

In-Patient Entrance Canopies: Two canopies, each measuring 6m x 12m, were installed at the in-patient entrances on the north side of the building. (Figure 3)

Pond Lookout: A hypar-shaped canopy was installed in a reflective rest area overlooking a pond. Its “natural” shape adds to the therapeutic nature of this rest area. (Figure 4)

Rooftop Canopy: A small canopy was installed on the rooftop above the parking garage to provide added shelter to employees of the hospital.

Bus Shelter Canopy: Another canopy, measuring 6m x 12m, was installed at the bus shelter to provide additional protection to staff and visitors coming to the hospital via public transit.

The biggest challenge was overcoming the intricacies of interfacing and staging the tension canopies with the new building construction schedule. Soper’s was able to deliver its product while working within specific timeframes and constraints.

The canopies, designed to have a 30-year life expectancy, have been well received by all those involved and also the people (patients, staff, and visitors) who frequent the hospital. Soper’s is proud to have been a player in a local project of such scope and hopes to replicate its success at other hospitals and medical centres across North America.

Bob Finch  

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www.sopers.com

Canopies for the Brampton Civic Hospital

WILLIAM OSLER HEALTH CENTRE, BRAMPTON, ONTARIO

Main Entrance Canopy: The main entrance canopy wraps around the front entrance of the hospital, boasting a signature showpiece to the outside world. Altogether, the 3-sided canopy measures over 60m in length. (Figure 1)

Radial Drop-off Canopy: This angulated radial-shaped canopy protects patients and visitors at the drop-off area beside the main entrance. This canopy, 90m in length, attaches to the main entrance canopy to provide a seamless transition along the front of the hospital. (Figure 2)

In-Patient Entrance Canopies: Two canopies, each measuring 6m x 12m, were installed at the in-patient entrances on the north side of the building. (Figure 3)

Pond Lookout: A hypar-shaped canopy was installed in a reflective rest area overlooking a pond. Its “natural” shape adds to the therapeutic nature of this rest area. (Figure 4)

Rooftop Canopy: A small canopy was installed on the rooftop above the parking garage to provide added shelter to employees of the hospital.

Bus Shelter Canopy: Another canopy, measuring 6m x 12m, was installed at the bus shelter to provide additional protection to staff and visitors coming to the hospital via public transit.

The biggest challenge was overcoming the intricacies of interfacing and staging the tension canopies with the new building construction schedule. Soper’s was able to deliver its product while working within specific timeframes and constraints.

The canopies, designed to have a 30-year life expectancy, have been well received by all those involved and also the people (patients, staff, and visitors) who frequent the hospital. Soper’s is proud to have been a player in a local project of such scope and hopes to replicate its success at other hospitals and medical centres across North America.

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Name of the project: Canopies for the Brampton Civic Hospital
Location address: Brampton, Ontario, Canada
Client: William Osler Health Centre
Function of building: Series of protective canopies
Year of construction: 2007
Architects: Adamson Associates Architects
Engineers: MMM Group
Main contractor: Ellis Don Corporation & Carillion Canada Inc
Design, engineering and manufacture membrane: Soper’s Engineering Fabric Solutions
Material of the membrane: glass-PTFE Sheerfill V fabric
**“MUNICIPAL SPORT PAVILION, RUBÍ, SPAIN”**

**DESIGNING FOR EASY MAINTENANCE**

**Introduction**

Textile roofs need periodic inspection and maintenance that often imply re-tensioning, cleaning or replacing. Accessibility for maintenance and repair is therefore a way to get these tasks done.

In Rubí (32 km², 70,000 inhabitants, 20 km from Barcelona), the City Council wanted to roof their 40m x 20m open air sport ground transforming it into a pavilion. Easiness of maintenance and accessibility were emphasized as main requirements, provided that they had to be in charge of a non-specialized municipal crew.

**Steel structure**

In order to consider these requirements, a textile roof supported by a tubular steel structure was designed. The structure is based on a series of four self supported frames, placed every 10m and composed by 4 arches leaning on 8 pillars.

Every arch is designed as a catwalk by means of 6 CHS Ø 50.3 braced with lattice girders Ø 30.2mm. The cross section is U shaped forming a 60cm wide catwalk protected by two railings. It results on a double triangular section stable without bracing and accessible for installation and maintenance.

The 8 columns are also latticed and made of CHS, 60cm x 80cm in plan. Their dimensions in plan allow for stability. The result is a diaphanous space, not interrupted by diagonals or ties. Fewer impediments procure clearness and flexibility.

The columns are lined with perforated curved plates for safety and to proportion volume in the aim of delimiting the space of the enclosure in a discontinuous non obstructive way.

Purlins between frames are not needed because the fabric is structural. (Purlins may account up to 40-50% of the total cost of the steel in a single storey frame building).

**Membrane**

The roof is PVC-coated polyester fabric resting on the ridge-beam and stretched against the arches and edge-beams by means of elastic rope. It provides translucency, natural diffused light and structural lightness.

Double curvature is obtained by the arches, (the lower chord is a 14m radius arch) and the 1m downwards sag in the longitudinal direction, (roughly a 10% of the distance between arches). Proper drainage is improved preventing flatness on top with a horizontal ridge-beam. The edge latticed beams at each side receive the membrane avoiding the diminishments caused by curved edges and allowing for vertical enclosures.

**Installation**

The installation of the membrane was considerably facilitated by the arches used as footbridges. The figures illustrate the whole process.

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| Name of the project: | Municipal sport pavilion in Rubí |
| Location address:    | Rubí, Barcelona, Spain |
| Client:              | Rubí City Council |
| Year of construction:| 1987 |
| Architects:          | Llorens & Soldevila |
| Manufacture and installation: | Arquitectura Textil (www.arquitecturatextil.com), Montmeló, Spain |
| Material membrane:   | PVC-coated polyester |
| Covered surface:     | 40m x 25m |
The international association TensiNet and Techtextil – International Trade Fair for Technical Textiles and Nonwovens are holding the 10th Student Competition on ‘Textile Structures for New Building.’

We cordially invite all students of architecture and building engineering, product design, or any other relevant subjects, to apply. We also hereby invite all new entrants to their professions who are practising these subjects, providing they took their degree after 1 January 2008. For purposes of identification please enclose a copy of your student identity card or degree certificate respectively with your registration documents.

This competition is designed to identify innovative thinking and innovative solutions to problems, featuring construction projects capable of concrete realisation which use textiles or textile-reinforced materials. A further aim is to encourage students and new entrants to the professions. The competition is further intended to strengthen contacts between the younger generation, the universities, the technical-textiles industry and broad sections of the building industry.

The competition will be run under the professional and technical supervision of Werner Sobek, Professor of Engineering at the Institute of Light Construction Design and Building (ILEK), University of Stuttgart.

Scope of competition

The competition covers all areas of textile building:
- Earth-moving, road building, landscaping, environmental protection
- Civil and industrial engineering
- Structural engineering – from construction using textile-reinforced concrete or plastics to construction using membranes for permanent and temporary, adaptable and mobile buildings
- Interior construction – including such developments as the use of polymer fibre-optic cables for light transmission, textile air-channel systems for draught-free air conditioning in rooms, movable sound insulation walls in production facilities, etc.
- Product design for architecture.

An additional focal theme has also been included: 'Suitability for re-use and recycling'.

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

Jury

The international jury judging the 'Textile Structures for New Building' competition will include well known representatives from the universities, eminent architects (textile building) and engineers. A representative of TensiNet will serve on the jury on behalf of the organizers. The chairman of the jury will be Professor Werner Sobek. The jury's decision will be final and incontrovertible. Individual reasons for refusal of a proposed submission cannot be given, for organizational reasons.

Prizes and categories

TensiNet will be providing the competition prize money of € 8 000.00

The jury will award prizes in the following categories:
- Macro-architecture
- Micro-architecture
- Environment and ecology
- Composites and hybrid structures

The prize money will be divided as follows:
First Prize: € 1 250.00 per category
Second Prize: € 500.00 per category
Third Prize: € 250.00 per category

Prizes will be awarded at Techtextil in Frankfurt am Main on 15 June 2009. The award of a prize will be confirmed by a certificate. Prize-winning projects will also be exhibited in a special show during Techtextil from 16 - 18 June 2009. The organizers reserve the right to exhibit projects at other Techtextil events. The organizers will further inform both the professional world and the public about all prize-winning projects.

More information on

www.tensinet.com/content/view/73/54/

Special Mention in the Micro Architecture Category, Jesús Flores Hernández, 2007

LITERATURE

TENSILE STRUCTURES

TENSOS ESTRUCTURAS

DESDE/FROM URUGUAY

Author: Arq. Roberto Santomauro
Language: Spanish and English
Size: 25x25cm, 128 pages full colour
Editor: Arq. Eduardo Folle Chavannes
Graphic design and Digital imaging: Rodolfo Fuentes Baez
Prefaces: Nicholas Goldsmith, FAIA, New York, USA.
Juan Monjo Carrió, Madrid, SPAIN. Bruce Wright, USA.

This book is available since the end of September and will be presented on the next 3rd Latin American Symposium on Tensile Structures in October 2008 (Acapulco, Mexico).

Internet sale: www.sobresaliente.com