International Expo
“water and sustainable development”

FLUVIAL BANK PERGOLAS

ARTICLE
MEMBRANE COMPONENTS
FOR THE MAN-MADE ENVIRONMENT

Structural Fabrics
DEPENDENCY OF LOAD TRANSFER
ON BOUNDARY CONDITIONS

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ULTRA-LIGHTWEIGHT
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TERMS AND CONDITIONS OF ENTRY TO THE 11TH STUDENT COMPETITION
During the last months, despite the economical crisis, tensile surface structures continue to expand in several fields.

- The current TensiNews issue contains student projects from different schools (University of Naples and the School of Architecture of the Technical University of Madrid) illustrating the interest of the young generation.
- We can again announce the international student competition on ‘Textile Structures for New Building’ which will be organised in 2011 by TensiNet and Techtextil – the International Trade Fair for Technical Textiles and Nonwovens.
- Two master courses offer the possibility to specialise: the Master course Membrane Structures at the Anhalt University of Applied Sciences (http://www.membranestructures.de) and the Master program Membrane Lightweight Structures at the Vienna University of Technology (http://mls.tuwien.ac.at).
- Research results and activities are in progress. This issue reports on the work done by Martin Synold at ILEK on the one hand and the demonstrators built by the Contex-T consortium at the other hand. Also the presentations at the TensiNet Symposium (http://tensinet2010.uacg.bg/, 16th - 18th September in Sofia) will discuss research and new developments.
- A new research initiative by Roberto Maffei for ultra light-weight temporary structures in cooperation with the Politecnico di Milano, TU Eindhoven and EMPA is announced.
- The work done by Antoon Versteeghe for ‘self sheltering’ with bamboo contains interesting ideas.
- Membrane Façade Design, like for the Space Home Pavilion (ShangHai, World Expo 2010) or the Aston Martin Lagonda building (Nürburgring), is a new field which allows for further growth in the sector.
- Interesting projects continue to be built.

The next Tensinews will be issue 20! For that occasion we would like to have the focus on ‘advanced’ projects! We look forward to receive your proposals.

On the 15th of September the TensiNet Annual General Meeting 2010 is scheduled after the Working Group meetings which will report on their activities in the afternoon. The Partner Meeting will take place the 16th of September at 7pm.

Since the current TensiNews issue will be distributed just before the TensiNet Symposium 2010 we kindly ask all our members to attend this event. To make it successful please inform your clients and colleagues! The program of the TensiNet Symposium 2010 is available online. We have selected experts from different fields and cover a large scope of contributions to support and stimulate the evolution of fabric architecture. We hope to meet you in Sofia.

Marijke Mollaert  Heidrun Boegner-Balz

Forthcoming Events

1. A retractable roof for court yard
Recently the famous restaurant De Librije in Zwolle, The Netherlands opened her hotel. For this hotel a most curious location was used, namely the formerly women's prison (built in 1739) of Zwolle. In this prison, called ‘Het Spinhuis’ (spinning house), female prisoners carried out spinning activities as forced labour.
Poly-Ned Textile Architecture designed a retractable roof with the longest hydraulic cylinder in the market for the coverage of the court yard of this characteristic building. During summer this roof is stored in a stylish box of 2x2x1.20m.

2. A metamorphosis of 2 older building
Poly-Ned Textile Architecture transformed 2 older buildings for the Aston Martin Lagonda Ltd. Nürburgring/Germany. Next to the race circuit Aston Martin purchased a building to create Aston Martin’s first purpose-built test facility. The existing structure was modified by Poly-Ned Architecture to create a modern fresh technical feel using advanced fabrics to cover this building. (Material used: ca. 1100 m² FT371 Ferrari).

3. A retractable roof for Market Place
Poly-Ned designed a retractable roof for the market place in the historical center of Franeker, The Netherlands. The lighting for the square is suspended from the masts on a permanent basis.

These masts, with a height of 24 meter each, do not need any rope. The membrane had to be lightweight and therefore vectran straps were used instead of steel cables.
Membrane Façade Design

The Space Home Pavilion is located in Zone D of the Expo Site, Shanghai China. The pavilion looks like a "magic cube" suspended in space. Supported by intricate pillars, it gives a feeling of space disorder and instigates the visitors' desire for exploration.

The design tries to convey the concepts of "technology", "energy" and "space" with a sense of simplicity. Based on the core concepts of "sky (outer space), land (city) and man (the explorer and creator)", the pavilion shows how aerospace and electronic technologies promote urban development and improve human life to the fullest extent.

The main structure is built with steel structure.

The aim was to make the Box "magic", to make it different and magnificent at sight. The best solution was to use membrane material (Fig. 1)! The building is 38m x 48m, and 19m high. Half of it is an exhibition hall; the other half contains four levels with offices. The membrane façade starts at the level of 5.75m and has a height of 13.25m. All together the façade area is ~3000m². The membrane shows aerospace paintings, it is highly translucent to provide day lighting for the offices and is a good screen for film projection. Hence the main criteria for the membrane material were high translucency, appropriate to be painted, with a high tensile strength (for the long span) and, since the pavilion is a temporary building, recyclable.

The FT381 made by Ferrari has been selected. It is a mesh fabric; it has a transmission factor of 34% for visual light. It has good capability for painting. The tensile strength is 3300N/5cm which is enough for the loading requirements. Fortunately, the Environment management system of Ferrari is ISO 14001. The façade membrane is braced with a vertical steel cable Φ=20mm at each 2600mm distance. The cables are supported by the tubular profiles of the main steel structure. Between the two adjacent cables, the membrane is supported by a steel ring, which makes a high point (Fig 2 and 3). The overall impression of the façade is flat with several sticking out ring points at regular intervals.

The Chinese program 3D3S has been used to do the form-finding, the nonlinear analysis, the Chinese standard of steel & membrane structure checking and the patterning. Forten3000 has been used to check the results. In fact, it was not really needed to do the 3D cutting pattern. It’s flat cutting. The difficulty was to arrange the painting; the painting patterns required high accuracy. When installing the membrane, the first step was to apply and adjust the pre-tension system placed at the top of the façade. The second step was to adjust the ring-supports to stick up the membrane. At the end, the stressed membrane façade is well done and the Space Home Pavilion is now on show.

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Membrane components for the man-made environment

Lightweight works for the housing welfare

Within the research on actions and works to meet one of the many aspects of housing welfare, membranes are able to assume a role not only functional but also expressive. They, in fact, draw and make accessible the spaces, offering the possibility of realize free and sinuous forms in order to accommodate social and at the same time flexible, transformable or transitional functions.

The text is divided into two parts, the first one describes lightweight works in urban environments and the second one tells some projects conducted in the "Laboratorio di tecnologie leggere per l’ambiente costruito" at the University of Naples. The works of Aldo Capasso in Naples reflect this line of action, in order to obtain usability and characterization of urban spaces such as squares, sites of representation, facilities for exhibitions, roads and trade areas.

Each of these projects comes as part of a broader research aimed at the study and increased use of lightweight structures by technological, environmental, functional character, conducted in the "Laboratorio di tecnologie leggere per l’ambiente costruito" at the University of Naples.

1. Lightweight works in urban environments

The Vela is a stand for the sale, adaptable in different urban contexts. In Naples, it was used and designed for very busy and densely populated roads, in order to give a functional and decorative order for trade areas. The project was realized as a prototype for Via Vergini in Naples and it was presented for the exhibition "The minor city" in Castel Nuovo of Naples in 1995. The Vela refers to the old stalls of the fish sellers in the nineteen century, whose simple wooden structure is reflected in this project in a demountable steel structure, while the large marquee tent becomes a tensile structure in PVC. As the historic stand, so this stand also provides shelves where sellers can display the goods (Fig. 1).

Table 1

<table>
<thead>
<tr>
<th>Name of the project:</th>
<th>Vela</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location address:</td>
<td>Via Vergini and Castelnuovo, Naples</td>
</tr>
<tr>
<td>Client (investor):</td>
<td>University “Federico II”, Naples</td>
</tr>
<tr>
<td>Function of building:</td>
<td>stand for sale</td>
</tr>
<tr>
<td>Type of application of the membrane:</td>
<td>Sail tensile structure</td>
</tr>
<tr>
<td>Year of construction:</td>
<td>1995</td>
</tr>
<tr>
<td>Architect:</td>
<td>Aldo Capasso</td>
</tr>
<tr>
<td>Contractor for the membrane:</td>
<td>Gimoflex, Nocera (SA)</td>
</tr>
<tr>
<td>Supplier of the membrane material:</td>
<td>Gimoflex, Nocera (SA)</td>
</tr>
<tr>
<td>Manufacture and installation:</td>
<td>Gimoflex, Nocera (SA)</td>
</tr>
<tr>
<td>Material:</td>
<td>steel and PVC</td>
</tr>
<tr>
<td>Covered surface (roofed area):</td>
<td>9m²</td>
</tr>
</tbody>
</table>

Figure 1. Sections, sketch by Aldo Capasso and installation of the stand for the sale "Vela" at Castelnuovo, Naples 1995
The Lilium assumes another social function. A stress-retractable umbrella both circular and square born from the experimental tensile membranes for recreation and exhibition spaces. The image proposed is a flower that, opening when it is appropriate, offers its shade to users of the spaces for which it is thought, allowing a pause for comfortable dining and relax. The umbrella was made and assembled in 1998 in three different places. The frame is made of aluminium, which consists of removable rods that allow the opening and closing motion, which is ensured by a system of steel cables and pulleys driven by a winch at the bottom along the bearing shaft. The funnel shape helps to channel rainwater into the underlying central planter, used as a decorative reinstatement to the counterweight of the steel base (Fig. 3).

**Figure 3. Sketch by Aldo Capasso, graphics of assembly sequence by Vincenzo Pinto and installation of the Lilium at Villa Scipione, Naples 1998.**

Even the Ventaglio Urbano is a project for the redevelopment of trade spaces. It is intended as a cover of stores and markets in Naples and it is included in the wider recovery and urban regeneration project, designed in 1998. The covering membrane is anchored to a metallic and fan-shaped structure, hence the name, which transfers the weight to two vertical pillars of support. The space below the cover is absolutely free and flexible to any construction and condition of sale (Fig. 2).

**Figure 2. Sketch by Aldo Capasso and installation of the Ventaglio Urbano at Via Vergini, Naples 1998.**

**Table: Lilium and Ventaglio Urbano**

<table>
<thead>
<tr>
<th>Name of the project:</th>
<th>Lilium</th>
<th>Ventaglio Urbano</th>
</tr>
</thead>
<tbody>
<tr>
<td>Location address:</td>
<td>Bar in Ravello (SA) – Bar Gambrinus - Villa Scipione Naples</td>
<td>Via Vergini, Naples</td>
</tr>
<tr>
<td>Client (investor):</td>
<td>private</td>
<td>Municipality of Naples, Urban Program</td>
</tr>
<tr>
<td>Function of building:</td>
<td>covering for recreation spaces</td>
<td>covering for stores and markets</td>
</tr>
<tr>
<td>Type of application of the membrane:</td>
<td>Umbrella structure</td>
<td>Fan structure</td>
</tr>
<tr>
<td>Architect:</td>
<td>Aldo Capasso</td>
<td>Aldo Capasso</td>
</tr>
<tr>
<td>Contractor for the membrane:</td>
<td>Gais – Gaetano Sessa, Arzano (Na)</td>
<td>GRS Pozzuoli (Na)</td>
</tr>
<tr>
<td>Supplier of the membrane material:</td>
<td>Gais – Gaetano Sessa, Arzano (Na)</td>
<td>GR5 Pozzuoli (Na)</td>
</tr>
<tr>
<td>Manufacture and installation:</td>
<td>steel and PVC</td>
<td>steel and PVC</td>
</tr>
<tr>
<td>Material:</td>
<td>aluminium and polyester/PVC</td>
<td></td>
</tr>
</tbody>
</table>
2. Projects conducted in the “Laboratorio di tecnologie leggere per l’ambiente costruito”

Inside the laboratory, an elegant sail indicates directly the purpose of research on the theme of lightness in architecture, contributing to the definition of a comfortable indoor environment with the ability to enhance artificial lighting. The sail, in fact, acts as a lighting element because, thanks to its clear and highly reflective surface, amplifies the artificial light produced by equipment on the inner walls of the room, and wraps gently the environment by defining a diffuse light that avoids effects of glare or visual discomfort. The sail is made of cotton, formed by two wings, each of which is realized through eleven pieces of fabric sewn together and cut out on the pattern of the project, connected to one point to the ceiling and to three points where the sail is anchored to the walls, through devices for tensioning. The two sails pay tribute to the flight of fantasy, from which the projects arise and then develop through the support of technology and the functional, environmental and morphologic choices. (Fig. 4).

The project by Roberta Caputo is inspired by the form of a pyramid inscribed in two concentric circles. The project, called THE FOUR CIRCLES, has been directed to the design of a product that could be suitable for industrial production. The structural elements are very simple and easy to produce: steel and aluminium profiles, rods and plates, welded and bolted together. The two circles are transformed into four arcs of circumference connected together, top and bottom, through steel and plate profiled with cross form. Each of the four arcs of circle rests on the ground through a steel tubular tilted and staked to the ground. Within the structure four aluminium tubular profiled constitute the skeleton of the tent which takes a truncated pyramidal shape. This form has allowed to create natural ventilation leaving open the top and protecting the interior through a small dome in plexiglass. (Fig. 5)

Monica Covito called her project UPSIDE-DOWN DIAMOND TENT, entirely governed by the principle of lightweight, found: in form, with the elevation of living space above the ground, responding also to the requirement of insulation against humidity and infiltration of microorganisms; in minimal use of materials, sizing plan and elevation because of the use of minimum space; in environmental sustainability, because the installation can not have any kind of impact on the environment, not including any foundation. Other measures for sustainability are the system of panels with solar cells on the top to produce energy that should be converted from other system components placed inside a box under the base, which ensures the supply of small equipments. A passive ventilation system with lower openings in the floor allows recirculation of air inside the tent, avoiding stagnation. The assembly takes place through the cleaning conjunction of several elements: the tubular profiles, the internal and external scaffolds, the pre-shaped

The architecture, by definition, comes from one of the primary human needs: to have a shelter. Over the centuries, the shelter has become a real organism that aims to improve the quality of life and human activities. The students have turned their attention to several aspects, invoking the technological, environmental and morphological requirements, which have resulted in projects from the most different forms, designed in different contexts, man-made or natural, which necessarily affect our lives. Designing a usable space, therefore, is interfering with the natural environment, that is somehow changed. The “Nuvola per abitare” arises as a material and conceptual synthesis of a responsible architectural design. The lightness is its primary goal and its first peculiarity: the ephemeral nature of its structure allows to design a housing type that is able of preserving the environment. So interference becomes interaction, towards an effective integration between nature and construction.

Figure 4. Picture at the “Laboratorio di tecnologie leggere per l’ambiente costruito”, Naples.

Figure 5. The four circles by Roberta Caputo.

Figure 6. Upside-down diamond tent by Monica Covito.

Figure 7. Pinwheel by Nicoletta Falanga.
fabric, attached to the tubular profiles by straps and closed by zips. (Fig. 6)

Nicoletta Falanga has called her project PINWHELL, a semi-circular form supported by steel feet with adjustable height in order to adapt to irregularities of the ground. The skeleton is composed of tubular steel arches. The floor consists of eight panels made in okumé, cut into wedges, which include two panels providing along one side two strips that allow the vertical attachment of the fabric. Two fabrics close the tent: one internal waterproof and breathable fabric is fixed to U-shaped hooks of upper crown, and to hooks arranged along the tubular arch and to screws placed along the outer side of L-shaped beam at the edge. The exterior fabric is made of aluminized polyester, coupled to the structure by the same process of the interior fabric, with a longer below attachment than the internal one to ensure better water tightness. A slice of the tent is made of photovoltaic fabric that allows to shield from the sun part of outer space and to have electricity. The adoption of two layers of fabric defines a central cavity that allows the air flow, contributing to cooling of the tent, to avoid condensation. (Fig. 7)

The project of Fatima Melis, called NAUTILUS TENT, uses materials chosen according to their characteristics. The will of the elevated supporting structure meets the requirement of lightness: the scale develops in a spiralling motion and invites to reach out to the outside looks like a point of light that levitates in the dark. (Fig. 8)

Francesca P. Piccolo has chosen for her project, called TENTOO, two different yet similar materials: steel and bamboo. Steel allows assembly of industrial products, studying the connections to be made in building yard, and then to form in workshop the separate components. Bamboo, best expresses the way that sustainable architecture is becoming: oriented to protect nature, but above all to be guided to it. Its exceptional physical and mechanical characteristics also allow it to be called natural steel. The high resistance to tensile and torsion stresses enables it to be the lighter and stronger vegetable material. The covering membrane is flexible: it allows different ways of combination, so as to adjust the envelope to the function selected by the user. It can serve as holiday accommodation and accommodate trade or entertainment functions. Its ephemeral composition does not damage the land. (Fig. 9)

The CUBIC TENT of Simona Scandurra is a simple, lightweight, easily mountable / removable, recyclable and cheap structure, without losing the ability to have a pleasing result to look at and a comfortable space to live in. Starting from the study of simple geometric shapes, the choice fell on the figure of the cube, simple and perfect in itself. The tent consists of external and internal structure in steel tubular profiles, which draw the edges of two cubes. The smallest cube is the living space of the tent, attached in the top to the outer structure through steel tubular profiles, so as it remains suspended from the ground in a central position related to the outer cube that supports it, providing an additional protection to users. The outer cube is made more stable by steel cables that form four brace triangles on each face. The tent is closed and defined by a membrane in polyester / PVC, that protects, repairs and, thanks to its translucency, let the natural light to penetrate throughout the day spreading it, and at night gives the impression of a floating “great cloud”. The joints are made through bolting and welding, the fabric is supported through ropes that wrap to steel tubular profiles. (Fig. 10)

The project of Cristiana Tarantino is followed by a study of simplification of the technological system, formally associated to a surface of rotation generated by a curve that rotates around an axis. The formal result is the torsion surface of the butterfly wings, that returns a pleasant aesthetic perception, so the project is called TORSION OF WINGS TENT. The inclination facilitates water-flow and the gradual growth in height at the openings contribute to natural ventilation, where air, that enters and warms, tends to rise up and leaves the indoor. From a functional standpoint the tent provides a central space for a relaxation area, the ends for passage and the sectors to complete the circular enclosed space for access and relax in opened areas. There is the opportunity to illuminate naturally the interior thanks to the physical characteristics of the membrane of Polyester / PVC, which has a good degree of translucency to allow diffuse light without shadows inside and with uniform visibility. The elements are easily transportable, light and small: steel tubular profiles, flat bars, membranes of Polyester / PVC, plywood and wooden shapes to compose a puzzle to make the decking. (Fig. 11)

These projects express a research aimed to satisfy new requirements closely linked to the findings of negative impacts on the environment and their solution, and a different way of living spaces dedicated to leisure. Today it is necessary to take into account sustainability in the design, which involves a search that exploits the modern cleaning assembly technologies to build reversible, maintainable, reusable and recyclable constrictions with low energy consumption. The tensile structures easily integrate environment favouring the interaction with the user.

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Figure 8. Nautilus Tent by Fatima Melis.
Figure 9. Tentoo by Francesca P. Piccolo.
Figure 10. Cubic Tent by Simona Scandurra.
Figure 11. Torsion of wings tent by Cristiana Tarantino.
At the School of Architecture of the Technical University of Madrid, a Seminar on Textile Architecture is given every year for the students after their second year, during the first semester (September to December). The seminar is in charge of professors Monjo, Tejera, de la Torre and Gámez. The main goal is to give a basic knowledge to the architecture students interested in this technology, that enables them to understand its functional and formal possibilities, as well as the characteristics of textile techniques and tensile surfaces in such a way, that if interested, they can study in depth further on doing some specific postgraduate course.

During the seminar, besides assisting to a series of theoretical classes, the students have to develop two practical assignments; a first one of critical analysis of textile solutions already built, and a second one where they have to design a new roof, up to the stage of cutting pattern layout. Within this second assignment the students have the option to design a small sized roof which afterwards, with their collaboration, will be built and placed inside a covered courtyard in one of the School’s buildings. Indeed, in the so-called School’s “New Building” there’s an interior covered courtyard, about 8m wide and 45m long, whose translucent roof is supported by 10 metallic structural frames that divide it in 9 modules. One of the objectives of the seminar is to place an internal cover as a “sail” every academic year until the 9 modules are completed, so they work as interior solar filter during the warmest months, which will reduce the courtyard’s temperature thanks to the existing ventilation in the translucent roof, over the new velaria. (Fig. 1)

In any case, said “sails” could be assembled and disassembled easily thanks to a pulley system attached to fastening rings previously placed at the base of the structural frames. (Fig. 2) The first of these roofs was done this year. It is a six points hyperbolic paraboloid, four in the corners that receive the upwards forces hanging from the aforementioned rings and the other two in the middle of the minor sides, from where the downwards forces are introduced, enabling the prestressing and tensile equilibrium of the roof. (Fig. 3) The fabric used was the Ferrari 371 mesh, with a high translucency coefficient, but enough reflection of the direct sunlight radiation. The perimeter was solved with a pocket made with Ferrari 502, and metallic rings attached with “trevira” belts 4cm wide, sewn to the fabric in the corners, to ensure the resistance to the forces located in the corner, and guarantee the adequate stress transfer. (Fig. 4) The erection and tensioning was carried out from the ground floor using the ropes and pulleys previously attached to the fastening rings. It was done manually and with great ease, thanks to the light weight of the roof and the lack of wind.

The firms Buro Arquitectura Textil (www.batspain.com) and Moñita (www.toldosmonita.com) have collaborated with this educational event.

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In January 2010, the work of research entitled: “Ultra-lightweight constructions for temporary uses: research about new membranes structures and their applications in temporary architecture” began. Roberto Maffei, graduated student from Politecnico di Milano is now collaborating with Technische Universiteit Eindhoven for a 4 year PhD research under the supervision of Alessandra Zanelli from Politecnico di Milano and Arno Pronk from the Technische Universiteit Eindhoven. Roberto Maffei’s background is Architecture but he spent the last year focusing on the comparison of the behaviour of pneumatic structures filled with air with the ones filled with water. In his PhD research, Tensairity® technology developed by Empa, will be the main focus. Goals of the research is to investigate new possible applications of this technology in architecture together with the supervision of Rolf Luchsinger and EMPA (Swiss Federal Laboratories for Material Testing and Research in Zurich). In the next four years, applications for the promising construction system of tensairity® are going to be investigate into detail.

As a result a clear and better range of application can be defined. Design and construction methods for these kinds of structures will be investigate too. Logistics and mounting phase on field will be also taken into account. More specific studies will be carried on the internal comfort control of membrane structures.

Ultra-lightweight constructions for temporary uses

Universities and research centres in collaboration for a 4 year-PhD research program about textile and architecture.

Politecnico di Milano, Technische Universiteit Eindhoven and EMPA

Four different fields of investigation have been defined from the first stage of the research:

TEMPORARY structures FOR EMERGENCY: In post disaster occasions, fast erection of large span sheltering is a challenging goal for architects and engineers. A large span shelter could host hundreds of people and give them a safe place where to stay for the first phase (up to one week) after the disaster. Moreover lightweight structures can be the right technology for building infrastructures too such as temporary bridges, roads but also water or waste barriers.

TEMPORARY structures FOR SHELTERING: Ultra-lightweight removable structures can be the solution for the covering and the protection of areas from seasonal risks (i.e. archaeological areas or open air spaces). Greenhouses and structures for agriculture are also considered in this category.

TEMPORARY structures FOR FUN: Temporary exhibitions or events, such as Expo 2015 in Milan, are occasions in which ultra-lightweight structures can be used to host people and exhibitions for a short period of time. The same system can be useful in the design of advertising and communication structures.

MOVEABLE DEVICES/APPLICATION FOR SPACE: Wings, boats... but also energy production systems, satellites or inflatable modules for Space habitat.

The key point of the research is the strict collaboration with the Dutch branch of the Red cross who wants to innovate the current technologies for emergency relief.

Figures: Turtle tent - community shelter for Red cross

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Fluvial bank pergolas

International Expo “water and sustainable development”

Zaragoza 2008, Spain

For the International Expo “Water and Sustainable Development” that took place in the Ebro River Banks during summer of 2008 in Saragossa, it was proposed to construct two tensile structures which mission was casting area shadows over the Event Audience, cooling the hot Zaragosa summer air thanks to the shaded areas and the water vaporizers installed in the Pergolas.

Idea

Due to the Saragossa summer heat, coinciding with the period in which the Exhibition would take place, made that in the planning period of whole the Exhibition ground was thought that it would be suitable to provide shaded areas to the audience. In this first stage, it was commissioned to “Batllé i Roig, arquitectes”, after a public tender, the urbanization of the Ebro Fluvial Banks, and among the public spaces in the showground, were chosen for providing shaded areas, the North Access and the space among the Thematic Plazas.

For that mission, they proposed the construction of two cable net structures with colored textile dots that would cast shadows over the ground, where the cable net would be supported by a steel frame. All these things were collected into a Basic Project. (Fig. 1)

The Entrance Pergola, covering a surface of 2362m², was settled, as mentioned, in the North Access and its mission was protecting the spectators from the sun while waiting in line before their entrance to the exhibition site. The Inner Pergola, was built among the Thematic Plazas, providing architectural unity to all of the Thematic Plazas and generating a shaded and refreshing area, thanks to the water vaporizers provided in the pergolas. Its planar surface was of 7500m², being its principal direction parallel to the Ebro River.

Construction of the Pergolas

For the Basic Project, the Expo published the competition for the construction of the Pergolas, which was adjudicated in order to their technical and economical offer to the Joint Venture “Mecanasa – Comercial Marítima”. Due to the degree of development of the project, as it was previously said, engineering assistance was needed to help the Basic Project in building the Pergolas, which was provide by Arenas&Asociados, that had previously helped the Joint Venture with the technical proposal.

Building project

Due to the definition of the Basic Project, it was needed to redefine the entire project of the structure, because it had been redacted in a short time, although the architectural conceptual idea was really brilliant. But the engineering concepts were not quite rights. Arenas&Asociados had to recalculate whole the structures, making changes over the initial structural designs that improved the behavior of the tensile structures and the aesthetic of the Pergolas, which was appreciated by the architects and the Expo technicians.

The first of the improvements consisted in the supression of the hinges designed in the Basic Project in the mast of the steel frame supporting structure, which was the original idea desired by the architects. That hinges made no senses, because forces didn’t follow the form, so fixing the masts in the foundation allowed a stress reduction in the elements and a saving in steel. The second change was the introduction of boundary cables instead of connecting the cable net to the horizontal tubular steel beams connecting the mast, which was geometrically impossible. The boundary cables gave a softer aspect to the cable net, which seems to float in the air. These changes were the most remarkable, because included design modifications, needed to analyze every aspect concerning with the erection of the Pergolas, including revision and reinforcement of micropiles foundations that had been built in a previous contract.

Elements of the Pergolas

The Pergolas consist in a supporting steel frame, the cable nets and the textile dots. (Fig. 2) In this section, these elements will be described. The steel frame is composed by masts and horizontal beams, being...
both elements built by means of tubular steel S-355 elements. 

The masts were designed as tripods, with a principal strut element and two tie secondary elements, but due to its conception, these elements have flexural forces too. The tripods couldn’t be changed so it was necessary to think in mechanisms for resisting the external actions. The masts have a height of 7,70m and are organized in plazas by means of two horizontal tubular beams, which have the connecting plates with the cable net. Detailed calculation models, using FEM were made for studying the force transmission from the cable net to the frame supporting structures, which validated the joints designed by the engineers of Arenas&Asociados, because that issue hadn’t even been thought in the Basic project. (Fig. 3) 

It must be said too, that a 1:1 scale model was built to be approved by Batllé i Roig, architects and Expo technicians, not only geometrically but color too. The color proposed by Arenas&Asociados was RAL 9023, and was accepted by the property owners. (Fig. 4)

The cable net is the result of ø26mm galfan boundary cables, and ø16mm inox net cables making a 2x2m grid, being inside this grid the colored textile dots. Non linear calculation, taking in account the stiffness of the mast were carried out, verifying the final geometry with the property owners in the monthly meetings which took place in their office in Zaragoza. Due to singularity of connections between net cable and boundary cables, singular connecting systems and clamps had to be designed in the building project with a successful result. It was a hard task, because an optimal aesthetical sight was looked for and there wasn’t almost time for erecting the Pergolas before the Expo started. That objective was reached, by spending a lot of time improving the detail design, in fact, it was satisfactory, and from our point of view, necessary. Both types of cables, boundary and net, had swaged terminals, which made possible tensioning them. The boundary cables had fork terminals too, swaging the swaged terminal in them. Because all the pieces were designed, breaking tests of boundary cables were made. That was a good idea, because it was detected that there were some problems with the steel resistance and geometrical design of the terminal, when the terminal collapsed at a lower load level than the cable one, which was unacceptable. Inside the cable net, textile dots were installed with the purpose of casting shadow. These dots had a diameter of 160cm and were made by an inox steel frame surrounding a circular textile disc of Soltis 92 made by Ferrari. Yellow and blue were the colors selected by the architects, placing them in a mosaic reminding the viewer of seen swimmers. An interesting effect was reached thanks to inox frame, and that was they reflected the colors of the bigger dots painted in the floor, in yellow, white and blue, an idea of Joan Roig, of Batllé i Roig. Those colors changed with the daylight.

Illumination 

Suspending from cable net crossing pieces, led illumination was installed. It had a funny effect in the hot summer nights of Zaragoza. (Fig. 5)

Erection of Pergolas 

As the foundations were built before the Pergolas contract were adjudicated to the Joint Venture, some design questions of the Pergolas were conditioned by the execution of foundations, such as orientation of mast, which weren’t properly orientated in some cases, due to a non rigorous calculation in the Basic Project. This matter supposed upper stress levels in mast, but this issue wasn’t really important compared with the damage suffered in the anchorage rebars due to construction traffic in the Expo showground. Almost 80% of rebars had to be replaced, slowing down the erection process. Once the anchorage bars were replaced, masts, which were welded in workshop, could be erected. The masts were threaded in the anchorage bars, leveling out its final position by means of topographical tools. This issue was especially important, because small leveling errors in base plates had a big repercussion in the mast heads due to its height of 7,70m, and could affect negatively to the cable net by over or under tensioning the whole net, forcing the need of manufacturing new cables, which was impossible for the limited time available for completing the erection process. All the masts and horizontal steel tubular beams between them were erected by small cranes thanks to their low weight.

As the masts were organized in “plazas”, it wasn’t necessary to wait for completing them all before installing the cable net. The cable net had to be installed beginning with the boundary cables, which were tensioned by mean of wrenches to the length defined in the Building Project. This could be done by using fork connectors with threaded fittings in the boundary cables. Trying to reduce the Pergolas erection period, all the boundary cables were marked in workshop by means of color code referring to the different clamps needed for the net cables. This decision was successfully, being appreciated by the erecting team. (Fig. 6)
CityCenter, an unprecedented urban metropolis on the Las Vegas Strip, is a joint venture between MGM MIRAGE and Infinity World Development Corporation. The project is made up of six separate buildings and has an interesting Light rail station terminal. The custom tensile fabric structure from FabriTec Structures and Gensler Architects forms the centerpiece of this terminal. Weaving between CityCenter’s buildings, the people mover was designed to facilitate the dynamic movement of residents and guests. The “floating cloud” PTFE fabric canopy has approximately 930m² in surface area and was designed with catenary edges and large compression ring openings penetrating the tilted truss masts. The truss in the center of the structure effectively creates 2 levels which allows for cross circulation and eases the air pressure beneath where the passengers load. The somewhat oval-shaped design of the fabric panels gives the structure a sense of motion. The center truss and the steel posts that are at the base of the structure were designed to mimic the look of the APM (automated passenger mobility) guideway that the tram runs on. The result is an attractive and affordable solution which create at night a glowing effect.

CityCenter’s buildings, the people mover was designed to facilitate the dynamic movement of residents and guests. The “floating cloud” PTFE fabric canopy has approximately 930m² in surface area and was designed with catenary edges and large compression ring openings penetrating the tilted truss masts. The truss in the center of the structure effectively creates 2 levels which allows for cross circulation and eases the air pressure beneath where the passengers load. The somewhat oval-shaped design of the fabric panels gives the structure a sense of motion. The center truss and the steel posts that are at the base of the structure were designed to mimic the look of the APM (automated passenger mobility) guideway that the tram runs on. The result is an attractive and affordable solution which create at night a glowing effect.

Finally, the led illumination and the water vaporizers (Fig. 7) were installed, completing the erection of the pergolas, which took less than 45 days.

Conclusion
At first, during Expo Planning, the Pergolas were intended only for the Expo duration, but thanks to the good appearance of the Pergolas, and the success reached among the visitors, it was decided to give them a permanent service. The 15th of June of 2009, the Pergolas were received by the Zaragoza Council, and became a permanent rest area of the new Ebro’s riverfront.

USA-SHADE

CityCenter, Las Vegas, Nevada USA

CityCenter’s buildings, the people mover was designed to facilitate the dynamic movement of residents and guests. The “floating cloud” PTFE fabric canopy has approximately 930m² in surface area and was designed with catenary edges and large compression ring openings penetrating the tilted truss masts. The truss in the center of the structure effectively creates 2 levels which allows for cross circulation and eases the air pressure beneath where the passengers load. The somewhat oval-shaped design of the fabric panels gives the structure a sense of motion. The center truss and the steel posts that are at the base of the structure were designed to mimic the look of the APM (automated passenger mobility) guideway that the tram runs on. The result is an attractive and affordable solution which create at night a glowing effect.

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The project is located in the leisure park “Ab-o-Atash” (meaning: “Water and Fire” in Persian language) in the North of Tehran, Iran. It’s a stage for sitting with a fabric roof over it, making an open amphitheatre. The concrete seating place, with a capacity of 750 seats, is the foundation for the roof. This roof is a one piece PVC-PVDF coated Polyester fabric of 709m² and covers a total area of 600m². The roof is suspended and tensioned by two 16m high steel masts in front with a span of 24m. The masts keep in tension four steel wire ropes connected to keep in tension the fabric in front and four other cables connected to the ground.

On the other side the fabric is fixed to steel trusses in the back part of the stage. A double curvature is created by high points and low points at the top of each truss in order to find the geometry which is structurally stable under wind load and snow load. The difference in height for the membrane is between 4m and 16m. The span between the trusses are between 4,18m and 13,05m. Because of the slope of the ground the stage is designed in a way that people can sit on both sides of it. The roof also extends back to provide the shelter for the ones who are using the back side. These two levels are connected by a ramp which goes round the stage. The stage has 8 platforms in total.

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CANOBIO has built three structures as final demonstrators for the Contex-T project (www.contex-t.eu) in order to show the results reached by the research activities in the different work packages during the last 4 years (2006-10). After the annual general meeting in Genoa (28-29 June 2010) the partners of the Consortium visited the structures in Castelnuovo (Italy).

Two more tensile surface building demonstrators have been built in Madrid and Lleida (Spain) in August 2010: the "Deployable demonstrator" and the "Weaving arches".

More information is available at www.context.eu.

With the second demonstrator called "Vela garden" the aim was to apply flexible photovoltaic cells - SioSOLAR from SIOEN - on the doubly curved tensioned membrane. Also here Vectran belts were applied on the borders. SioSOLAR is a flexible photovoltaic laminate that was specially developed for application on PVC coated textiles such as tents and textile architecture structures. Each laminate consists of a highly flexible photovoltaic unit (104 cm x 360 cm) that is laminated with a unique adhesive onto an advanced PVC foil (140 cm x 400 cm), thus resulting in a durable PV laminate that can be connected permanently (via direct welding) or non-permanently (via zipper mechanism) onto the PVC coated textile structure. The electronic parameters for the SioSOLAR laminate are the following:

- Power [Wp]: 150
- Module Vmpp [V]: 46
- Module Voc [V]: 64
- Module Impp [A]: 3.30
- Module Isc [A]: 4.45

SioSOLAR supplies enough energy for lighting, ventilation, charging of electronics (laptop, mobile phone, GPS, etc.), cooling, etc. It can be applied onto NGO and military tents, textile architecture structures such as parking lots, sun protection structures and many more. SioSOLAR comes with all necessary electronics.

After the belts had been welded to the membrane with pre-tension there were wrinkles along the borders once this pre-tension was released. A first erection was done to check the structure under pre-tension. Next the flexible photovoltaic cells have been attached to the membrane in such a way that they do not take any tension from the membrane.

In this design the photovoltaic cells provide - for instance when placed at the beach - the opportunity to recharge a mobile phone or a laptop.

The first demonstrator called "Cube sail" is a self-carrying structure built to test on the one hand the membrane material T2109 - which is a type II PVC/PES membrane top coated with a unique easy cleaning/self cleaning lacquer from SIOEN - and the application of Vectran belts - provided by BEXCO - without stitching. The design, analysis, drawing of the cutting patterns, fabrication and detailing all have been done by CANOBIO. If applied properly - like in this demonstrator - the use of belts realises a smooth and flexible transition of the curved geometry as well as of the stresses in the membrane to the bending-stiff corner plates.
The third demonstrator called “Parking module” is a single standing module which can be coupled with others - in which case they have a common boundary. The inflated cushion is supported by a rigid steel frame and consists of 3-layers of materials, one PVC membrane (Sioen B7145) at the bottom and 2 ETFE films clamped on its perimeter. A photovoltaic carpet was fixed on the intermediate layer with a special adhesive ETFE film. A led lighting system used the electricity gained during the day to enlighten the cushion at night. Again the design, analysis, drawing of the cutting patterns, fabrication, detailing and installation all have been done by CANOBBIO.

The four photovoltaic panels used in the parking module are Konarka 1140 modules with the following properties:
- Power [Wp]: 28.6
- Module Vmpp [V]: 15.8
- Module Voc [V]: 22.6
- Module Impp [A]: 1.8
- Module Isc [A]: 2.2

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Dependency of Load Transfer on Boundary Conditions

Objective
At first glance, edge detailing seems to be a very specific issue in membrane design, but – on second thoughts – it turns out to be of major importance. As always with lightweight structures the basic challenge of combining different structural and functional elements to transfer forces and deformations simultaneously has to be met. While the structural behaviour of fabric membranes has been widely explored with regard to their inner region, there is a lack of profound knowledge on the structural detailing of their edge regions. The all too common use of elements with extreme stiffness ratios may – due to their incompatibility – lead to wrinkles or even to the destruction of the membrane (Fig. 1). When designing multi-functional structures, lots of various or even contradictory influences and constraints need to be reflected. Thus, there is of course no universal or “one and only” design solution. Good design requires “material adequacy”: simply using adequate materials for elements or joints on specific conditions. It results in combining different materials optimally according to their specific properties and shall include not only mechanical and geometrical, but also functional aspects.

Hyperbolic curvature and the influence of boundaries
The decisive influence of edge details both on global geometry and on force distribution in mechanically prestressed membrane structures becomes evident by means of analytical considerations. The membrane forces can be determined by the well known membrane equation according to Pucher (equation 1).

\[ \frac{\partial^2 F}{\partial x^2} \frac{\partial z}{\partial y} - 2 \frac{\partial^2 F}{\partial x \partial y} \frac{\partial z}{\partial x} + \frac{\partial^2 F}{\partial y^2} \frac{\partial z}{\partial y} + p = 0 \]

Due to the mechanical prestress, the membrane surface has a negative Gaussian curvature and the differential equation is of hyperbolic nature (equation 2).

\[ \Delta = \frac{\partial^2 z}{\partial x^2} - \frac{\partial^2 z}{\partial x \partial y} + \frac{\partial^2 z}{\partial y^2} \]

Contrary to elliptic differential equations, there are two families of real integral curves (equation 3), which correspond to the asymptotic curves of the surface.

\[ \frac{\partial^2 z}{\partial x^2} (\partial x^2 + 2 \frac{\partial z}{\partial x} \partial x \partial y + \frac{\partial^2 z}{\partial y^2} (\partial y)^2 ) = 0 \]

Basar and Smith [2] have shown that discontinuities in the initial conditions propagate along the integral curves. For the structural behaviour of anticlastic membranes this results in 4 major consequences:
- Discontinuities in the initial conditions propagate through the entire membrane width and are not limited to a small region.
- They propagate along the asymptotic curves.
- If the asymptotic curve meets another surface boundary, this boundary value is given, and can not be chosen freely.
- The location of the discontinuity clearly defines the pair of asymptotic curves. They only depend on the geometry of the membrane surface, but not on the nature and direction of the discontinuity.

This mathematical fact can be illustrated with an isotropic catenoid and a so-called apes saddle. Fig. 2 shows the analytical solution for various pairs of asymptotic curves and the numerical solution for the load path of a singularity at a free edge. If the load path (represented by the maximum principal membrane force) meets another boundary, it will be reflected or absorbed according to the actual boundary condition.

Because of their hyperbolic nature it can be deduced that boundary discontinuities do not act only locally, but spread along the two characteristic integral trajectories through the entire membrane width. Therefore, the structural detailing of the edge affects not only a restricted area, but influences the load-bearing behaviour and the deformations of the whole membrane structure.

The dependencies between structural behaviour and Euclidean geometry imply the assumption of a homogeneous, isotropic and rigid material. However, due to large deformations or geometric boundary constraints, the material properties need to be included in the structural analysis of membranes. Thus, in addition to the global geometry, the strong orthotropic material behaviour, the cutting pattern and the curve of warp and weft [3] rule the flow of forces and the load transmission from fabric membrane into edge elements. As an example, the common change of a parallel cutting pattern to a radial one at high points evidences the mandatory sensitivity to material adequate design (Fig. 3).

Methodology
To evaluate design principles of membrane edges systematically, it was necessary to provide an objective classification. The commonly used categorizations (e.g. depending on the bending stiffness of the edge element) turned out to be not consistent or incomplete. Contrary, the classification system according to Table 1 is based on the compatibility of fabric membrane and load transmitting elements. Edge details are distinguished in terms of their kinematic dependencies: The system differentiates between movements and deformations of the entire edge or its sub-elements as well as their dependencies or couplings.

Based on this methodology, various principle design solutions for edge as well as corner
details have been investigated systematically according to their kinematic constraints and decisive geometrical and mechanical parameters. The design principles are compared to each other and then evaluated with regard to material adequacy. Analytical and numerical evidence demonstrates that especially large deformations of edge elements in combination with very low strain as well as relative displacements and perforations of edge details result in high concentrations of membrane force and shear deformations of the fabric (Fig. 4).

Investigation of influences and parameters: kinematic edges

The most interesting type of edge structures are kinematic edge elements with equilibrium shape. Due to the strong interaction with the membrane, the exact geometry of the edge axis is not known initially.

The edge curve, the osculating plane as well as the tangential plane of the membrane surface (Fig. 5) can be written in parametric form:

\[x = t \quad y = f(t) \quad z = z(t, f(t))\]

Now, the static equilibrium can only be satisfied if the tangential plane (equation 5) and the osculating plane of membrane’s boundary curve (equation 6) are identical:

\[0 = \left( \frac{\partial z}{\partial x} (y - y_c) + \frac{\partial z}{\partial y} (z - z_c) - (z - z_c) \frac{\partial y}{\partial x} \right) + (y - f) \frac{\partial z}{\partial y} - (z - z_c)\]

\[0 = (x - f) \left[ f' \left( \frac{\partial z}{\partial x} \right)^2 + 2 \frac{\partial z}{\partial x} \frac{\partial z}{\partial y} f' + \frac{\partial z}{\partial y} (f')^2 \right] - \frac{\partial z}{\partial x} + (z - z_c)\]

The two planes coincide, if and only if the following condition is satisfied (equation 7):

\[\frac{\partial z}{\partial x} + 2 \frac{\partial z}{\partial y} f' = 0\]

With this ordinary differential equation the boundary curves can be determined, i.e. the geometry of the boundary curve is no longer – as originally expected – independent. Interestingly these are again the earlier mentioned integral curves (Fig. 6).

Consequently, the geometry of the axis of a kinematic edge element must correspond to an asymptotic curve of the membrane surface (caution: the applicability with respect to cables needs to be checked additionally).

That means: if the membrane shape is given and only one corner point is specified, the edge curve is defined uniquely. Or, with other words, it is not possible to specify two anchor points arbitrarily without changing the surface shape. As an example, this fact is shown here for the transition from a hyperbolic paraboloid to a saddle shaped sail (Fig. 7). The hypar with a fixed edge has a concentric curvature distribution (dotted line in diagram and left plan view).

Converting the fixed edge into a kinematic
edge element results in an equilibrium shape with a significant redistribution of Gaussian curvature. The membrane curvature in the centre increases and the corner areas become flat depending on the sag of the edge curve [4].

For kinematic edge elements the influence of their axial stiffness was checked under vertical load applied to the membrane surface (Fig. 8). The upper two diagrams show the maximum vertical deformation and the shear angle dependent on the relative stiffness. The interesting point is that the location of the maximum deformation moves from the centre of the membrane to the corners with decreasing edge stiffness. With increasing stiffness the shear deformation rises due to the incompatibility. This result matches analytical considerations regarding an “optimum” edge stiffness.

The lower 3-dimensional diagrams show the tangential and the normal strain along the edge curve. Both values are normalised with regard to the prestress. Very flexible edges activate both directions for load transfer. With rigid edges the tangential strains are frozen to the prestress value and the only load transfer is perpendicular to the edge. This fact explains the larger shear deformation.

Relative movability between sub-elements

Based on kinematic edges a relative movability between individual components of the edge structure has been introduced. For reasons of comparability the investigations of decisive parameters regarding the load transfer have been performed with the same saddle shaped sail. To represent a cable in a membrane pocket, a special element pair was defined for nonlinear sliding contact conditions with distance restrictions (Fig. 9). The tangential coupling was idealised with Coulomb friction. Since the distribution of the load transfer between these sub-elements depends on the coupling conditions, it is necessary to vary the coupling between frictionless $\mu=0$ and fixed (“uv”). (From an earlier test the friction coefficient between a spiral cable and a PVC-coated polyester membrane has been recalculated to be 0.3.)

The diagrams in fig. 10 show the normalised strains of the edge cable, the textile belt and the warp of main fabric. As expected with a fixed coupling the stiff edge cable takes all loads. But, the smaller the coupling between the membrane pocket and the cable is, the more load is transferred by the belt. This transfer is accompanied by a relative displacement between the membrane pocket and the cable. Mechanically, this recurring displacement results in abrasion of the membrane coating. The inelastic behaviour of the coupling becomes evident when the external load is removed: for realistic friction values the strains do not return to their initial prestress level, but there remain residual strains in all sub-elements.

It should be noticed that the belt takes not only the tangential but also radial membrane forces. Consequently, a dimensioning of the belt for tangential forces only – as it is usually done – is not safe.

Perforations in fabrics

In many cases membrane edges are designed with perforations. Even if the perforation is not subjected to direct bearing pressure, there form huge force concentrations besides the perforation. Sawin and Lekhnitskii [5] have identified an analytical solution for the concentration factor at a circular perforation in rigid orthotropic material loaded with uniaxial tension (equation 8).

$$K_{x,\text{max}} = \frac{E_t}{E_i} \sqrt{\frac{E_t}{E_i} \cos^2 \varphi \left( 1 - \frac{1}{2} \frac{1}{\cos^2 \varphi} \right)} \sqrt{\frac{E_t}{E_i} \sin^2 \varphi}$$

With this idealised assumption the force factor $K$ for standard fabric material is something around 7 to 10, what is much higher than the usual safety factors. (Note: This effect of stress concentration is one cause of the bad tear resistance of fabrics.) For isotropic materials, the factor $K$ is only 3.0. Numerical analyses with fabrics without compression stiffness show that the influenced area with considerably reduced stress at the vertex is about 8 times the diameter of the perforation dependent on the shear stiffness (Fig. 11).

Corner regions

As an example of load paths and stress concentrations, a typical membrane corner structure is shown in fig. 12. The decisive influence of the interface conditions between a cable and its membrane pocket rules the load bearing behaviour of the fabric membrane and may lead to load factors that are higher than the usual safety factors. Based on the knowledge regarding perforations, the structural behaviour in the more or less flat corner region can be explained easily. The principal membrane forces follow the orthotropy axes, at which the forces in warp direction concentrate at the intersection with the belt and the weft forces.
Concentrate tangentially at the vertex of the bow. There does not form any bowed tie as one would expect in isotropic materials. The lower diagrams show the normalised strains in warp and weft direction along the corner bow with a concentration factor of about 2 for the prestressed state. Under snow load the factor for the warp direction rises up to factor 8. Only the weft force depends on the geometry of the bow. The opening angle of the corner has only a minimal influence on the concentration.

However, the importance and effect of these ever occurring phenomena can be actively controlled by smart engineering.

**Development of a textile edge reinforcement**

Based on the findings of the research work, the intention cannot be designing a nice but separate edge element; the goal is to develop an integrated edge reinforcement. With a textile edge reinforcement made of high-performance fibres a mechanically adequate behaviour can be achieved (Fig. 13). Such a reinforcement can adequately transmit the tangential as well as radial forces out of the membrane to the supports. With the 3D warp-interlaced technology it is possible to transfer the membrane forces reliably. This volume forming technology uses only two threads instead of three, what allows for an easier connection to the main fabric.

With this technology a three-dimensional fabric with a continuously tapering cross-section can be built up. Along the edge there are incorporated high strength yarns with different thread types and thicknesses. The addition of yarns is also possible. Due to the high strength it is possible to minimise the necessary cross section. Thus, the compact cross section can be adapted to small edge radii much better than common textile belts. The dimensional stability of the edge reinforcement is ensured by interweaving of the individual warp layers. In weft direction the same yarns as for the main fabric can be used. The edge reinforcement transfers the entire membrane forces to the corners for anchorage at the supports. Instead of attaching bulky end terminations (like at steel cables), the forces can be transferred indirectly by deviating the edge reinforcement. The smaller differential forces are taken by clamps (Fig. 14).

Due to their trumpet-like shape, they can be used for a big variety of geometric situations independent on the corner angle. Thanks to this little structural effort and the very compact elements, this design leads to a significant aesthetic improvement of corner details at structural membranes.

**Conclusions**

Based on analytical and numerical investigations, the most important fact during the design is to be very sensitive to all compatibility issues between the edge element and the fabric membrane. These findings can be summarised as follows:

1. Detailing is of major importance in the design of membrane structures.
2. The details of mechanically prestressed membrane structures have an impact on the structural behaviour of the entire membrane surface.
3. The global load transfer can be actively controlled by smart engineering.
4. A design approach that respects the compatibility and deformation issues is much more adequate than only looking at membrane forces.
   - Huge stiffness ratios should be avoided.
   - Relative movements or sliding between sub-elements need to be reduced.
   - Perforations are not adequate and should therefore be avoided if ever possible.
5. A systematic knowledge of material adequate detailing provides the opportunity to create new elements and shapes.
6. A textile edge reinforcement instead of a separate edge element can be tailored to the specific requirements of the fabric membrane.

Moreover, the knowledge and the sensitivity to structural detailing shall emphasize the lightness and the playfulness of membranes and shall preserve the joy of designing.

**References**

A comprehensive list of references can be found in [1].

Introduction
The purpose of this brief article is to acquaint the highly developed skills and knowledge base of TensiNews readers with related low-tech yet artistic structural techniques directly applicable to long-term cultural sustainability via fulfilling the basic human need for shelter. This article is a brief introduction to a world-wide, loosely knit and growing community involved with bamboo, pole or rope structures which may be sheathed with fabric or other membrane material.

We explore this through recent work of visual artist Antoon Versteegde. He has mainly sought his artistic freedom outside established institutes and exhibition spaces, in public locations with free access for everyone. He has accomplished large artistic constructions as transient outdoor installations constructed with lightweight materials such as bamboo, flags, rope and rubber bands. Through this process he has gained experience with large-scale interactive projects and developed world-wide relations with other artists, builders and scientists. The techniques developed have proven to be highly successful for realizing huge sculptures in a short time, working with groups of artists and volunteers. His construction techniques are easily passed on to people who decide to cooperate spontaneously, the use of rubber bands proved ideal for public installations because interested individuals can become involved without needing protective clothing or gloves.

Rubber bands and cement
Framing is best visualized as if it were standard construction lumber substituted for with bamboo. Binding techniques used in an actual construction does not employ rubber bands, two centimeter wide duct tape works well for a preliminary binding of a prototype or single construction. Three centimeter wide strips of utility muslin soaked with cement and acrylic is then wrapped over the duct tape. Jute bailing twine soaked in cement and acrylic accomplishes the same idea but is not as easy to keep neat. The duct tape preliminary wrap is not needed when a jig is made from a prototype frame and subsequent identical frames are assembled in the jig. Detailed construction processes are explained more fully at the ferrocement.com website. (Fig. 1) Although the binding system shown here would not be used in actual construction, Antoon Versteegde has used rubber bands to illustrate that building very large structures with many untrained individuals creates solidarity among the participants and unleashes creative strengths the isolated individuals did not realize they possessed. It is precisely because the public takes on an active role of participation that great energy is focused and channeled into the particular structural shape that Antoon has planned. His bamboo installations leave a lasting impression among participants as-well-as spectator’s, although his works have mostly been for temporary display and consequently have vanished, memories and photographs remain after the artwork has been taken down. The process underlying Versteegde’s art is a prime aspect that transforms transient into a transcendent experience in ways suggestive of enterprise formats which architects and engineers might employ in designs contributing to sustainability.

Interactive projects
Many of the photos illustrate interactive projects with geometric shapes and structures. Working with large groups of people who want to co-operate spontaneously suggests opportunities for the entrepreneur or excess labor idled by disaster or poverty (Fig. 2 & Fig. 3). It is the public aspect of these artistic works which establishes Antoon as a master of art
happenings eminently qualified to discuss and help define self-sheltering for billions who are without adequate shelter; he has witnessed and facilitated large spontaneous groups in ways applicable to an enterprise start-up or underutilized labor in a temporary refugee camp.

Self sheltering
Self-sheltering utilizes techniques with sculpturally beautiful and durable light-weight materials, it opens broad intellectual vistas for examination of a sustainable human culture which includes everyone and anyone who learns these techniques and then provides themselves with super low-cost shelter, potable water and sanitation. This concept does not detract or even compete with private enterprise contributions utilizing the same techniques and materials.

Spontaneous public participation in creation of art immerses one in the realization that expression of life is beautiful. Creative spirit is released to the benefit of all when folk art becomes self-sheltering.

Bamboo, the poor man’s timber
Bamboo is a wonder plant, its many uses include erosion control, watershed protection, soil remediation, and environmental greening. It is the fastest growing timber plant on earth with many applications as a wood substitute. Increased awareness of bamboo’s immense potential will create livelihood opportunities and contribute to the well-being and quality of life, cultivation and use of bamboo as a timber substitute will reduce the pressure on hardwood forests and shelter the homeless. Today, bamboo is again much prized. It is a multipurpose plant with secondary economic benefits that do not easily compute in methods utilized by modern economies. Secondary economic benefits of self-sheltering are equally elusive numerically, even so, environmental and social benefits will clearly contribute to a sustainable human culture, especially if engineers and architects discover applications of their advanced techniques using these traditional and low-tech materials.

Bamboo sheltering
Shelter is among the most basic of human needs. Bamboo is so beautifully practical that it was probably used to make shelter the moment people first noticed it. Bamboo shelters are used for both temporary and long-term residence. Shelter is accomplished by sheets of fabric or thatch over a frame of bamboo poles attached to the ground. Temporary shelters may evolve into artistic sculptures which will last many years, even generations. Temporary or permanent bamboo shelters range in size from single person tents to an architecturally beautiful structure large enough for a hospital or school (Fig. 4, Fig. 5, Fig. 6, Fig. 7 & Fig. 8))

Bamboo shelter designs can be inspired by tents, even including the use of a lashed catenary tensile bamboo ridge. Such shelters can be used in humanitarian emergencies, such as war, earthquakes and fire, instead of tents, which are more expensive per unit of floor area, and usually not large enough for normal family living. At times, however, these temporary shelters may well become semi-permanent or even permanent homes, especially for displaced people living in refugee camps who can’t return to their former home and for whom no replacement homes are available.

Self-sheltering has been suggested for restoring the productivity of billions of people who have been displaced through natural disasters, war and the scramble for industrial scale resources, production and agriculture. The above photos support brief mention made of using the same techniques for larger infrastructure such as schools and hospitals. Note that this light structure design vector is secure in earthquake zones as it rides over the surging land waves just as a boat rides them at sea.

Garrett Connelly (text contribution)
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The international association TensiNet and Techtextil – International Trade Fair for Technical Textiles and Nonwovens are holding the 11th 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 2010.

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.

TEXTILE STRUCTURES FOR NEW BUILDING 2011
TERMS AND CONDITIONS OF ENTRY TO THE 11TH STUDENT COMPETITION

Prizes and categories
TensiNet will be providing the competition prize money of € 8,000. 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 and Third Prize: € 250.00 per category.

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.

Timetable
28 January 2011 Closing date for receipt of entries
14 - 18 February 2011 Submission of projects
23 May 2011 Presentation of the prizes at Frankfurt Fair and Exhibition Centre
24 - 26 May 2011 Techtextil fair in Frankfurt am Main

Further information
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