SLTE 2018 Seventh Latin American Symposium of Tensile Structures

The Seventh Latin American Symposium of Tensile Structures was held in the Ccori Wasi Cultural Centre, Lima, in September 2018. It was organized by the Ricardo Palma University of Lima and chaired by Roxana Garrido and Jesús Peña. It was the seventh in a series of symposiums that began in São Paulo in 2002, followed by one in Caracas in 2005, in Acapulco in 2008, in Montevideo in 2011, in Santiago de Chile in 2012 and Brasilia in 2014.
The main topics focused on recently-executed projects, as well as applications, design, current research, and education.

OVERVIEWS

In his "Introduction to lightweight structures" Pedro Alva, from the Technical University of Perú, summarized their main characteristics and applications. Simplicity, efficiency and sustainability were mentioned together with a varied typology. He started from the antecedents of Joseph Plateau, Frederick Lanchester and remembered Buckminster Fuller, Felix Candela, Pier L.Nervi, Eduardo Torroja and Frei Otto. Nature as a model was also illustrated with several examples highlighting the variable radius geodesic domes (Fig. 1).

Alfredo Mujica, from the Ricardo Palma University presented alternatives to conventional reinforced concrete structures such as:
a) folded plates, based generally on laminar triangles that make up three-dimensional systems. The union of their edges are dihedral angles and the rigidity of the whole is given by the shape of the components and their connections. The folds can be parallel, radial or mixed.
b) hyperbolic paraboloids, that are usually combined and provide curved profiles.
c) tensile surfaces, the most efficient structures that provide more span with less material.
d) polyhedral structures. Considering that "the polyhedra are the bricks of the universe", professor Mujica showed several experiences made by his students (Fig. 2).

In "Learning by making. Academic experiences", Ruy Pauletti from the Technical University of Sao Paulo, reviewed the basic ideas concerning tensile ("taut") structures beginning with meaningful examples such as the windmills, the Golden Gate Bridge and the umbrellas (that are stiff because they are tensioned). He pointed out that they are light because they weigh less than what they support. He also clarified distinctive features by appropriated comparisons between rigid and flexible structures. Flexible structures change drastically the shape when the load pattern varies because they are funicular, meaning that the form has to follow the loads, paradoxically unlike the rigid structures that admit so called "free" forms. The design process was also summarised with special mentions to the equilibrium conditions and patterning. The talk was illustrated with several examples highlighting membrane tensegrity sculptures developed in the context of a graduate course on light structures at the University of São Paulo (Fig. 3).


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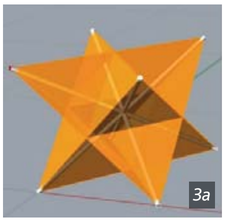
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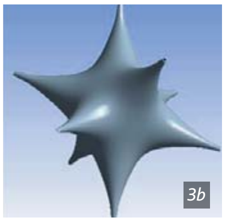
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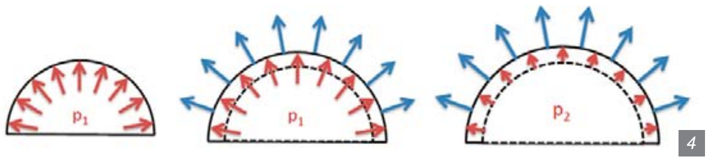
Figure 1: K.Tejlgaard & B.Jepsen, 2012: "Deconstructed" geodesic dome, Allinge.
Figure 2: A.Mujica, 2014: Students made a geodesic dome in Barranco.
Figure 3a/b: R.Pauleti, 2017: Cusped octahedral sculpture.

DESIGN

Jürgen Holl, (technet GmbH), presented the mean features of the software Easy for the integrated planning and calculation of lightweight surface structures accredited by 400 licenses in 40 countries. He began referring to modelling as an abstraction to approach the reality with the purpose of understanding and predicting. To get enough accuracy and savings, he preached the need for modelling hybrid structures instead of calculating each part separately. He illustrated it with the chambered pneumatic structures of the Expo in Switzerland. The separation of the substructure on two subsystems (pneumatic membrane plus steel ring, struts and cables) would imply increases of 67% and 100% in the computed values of the maximum bending moment and deformation respectively. Comparably, when it comes to pneumatic structures, satisfying the gas-law means a reduction of 67% and 52% in the computed values of the inner pressure and maximum stress respectively (Fig. 4). He also showed the advantages of using accurate models for textile halls considering sliding supports, shear stiffness and crimp. He finally presented the PreDesigner free tool addressed to all people who are interested in the predesign of textile membrane surfaces or cable nets. It helps to find a pre-design for 3D surfaces.

In "Architectural design of lightweight membrane structures", F.Alvarado presented on behalf of R.Roithmayr, the software "formfinder" as easy to operate as a sheet of paper and a pencil. It assists architects and project planners in the design, planning and cost-effectiveness assessment for the implementation of form-active structures (Fig. 5). Form-active structures are made of flexible non-rigid materials ranging from, for instance, a simple awning to "textile façades" and the roofing over sports stadiums. He also mentioned the capability of simulating different options according to the shape, size, curvature, sag/span ratio, proportions, loads, drainage, sun and shading in connection with an extensive database of typology and projects as a reference.

J. Llorens summarized the Joint Research Centre Science and Policy Report of the European Commission: "Prospect for European Guidance for the Structural Design of Tensile membrane Structures" to support the implementation of the future "Tensioned Membrane Structures" Eurocode. Although the geographical coverage of legal application of the Eurocodes is limited to that of the countries of the European Union, its content could be used as a reference for the standards of the Latin American region. The most relevant aspects of the document were discussed such as material properties, bases of design, durability, structural analysis, ultimate and serviceability limit states, details and execution. The annexes were also mentioned.



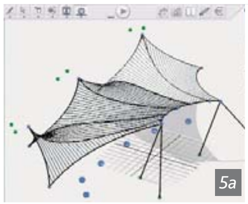
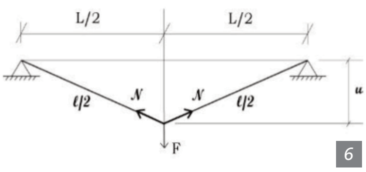
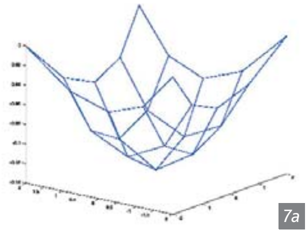
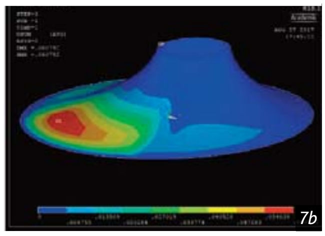


Figure 4: Pneumatic structure. Left: No external loads. Volume V1. Inner pressure p1. Middle: External load (wind suction). Gas low not satisfied. The inner pressure and the volume remain the same. Right: Gas law satisfied. Volume V2 > V1. Inner pressure p2 < p1.
Figure 5a/b: Velden Gemonaplatz sail, designed with Formfinder.
Figure 6: Tensioned rope subdivided into two elements.
Figure 7a: final geometry of the net.
Figure 7b: displacements of the conoid in the z direction.







Non-linearity was the topic of K.Rocha (Technical University of Sao Paulo) and R.Sastre (Technical University of Catalunya). Assuming that the magnitude of the deformations significantly affects the results, both speakers addressed the issue. Professor Sastre focused on the basics such as the justification of its necessity, the procedure of approaching it, its advantages and disadvantages. K.Rocha went into three models: a tensioned rope subdivided into two elements (Fig. 6), a net and a conoid (Fig. 7). The tensioned cord showed the significance of the geometric non-linearity. With the net, a routine developed with MATLAB was validated with the results obtained with ANSYS. And with the conoid, the search for the shape was explored aiming to a minimal surface. It was concluded that to discretise it as a net, radial and circumferential cables should be used and, as expected, the more refined the cable net, the greater the accuracy.

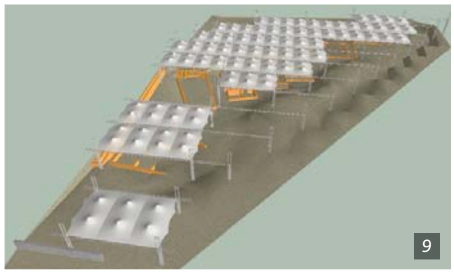
CURRENT RESEARCH

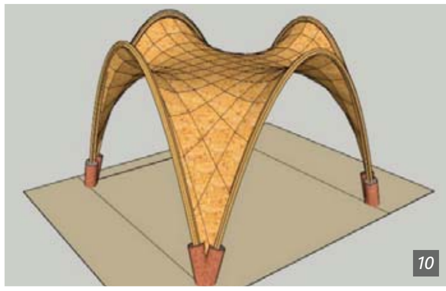
"Morflex", presented by R.Garrido from the Ricardo Palma University, is a morphostructural laminar system based on the tensegrity principle. This structural feature is manifested in the spatial order of the components, which are complemented through tense–compressive efforts. The main property of the Morflex system is to optimize the entire configuration through its flexible elements. These elements are arranged so that they allow release the potential energy generated by themselves. The application of Morflex system for this contribution is the design of a lightweight thematic pavilion (Fig. 8). The proposed lightweight structural innovation inspires its configuration in the jungle, as it seeks to sensitize the preservation of the Amazon, mainly affected by informal mining.

"Suitability of structural membranes to the refurbishment of historic buildings and protection of archaeological remains" was the presentation of J.Llorens from the technical University of Catalunya. The characteristics that make structural membranes suitable for the refurbishment of existing buildings have been investigated by analysing 80 interventions in 24 countries. The cases have been classified chronologically, distinguishing them by fields of application, by countries, and by the type of installations, whether they are mobile or fixed. Several design strategies have been identified and contrasted with the principles set by the International Council on Monuments and Sites. The results were illustrated with examples chosen from the cases investigated, with the aim of highlighting how membrane structures can fulfil the most important principles of the preservation of architectural heritage (Fig. 9).

"Hybrid shell structure in Colombia using wild cane and cementitious materials" by E.Cortés (University of Cambridge) explores the suitability of wild cane as an active bending material, corroborated graphically and mathematically with data obtained from previous research. Elastic deformation used as a self-forming process can be approached by three ways: behaviour-based, a geometry based and an integral approach. A behaviour-based approach describes vernacular methods of construction with wild cane. This research is focused on a geometry-based approach where geometry is defined by analytical and experimental form-finding methods. Currently experimental work with wild cane arches searches for a feasible spatial configuration with optimal behaviour under compression stresses (Fig. 10).

In "Air chain of bamboo" J.Simón (Technical University of Perú) showed a full-scale prototype of a dome based on the implementation of the "Bambú-Flex" mechanism seeking lightweight construction alternatives and searching for the efficiency of the structural design. Its flexibility, adaptability and modular design allows the achievement of the project with prefabricated parts post-formed during installation. (Fig. 11). This evolution of the "Bambu-Flex" mechanism is the result of the experiences and reflections conducted at "Bambú-Lab" since its formation in 2012. (https://www.facebook.com/bambulab.peru/). Lightweight bamboo structural systems have been investigated taking advantage of its qualities as a rapidly recovering renewable resource, non-polluting, low-cost and feasible





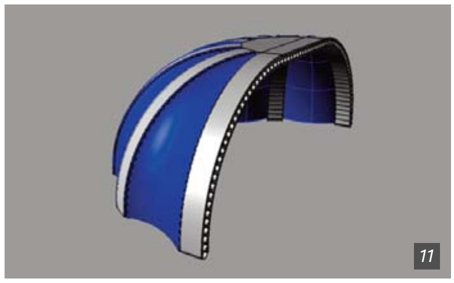


Figure 8: Morflex Amazon Pavilion (IASS 2015 Amsterdam Symposium).
Figure 9: Modulated, lightweight and translucent textile roof for the "Amphitheatre Roman House" in Mérida (J.Llorens with Arqintegral, 2002).
Figure 10: Anticlastic wild cane structure.
Figure 11: Air-chain of bamboo prototype.

both as an industrial and handcrafted construction; which gives it high adaptability by integrating its lightweight and flexible nature with its morph-structural potential.

J.Espinoza (Ricardo Palma University) addressed the possibility of obtaining variable geometries through funicular tensegrities. He started from a previous idea of a super elastic tensegrity model (Fig. 12). Introducing bows and pulleys mechanisms, he hinted at the possibility of covering large surfaces with retractable roofs mounted on mobile rails supported by funicular systems. He considered the syncretic fusion of the concepts "tensegrity" and "funicular" a simple idea full of innovation and options for unsuspected structural uses. M.Rodríguez (Ricardo Palma University) reported on an "Application of a post-tensioned reticular system made of guadua angustifolia". It is a system developed from a modular grid of bamboo easily assembled and adaptable to places with limited possibilities of anchoring (Fig. 13). The sections are hinged with pins forming an adaptable grid stabilized by embedded post-tensioned cables (Ø1/4") that run between the fixing points and the pinned joints.

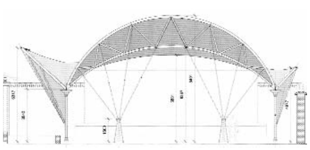

12a


12b


13a


13b

Figure 12 a/b: Loose (a) and stretched (b) variable geometry obtained through a funicular tensegrity.
Figure 13a/b: Post-tensioned grid of bamboo for "Safari Kids", Jockey Plaza, Lima.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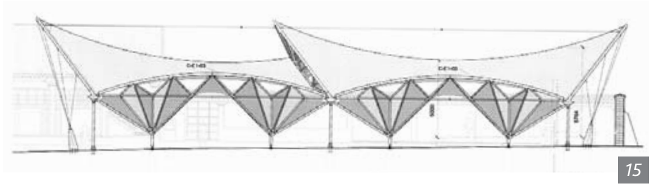
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Figure 14: J.León, Architect with Grupo ESTRAN, 2016: Central arch. Coffee drying patio, La Estancia, La Floresta.
Figure 15: J.León, Architect with Grupo ESTRAN, 2016: Lateral arch. Coffee drying patio, La Estancia, La Floresta.
Figure 16a/b: Grupo ESTRAN, 2017: Roof-top terrace. Waldorf Hotel, Caracas.


16a


16b

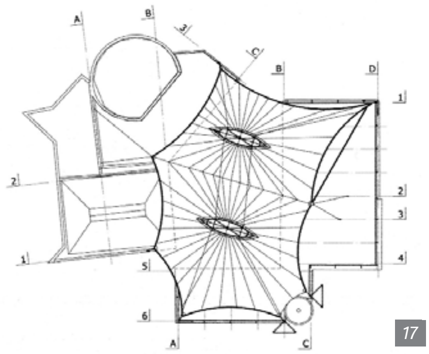
The system could be accommodated to prisms and polyhedra and the fixing points at the ends of the bars could be aligned or not for complex arrangements.

RECENT PROJECTS

Professor C.Hernández (Central University of Venezuela) reviewed 30 years of his professional activity dedicated to transformable architecture and membranes highlighting two recent works. The 615m² roof of the coffee drying patio at La Estancia (La Floresta) was distinguished because it was designed totally independent of the existing historical and protected colonial building. It is subdivided into two structural modules framed between 3 central arches (ℓ =14m, Fig. 14) and 4 lateral arches (ℓ =15m, Figs.14-15) complemented by micro perforated fabric shading panels. The roof-top terrace of the Waldorf Hotel in Caracas was also presented. It consists of a series of modules tensioned between the cornice, high points suspended from booms and low points attached to the parapet, the whole not interfering with the panoramic views of the city (Fig. 16).

Dr.Juan Gerardo Oliva Salinas (UNAM) described five of his works on existing buildings in Mexico. They are the "Artists Promenade" of the Azteca TV, the "Danzantes" restaurant in Oaxaca, the UNAM University Cultural Centre and the courtyards of the Oaxaca Government Palace and Mexico D.F. "Palacio de Minería". For the Cultural Centre of the UNAM, he designed, together with the Architect M.J.Ontiveros, a textile roof over the square left between two buildings so that it can be used as a forum for performances. It is a translucent membrane anchored in the existing buildings and supported by two central flying masts provided with quasi-transparent polycarbonate skylights on top (Figs. 17 to 19).

Professor R.Sastre (Technical University of Catalunya) on behalf of O.Avellaneda (Monterrey Technical Institute) showed the 90m² Vertex prototype of a retractable pavilion made of 378 articulated straight bars supposedly intended for hosting student events. It has been designed by the research group as part of a PhD (Fig. 20).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J.G.Oliva & M.J.Ontiveros, 2012: Cultural Centre of the UNAM, México.
Figure 17: Plan.
Figure 18: View.
Figure 19: Detail.

W.Runza, from WAGG Arquitectura Textil, de-

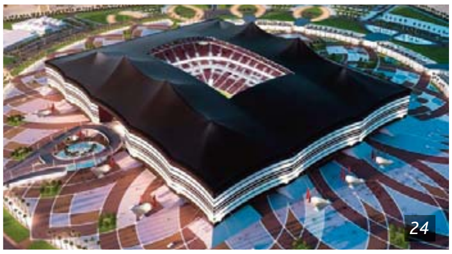

20

Figure 20: O.Avellaneda & J.Talamas, 2017: Vertex pavilion, Monterrey.

scribed the Bus Station of Puerto Madero, Buenos Aires (Fig. 21). It consists of four conoids supported by pairs of central masts finished with skylights. Three inverted conoids are interspersed between them for drainage purposes avoiding flat surfaces and reversing the curvature. Regarding the installation, although the manufacture of the 2.500m^2 was divided into three pieces, they were assembled onsite before lifting in order to hoist everything at once, including masts (Fig. 22). As a result, the 2.000m^2 of the bus station were covered providing visual identity to the project and the place (Fig. 23).
The most astonishing spectacular recent real-

WAGG Arquitectura Textil, 2015: Bus station at Puerto Madero, Buenos Aires.
Figure 21: General view.
Figure 22: Installation.
Figure 23: Interior view.

ization was shown by S.Taberner, from gmp Architekten, Berlin. She began by recalling their general philosophy summarized by simplicity, clear solutions, variety, uniformity, distinctiveness and structural order avoiding monotony. She tried to illustrate some of them with an outstanding example: the 770 millions of euros Al Bayt Stadium in Al Khor City, Qatar (Fig. 24). Its design is based on the Bayt Al Sha'ar, a black and white tent used traditionally by nomadic people in Qatar as a welcome symbol of hospitality for desert travellers. Especially surprising were the dimensions (311x 273m), the change of scale with respect to the original model (Fig. 25), the trussed steel structure above the reinforced concrete (Fig. 26), the retractable roof, the 6 different kinds of membrane (Fig. 27) including the one specially customized, and the services, comprising conventional energy-consumer air conditioning. The perimeter ties along with their anchors, which are not necessary at all, will remain as witnesses of the lack of adequacy of the original model.
A.Paredes from Paredes & Alemán, Architects,



Al Bayt Stadium, Al Khor City, Qatar.
Figure 24: gmp Architekten (optimization):
Figure 25: Bedouin black tent.
Figure 26: trussed steel structure above the reinfor ced concrete.
Figure 27: installation of different kinds of membrane.

Guatemala was concerned with complex geometries and digital design. He illustrated them profusely with diverse experiences and realizations such as the textile formwork to obtain different textures or the sculptural decorations to characterize interior spaces (Fig. 28).
Figure 28: Paredes & Alemán, Architects: Recycled bottles at

"Zona Pradera", Guatemala.

EDUCATION

Professor Jesús Peña, form the Ricardo Palma University, Lima, presented his experience of teaching tensile structures carried out at the University. The academic environment emphasizes the research of tensile structures such as membranes, cables and tensegrities among others in order to encourage innovations based on lightness, which brings a lower energy impact, making a valuable contribution to sustainable development, unlike other conventional building systems. A group of students and teachers including Morflex and Bambulab have been theorizing and systematizing the information of these systems, recently incorporating biomimicry, active bending, and the use of digital manufacturing as a complementary tool to analogical modelling.

C.Huanambal, from the Chiclayo University showed his experiences in teaching and learning with geodesic domes that help to handle new digital techniques achieving constructive and structural efficiency. F.Martínez from the Southern Scientific University showed that geodesic domes can also be designed from other regular polyhedrons besides the icosahedron, which is the usual one (Fig. 29).

Figure 29: F.Martínez Cendra: Regular polyhedral dome.

ROBERTO MACHICAO TRIBUTE

A special tribute was paid to Professor Roberto Machicao Relis (1934, Fig. 30), civil engineer graduated from the National University of Engineering (UNI) and honorary architect by the Private Antenor Orrego University (UPAO). After studying at the IL Institute he became a precursor of teaching lightweight structures in Peru leading the study of innovative structural systems such as textile roofs, tensile structures, hyperbolic paraboloids, laminated wood structures, funicular structures, geodesic domes, spatial structures and wave vaults among many others. During his long career, he has been coordinator and professor of the first Master of Architecture and the Diploma in Design for Tensile Structures. He has been also in charge of the UNI materials testing laboratory.

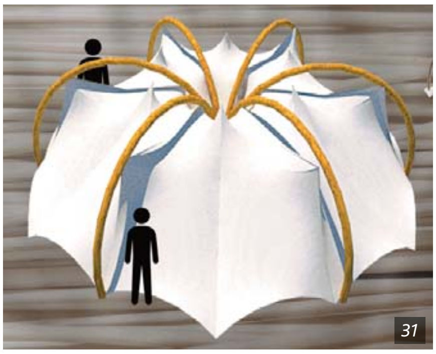
Figure 30: Professor Roberto Machicao Peris

He is currently professor at the Universidad Ricardo Palma (UPRP), and advisor of the company CIDELSA that provides comprehensive solutions for textile architecture and engineering.

Former students in the tribute panel emphasized that Professor Machicao managed to awaken the interest in exploring efficient forms because his knowledge focused on the introduction and understanding of structural criteria. He envisioned the pedagogical future and developed a multidisciplinary methodology unifying mathematics, physics, mechanics and structural morphology from natural methods instilling in the audience a taste for exploration and application of contemporary light structures.

STUDENT COMPETITION

The competition for design projects that make use of textile, cable, or tensegrity structures was open to architecture, engineering, and design students. The jury was made up by Roxana Garrido (Ricardo Palma University, Perú), Carlos Hernández (Central University, Venezuela) and Josep Llorens (Technical University of Catalunya, Spain). They gave the main award to S.Marañón, V.Cáceres and K.Valenzuela (Ricardo Palma University) for the shelter "Khili Wayka" (Fig. 31) and a second prize was awarded to R.Cabanillas, A.Valenzuela and V.Romero (Technical University) for their bamboo modular emergency shelter (Fig. 32).



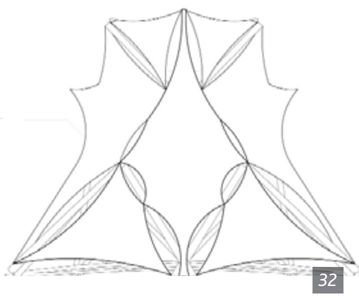


Figure 31: S.Marañón, V.Cáceres and K.Valenzuela, 2018: "Khili Wayka" shelter. Winning entry to the VII SLTE student's contest.

Figure 32: R.Cabanillas, A.Valenzuela and V.Romero, 2018: Bamboo modular emergency shelter, second prize of the VII SLTE student's contest.

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LA TENSORED.

The Latin American Network of Tensile Structures

The Seventh Symposium was also an occasion to meet the members of the Latin American Network of Tensile Structures. They updated the management team and decided to held the VIII Symposium in Buenos Aires in 2020. The participant A.Paredes from the Francisco Marroquín University showed his interest in organizing the IX edition in Guatemala, 2022. More information and the full text of the proceedings are available at: http://www.latensored.org

LEADER HEIDRUN BÖGNER-BALZ SET UP A CODE OF CONDUCT TO IMPROVE QUALITY

Within the TensiNet working group Good Practice a series of Good Practice rules were elaborated. The TensiNet Association wants to ensure, that members committing to the code of conduct offer exclusively products and services on the market which fulfil the quality ordered by the client and which meet the applicable norms, standards and laws. In addition, they agree to take into account the state of the art (technology).

GENERAL ASPECTS

- The specification of the client is fulfilled in all issues.
- Relevant standards, directives and laws are considered. Particularly, legal requirements for employed persons and for workplaces are achieved and considered. Employees and persons commissioned receive at least the mandatory minimum wage. The state of the art is applied.
- Consumption of natural resources and any burdening of the environment has to be considered.
- Offers shall be made according to legal requirements.
- The member shall be ISO 9001 certified or follow comparable standards. The involved party has sufficient capacity (personnel and material) as well as sufficient professional knowledge to manufacture or deliver the ordered services and products in the ordered quality. The party may use appropriate subcontractors.
- Subcontractors shall also follow all formulated rules in here.
- The company shall have an adequate quality assurance system ensuring the quality of the ordered services, the products manufactured and the intermediate products used.
- The company shall ensure the traceability of all products from the place of use back to the origin of the single components. An end of life treatment shall be taken into account.
- Involved Parties in tensile architecture for which individual rules have been formulated in this document are:
  - Raw material suppliers,
  - Membrane material producers,
  - Membrane manufacturers
  - Architects
  - Designers / Engineers

SUBSCRIBE THE TENSINET GOOD PRACTICE CODE OF CONDUCT

TensiNet members who want to subscribe the TensiNet Good Practice Code of Conduct should send an email to info@tensinet.com mentioning:

- Individual party is a Raw material supplier, Membrane Material producer, Membrane Manufacturer, Architect or Designer/ Engineer (select)
- Company name; First name; Last name; email & address
- "We follow the approved standards of good practice rules of TensiNet"
- "We agree to terms of publishing to above information"

Please notice that all **TensiNet members subscribing the TensiNet Good Practice Code** of Conduct will be mentioned in the online **TensiNet Good Practice Code of Conduct List** (see https://tensinet.com/index.php/about/good-practice-database).