TensiNews

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Newsletter of the European based Network for the Design and Realisation of Tensile Structures

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n°43

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TensiNews INFO

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Edito

Dear Reader

I am sure all of you enjoyed to meet again in presence in different events happening this year. Textile Roofs took place in Berlin, as well as the Techtextil fair in Frankfurt, where we held our annual general meeting. Followed up by Contess 2022 in Brixen and the Essener Membranbau Symposium, there will now be soon the Advanced Building Skins Conference in Bern. TensiNet will chair two sessions and will have again a booth. The conference is be rounded up by our TensiNet and Friends meeting at the end of the first conference day. I hope that many of you have the chance to come.

We are now official Partner of the New European Bauhaus, an initiative connecting the European Green Deal to our living spaces and experiences. Our partner, the Politecnico di Milano hosted The Architecture Fest, a side event of the Festival of the New Bauhaus in the TemporActive Pavilion, which was installed first in 2019 for our TensiNet Symposium in Milan. Earlier this year they hosted also the Textile Architecture Week in this pavilion. You find two articles in this TensiNews about the two events.

Just a few weeks ago, the future Technical Specification for membrane structures prCEN/TS 19102 has been submitted to CEN for formal approval. Our working group Specification and Eurocode has contributed to this document in order to make this standard become real. Please vote for it, or encourage the relevant people in your country to do so.

In only a few months we will have our 7th International TensiNet Symposium "Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment", taking place in Nantes beginning of June 2023. You find detailed information in this TensiNews, on our website, and on the conference website. As first teasers you can find here an article of a keynote lecture about pneumatic temporary structures, and an article provided by Jörg Tritthart about the Wrapped Arc de Triomphe, whose film on the progress between summer 2019 and the dismantling in October 2021 will be shown.

Please enjoy this issue of TensiNews and I hope to meet you soon.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

Please verify if events haven't been cancelled, postponed or replaced by a tele-conference due to COVID 19 virus

IFAI EXPO

IFAI EXPO | *12–14/10/2022* | Charlotte, NC 28202 USA | **https://ifaiexpo.com/**

ADVANCED BUILDING SKINS

International Conference on Advanced Building Skins 2022 | *20–21/10/2022* | Bern, Switzerland | **www.abs.green**

textileroofs

Textile Roofs 2023 | *3-5/05/2023* | Berlin, Germany | **www.textile-roofs.com/**

TENSINANTES 2023

TENSINANTES 2023 TensiNet symposium at Nantes Université | *7-9/06/2023* | Nantes, France
https://tensinantes2023.sciencesconf.org/

Advanced Building Skins 2022 Conference and Expo - 20-21/10/2022

TensiNet will be present at Advanced Building Skins 2022 with interesting presentations and a TensiNet booth

SESSION Architectural Membranes for High-performance Building Skins
Chair Marijke Mollaert

- Fabric façades from recycled PET bottles
  Katja Bernert, Mehler Texnologies
- Special grades of ETFE film for unique projects
  Ben Runhaar, AGC Chemicals Europe
- Prediction of rain noise in large halls covered by structural skins
  Monika Rychtarikova, KULeuven
- Transparent ETFE cushion roof - Fridolin Mall, formTL
- Moveable structures as 5th skin
  Christoph Paech, schlaich bergermann partner
- The long way to 1000m³ ETFE-Cloud
  Thomas Toepfer, se cover

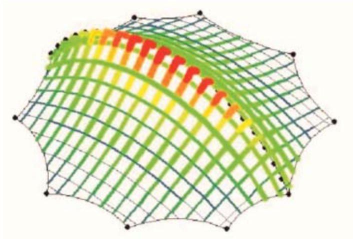
SESSION Building a Sustainable World
Chair Carl Maywald

- Membrane structures and embodied carbon reduction
  Marijke Mollaert, Vrije Universiteit Brussel
- How can teaching influence the understanding of sustainable construction? - Heidrun Bögner-Balz, HFT Stuttgart

SESSION Life Safety and Fire Prevention in Façades
Chair Zomraude Chantal Chalouhi

- Classification of façade structures regarding fire safety
  Carl Maywald, Vector Foiltec
- Non-combustible vertical façade membranes
  Allan Hurdle, Serge Ferrari

Thursday 20th October 2022
18.00 – 19.00 TensiNet & Friends meeting



TEXTILE ROOFS 2022

Textile Roofs 2022, the twenty-fifth International Workshop on the Design and Practical Realisation of Architectural Membranes, took place on 9–11 May 2022 at the Archenhold Observatory, Berlin, and was chaired by Prof. Rosemarie Wagner (Karlsruhe Institute of Technology) and Dr.-Ing. Bernd Stary (Academus GmbH). It was attended by 104 participants from 18 countries covering three continents. Once again, the attendance demonstrated the success of the event, which has become firmly established since it was first held in 1995.

The energy of the early days, how Textile Roofs began...

Dipl.Arch Horst Dürr, ETH Zürich

Horst Dürr, in the first presentation referred to the motivation behind Textile Roofs. He qualified in 1995, the year of Textile Roofs' birth, as belonging to the Frei Otto era, characterized by a new building technique born in 1954 from the collaboration between Frei Otto and Peter Stromeyer. Four relevant works from this period were mentioned: the Music Pavilion, Kassel 1955; the High Tension Test Station, Köln 1962; the convertible roof of the open air theatre in Bad Hersfeld 1968 (Fig. 1) and the German Pavilion at the Expo Montreal 1967. "They arose the credo of textile buildings in Germany". There were major changes in the material development, especially due to the company Verseidag. The need for those buildings was created by some architects, for example AIC, together with engineers like Schlaich & Bergermann, IPL and IF. They made it possible to calculate the stability. Textile manufacturing companies should also be mentioned as Cenotec, Koch, Canobbio and Pfeifer because they developed the manufacturing methods and the necessary details. Installation companies should not be neglected either, and more important, the energy of that time that came from motivation, will, perseverance, interest, curiosity and enthusiasm. In the nineties Lothar Gründig founded TechNet, an engineering office. He was appointed to the Geodesic Institute of the University of Berlin and in 1995 he organized together with Bernd Stary the first public lectures on Textile Roofs bringing together experts from all over the world so that civil engineers, clients, architects and manufacturers met. Different tasks were dealt with such as professional experience, knowledge, factory information, problem solutions, etc. In addition, students worked in small groups while the majority of presentations were on work reports on the buildings of the past year, publicity and research. The client architects were a bit neglected because the engineering aspects prevailed but it's necessary to take into account that buildings have two fathers: the architect and the engineer. At present, times have changed the way and methods that architects and engineers work. Sustainability, climate, and digitalization have emerged, and more and more applications will be found.
In addition, "old makers" are retiring and there is a lack of experience, so the decision of a builder for a textile building is becoming more difficult. It would therefore be advisable to make some changes to Textile Roofs incorporating new people, new working fields and new materials and above all insufflating again motivation, will, perseverance, interest, curiosity and enthusiasm. He ended with a special mention to Bernd Stary and Lothar Gründig.

Figure 1: Convertible roof of the open-air theatre in Bad Hersfeld 1968 (replaced in 2019).

1.DESIGN

Computational modelling

Dipl.Ing Jürgen Holl, technet GmbH

Jürgen Holl went into some important aspects of computing: model generation, form finding, statics, patterning and automation.
A computer model tries to represent the main features of the reality by sufficiently simple geometric and mechanical assumptions including discretization, boundary conditions and topology.
The form finding is the search for a geometry in equilibrium, with ideal force flow, and a favourable distribution of membrane stresses, considering aesthetic and constructional aspects. It should include bending elements if any in order to end up with the desired pre-stress. Static analysis is based on a non-linear system that need approximate values, material properties and external loads.
It achieves a solution with the energy method provided that equilibrium, material law and geometrical compatibility are fulfilled.
Regarding the external wind loads, C_p values and load zones can be obtained through a digital wind tunnel test. In addition, the model integrates the membrane and its structural support to take into account the significant interaction between them. It has been illustrated by a chambered pneumatic structure confined in a ring subjected to bending. Disassembling them, as it is often done, leads to 0,5m of maximum deflection and 30.000kNm of maximum bending moment, while in the hybrid system these values decrease to 0,25m and 18.000kNm respectively. Therefore, separation of nonlinear lightweight systems is an imprecise and expensive estimation. The task of cutting pattern generation is to bring a double-curved pre-stressed surface onto a flat material of limited width to build up the shape modelled in the computer. The patterns are strips as straight and wide as possible with a reduction on size to give rise to the pre-stress when they are assembled. It is also worth checking the corresponding seam lines of the same length, especially in very curved surfaces. Cutting patterning generation can be automated as

well as repetitive cases, especially when a large number of repetitions are involved. It was the case of the Allianz Arena in Munich (Fig. 2) and the Khan Shatyr Entertainment Centre in Astana (cable net with 836 triple-layer ETFE cushions). More information at: www.technet-gmbh.com/en/



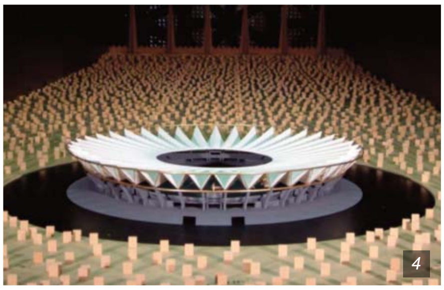



Figure 2: Allianz Arena, Munich: 2.784 pneumatically pre-stressed ETFE cushions.
Figure 3: Membrane viewer "formfinder".
Figure 4: Boundary layer wind tunnel.
Figure 5: A continuous vaulted space with high values of reverberation time, background noise and poor intelligibility. It needs improvement.

Form finding

Dipl.Ing. Dr. techn. Robert Roithmayr

The Robert Roithmayr favourite quote from Frei Otto headed the presentation: "You have to dig deep to fly high". After a general mention to space and architecture on the one hand and structure and engineering on the other, he commented on some key issues of the design of textile roofs such as the sag of cables and surfaces, waterponding, curvatures, wind loading and proportions. The research and book of DEKRA/Dr.Blum were also mentioned to introduce the postgraduate master MEng programme "Lightweight Membrane Structures" held at the Donau University Krems for individuals working in the field of lightweight membrane structures and related fields, ranging from design and architecture, engineering, business administration, manufacturing, installation, textile industry and related sciences. The course includes guiding principles, architecture and engineering, tools for design, materials, details, management, manufacturing, installation and master's thesis. It is supported by "formfinder", the computer assisted design of Lightweight Membrane Structures, and its data bases. More information at: www.donau-uni.ac.at/dbu/membrane and https://www.formfinder.at/ .

He recommended to take Nature as inspiration as "Flectofin", a hinge less flapping mechanism where the elastic deformation of the entire structure replaces the need for local hinges inspired by the bird of paradise flower. More information at: stacks.iop.org/BB/6/045001.

He ended up presenting the "Membrane viewer formfinder" to scan an environment and place an object. It is an augmented reality App utilising 3D content generated via the "membrane.online" platform that supports the communication and collaboration between designers, architects and their customers and clients. He applied it to the rapidly retractable at any time "Bionic Umbrella" unique design for sun and rain protection (Fig. 3).

Wind engineering. Wind loads on fabric roofs

Dipl.Ing. Michael Buselmeier, Wacker Ingenieure

Realistic wind loads including dynamic effects on complex and flexible shapes are not covered in codes like EN 1991-1-4 or ASCE 07-2016. That is why Wacker Ingenieure, founded in 1992 as a spin-off company of the University of Karlsruhe, offers technical-scientific services within the scope of applied building aerodynamics and indoor airflow. It is equipped with wind tunnel laboratory (Fig. 4), model fabrication shop, measurements systems, in-house open-source and commercial codes and high-performance-cluster system for numerical calculations. With these facilities it is possible to investigate special constructions not covered directly within standards and wind load situations extremely case-dependent to which other experiences are not applicable. The list of projects includes stadiums, roofs, façades, bridges, high-rise and public buildings solar projects, towers, airports, hangars, stations and more. The basics of wind tunnel simulation were presented together with some examples of application. The results are transferred to a computational grid and the surface pressure distribution is calculated. Rigid structures avoid dynamic effects, but flexible structures have to take them into account. Wind effects are often the main design parameter for fabric roofs and thus are often dominant for the roof design. Wind tunnel testing is still the most exact and affordable tool to determine design wind loads and subsequent dynamic and statistical computations are essential in order to obtain optimized and safe load distributions for the structural engineer. https://www.wacker-ingenieure.com/

Acoustic performance of textile roofs

Prof. Josep Llorens, School of Architecture, Barcelona

The acoustic behaviour of textile roofs was introduced pointing out that it is very often not satisfactory due to the low mass of the membrane and the geometry of the enclosed space (Fig. 5). Therefore, the basic concepts of acoustics were reviewed including sound, noise, wavelength, frequency, sound pressure, speed of sound, sound focussing, transmission, absorption and reverberation. Regarding the materials, the sound absorption coefficient and noise reduction factor were presented, noting that they can be improved by liners, insulation, double membranes and cavities. The geometry was also mentioned as a primary acoustic factor because it determines the sound paths, reflections and reverberation. Plan and cross sections were observed from these points of view, remarking the role of absorbing and structured surfaces. Examples to illustrate these principles were a successively convex and concave roof and a pneumatic structure. In situ measurements showed that absorption values are usually not appropriate, reverberation time is too long, and disturbing background noise reveals poor soundproofing. A particularly unfavourable case is that of the sport halls due to the large volume and hard non absorbent materials. To deal with such difficulties, it was advised to size the volume and shape the surfaces, choose materials and control the sound paths in order to adjust the reverberation time, increase acoustic insulation and avoid focussed reflections. Some successful examples illustrated this advice. Improvements are also possible providing absorption with double layers with cavity and insulation in between or hanging devices, lining with porous fabrics, reducing or increasing the volume, avoiding loud environments and sound transmissions from outside or using sound barriers. A collection of measured practical examples completed the presentation.

Pneumatic structures: Safeguarding against failure

Dr. Carl Maywald, Vector Foiltec GmbH

Dr. Carl Maywald presentation also began with a sentence, in this case from Werner Sobek (Frei Otto's successor at the ILEK), 2021: "In order to provide the same building standard for all people in the world, the amount of 2·10^12 tons of building materials have to be allocated immediately". It means building with less material for more people (lightweight design), introducing the principle of recycling in the building industry and using solar radiation and saving energy. The illustrations were the Buckminster Fuller's dome over Manhattan 1960, the Home Insurance Building in Chicago 1885 and contemporary buildings. He concentrated on ETFE envelopes, such as the Eden Project, Cornwall 2001, (milestone in material and energy savings), the Khan Shatyr Entertainment Centre, Astana 2010, the Parkview Green Fang Cao Di, Beijing 2009, Gondwanaland at Zoo, Leipzig 2010 (Fig. 6) and The Avenues, Kuwait 2018, covered streets. He was particularly concerned about ponding which can lead to leaking, failures and damage. Several systems were presented to drain cushions such as rigid or flexible tubes and valves. He also referred to snow that slides down slopes and is more difficult to remove. The presentation ended with the "Shed", an art and cultural centre in Manhattan consisting of an eight-storey building with a rolling shell. The rolling shell is an inverted U shaped envelope with 148 fritted air-filled ETFE cushions that moves on rails driven by giant wheels and doubles the usable indoor space of the building making it a multifunctional masterpiece (Fig. 7). https://www.vector-foiltec.com/

Figure 6: Gondwanaland, Leipzig Zoo.
Figure 7: The Shed Center for the Arts, NYC.

2. PROJECTS

The "Olympic Roof" in Munich 1972. How it was done in time

Prof. Dr. Ing. Jos Tomlow

Jos Tomlow told the story of the Munich Olympic stadium roof project, which was not without doubts and discussions. The main concept of the project presented by Behnisch and Partner was a sport park instead of a building. Therefore, the idea of the tent structure experimented in Montreal won out (1967), although there was some initial reluctance. In addition, many of the construction solutions that were adopted for the roof of the Munich Stadium could be drawn from the Montreal pavilion and its re-use to house the IL. J. Joedicke, H. Isler, F. Otto, F. Leonhardt, J. Schlaich and K. Linkwitz among others were involved in the development and discussions, standing out aspects related to form finding and calculation, which relied on simple and meticulous physical modelling and photogrammetry and incipient numerical analysis that had to be debated and tested for the occasion.

The most visible aspects are some of the construction details. The cables of the net are doubled providing resistance and admitting rotation before fixing. They are 75cm apart that makes 1,78nodes /m^2 instead of 4nodes/m^2 in Montreal. The connexions are aluminium press clamps with a flexible rubber net support. The main cables have to be flexible to round a 80cm radius and to adapt to 3D twisted shapes. Three types of foundations were used for tension forces: slot-and-wedge foundations, dead-weight foundations and ground-anchor foundations. But the contribution that has subsequently been used the most is the flying mast to increase the mast number without interfere (Fig. 8). Jos Tomlow devoted the last slides to the Öko-Haus designed by F. Otto and R. Krier in 1969, a visionary eco-house conceived as a bungalow surrounded by a big buffer space covered with a grid shell.

L'Arc de Triomphe, wrapped

Dipl.Ing. Jörg Tritthardt, büro für leichtbau

The special guest session was a long film entitled "L'Arc de Triomphe, Wrapped", a description of the implementation of the temporary artwork for Paris projected by Christo and Jean-Claude and engineered by "büro für leichtbau" and sbp. The Arc de Triomphe was protected and wrapped in 25.000m^2 of recyclable polypropylene fabric and 3.000m of red rope. A pre-assembly was done on a scaffolding structure, which resulted in some changes. An auxiliary steel structure protected the monument and its sculptures before wrapping. Several particularities of the

Figure 8: The flying mast, an invention of Frei Otto and his team.
Figure 9: The wrapping of the l'Arc the Triomphe. Intermediate situation.
Figure 10: Lunar Dome.

manufacturing and handling were explained in detail. It should be noted that there were (unexpected?) intermediate situations that could be considered as artistic (or more?) than the final result (Fig. 9). The wrapping of the "Arc de Triomphe" was on view for 16 days from Saturday, September 18 to Sunday, October 3, 2021. 36 Years before, Christo and Jean-Claude wrapped the "Pont Neuf", also in Paris, with 41.800m^2 of woven polyamide fabric restrained by 13km of rope secured by 12.100kp of steel chains. Wrapping the Pont-Neuf meant it metamorphose into a new sculptural dimension, transformed for 14 days into a work of art. The principal shapes were maintained, the relief and proportions were accentuated. In 1995 it was the turn of the Reichstag with 100.000m^2 of thick woven polypropylene fabric with an aluminum surface and 15,6km of blue polypropylene rope Ø32mm. Unfortunately, Christo Vladimiro Javacheff passed away on 31 May 2020.

Lunar Dome - Tent for the Apollo 11 road show

Dipl.Ing. Bernd Stimpfle, formTL

The year 2019 marked the 50th anniversary of the first moon landing. For this occasion, a road show was planned in several cities throughout the United States of America. For this road show, a large temporary theater tent housing 1.600 seats was designed (Fig. 10). The tent was created as a temporary structure, optimized for quick assembly and easy transport. It consists of a main membrane supported by 4 trussed arches, an elastic projection dome and a large ETFE facade. The main structure is formed by 4 trussed arches. The two slightly inclined centre trusses have a span of 56m, a height of 27m and carry the primary load of the tent structure. The 11m high smaller lateral trusses in the foyer and backstage area are set at a higher inclination. Hanging from these elements is a 4.900m² membrane made of PVC-coated polyester fabric type III. The interior includes a projection dome above a surrounding timber wall. This dome has a diameter of 46m and a height of 15m. It consists of a lightweight PVC-coated polyester fabric with micro-perforations, which absorbs about 65% of the sound. It is suspended from the main arches with elastic cables to allow the prestress to change only slightly if the outer shell is deformed (for example, due to strong wind). Located under the foyer arch is the façade made of ETFE cushions attached to the arch but not receiving loads because elongated holes provide decoupling. The foundation for the arches includes large steel plates with 6x200cm piles designed according to EN 13782 and verified in a pullout test. The planning, production, and assembly were completed in one year. Pasadena, California was the first stop for the travelling theatre for "Apollo 11 - The Immersive Live Show" in the summer of 2019.

Rynek Lazarski - Just the biggest one chamber ETFE foil cushion roof (?). Chances and risks

Dirk P. Emmer, Temme//Obermeier

The rearranged Rynek Łazarski in Poznań has been covered by a circular cushion roof (Fig. 11). It covers an area of 2.400m². A structure like a steel table is formed by an outer ring, an intermediate ring and an inner ring. These rings are connected with an orthogonal grid, supported by columns underneath. Two large cushions are attached to these rings, to form the pneumatic roof. The outer cushion has a constant span of approximately 13.5m, while the inner cushion has a maximum span of 17m, which is reduced to less than 1m at the opposite side. To allow these spans, arrays made of 12mm stainless steel cables form the structural cushion. The inner pressure applies the tension to these cables through the ETFE foil in-between. The lower foil is penetrated by the steel columns. Around these columns the cushion has flying clamping joints. The upper and the lower foil are separate layers. The total volume of the two cushions is 5.150m³. Three blower units provide the cushions with supporting air pressure. The blowers are located on two pavilions under the roof structure. The regular cushion pressure is 300Pa. In case of snow this is increased up to a maximum of 800Pa, controlled by a snow sensor. The single panels have more than 400m² of surface area. To minimise the handling of the panels a suitable confection site has been chosen. Prior to fabrication a mock-up has been installed with different printing to shade the place underneath. After a visit of the mock-up the client chose the print pattern. The printing was applied to the lower foil, so that the rather linear steel structure is not too dominant, seen form below. The installation started with the inner cushion, which allowed to put it under pressure immediately after closing the cushion. Then the outer cushion has been installed starting from the top. This outer cushion forms the biggest one-chamber cushion worldwide today. (B. Stimpfle, TensiNews 42).

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Figure 11: Rynek Lazarski Circular ETFE cushion, Poznan.
Figure 12: Vertical axis wind turbine prototype.
Figure 13: Batumi Stadium.

Un_Minimal Surfaces / Unbalanced Tensions to Maximize Architectural Expression!

Eng. Nelson Fiedler, Fiedler Engenharia Ltda, Brasil

The presentation was a spectacular display of tensile structures brighten up with technical considerations, conceptual hints and personal stories around Nelson Fiedler and his 43 years old firm, after designing around 2.000 projects in South America and Europe (Fig. 12). He ended the presentation by stating that " in Nature shapes are determined by function" and "a structure becomes beautiful when the design of its lines follows the flow of forces", a vindication of funicularity.
https://www.fiedler.eng.br/

Designing tensioned fabric skins for stadiums: a case study of Batumi Stadium

Dr. Fevzi Dansik & Dr. Meltem Sahin, Asma Germe

Asma Germe is a Turkey's tensile architecture contractor that provides solutions with PVC coated polyester, PTFE or silicon coated glass fabric, PTFE and ETFE with more than 1.500 structures designed and built over 25 countries under every climate. Dr. Fevzi Dansik showed several tensioned fabric skins for stadiums and focused on the stadium of Georgia's Black Sea city of Batumi (Fig. 13). It was designed by the Turkish firm Bahadır Kul Architecture according to the the requirements of UEFA category 4 and can hold 20.000 spectators. It was completed in July 2020 with a cost of 117 million Georgian Laris (34,2 million Euros). The steel structure of the roof is based on trusses and cantilevers, but the outstanding feature is the exterior envelope consisting of a series of overlapping panels illuminated at night inspired by the swirling dynamic effect of traditional Caucasus dances.
https://www.asma-germe.com/

3. RESEARCH

Concepts of insulated and adaptive membranes

Dipl. Ing. Stev Bringmann, 3dtex, GmbH

Stev Bringmann introduced his presentation showing some innovative works. For Lonas Lorenzo S.A. in Nuevo León, Mexico, 3dtex developed and realized in 2015 the first ETFE cushion roof in Central America (Fig. 14). The sculptural roof entitled "Cubierta Voronoi" covers the central plaza of the Nativa Shopping Mall in Monterrey. 100 cushions made of white translucent ETFE films cover an area of 1.600m². The project received the "Award of Excellence" from the IAA. For the artist Tomás Saraceno's project, NYC in 2022, a 39m diameter inflated installation with an

accessible metal mesh web to hone the spidery sense in a large-scale exhibition and sensory experience with spider webs was realized (Fig. 15). He then proposed two solutions to improve the thermal performance of membranes. First was multi-layering including insulation materials. Second was the adaptability of lamellae to change light transmission and allow solar heat gain in wintertime combined with summer heat protection with a wide range of transmission grades from 0% to 70%.
https://www.3dtex.de/

Simple numerical methods for the analysis of tensile structures

Prof. Ruy Marcelo de Oliveira Pauletti, Polytechnic School, University of São Paulo

Professor Pauletti started his presentation with some basic concepts of the design of tensile structures. Tensile structures are light taut structures with a very low ecological footprint. They also differ from stiff structures such as a beam because they can change drastically their shape when loading varies and must comply to funicular shapes, following the paths of the loads. He also went into the double curvature, the shape finding, the equilibrium of membranes, the soap film analogy and the consequences for minimal surfaces. He analysed in more detail the geometric nonlinearity and different methods to cope with it including sliding cables, wrinkling models, wind loads, cutting patterns and residual stresses. He closed the first part of his contribution with the natural force density method. He devoted the second part to some practical applications and academic experiments (Fig. 16).

Textile biogas storage systems - Thermal and structural behaviour

Prof. Dr.-Ing. Rosemarie Wagner, Karlsruhe Institute of Technology

Methane gas is produced from agricultural residues and frequently stored in membrane gas holders. To investigate their thermal and structural behaviour, a research project has been launched. Using a test tank, scientists of the Karlsruhe Institute of Technology studied the effects of environmental conditions on hemispheric fabric membrane gas holders (Fig. 17). The test plant was equipped with two pressure-stabilized fabric layers and air blowers were used to simulate various filling levels. Pressure sensors and cameras were applied to observe the behaviour of the holder over the seasons under varying weather conditions such as wind, snow, temperature, atmospheric pressure and sun radiation. There were also operational impacts to be investigated such as

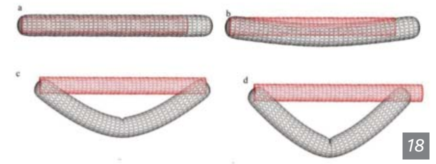


Figure 14: Cubierta Voronoi, Nuevo León.
Figure 15: Tomás Saraceno accessible spider web.
Figure 16: Morro da Urca, Rio de Janeiro.
Figure 17: Hemispheric gas holder.
Figure 18: Behaviour of pneumatic beam under bending.

air and gas pressures, folding of the gas membrane, temperature of the membrane and the possibility of providing large storage volume increasing the ratio height/diameter despite the effect of the wind. It was observed that both in summer and winter the temperature of the outer membrane is well above the environmental temperature. More information is available at: https://www.fnr-server.de/ftp/pdf/berichte/22403315.pdf

Pneumatic beams for structural applications

Ass. Prof. PhD Jean-Christophe Thomas, University of Nantes

After recalling the typology, advantages and limitations of the pneumatic structures formulated by Thomas Herzog in 1976, Jean-Christophe Thomas mentioned the elementary parts of basic air-inflated elements: tubes, cones, toroids, arches and plates. He has developed some analytical methods to study the behaviour of inflatable beams where the prestress comes from the inside pressure and ensure its properties and stiffness. He described their behaviour under bending noting that wrinkles appear well before collapse.
Step 1: with inflation stiffness is achieved. The natural state is considered when the beam is submitted to a very low pressure which balances its own weight and ensures that the section is quasi-circular (in red in figure 18a). At the end of the pressurization process the state is considered initial (in grey in figure 18a).
Step 2: deflected beam. The deflection depends linearly on the load provided that a certain level of loading is not exceeded (Fig. 18b). The longitudinal stresses due to inflation are superimposed with the longitudinal stresses due to bending.
Step 3: a wrinkle appears at the end of the linear phase (Fig. 18c). The principal stress of the beam vanishes.
Step 4: propagation of the wrinkle around the section.
Step 5: the collapse occurs when the wrinkle reaches the middle of the beam section (Fig. 18d). After the detailed description of the behaviour, Professor Thomas went into the beam analytical static and dynamic modelling validated by experiments.

4. PRODUCTS

Flexible photovoltaic - bendable PV modules for (textile) constructions

Dipl.Ing. Lutz Tippmann, Heliatek GmbH

Under the slogan "the future is light", Ing. Lutz Tippman showed the Heliatek flexible photovoltaic modules (Fig. 19) that turn every building into a green electricity generator. They can be adhered or fastened on roofs of any material creating the greenest solar technology, with an ultra-low carbon footprint of less than 10g CO_2e/kWh, free of scarce materials and toxic heavy metals like lead or cadmium. The ready-to-use solar films are applicable on a variety of substrates with no need for supporting structure and no penetrating the existing roof. He also emphasised the ease of assembly by adhesion, but railing, sewing or tying are also possible in cases where there may be problems of adhesion due to the difficulty/impossibility of preparing the installation surface.
https://www.heliatek.com/en/

Plastic fantastic: textile wraps of upcycled PET bottles

Dipl.Ing. Arch. Katja Bernert, Mehler Texnologies

The subtitle of Katja Bernert's presentation "Sustainability matters" summarised the content of her presentation. She focused on

Figure 19: Heliatek modules on show at TR2022.
Figure 20: Al Janoub Stadium, Al Wakrah.
Figure 21: Rosalie Light Sculptures, 2017 at Elbphilharmonie for the "Symphony of a Thousand".
Figure 22: Gas holder on a platform.

the sustainability of recycling and the sustainable application of recycled materials. She alleged that Mehler has been recycling since the beginning. Every year they recycle about 100.000T of PET bottles which correspond to 2.800 billion units that laid end to end would go around the earth 17 times. Recycling is a long-term action that means less waste, (otherwise sent to disposal), saving natural resources, less CO_2 emissions to air (more than 100 million kg per year) and less water consumption (50% less per year). Regarding the sustainable applications of recycled materials, she mentioned the benefits of textile façades such as shading, cooling, eye catching, upgrading, protecting against extreme weather conditions, savings in tons of material, savings in ventilation effort and customising by colour or print. She ended up showing recent projects allegedly sustainable (Fig. 20).
https://www.mehler-texnologies.com/

Lightning design in textile ceilings

Dr.-Ing. Richard Müller, ETTLIN LUX Spinnerei und Weberei Prod. GmbH & Co

A combination of fabric interacting with linear or plane light sources was shown. It creates luminous 3D patterns that can be static or dynamic to create a sense of depth and colour, produce a moving display and react to audio visual signals, creating in either case an optical illusion of more depth. It is basically an aluminium frame with a LED installation on a back plate covered by a silicon sealed textile. Different light effects can be achieved depending on the light source (static, dynamic, including TV screens) and the placement of the textile. Some applications are ceiling installations, modular wall systems, light frames with dynamic effects, striking ring lights, 3D light effect mirrors, large scale ceiling installations, kitchen backsplash and sculptures. It is an easy-to-integrate solution for lighting design projects with functional properties that can also be applied to interior design in wellness areas, hotels, airports, offices, entrance areas and in retail. Several examples were presented (Fig. 21). Other products of ETTLIN are new materials such as laminated wood veneers, 3D effects in mirror glasses, acoustics absorbers and disintegrators of smells and cigarette smoke. A further development consists of a 2m wide integrated textile LED-carrier with single LEDs which are currently integrated manually by one row stitch-weaving during the production process. Project goals are the automated integration of LEDs during the production via feeding mechanism and the intelligent dynamically coloured LEDs that could be used as light source for ETTLIN LUX® products.
https://ettlinlux.com/

Concepts for multimembrane gasholders

Ing. Lorenzo Spedini, ECOMEMBRANE s.r.l.

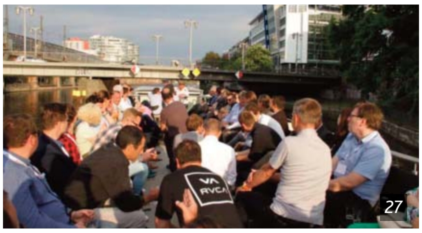
Ing. Lorenzo Spedini showed some of the products of ECOMEMBRANE s.r.l. consisting of gas holders, covers for slurry and clarifier tanks and protective membranes. They designed 2 layer and 3 layer gas holders on ground under constant pressure to store biogas made from anaerobic digestion of organic waste and sludge. They are manufactured with biogas resistant polyester reinforced PVC membranes seam welded by high frequency electronic machines. The welding of the internal membrane is made adding an Eco-Safe layer of pure PVC that stops every porosity of the fibbers to the biogas. They have also gas holders on tanks with domes for industrial, agricultural and municipal plants that can be installed quickly and manufactured with different materials and shapes to suit the needs of the customers. Special high pressure covers can also be manufactured with reinforced membranes and oversized welding. Cones are used to cover pre-tanks and post digestion tanks. They can be designed to cover the slurry tank for odour containment and rainfall protection or even to be gas tight and to serve as gas single membrane. Gas holders can also be cylindrical, prefabricated and placed on a platform with no concrete foundation and no installation cost (Fig. 22). There is also the possibility of building giant gasholders for thousands of cubic meters of gas measuring 50 to 60m in diameter and a capacity of 20.000 to 40.000m^3. A comparison between the spherical and cylindrical shapes reveals that the sphere has the best volume/surface ratio to store more with less surface, it resists equally the wind from any direction and the tension T of the membrane is p·R/2, dependent on the pressure and on half the radius. On the other hand, the tension of the cylinder is double T = p·R, it needs more surface for the same volume and its behaviour under the wind is anisotropic. But it can be built with any length without changing the tension on the membrane and it is easier to cut and weld. Finally, a gasholder for 600.000m^3 was envisaged measuring 400m (length) x 76m (width) x 32m (height), reinforced with cables to discharge the outer membrane.
https://www.ecomembrane.com

Figure 23: The participant's project.

5. PARTICIPANT PROJECT

Janek Jeschke, Stoffdach GmbH

Stoffdach was in charge of the participant's project consisting of a tent structure made of a Soltis 502 membrane with double curvature, designed as an 8-point sail with alternating high and low points and edges bound by polyester webbing submitted to loads according to EN 13782 (Fig. 23). The welding of the seams was completed in the Karsten Daedler premises. The edge belt was sewn on site under pre-tension. Edge belts instead of cables avoid damaging during the installation process. On-site layout included positioning, orientation, adjustment of angles, distances, marks and levelling. The ties were not anchored to the ground with counterweights, but with recoverable screw anchors Ø 50mm, ℓ = 1.260mm.
https://www.stoffdach-construction.de/ and https://www.igelgmbh.de/



Physical and computer modelling, barbecue, cruise and banquet

As traditional at Textile Roofs, the workshop was completed with physical (Fig. 24) and computer modelling (Fig. 25), a barbecue (Fig. 26), the cruise on the Spree (Fig. 27) and the banquet, which brought together more participants than the presentations.

Figure 24: Physical modelling.
Figure 25: Computer modelling.
Figure 26: TR 2022 barbecue.
Figure 27: Spree river cruise.

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TEXTILE ROOFS 2023

The twenty-sixth International Workshop on the Design and Practical Realisation of Architectural Membrane Structures will be held on May 3rd to 5th, 2023. Its format will be similar to that of TR 2022, with seminar-style lectures, hands-on activities, barbecue, river cruise and banquet. The main objectives of the workshop are to provide fundamental information, as well as presenting the state-of-the-art in textile roof engineering and getting together. More information at: http://www.textile-roofs.de.

Bouncing Bridge

Paris, France

AZC Atelier (Atelier Zündel Cristea, architecture office founded in 2001 in Paris) and Ramon Sastre are invited to give a joined keynote lecture on pneumatic temporary structures at TENSINANTES 2023, the TensiNet Symposium at Nantes Université (7-9.06.2023). One of their amazing projects is the Bouncing Bridge. This project won an international competition "Contemporary Bridges in Paris", organised by ArchTriumph (London) in 2012, with a bridge across the River Seine.

The project consisted of three tubular pneumatic 3D rings, 30m diameter, with a trampoline in their interior. Each ring was a double symmetrical 3D ring with two lower points touching the water and the other two high points, at the middle, of the ring (Fig. 1). Once the architects won the competition, they had the possibility to build variants of this project around the world, so they started to look for a firm who could build the project. Finally, they decided to order the project to a Catalan firm, near the French border, "T&P Construcció Tèxti s.c.p." whose CEO was Ton Miserachs, an industrial man (industrialist?) who through the years had become a friend of mine. As soon as he received the commission, he asked me to develop the technical project. In fact, the technical project was a hard challenge because:

1. It was a floating structure, which means a lot of nautical knowledge that was beyond my field of expertise. (I mentioned that if it was going to be built in a river, I wasn't able to produce a project with the necessary resistance to the water current forces);
2. It was about a tubular pneumatic structure, which meant a design and construction challenge.

We started with the floating design. First of all, we changed the contact of the ring with the water. We sacrificed the double symmetry in order to gain stability. The ring passed from a double symmetry to a single symmetry, creating a piece of tube straight instead of the lower points, allowing to maintain better stability. The higher points stayed.


4a


4b


4c


5a


5b


5c

Figure 1. Bouncing Bridge over the Seine
Figure 2. Movable pavilion 'Pavelló de fira' by T&P, 2006
Figure 3. Analysis of a pneumatic beam, T&P, Cornellà de Terri, 2007
Figure 4a/c. Prototype with 3m diameter, 2013 © Ramon Sastre
Figure 5a>f. Prototype with 10m diameter, 2013 © Ramon Sastre
Figure 6. Peace Pavilion, AZC, London, 2013


5d


5e


5f

Once we made these changes to improve floating, we had to front the second challenge: the construction of the tube. In fact, it was something that affected directly to T&P. We had already made some projects with tubes (Fig. 2) and carried out some tests with tubes (Fig. 3).

We had to decide which internal pressure to apply and how to design tubes patterns in order to facilitate the task of constructing those tubes. At the same time, in this preliminary phase, AZC and T&P decided to make two different models or prototypes: the first one very small (3m diameter) (Fig.4) and the second one middle size (10m diameter) (Fig. 5). So, we started with the first one. It served, among others, to see how connect the trampoline membrane to the tube, how to build the tube and to check different interior pressures.

This small prototype can be seen nowadays at the Centre Pompidou (https://www.centrepompidou.fr/en/ressources/oeuvre/SagehIr) under the name "Prototype de bouée". It was decided to create a pattern with multiple rings to create de tube. These rings could not be too wide to allow the curvature without wrinkles. Importing the axe of the tube and creating the pneumatic tube afterwards was the natural way for us to design. In this project internal pressure was very high and at the first idea was to increase it until the structure explode, but finally we stopped at a pressure of 0,1MPa.

But when we had to develop the second prototype with 10m diameter, we decided to develop our software WinTess in order to create automatically any type of tube (its geometry and its patterning). It took time but it is valid for any future project with tubes.

Another temporary intervention designed by AZC and realised by T&P is the Peace Pavilion for the Museum Gardens in London (Fig. 6).

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6

Name of the project:	Bouncing Bridge
Location address:	Paris (originally)
Client (investor):	Competition
Function of building:	Bridge or playful object
Type of application of the membrane:	Pneumatic
Year of construction:	2013
Architects:	AZC, Paris
Multi-disciplinary engineering:	Ramon Sastre
Structural engineers:	Ramon Sastre
Consulting engineer for the membrane:	Ramon Sastre
Engineering of the controlling mechanism:	T&P and Ramon Sastre
Main contractor:	T&P
Contractor for the membrane (Tensile membrane contractor):	T&P
Supplier of the membrane material:	Serge Ferrari
Manufacture and installation:	T&P Construcció Tèxtil s.c.p.
Material:	Fluotop-T2-1302
Covered surface (roofed area):	Tubular ring of 3 and 10m diameter

Digital Modelling Analysis and Fabrication of Deployable Structures for Kinetic Architecture

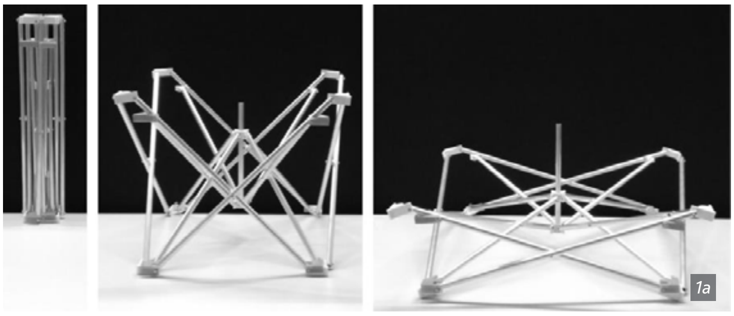
As a result of the human mobility needs and the progressive technological advances over time, varied deployable structures utilising scissors and sliding mechanisms have evolved for transformable and transportable functionalities. In recent decades, this topic has piqued the interest of professionals within several fields - the Arts, Industrial Design, Architecture and Engineering - leading to an extensive database of publications in journals, conference proceedings, books, and patents. Gaps between theory and practice can sometimes restrict prospective applications due to structural complexities compromising the material capacities during installation, service, or dismantling.

In 2016 the Colombian Administrative Department of Science, Technology, and Innovation COLCIENCIAS (forgivable educative loan for supporting doctoral studies abroad: Call No 728 of 2015) funded a PhD research project to develop alternative solutions for stabilising the angular distortions of quadrangular expandable grids, controlling the deflection limits, and enhancing the structural behaviour of large-span constructions requiring transitory processes, with a rapid installation or a frequent relocation.

The research was carried out by Daniel Enrique Gómez Lizcano at the University of Nottingham under the supervision of Dr. Paolo Beccarelli, Dr. Davide De Focatiis and Prof. John Chilton. The work employed the latest digital modelling tools to evaluate complex projects from the early design phases, collecting real-time data from parametric environments, movement simulations, and simplified structural predictions. In addition, physical to-scale models have been created by additive manufacturing and standard portable tools, granting rapid testing. A holistic and reciprocal approach was adopted to obtain an overall spatial evaluation, validity, and reliability. The study identified eight cases to study the viability of achieving structural strength, stability, and rigidity through diagonal stress-free mechanisms, rectifying the primary instabilities during the size and shape transitions.

The results have been validated through a hypothetical transportable tent used to compare the stabilisation of diagonal scissors and triangulations by passive cables. Tensioned locking devices aim to control the deflection limits of span/250, according to Eurocode, at the deployed position associated to weather loads.

The research resulted in the successful development of a complete design process for mobile architectural applications which maintain a degree of freedom. After discussing the efficiency of the setting-up procedures, the suggested active-cables outline demonstrated superior structural performance under each loading scenario, preventing time-consuming tasks required by manual locking and facilitating the components adjustment from the ground level. Transformable umbrellas may adopt the proposed structural analysis methodology; however, researchers should correlate detailed engineering studies and full-scale testing to validate practical results.



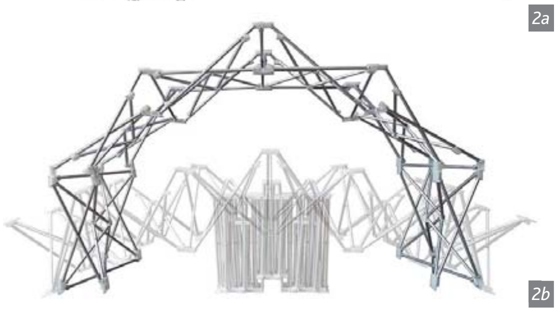


Figure 1a. Manufactured sample of a stress-free trapezoidal cross-section prism with double diagonalisation.
Figure 1b. Manufactured sample of a stress-free trapezoidal cross-section prism with a single diagonalisation and the membrane attached.
Figure 2a. A deployable single curvature tent from case study 1, 3 and 4.
Figure 2b. Scale model of a deployable single curvature tent from case study 1, 3 and 4.
Figure 2c. Scale model of a simplified case study 4
Figure 3. Experimental scale model load deflections: (a) symmetric, (b) asymmetric.

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LANTERNA CLOUDS
An inflatable pavilion for the Trento Aperta seasonal activities

Trento, Italy

Trento Aperta is a summer festival organized by the municipality of Trento (Italy) with touristic events focused on food, cinema, arts, sport, music, theatre, nature and literature.
The Lanterna Clouds Pavilions 2021 is an example of how membrane structures are a potential answer to challenging requirements which include a distinctive architectural appeal, reduced installation time and costs, optimized weight of the components, reduced packaging volumes and environmental impact of the structure (Fig. 1).
A set of five pneumatic shelter were designed to host some of the activities organized in summer 2021 in the city of Trento.

The design concept

The design concept has been developed by Monica Armani in collaboration with Maco Technology and the University of Nottingham. The pavilion is based on a timber floor slab designed to support the external circular timber walls and the rigid aluminium frame of the pneumatic membrane roof. The overall project includes a total of five pneumatic roofs, one installed as a single pavilion, and four grouped in pairs on a double timber floor slab (Fig. 2). The pavilions are arranged in Cesare Battisti square and provide protection from the weather.

Timber structure

A 120mm thick timber loadbearing deck is used to obtain a stable basement for the pavilion providing a robust anchoring point for the superstructure and contributing to the ballast required to balance the uplift forces associated with the wind loads. The overall dimensions of the basement are 16mx8m for a double timber floor slab and 8mx8m for of a single circular pavilion. The vertical walls are made of prefabricated timber panels made of a rigid solid timber frame cladded with a thin layer of timber easy to bend.

Pneumatic membrane roof

The horizontal membrane roof of the pavilion is made of a double-layer pneumatic mattress with twenty-four vertical webs arranged in a radial direction to reduce the thickness of the pneumatic cushion and to provide the housing of the loadbearing aluminium frame.
The membrane roof is designed for a maximum wind load of +0.171 kN/m2 (uplift) and -0.089 kN/m^2 (downward) and requires a loadbearing aluminium frame to transfer the applied load to the timber basement. The aluminium structure is made of one central tubular column (Ø 400mm, 2mm thick), twelve radial tubular beams (Ø 60mm, 5mm thick) and twelve vertical tubular columns (25mm, 2mm thick) integrated into the timber vertical panels.

The inflatable mattress is made of PVC-coated polyester fabrics with an opaque silver coating (upper layer) and a clear PVC foil reinforced with a polyester mesh (lower layer and vertical webs) and includes radial pockets for the installation of the aluminium structure. The inflated geometry of the mattress provides the required slope for the water drainage towards the central column of the pavilion (Figs. 2-4).

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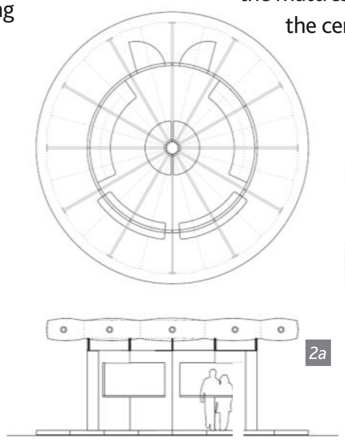
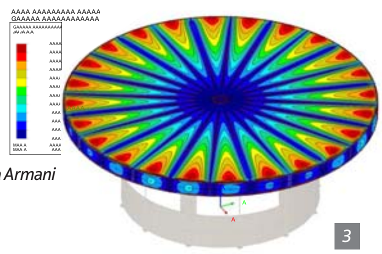
1


2a


2b


3


4

Figure 1. Detail of the installation procedure © Paolo Beccarelli
Figure 2a. Plan view and elevation of a single pavilion © Monica Armani
Figure 2b. 3D view of a double timber floor slab with two pneumatic roofs © Monica Armani
Figure 3. Detail of the FEM structural computer simulations © Maco Technology
Figure 4. Detail of the integrated aluminium tubular column © Paolo Beccarelli
Figure 5. The Cesare Battisti Square with the pavilions installed © Paolo Beccarelli


5

Name of the project:	Lanterna Clouds
Location address:	Trento
Client:	Comune di Trento
Function of the building:	Exhibition Pavilion
Type of application of the membrane:	Temporary
Year of construction:	2021
Design, project development and management:	Monica Armani Architects
Engineering and membrane roof:	Maco Technology srl
Material:	Serge Ferrari Précontraint 502, Giovanardi Vinitex 9x9
Covered Surface:	250m^2

Christo and Jeanne-Claude "L'Arc de Triomphe, Wrapped" Backstage - engineering for a work of art

Paris, France

Start of the realization phase of the project began in September 2019 with the design and construction of a large-scale mock-up. The Installation of the project "L'Arc de Triomphe, Wrapped" was scheduled for September 2020. Based on this mock-up, Christo decided the colour of the fabric (type of blue) and the number and diameter of the red ropes (Fig. 2).

Büro für leichtbau (bfl) developed the tensioning system for the fabric in the vaults and designed the configuration of the steel pipes for the tensioning of the vault and façade panels at the front edge of the vaults. A vault tensioning test was made in Lübeck at "geo die Luftwerker" to check that the fabric is really horizontal tensioned for the 23m free span (Fig. 3).

Based on the hullgeometry of Christos drawings, the position of linear steel pipes is defined. Sbp developed and analysed the support structure for these pipes and their anchoring on the Arc as well as the 4 steel cages on the main façades. Then bfl analysed the stress in the fabric, the red ropes and the textile shackles for the fixing at the supporting structure behind the fabric based on the wind tunnel test report of Wacker Ingenieure. The fabric details were tested in the Lab of DEKRA, Stuttgart. Special brackets and clamps were designed and produced for the testing. Bfl developed the folding and cutting patterns for the fabric as well as the fixings of the fabric on the roof and the façade. They used the same anchoring system on the base as on Christo's "Wrapped Reichstag" project adapted to the special situation with the stone bench. They managed the flow of material, which were needed for the manufacturing.

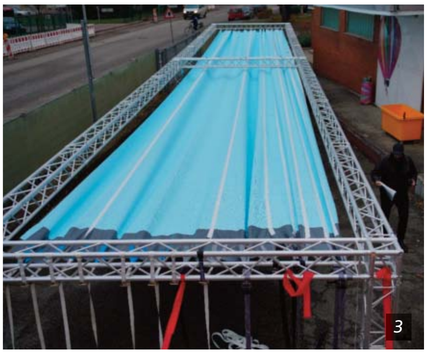
Bfl made all the tests for the elongation parameters of the fabric inhouse and for the red ropes in a factory of Arnegger GmbH. They clarified with Christo the final position of the vertical and tensioned horizontal red ropes based on the geometry of the cages. A 1:3 corner mock-up was built in Berlin at Gerüstbau Tisch GmbH to check the details at the corner with the type of patterning based on a 1:20 mock-up built in the bfl office in Radolfzell (Fig. 4).

At the end of April 2020 Christo decided cause of the Covid situation to shift the installation to September 2021.In May 2021 Christo passed away. Bfl supervised the folding and rolling process and preparing the fabric for the installation at "geo die Luftwerker" near Lübeck. An installation test with unrolling of the fabric were made with the Installation company JADE in the industrial climber trainings areal in Dunkerque (Fig. 5). Bfl introduced JADE in the installation process based on the experience of the "Wrapped Reichstag" project.

The project L'Arc de Triomphe, Wrapped, was only on view for 16 days from September 18th to October 3rd 2021. 800.000 samples of the fabric (7cmx7cm) were made to be given away. With a bit of luck, you might be one of the happy owners!

2a

2b



3

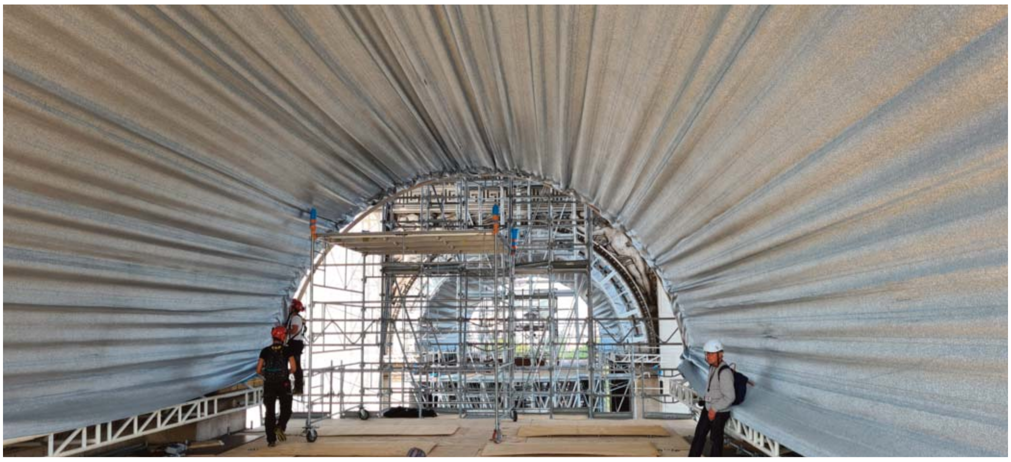
4a

4b

5a

5b

Figure 1. The Arc de Triomphe wrapped in 25.000m² of recyclable polypropylene silvery blue fabric with 3.000m of red ropes.
Figure 2a/b. First large scale mock-up.
Figure 3. Vault tensioning test for 23m free span at geo die Luftwerker.
Figure 4a. Patterning the fabric. 1:20 corner mock-up built at bfl office.
Figure 4b. 1:3 mock-up at Gerüstbau Tisch GmbH.
Figure 5a/b. Installation test with the unrolling of the fabric.



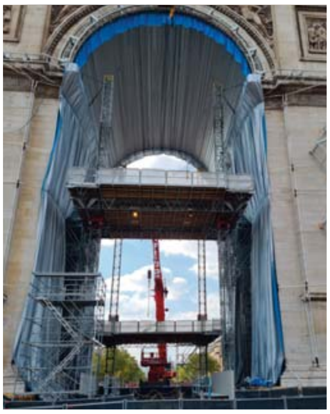


Figure 6. After the numerous tests and the realisation of mock-ups, the Arc de Triomphe is wrapped!

Name of the project:	L'Arc de Triomphe, Wrapped"
Location address:	Paris, Place Charles de Gaulle
Year of realisation:	2021
Client (investor):	CVJ CORPORATION, 48 Howard Street, New York, NY 10013 (Christo Vladimir Javachev)
Cost:	14. Mio. Euro financed by CVJ CORPORATION by selling original paintings as merchandizing and sponsoring is not accepted (base of the freedom of the artists for their work).
Artist:	Christo and Jeanne-Claude (www.christojeanneclaude.net) and nephew Vladimir Yavachev
Multi-disciplinary engineering:	Consulting engineer for the fabric, rope, tensioning system, ballast, project and material management for all textile parts, testing of elongation of fabric and ropes and consulting for installation of fabric and ropes: büro für leichtbau, Jörg Tritthardt (www.bfl-tr.com)
Consulting engineer for steel support structure:	sbp, Anne Burgharz (www.sbp.de)
Windtunneltests:	Wacker Ingenieure, Alexandra Richter (www.wacker-ingenieure.de)
Firetestinglab:	Prüfinstitut Hoch
Fabric details testing for tensile strength:	Dekra
Textile rope, textile shackles, splices and further details testing for tensile strength:	Gleistein; Trenčín (www.gleistein.com)
Supplier for wooden construction, installer (with 50 workers) for wooden and steel construction, workshop drawings for wood and steel:	Les Charpentiers des Paris, Sebastien Roger, Paul-Lin Debate (www. les-charpentiers-de-paris.fr)
Supplier of steel structure:	Canametal (www.canametal.fr)
Supplier of steel ballast:	ArcelorMittal
Installation of tensioned steel cables below Grande Corniche:	Freyssinet, Thibaut Hilly, (www.freyssinet.com)
Installation unrolling fabric outer façade and installation of red ropes (with 95 industrial climbers):	JADE, Francoise-Yves Jolibois (www.reseau-jade.com)
Recycling of fabric:	yarn producer Saxa Syntape (www.saxa-syntape.de); Head of Parley (www.parley.tv)
Recycling of red rope:	Atmos
Covered surface:	25.000m²

FACTS AND FIGURES ON THE MATERIAL	
Yarn for weaving:	Saxa Syntape GmbH
Woven fabric of blue (pantone 3005C) and grey polypropylene (fire retardant B1); width 1,62m:	Setex Textil GmbH
Aluminium for metallisation of the fabric, coated with thin aluminium layer via thermal evaporation:	Rowo-Coating
Fabric panels:	40 pieces made of 432 strips
Sewing seams:	104km; sewed with 440km thread by Gütermann GmbH
Red polypropylene rope with diameter of 36mm; 3km red rope:	Gleistein and Trenčín
Oher ropes, cords and strings:	12,8km by Gleistein and Trenčín
Red rope crossing clamps: 263 pieces holded back with textile dyneema shackles:	Gleistein and Trenčín
88 thimbles for horizontal 36mm ropes:	Friedrich Höppe GmbH
Ratchet Belts:	2616 pieces by Dolezych
Woven belts:	5,2km by Güth&Wolf
Woven loop webbing:	6,7km by Bowmer Bond Narrow Fabrics Ltd
Fabric reinforcements:	969m² PVC-coated Polyester fabric, Type 5 by Verseidag and Serge Ferrari

Dipl.-Ing. Jörg Tritthardt
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At TENSINANTES 2023 the film on the progress of L'Arc de Triomph between summer 2019 and the dismantling in October 2021 will be shown.

Report of the CEN/TC 250/ Working Group 5, MEMBRANE STRUCTURES

End of May the Technical Specifications prCEN/TS19102 Design of tensioned membrane structures were reviewed by the different national Mirror Groups. During several online meetings, the comments provided by the Mirror Groups, were discussed and the document was improved. During the WG5 meeting of the 28th of July, consensus was reached.
The secretary launched the Committee Internal Balloting (CIB). Till the 30th of September the new version of prCEN/TS19102 is circulating within CEN/TC 250, seeking feedback and approval to proceed to Formal Vote.
Via CIB the following questions are asked:
- Do you agree that the draft may proceed to Formal Vote?
- Are there any major technical concerns with the draft that could lead you to vote negatively?
- Are there any matters that you would like Working Group 5 to consider, should they decide to convert the CEN Technical Specification text to EN status?

In the meantime, countries are still invited to submit their comments.
WG5 hopes to receive constructive comments, and a positive outcome from the CIB, so that membrane structures will become a fully-fledged member of the Eurocode suite.

Figure 1. Banner of TS19102 © European Union, 2021

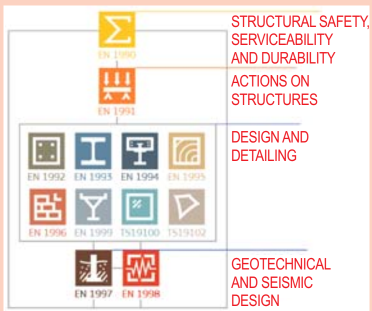
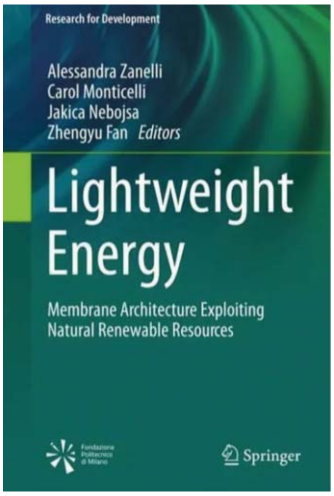


Figure 2. TS19102 as one of the Eurocodes of Design and detailing © European Union, 2021

Marijke Mollaert
Convenor of CEN/TC 250/ WG5

BOOK REVIEW

Enhancing lightness through Membrane architecture



Lightweight Energy
Membrane Architecture Exploiting Natural Renewable Resources

Edited by: Alessandra Zanelli, Carol Monticelli, Nebojsa Jakica, Zhengyu Fan
Publisher: Springer Cham – Research for Development
ISBN: 978-3-031-08153-8
Price: 166,39€
Reviewed by: Maria Giovanna Di Bitonto Politecnico di Milano
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Lightweight Energy aims to be a novel starting point for designers, manufacturers and researchers. It introduces an innovative approach for the development of sustainable construction, in the key of lightness, referring to the energy demand, the weight of the construction itself and also the environmental one. In a scenario of huge challenge, deriving from the climate emergency, but also of resources crisis, the adoption of sustainability strategies still represents a trigger point. This book addresses the environmental issues through a new prospective in architecture, which is the exploration of membranes potentialities, in the dual concept of light-weight and light-energetic buildings.

Membrane structures are generally known for their capacity of diffusing light, derived from the thin and flexible layers, also able to carry tension, reversing the relation between carried loads and self-weight. Moreover, membrane architectures are usually associated with pavilions or temporary buildings. This book means to amplify the view of the reader, providing new field of application and functions, that those thin layers can embody. Membrane architecture does not yet have a room on the market that would deserve, given the advances in the field for longevity and high performance of textiles, in respect to traditional constructions. This is probably due to the lack of shared knowledge on how to make those structures energy efficient, this represents the challenge that the authors are addressing.

Lightweight Energy provides a set of strategies customized for designing with thin and reactive layers in several climate conditions, to guarantee a comfortable indoor environment, renovating the scenario of the building sector, and, at the same time, ensuring the preservation of the context.

The book is organized in two parts. The first one provides a theoretical and methodological framework on how to take advantage of renewable resources as sun, wind and water, through membrane architecture design; and also it indicates the life cycle of the structure. In this phase the authors developed a climate-based design technology exploration and life cycle thinking strategies investigation, presenting some case studies. The second part, deepen the concept exposed, showing four applied researches, which have seen the authors involved in the recent years; the first two deals with the Photovoltaic technology applied in membrane architecture, the third explores the potentiality of membrane architecture to be water self-sufficient, embedding fog and dew harvesting. The last one explores the energy efficiency and energy storage of a membrane pavilion.

These emblematic cases of light-weight and light-energetic architecture can encourage, architecture- engineering firms and manufacturers, to embrace this challenge, and promote membrane architectures as valuable alternative to the traditional massive structure, but, more importantly, to enhance its potentiality. Moreover, some suggestions for improvement can also be deduced for transforming the conventional constructions in a lighter way: lighter appearance, lighter form for a lighter eco-efficiency.

The book collects the contributions of:
Alessandra Zanelli – Politecnico di Milano, Architecture, Built Environment & Construction Engineering Department, Italy
Carol Monticelli – Politecnico di Milano, Architecture, Built Environment & Construction Engineering Department, Italy
Nebojsa Jakica - University of Southern Denmark, Civil and Architectural Engineering, Department of Technology and Innovation, Denmark
Zhengyu Fan - Xi'an University of Architecture and Technology, China
Carlotta Mazzola - Politecnico di Milano, Architecture, Built Environment & Construction Engineering Department, Italy
Maria Giovanna Di Bitonto - Politecnico di Milano, Architecture, Built Environment & Construction Engineering Department, Italy
Qinxiang Li - Politecnico di Milano, Architecture, Built Environment & Construction Engineering Department, Italy

A critical overview for the use of fiber reinforced polymer in Construction Textile Architecture Week

Lightweight or sustainable versus lightweight and sustainable

Politecnico di Milano, TemporActive Pavilion, Milan, Italy

The Politecnico di Milano, ABC Department's Lab Unit TAN-Textile Architecture Network, hosted the Textile Architecture Week TAW, which ran from March 14 to March 18. TAN Doctoral candidates, post-docs, and researchers organized it. The program included a few workshops and educational seminars where the study topics were state-of-the-art in membrane architecture and lightweight construction. Five multidisciplinary didactic sessions were used to organize the tasks.

1. DESIGN OPTIMIZATION, coordinated by: Milan Dragoljevic, Ph.D. Candidate - Politecnico di Milano, which hosted the presentations of Bernd Stimpfle and Rémi Journo, formTL, Sebastiano Granetto, Arch. Director – Simplex, Gianluca Rodonò, Angelo Monteleone, Vincenzo Sapienza – University of Catania.

2. SUSTAINABILITY (Re-up) coordinated by: Carol Monticelli - Politecnico di Milano, hosting Tatiana D'Angelo, TAN Intern - University of Milano Bicocca, Samika Sadik Visiting Ph.D. Candidate - University of Helsinki, Elena Ferrero, Atelier Riforma, Alessio Colombo, Rice House.

3. CLEAN ENERGY coordinated by Giulia Procaccini, Ph.D. Candidate - Politecnico di Milano, with the following guests: Qingxiang Li, Ph.D. Candidate - Politecnico di Milano, Carlo Vannelli, Canobbio Textile Engineering, Nuno Dinis Cortiços, University of Lisbon, Giovanni Ciampi, University "Vanvitelli" Caserta, Italy.

4. WATER MANAGEMENT, coordinated by Maria G. Di Bitonto, Ph.D. Candidate - Politecnico di Milano, hosting Michelle Rodriguez, TAN Intern - Politecnico di Milano, Manfredo Guilizzoni, Politecnico di Milano, Roberta Caruana, Politecnico di Milano, Ricardo Gil, Nieblagua S.L., Mirnes Imamovic, Essedea, Alara Kutlu, Politecnico di Milano.

and the last session

5. STRUCTURE EFFICIENCY, coordinated by the author, had as guests Alberto Fiorenzi, i-Mesh, Rebeca Duque Estrada, ICD, Maria Anishenko, Politecnico di Milano, Farzaneh Oghazian, Penn State University.

Figure 1 a/b. Educational seminars and workshops during TAW

The focus of the present article mostly takes into account the fifth day of this week, which is dedicated to the use of fiber-reinforced polymer (FRP) as a novel and new material in the construction industry. Two case studies were built with fiber-reinforced polymer and displayed at two important architectural exhibitions: the Biennale di Venezia, which hosted the Maison Fibre, and EXPO DUBAI 2020, which hosted I-MESH Canopies, were represented on this day by invited guests. It is no secret that the use of fiber-reinforced polymer in the construction industry results in a significant reduction in the weight of load-bearing elements, which can normally weigh more than half as much as the other systems involved. On the other hand, the new European Green Deal states that in ten years, we must reduce CO2 emissions by 55%, which means changing the technology we use to produce materials, build buildings, operate buildings, and demolish them. Now is the time to ask ourselves if these new and lightweight materials (FRPs) are compatible with the new regulations or not. Investigating the current state-of-the-art shows that although these materials have been used in different industries for years, they are totally new in the construction sector. The presented case studies utilize continuous glass/carbon fiber plus thermoset matrix and glass fiber with thermoplastic matrix, respectively.

Nowadays, the thermosetting continuous FRP, which is considerably more prevalent than thermoplastic, can be recycled by thermal, chemical, and mechanical processes. One of these processes generally results in a loss of mechanical properties because the continuous FRP is shred (Mechanical Recycling).

Typically, these techniques are used to recover more valuable carbon fibers. The disposal and burning of FRP will no longer be permitted due to the new regulation (European green deal). In the opinion of the author, considering the new regulations and growing use of FRP in the building industry, now is the time to think about the circularity and end-of-life of these materials to maximize their benefits in the next decades.

The shared experiences in-between the researchers, the companies and the design and engineering societies within the TAW highlighted as always the integration of competencies and knowledges are necessary: from one side the presented researches demonstrated high potentials and innovation inputs to aim to a sustainable design of membranes and composite solutions, and on the other hand the companies highlighted the possible criticalities that match the environmental needs and the market rules. The need is in general avoiding the simple "green washing" and aiming to real changes in the design process and the environmental sensibility, balanced with the economic rules

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Textile Architecture Fest

The Festival of the New European Bauhaus

TAF

Politecnico di Milano, TemporActive Pavilion, Milan, Italy

Held on June 9th and 10th, 2022 at the TemporActive Pavilion, the Textile Architecture Fest (TAF) took place as a side event of The Festival of the New European Bauhaus by the coordination of Prof. Carol Monticelli, with the aim to enhance the state-of-art and the most recent advances in membrane architecture.

New European Bauhaus beautiful | sustainable | together

TEXTILESHUB POLITECNICO MILANO 1863

Figure 1. The TemporActive Pavilion during the Festival of the New European Bauhaus.

The main goal established by the New European Bauhaus (NEB) is to combine science and technology with art and culture by bringing together individuals from all areas of life to build connections, exchange ideas, and explore science, art, design, politics, architecture, and technology. Therefore, the TAF was conceived as a set of citizen participatory research workshops and dissemination of videos.

Under these criteria, it is also worth mentioning that the space where the TAF was held, TemporActive Pavilion, was installed for the second lifespan of 4 months in the PoliMi Leonardo Campus to host events, such as the Textile Architecture Week and the Textile Architecture Fest, as well as research studies and measurements. The pavilion is a temporary open space of 100m² designed in the framework of the Ph.D. Arch. Carlotta Mazzola and Prof. Alessandra Zanelli as project manager, with the economic support of TensiNet Association (Belgium), and the technical support of form-TL (Germany) for the structural analysis and Canobbio Textile Engineering (Italy) for the membrane manufacturing and installation. It was installed for the first time in June 2019 for one week lifespan as the main entrance of the International TensiNet Symposium "Softening the Habitats"; the structure is composed of a transparent foil membrane supported by GFRP bending-active arches, developed to demonstrate the fast assemblage potential of the ultra-light¬weight building system.

The consolidation of public engagement through the initiative was envisaged in order to strengthen both the academic visibility of DABC and the enhancement of doctoral activities through the activation of national and international networks. The proposed research topics are innovative concerning the state of the art of membrane architecture and lightweight constructions; therefore, the workshops were organized through 3 multi-disciplinary didactic sessions:

W1. Form finding of minimal surfaces - MINIMAL NATURAL SOAP FILMS
W2. Programmable textiles for 4D printing - BIOMIMETIC TEXTILE SHAPES
W3. Dew and fog harvesting meshes - CATCHING WATER FROM THE AIR

Figure 2a/c. Workshops organised at the TemporActive pavilion

Form finding of minimal surfaces

A soap bubble is naturally spherical. However, dipping a wire frame in a solution of soap and water can produce different geometrical shapes. The variety of shapes produced, which are usually not spherical and eventually different than what is expected by the observer, is due to the ability of soap bubbles to obtain the smallest surface area possible. By obeying the laws of nature, a soap film contorts itself to reduce its potential energy, which also means minimizing its surface area.

Architect Frei Otto, who was highly specialized in lightweight tensile and membrane constructions, conducted one of the first examples of soap bubble surface testing. Otto's architectural forms arose from the concept of form finding, which was informed by a series of soap bubble experiments. During this workshop, experiments of Frei Otto were replicated by Arch. Alara Kutlu under the supervision of Prof. Alessandra Zanelli to place the written rules of physics in real life and demonstrates nature's form finding ability. To carry out the experiments, different forms of wireframes were dipped into the soap solution. While being subject to some limitations, which were wireframes, the surface of soap bubbles consistently reduced the total surface area as expected. For each configuration of the wireframe, the soap film clinging from the edges of the wire created a unique solution.

Programmable textiles for 4D printing

Thanks to the development of digital fabrication and computer-aided architectural design, complex shapes can be printed by utilizing 3D printers. After modeling and slicing the 3D object, the 3D printer will print layer after layer (additive manufacturing). The deposition of material on the print bed will generate the designed shape. But, what if the material was deposited on a pre-tensioned knitted textile rather than a print bed?

Some materials can self-assemble, meaning their shape can automatically change to reach the equilibrium of stability. This can also be called "4D printing." This workshop aimed to investigate how pre-tension knitted textiles could change their shape after the deposition of different shapes of PLA. The process was started by putting the knitted textile under the maximum possible tension and attaching it to the printer bed. Different closed geometrical shapes with small thicknesses were designed by students driven by Arch. Amirhossein Ahmadnia under the supervision of Prof. Carol Monticelli. The surrounding area contracted after PLA fusion and printing the designed shape on the knitted textile, and the knitted textile quickly tried to change its shape to achieve stability.

Dew and fog harvesting meshes

Fog harvesting technology provides an additional supply of water in places where fog levels are naturally high. The concept is based on the existence of horizontal rain, which occurs when enough moisture in the atmosphere collides with a surface, accumulating drops that eventually precipitate into the ground. Like plants, fog catchers are designed so that when the cloud mass passes through them, drops are caught by the textile mesh that is part of the structure. The collected water can be used for agriculture and/or domestic purposes.
The workshop focused on demonstrating, through laboratory equipment, how fog harvesting technology works as well as the behavior of different commercial meshes, both 2D and 3D, against the phenomenon of fog. During the workshop, observations and characteristics of the meshes were shared based on parameters related to the opening geometry, opening scale, filament shape, filament dimension, and filament orientation, obtained during test campaigns carried out both in field and laboratory by PhD. candidate Maria Giovanna di Bitonto and Arch. Nathaly Michelle Rodríguez under the supervision of Professor Alessandra Zanelli.

The meshes samples used were supplied by the European companies Arrigoni SPA (Italy), Serge Ferrari (France), Nieblagua S.L (Spain), Müller Textil (Germany), and Aqualonis (Germany).

Authors: Nathaly Michelle, Rodríguez Torres -fellow- and Alara Kutlu -MSc. student-; Textiles Hub, ABC Department, Politecnico di Milano, Milan, Italy.

TENSINANTES 2023

TENSINET SYMPOSIUM 2023

at Nantes Université

Membrane architecture: the seventh established building material.

Designing reliable and sustainable structures for the urban environment

Wednesday 7th till Friday 9th June 2023

The TENSINANTES 2023 symposium is in full preparation. The review process of the more than 50 abstracts is ongoing and for now, the keynote speakers Dominique Perrault Architecture, AZC Atelier together with Ramon Sastre (see contribution on page 10-11) and Karsten Moritz (Taiyo) have confirmed their interest. The event will take place on the wooded campus of the Faculty of Science and Technology of Nantes Université located in the north of the city of Nantes, next to the Erdre, one of the most beautiful rivers in France. The campus is easily accessible by public transport, car, motorbike, tram, bicycle and, of course, on foot. As during the TensiNet 2019 symposium, a temporary pavilion for this event will be established, in accordance with the specialties of the local team.
There is the opportunity to be a sponsor of the TensiNet 2023 symposium. There are 4 categories with corresponding benefits:

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February 1st, 2023

Revised paper submission
March 1st, 2023

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