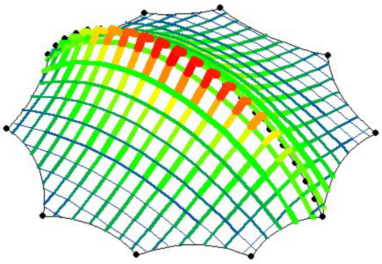


Textile Roofs 2022

May 9th - 11th, 2022

Prof. Rosemarie Wagner, KIT

Dr.-Ing. Bernd Stary, academus GmbH

Archenhold Observatory, Berlin

Report. **Prof.Dr.-Architect Josep Llorens.**
School of Architecture - Technical University of Catalunya (UPC). Barcelona, Spain
ignasi.llorens@upc.edu

Introduction

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.

AMMA architectural membrane association — DAEDLER KONFEKTION VON PLANENSTOFFEN UND FOLIEN — formfinder — MEHLER TEXNOLOGIES — Teufelberger · Redaelli — STOFFDAC — TECHNET — TensiNet — Heliatek The future is light — büro für leichtbau — KIT

The energy of the early days, how Textile Roofs began... - Horst Dürr, Dipl.Arch ETH Zürich

Horst Dürr in the first presentation referred to the motivation behind Textile Roofs.

1995: Frei Otto era.

He qualified 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 (figures 1 to 4).



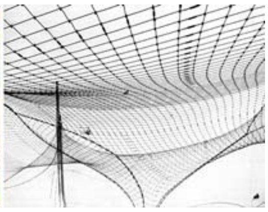



Fig.01: Music Pavilion, Kassel 1955. Fig.02: High Tension Test Station, Köln 1962. Fig.03: Convertible roof of the open air theatre in Bad Hersfeld 1968 (replaced in 2019). Fig.04: German Pavilion Expo Montreal 1967. "They arose the credo of textile buildings in Germany".

There were major changes in the material development, specially 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. For their part 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.

From 1995 up to 2022

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 and it's necessary to take into account that buildings have two fathers: the architect and the engineer.

The future

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.

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 0,5 m of maximum deflection and 30.000 kNm of maximum bending moment, while in the hybrid system these values decrease to 0,25 m and 18.000 kNm 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.



Fig.05: Allianz Arena, Munich. Fig.06, 07: Khan Shatyr Entertainment Centre, Astana

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 (2.784 pneumatically pre-stressed cushions made of ETFE foil, figure 05) and the Khan Shatyr Entertainment Centre in Astana (cable net with 836 triple-layer ETFE cushions, figures 06, 07).

More information at: https://www.technet-gmbh.com/en/

Form finding - DI. 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/*

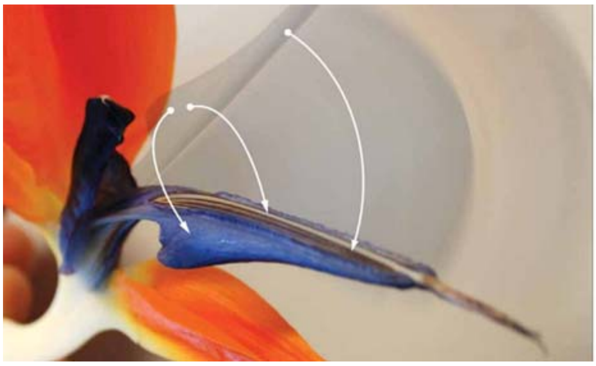


Fig.8: Bird Paradise Flower

Fig.9: Thematic Pavilion EXPO 2012, Yeosu

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 (figures 08,09). More information at: *stacks.iop.org/BB/6/045001*.

Fig.10, 11: Membrane Viewer formfinder applied to the Bionic Umbrella

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 (figures 10, 11).

Wind engineering. Wind loads on fabric roofs - M.Buselmeier.

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.

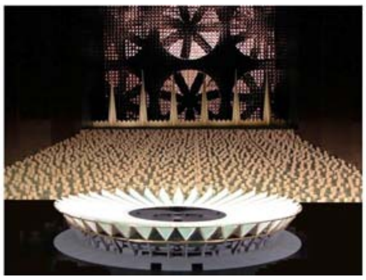




Fig.12, 13: boundary layer wind tunnels *Fig.14: model fabrication*

It is equipped with wind tunnel laboratory (figures 12,13), model fabrication shop (figure 14), measurements systems, in-house open-source and commercial codes and high-performance-cluster system for numerical calculations. With this 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 include stadiums, roofs, façades, bridges, high-rise and public buildings solar projects, towers, airports, hangars, stations and more (https://www.wacker-ingenieure.com/)

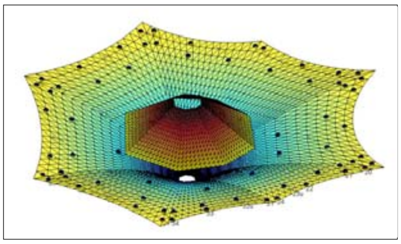
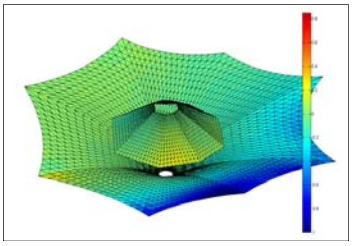




Fig.15: wind tunnel model of an umbrella with integrated pressure taps. Fig.16: computational grid with indication of measurement points. Fig.17: calculated Cp distribution.

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 (figures 15, 16, 17). Rigid structures avoid dynamic effects but flexible structures have to take them into account.

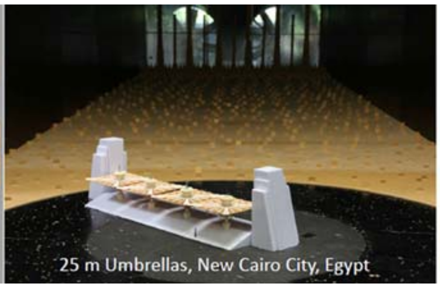


Fig.18, 19, 20: Selection of current projects

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.

Acoustic performance of textile roofs - Prof. J.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. 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 this principles were a successively convex and concave roof (figure 21) and a pneumatic structure (figure 22).

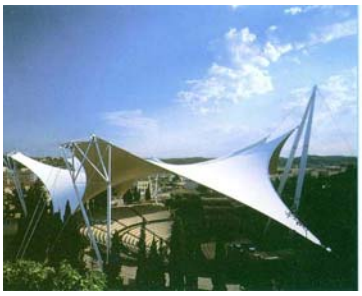
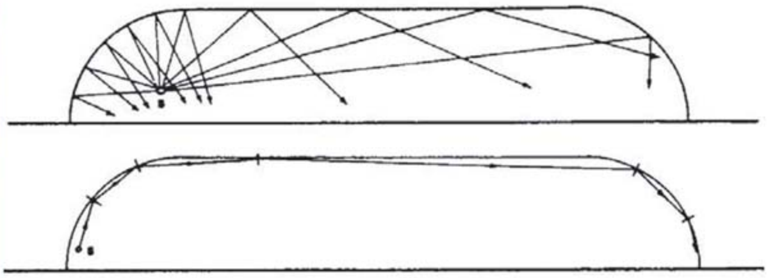



Fig.21: due to successive convex and concave surfaces the sound is alternatively focussed or diffused. Fig.22 (top): the reflected rays concentrate in the ends. Fig.23 (bottom): the sound is enhanced at long distances.

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.

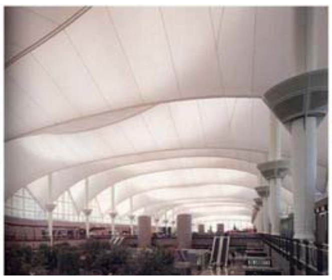




Fig.24: Pier 6 Pavilion, Baltimore. Fig.25: Denver Airport. Fig.26: Suvarnabhumi Airport

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 (figures 24 to 26).

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.

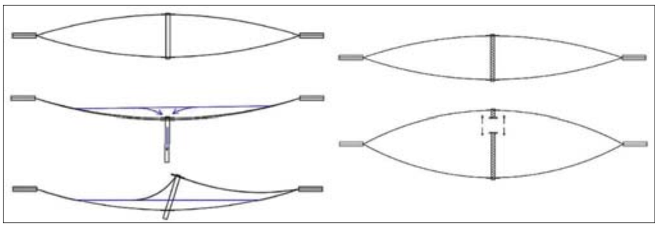
Pneumatic structures: Safeguarding against failure - Dr.Carl Maywald - Vector Foiltec GmbH. https://www.vector-foiltec.com/

Dr.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 $2 \cdot 10^{12}$ 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.

Fig. 27: Gondwanaland, Leipzig Zoo, 2010.

Fig.28: The Avenues, Kuwait 2018

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 (figure 27) and The Avenues, Kuwait 2018, covered streets (figure 28).



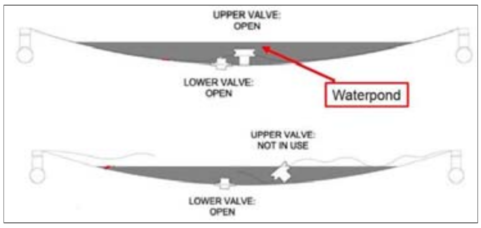
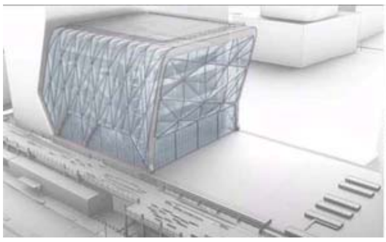
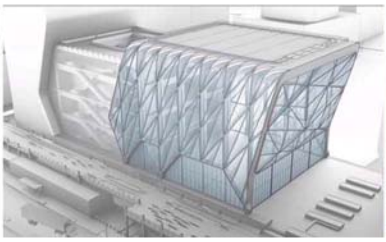


Fig.29: drainage by rigid and flexible tubes. Fig.30: failure of air supply and rainfall (top), upper foil damaged and rainfall (bottom)

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 (figures 29, 30). He also referred to snow that slides down slopes and is more difficult to remove.





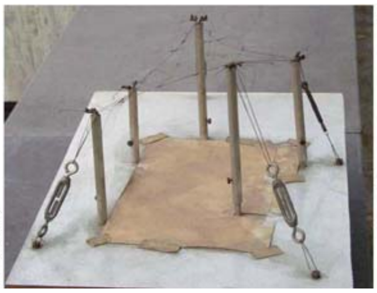
Figs.31, 32, 33: Diller Scofidio & Renfro, 2019: The Shed Cultural Centre, New York.

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.

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 (figure 34).

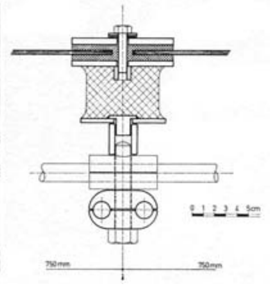


Fig.34: the "eye-loop" was invented to avoid force concentration in the net. Fig.35: small wire model. Fig.36: one of the 137.000 cable net intersection points. Fig.37: panel joint and net supporting point.

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 (figure 35) 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 75 cm apart that makes 1,78 nodes /m^2 instead of 4 nodes/m^2 in Montreal. The connexions are aluminium press clamps (figure 36) with a flexible rubber net support (figure 37). The main cables have to be flexible to round a 80 cm radius and to adapt to 3D twisted shapes (figure 38). Three types of foundations were used for tension forces: slot-and-wedge foundations, dead-weight foundations (figure 39) 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 (figure 40).



Fig 38: Ten bundles of 55 strands for the main edge cable. Fig.39: Heavy weight foundation for a lightweight structure.Fig.40: Flying mast, an invention of Frei Otto and his team.

Jos Tomlow devoted the last slides to the Öko-Haus designed by Frei Otto and Rob 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.

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.



Fig.41: Scaffolding mock-up.   Fig. 42: Protection of the monument.   Fig. 43: Manufacturing.

The Arc de Triomphe was protected and wrapped in 25.000 m^2 of recyclable polypropylene fabric and 3.000 m of red rope. A pre-assembly was done on a scaffolding structure (figure 41), which resulted in some changes. An auxiliary steel structure (figure 42) protected the monument and its sculptures before wrapping. Several particularities of the manufacturing and handling were explained in detail (figure 43).

Figs.44 to 47: Intermediate situations during the wrapping and unwrapping.

It should be noted that there were (unexpected?) intermediate situations that could be considered as artistic (or more?) than the final result. The wrapping of the "Arc de Triomphe" was on view for 16 days from Saturday, September 18 to Sunday, October 3, 2021.

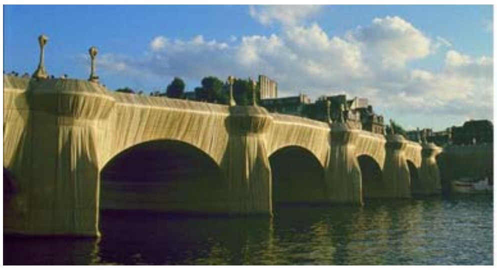


Fig.48: Pont Neuf wrapped, Paris 1985. Fig.49: The Reichstag wrapped, Berlin 1995. Fig.50: The "Arch de Triomphe" wrapped, Paris 2021. (https://christojeanneclaude.net/artworks)

36 Years before, Christo and Jean-Claude wrapped the "Pont Neuf", also in Paris, with 41.800 m^2 of woven polyamide fabric restrained by 13 km of rope secured by 12.100 kp of steel chains (figure 48). Wrapping the Pont-Neuf meant its 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 100,000 m^2 of thick woven polypropylene fabric with an aluminum surface and 15,6 kilometers of blue polypropylene rope Ø32 mm (figure 49).

Unfortunately, Christo Vladimiro Javacheff passed away on 31 May 2020.

Lunar Dome - Tent for the Apollo 11 road show. Dipl.-Ing. Bernd Stimpfle.

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.

Producer	Matthew Churchill Production Ltd. and Nick Grace Management Ltd.
Architectural Design	Teresa Hoskyns and Matthew Churchill
Membrane Structural Engineering and Workshop Drawings	formTL ingenieure für tragwerk und leichtbau GmbH Radolfzell, Germany. www.form-tl.de
Membrane contractor	Canobbio Textile Engineering www.canobbio.com
Supplier	Serge Ferrari - Verseidag Indutex GmbH

The tent was created as a temporary structure, optimized for quick assembly and easy transport. It consists of a main membrane supported by four 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 56 m, a height of 27 m and carry the primary load of the tent structure. The 11 m high smaller lateral trusses in the foyer and backstage area are set at a higher inclination. Hanging from these elements is a 4.900 m² membrane made of PVC-coated polyester fabric type III (figure 51).

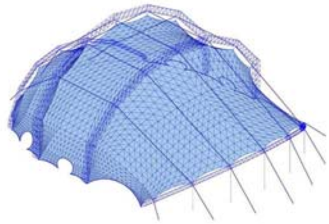
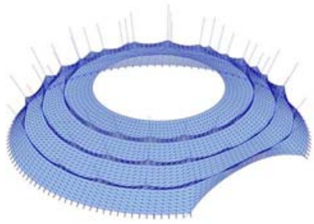
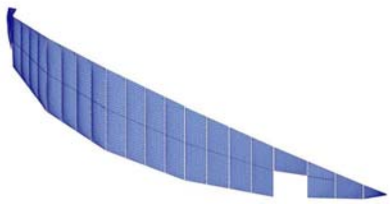




Fig.51: Main membrane. Fig.52: Projection dome. Fig.53: ETFE cushions (foyer façane)

The interior includes a projection dome above a surrounding timber wall (figure 52). This dome has a diameter of 46 m and a height of 15 m. 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 pre stress 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 (figure 53).



Fig.54: base plate. *Fig.55: Installation.* *Fig.56: Final result.*

The foundation for the arches includes large steel plates with 6 x 200 cm 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 (figures 57, 58). It covers an area of 2.400m^2. 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.


Fig.57: General view of the cushion. Fig.58: Plan view

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 12 mm 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 5.150m^3. 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 300 Pa. In case of snow this is increased up to a maximum of 800 Pa, controlled by a snow sensor.


Fig.59: Installation. Fig.60: Rain during installation.

The single panels have more than 400 m^2 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 (figures 59, 60). This outer cushion forms the biggest one-chamber cushion worldwide today. (B.Stimpfle, TensiNews 42).

More information at: https://www.to-experts.com/en/

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 2.000 around projects in South America and Europe.

Figs.61, 62: Formula 1 Interlagos Pavilion 1

Figs.63,64,65,66: Formula 1 Interlagos Pavilion 2. Lack of accessibility and space forced to assemble the modules outside and install them with cranes.

Figs.67,68: Wide span mega halls: life span over 40 years, low maintenance, lighter and cheaper than conventional halls, with natural day lighting.

Figs.69, 70, 71, 72: Vertical-axis wind turbine prototypes from the research and development project carried out by CPFL, V/LEAF and Fiedler.

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.

More information at: 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 (https://www.asma-germe.com/).


Figs.73, 74: Batumi Stadium, Georgia

Dr. Fevzi Dansik showed several tensioned fabric skins for stadiums and focused on the stadium of Georgia's Black Sea city of Batumi. 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).


Figs.75, 76: Batumi Stadium dynamic façade

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.

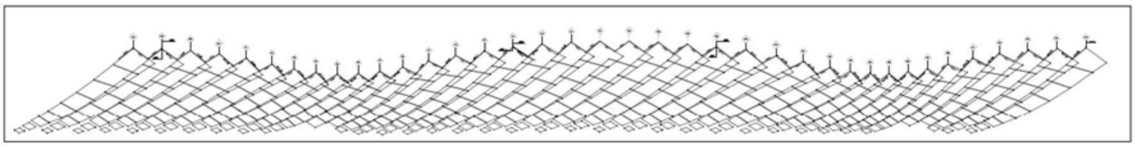


Fig.77: façade development

Basic data: Fabric surface area 19.282 m^2; polycarbonate roof surface 1.615 m^2; roof steel 2.380 T; façade fabric surface area 15.209 m^2; façade steel 570 T. Dead load: 0,01 kN/m^2; prestress: 4 kN/m in warp direction and 3 kN/m in weft direction; base snow load: 3 kN/m^2; non uniform snow load 1,6 kN/m^2 up to 4,8 kN/m^2; sag condition checked for 0,5 kN/m^2 snow uniform load.

3 Research

Concepts of insulated and adaptive membranes. Dipl.-Ing.Stev Bringmann, 3dtex, GmbH. *https://www.3dtex.de/*

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 (figure 78). 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 1,600 m^2. The project received the "Award of Excellence" from the IAA.




Fig.78: Cubierta Voronoi. Fig.79: Fencing piste. Fig.80: Oxígeno Shopping Centre. Fig.81: Tomás Sarraceno accessible spider web.

Temporary inflatable roof for a fencing piste, Olympic Games in Rio de Janeiro 2016 (figure 79). Two intersecting 30 m pneumatic arches consisting of Ø1,5 m tubes are the load bearing structure for a 200 m^2 transparent ETFE foil.

In the "Oxígeno" Shopping Centre, Heredia, Costa Rica, 2018; the technology of large rope-supported ETFE cushions was developed (figure 80). A circular area Ø 45 m was transparently roofed. A classic roofing with glass on a steel structure would not only have been significantly more cost-intensive, but would also not have been able to be designed with such a light appearance. The 1.600 m^2 ETFE cushion is reinforced by a steel cable 1,2 m x 1,2 m net, which collects the forces, structures the cushion and makes the spatial form tangible. It remains safe even in the event of failure of several redundant blowers because special rainwater emergency valves were developed.

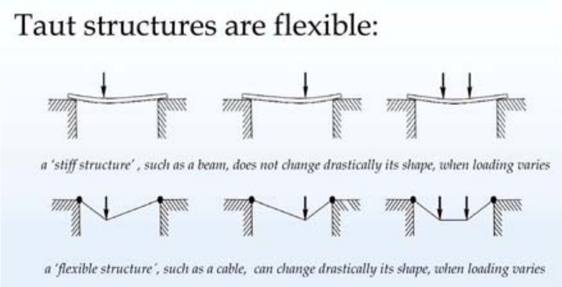
Tomás Saraceno, NYC, 2022: 39 m diameter inflated installation with an accessible metal mesh web to hone the spidery sense in a large-scale exhibition and sensory experience with spider webs (figure 81).


Fig.82: Treehouse Hotel. Fig.83: Adaptive membrane

He then proposed two solutions to improve the thermal performance of membranes. First was multi-layering including insulation materials (figure 82). Second was the adaptability using lamellae to change light transmission, allow solar heat gain in winter time combined with summer heat protection (figure 83). A wide range of transmission grades from 0% to 70% is possible.

Simple numerical methods for the analisis of tensile structures. Ruy Marcelo de Oliveira Pauletti, Polytechnic School, University of Sâo 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 (figure 84) and must comply to funicular shapes, following the paths of the loads (figure 85).



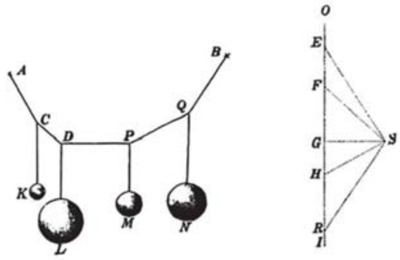


Fig.84: stiff and flexible structures. Fig.85: Funicular polygon (P.Varignon, 1725).

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.

Fig.86: Goiânia Open Market, 2006. Fig.87: Feira da Cidade de Ananindeua, 2006. Fig.88: CENPES II, Rio de Janeiro, 2010. Fig.89: Morro da Urca, Rio de Janeiro, 2014.

He devoted the second part to some practical applications and academic experiments (figures 86 to 89).

Textile biogas storage systems - Thermal and structural behaviour.

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

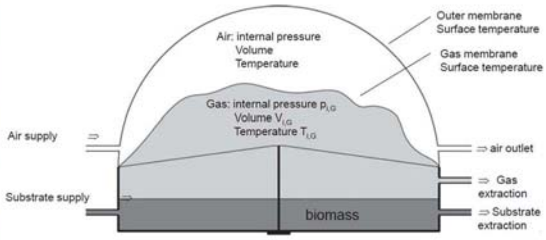
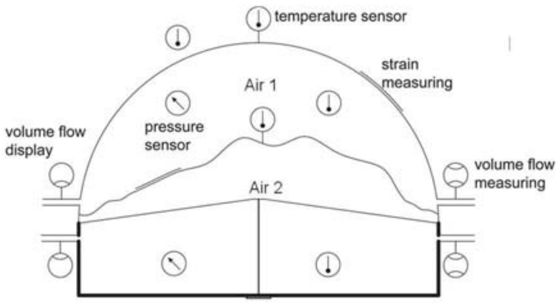


Fig.90: Test tank. *Fig.91: Scheme of the system*

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 (figures 90, 91).



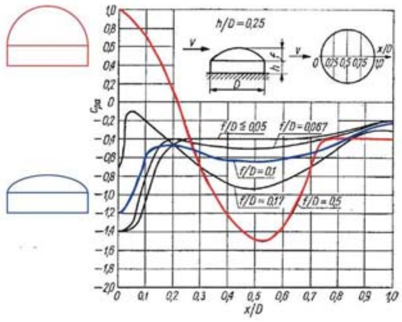
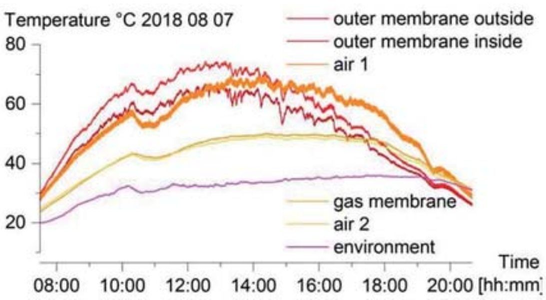


Fig.92: Measurement devices. Fig.93: The wind load acting on the surface is related to the height of the spherical segment as only suction (in blue) or pressure and suction (in red).

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 (figure 92) such as wind, snow, temperature, atmospheric pressure and sun radiation. There were also operational impacts to be investigated such as 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 (figure 93).



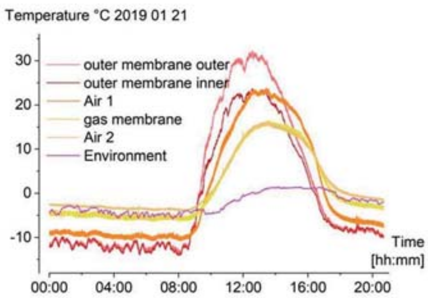


Fig.94: temperatures measured on 07/08/18 and fig.95 on 21/01/19

It was observed that both in summer (figure 94) and winter (figure 95) 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 pre-stress comes from the inside pressure and ensure its properties and stiffness. He described their behaviour under bending noting that wrinkles appear well before collapse.



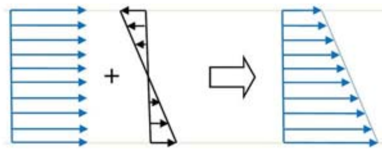


Fig.96: natural and initial states. Fig.97: deflected beam. Fig.98: Longitudinal stresses of the deflected beam.

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 96). At the end of the pressurization process the state is considered initial (in grey in figure 96).
Step 2: deflected beam. The deflection depends linearly on the load provided that a certain level of loading is not exceeded (figure 97and green dot of figure 103). The longitudinal stresses due to inflation are superimposed with the longitudinal stresses due to bending (figure 98).

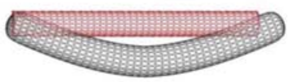
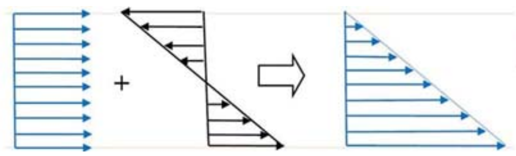
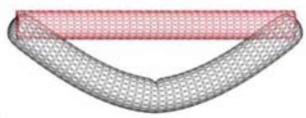
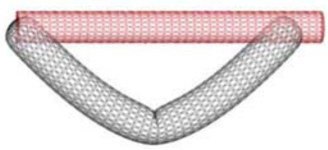
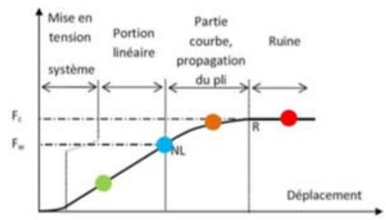




Fig.99: a wrinkle appears. Fig.100: the principal stress vanishes. Fig.101: propagation of the wrinkle.

Step 3: a wrinkle appears at the end of the linear phase (figure 99 and blue dot of figure 103). The principal stress of the beam vanishes (figure 100)
Step 4: propagation of the wrinkle around the section (figure 101 and orange dot of figure 103).

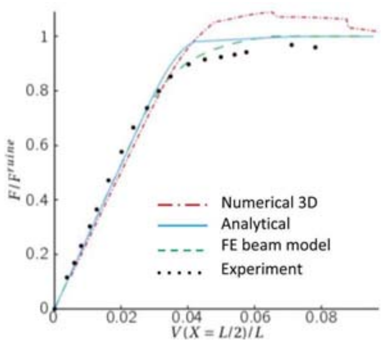


Fig.102: collapse. Fig.103: sates of the inflated beam. Fig.104: experimental validation.

Step 5: the collapse occurs when the wrinkle reaches the middle of the beam section (figure 102 and red dot of figure 103).

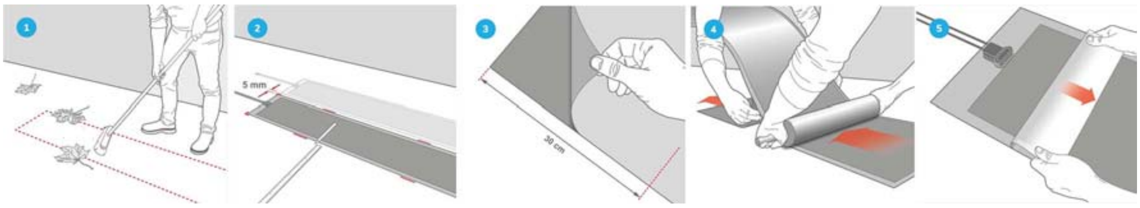
After the detailed description of the behaviour, Professor Thomas went into the beam analytical static and dynamic modelling validated by experiments (figure 104).

4 Products

Flexible photovoltaic - bendable PV modules for (textile) constructions.
Dipl.-Ing.Lutz Tippmann, Heliatek GmbH.

Fig.105: Heliatek modules on show at TR 2022. Fig.106: Paranet air dome. Fig.107: Roland Garros Tennis Court.

Under the slogan "the future is light", Ing.Lutz Tippman showed the Heliatek flexible photovoltaic modules (figure 105) that turn every building into a green electricity generator. They can be adhered or fastened on roofs of any material (figure 106) 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 (figure 107).



Figs.108 to 112: installation of the solar film by adhesion: 1 Prepare the installation surface. 2 Position the solar film on the installation surface. 3 Remove the backside adhesive protection liner. 4 Fix the solar film with a roller. 5 Remove the front protection liner

Figs.113: riveted rail. Fig.114: keder rail. Fig.115: sewed. Fig.116: tyied.

He also emphasised the ease of assembly by adhesion (figures 108 to 112), but railing, sewing or tying (figures 113 to 116) are also possible in cases where there may be problems of adhesion due to the difficulty/impossibility of preparing the installation surface. More information at: https://www.heliatek.com/en/

Energy: flexible lightweight photovoltaic. Mr.Shemesh Yaniv, Keshatot CEO. https://www.lumiweave.com/

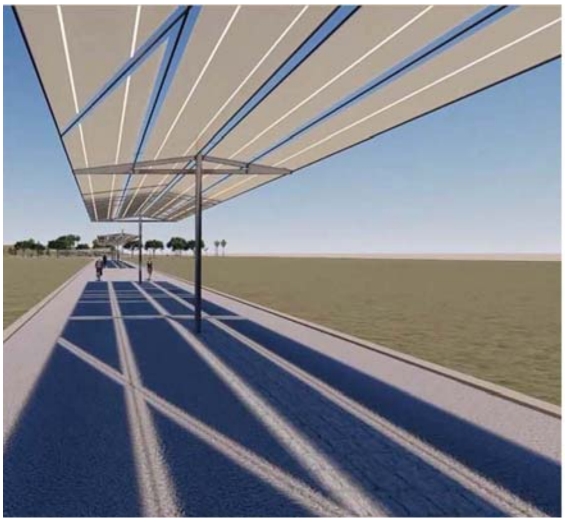


Figure 117: daytime shading.

Fig.118: night time illumination

Mr.Yaniv presented the Lumiweave sheet, an embedded solar-power harvesting and illuminating fabric, completely green, unplugged (off-grid), standalone, flexible and lightweight. It provides daytime shading (figure 117) and night time illumination (figure 118) while eliminating both, fossil-fuel emissions and light pollution and saving on heavy duty construction costs.

Figs.119, 120: install anywhere with safety, flexibility and sustainability.

He insisted on the main features of the system: off-grid (no connection to the electrical general infrastructure), shadowing, energy harvesting, controlled auto-illumination, customization, zero emissions and durability (figures 119,120).

Figs.121: daytime shading.

Fig.122: night time illumination

As an application, Lumiweave has developed the product "Smartsol", a flexible, safe (12V DC power), easy to install and stylish parasol with cool features such as cell phone charging and automatic shadow position adjustment (figures 121, 122).

Plastic fantastic: textile wraps of up cycled PET bottles. Dipl.-Ing.Arch.Katja Bernert, Mehler Texnologies. *https://www.mehler-texnologies.com/*

The subtitle of Katja Bernert's presentation "Sustainability matters" summarised the content of her presentation. She focused on 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 100.000 T 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).

Fig.123: Ludwigsparkarena, manufactured by Velabran

Figs.124, 125: Al Janoub Stadium manufactured by Pfeifer

Figs.126, 127: Santiago Bernabeu Stadium manufactured by Taiyo Europe

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 (figures 123 to 127).

Lighting design in textile ceilings - Dr.-Ing.Richard Müller - ETTLIN LUX Spinnerei und Weberei Prod. GmbH & Co. https://ettlinlux.com/

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 (figure 128). Different light effects can be achieved depending on the light source (static, dynamic, including TV screens) and the placement of the textile.

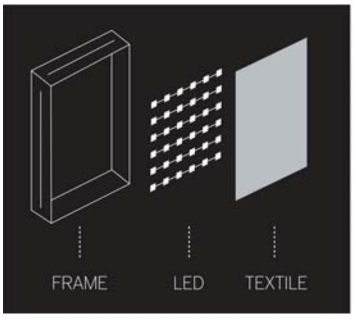



Fig. 128: Basic system: frame+LED+textile. Fig.129: Dynamic ceiling over fast lane. Brussels Airport. Fig.130: Bar ceiling installation. Brussels Airport.

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 (figures 129 to 131).

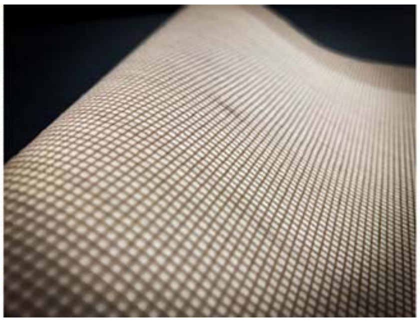




Fig.131: Rosalie Light Sculptures, 2017. Elbphilharmonie "Symphony of a Thousand". Fig.132: Laminated wood veneer. Fig.133: 3D effects in mirror glass.

Other products of ETTLIN are new materials such as laminated wood veneers (figure 132), 3D effects in mirror glasses (figure 133), acoustics absorbers and disintegrators of smells and cigarette smoke.

A further development consists of a 2 m 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.

Concepts for multimembrane gasholders - Ing.Lorenzo Spedini - ECOMEMBRANE s.r.l: *https://www.ecomembrane.com*

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 (figure 134).

Fig.134: gas holder on ground. Fig.135: gas holder on tank. Fig.136: cones.

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 (figure 135). 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 (figure 136).

Gas holders can also be cylindrical, prefabricated and placed on a platform with no concrete foundation and no installation cost (figure 137). There is also the possibility of building giant gasholders for thousands of cubic meters of gas measuring 50 to 60 m in diameter and a capacity of 20.000 to 40.000 m^3 (figure 138).

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 $p \cdot R/2$, dependent on the pressure and on half the radius. On the other hand, the tension of the cylinder is double $T = p \cdot R$, 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 (figure 139).

Fig.137: gas holder on platform. Fig.138: giant gasholders. Fig.139: cylindrical gas holder.

Finally a gasholder for 600.000 m^3 was envisaged measuring 400 m (length) x 76 m (width) x 32 m (height), reinforced with cables to discharge the outer membrane.

Participant project - Janek Jeschke, Stoffdach GmbH
https://www.stoffdach-construction.de/ and https://www.igelgmbh.de/

1 Presentation of the tent structure (figures 140, 145).



Fig.140 the design of the tent. Fig.141: sewing on site. Fig.142: testing the anchor

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.

2 Production. The welding of the seams was completed in the Karsten Daedler premises. The edge belt was sewn on site under pre-tension (figure 141). Edge belts instead of cables avoid damaging during the installation process.

3 On-site lay out: positioning, orientation, adjustment of angles, distances, marks and levelling.



Fig.143: an anchor loosened. Fig.144: reinforced anchor. Fig.145: the result was satisfactory

4 Installation of ground anchors and tent. The ties were not anchored to the ground with counterweights, but with recoverable screw anchors Ø 50 mm, ℓ = 1.260 mm (figure 142). Observe that, as one of them loosened (figure 143), it had to be reinforced adding another one. It was possible because the base plates are designed to receive one, two or three pegs (figure 144). It would have been better if the lateral wings of the plate were bent upwards like the one receiving the tie, so that the stakes would open up and involve a larger volume of soil.

Physical and computer modelling, barbecue, cruise and banquet

Fig.146: Physical and computer modelling, barbecue and cruise

As traditional at "Textile Roofs", the workshop was completed with physical and computer modelling, a barbecue, the cruise on the Spree and the banquet, which brought together more participants than the presentations.