REPORT

STRUCTURAL MEMBRANES 2019

IX International Conference on Textile Composites and Inflatable Structures

The "Ninth International Conference on Textile Composites and Inflatable Structures" was held in Barcelona in October 2019 together with the IASS Symposium 2019. It was organized by the International Centre for Numerical Methods in Engineering (CIMNE) and was chaired by E. Oñate (UPC), K. U. Bletzinger (TUM) and C.Lázaro (UPV). It was the ninth of a series of symposiums that originated in Barcelona in 2003. The next session will be held in Munich in 2021. https://congress.cimne.com/Formandforce2019/frontal/default.asp

At the four-day conference, 15 plenary lectures and 593 presentations in 114 sessions were given to 887 registered participants. The wide range of topics that were covered included from the design to the realization of (almost) all kind of structures and materials with a special concern for environmental aspects. Structural membranes were the subject of a number of dedicated sessions:

- Membrane materials
- Conceptual and parametric design
- Structural morphology
- Form finding
- Analysis. Computational methods. Numerical methods and modelling
- Wind engineering and fluid-structure interaction.
- Optimization
- Manufacture, detailing, installation, realizations
- Inflatable, pressurized membrane structures
- Adaptive, deployable, transformable lightweight structures
- Bending active systems
- Tensegrity systems
- Environmental compatibility and life-Cycle
- Teaching and education

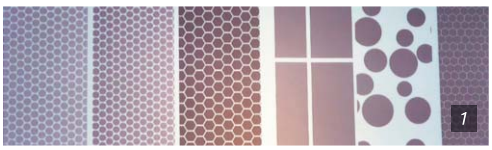
It was not possible to attend all presentations (they were held in 12 rooms at once!). Nevertheless, they can be downloaded at: http://congress.cimne.com/formandforce2019/frontal/doc/Ebook2019.pdf

MATERIALS

Almost all the materials used in membrane architecture were mentioned but, as usual in the last meetings, ETFE was frequently referred to. Sophie Gledhill, from the Fraunhofer Institute for Solar Energy Systems, addressed ETFE coatings to improve its performance. ETFE cushions have low thermal insulation and high solar transmission to which spectrally selective coating solutions can be applied resorting to low emissivity and solar control. Dr. Gledhill explained the challenge of applying this technology and presented the sputter system and lacquered layer that have been developed and tested in realistic conditions with flaws, weld-seams and joints, identifying a suitable lacquer for flaws which occur in cushion construction. She announced a 1x1m demonstrator ETFE coated cushion under development.

Carl Maywald from Vector Foiltec went also into improvements of ETFE by coating including ink, intensity and geometry (Fig. 1). He provided a brief introduction into the development of coating and printing on ETFE in particular, as well as an introduction into different techniques for solar shading of ETFE cladding systems in architectural buildings. He stated that a well-balanced relation between adhesion and cohesion is a fundamental requirement because the pigments have to remain stable on the foil surface even under conditions of multiple cyclic deformation. In order to allow for quality assessment of these coatings taking into account elastic and plastic deformation of the target material, he introduced a new test procedure for coated ETFE.

Katja Bernert from Low and Bonar expanded the concept of smart fabrics beyond sustainability. She highlighted the merits of fabric meshes as lightweight materials because they are apt to wrap buildings at a fraction of the material need for other aesthetical enclosures as stone or aluminum façades. Savings in weight, hence sub construction and material consumption are smart in terms of sustainability. But she also considered that actual smartness is evolving towards a fabric as a matrix for all sorts of applications, ranging from leading electricity through its veins to supply lighting. She gave a brief introduction regarding the interrelation between material science and design of smart fabrics and focused on recent material developments and their input for actual projects. With a variety of today's applications (Fig. 2) she led to the conclusion that future research will deal with smart composite materials.



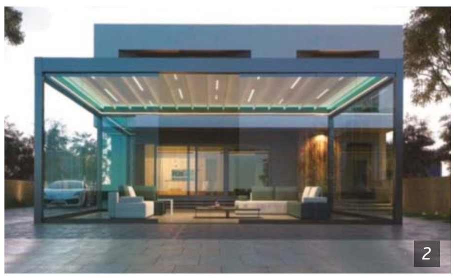


Figure 1. ETFE coatings. different print intensities and geometries (C. Maywald).
Figure 2. Valmex System: a coated fabric integrates tube-like bags to be filled with LED light strips, steel cables, insulation material or heating wires.

Hubertus Pöppinghaus from IF-Group dealt with reinforcement belts for textile structures. They are an important part of retractable/transportable structures because they can be folded together with the membrane. But two shortcomings limit broader applications to all kind of structures: fixation techniques and appropriate stiffness. That's why a new weldable protected belt has been developed and tested comparing it with a standard pretensioned polyester belt (Fig. 3). The results expanded the knowledge in the field but still did not yet lead to a viable product for the market.

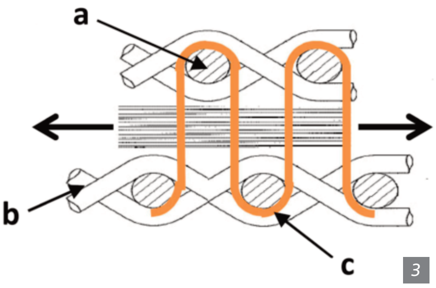


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Figure 3. New Dyneema®-stem-thread-belt protected by PVC coated fabric in plain wave. a) PVC coated weft threads. b) PVC coated warp threads. c) Uncoated binder threads.

DESIGN

The bases of structural analysis for membrane structures were addressed by Nick Gibson from Tensys. Tensile structures are complicated 3 dimensional structural systems difficult to simplify into 2 dimensional problems to be solved by simple hand or numerical tools. They suffer large deflections which are outside normal building deflection limits. Their complex shapes require form-finding and detailed load distributions to be considered which might be derived from wind tunnel test or CFD analysis. In addition, they suffer large geometry deflections and reductions of prestress when supporting these loads. That's why the analysis tools must be able to accommodate large scale geometry changes, handle the characteristics of the materials and deal with the detailed review of possible water ponding. As a consequence, he asked for detailed studies before partial factors are set by the forthcoming Eurocode.

Tim Finlay from Buro Happold Engineering showed gravity stressed cable net stadia roofs starting from the transformation of the London Olympic Stadium and the delivery of the Education City stadium for the Qatar World Cup (Fig. 4). He exposed the development of a parametric matrix based design tool for form-finding of the system and its use in the development of design solutions for a Premiere League stadium. The particular challenge of finding the 3D equilibrium geometry for a system where the geometry of the elements is fixed on plan (as might be dictated by the stadia bowl geometry or architectural requirement) was described along with the non-iterative matrix based solution. The solution was implemented within Grasshopper for Rhino, a parametric visual scripting environment.

Dieter Ströble from technet compared and discussed a radial cutting pattern with the results of a parallel cutting pattern (Fig. 5) dealing with the two membrane envelopes of a double membrane system of biogas containers. Different scenarios, e.g. the situation under internal operating pressure and the situation under a gust of wind, were simulated. In the case of 'fast' loads (wind), the gas law applies and, in the case of rapidly occurring loads, it must be investigated whether the outer shell and the gas membrane touch each other. He also took into account the wind loads and the deformations in the iterations. The material properties were defined by warp and weft stiffness, including the so-called transverse and shear stiffness in order to simulate a realistic behavior in the radial or parallel directions. It turned out that the differences between the radial and parallel cutting patterns in relation to the size of the maximum membrane stresses were very small. This means that the parallel cutting patterns, which are much easier to produce, can be used in the future.

An optimum cutting pattern generation of membrane structures considering welded seams was the topic of Professor Yan Yang from the Shanghai Jiao Tong University. Using 2D displacements of the membrane elements as key variables, the proposed iterative method utilizes a geometrically nonlinear finite element analysis, based on the initial cutting patterns. The simulation of welded seams is integrated in the full cutting analysis and the deviations of stress and shape from the target values are minimized simultaneously. The numerical results show that the method achieves high accuracy of patterning and assembly.

In the closing session, Kai-Uwe Bletzinger from the Technische Universität München set out the role of simulation in design, noting the progress in the availability of numerical analysis. He dared to mention hot topics, most treated and pending aspects of the numerical simulation technologies. Parametric and interactive design, graphic statics, CAD/FEM/BIM integration, digital processes, optimization, form finding, reliability, sustainability, adaptability, material modeling, active bending, fluid-structure interaction, large deflections and complex modeling were mentioned among many others. He distinguished the requirements of low fidelity approaches for preliminary design options from those of high fidelity approaches for final design solutions.

TESTS and STANDARDS

Carl Maywald from Vector Foiltec drew attention to the need to characterize the structural behaviour of ETFE foil through biaxial tests. To date, the commonly used method for determining the ULS and SLS of ETFE foils in roof and façade structures is based upon mono-axial tensile strain and creeping tests, which only reflects one-dimensional properties of the ETFE material. However, in all roof structures, where inflatable ETFE-cushions have been used so far, membranes are exposed to biaxial stress. That's why he presented the results of biaxial tests to get the elastic and viscoelastic properties including the time constants for creeping (Fig. 6). He could conclude that biaxial hysteresis measurements show an enhanced elastic modulus after exposure to the first load cycle, saturation of plastic deformation for each stress level up

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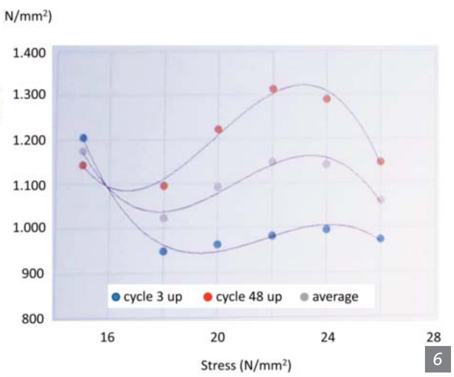

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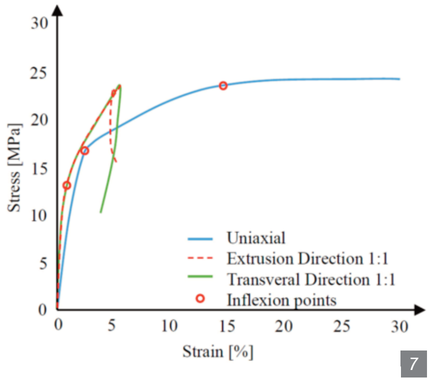
Figure 4. Fenwick-Iribarren Architects, 2019: Education City Stadium, Al Rayyan.
Figure 5. Radial (left) and parallel (right) cutting patterns.
Figure 6. Variation of biaxial E-modulus for 6 different foil stress levels.



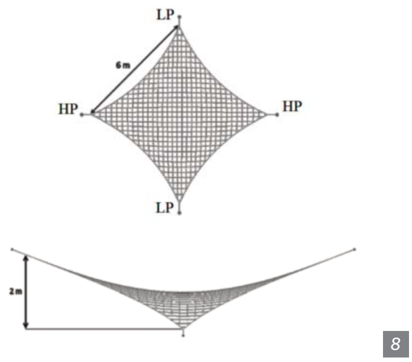


Figure 7. Comparison between uni- (1:0) and biaxial (1:1) material behaviour of ETFE foil (T=23ºC, vT=100mm/min).
Figure 8. Top view and side view of the hypar membrane structure.
Figure 9. Richter Dahl Rocha & Associés, 2014: Swiss Tech Convention Centre, Lausanne.

to 24MPa, higher load capacity of cushions due to plastic deformation and the relaxation of foil after 1.000sec.

Testing ETFE foil was also the topic of Natalie Stranghöner from the University of Duisburg-Essen. She stated that uniaxial tensile tests are performed to determine the mechanical characteristics of ETFE. However, ETFE-foils show a different mechanical behaviour in uni- and biaxial tensile tests (Fig. 7). For this reason, she claimed that mechanical properties of ETFE-foils used in biaxial tensioned structures should be consequently determined in tensile tests under biaxial loading. That's why experimental investigations into the uni- and biaxial tensile behaviour of ETFE foils have been carried out applying certain load levels, unloading and measuring the resulting residual strains. The achieved knowledge will contribute to the current development of the Technical Specification for Membrane Structures.

Marijke Mollaert in "The calibration of the partial factors for the design of a typical hypar membrane structure" investigated an existing calibration method to obtain the partial factors to be used for the design of a typical hypar membrane structure (Fig. 8). The reliability analysis was performed using a First Order Second Moment method in combination with Latin Hypercube Sampling. The study was performed for the load cases snow load and wind uplift load. The conclusions state that the proposed method to perform the reliability analysis is applicable to other membrane shapes besides the studied hypar membrane structure, but further research is needed to find partial factors that can be used for a wider scope of membrane structures and more reference cases should be investigated.

Bernd Stimpfle formulated the obvious question: "Do we need technical specifications for membrane structures?". The affirmative answer is based on different reasons:

- it helps to increase the market
- it helps to minimize approval processes
- to have a technology as an established building technology and not only a niche market with high risk
- with harmonized safety levels, and commonly agreed quality standards, the quality of the industry is improved and doubts of clients are avoided
- all players respecting the same high quality standards will result in a fair competition
- to favour the integrated design of the membranes, avoiding their consideration as add-on cladding, neglecting their contribution. Two significant examples of the increase of costs involved in the independent treatment of the ETFE foil façades were the Allianz Arena and the Unilever Building.

"Monitoring forces in tension structural members of lightweight architecture" was the contribution of Martin Jenni from Pfeifer. He showed the Loadscan measuring system to enable simple, permanent and accurate check of tension forces in structural members such as cables or tension rods by the means of ultrasound technology for the detection of structural anomalies during the use of the structure and the management of proper maintenance. He illustrated it with the Swiss Tech Convention Centre of Lausanne (Fig. 9), where the shed roof is pulled into its correct position by two monitorized cables. If the tension in the cables were too low due to the snow load, an alarm would sound at the security office. In other cases, the installation could be closed or, in pneumatic structures, the pressure increased.

INSTALLATION

Under the general topic "Innovative solutions to practical problems", Thomas Hermeking from Pfeifer addressed the refurbishment of stadia that age and experience changes in regulations or rising requirements such as the sheltering of the spectators. He demonstrated that summer breaks in between the season schedules of professional sport clubs provide a tight but sufficient building period for refurbishment or even a new roof structure. He illustrated it with two examples: the 80 additional ETFE cushions (4.700m²) of the San Mamés Stadium roof extension (www.youtube.com/watch?v=xmiUA2mZkzA and Fig.10) and the Mercedes Benz Stadium 38.000m² roof replacement (www.youtube.com/watch?time_continue=2&v=bqmXfxQDR9k and Fig.11).

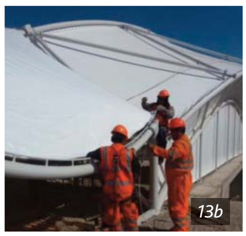
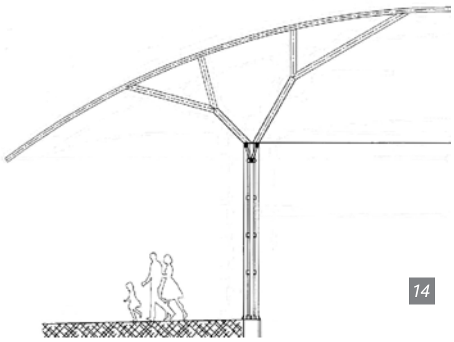


Figure 10. San Mamés Stadium roof extension process.
Figure 11. Mercedes Benz Stadium roof replacement
Figure 12. Jackson Architecture with Tensys, 2006: Royal Melbourne Showground's Grand Pavilion under construction.
Figure 13 a/b/c. "Polideportivo I.E.República Argentina", Chicote 2017. Installation of the central and side modules.

Peter Lim from Tensys showed the Royal Melbourne Showground's Grand Pavilion for agricultural show days, exhibitions, concerts, and other events, one of the largest tensile fabric membrane structures in the Southern Hemisphere (Fig. 12).

Its roof structure consists of a 13.250m^2 of high tensile PVC fabric subdivided into eight segments to enclose 98x84m^2 of indoor exhibition space. It is tensioned over six central conic masts topped with pinnacles that provide anchorages for internal rigging and access to high areas for lighting, sound systems and other services. The installation was based on the erection of the completed masts and pinnacles, which allowed to reduce the assembly time. The pavilion construction timetable allowed four months for steel fabrication and fabric procurement and four weeks on-site for support installation and erection of the fabric roof. Cost and deadline were substantially lower than those of a conventional building of the same covered area.



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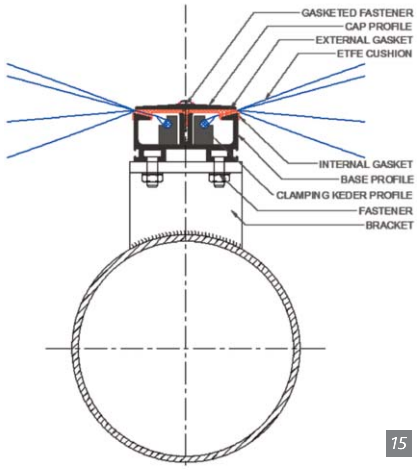

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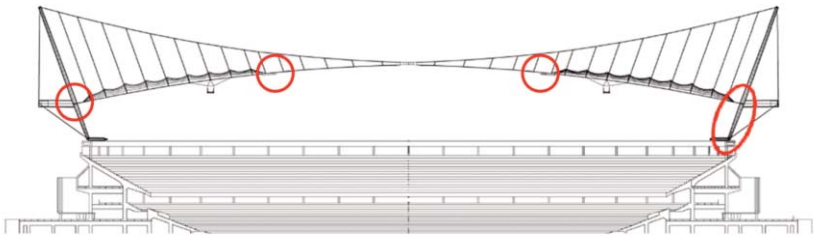
Figure 14. Branched mast. Arquintegral with J.Llorens, 2007: Almuñécar Aquarium.
Figure 15. Aluminum section for ETFE cushions.
Figure 16. Large deformation locations, BC Place, Vancouver, 2011.



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Another interesting contribution concerning the assembly process was that presented by Miguel Cárdenas from CIDELSA. It was the installation of the "Polideportivo I.E.República Argentina", Chicote 2017, conceived by Aurora Pérez (†), head of the CIDELSA Architecture Department. The design consists of a series of arches which define 2 main areas linked by a central space. For the manufacturing process of the membrane the entire area was divided into 3 blankets: 2 of approximately 1.500m^2 and a 200m^2 central blanket, in addition to the vertical side enclosures (Fig. 13). For the assembly process it is important to establish a step-by-step installation procedure, coded parts and a detailed planning. It is even more important for large projects since installation can involve damaging a well-fabricated membrane. Not forgetting the climatic factor, because a blanket of more than 1.200m^2 under the wind could be easily be spoiled according to the lifting procedure.

DETAILING

Three papers (at least) delved into detailing, which is not much discussed at symposia despite requiring a lot of research. One was "Detailing masts" by the Professor Josep Llorens, from the Technical University of Catalonia. As the efficiency and appropriateness of structural membranes depends to a large extent on the supports, a research has been launched on the current design and the possibilities of optimizing the sections and the detailing. Three types were identified: boundary, internal and external masts. The three types accept different strategies to cope with over-dimensioning imposed by buckling on such long elements. They include the use of circular hollow steel sections improved by tapering, trussing, tying, branching (Fig. 14) or coupling. Apart from the section of the shaft, the ends also have a considerable impact on cost, appearance and ease of installation.

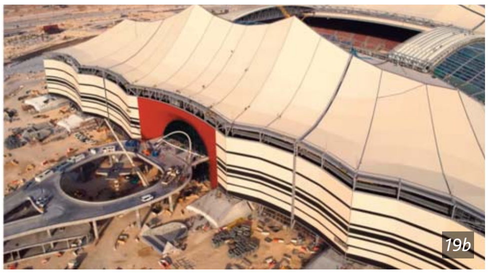
Regarding ETFE foil, Jaume Saló focussed on the detailing and connections between ETFE systems and the other parts of the building that are essential for fulfilling the watertightness, airtightness, and thermal insulation requirements of construction. The most common connections between an ETFE roof and the other parts of the building such as gutters, walls, roof ventilation devices and standard waterproof roofs were discussed (Fig. 15).

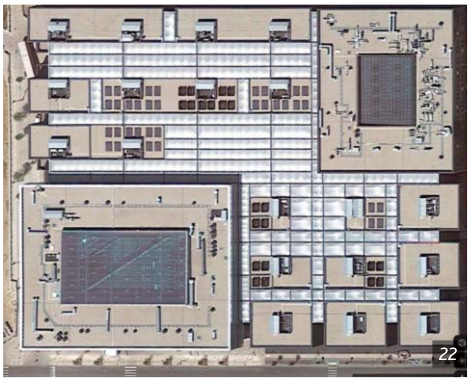
"Details of design of large deflection structure building enclosures" by David Campbell from Geiger Engineers dealt with the joints of flexible structural systems that are employed for roofs, facades, atria and other building envelopes. These flexible envelopes must frequently be sealed at the boundaries between large and small deformation elements. That's why innovative connections and closure details are required. Three examples were mentioned. The Capital Center Arena, Landover 1973, was a cable net supported by a compression ring of 122m in diameter roofed by a metal deck (demolished 2002). The Cumberland County Crown Complex, Fayetteville 1997, is a cable dome roofed with rigid panels because they wanted an opaque roof. And the BC Place Stadium, Vancouver (renovated 2011), has to deal with deformations due to snow (Fig. 16).

REALIZATIONS

The most presented topic of the symposium was that of recent projects. Marijke Mollaert from the Vrije Universiteit Brussel was in charge of the tendencies and challenges of contemporary tensile structures in Europe. She alluded to architecture, creativity, lightness, softness, acoustic comfort, adaptability and natural day lightning illustrating them with some of the examples presented in the Symposium. She also referred to the technical specifications that are being drafted by the CEN/TC 250 technical committee. Her summary of challenges was condensed in: "Take care of the planet. Lightweight architecture should not only stand for a physical low weight, but also support well being in the broadest possible sense".

Josep Llorens, from the Technical University of Catalonia focused on the second decade of the 21st century considering that membrane structures have been characterized by the diversification of applications, the increase of the structural efficiency together with new developments and the improvement of the environmental behaviour. Progress is being made in the understanding of the appropriateness of membrane structures. Although bending is expensive, as it was already clear in the 50s pioneering experiences of Frei Otto and his team, many contemporary designs do not take it into account to the point that membrane structures frequently end up being conventional steel structures. Some recent realizations are not yet rid of this drawback but others have assumed it to the point of improving the be-





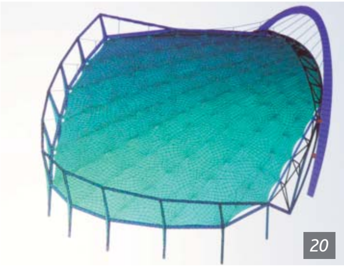


Figure 17. Two approaches to structural membrane design. Left: relying on bending. Right: taking advantage of the benefits of membranes.
Figure 18. Combination of ETFE foil with cables at the SoFi Stadium, LA.
Figure 19. Al Bayt Stadium © Qatar2022 (https://www.youtube.com/watch?v=QOlMrHMPIew)
Figure 20. Retractable roof for the Munjung Cultural Valley, Seoul.
Figure 21. Airport City Belgrade membrane structure.
Figure 22. OMA with IASO: École Centrale, Paris-Saclay University, 2017.
Figure 23. Passage Projects: the roof of the 50 m span "free-form" roof under construction, Bangkok, 2018.

haviour of the structure even more. It is the case of the spooked-wheels, the Tensairity system, cable-beams, active-bending and flying masts, among others (Fig. 17).

Kais Al-Rawi unveiled digital workflows to process and visualize large amounts of structural analysis data to understand and detail the interface between the structure and enclosure. They are especially relevant in lightweight structures, where the geometric non-linearity and long-span tensile elements result in small stiffness with large displacements. Such displacements may not govern the stability of the structure but they can have significant impact on the enclosure systems and detailing. It was illustrated by the combination of ETFE foil and cables of the SoFi Stadium at Hollywood Park, Los Angeles (Fig. 18).

Christoph Paech from sbp showed the Al Bayt Stadium, one of the five new football stadiums being constructed in Qatar, the future host of FIFA 2022 Football World Cup. Its current capacity stands at 60.000 to allow for one semi-final game in 2022. It is supposedly inspired by the Bayt Al Sha'ar tent used traditionally by nomadic people in Qatar, but it is neither a tensile structure nor an active form. It has become an 18.000T cantilevered steel structure that implements membranes (Fig. 19). It has been necessary to transfer the manual pattern of the drawings based on natural fibres to the mechanical loom. And, in addition, it will be necessary to resort to air conditioning to achieve bearable environmental conditions, that were resolved without energy input in the original model. The impressive installation of the stadium can be viewed at:
https://www.youtube.com/watch?v=QOlMrHMPIew

The Korean joint research project which has the task to develop the basics for an economical and light retractable roof solution was presented by Alexander Hub from Alfred Rein Ingenieure GmbH. Different project teams from the field of research and economy have developed new approaches to this topic in the former two years. At the symposium, Alexander Hub introduced an application to enable the validation of the results by control and analysis of the operation of the construction. It is a retractable roof for the Munjung Cultural Valley, Seoul. The final completion is scheduled for spring 2020. Currently, a testbed has been carried out containing both a rail and a rope based moving concept, considering that the different driving axes have strong varying total lengths (Fig. 20), which have to be controlled by a sophisticated control system.

Aleksandar Vučur from ArTech inženjering showed a covered space between two contemporary office buildings with curtain wall glass façades in Belgrade in order to protect a pedestrian area and create a plaza (Fig. 21). The membrane is an hypar that covers 487m^2 with a span of 28m with PVC-PES type III. Steel has been adopted for the other structural members and novel solutions have been developed for the corner details and boundary edges that asked for new advanced solutions to introduce pretension at the corners by the elastic deformation of the curved trusses, that's to say relying on active bending. The detailed description of the design, production and installation allowed to get a comprehensive idea of the full process.

Feike Reitsma from IASO showed the construction of Ferrari Flexlight stretch membrane canopies coupled with ETFE cushions on the underside to improve the thermal and acoustic comfort of the "Centrale Supélec", Paris (Fig. 22). The totality of the covers of the hall occupies an area of 4.700m^2 divided into 103 modules of rectangular shape and variable dimensions. The roof of the hall consists of tensile membrane elements that make up the tight outer skin of the cover, ETFE cushions that make up the inner skin of the blanket (powered by an air supply system) and a plenum. This air-tight space is slightly over-pressurized with dry air and dehumidified to avoid the risk of condensation and deposition of dust. Each ETFE cushion is formed by 3 films of varying thickness: a printed top film of 200micron, a transparent intermediate film of 100microns and a transparent lower film of 200microns.

Catherine Poirriez from Passage Projects described in detail the design of a 50m span "free-form" steel roof covered with ETFE foil in Bangkok. Several shapes and structural systems were explored at early stage to best integrate the roof in its environment. The resulting shape is a quiet and smooth surface providing shade, natural light and ventilation to the spaces below. Although complex, the geometry was generated to fully take into account the buildability. All the steel members were translated in a language of plates and single radii understandable for the manufacturer. Initially made of conical surfaces, the edge beams section geometry was rationalized through parametric modelling in order to be only made of cylindrical surfaces which are developable and therefore easy to fabricate (Fig.23).

REFURBISHMENT

The timber membrane roof of a small soccer Stadium in Böblingen had to be renovated after a storm ripped off parts of the drastically aged Polyester PVC membrane from the 1970's (Fig. 24). Following the wish of the client to maintain as much of the existing timber structure as possible, the original documents were reviewed. The original analytical calculations and load conditions were compared with the results of a FEM analysis giving insight into the developments of membrane engineering over the last 40 years (Table 1). The new design and formfinding process were discussed to show how ridge cables were used to guide the forces towards the parts of the structure were the highest load reserves were detected (Julian Lienhard from str.ucture GmbH).

Thomas Moschner from sbp was in charge of presenting the new roof structure for the Camp Nou Stadium, Barcelona, the biggest soccer stadium in Europe and number 4 worldwide (Fig. 25). It is going to be renovated from 2020 to 2023. The Japanese architects from Nikken Sekkei won the design competition in 2015 and sbp is one of the General Planners team members and responsible for the roof design. In addition to extending the grandstands to 105.000 seats and upgrading the business areas, the renovation includes a complete roofing of the stadium which sums up to 50.000m². Sbp designed a special kind of cable net structure, considering various demands such as limitations coming from the historical building, time constrains, functional constraints (the entire stadium has to be renovated under full operation, providing min. 80.000 seats during the whole construction phase) and limited access, among others. The presentation explained the roof structure itself and gave an overview about how the various challenges will be handled.

Figure 24. str.ucture GmbH: re-design of the Dagersheim Stadium roof.
Table 1. Re-designing of the Dagersheim Stadium. Original calculations compared with the results of a FEM analysis.
Figure 25a/b. The new roof for the Camp Nou Stadium, Barcelona.

Tabel 1	Max. compression (masts)		Max. cable forces	
	Mid span (kN)	Side span (kN)	Mid span (kN)	Side span (kN)
Original design (hand calculation)	-179	-180	56	98
Original design and loading (FEM)	-219	-182	88	112
Original design. New EC loading (FEM)	-256	-188	112	135
New design. New EC loading (FEM)	-283	-219	68	82

RESEARCH

Replacing Rainer Blum from DEKRA, Robert Roithmayr from formfinder GmbH referred to the research opportunities for membrane structures starting with the properties of materials and test methods. The role of the elastic modules and their determination was mentioned. Microscopic pictures of the coating of materials after 20 years of use illustrate the importance of the coating and its behaviour under the influence of the ambient. Thus the improvement of material starts with the improvement of the coating. The building physics of membrane materials and membrane structures, especially the energy saving properties, were also discussed. A new development is the air bubble film used for a new sports hall in Bavaria (Fig. 26).

Figure 26. The new air bubble film used for a new sport hall in Bavaria.
Figure 27. Modified textiles mounted on the frame under the wind.

"Could the shape and internal structure of the fabric be worked to design architectural structures which become kinetic under the wind? Could the wind be seen as a positive parameter for architectural textiles?" was the challenge assumed by Erica Hörteborn, from the Chalmers University. Smart textiles, whose structure can be changed using heat, were employed to explore how the geometrical expressions of textiles under wind load can be affected through internal property changes. She found that a combination of the digital and the physical design tools enables the creation of an unique workflow to generate architectural design typologies (Fig. 27).

Rosemarie Wagner from the Karlsruhe Institute of Technology presented the research and development of a fabric made of straight monofilaments in warp and weft directions. She included the material properties such as ultimate tensile strength and elastic constants under uniaxial and biaxial loads (Fig. 28). The material showed a different behaviour in warp and weft, translucency, high UV-resistance, water tightness (to a certain amount), high sensitivity to clamping and very little load transfer between single yarns that broke distributed in the whole test sample. The development of seams was difficult because of the sliding of the yarns in the welded seam. A shading structure placed at the location of the producer is planned to demonstrate these specific properties.

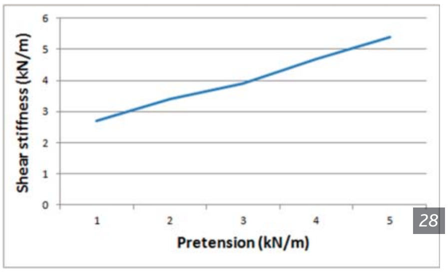


Figure 28. Prestress increases the shear stiffness of fabric with straight yarns.

EDUCATION

Robert Roithmayr from formfinder exposed the bases of his Master's Program for "Tensile Membrane Structures" taught at the Danube University in Krems: https://www.formfinder.at/masters-program/. A collaborative researching and learning method is applied together with a massive amount of content provided by world-class experts including Rainer Blum. The huge amount of information is growing constantly but it is possible to keep the access simple and effective because the content is integrated in a semantic database, including existing building projects, typology, details, products, experts, companies, glossary, details and literature: https://membrane.online/

EXPO PAVILIONS

The IASS WG21 "Advanced manufacturing and materials" invited artists, designers, engineers, researchers and students to submit innovative lightweight pavilions of maximum external dimensions of 4x4x4m. The call was a great success and the jury awarded four winners: the "Elastic rod deployable pavilion, EPFL" for its innovative optimized deployment mechanism (Fig. 29), the "Knit tensegrity shell, Singapore University" for its constructability and artistic expression (Fig. 30), the "Push puppet, Graz University" for its performative character, originality and constructability (Fig. 31) and the "Flexmaps pavilion, CNR-ISTI" for its structural innovation of bending-twisting system, connection constructability and exquisite craftsmanship (Fig. 32). It also deserves to be highlighted the "Quipustructure, Palma University" for its low tech use of local materials like bamboo and reed rope combined with the building techniques developed by the Incas (Fig. 33).

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Figure 29. Elastic rod deployable pavilion, EPFL.
Figure 30. Knit tensegrity shell, Singapore University.
Figure 31 a/b. Push puppet, Graz University.
Figure 32. Flexmaps pavilion, CNR-ISTI.
Figure 33. Quipustructure, Palma University.

NEXT CONFERENCE

The next international Structural Membranes conference will be held in Munich in 2021 at the Technical University.
Further information will be made available at: http://congress.cimne.com/membranes2021/frontal/default.asp