TensiNews

Newsletter Nr. 50
April 2026
PUBLISHED TWICE A YEAR
PRICE €15 (POST INCL)
www.tensinet.com

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

REPORT

STRUCTURAL MEMBRANES 2025

Form and structure in Osaka 2025

PROJECTS

Transformative Architecture

Renewing Membrane Roofs

Membrane roof of the Health Centre in Masserberg © formTL

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TensiNews INFO

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ISSN 1784-5688

Price €15 / postage & packing included

Remarkable – membrane chimney that scrubs pollution

© © Kanadevia Corporation

While The TensiNet association has engaged Chemservice to collect information on the socio & economic impact of a PFAS ban and to prepare a dossier to reply to the Committee for Socio-Economic Analysis (SEAC) we have noticed that an industrial chimney that neutralizes air pollution was honoured with an award by the Membrane Structures Association of Japan (MSAJ). The material used is a PTFE membrane, which is considered as not 'environmentally friendly' in Europe. We have asked Ken'ichi Kawaguchi for some background.

The normal lifetime of the incinerator chimney is about 40 years as each incinerator boiler lasts about 40ys. They must be rebuilt about every 40 years. In Japan, the covers of the incinerator chimneys are mostly constructed by heavy concrete panels. So, these are heavy structures that require a lot of energy and CO2 emissions for

Edito

Dear Reader

Shortly after our 25th anniversary, which we celebrated last year, we are glad to share with you the next jubilee, the 50th edition of TensiNews.

Within these 25 years we have published many projects in tensile architecture, as well as promising research results and of course also the development in technology and materials over the year. Having contributed also to the technical specification for membrane structures we have done a lot to bring lightweight architecture out of the niche and become a more and more established building technique. We strongly believe in the future of textile architecture, which plays also an important role in the sustainable development of the building industry, by reducing material quantity and weight. Technical development led to longer lasting materials which allow for a much longer service live and if the end is reach, they can be easily renewed by just replacing the building skin.

Our webinar about PFAS in February this year initiated our series of webinars. It was a great success with a tremendous number of participants. The goal was to inform about the risk in the materials we use and initiated the socio economic analysis carried out by Chemservice. With their help, we are collecting data from our members in order to prove to the European Chemical Agency that building with Fluor Polymers is essential for our industry in order to keep our projects long-lasting and sustainable, and at the same time that their production, processing and use is save and not harmful.

This first webinar was meanwhile followed up by a webinar on Life-Cycle Assessment, and the next episode is already in preparation. We plan to have these webinars on a regular basis and with varying topics. We will inform about this in the upcoming TensiNewsflash.

Meanwhile please enjoy this jubilee edition of TensiNews. We present three milestone membrane projects of the 90s, which were currently renewed with a new membrane skin, and so enlarging with few new material the life span for another 20 or more years. Beside this a chimney made from light and easy cleanable membrane, a transformable Expo façade to be used on three Expos and a new ETFE covered climate house in Amsterdam is presented. Two reports complete the picture. Josep Llorens with an extensive report on the structural membranes conference in Munich and Julian Lienhard on lightweight architecture projects on the Expo in Osaka.

I will be glad to meet you soon in Frankfurt where we hold our General Assembly, in Turin at IASS or, as a must, in Essen at the TensiNet Symposium.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

Techtextil and Texprocess 2026 | *21-24/04/2026* | Frankfurt, Germany | **https://techtextil.messefrankfurt.com**

General Assembly TensiNet at Techtextil
22/04/2026
The General Assembly will be held at Techtextil (*meeting room "Transparenz 1" in the Portalhaus*) on Wednesday 22nd April from 14.00 till 15.30. Members who can't come to Frankfurt can join by Teams.

IASS Annual Symposium 2026 and IWSS 2026 | R-EVOLUTION OF SHAPES: SUSTAINABILITY, RE-USE, AND NEW DESIGN PARADIGMS | *14-18/09/2026* | Politecnico di Torino, Turin, Italy | **www.iass-iwss2026.org**

8th TensiNet Symposium 2026 & 7th Essener Membranbau Symposium 2026 | Shaping the pathway to future tensioned membrane design | *30/09-02/10/2026* | Institute for Metal and Lightweight Structures, University of Duisburg Essen, Germany | **www.uni-due.de/iml/tensinet-ems2026.php**

21st Advanced Building Skins 2026 Conference & Expo | *3-4/11/2026* | Bern, Switzerland | **https://abs.green/home**

construction. In order to keep the durability, the concrete panels require special chemical paintings, which should be repainted every 15 years. Since we have earthquake, the heavy chimney should be designed very strong with much material just to stand against its earthquake loading. This is the background of why we needed a lighter chimney cover, and we awarded the project of PTFE panel cover for Incinerator Chimney. The expected lifetime of the chimney is about 40 years. The maintenance of a membrane chimney is also much easier than the conventional one and it has a much less environmental impact than a conventional construction with heavy concrete panels. It is true that chimney with flexible membrane also expands its design possibilities. Lighting up from inside at night may change the impression of an industrial chimney to a regional symbol tower.
The TiO2 coating is also applied exterior surface of the membrane. They mention that it adds not only self-cleaning but also air-cleaning function by decomposing NOx in the air. I suppose air-cleaning effect might be only additional and not so significant. A PTFE membrane is one of the best options as a permanent membrane material. On the other hand, it is true that PTFE is currently not a recyclable material so far. When the chimney finishes its function, about 40 years time, the situation might be changed. The technological development is always progressing very rapidly. There are many cases where a thing once thought to be impossible, became possible and even easy. We never considered that PTFE membrane has a negative effect directly to our health. Replacement all plastics to biodegradable ones might be another big future challenge for human being!

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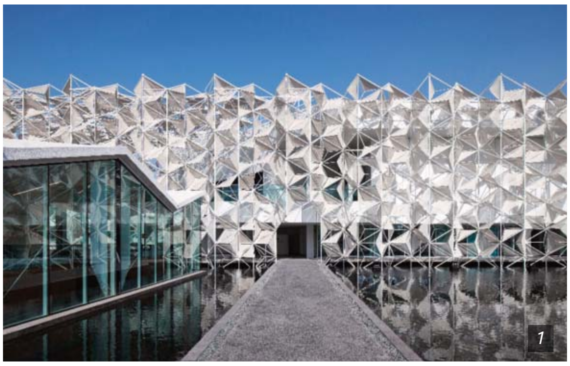
https://fabricarchitecturemag.com/2025/11/01/taiyo-kogyo-honored-for-fabric-chimney-that-scrubs-pollution/

Transformative Architecture

The Reuse and Transformation of an Architectural System

multiple World Expositions Dubai 2020 – Osaka 2025 - Yokohama 2027

Originally developed for the Japan Pavilion at Expo 2020 Dubai (Fig. 1), the facade has been reassembled for the Women's Pavilion in collaboration with Cartier at Expo 2025 Osaka, Kansai and is currently being repurposed for a third application at the Japan International Horticultural Expo 2027 in Yokohama. The reuse project, termed "transformative architecture", demonstrates how lightweight ball-joint structures and membrane materials can be reused across different sites, layouts, and scales (Fig. 2).



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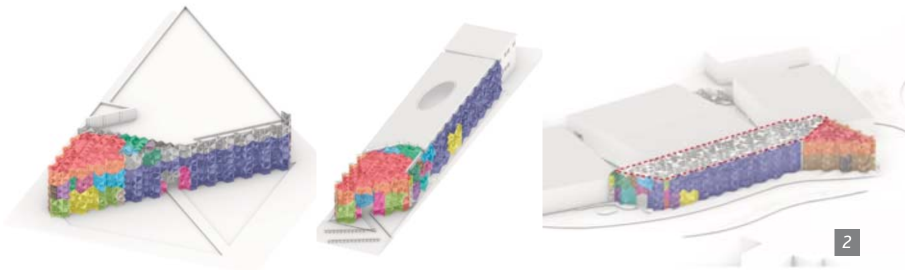

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Figure 1. EXPO 2020 Dubai Japan Pavilion
Figure 2. Diagrams for Dubai, Osaka and Yokohama © Yuko Nagayama & Associates

The core architectural element is a three-dimensional geometrical lattice called the KUMIKO facade. The façade design was inspired by the similarity between the traditional Japanese asanoha (hemp leaf) pattern found in Japan's kumiko woodworking technique, and the arabesque in the Middle East. It was constructed using a technique called the ball-joint system. Much like a plastic model kit, this system enables multi-directional connectivity while maintaining structural efficiency through minimal material use.

From the outset, the pavilion was conceived as a demountable structure. The ball-joint system allows all primary components—tubes, nodes, and membranes—to be dismantled. This modularity is essential for reuse. The PTFE membrane is selected for its low weight, high tensile strength, ultraviolet resistance, and long-term durability. It also functions as an environmental moderator rather than a sealed enclosure. In Dubai's hot climate, it filtered intense solar radiation, reduced heat gain, and allowed air movement through the facade. In Osaka too, the membrane unified interior and exterior zones, controlled daylight and glare, supported natural ventilation, and visually integrated diverse spaces (Fig. 3).

3

Figure 3. Women's Pavilion in collaboration with Cartier at Expo Osaka 2025, © OMOTE Nobutada

The technical challenge of reusing the KUMIKO façade in Osaka was reassembling the parts to fit a new site with a completely different footprint. At Dubai, we designed an isosceles triangular building on a large trapezoidal site using Japan's traditional silver ratio. In contrast, the Osaka site allocated for the Women's Pavilion was long and narrow, with a frontage of 18m and a depth of 110m.

This transformation required extensive digital coordination. In collaboration with ARUP Japan, we conducted extensive structural analyses and spatial simulations to determine how existing components could be placed within the new geometry. Approximately 70% of the original 10.000 components were reused, including both structural components and membranes. Our goal during this process was to solve this difficult puzzle without fabricating new parts. This task alone took us three months. Furthermore, the nodes had unique, individually identified shapes, and the tube wall thickness varied depending on the force distribution. Thanks to Obayashi Corporation's visual process management system, ProMIE, the team was able to sort the parts, ascertain the installation location, and manage the delivery and assembly of materials by attaching a QR code to each part while linking it to the BIM model (Fig. 4).

Through this consistent reuse project, we gained the expertise—from design to construction—to not simply relocate a building but to transform it into a different structure tailored to the next site. This knowledge is leveraged for the next reuse project – indoor exhibition shared facilities at the Yokohama GREEN × EXPO 2027 (Fig. 5). This new facility will be approximately three times the size of the Women's Pavilion, and the KUMIKO facade will have to be reassembled into a completely different form again. This is a yet new challenge for the second reuse project.

Figure 4. Dismantling the Japan Pavilion at Expo 2020 Dubai © Takamitsu Miyagawa
Figure 5. "GREEN × EXPO 2027" in Yokohama © Architect: TSP TAIYO Inc. and Yuko Nagayama & Associates; © Renderings: Yuko Nagayama & Associates

Architecture is designed to be rooted in land and intended to remain there permanently; in contrast, Expo architecture exists in place only for six months. In response, we proposed — and have repeatedly realized — a transformative architecture challenging this repeated cycle of "scrap and build" surrounding the World Expo. While the circulation of existing architectural materials is a truly challenging task, we continue to face the challenge with our pavilion, from Dubai to Osaka, and now to the third site, Yokohama. We believe that these transformations were made possible because of the small and simple modules created by the ball-joint system, the technology supporting material circulation, and an increased social awareness and understanding. Through this project and its many transformations, we hope the reuse movement will continue to expand beyond the context of World Expos.

Yuko Nagayama
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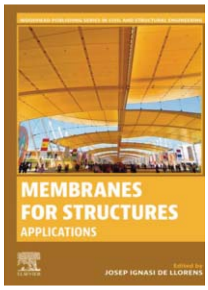
Name of the project:	Women's Pavilion in collaboration with Cartier
Location address:	Osaka, Japan
Function of building:	Expo pavilion
Year of completion:	January 2025
Architects:	Yuko Nagayama & Associates
Multi-disciplinary engineering:	Ove Arup & Partners Japan Ltd.
Structural engineers:	Ove Arup & Partners Japan Ltd.
Facade engineer:	Ove Arup & Partners Japan Ltd.
Main contractor:	Obayashi Corporation
Contractor for the membrane (Tensile membrane contractor):	TRA・K
Supplier of the membrane material:	Serge Ferrari
Material:	Steel frame structure, partially with system truss
Covered surface (roofed area):	252,6m^2

BOOK REVIEW

Membranes for Structures. Fundamentals. Applications

Publisher: Woodhead Publishing - Elsevier
Edited by Josep Llorens, Barcelona School of Architecture (ETSAB), Polytechnic University of Catalonia (UPC)
ISBN: 9780443224072 and 9780443224058
Language: English - Published: 2025

A growing use of membranes for construction purposes has recently been encouraged by their environmentally friendly characteristics. To offer a timely and extensive, research-grounded compendium on structures made with fabrics and foils, the most relevant facets of the state of the art are covered in two sister titles.



After a moving remembrance of Marc Malinowski, a great promoter of membrane structures, **Membranes for Structures - Fundamentals** begins with a brief historical review of the development of design tools for membrane structures. Part One follows, discussing design fundamentals in the light of recent experiences and modern technologies. Part Two updates knowledge of products and materials, with a special focus on fire performance, the incorporation of photovoltaic cells, and ETFE. Part Three deals with other considerations related to design and installation, such as acoustic performance, post-failure stability, wind loads and lifecycle analysis, with special mentions of textile halls and biogas containers. A look into the future is proposed in Part Four, where some interesting, present-day research on ageing and applications is included.

Membranes for Structures - Applications is steeped in fascinating, functional examples: in fact, a selection of detailed case studies is presented in Part One, preceded by the description of two relevant historical antecedents, which are the circus tent and the "envelat". The particular case of the successful spoked wheel structural system for the construction of large stadiums is the subject of Part Two, including descriptions of four significant case studies. Two growing fields of application are the focus of Part Three, which is dedicated to façades that give buildings a unique appearance, and Part Five, which addresses replacements, renovations, and refurbishments-activities that are frequently encountered in today's construction industry. And Part Four presents the latest application developments in different countries across the globe, with achievements in China, Latin and North America, Japan, and Europe being highlighted.

The well-amalgamated contributions, authored by international experts, produce a comprehensive reference to keep students and researchers as well as industry professionals and various other stakeholders abreast with the latest advancements. They incorporate recent developments that are poorly documented in other literature available, describe functional, structural, and decorative applications of membranes in buildings and include various relevant case studies from around the world.
Available at: https://shop.elsevier.com/books

STRUCTURAL MEMBRANES 2025

XII International Conference on Textile Composites and Inflatable Structures

The "XII International Conference on Textile Composites and Inflatable Structures" was held in October 2025 at the Technische Universität München, organized by the International Centre for Numerical Methods in Engineering (CIMNE) and was chaired by A.Goldbach (TUM), C. Lázaro (UPV), R.Rossi (CIMNE/UPC), and R.Wüchner (TUM). It was the twelfth of a series of symposiums that originated in Barcelona in 2003.

At the three-day conference, 6 plenary lectures and 58 presentations were given to 101 participants from 14 countries. The programme was completed with the welcome reception, student's projects exhibition and banquet dinner.

PLENARY LECTURES

In the first plenary session Knut Göppert, from sbp, presented the planned rehabilitation works 2025-2029 for the Munich Olympic Stadium Roof. He began recalling some aspects of its history as well as some of its main characteristics. He highlighted the innovative nature of the project, which raised the question: "Can it be built?". He mentioned the development of structural systems, analysis methods and details that were not done before, together with experimental setups and the re-invention of cast steel components (fig. 1). He also pointed at the installation process for which the need for scaffolding was discussed at the time (fig. 2).

A review was engaged in 2019 with 3D scans, force measurements, form finding and re-calculation. Very little deviation from what was built was found, neither were they found overstressed elements (except one). Only some corrosion topics on cables that had to be re-coated after careful blasting. It means that, with all the possibilities there are now, it could not be designed better. In addition, rehabilitation works have been budgeted for the period 2025-2029, including foundations, anchorages, cables, struts, masts, connections, floodlights and the replacement of the roof cladding. In summary: the Munich Olympic Roof is ready for another 50 years. More information at: https://mascontext.com/observations/the-super-roof-turns-50 (visited 16/10/2025).

Feike Reitsma from IASO starred in the presentation of "The new inflatable and retractable Santiago Bernabeu Stadium Roof". The Real Madrid CF has undergone an ambitious transformation (fig. 3) in which IASO has been in charge of the design, manufacture and installation of the 5.755m² retractable roof that crowns the new stadium, an advanced solution to provides weather protection, optimised lighting and structural lightness. It consists of 10 inflatable cushions, measuring 72,5mx8m, supported by steel sliding trusses that can be opened and closed in under 25min. (fig. 4). The membrane of the cushions is Tenara 4740HF under standard pressures of 500Pa/700Pa to resist 0,60kN/m² of snow load and wind according to the wind tunnel results. The design has been validated by a large scale prototype and testing materials and details, which highlighted the need to introduce belts. For the installation, everything possible was assembled on the ground before lifting and a special auxiliary tool had to be designed because no crane was available to unfold the cushions on top of the girders (fig. 5).

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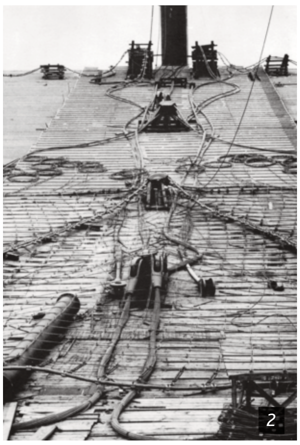

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Figure 1. Cast iron connections: intersection point at the rear edge of the stadium roof.

Figure 2. Putting the net and cables on the stands before lifting.

3

Figure 3. Transformation of the Santiago Bernabeu Stadium, Madrid (1946-2023). The 2023 version was designed by L35, GMP Architekten and Ribas & Ribas Arquitectos.

4a 4b

5

Figure 4a/b. The retractable roof open and closed.

Figure 5. Auxiliary tool to unfold the cushions.

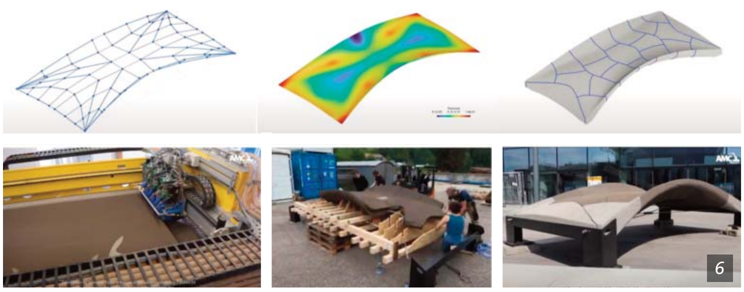

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Figure 6. 3D printed pedestrian bridge: form finding, thickness optimization, segmentation, fabrication, installation and final result.

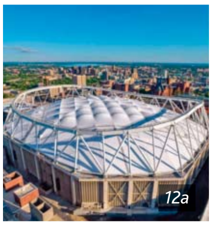


Figure 7. Living bridge made of woven aerial roots.
Figure 8. Baubotanik Footbridge.
Figure 9. Tanzlinde, Peesten.
Figure 10. Arbor Kitchen, Wald-Ruhestetten.
Figure 11. Arbor Forum. Baubotanischer Pavilion, Campus Garching.

Figure 12a/b/c. Geiger Engineers, 2020: JMA Wireless Dome, Syracuse University, NY: completed, under installation and detail.
Figure 13. Hawar Hotel, Bahrain.
Figure 14. "Rikudometro", a recreational area made by WAGG Argentina with Serge Ferrari.

Kathrin Dörfler from TUM explored through case studies how integrating appropriate materials with robotic building processes achieves a balance between functionality, resource efficiency, and architectural design. As in the case of a 3D-printed concrete pedestrian bridge "Bridge the Gap", a full-scale prototype of a 5-meter-span bridge that was structurally designed, engineered, and manufactured as a collaborative demonstrator additively manufactured with particle-bed 3D printing by Selective Cement Paste Intrusion (fig. 6). The initial design concept was developed using computational tools for structural form-finding in combination with digital fabrication technologies for additive manufacturing. In this context, structural form-finding allowed for the effective use of material resources by taking advantage of the interplay of form and forces. Graphic-statics-based form-finding approaches were employed, and the geometry of the bridge was specifically optimized to take advantage of the innovative 3D-printing method Selective Paste Intrusion. As a result, the primary structure of the bridge was designed as a thin, vaulted geometry made of 3D-printed concrete segments under compression. Other approaches were: one-component building elements considering thermal and load-bearing requirements, the climate-responsive robotic brickwork for monolithic building envelopes and the intrusion air additive manufacturing for earth-based material mixtures. In summary, the need for technological advancements and collaborative efforts across architecture and engineering to take on the energy transition and enable sustainable digital construction was highlighted.

Ferdinand Ludwig, from the Office for Living Architecture - TUM, was in charge of the fourth plenary lecture: "Growing architecture". Starting from our built environment where heat-related mortality is increasing, he looked to the trees as a solution. Inspired by the living bridges of the indigenous Khasi people (fig. 7), he proposed to merge buildings with trees showing how human can inhabit the treetops of growing architecture such as the Baubotanik Footbridge, built in 2005 near Lake Constance (fig. 8) or the Tanzlinde in Peesten, an emblematic example of the fusion of tree and building (fig. 9). The Arbor Kitchen is another attempt to take a group of trees to support a roof (fig. 10) and the case in which a textile roof is supported by trees (fig. 11). More about these ideas and essays in F.Ludwig & D.Schonle, 2023: "Growing Architecture. How to Design and Build with Trees", Birkhäuser, Basel.

Next plenary lecture (the fifth) "Planning, Designing, Engineering, and Constructing a Long-Span Lightweight Tension Structure Project", was carried out by David Campbell, principal of Geiger Engineers. He summarized the development of the new roof for the Syracuse University Stadium, the JMA Wireless Dome (formerly Carrier Dome). It began in 2017 and was completed in September of 2020. The 1980 Carrier Dome, a multipurpose 50.000 seat stadium was covered by a low-profile cable restrained air-supported fabric roof, engineered by Geiger Berger Associates. As its PTFE-coated fibre-glass fabric was approaching the end of its service life, Syracuse University engaged Geiger Engineers to replace the roof with a passive long-span structure, taking into account that unique circumstances such as client preferences and constraints of replacing the roof structure of an existing stadium led to considerations not typically encountered in design of new facilities. Geiger Engineers had recent experience in the new roof for BC Place in Vancouver, BC which was invaluable in informing the design and development of the Carrier Dome new roof. The development of the primary long-span cable-net truss structure, the use of tension membrane, the selection of the type of tension membrane were presented along with the construction of the new roof (fig. 12).

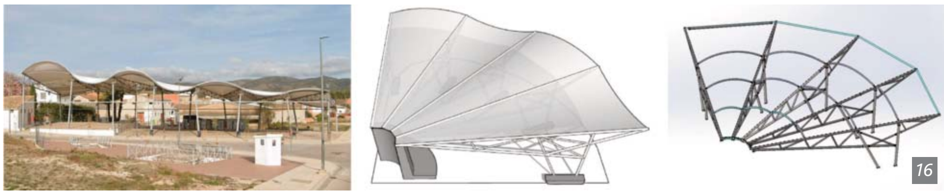
The last plenary lecture "Sustainability and lightweight architecture" was given by Françoise Fournier from the Serge Ferrari Foundation. She focused on three points: function, conception and education. Related to the function, she centered on the buffer zones that can be created to provide additional shelter and functional square meters like those of the Chrifia Golf Club in Morocco (TensiNews nº36 p.9), Hawar Hotel in Bahrain (fig. 13), the Camp in Aix en Provence (TensiNews nº34, p.4) and the covered Mshereib Plaza in Doha (TensiNews nº29, p.14). She also referred to durability, recycling and carbon footprint with an interesting comparative case study between a metal and fabric roof (TensiNews nº45 p.13). As for the conception, she showed the "Rikudometro", a recreational area made by WAGG Argentina with Serge Ferrari which did not require more than 4,4kg/m² (fig. 14). Regarding education, she mentioned the shortage of Architecture and Engineering schools teaching lightweight architecture despite its suitability to support populations who suffer from climate changes, natural disasters and wars, the raising awareness towards a green transition and the contribution to build a better tomorrow. She finally announced the support of the Ferrari Foundation to the IMS Bauhaus degree: "Archineer in Membrane Structures "and the South Africa SEA: School of Explorative Architecture, the Africa's first independent non-profit school of Architecture.

DESIGN

Carlos Angulo from Carpas Zaragoza recalled the basic principles in a rejuvenating and refreshing presentation: "Fundamental Design Principles for Tensile Membrane Structures: A Call for Structural Awareness in Architectural Practice", where curvature was qualified as a "friend" and double curvature was qualified as a "lover". He mentioned key aspects such as the form, appropriate levels of pre-stress, and sufficient stiffness of the usually metallic supporting structure. He also advocated for the adoption of self-supporting systems to minimize foundation demands, especially avoiding overturning forces that result in oversized, cost-intensive foundations. Additionally, well-considered detailing can significantly improve constructability and cost-effectiveness because efficient detailing reduces on-site issues, shortens construction times, and contributes to the overall profitability and success of the project. Some case studies illustrated these principles: one that failed (fig. 15), others that could be amended adding arches to increase curvature and help the drainage (fig. 16).

Josep Llorens from the School of Architecture of Barcelona dedicated his presentation to the stabilization of a cable dome. The need for stabilisation of a cable dome starts at the design stage because ridges, diagonals and hoops are cables in tension, meaning that they have to be pre-stressed to achieve rigidity, find the form, withstand the loads and limit deformations. That's why an adjustment method starting from the desired shape and counteracting compressions by pre-stressing has been developed (fig. 17). Structural decomposition and the equivalent simplified planar model methods have been applied. On the other hand, to overcome the difficulties that arise when it comes to assembly, some adopted solutions were presented with special mention to cranes, scaffolding, lifting platforms, cherry pickers and the big lift of spoke wheels (fig. 18).

Kai Heinlein from Technet introduced: "Cable and Cable-Net Reinforced Membranes" pointing out the increasing demand on the costumer side, because permissible stresses of membranes are limited, so that cables or cable nets can be used as reinforcements, fixed in cable pockets or sliding freely on the surface. Therefore an integrated software is needed to calculate the contact of cables and nets on surfaces quickly and easily. He mentioned several examples such as the Bus Station in Aarau, the "Oxígeno" ETFE roof in Queretaro and cable net reinforced air halls (fig. 19). He also showed the difference of considering fixed cables (submitted to not constant axial forces and friction) or sliding cables (submitted to constant axial forces and no friction), whose



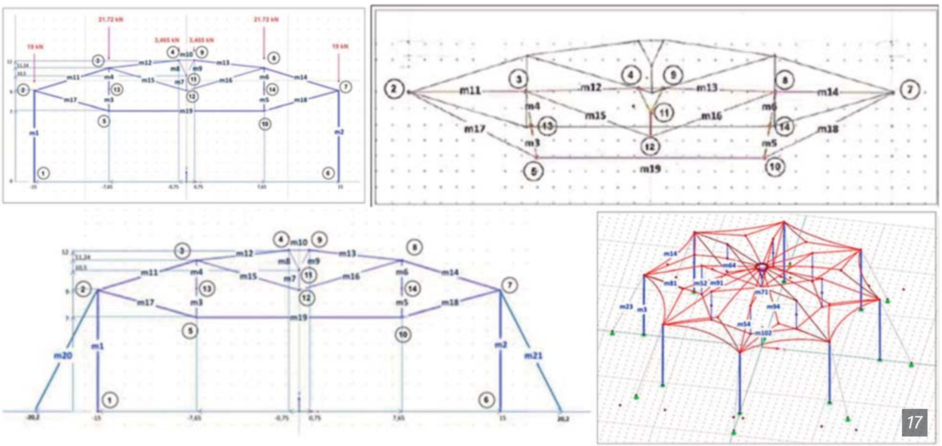
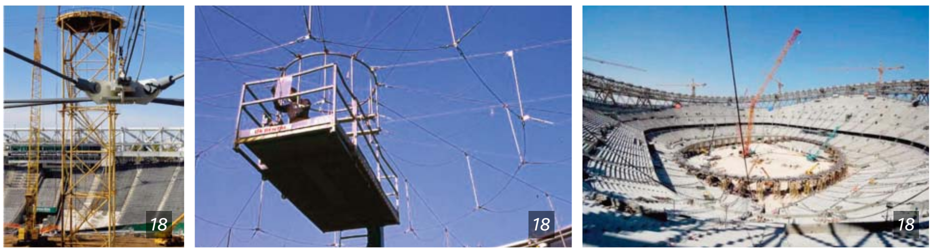
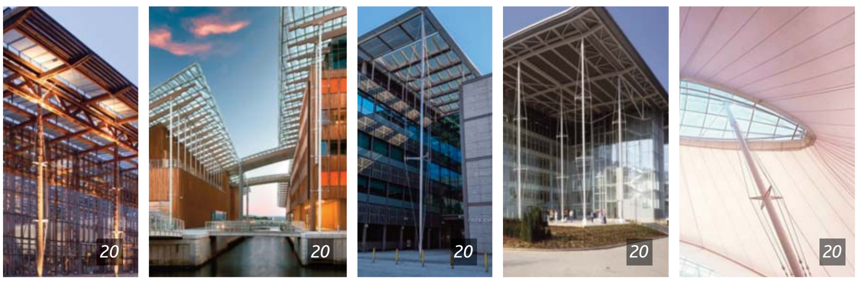


Figure 15. Flat panels and rigid edges lead to ponding.
Figure 16. Increasing curvature and helping the drainage by adding arches.
Figure 17. Four steps toward dome stabilization design.
Figure 18. Temporary auxiliary erection tower, platform lift and "big lift".
Figure 19. Vehkahalli in Jyväskylä.
Figure 20. Cable-stayed masts. From left to right: Training Academy Mont-Cenis, Herne; Astrup Fearnley Museum, Oslo; Frick Chemistry Laboratory, Princeton; Smithkline Beecham Biologicals, Rixensart; Rita Rossi Center, Baltimore.
Figure 21. "Strategyfinder" helped to meet the client expectations for the Hotel Glemmtalerhof extension, Saalbach.





position has to be a geodesic line, in which the normal vectors of the line and the surface coincide at all points. He ended up referring to the characteristics and advantages of equidistant meshes.

"Connection Detailing and Erection of Prestressed Stayed Masts: Structural Integration and Construction Methodology" was the contribution of Sudarshan Krishnan from the University of Illinois. Pre-stressed stayed masts are slender compression members stabilized through tensioned cables or rods connected via transverse cross-arms. Professor Krishnan focused on the detailing and erecting them, highlighting how these influence load path continuity, buckling capacity, and in-service behaviour. He outlined typical mast configurations and analysed connection strategies at critical interfaces — such as at mast ends, cross-arm junctions, and stay anchorages. The influence of cross-arm rigidity and geometric arrangement on mast stiffness and stability were also discussed together with erection methodologies, including prefabrication of mast assemblies, vertical lifting operations, and staged pre-tensioning of stays. The sequence of assembly and tensioning was shown to significantly affect the initial force distribution and the mast's response under axial loads. He illustrated his presentation with several examples (fig. 20).

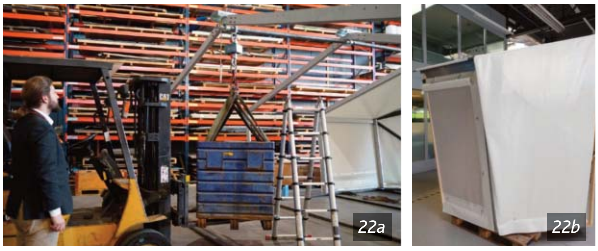
"Integrating Client Vision and Execution Details through Strategyfinder: A Case Study on Architectural Collaboration" by Robert Roithmayr from Formfinder presented a detailed examination of how "Strategyfinder" was instrumental in bridging client expectations with architectural execution in the design and construction of a hotel extension. The project's success largely hinged on seamless integration between the client's vision and the detailed architectural plans because "Strategyfinder" provided a platform for dynamic interaction and real-time updates, ensuring all stakeholders remained aligned throughout the project. It resulted in a significant improvement in client satisfaction and project outcome enabling the capture and integration of detailed client feedback into architectural plans, enhancing the project's adherence to envisioned aesthetics and functionality.
This case study (fig. 21) demonstrates that effective digital collaboration tools can significantly enhance the detailing process in architectural projects, leading to more successful outcomes and client satisfaction.

REALIZATIONS

Thommas Thommen from Bieri Tenta AG offered a focused insight into an executed tent-based textile system at the Centro Sportivo Tenero, highlighting selected decisions and outcomes. The goal was to achieve summer comfort without mechanical cooling. The method combined integrated detailing across structure and envelope with iterative verification: a 1:1 decision mock-up, geometry FEM pre-design with semi-rigid joints, a full-scale portal-frame test for joint parameter calibration (fig. 22), a hall prototype, and in-use monitoring. Structurally, the eaves strut could be eliminated by activating moment resistance at the eaves and ridge; the semi-rigid M–φ behaviour was captured by calibrated nonlinear rotational springs. On the envelope side, a back-ventilated double-layer roof with low-emissivity inner faces was detailed and manufactured under coating-related constraints. Field measurements against a legacy army tent showed markedly lower indoor temperatures in the prototype, with differences up to about 20K at ridge level and 15K near the floor, and a substantial reduction of condensation risk. The approach is transferable to tent-based textile applications where comfort, speed of installation and robust detailing are critical. He concluded with lessons learned and priorities for further monitoring and standardisation.

Bernd Stimpfle, from formTL, described the new multi-purpose roof structure of the Urban Thermal Park of Abano Terme, supported by a Mero space-frame (fig. 23) [1]. The overall geometry was carefully studied to ensure a high level of surface uniformity and optimal distribution of membrane tension, made possible by the use of nodal supports and pre-tensioned perimeter cables. One of the most innovative aspects is the rainwater management system with three central openings that have been designed to collect and channel rainwater to the buildings below. Soft up stands integrated into the membrane guide the water in these openings, and structural ring cables allow the structure to absorb local stresses and efficiently transfer vertical loads to the main frame. The membrane was produced as a single continuous piece, completely eliminating joints which significantly enhanced the overall aesthetic, giving the structure a smooth, uninterrupted appearance. The installation was carried out by a team of highly skilled technicians, who tackled the logistical and operational challenges of such a complex structure with precision and expertise, particularly for the position of the nodal points (fig. 24).

The temporary membrane cover of the glass roof of the Grand Palais, Paris, was the subject of Chloé Lefeu, from T/E/S/S (fig. 25). It was about mitigating and control the light intensity, standardize contrasts, and protect from direct sunlight the 2024 Olympic competition areas of fencing and taekwondo. The solution was a 17.000m² large-scale curved interior ceiling made of fabric panels so that the chosen fabric and its installation allow the roof framework to cast shadows on the fabric, preserving the identity of the space while highlighting the heritage of the building. It had to be justified that the loads were compatible with the existing historic structure as well as the adequacy of the temperature to ensure no risk of thermal breakage or overheating of the existing glazing. There was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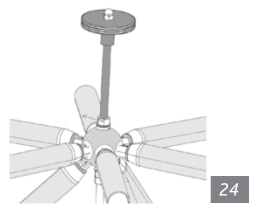
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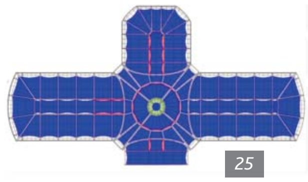
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Figure 22. a/ Full-scale portal frame test and b/corner.
Figure 23. Multi-purpose roof, Abano Terme.
Figure 24. Nodal detail.
Figure 25. Temporary textile ceiling to filter the sunlight for the Grand Palais, Paris.

also a concern for lighting and appearance under natural light in strict adherence to the criteria set by media broadcasters, sporting federations, and the Architecture Department of the Project Management team. In addition, the overall design and the development of the details were also conceived so as not to affect the structure and allow for rapid assembly and disassembly of the elements at the conclusion of the events. More information at: https://www.tess.fr/projet/voiles-grand-palais# (visited 27/10/2025).

The difficulties of refurbishment of historical buildings with membranes was addressed by Carlos Armendariz with his "Single Layer Membrane Solution for External Roofs in a Historical Building. Palacio Nacional de la Cultura, Guatemala". The challenge was to replace and improve the deteriorated and collapsed textile roofs installed in 2004 on the courtyards of the "Palacio Nacional de Cultura", a historical landmark supervised by the Institute of Anthropology and History (fig. 26). The structure has been reinforced (not replaced) to cope with the results of the wind tunnel test made on purpose and the roofs have been enlarged for better protection against sun and rain improving stability [2]. The installation had to be done with the building being fully operational, without cranes from the street or the patios. There were also difficulties arising from the protection of the architectural ornaments and the restrictions caused by the pandemic that affected workers, materials and suppliers. The initial cost (2021) of 450.000$ increased to 600.000$ for 2.400m^2 of covered surface (250$/$m^2$) due to the reinforcements of the structure. Completion time: 3 months.

Figure 26. Palacio Nacional de Cultura, Guatemala, aerial view and detail.
Figure 27. Renovation of Dresden Central Station membrane roof. Aerial view.
Figure 28. Renovation of Dresden Central Station membrane roof. Installation.

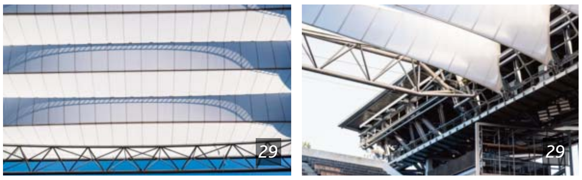
Thomas Hermeking form Pfeifer Structures showed the "Renovation of Dresden Central Station membrane roof". Dresden Central Station opened in 1898 and was severely damaged during the WWII. It had been substantially overhauled following the design of Sir Norman Foster in the years 2006/2007. The roof had been given a translucent PTFE/glass membrane cover but a lot of influencing factors during engineering, production and installation at that time, as well as problems with ice and snow have triggered the necessity to do a comprehensive renovation on this roof cover, again. Consequently, the membrane has been completely changed dividing each bay into 6 panels instead of 2 for better handling to prevent damages to the PTFE/glass and new laminated heat strengthened glass skylights on steel frames have also been incorporated to prevent snow and ice on drain funnels (fig. 27, [3]). Clamped joints have also been reviewed to allow for adjustability and absorb tolerances. The conditions of installation were highlighted because they have been extremely demanding as the operation of the station had to be maintained (14 platforms, 370 trains daily, 44 shops and 3.000m^2 of offices and service area). There was very limited space for preparation areas and scaffolding for passenger protection was necessary. Mobile cranes from the exterior sides proved to be more effective and most of the works have to be done at height with nets for protection of workers and travellers (fig. 28). Basic quantities: 32.000m^2 glass/PTFE membrane, 200T steel, 600m^2 glazing, 26.000m^2 deterrent nets against pigeons, 21.000m^2 nets for dust protection. Timeline: from July 2021 (qualification process) to November 2028 (warrant period). Execution time: from 15/03/2022 to 2025. More information at: https://www.sergeferrari.com/references/membrane-roof-renovation-dresden-central-station (visited 28/10/2025)

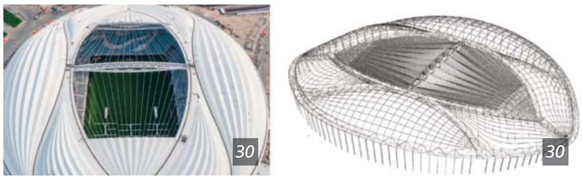
RETRACTABLE

Among the presentations dedicated to realizations, those dedicated to retractable roofs were particularly noteworthy.

Simon Aubry from T/E/S/S expanded on the presentation made at SM 2023 dedicated to the mobile roof of Suzanne Lenglen court at Roland-Garros (TensiNews 46, May 2024, p.11). In 2019, the French Tennis Federation held a competition for the design of a retractable covering for the Suzanne Lenglen court. The aim was to enable matches to be played in all weather conditions and at all times of day, including the festivities of summer 2024 in Paris. This project, designed by architect Dominique Perrault and T/E/S/S, reached one year and a half of exploitation. Its fabrication and assembly of the membrane roof, the challenges met during this phase and feedback of the project after one year of use by the client were shown (fig. 29). The mobile membrane roof is made of TENARA PTFE membrane, composed of 21 V-shaped tensioned fabric modules which span between ridge and valley cables. The membrane covers a total area of 4.800m^2. Each module is 5m wide and 44m long. When the roof is deployed, the cables are tensioned and maintain a back-to-back catenary configuration which resists both positive and negative vertically applied loads, while providing the form-found geometry for the membrane. This large retractable roof is paired with the Philippe Chatrier one, also at Roland Garros, completed in 2020.

Martin Jenni from Pfeifer Systems described the replacement of the Al Janoub Stadium retractable roof in Al Wakrah, Qatar (fig. 30). It turned out that after making the translucent retractable cover, they needed it to be weatherproof and opaque to meet temperature, humidity and light transmission standards in a very short time. Therefore, there has been no other option but to reduce components and welds with less layers and a special concern for belt sewing in 2 months. Gaps between the membrane and the fixed aluminium roof had to be closed which has required 11.000m^2 of opaque membrane and 4.000m^2 of closure flaps. The key question was: how to tackle this full speed project? The timeline began in February 2025 and will end next January 2026 (11 months), that is less than half of the original duration. For this purpose, the design has been updated for easier fabrication with similar design teams and identical suppliers. Special fabrication machines have been used allowing for more





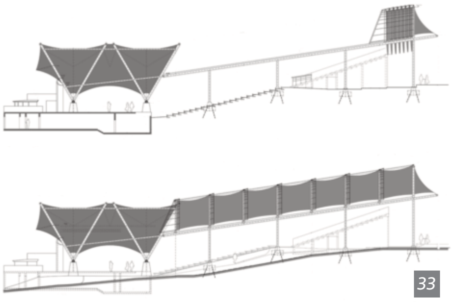


Figure 29. Suzanne Lenglen court retractable roof, Roland Garros.

Figure 30. Al Janoub Stadium retractable roof in Al Wakrah, Qatar.

Figure 31. Movable acoustic panels of the Avicii Arena, Stockholm.

Figure 32. Left: acoustic panels during deployment. Their connection to the rails is flexible to remain independent from local deviations of the rails. Right: bent angle-cut rails connected to the cable net.

Figure 33. Retractable roof over the historic natural theatre in Bad Elster.

Figure 34.a/roof in parked position. b/ roof closed.

work in parallel in China and Austria to end up in Qatar with the transport carried out by air with size limitations. This process includes the removal of the old roof without it yet having been assigned a destination. In summary: an experience-driven, adaptive approach will achieve the dual objective of delivering the highest quality membrane architecture within compressed project timelines.

"The Avicii Arena retractable ceiling: innovative design and installation" was the contribution of Thiago Perez de los Santos, from Lanaro SRL. The Avicii Arena in Stockholm, required a refurbishment to adapt its acoustics for both concerts and ice hockey events due to its perfect sphere shape (fig. 31). Concerts required improved reverberation control through suspended acoustic panels, while sports events required the maximum possible volume. The project therefore demanded the installation of a retractable ceiling system that could transform the acoustic behaviour of the arena within minutes. It features a lightweight acoustic membrane mounted on aluminium frame panels, guided by motorized trolleys and chain drives (fig. 32). Controlled via an advanced software interface, the roof can transition from fully open to fully closed in less than 10 minutes, covering a maximum distance of 60m in the longest bay. The project's modular design ensures adaptability, while preventive maintenance procedures maintain the system integrity. The presentation highlighted the design, manufacturing, and installation process, emphasizing the challenges overcome, key innovations, and lessons learned from modernizing an existing venue.

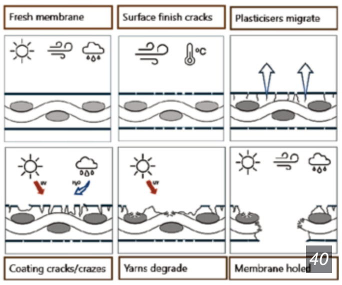
Alexander Hub from AR Ingenieure showed the retractable roof over the historic natural theatre in Bad Elster. The Naturtheatre in Bas Elster is sheltered by a stationary roof over the stage and a retractable roof over the audience (fig. 33). The two roofs were implemented in separate construction phases, but were planned as an integrated solution from the outset. In order to minimize the impact of the retractable roof on the open-air character of the facility, the spectator roof was mounted on two parallel, 48m-long rails, each of which supported by 4 columns along the side of the seating area. A series of specially developed details enabled the design of a simple, lightweight roof construction. The base point detail of the sliding tubular steel arches was designed to ensure both the lateral clamping of the roof's arches, while allowing them to be moved as close together as possible in the parking position. Since the parking position is at the highest point of the structure, a solution was developed to eliminate the need for a fixed, secondary protective roof for the parked membrane (fig. 34). In summary: the requirements of this project are characterized by the integration of design, structural, and, in particular, technical aspects. Careful coordination of the interplay between kinematic and structural requirements has been necessary to guarantee the flawless operation of the completed system.

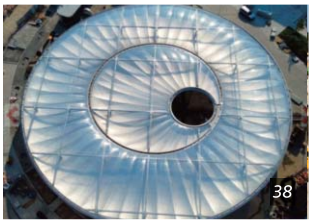
EDUCATION

A modular wooden pavilion with a membrane roof to house the student association has been built in the Stuttgart Technical University of Applied Sciences and presented at the conference by Jan Cremers (fig. 35). The building is a place for meetings, research, transfer and teaching. The project fulfils the highest standards of sustainability, e.g. no coatings or glue, no nail plates, but instead single-material, detachable timber connections, use of calamity wood and a maximum of re-use-material. The modular primary timber construction is equipped with interchangeable rigid and movable filling elements, which will be used to investigate renewable raw materials in teaching and research projects. As many joints as possible have been produced in the students'

Figure 35. Modular wooden pavilion, Stuttgart Technical University of Applied Sciences.

workshops. The membrane material came from a local construction site and has been processed, cut and cleaned by students at the university and put together with the help of a specialized company. During operation, the prototype will act as a "living lab", providing further scope for investigations and user-specific issues such as climatic comfort, flexibility, variability and forms of utilization.





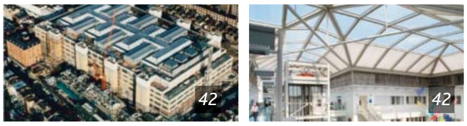


Figure 36. Cable car Olang, Kronplatz.
Figure 37. New entrance Messe Düsseldorf.
Figure 38. Rynek Lazarski market, Poznan.
Figure 39. Adidas home of football, Berlin.
Figure 40. Weathering pathway: stages of degradation resulting from environmental conditions.
Figure 41. Ludloff Architekten 2010: Sedus Stoll AG Innovation and Development Centre, Dogern.
Figure 42. Chelsea and Westminster Hospital ETFE roof.
Figure 43. Recycled meshes for textile façades: UC Gardner Neuroscience Institute.

SUSTAINABILITY. LCA

Dirk Emmer from Temme/Obermeier GmbH championed how individual architectural visions in membrane construction can be transformed into systematized solutions through intelligent detailing, strategic planning, and high levels of prefabrication by following sustainable aspects too. He presented recent projects showing distinct challenges in geometry, integration, and execution from both: foils and coated fabrics (figs. 36 to 39). He highlighted how early involvement in the design process, combined with digital tools and close interdisciplinary collaboration, allows for the optimization of membrane detailing – from special connection points to edge details and supporting structures. Some strategies for modularization, tensioning concepts, transport-friendly prefabrication and on-site installation were shown. The sustainability was also addressed. The lightweight nature, minimal material use, and high degree of prefabrication contribute to reduced resource consumption, lower embodied carbon, and minimized environmental impact during transport and construction.

Paul Romain from the University of Bath noted that many membranes have reached their life expectancy and degradation is becoming increasingly relevant. Therefore a growing body of recent research is revisiting this topic. Beyond focusing on the degradation of mechanical properties, he presented an alternative perspective based on visual and microscopic inspection of a selection of new fabrics, unused old stock and samples taken from real world naturally weathered structures (fig. 40). The observations point toward nature-based activity – such as biological growth or surface contamination – as a potential accelerant in the degradation process challenging current assumptions and offering a new perspective on membrane condition assessments. He reflected on how 'end-of-life' is defined and measured in the new paradigm of climate change. The discussion considered whether visual deterioration and acceptance criteria should be more precisely defined to customize cleaning regimes and manage client expectations; the appropriate use of high-performance coatings so as not to over specify; and how the industry may better advise clients and practitioners with respect to maintenance and inspection to extend the life expectancy of structures.

"The impact of textile shading systems in façade retrofitting: evaluating the operational phase in the LCA" was the topic addressed by Giulia Procaccini, from the Politecnico di Milano. Since buildings account for 40% of global energy consumption and CO2 emissions, making functional improvements - particularly façade energy performance - are crucial for reducing environmental impacts. Among de-carbonization strategies, façade retrofitting stands out as highly effective, addressing both the functionality and aesthetics of existing buildings. Textile-based solutions offer distinct advantages compared to traditional methods, including lightweight characteristics, minimal thickness, and ease of installation, facilitating flexible and minimally invasive interventions that reduce structural loads and limit modifications to existing structures. Their environmental performance has been assessed through a comprehensive LCA accounting for the operational phase which is often overlooked. A case study was used as reference to conclude that energy consumption during the building's use is the most significant environmental factor in the long term (fig. 41). Façade retrofitting, by improving the building's energy performance, allows for a drastic reduction of this impact, compensating for and outweighing the initial environmental burden associated with material production and installation.

Kentankumar Solanki from the Politecnico di Milano proposed the recycling of ETFE instead of the PFAS ban, a move that can be supported unanimously by manufacturers and service provider companies as well as may help save the lightweight architecture industry, which is one of the most optimal solutions to reduce the overall environmental impact. Therefore, it needs to be defined the extent to which ETFE foils can be reintroduced in the system and the first steps towards establishing a realistic life-cycle process for ETFE foil recycling. In this regard, an analysis has been conducted of the recycling of the Chelsea and Westminster Hospital roof project (London, UK), which was built in 1990 and was dismantled in 2023, that is 33 years later out in the environment, showing some damages related to bird foot marks as well as some wrinkles due to the removal process (fig. 42). The 2.444kg of reclaimed ETFE foils (2235kg of transparent foils and 209kg of printed foils) were recycled and transformed into various formulations of PCR (post-consumer recycled) base ETFE foils. The entire recycling process (dismantling, cleaning, extrusion) was described. The research will continue towards modelling the Life Cycle Assessment of recycling ETFE foils as well as assessment through experimentation of comparative material characteristics analysis, the acoustic, thermal, optical, and mechanical properties between PCR base ETFE foils as well as virgin ETFE foils to determine the efficiency of recycled ETFE foils.

The enthusiastic presentation of Katja Bernert from Mehler-Heytex: "Too much tension? Textile structures in tense environments", mentioned the rumbling times that the industry has recently encountered, coming from economic reasons and environmental aspects such as the chemical PFAS, for which palliative measures and alternatives can be sought but which remains a challenge for the coming years. There is also a lack of recycling systems because chemical as well as mechanical procedures failed to provide raw material for new coated fabrics to be used in tensile projects, although an approach has been present on the market: using recycled polyester, e.g. from PET bottles, for spinning the yarn and hence weave recycled fabrics. A slow progress in establishing these recycled meshes – for example for textile façades – showcase another good idea awaiting implementation (fig. 43). Apart from these environmental challenges, some key players of the industry are closing their business and essential raw materials are under heavy tariff pressure, resulting in a price increase that challenges one of the industry's main assets: apart from being lightweight, being a low cost material due to the mere savings on mass.

RESEARCH

The contribution of Jörg Uhlemann from the University of Duisburg-Essen: "Assembly influences on the long-term load-bearing capacity of glass/PTFE fabrics" provided an overview of the current state of knowledge on the influence of weathering and creases on the long-term load-bearing capacity of glass/PTFE fabrics as well as recommendations for the correct installation of such membrane structures in order to avoid long-term damages. He was based on tests made on the fabric used to roof the Dresden Station, where crease folds appeared reducing long-term capacity of the membrane and causing its replacement before the end of its planned service life (fig. 27).

It was found that:
- Rolling up of the manufactured membrane, its packaging and transport and its installation on site are particularly important factors in terms of load-bearing capacity of the glass/PTFE fabric, meaning that special care must be taken to avoid creases of any kind.
- Tight external inspections carried out by specially trained personnel are necessary for the manufacturing process, during packaging, when loading onto the truck/ship container, during unloading and installation.
- Stepping on the membrane during installation should be kept to a minimum and avoided if possible, while stepping on existing creases must be strictly prohibited.
- Weld shrinkage folds and sharp creases must be assessed from and engineering perspective to determine whether they can remain or whether the corresponding panels need to be replaced.

Karl Kopelmann from the TUD Dresden University of Technology with his presentation "Monitoring of Structural Membranes through a novel integrally manufactured Strain Sensor Network", was interested in determining the actual condition and state of degradation of installed membranes as well as the possibility to detect and locate damages or critical loads experienced through environmental conditions. For that he presented a successful prototype of strain sensors incorporated into the woven fabric to obtain its mechanical characterization implementing an AI-based regression model. Further research will scale-up to larger structures, adapt to complex shapes, provide guidelines for sensor layout and processing units and improve computational processing to reduce effort for model training.

With "Development of a pneumatic actuator based on bio-PU coated fabrics for architectural applications" Paolo Beccarelli from the University of Nottingham showed the development of a pneumatic actuator based on bio-PU coated bio-PA fabrics (fig. 44). The soft textile-based pneumatic actuator consists of a coated fabric structure that can be pressurised. The demonstrator is based on the concept of a flexible tube divided into two airtight chambers. The pressure/vacuum applied to the two chambers develops a tensile force which is transferred to the fins (i.e. the movable parts), achieving the desired movement (open/closed). Aims of this research are to demonstrate the use of bio-PU fabric as pneumatic envelope and find the implementation of sustainable fabric on adaptive building envelopes.

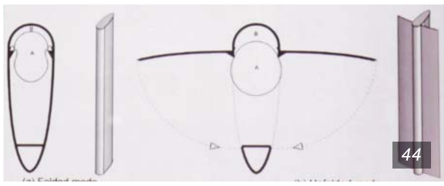
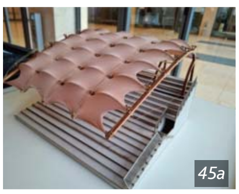


Figure 44. Adaptive building system actuated by air pressure.

OTHER ACTIVITIES

Apart from the reported lectures, 34 other presentations were held in parallel related to numerical methods, challenging conditions, fluid-structure interaction, parametric design and ETFE films. The welcome reception was held in the TUM Immatrikulationshalle together with the exhibition of TUM selected students' Membrane Workshop projects, a joint teaching activity of the chairs of Structural Analysis and Structural Design, taught by Ann-Kathrin Goldbach and Lars Schiemann (fig. 45). The conference dinner was at Cafe Reitschule, a historic venue with more than 100 years of tradition, located in the heart of Munich near the Englischer Garten (fig. 46) while meals were served in the impressive Louis Khan style TUM cafeteria (fig. 47).

Figure 45. TUM Membrane Workshop projects.
Figure 46. Cafe Reitschule, Munich.
Figure 47. Brutalist TUM cafeteria.



NEXT CONFERENCE

The thirteenth International Structural Membranes Conference will be held in Barcelona, 2027. Further information will be made available at: https://structuralmembranes2027.cimne.com/

REFERENCES

[1] M.Canobbio & B.Stimpfle, 2025: "Completion of the new multi-purpose roof in urban park Abano Terme", TensiNews 48, April, p.4-5.
[2] C.Armendariz & F.Rigato, 2024: "Palacio Nacional de la Cultura. Guatemala", TensiNews 44, April, p.8-9.
[3] T.Hermeking, 2024: "Renovation of the Dresden Central Station roof", TensiNet 47, September, p.18-19.

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REPORT

FORM AND STRUCTURE at the World Expo in Osaka 2025

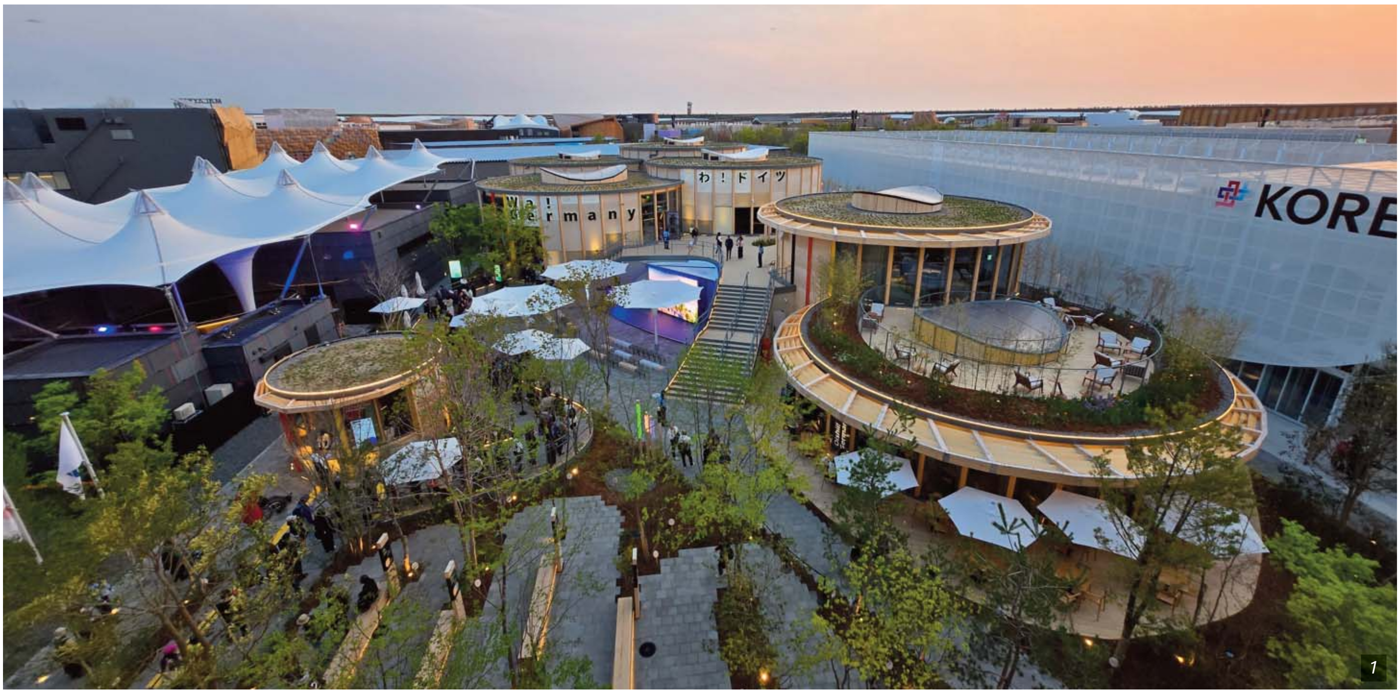

Figure 1. View of the exhibition site, with the pavilion for Luxembourg, Germany and Korea © Julian Lienhard

Two structural strategies for sustainability

1 — Minimising material through form–structure relationships

The first strategy follows the classical logic of lightweight construction: reducing material by carefully aligning architectural form with structural behaviour.

Historically, this approach has produced some of the most influential structures in Expo history. Frei Otto's German Pavilion at Expo 1967 in Montreal demonstrated how cable-net structures could emerge directly from physical form-finding processes.

At Expo Osaka 2025 only a few examples could be found that consistently followed this approach. The roof of the Luxembourg Pavilion (SteinmetzDemeyer Architects, Ney & Partners) was one of the only mechanically pre-stressed membrane structures showcasing some geometric complexity. Another example of form-driven structural thinking was the Blue Ocean Dome by Shigeru Ban Architects. The three shells were constructed with three different materials, Carbon fibre tubes, elastically bent timber and paper-tube, showcasing what is currently possible in gridshell design.

Especially in light of the breakthrough achievements in textile architecture at Expo Osaka 1970, it was surprising that the majority of membrane structures did not explore the structural potential of membranes. Structures such as the Osaka Healthcare Pavilion by Tohata Architects & Engineers claim to be *"environmentally symbiotic architecture that contributes to the realization of SDGs and a decarbonized society"*, yet construct a massive steel space frame to force an ETFE film into a membrane-like geometry of intersecting spheres that apparently cannot free-span. Fifteen years ago, at Expo Shanghai 2010, we saw the world's largest membrane structure in the form of the Expo Axis. While no data is publicly available, one can only assume that the amount of steel per square metre differs significantly between these two projects.

Structural engineering ultimately deals with measurable physical phenomena: forces, material behaviour, and energy flows. Resource efficiency therefore depends on quantifiable parameters such as embodied carbon, material consumption, and life-cycle performance. Consequently, projects that claim to be sustainable through lightweight construction should prove their case less through words and more through numbers. A mechanically pre-stressed membrane can be built with steel structures using less than 20kg/m^2, gridshells less than 35kg/m^2, and space frames less than 50kg/m^2.

Projects that formally and materially suggest belonging to these typologies yet remain far from achieving these minimal weight criteria should re-examine the relationship between form and structure. It is as simple as that. Yet it is precisely this fundamental principle—the inseparable relationship between form and structure—that seems to have been forgotten at a moment when it is needed most to address the pressing resource questions of the building sector.

The Qatar Pavilion (Kengo Kuma & Associates) illustrates this tension. From a distance, the building presents an elegant image: a white membrane roof reflected in water, accompanied by narratives referencing sailing and lightness. A closer inspection reveals that the membrane spans only a few metres between structural supports, while the primary structure consists of a robust steel frame clad in timber.

A similar ambiguity can be observed in the Swiss Pavilion (Manuel Herz Architects), where the imagery of lightweight architecture—initially planned as pneumatic bubbles—contrasts with a comparatively

Figure 2. Qatar pavilion © Julian Lienhard
Figure 3. Spatial backbone of the exhibition "The Grand Ring" @ Paolo Beccarelli

conventional structural steel system covered with poorly executed ETFE cushions. The claim that *"the shell of the exhibition spaces is composed of a foil supported by a lightweight construction. It weighs no more than 450kg—just 1% of a conventional building shell"* raises further questions: what about the underlying steel structure? And how is it possible that, 55 years after the Expo that demonstrated breakthrough pneumatic structures in Osaka, a steel support structure was required at all?

This raises an uncomfortable question: have we reached a point where the architectural image — and what is proclaimed through communication and social media — has become more important than the structural reality of the building itself?

2. Maximising reuse through demountable systems

A second strategy, more convincingly present at Expo Osaka, approaches sustainability from another direction: maximising the reuse potential of construction systems.

Expo history again provides early precedents. Joseph Paxton's Crystal Palace (1851) was based on prefabricated iron components assembled with reversible connections, allowing the building to be dismantled and relocated after the exhibition. At Expo Osaka 2025 several pavilions adopted this logic.

The German Pavilion (LAVA Architects with structural engineers str.ucture) uses a prefabricated timber structure designed for disassembly. The timber elements are currently being shipped back to Germany for reuse, while parts of the steel structure were leased and returned to suppliers after the Expo.

The most prominent structural element of the Expo, however, is the Grand Ring, designed by Sou Fujimoto Architects. The monumental circular timber structure forms the spatial backbone of the exhibition and creates a powerful collective space. Even if it cannot be considered the most material-efficient structure at this scale, it remains structurally honest: its architectural form clearly expresses the constructive system.

Encouragingly, the afterlife of the structure is already being organised. While dismantling began shortly after the Expo closed, a section of approximately 200 metres of the nearly two-kilometre ring will remain on site. The remaining timber is being distributed across Japan through a coordinated reuse programme, supporting reconstruction projects in Fukushima, new university buildings, and other public initiatives.

In total, 26 of the Expo's 84 pavilions are expected to be reused in some form, exceeding the circularity target of at least 17 originally set by the organisers.

When both strategies meet

True innovation emerges when both strategies — structural optimisation and reuse potential — are combined within a single project.

Again, the Luxembourg Pavilion managed not only to claim its reuse potential but also to document after the Expo where each component of its structure would be reused.

One of the most convincing examples at Expo Osaka 2025 is the Bahrain Pavilion (Lina Ghotmeh – Architecture with structural engineers Bollinger + Grohmann). Its timber and textile structure establishes a clear dialogue between form and structural behaviour while remaining compatible with disassembly and reuse. A similar ambition can be observed in the reciprocal timber roof of the German Pavilion, where geometric structural logic and prefabricated demountable elements work together.

These projects demonstrate how structural clarity can simultaneously support architectural expression and circular construction strategies.

A call to the lightweight community

For architects and engineers working with lightweight structures, Expo Osaka 2025 offers both encouragement and warning.
The aim should not be to maximise the use of membrane materials as façade cladding while abandoning their structural potential. Materials such as textile membranes historically carry a strong association with structural intelligence precisely because they enabled highly efficient load-bearing systems.

Rather than reducing them to decorative skins, we should insist on continuing the dialogue between form and structure — a dialogue that has defined the history of lightweight architecture at World Expos from Paxton to Frei Otto and well beyond.

World Expos have always provided the stage for such experimentation. If they are to remain relevant laboratories for structural innovation, they must continue to encourage bold structural thinking.

The next breakthroughs will not come from architectural imagery alone, but from young architects and engineers who understand the Expo as a place where form, structure, and circular construction can evolve together.

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Climate House Hortus Botanicus

Lightweight ETFE technology enabling structural reuse

Amsterdam, The Netherlands

In Amsterdam's green Plantage district stands a remarkable building: the Climate House of the Hortus Botanicus Amsterdam. Known for its contemporary high-tech steel-and-glass structure, it harmonizes with its historic surroundings through its stepped height and refined gridwork. Since 2025, its sustainability upgrade has become just as visible as the structure itself. The single-glazed façade has been replaced with insulating double glazing, and the roof now features lightweight, insulating triple-layer ETFE air cushions. ZJA Architects & Engineers, the original designers of this iconic structure in 1993, also led the redesign, while Buitink Technology realized the innovative roof (Fig. 1).

Figure 1. Aereal view of the renewed Climate House of the Hortus Botanicus Amsterdam © Buitink Technology

Sustainable renovation

After three decades, the greenhouse required a major renovation. The Hortus seized this opportunity to comprehensively renew the building with sustainability as a guiding principle. Since 2016, the greenhouse has shared heat and cold with the nearby H'ART Museum. Following the renovation, it has become the first gas-free public greenhouse in the Netherlands. The core principles of the original design were preserved — lightweight and transparent to ensure optimal daylight for the plants.

Engineering at 1% Mass

The new roof over the Climate Greenhouse can rightly be described as a technical and aesthetic achievement. Because the existing structure was reused and could not support a heavy glass roof, the designers chose for an innovative ETFE air-cushion roof. At only 1% of the weight of glass, ETFE is exceptionally lightweight, while offering 95% light transmission and a high degree of transparency. It consists of 117 ETFE cushions with a total surface area of approximately 1.500m². Nearly all cushions have a unique shape — triangles, rectangles, and chamfered rectangles — forming part of a three-dimensionally curved and domed roof surface (Figs. 2 and 3). The complete design, including the cushions and the additional supporting structure, was fully developed in BIM based on a 3D survey.

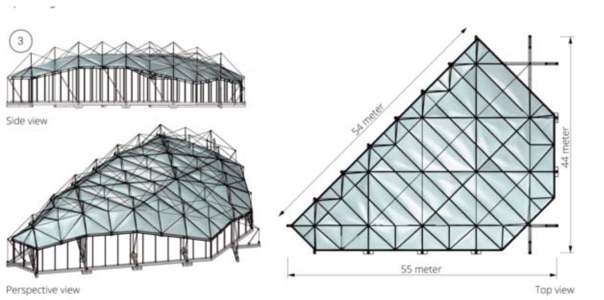

Figure 2. Drawings of the ETFE roof © Buitink Technology
Figure 3. Detail of the facade and roof © ZJA Architects & Engineers

All about climate

In addition, ETFE is highly durable (35+ years) and is resistant to UV radiation, air pollution, and other forms of contamination. Seven automated windows are integrated into the air-cushion roof and are also made of ETFE cushions. These can be opened and closed to provide natural ventilation and climate control without compromising light transmission or thermal insulation. Thanks to the upgraded climate systems, centralizes and conceals behind a new waterfall, and the reorganization of the plant collections, the greenery can now make optimal use of the building and its orientation. The perfect place for the Hortus to tell the story of biodiversity and climate change on a global scale.

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Figure 4a/b. External view © ZJA Architects & Engineers
Figure 5a/b. Internal view showing one of the automated windows © ZJA Architects & Engineers

Name of the project:	Climate House – Hortus Botanicus Amsterdam
Client:	Hortus Botanicus Amsterdam
Architect:	ZJA Architects & Engineers
Landscape architect:	BOOM Landscape
Interior Design:	Designwolf
Structural Engineer:	ABT
Main Contractor:	AKOR
Project Management:	C&R Hospitality Services
Installation Consultancy & Project Management:	Infinitus Solutions
Steel Construction:	Vic Obdam Staalbouw
Roof Supplier:	Buitink Technology
Façade Supplier:	Kingspan Light + Air
Installer:	Lek/Habo
Greenhouse Interior:	Copijn

Renewing the Membrane Roof of Hamburg's Volksparkstadion

Hamburg, Germany

Ahead of UEFA Euro 2024, Hamburg's Volksparkstadion underwent a targeted modernisation to enhance spectators' comfort. Besides an upgrade of specific areas of the bowl, another focus was on the roof, where a new audio system, new LED floodlights and architectural illumination was added. Regular inspections in 2021 revealed furthermore a marked loss of tensile strength in the original PVC-coated polyester membrane from 1999, meaning the safety margins defined in the project-specific approval were no longer met. As a consequence, the 22-year-old PVC-coated polyester membrane also had to be replaced as part of the targeted modernisation. Current codes also prescribe higher snow loads for Hamburg than those used in the original design. These factors required a complete membrane replacement and a full re-verification of the roof structure while maintaining stadium operations. The planning, verification and coordination of the works were led by schlaich bergermann partner (sbp).

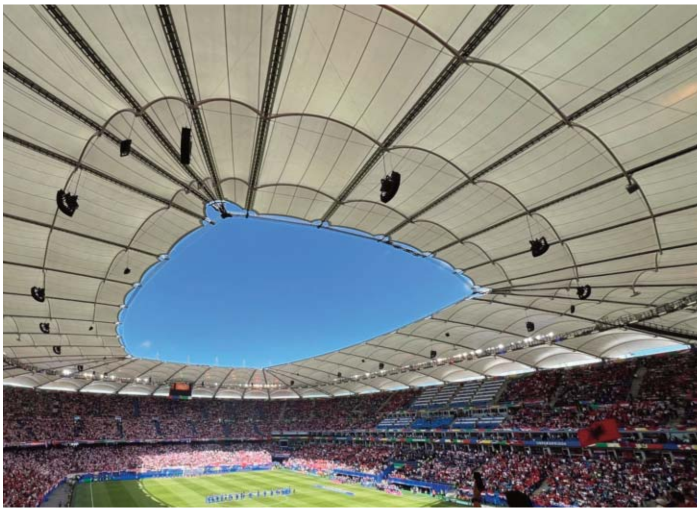

Figure 1. The renewed spoke-wheel membrane roof © sbp

The existing roof, completed in 2000, is based on a spoke-wheel system supported by 40 masts. Between the outer compression ring and the inner tension ring a layer of lower radial cables is spanning. For downward-acting loads, an additional layer of upper radial cables spans from the inner tension ring to the top of the masts. The upper and lower radial cables are connected via vertical hanger cables. The 37.400m² membrane cladding is prestressed between the lower radial cables. To shape the membrane's double-curved surface geometry, steel tube arches span tangentially between the lower radial cables. The existing structural concept served as the basis for modernisation, ensuring that the building's global behaviour and geometry were preserved while performance parameters were enhanced to align with current requirements.

Due to building permission requirements, the stadium roof structure had to be verified according to the latest standards applicable in Hamburg. Verification according to DIN EN 1991-1-3/NA prescribes a global design snow load of 1.34kN/m² for Hamburg and an exceptional snow load of 2.04kN/m² for the North German lowlands. These loads are significantly higher than those specified in the applicable Hamburg standards from 1999. To comply with these provisions, the membrane strength was increased and selected components of the primary structure were locally reinforced, without altering the spoke-wheel behaviour or the architectural character of the roof.

With the updated requirements defined and the necessary strengthening measures in place, the membrane replacement took place between August and December 2023 during ongoing matches and events. The installation was carefully sequenced to keep the cable system stable while minimizing open roof areas and ensuring that the venue's event schedule remained uninterrupted. After installation, on-site measurements verified the required prestress and geometric fit.

The new PVC-coated polyester membrane is dimensioned to the higher design actions and specified safety levels. The prestress ensures the membrane maintains its double curvature, provides reliable drainage and interacts smoothly with the arch line.

Local reinforcements were introduced at terminations, penetrations and edge zones of the membrane cladding. Fabrication and testing followed the relevant standards as specified by sbp and have been validated by an independent third party.

In parallel with the structural works, the technical systems in the roof were renewed. Cable routes were reorganized and expanded, and the stadium received a new floodlighting system and an architectural lighting scheme that enhances the perception of the roof and improves the visitor experience during evening events. All measures were completed on schedule for Euro 2024, leaving the stadium with a bright, uniformly white roof surface that reflects both the renewed membrane and the upgraded lighting.

The modernisation preserves the architectural identity of the Volksparkstadion while restoring structural performance and serviceability under current code requirements. The project demonstrates how a mature spoke-wheel membrane roof can be renewed within its existing framework to meet contemporary expectations for reliability, durability and uninterrupted operation ahead of a major tournament.

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Christoph Paech is keynote speaker at the TensiNet Membranbau symposium 2026. His lecture will focus on *Durability assessment and enhancement of membrane structures.*

Name of the project:	Modernisation Volksparkstadion Hamburg. Hamburg, Germany
Owner:	HSV Fußball AG, Hamburg
Features:	Building Refurbishment, Membrane, Roofs & Canopies
Architect:	schlaich bergermann partner
Executing company for membrane replacement:	Pfeifer Structures
Technical Data:	Roof area 37.400m²; Roof depth approx. 62m; Height 59.5m; Length 240m; Width 200m

A new membrane for the former Research Laboratory M&G Ricerche

Venafro, ITALY

The M&G Ricerche chemical industry research centre in Venafro was designed by Philippe SAMYN and PARTNERS, architects & engineers, and completed in 1991. It is part of an industrial area located in a valley surrounded by hills near Venafro. In the early 1990s, this was one of the first designs in which a membrane structure effectively served as a building with a controlled indoor climate. This meant that it became more than just a sculptural canopy.

Figure 1. The building after renovation. On this picture the oval pool still needs to be filled, Architect: Philippe SAMYN and PARTNERS, architects & engineers, photo © Canobbio Textile Engineering

The membrane was recently renewed. The renovation was carried out by the original contractor, Canobbio Textile Engineering. After 35 years, this building still has a unique appearance and architectural qualities (Fig. 1).

The research laboratory for the chemical industry was housed under one large tent-shaped roof. The programme of requirements included laboratories for heavy experiments as well as for delicate research, supplemented by function-supporting spaces. The plan allowed for the possibility of adjustments to the programme. An optimal shape for the hall led to an elliptical design (Fig. 2). The building was also designed with a focus on optimal climate control. Temperatures outside can reach 40°C in summer, while snowstorms can occur in winter. In the original building, the 'cracking' unit generated heat that was beneficial in winter. The oval reflective pool on which the building stands has high thermal regulation properties. In summer, it cools the building by drawing air in from underneath the pool.

The oval floor plan (85m by 32m) is spanned by six truss arches with a maximum height of 15m. The optimal span for the roof membrane is between 12m and 15m, which determined the number of arches. The triangular cross-section varies along the length of the arch, with maximum dimensions at the top, and taps towards the arch support. The arches are connected to each other by pre-stressed cables. These stabilising cables are connected to the arches via pyramid-shaped supports (Fig. 3). Daylight is allowed into the spaces below by a PVC-coated polyester membrane stretched between the arches.

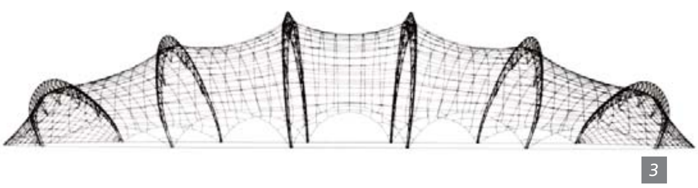

Figure 2. Original model © Philippe SAMYN and PARTNERS, architects & engineers
Figure 3. Digital model of the structure © Philippe SAMYN and PARTNERS, architects & engineers.

New owner, new function

The tensile structure and the entire surrounding area were acquired several years ago by RES – Recupero Etico Sostenibile, a company operating in the waste recovery sector. Under the existing membrane structure, RES installed a series of laboratories dedicated to material recovery testing and experimentation. Prior to our intervention, the client had already carried out a thorough cleaning and redevelopment of the site, restoring order and operational functionality to the area.

Renovation project

The first phase of the work of Canobbio Textile Engineering involved the replacement of the skylights. The existing membrane was already aged and had undergone modifications over time; therefore, the new skylights had to be designed with an adapted solution compared to the original project. A valance system with an internal tensioned cable was introduced, installed over the existing membrane, as any attempt to weld onto the aged fabric would have been ineffective and technically unreliable. Before installing the new skylights, the steel structure was also repainted and restored, improving both protection and durability.

The following year, after an exceptionally severe storm, the membrane panels - which had already reached the end of their service life - suffered extensive tearing. At that point, a complete replacement of all roof panels became unavoidable. The first step was to return to our historical archives to retrieve the original documentation, construction details, and fixing systems used at the time of the initial installation, including all modifications and improvements introduced over the years.

During the negotiation phase, we emphasized a key differentiating factor: our direct and in-depth knowledge of the original project. It is essential to understand the special fixing details, critical areas and modifications carried out in a structure of this complexity. Entrusting such an intervention to companies that have never operated on the structure represents a tangible technical risk. This awareness, combined with our specific expertise, ultimately led the client to appoint us for the refurbishment.

Once the project was launched, formTL was engaged to design the new roof membrane system (approximately 3.150m^2), including arch closure flaps, special lower closure flaps, membrane cable systems, and secondary steelwork. Serge Ferrari 1202 S2 membrane (2,65m roll width) was selected, consistent with the performance and characteristics of the original material. formTL reconstructed the cutting patterns based on the

Figure 4a/b/c/d. A challenging execution phase © Canobbio Textile Engineering

recovered historical data, accurately integrating flap geometries into the cutting models and producing complete workshop drawings, including structural steel details and cable layouts. Throughout this delicate phase, we actively supported and assisted the design process to ensure full coherence with the structural realities of the existing framework.

The execution phase represented the most challenging part of the project. Unlike the original installation in the 1990s - when the space beneath the structure was completely empty - the refurbishment had to be carried out above fully operational laboratories and technical systems. This required extremely careful planning of dismantling and installation operations.

The works were executed by our specialized rope-access team, highly experienced in tensile structures and accustomed to operating at height under complex logistical constraints. A network of webbing straps was installed between arches to allow controlled handling and deployment of the membrane panels. The crane initially planned for installation proved too heavy following ground load verification, requiring a complete reorganization of logistics. A lighter truck-mounted crane and a forklift were used instead, operating simultaneously. Adverse weather conditions further increased the complexity of the installation, yet thanks to the team's experience and coordination, all panels were successfully installed and tensioned in accordance with the design specifications (Fig. 4).

Another delicate aspect concerned the terminal portions of the panels. In the original structure, these elements had been custom-made on site with hinge systems and elastic absorption mechanisms. Replicating the same functional behaviour required testing and on-site adjustments. Furthermore, while the original project had used Crystal material for these terminal parts, the refurbishment opted to use the same membrane as the roof panels, ensuring homogeneous aging performance and improved long-term durability. Once installation and tensioning were completed, the structure was handed over ready for reopening.

This intervention highlights three key strengths: the ability of Canobbio Textile Engineering to interpret and manage a technically layered and historically complex structure; the rigorous engineering contribution of formTL in reconstructing and optimizing the membrane system; and the high operational competence of the specialized rope-access team, capable of handling a constrained and logistically demanding site without compromising safety or quality (Fig. 5).

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Project:	New membrane Research Laboratory M&G Ricerche
Location address:	Venafro, Italy
Client (original):	M & G Ricerche
Client (of the renovated structure):	RES – Recupero Etico Sostenibile
Function of building:	Laboratories and research centrum
Year of construction:	1990
Year of renovation:	2024
Architects:	Philippe SAMYN and PARTNERS, architects & engineers
Structural engineers:	formTL
Tensile membrane contractor:	Canobbio Textile Engineering
Manufacture and installation:	Canobbio Textile Engineering
Material:	Serge Ferrari 1202 S2 membrane
Covered surface (roofed area):	2700m²

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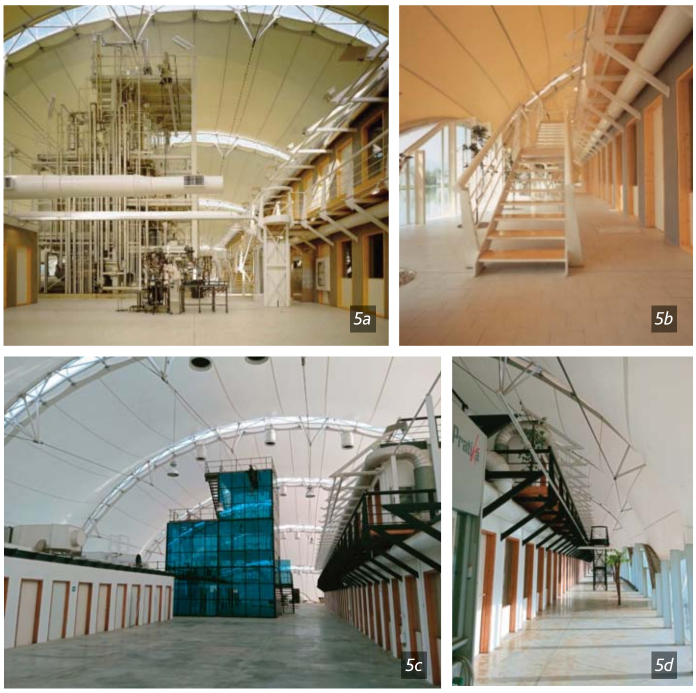

Figure 5. a/ b. Pictures of the original membrane structure © Philippe SAMYN and PARTNERS, architects & engineers; c /d. Pictures of the renovated membrane structure © Canobbio Textile Engineering

Masserberg Health Centre

Germany

Completed in 1994 the membrane roof of the Health Centre in Masserberg, Thuringia is the only architectural membrane project that was ever realised with the PVC-coated membrane Type VII, a material with a tensile strength of 400kN/m. Today material available on the market reach only half of this strength. Due to the very thick coating on this membrane material with a total thickness of almost 3mm, the fabric is protected very well, which is one reason why the membrane has aged only very slowly (Fig. 1).

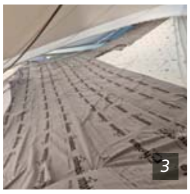

Figure 1a. Membrane roof after installation - 1994 © formTL
Figure 1b. Membrane roof inspected – 2020 © formTL
Figure 2. New membrane and cone tops during the ongoing installation © formTL
Figure 3. Insulation and breathing membrane © formTL
Figure 4. New corner plates in comparison with the existing plates © formTL
Figure 5 a. New membrane with integrated translucent skylights © formTL
Figure 5 b. Skylights integrated in the inner membrane © formTL

The bath area and the gymnastic zone was constructed with a double-layer roof thermally insulated with mineral wool on the inner membrane. The insulation consisted of two layers with 80mm thickness, fixed with metal pins on the membrane.

The outer membrane in PVC-PES type VII covers an area of approximately 3.300m². The membrane consists of six cones supported by six primary masts with 508mm diameter and tensioned towards the outside by a total of 33 columns with tie down elements such as cables or steel pipes.

The inner membrane made of PVC-PES type III membrane covers two third of the project and forms together with the perimeter façades an air- and watertight envelope. The inner membrane is supported with additional steel rings on the main masts and linear fixed along the façade.

The Thuringian Forest region is undergoing a state-funded touristic repositioning. Within this framework, the bathing facility will be completely refurbished, significantly increasing its appeal. The membrane roof, as a defining architectural feature, forms an integral part of the project. Its modern design not only enhances the visual identity of the building but also contributes to sustainable operation by using durable materials and improved insulation (Fig. 2).

The external membrane is replaced with PVC-coated polyester fabric Type V, which, unlike the original material, meets the required fire classification “flame-retardant”. Being only half as strong as the original material, in the areas of the cones, the membrane is locally reinforced in accordance with the acting loads. This results into zones with double and triple layer membrane.

The existing inner membrane remains in place, as it is still in good condition. To enhance the thermal performance of the roof, the current mineral wool insulation is replaced with a 240mm thick polyester fleece insulation. The insulation as well fulfils the requirement “flame-retardant”. The thermal transmittance (U-value) of the insulated membrane structure is so improved form the former 0.24W/m²K to now around 0.16W/m²K (Fig. 3).

The cone tops of the inner membrane were previously insulated and opaque. To introduce daylight into the interior at these locations, they are now fitted with insulated glazing. At the same time, the existing sheet metal cladding of the outer cone tops is replaced with a highly translucent membrane (Fig. 5).

The corrosion protection of all steel elements as well as that of all reused cables is reinstated. Membrane cables are replaced.

The installation is still ongoing. The main membrane is in place, the new roof lights are integrated on the inner membrane together with the installation of the new insulation system. The insulation work continues now in the rigid zones together with the installation of new services bridges to access the technical facilities without damaging the insulation.

Now after the winter the membrane will be tensioned into its final position and to the final stress level, and with the higher temperatures also the corrosion protection work can be finalised, with the goal to do all this before the summer.

As the interior refurbishment of the bathing facility has only just begun, a little more patience is required before visitors can once again swim or relax beneath the new roof.

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Project:	Gesundheitszentrum, Masserberg, Thuringia, Germany
Client:	Municipality of Masserberg
Membrane Contractor:	Temme // Obermeier, Rosenheim, Germany
Manufacturing:	Canobbio Textile Engineering
Membrane installation:	Montageservice LB, Germany
Membrane Material:	Sattler, Austria, 780 Atlas Architecture Type V
Cables:	Fatzer, Switzerland
Surface Area:	3670m²
Dimensions:	135m length, 60m width, 25m height