TensiNews

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ARTICLE

TENSINET WORKING GROUP SUSTAINABILITY AND COMFORT: EPDS

RESARCH

THE MEMBRANE HOUSE

PROJECTS

ENTRY CANOPY FOR KANCHAN BUNGALOW

AL MARYAH ISLAND SPORTS DOME

THE THREE-DIMENSIONAL FAÇADE OF THE DELANCEY AND ESSEX MUNICIPAL PARKING GARAGE

HULASOL PARASOL IN TERVUREN, BELGIUM © STUDIO 360

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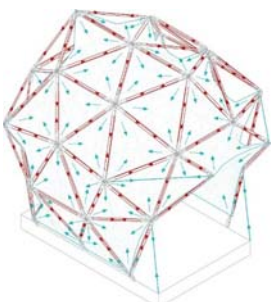
Sustainability & Comfort Working Group TensiNet



Edito

Dear Reader

Just some days have passed since the Structural Membranes symposium took place as a virtual conference. It was a pleasure to see and meet colleagues and friends in virtual coffee or lunch breaks, and to listen to their interesting contributions.

Another symposium approaching fast, is the Advanced Building Skins Conference in Bern. TensiNet will chair two sessions and will have a booth there. I hope that many of you have the chance to go there. The organisation of our next TensiNet Symposium, taking place in Nantes, is also advancing. We have defined our main topics, and will soon launch a call for abstracts. The exact date still needs to be defined, but it is supposed to be before the summer 2023. You find more detailed information in this TensiNews and on our website about these conferences.

Our working group Specification and Eurocode has contributed together with the European and National committees to the final draft of a Technical Specification for membrane structures. We look forward to the finalisation of this document, and the submission to CEN. We are very proud about the vital input to our working group Sustainability and Comfort during the last year. Some articles herein are dedicated to this topic. One reports about the internal seminars on EPDs, while another describes the creation and publication process of EPDs. A new material made of fully upcycled polyester is also contributing to the topic sustainability.

Research results are presented about the impact of climatic loads to a thin bending active shell, and the development of a modular membrane house, for temporary use, as a sustainable solution to create emergency architecture where needed.

Beside this you find also interesting projects presented, a canopy in India made of cable net and membrane, a large air dome in Abu Dhabi and a façade project with synthetic cables in the USA.

I hope that many of you will come to Bern to our sessions and booth, so that we can meet again in real. Meanwhile please enjoy this issue of TensiNews and stay healthy.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

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

International Conference on Advanced Building Skins 2021 | *21–22/10/2021* | Bern, Switzerland
www.abs.green

Aachen-Dresden-Denkendorf International Textile Conference 2021 | **VIRTUAL EDITION** | *9-10/11/2021* | Stuttgart, Germany |
https://www.aachen-dresden-denkendorf.de/en/itc/

Textile Roofs 2022 | *9-11/05/2022* | Berlin, Germany | **https://www.textile-roofs.com/**

Techtextil & Texprocess 2022 *Beyond innovation*
21-24/06/2022 | Frankfurt am Main, Germany |
https://techtextil.messefrankfurt.com/frankfurt/en.html

IASS Annual Symposium and Asia-Pacific Conference on Spatial Structures (APCS) 2022
Innovation, Sustainability and Legacy | *19-23/09/2022* | Beijing, China |

TensiNet Activities

TensiNet at Advanced Building Skins 2021

TensiNet will be represented at the 16th Conference on Advanced Building Skins with two TensiNet sessions on Membrane Architecture: **"Skins from fabrics and foils"** and **"Building Membrane Cladding Systems"**. TensiNet will welcome members and non-members during the TensiNet & Friends meeting. Finally a Permanent Members meeting will be organised as well.

Thursday 21st October
18.00 – 18.45 TensiNet & Friends meeting
18.45 – 19.15 Permanent Members meeting
Friday 22nd October
08.30 – 10.00 Skins from fabrics and foils
10.45 – 12.30 Building Membrane Cladding Systems

ONE OF THE 25 BELGIAN DESIGNS AT MILAN DESIGN WEEK 2020

The Hulasol parasol

Lin Bertels and Peter Mortelmans of Solspiration have dedicated five years of research and development to make the new Hulasol parasol (diameter 270cm) which has a nice shape open as well as closed.
The fabric used is made of premium high strength solution-dyed polyester, a patented outdoor performance fabric, which guarantees that colours resist fading, and fabrics will not degrade after many years of exposure to the sun.
The Hulasol parasol is functional during the day and at night, as it has an integrated Bluetooth-controlled LED lighting.
Moreover, one person can easily open and close the parasol when needed.

HULASOL PARASOL, CLOSED AND OPEN © KOLLECTIV NEGATIV

SATTLER PRO-TEX GMBH

Entry Canopy for Kanchan Bungalow

India

1

2

There is nothing more impressive than making a grand entry. If you are able to attempt something that has never been attempted in India while making that grand a statement, so much the better.
This membrane canopy structure was designed and conceptualized with Mr. Vipul Mehta, who introduced this to the client. Being an engineer, the client loved the concept and the experimental nature of the structure and commissioned the roof. The membrane canopy structure was to display the extraordinary capability of Sattler 745 Polyplan Tent Light fabric, as it was intended not to be used as a tensile canopy, but more as a "cover", over an existing grid of a doubly curved cable net structure. Since this is a private client, albeit a very high profile one, the intent was to provide a product that gives the best performance at the same time delivering the beauty of the form.

Design

A firm belief of Schafbock Design Workshop is that not every "great project" has to be big, cost a fortune or be for the purpose of "public service". When it is designed by someone who masters the fundamentals of surface tensile structures, understands how forces flow through a system, blends physics and mathematics in simulation and unlocks the beauty of the natural forms, where all forces are "simply" in equilibrium, it results in something beautiful, inspiring, timeless and inspirational. Along with demonstrating these principles it needs to be designed with acute detailing and with understanding of the flow of water over the system (so that there are no ugly drips over a period or corrosion marks); in addition the choice of materials is something that was specially of interest and a challenge for this project, as the land is prone to fungal attack and corrosion due to the sparse landscape.
The Design was conceptualized simply as a typical "pringle chip" shape using a 12m diameter structure as the centerline. Everything was extrapolated from the system. Due to the fact that LS-Dyna, ixCube 4-10, Rhinoceros 3d and Grasshopper were used for various aspects of the job, it was of utmost importance that all the software spoke the same language. This was achieved by using "mathematics". All information flow between the software happened through numbers, be it in terms of connectivity of members, exchange of prestress forces or geometry coordinates. IxCube 4-10 as a software was very

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SATTLER PRO-TEX GMBH

Al Maryah Island Sports Dome

Abu Dhabi, UAE

THE BIGGEST AIR SUPPORTED DOME STRUCTURE IN THE MIDDLE EAST

The new indoor sports facility is a fully air-conditioned sports dome, built in the strategically located recreational area of Al Maryah Island, Abu Dhabi, by DUOL with SATTLER membranes. C&G Engineering Service S.r.l. from Italy was doing load calculations because the authorities wanted to have a full analysis of the air dome.

Insulated air dome

The world-class indoor football facility is the first dome with the DUOL ECO Ultra insulation in the UAE. The insulation is specially designed for air domes and extreme weather conditions. It increases immensely the membrane insulation efficiency and significantly reduces the U-value. The lightweight insulation system reduces the required cooling by 70%, minimizes the heating and/or cooling costs, has a rock-solid design as well as a long lifespan.

DUOL developed this tremendous efficient insulation system with the "Titan" under the membranes, the so-called **ATLAS Architecture Type 4 (art. 760)** and **POLYPLAN Tent Antiwicking (art. 787)** produced by SATTLER.

helpful in developing the information flow. Using ixCube 4-10 also helped in developing accurate cutting patterns which significantly reduced production time and errors on site. A 3d site survey that was undertaken on site after finishing the steel structure, gave a very small deviation from the original design: this stands testimony to the fact that the quality check, design detail geometry, quality of work and continuous monitoring of the structure during production really paid off in the long term.

Figures 1-2. Front and side view of the entry canopy © SCHAFBOCK DESIGN WORKSHOP
Figures 3-5. Erection process © SCHAFBOCK DESIGN WORKSHOP

Challenges

To be able to translate a trigonometric curve onto site, is an arduous task, especially while dealing with craftsmen who are illiterate and depend on two dimensional drawings to be able to fabricate work. Therefore, programs were written, multiple sampling and testing were carried out for cables, junctions as well as the fabrication protocol, to ensure that the structure geometry would not pose any surprises when it was assembled on site. The Software ixCube 4-10 had a big role in simplifying the process, thanks to its flexibility and ease of operation.

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Name of the project:	Entry Canopy for Kanchan Bungalows
Location address:	Kanchan Bungalow, Bhuj, Gujarat, India
Client (investor):	Agrocel Industries Ltd., Mr. Dipesh Shroff
Function of building:	Entry canopy
Type of application of the membrane:	Drop off canopy
Year of construction:	2020
Architects:	Mr. Vipul Mehta
Multi-disciplinary engineering:	SCHAFBOCK DESIGN WORKSHOP
Structural engineer:	Mr. Vipul Mehta
Consulting engineer for the membrane:	SCHAFBOCK DESIGN WORKSHOP
Software used:	ixCube 4-10; LS-Dyna; Rhinoceros 3d; Grasshopper
Contractor for the membrane : (Tensile membrane contractor)	SCHAFBOCK DESIGN WORKSHOP
Supplier of the membrane material:	Sattler PRO-TEX Gmbh (through B&V Membranes in India)
Manufacture of the membrane:	B & V Membrane, MHAPE, Mumbai
Material:	Sattler 745 Polyplan Tent Light.
Covered surface (roofed area):	130m²

- ATLAS Architecture membranes stand for aesthetic design, strength, protection and longevity. The ATLAS membranes are revolutionary and unique fabrics, based on a better PVC-coating and an innovative ATLAS weave structure applied to architecture membranes. These fabrics open a wide range of new and amazing possibilities for your projects. The block-out version of this membrane offers 100% protection against light and UV-rays and darkens a room completely.
- POLYPLAN Tent Antiwicking is a high-strength anti-wicking polyester fabric with increased UV-stabilized soft-PVC coating on both sides. The membrane has a white fungicide finish, is lacquered on both sides and is flame retardant according to the most common standards.

Both membranes were perfectly suited for this project.

The dome's headline act will be a full 11-aside FIFA-approved turf pitch with a spectator area, giving year-round functionality, for play, competitions and private functions. It will host Manchester City's Abu Dhabi program, City Football Schools, and LaLiga Academy, helping players improve their football skills. It will also features the Zayed Sports City academy. A spokesperson for Al Maryah Island said, "We have collaborated with global leaders in recreation and entertainment to bring the Abu Dhabi community the best experience. These plans are also enabling Al Maryah Island to further their horizons to deliver on bespoke community events and strengthen Abu Dhabi's position in the global tourism market."

Figure 1 – 2. External and internal view of the air dome © DUOL doo

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Name of the project:	Al Maryah Island Sports Dome
Location address:	Al Maryah Island, Abu Dhabi, UAE
Client (investor):	Government of Abu Dhabi
Function of building:	indoor football facility
Type of application of the membrane:	Air supported structure
Year of construction:	2021
Structural engineers:	DUOL doo, Kapalniska pot 2, 1351 Brezovica
Main contractor:	Hadir Projects & Environment Systems LLC (DUOL's exclusive distributor in the UAE)
Tensile membrane contractor:	DUOL doo, Kapalniska pot 2, 1351 Brezovica
Membrane supplier:	Sattler PRO-TEX GmbH
Manufacture and installation:	DUOL doo, Kapalniska pot 2, 1351 Brezovica
Material: Outer membrane:	ATLAS Architecture Type 4, Art. 760 (appr. 17.000m²)
Inner membrane:	POLYPLAN Tent Antiwicking Art. 787 114 (appr. 17.000m²)
Covered surface (roofed area):	9.000m²

Structural Behaviour of Bending Active Structures

THE IMPACT OF LOAD DISTRIBUTION, GEOMETRY, TEMPERATURE AND WIND LOADS ON THE STRUCTURAL PERFORMANCE

With the advanced development and growth of engineering in the construction industry, the use of lightweight structures has received a significant attention due to their many advantages, such as lightness, portability and multi-purpose uses. Therefore, novel ideas and methods in construction and design have gained popularity in the building sector. The development of the Bending Active Theory plays a crucial role in the development of a new generation of lightweight structures.
A PhD research project carried out at the University of Nottingham by Mohammadmahdi Barari Reshtehroudi under the supervision of Dr. Paolo Beccarelli, Prof. John Chilton and Prof. Jonathan Hale investigated the impact of load distribution, geometry, temperature and wind loads on the structural performance of Bending Active Structures. The research helped to develop insight into the architectural design, assessment of the structural performance, validation of the numerical methods with experimental tests and manufacturing of one-to-one scale structures and mock-ups. The research is based on the extensive use of experimental tests and numerical simulations, providing valuable resources for architects and engineers to support the design and manufacturing of lightweight bending active structures.

Experimental research

The experimental research focused on two main areas: 1/ the evaluation of structural behaviour and material performance and 2/ the investigation of the lateral force's impact by means of structural tests and wind tunnel tests.

The structural behaviour of bending active members and material performance were investigated through several laboratory tests which included bending tests, loading tests, tensile tests and tests designed to understand the effect of temperature. Wind tunnel tests were carried out to assess the effects of lateral force, such as wind load on light and flexible structures. A scale model was manufactured and tested in two configurations, open and closed, to measure the aerodynamic data at different angles with incremental steps of 15 degrees.

Numerical modelling

Numerical models have been used in conjunction with physical models when the experimental tests were affected by unexpected limitations such as construction costs, model's size, access to the labs and testing inaccuracies. The numerical models were initially calibrated with the experimental results and then employed to investigate the following key factors:

- The structural behaviour of different materials and introducing suitable materials for the bending active structures applications.
- The effect of various cross-sectional area on bending active structure performance.
- The behaviour of bending active structures with different f/L ratios.
- The behaviour of bending active structures with various dimensions and equal f/L.
- The behaviour of bending active structures under various loading situations.

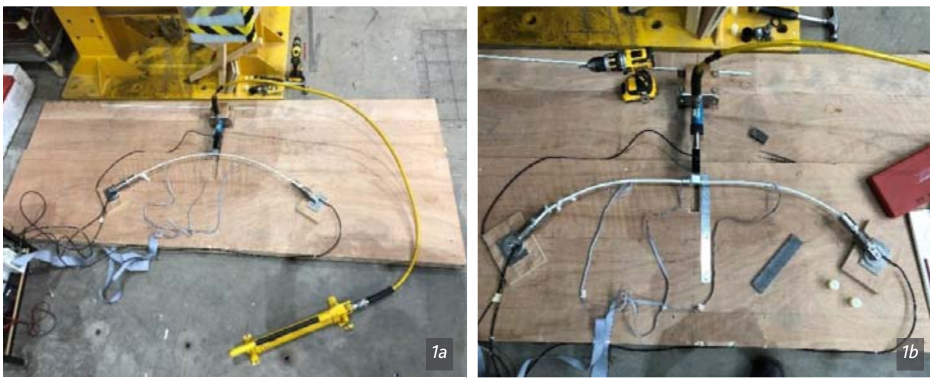

Figure 1a-b. Experimental setup for the point loading test

Computational Fluid Dynamic (CFD) was adopted to investigate the effect of wind on bending active structures and address some limitations of the experimental activity, such as time and costs associated with each geometry tested. This study evaluated the reliability of CFD simulations in ANSYS by comparing the results obtained from the experimental data and the numerical model's output.

Key Results

Results obtained from temperature loading indicated that the GFRP materials' behaviour and resistance parameters were influenced by temperature loading. In the case of a single temperature change, target temperature loading, the modulus of elasticity, and yield stress did not change significantly. However, with cyclical temperature changes, the material became more brittle and the range of elastic behaviour decreased. As bending active structures' behaviour is defined only in the elastic range, therefore, by increasing the modulus of elasticity, the amount of stress created in the structure increased and the structure would enter the plastic range with less stress created. Therefore, this becomes an essential aspect of being considered in the design and manufacturing of bending active structures.

From the wind tunnel experiments and the CFD simulations, could be observed that, as expected, each part of the structure facing the wind flow was under positive pressure. Velocity changes in the Reynolds number range had no significant effects. However, at low velocities, scattering of the mean pressure coefficients was greater. In closed models, the structure behaved similarly to low-rise buildings. Under the wind flow perpendicular to the span (90 degrees angle), the structure was subjected to negative pressure on the edge of structure. On the contrary, in open models under the same wind conditions, due to the thin thickness of structure facing the flow, the pressure distribution values in the same area were considerably lower. In addition, in open models, the pressure values dropped significantly by changing the flow angle from parallel to perpendicular to the span. Moreover, with increasing height and the f/L ratio of the models, on the windward side near the ground, a horseshoe vortex area was observed which affected the distribution and intensity of the pressure on the model.

After performing laboratory testing in a wind tunnel, numerical simulations were performed in ANSYS software in two modes of rigid and flexible. In rigid numerical modelling, due to the non-application of structural features in modelling, the pressure coefficients obtained were lower than the laboratory values. However, when simulating a flexible model, the estimated numerical modelling results showed a good correspondence with the laboratory results.

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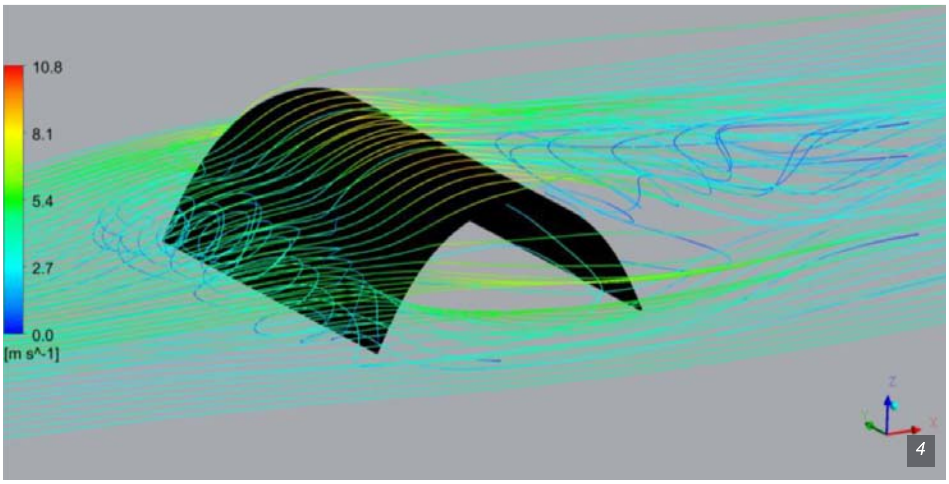


Figure 2a-b. Wind tunnel setup:Left) Spires and roughness elements. Right) Roughness elements and the structural model placed on the turntable

Figure 3a-b. Installed pressure taps
Figure 4. Flowlines in model MO716 (t=2sec) exported from Ansys software

TensiNet Symposium 2023 at Nantes University

The next TensiNet Symposium 2023 will be organized in collaboration with Nantes University in May or June 2023.

The focus will be on ***Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment.***

The 3 main topics are:

1. STRUCTURAL MEMBRANE:
contemporary, innovative, adaptive daring and impactful solutions
In Jules Verne's hometown, with its focus on innovation and futuristic issues, membrane architecture can provide answers to current problems, especially for ever denser cities and for a world that is always on the move.

2. TENSIONED MEMBRANE STRUCTURES:
the seventh building material
Recent advances in the design of membrane structures, development of a Eurocode dedicated to structural membranes: the word membrane must now be part of the daily vocabulary of architects, designers and decision-makers, and the specificities of membrane design must be part of the knowledge of all structural engineers.

3. STRUCTURAL MEMBRANE:
an answer to issues of the 21st century
Lightweight design, well-being, environmental impact, energy and acoustic performance, life cycle of materials and structures, end of life of membrane structures: these keywords are part of the current and future construction challenges and are an important message for the younger generations.

More information will follow in the upcoming months!

ARTICLE

Sustainability & Comfort
Working Group TensiNet

WG INTERNAL SEMINARS on the experiences with EPDS

OF MEMBRANE MATERIALS AND SYSTEMS OF THE COMPANIES

Thanks to the numerous participations of the 24 members, the activity of the Working Group *Sustainability and Comfort* during this first part of the 2021 is focusing on the working area of the Life Cycle Design, in-between the ones defined in the re-activation meeting (Tensinews n.39) and specifically on the Life Cycle Assessment LCA and the Environmental Product Declaration EPD for textiles and foils.

Three seminars, internal to the WG, were successfully organized thanks to the companies who have experienced recently the LCA and EPD of their products.

The aim of the EPD internal meeting has been i. the deepening of the ground reasons to develop and EPD, ii. the deepening of the potentials and limits of the EPD, iii. a group reading of the numbers/outputs of the EPD regarding the impacts along the life cycle of the products, aiming to understand its content, iv. how architects can use the LCA/EPD data to compare products during the membrane design stage.

In the first internal seminar (7th of May 2021) the speeches of Karsten Moritz and Saba Danusso from Taiyo Europe GmbH, *TAIYO_TensoSky_with_AGC_EPD*, of Katja Bernert from Mehler Technologiesâ, *LCA and EPD approach of PET/PVC Mehler Technologies* were scheduled. The second internal seminar (23rd of June 2021) saw the participation of Carl Maywald of Vector Foiltec, *new version of the* EPD *Texlon®-System Vector Foiltec GmbH*. And the third one (21st of July 2021) Farid Sahnoune and Francoise Fournier of Serge Ferrari presented the company approach on the *LCA and the EPD of PVC membranes Serge Ferrari*, and Maxime Durka of Sioen, so far, introduced the *EPD Polyester PVC membrane Sioen*, actually in progress.

Overall the three appointments, advantages and disadvantages of the EPD editing process have been analyzed with a major focus on how to produce general codes and values in order to be able to achieve a comparison between materials/products.

An Environmental Product Declaration (EPD) is a transparent and objective report based on LCA. EPDs communicate the product's ingredients, processes and how it impacts the environment across its entire life cycle following a standardized format. An LCA is a systematic analysis of the potential environment impacts of products or services during their entire life cycle. It includes also the upstream and the downstream. A natural step in delivering the kind of information that is standardised through a group of similar-in-function products or materials, as an integral part of generating an Environmental Product Declaration, are the Product Category Rules (PCR). PCR are particularly useful where the environmental impacts of products within a category group are to be compared - perhaps as part of a product specification process.

The calculations needed for the EPD considers the whole process chain of each component, including intermediate steps of preparations and considers the different vehicles used and the related distances. It takes into account the 5 stages of the LCA:

- Product stage
- Construction process stage
- Use stage
- End of life stage
- Benefits and loads beyond the system boundaries

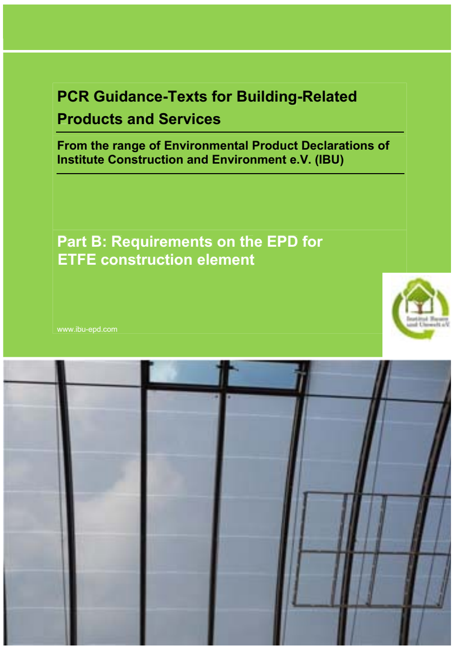
This kind of analysis is becoming necessary because 1/3 of CO_2 emissions, 40% of energy consumption, 25% of water consumption, 40% of resource use, 60% of electricity are caused by the construction sector. The International Organization for Standardization provides guidelines and requirements for conducting an LCA according to ISO standards (ISO 14040 and ISO 14044). The EPD is defined by the Eurocode (based on EN 15804: 2012+A2:2019 – mandatory by July 2022 – and EN 14020), it is not valid in USA (there is ULE) and in Norway (Norge EPD).

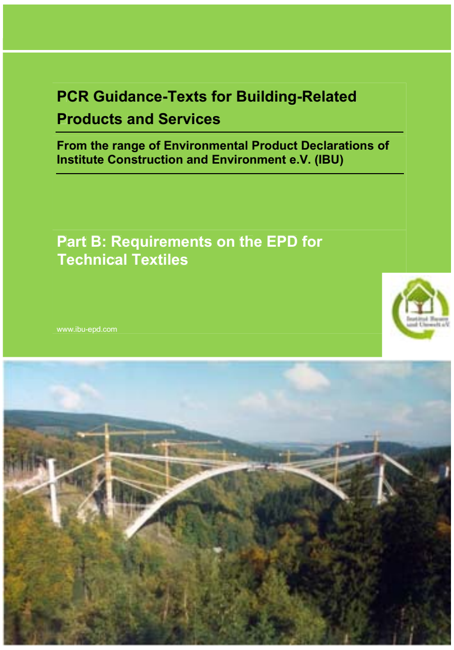
A verified EPD supports LEED, BREEAM, DGNB and other so-called "green building rating system".

From the discussion benefits of EPD have been found out:

1. The impacts of the own product to the environment (by numbers);
2. Obtaining basic data for the environmental relevant improvement of the own products:
   eg. Shortening of transport routes;
   eg. Selection of environmental-friendly subcontractors…
3. Comparison of the own product with substitute products due to impacts to the environment.

Till now the EPD has been seen by the companies as an internal "litmus test" to derive insights on hotspots of the production chain and of the impacts of the raw and primary materials and to define the life cycle priorities (reducing energy consumption reorganizing the production process with a consequent reduction of the Embodied Energy of the final product, saving materials reducing the primary materials exploitation, …). But the TensiNet WG S&C members discussed about the relevance of the EPD also as a marketing strategy and the aim of the Working Group into the TensiNet association and the Membrane field in general is to introduce and spread the understanding of the EPD meaning into the market. In Germany DGNB required the EPDs of products to introduce them into new sustainable buildings. In France from 2020 the Thermal Regulation RI2020 includes thermal and environmental requirements. This is showing how the EPD is becoming more and more meaningful. In the last ten years the EPD as voluntary product declaration was not sufficiently taken into account probably because of a lack of good





marketing or because the business was too young and the market was not ready yet to accept it. The demand for EPD was indeed very low and therefore not truly considered.

Where is actually the bottleneck of the diffusion of the EPD as a tool for the product choice during the design stage? In the internal meetings, the highlighted drawbacks of the EPD consist in the lack of boundary conditions and interactions with the environment. Indeed, the Life Cycle Impact Assessment (LCIA) covers all relevant inputs from the environment as well as emissions into air, water and soil – also the interactions with the other systems of the building. Since some aspects are not considered yet, it is not possible to compare different products and two EPD cannot be compared.

Another aspect that must be considered is that values are still too far from our knowledge and therefore, taken as they are, it is difficult to understand their meaning at the first glance.

And from the procedural point of view conducting the EPD editing is useful not only for having the EPD itself but for collecting all the data, in order to have them before starting the process. Indeed, it is a hard work and impossible to derive all the data by yourself, it is necessary to have the contribution of the materials' suppliers. Additionally, the collection of data takes time, if successful: sometimes it is difficult to collect such data.

Consequently as TensiNet Association, the S&C Working Group discussed about two possible next steps, convenient for the members of the association.

A first hypothesis: rather than specific EPDs it would be better to have them based on categories rather than products in order to provide a basic set of data available for customers or suppliers. The difficulties seen behind this proposal are that it is difficult to unify and have different suppliers in one EPD and that some parts of the LCA would be missed because they actually depend from time to time. Additionally, it is difficult to determine an average value related to membranes (considering that coated textiles have a different history from the foils). Additionally, EPD is actually composed for the 50% of information that we can read, while the other half is detailed knowledge that suppliers won't share with competitors (although it has been done for the Eurocode, so there might be an option for doing so while keeping the data protected).

Not all companies, member of TensiNet, have an EPD of their products, hence, to compare the environmental impact of different products is difficult. Consequently, several producers in the Tensinet Association shared the willingness to try to collect data from different production chains of similar membrane products and define an average value of the environmental footprint for each type of material (PES/PVC, Glass/PTFE, ETFE,…).
The hypothesis to proceed with an average EPD is under discussion.

The second hypothesis: A major attention could be focused on the Product Category Rules (PCR), that are necessary to write and start the EPD process and could be unified. PCR could combine all the different aspects of the different components and then they could be useful to have common data. PCR (Product Category rules) for building-related products and service is composed of: Part A: calculation rules for the LCA, Part B: product-specific part - existing requirements to different system components and products.

Regarding membranes there are no PCR, with the exception of the Waterproofing membranes. So the WG S&C aims to deepen what is needed as TensiNet Association to support at the European Level the definition of the Architectural membrane PCRs, considering that two main families of products (textiles and foils) exist. The interest is focus on harmonising the PCRs for this specific sector and defining common rules such as the LCA system boundaries to be considered, the end of life scenarios, the functional unit as a basic rule to allow the comparison of the EPD data at the end of the process.

In this case a third party, skilled and able to manage the PCR definition process is needed and actually the WG S&C is investigating a possible collaboration with the German Institut Bauen und Umwelt e.V., in order to set up the specific category rules and facilitate the EPD process for the TensiNet members if needed.

Lastly the intention is to organize a public seminar regarding the EPD topic, to spread the knowledge and the experiences of TensiNet members that worked on the topic in the last ten years to all the TensiNet members and to the architectural membrane community.

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ARTICLE

Sustainability & Comfort
Working Group TensiNet

OWN EPDS
The effort is worthwhile!

With the publication of EPDs by IBU, not only does the quality of life cycle assessments increase, but also further use of the data becomes significantly easier.

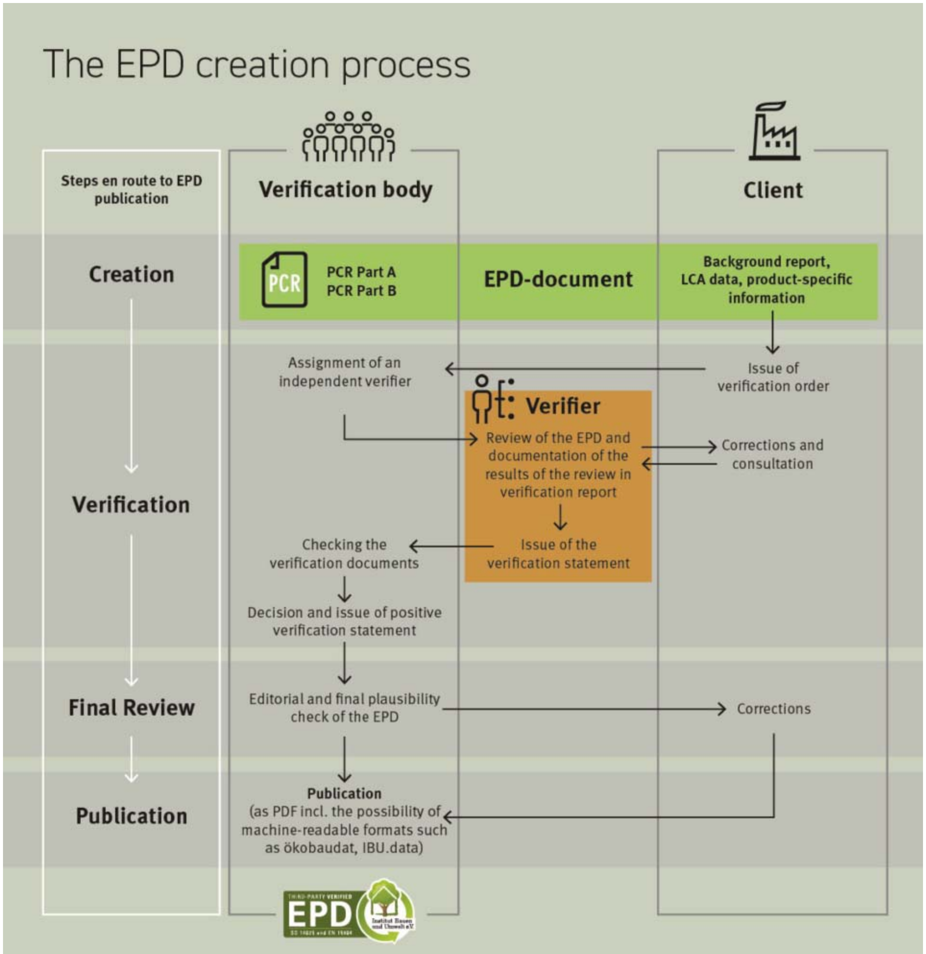
For companies, the time and cost involved in creating their own environmental product declarations (EPDs for short) in cooperation with programme operators such as Institut Bauen und Umwelt (IBU) are certainly worthwhile. For example, in this way the assessment in the certification system of the Deutschen Gesellschaft für Nachhaltiges Bauen (DGNB) is improved by up to 15 percent for certain environmental impacts. This was shown by a study of the Fraunhofer Institut in 2019. Building certifications to the DGNB or US American LEED standard are frequently demanded, especially for new public and commercial buildings.

The Fraunhofer researchers therefore compared life cycle assessments on the basis of EPDs with so-called generic data, which are provided on the basis of generally accessible sources, for example, in the ÖKOBAUDAT database of the German Environment Agency. The result: Especially in particularly energy-efficient buildings, where the building fabric accounts for a larger share of the environmental impacts of the building than the energy consumption during the use phase, environmental impacts from construction materials were shown to be lower by up to seven percent. Because EPD data are checked independently, they are significantly more precise than the generic data. This is what accounts for the quantifiable difference here. Companies, of course, also benefit from other EPD advantages: This is because they generate valuable information about the ecological properties of their product. Potential for optimisation can then be derived from this. EPDs are also useful in communication with business partners and can potentially provide the decisive competitive advantage in calls for tender.

The certification process facilitates orientation

However, small and medium-sized companies especially are often sceptical: After all, they not only have to fulfil the requirements of the European "EPD standard" EN 15804. They should also bear in mind various national and international provisions, especially for international projects.

EPD programme operators such as the IBU ensure orientation here in the jungle of declaration and certification systems. A clear time schedule serves as a guide rail. Companies that aim to create an environmental product declaration for a specific product or product group opt for a product category rule (PCR) and, with the help of life cycle assessment experts, create a life cycle analysis of the respective construction material or the component. Together with additional information, the data are then transferred into suitable forms in the IBU online tool and are checked by an independent verifier. After any questions have been clarified the IBU publishes the EPD. This means that companies can be certain that their environmental product declarations will be useable in diverse contexts. The key words are digitalisation and standardisation. Because in the meantime the



IBU provides all EPD data in the IBU.data database, machine-readable in the open XML standard. After registering, end users can view all data records free of charge, they can even download them and, for example, import them into their own design tools.

IBU is committed to more standardisation

Once they have been published in IBU.data, the EPD data also find their way into other data sources. Interfaces exist, among other things, with ÖKOBAUDAT and with the "eLCA" tool for building LCA that was developed by the Federal Institute for Research on Building, Urban Affairs and Spatial Development ("Bundesinstitut für Bau-, Stadt- und Raumforschung" - BBSR) for building LCA.

The IBU also cooperates with the BBSR within the international "InData" network, which aims to simplify the exchange of environmental data. EPDs should be provided in an open format and web-based.

The IBU product information system SuPIM is also moving in a similar direction. It can be used to collect product-related sustainability data in a central location in the EPD online tool and transferred into datasheets, which each meet the requirements of building certification systems such as DGNB, LEED, BNB and BREEAM. Auditors for these programmes as well as planners and designers, architects and consultants and owners or developers can search in and view all relevant product data and verification documents.

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ARTICLE

TF 400 Green

Mehler Texnologies

CONTRIBUTING TO A MORE SUSTAINABLE WORLD

Upcycling

Sustainability is one of the most important topics of our times – particularly in the building sector. Mehler Texnologies shows its commitment to contribute to a more sustainable world by issuing the first product within the textile architecture range which is made of recycled material. The mesh fabric with the working title "TF 400 Green" consists of 100 % upcycled PET bottles. The weavers managed to get the technical properties very close to the ones of the standard material. The physical properties are matching completely, the tensile strength is only slightly lower. Given that in textile façades the panel sizes are generally smaller than in canopies, the slightly lower tensile strength is no real issue.

Sustainability Week 2021, Berlin

For the 2021 edition of the "Sustainability Week" or "Woche der Umwelt" which took place in Berlin this summer, the product was chosen by a jury of the German Federal President. Architect Dr Jan Serode from the University in Aachen additionally applied a NOX filtering lacquer to the black mesh – proving not only the positive impact on the comfort in our cities but at the same time the good visual effect of a black sun shading screen in front of an office building. A fabric made of upcycled PET bottles in combination with an NOX filtering coating is definitely a convincing product.

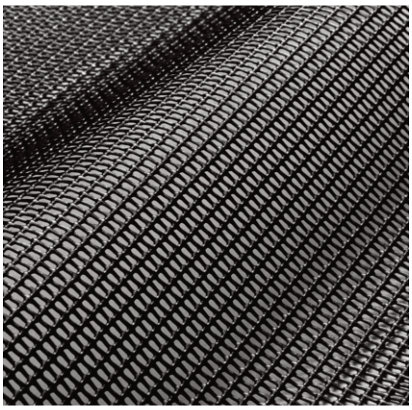

Figure 1. Mesh fabric made of upcycled PET bottles.

Improving sustainable aspects

Generally there are many options for improving sustainability aspects - starting with the applied chemicals and the production process until the end of life. All chemicals used in Mehler Texnologies' products are in line with the chemicals regulation REACH and hence prevent a negative influence on humans and the environment. The experts in the Research & Development Department constantly check the revisions of REACH regulations to assure that production and products are up-to-date. During production in-house waste is recycled for the fabrication of new products. This is a very important step towards a circular economy. Mehler Texnologies' company policy and future strategy includes aspiring a zero-waste production. Furthermore, Mehler Texnologies is part of VinylPlus, the sustainable development program of the European Vinyl industry. That means for example that customers have the option of returning fabrics after use. Regrettably there are just very few cases where fabrics are actually returned. This is particularly discouraging because the challenge is just to put the fabric in the original condition, that's to say to remove belts, keders or eyelets for example.

Particularly regarding the slow successes in recycling used fabrics it is more than obvious that using recycled materials in the first place is a good means in saving resources. As part of the Freudenberg group Mehler Texnologies belongs to the biggest European processors of recycled PET bottles.

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THE THREE-DIMENSIONAL FAÇADE OF THE DELANCEY AND ESSEX MUNICIPAL PARKING GARAGE

New York, USA

Synthetic Cables and their Increasing Relevance in Architectural Design

The award nominated Delancey and Essex Municipal Parking Garage in New York features a façade comprising a three-dimensional surface of lines produced by offsetting two layers of synthetic cable on galvanised steel rods (Figure 1). Constructed in 2017, the façade demonstrated the suitability of synthetic cable as both a decorative and constructional element in architectural design. It shows the application of synthetic fibre cable in a static application. This article reports on the façade's construction before bringing the reader up-to-date with the latest developments in synthetic cables that make them an attractive proposition for a variety of civil engineering designs, including tensioned membranes structures.

Figure 1. The Delancey and Essex Municipal Parking Garage showing the woven façade © Paul Warchol Photography

Context

The Delancey and Essex Municipal Parking Garage is in the Lower East Side of Manhattan. In 2016, the NYC Department of Design and Construction and NYC Department of Transportation undertook the rehabilitation of the five storey car park. Entry to the car park is through gated entrances on two streets. In addition to renovating the ground floor office, and creating a parking space for 22 bicycles, various structural repairs were undertaken, and the roof and elevators replaced.

Michielli + Wyetzner Architects chose to replace the precast concrete panel façades facing Essex and Ludlow Streets with a lightweight façade comprising a three-dimensional surface of lines produced by offsetting two layers of stainless steel-jacketed, composite synthetic fibre cables. "We were looking for a unique solution for a garage façade," said Frank Michielli. "One that allowed us to create a dynamic visual effect, which also captures the textile history of the local area."

By offsetting the two layers of 1 ¼" (3.175 cm) composite cables, a dynamic visual effect was produced. When the two layers - one planar and the other folded - are viewed together, moiré patterns are created by the interference of the crossing lines. The patterns seemingly move across the face of the building as the viewer's position changes. Depending on the viewer's vantage point, the façade appears to shift from a solid, metallic folded surface to a lightweight scrim to a transparent web of lines. (Ref 1).

The synthetic fibre cables span from the first floor to the roof and are fastened to stainless steel end-fittings with integral turnbuckles for adjustability (Figure 2). At the intermediate levels, stainless steel "O-rings" attach the outer layer of cables to galvanised steel "combs," anchored to the floor slab at each level. The cables are positioned to give the appearance of being woven on a loom. The inner layer is composed of straight lines that are attached only at endpoints. (Ref 2).

Phillystran, a US-based high performance synthetic rope manufacturer, supplied the synthetic fibre cables for the façade. The 1 ¼" (3.175 cm) diameter cables are an aramid fibre strength member with fibreglass braided core and stainless steel over braid for enhanced abrasion resistance (Figure 3), producing a Rated Breaking Strength of 3,500lb (15.57kN). One end termination consists of a stainless steel toggle / forked clevis fitting with a stainless steel clevis pin and black anodised aluminium fitting body. The other end also includes a stainless steel threaded rod with stainless steel toggle / forked clevis fitting with a stainless steel clevis pin and black anodised aluminium turnbuckle with locking nuts.

Each cable was terminated at the first floor and ran up the building, secured to intermediate floors by an adjustable O-ring connector. At the top of the car park, the cable wrapped over a galvanised steel tube and was terminated on the fifth floor concrete platform (Figure 4). In total the Delancey and Essex Municipal Parking Garage used 19,974 ft (6,088m) of synthetic fibre cable and included 415 termination and O-ring assemblies.

For the façade, a mechanical termination was used rather than the more common resin infused termination, a well-established technique developed by Phillystran in the mid 1970s, as it eliminated the need to remove the resin plug for inspection.

Frank Michielli again. "The cable was easy to install and dropped down well. As well as creating the textile visual effect, the strength of the cable was important in ensuring it stayed taut without exerting too much load on the structure. The composite of stainless steel woven jacket and synthetic fibre meant we didn't have to weather out the façade and it is essentially maintenance free. It looks as good today as the day it was installed!"

Fibre Developments

Many innovative structures have been designed and built around the world incorporating advanced synthetic fibre cables. Typically, they are deployed in environments where weight reduction is required, coupled with continuous cyclic strain and high creep resistance requirements. Traditional steel materials cannot provide the same long term, maintenance free performance. Synthetic cable provides the architect with the ability to optimise designs in a far simpler way than using steel. It also has the benefit of being easier to handle and install. A synthetic aramid cable is a fraction of the weight of a steel cable for the same strength, additionally, radio and WiFi signals are not obstructed as there is no Faraday cage effect.

For environments where corrosion is a potential problem, such as in coastal areas, synthetic fibres are preferred. Their resistance to corrosion allows significant savings in inspection and maintenance especially in areas where corrosion needs to be prevented. In static applications, aramid fibre exhibits high tenacity and creep resistance, even in elevated temperatures.

A typical static application is antennae support at One World Trade Center (1WTC) in New York. Phillystran synthetic cables support the 400ft (122m) antennae on the top of the building, taking the building to a height of 1,776ft (541m) and making it the tallest building in the Western Hemisphere.

High performance tower guys (HPTG) synthetic cables are made from stranded aramid fibres with an extruded urethane jacket. The guy lines are supplied as a complete guying system, including a wide range of standard and custom fittings. The cables are non-conductive and do not interfere with Wi-Fi, Radio or Cellular networks. The key technical challenges for the 1WTC system included the requirement for 8 non-corrosive guy lines just 149mm diameter and with 7,840kN break strength. Typically, these antennae support cables will last 30 years, and have been known to still be in service after 40 years.

Dynamics within Structures

When considering dynamics in structural applications, synthetic fibres have some interesting physical characteristics compared with steel wire. As stated previously, fibre is typically a fraction of the weight of steel for the same strength, making it easier to install and uninstall, where necessary. In addition, the self-weight of the entire structure is reduced substantially.

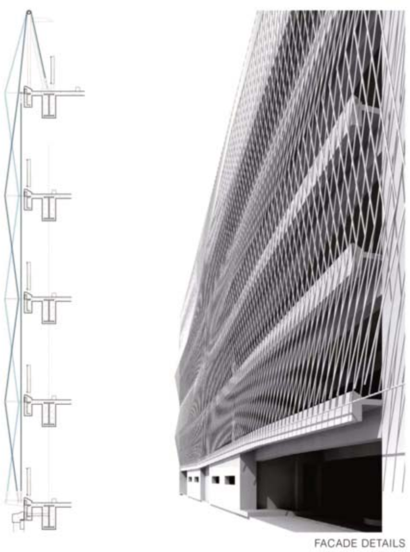
Steel wire frameworks are essentially rigid structures with load and load shifts concentrated on the wire terminations. Synthetic fibre, on the other hand, can be designed to slightly 'elongate under shock loads, allowing load shifts to be partly or wholly absorbed by the fibres. Essentially, it's a better shock absorber than steel, allowing a simpler structure that can reduce overall project costs.

A common misunderstanding relates to differences in tolerance between steel and synthetic fibre. For a steel cable to stretch to accommodate a load shift would require significantly more force than for a synthetic cable. The difference in tolerances can be used to advantage, allowing a major reduction in the size and capacity of installation equipment. Allowed length tolerances too can be greater with synthetic fibre bearing in mind that a small uneven load will be negligible in a 1.5 million lb (6,672kN) rated rope.

For a steel cable to elongate to accommodate a length differential, it would take a significantly greater force than for an equivalent strength synthetic cable. Due to this, the length tolerances needed in synthetics to make sure the loads are shared equally, within a reasonable range, in a multi-cable system are much less tight than what is needed in steel.

In summary, synthetic fibre creates many opportunities for the imaginative architect working with membrane and inflatable structures (Figure 5). In addition to structural and practical advantages compared to steel wire, synthetic fibres offer cosmetic benefits too by enabling the use of coloured fibres and jacketing compounds.

Name of the project:	three-dimensional façade of the Delancey and Essex Municipal Parking Garage
Location address:	Manhattan, USA
Client (investor):	New York City Department of Design & Construction, Division of Structures and New York City Dept of Transportation.
Function of building:	parking garage
Year of construction:	2016
Architects:	Michielli + Wyetzner Architects
Structural engineers:	Engineering Group Associates
Supplier of the material:	Phillystran
Manufacture and installation:	Applied Fiber, Neoparies, TQ3, Phillystran
Material:	stainless steel-jacketed, composite synthetic fibre cables
Surface:	108.000m^2



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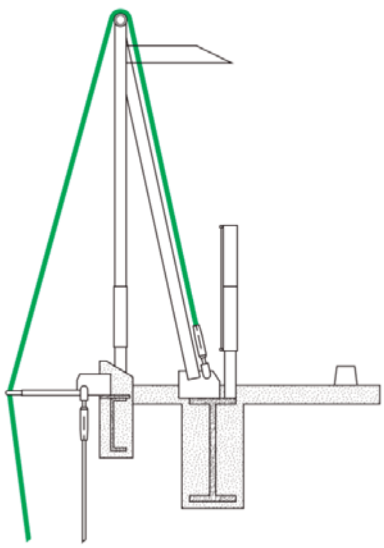

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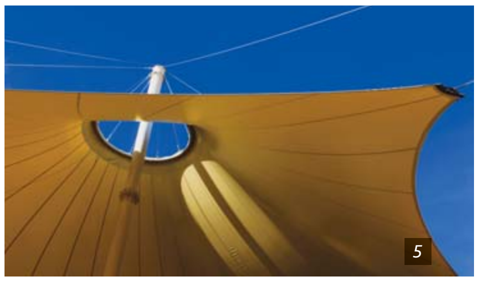

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Figure 2. The cable façade x-section showing the cable termination and intermediate floor O-ring connections © Phillystran
Figure 3. Connection detail of the cable termination on the fifth floor © Phillystran
Figure 4. Detail of the stainless steel jacketed cable © Phillystran
Figure 5. An example of the kind of dynamic structure suitable for synthetic fibre cables © Sinn P. Photography/Shutterstock.com

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markfrolich@wireco.com
http://www.phillystran.com

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THE MEMBRANE HOUSE

THE MORPHOGENESIS PROCESS AND THE CONSTRUCTION PHASE OF THE MEMBRANE HOUSE (MH) PROTOTYPE

This prototype is the practical example of the doctoral research of Beatriz Arnaiz Barrio, in which a documentary [reproductive] process and an experimental [productive] process constantly converge. The inflection points that unite these axes generate a discourse on the design process of tensile structures, suggestive for the professional and academic field of architecture. The MH prototype is the protagonist of the research because its development process has meant the consolidation of the discursive approaches of morphogeneration and has been a laboratory in which to experiment from the non-conclusive.

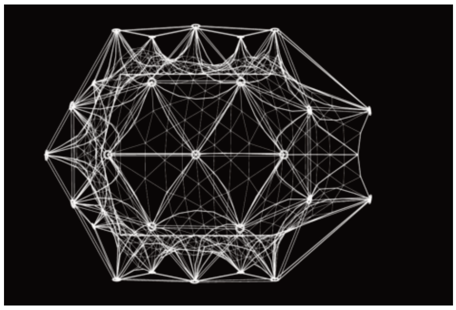
MH Morphogenesis

Membrane House was created in response to the eme3 "Contingency and Praxis" 2016 competition, under specific conditions of volume and functionality. The function proposed by the competition was an emergency shelter for situations such as refugee camps. If the aim is to solve these very serious problems, contingency architecture is proposed in order to make them visible and reflect on them. This is the intention behind the competition.

The starting point was to find a way to optimise the volume of interior space from the size of 2x3m in plan and 4m in height, being able to expand half a metre more around the perimeter without touching the ground. The most efficient way to expand volumetrically would be to be able to inflate like a balloon touching all possible maximum limits. To solve this geometrically and structurally inflated shape, a triangulation of the surface is chosen. The size of the triangulation bars must be sufficiently manageable and transportable, but large enough to ensure rapid assembly. If possible, a certain degree of symmetry facilitates the manufacture, design and construction, as well as the coupling of the possible combinations or groupings of the prototype. Textile architecture is ideally suited to these conditions.

This is the starting point of the form-finding process, one could say that it is the genetic code for the generation of form.

The Membrane House is the case study presented in the doctoral thesis "Fundamentals in the Morphogenesis of Tensile Structures. Membrane House" as an experimental example of the theory developed in the thesis, which provides a foundation for the fundamentals of tensile structure design. These foundations seek to impact on the approximation of theory and technique, in favour of the proliferation of the production of more efficient and higher quality tensile structures. The discursive line of the thesis has a transdisciplinary nature, adding views, concepts and reflections that support an argumentative basis to defend a design process of tensile structures that can have repercussions in the academic and professional world. The design of the MH prototype is a structural solution based on the morphogenetic foundations defined in this doctoral thesis.



Matter

> *The resources involved in the genesis of form are immanent to matter itself.*
> *Manuel de Landa, on Gilles Deleuze (2017)*

The material to be used in the prototype has specific characteristics and properties that are taken into account from the beginning of the design process. They are the starting point, as part of this genetic material.

The bars are made out of wood, appealing to its capacity for compression due to its longitudinal shape and its internal material density. It is a rigid material. The resistance offered by these bars is at its maximum against compressive stresses. Wood is a material that is easy to acquire and manipulate. It can be easily cut and drilled with basic tools. Wood has the risk of cracking or splitting under shear stresses, but if the stresses are compressive, it will respond positively. On the other hand, the membrane is a flexible material with high tensile strength. The deformability of Lycra is much higher than that of the membrane material used in the prototype, but its structural performance will

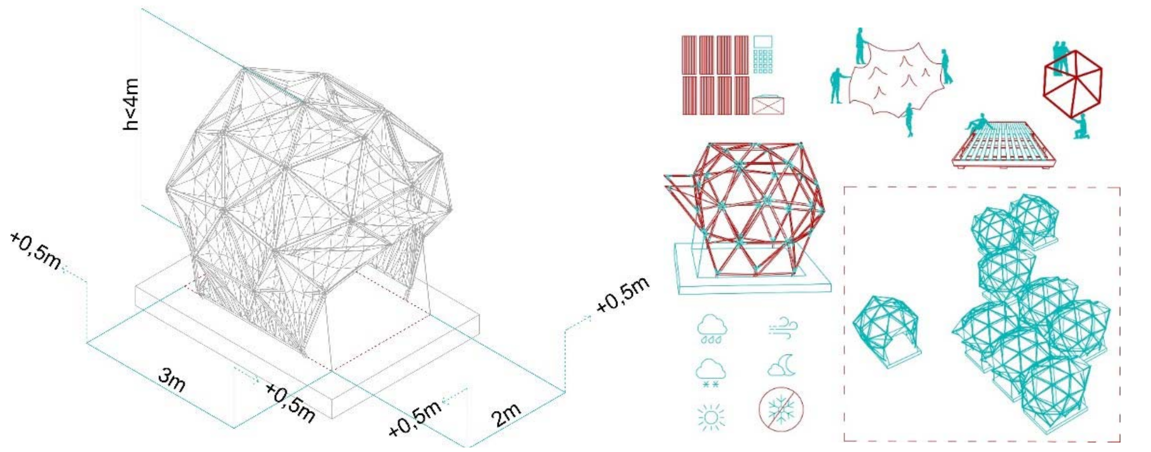


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Figure 1. Components of a MH unit and its combinations possiilities © Beatriz Arnaiz Barrio / LHRC Architecture Collective

be similar, so it is this material analogy that allows us to experiment with a model and then transfer it to the prototype.

These two elements combined in an efficient way in a structural system seek to distribute their efforts to exploit their resistance. The solution of the nodes is fundamental to allow these materials to be subjected to the stresses corresponding to each one: tensile membrane and compressed bars.

The free knots allow the position of the knots linking the membrane and the bars to be balanced at the optimum point, allowing the material to take its shape and be placed in its position. The knots in the model do not allow the bars to withstand traction, as they would come loose if this happened and the membrane by its nature cannot be compressed. It is therefore important that the shape of the model is worked from this format of knots in which it is ensured that each element is working from the inertia of its material.

When applying on the prototype, the knots do not comply with this same format, as making it on this scale made other aspects difficult, such as the ease of acquiring the material, their manufacture and assembly. Therefore, work is carried out on the shape at the scale of the model, and it is assumed that when extrapolating the shape and structural system to the prototype scale, the elements will continue to be subjected to the stresses corresponding to each material.

Although this works correctly in theory, when it is materialised, certain changes occur that can lead to some of the bars (those anchored to the base) withstanding certain tensile stresses and the membrane (which has some wrinkles in the prototype) not being subjected to sufficient traction over its entire surface. This is part of the experimentation, and despite the difficulties encountered in the process of making the prototype, they are resolved according to the means and resources available, in order to go through the process of building a prototype from which empirical conclusions can be drawn on the issues that work according to the theoretical findings, and the issues that do not work or fail in practice.

The prototype is the result of an experimental process with the subject matter at different scales, in which learning is incorporated. The process of experimenting with the material and putting it into operation, its various tests and the decisions taken in the process are much more valuable than the result itself as a product. This process of researching a structural system based on the properties of matter in structural operation does not end with the construction of the prototype; it is an open process.

Volumetric exploration and form finding

> *The computer can only calculate what is already conceptually inside it; in computers you only find what you are looking for. With free experimentation, however, you can find what you have not been looking for.*
> *Frei Otto (2008)*

A volumetric exploration is carried out with various experimental models. The form and the system of equilibrium are found through one of them. This exploration is the analogical-material origin of the form-finding phase.

In the process of finding the shape from the virtual model generated from the analogue model, we work with the membrane in WinTess 3 (a programme designed by Ramon Sastre), importing the model created in Rhinoceros.

By anchoring the fixed points and applying tension to a mesh, to which the characteristics of the material to be used in the prototype have been assigned, it finds its shape. It describes an anticlastic curvature of the surface that joins the points as vertices of conoids combined with each other. If the curvature found at this stage corresponds to the qualities and properties of the material to be used in the construction, the precision of the manufacture can be very accurate. This way, the material efficiency can be used to make the most of the nature of the textile material towards highly optimised states of the material.

In this case, the process of mesh generation and positioning could certainly be refined. The elements do not have a very homogeneous finish, which will have an impact on the patterning of the membrane. But given the scale of the prototype and its experimental vocation of a structural system and taking into account the limited time for its development in order to be presented in the competition from which the idea originated, the priorities of the process were thus set.

The programme still requires extensive manual intervention, it is not all automated, but allows us to play with the parameters associated with the behaviour of the textile material with a structural function. The design of the mesh, the position of the anchor points, the fidelity of the materials in the database or the qualities defined as specific to the material to be used must be worked on. The programme offers a simulation of the shape and behaviour of the mesh that allows this search and finding phase. This phase is very important for textile materials, otherwise the curvatures can become too random. It is not possible to draw the exact shape that a flexible textile material will acquire when subjected to traction, without taking into account the parameters associated with its qualities of resistance, pretension and deformability. In this process of generating the shape, linking with the material reality, mock-ups, prototypes and software with these characteristics are fundamental tools.

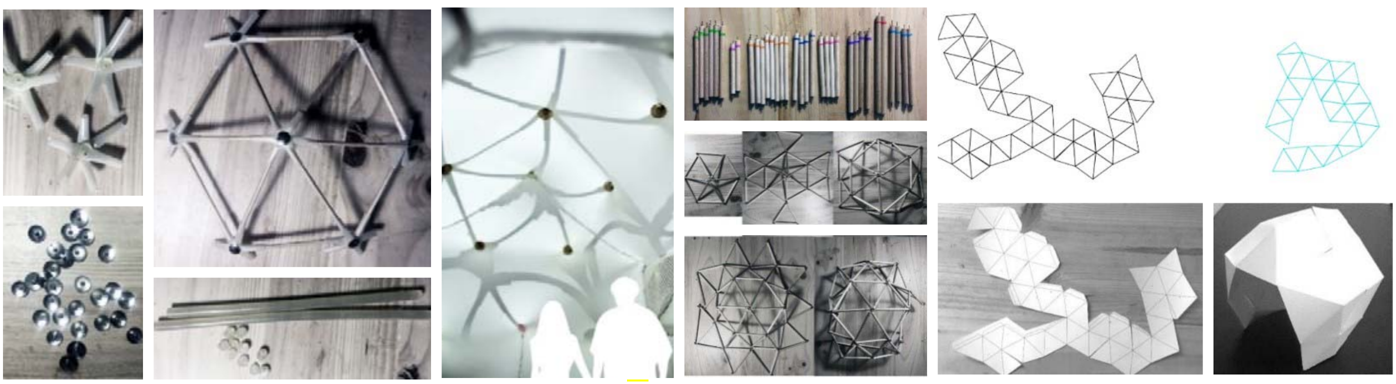

Figure 2. Exploring various experimental models © Beatriz Arnaiz Barrio / LHRC Architecture Collective

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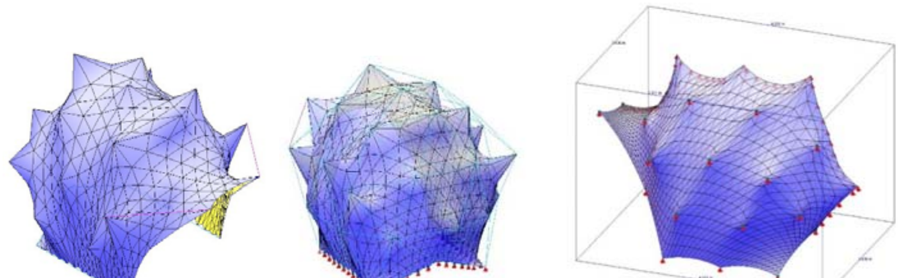

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Figure 3. Modeling the membrane using WinTess 3 © Beatriz Arnaiz Barrio / LHRC Architecture Collective

Tension balance

Each material has a different specific personality, and each form imposes a different tensional phenomenon.
The natural solution to a problem -art without artifice-, optimal in the face of the set of previous taxes that originated it, impresses with its message, satisfying, at the same time, the demands of the technician and the artist.
Eduardo Torroja Miret (1957)

The Membrane House is a prototype whose geometry responds to the deformation of the triangulation of a regular geodesic dome, which works through the compression of the bars that compose it, stabilised together with a tensile membrane that joins all the points of union of the bars (nodes) and makes it work as an integral structural system. The membrane is composed of triangular patterns that respond to the triangulation of the bars and has a performance of strength and lightness appropriate to the rest of the structure.

The combination of elements, wood and membrane, in addition to the triangulation, give great rigidity to the whole. Using the tensegrity principle, the compression of the wooden bars is combined with the traction of the fabric. Both elements need each other to consolidate the shape of the prototype. The combination of hexagonal and pentagonal modules gives the space an optimal volume according to the maximum floor plan occupation.

The balance of the structure and its stability is based on the combination of tensile and compressive forces balanced against each other. The nodes or connections are the anchorage points between the membrane and the triangulated network of bars. From these connection points, the two elements work structurally, generating a balance of forces that provides an integral and stable result. The system needs all its elements working together to find its shape and stabilise itself.

Connecting the nodes in itself is not enough to create a stable structure. Only when the nodes are connected by the membrane the structure finds its equilibrium.

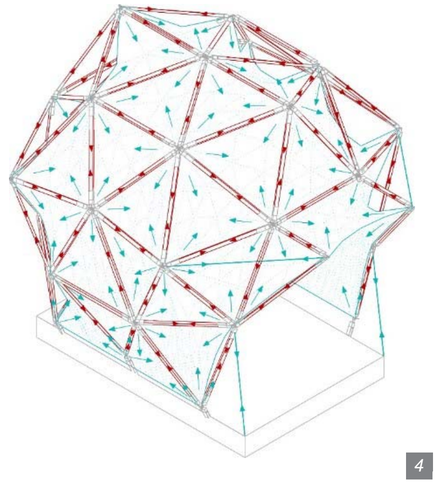

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Figure 4. 3D model showing the tensegrity principle of the wooden bars and the membrane consisting of triangular patterns © Beatriz Arnaiz Barrio / LHRC Architecture Collective

This is the theoretical basis for the principles of equilibrium on which the Membrane House structure is based, but it is necessary to clarify that not all the bars are exclusively compressive. As it is an open tensile structure, anchored to the ground, this closed system approach cannot be fully realised. The system continues to operate according to the same principles, but at the points where it is anchored to the ground, a different connection to the nodes of the rest of the structure appears. At these points where the bars are anchored to the ground in an equally articulated node, the behaviour of the forces is different from the rest of the nodes of the structure. Due to the weight of the structure and the tension of the membrane towards the interior, the bars are compressed as explained in the general functioning of the system in equilibrium but when a suction force appears, these bars will also be subjected to tensile stresses. There is a tendency to find this pure equilibrium system, but obviously, when it is materialised constructively and subjected to certain contextual circumstances, stresses may appear that occasionally deviate from the theoretical scheme described above.

For the construction of the prototype, the structure was not subjected to an exhaustive calculation, but a verification and checks of the established intuitive dimensioning was carried out on the analogue model.

Once the 3D model of the support structure has been drawn in AutoCAD and Rhinoceros, this skeleton of bars is exported in dxf as auxiliary lines to proceed with the analysis of the membrane. This process is carried out thanks to the WinTess3 programme, which works in three different phases: shape search, calculation of the structure and patterning of the fabric.

The structure calculation phase in the WinTess3 programme uses the matrix method. In this calculation phase, working on the shape already found, the wind and snow loads to which the structure may be subjected are applied, and the state in which the structure is balanced is sought. When the wind and snow loads are applied, the necessary dimensions of the elements are edited until it is verified that each element will support the load that it will eventually receive. The correct drainage of the roof is also checked. It is an iterative process in which it must be manually evaluated whether the results are coherent or not. Also the data input must be done according to certain structural calculation codes.

In this phase of calculation, the dimensions of the auxiliary cables, the elements that compose the structure and the reactions of the anchorage to the base are defined. These data are used to define the construction details.

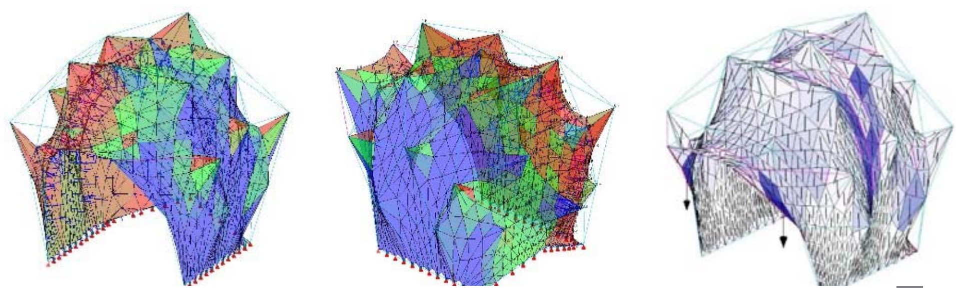

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Fig. 5. Membrane calculation graphs (without structure) with wind load applied in the x-direction and roof drainage graph (WinTess 3 software) © Beatriz Arnaiz Barrio / LHRC Architecture Collective

MH PROTOTYPE

Drawing is a kind of failure to achieve a clear and unique result; prototyping is a kind of failure to achieve a final solution.
John Maeda (2019)

Under the previously stated boundary conditions, established by the eme3 2016 competition, an efficient solution is chosen to facilitate a quick assembly made by not necessarily skilled hands seeking the low-tech concept for textile architecture. The design process continues after the construction phase with certain proposals for improvement after having evaluated the performance of this first prototype.

Construction details

The defined details are as follows

- Detail of components at the junction (left top)
- Upper timber structure connection with textile membrane (left middle)
- Tensioning system with inner nut (left bottom)
- Meeting between bars (right top)
- Encounter of bars with the anchor plug of the base (right middle)
- Meeting of bars with base and with membrane (right bottom)

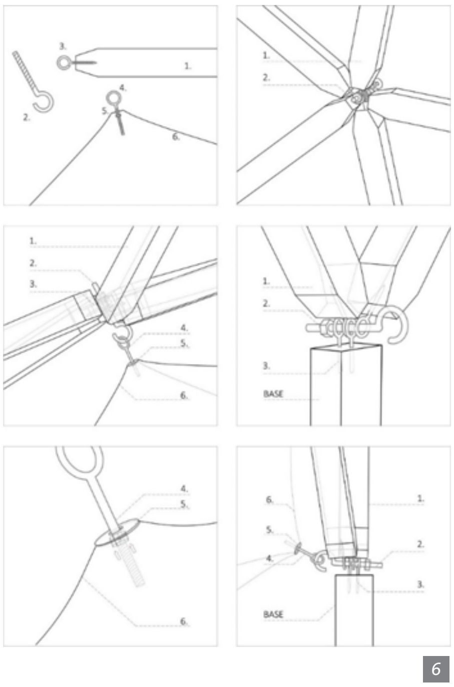


Figure 6. Construction details: (1) Brushed pine wood strip 36x36mm; (2) Open steel bolt Ø15mm; (3) Eyebolt with wood thread; (4) Closed steel bolt Ø10mm; (5) Eyelet riveted to the membrane and (6) Textile membrane © Beatriz Arnaiz Barrio / LHRC Architecture Collective

Support structure

The structure works on the principle of tensegrity, forming an open structure, which means that it has to be anchored to a base to reach the equilibrium position. This base, on which the whole structure rests, is made to measure for these given dimensions of 2x3m with 7 anchor points where the structure is fixed and supported. These points are solved constructively in a similar way to the constructive details designed for the nodes, maintaining the integrity and constructive coherence for the whole system. The base is a perimeter box that is disassembled into 6 pieces, 2 of 2.30m on the transverse sides and 4 that are composed 2 by 2 for the longitudinal sides of 3.30m, with a length of 1.65m each. This base imposes a fixed settlement to the ground in its position. The weight of this support added to the floor built as a platform ensures its stability without the need for foundations or anchoring anything to the ground, adapting to any surface when assembled.

Figure 7. Wooden basement © Beatriz Arnaiz Barrio / LHRC Architecture Collective

The structure consists of 84 bars of treated pine wood for outdoor use, with a section of 40x40mm, with an estimated life of 15 years. There are a total of 9 different types of bars. These types of bars were defined with an original measurement and then lengthened proportionally in one of the improvements made after several assemblies. The dimensions and quantities for the assembly of the MH can be seen in the table below.

The entire bar structure was replaced 2 years later with 8cm longer bars, with a 36x36mm reduced section which lightens the structure, an essential issue for transport and assembly. This improves the quality of the structure and the state of tension of the membrane.

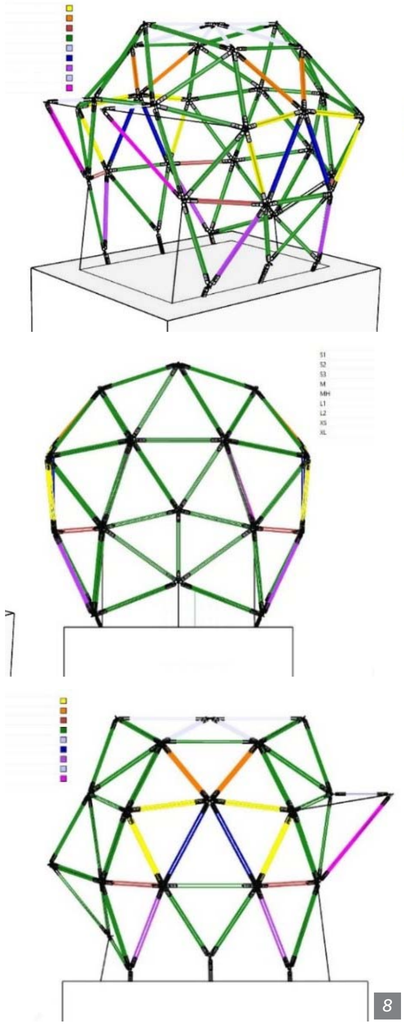
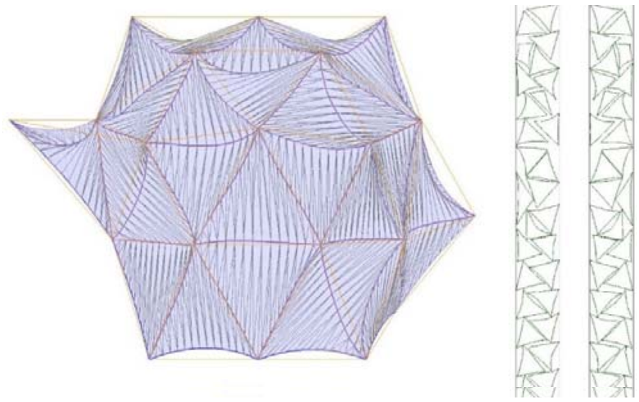


Figure 8. 3D model of the bar structure mentioning the different types of bars © Beatriz Arnaiz Barrio / LHRC Architecture Collective

Membrane

The material used for the membrane was donated by Serge Ferrari, Precontraint 502 Satin membrane model in white. The manufacture was commissioned to the company TP Arquitectura Textil (Girona). The aim was to use a specific membrane for textile architecture which would offer real protection against the weather and be resistant to withstand the stresses that arose from the idea of tension equilibrium between the bars and the membrane. It is one of the lowest grammage membranes offered by this company and commonly used in textile architecture. The light transmission of the

Type of timber	Original size (cm) *section 40x40mm	Enlarged length (cm) and reduced to section 36x36mm	Quantity
XS / XL (door)	80 / 160	88 / 168	2 / 2
S1	106	114	8
S2	111	119	4
S3	98	106	4
M / MH	118	125 / 129	50 / 6
L1	124	132	4
L2	126	134	4



9

10a

10b

Figure 9. Pattern lines of the membrane © Beatriz Arnaiz Barrio / LHRC Architecture Collective
Figure 10a/b. Internal and external view of the MH © Beatriz Arnaiz Barrio / LHRC Architecture Collective

membrane allows the interior to be illuminated during the day and at night creates a very striking light effect from the outside. The pattering lines are integrated into the interior spatial distribution and from the outside they are perceived combined with the bars of the structure, consolidating an aesthetic whole that is the product of structural sincerity and constructive coherence.

The shape of the patterns is triangular. For co-herence with the structural system and to favour the formal and structural integrity of the prototype, it was decided to follow the ar-rangement of triangles already drawn by the network of articulated bars at the nodes. Being a double curvature surface, in this case anti-clastic, to build it, it is necessary to join pat-terns obtained from a flat membrane, served in rolls of a width of 180cm. The aesthetic quality of the tensioned membrane depends to a large extent on this phase of the process, and the structural behaviour may be affected. The ver-tices where the membrane meets the bar web can be understood as cusps of conoids. The en-tire surface of the mem-brane, except for the gate and the lower boundaries (perimeter) can be understood as a combination of conoids ori-ented in different directions.
Sewing is used to join the patterns, as the patterns have very curved sides, and joining by welding would have to be done by very short segments, which implies an effort and an increase in the cost of this process that is not in accordance with the principles proposed in the design and manufacture of the prototype. It is established that the simple seam has a guarantee of durability in accordance with the rest of the structure, and is therefore suitable as a solution for this case.
Also at this stage a percentage reduction had to be applied to the patterns to cut them a little smaller to ensure that when placed in position, the membrane is tractioned. This was complicated for two main reasons: on the one hand, the fact that the support structure is external and has no margin to expand to tension the membrane; on the other hand, the desire to assemble it without auxiliary means is also a difficulty, given that the traction that can be exerted on the membrane to anchor it to the nodes of the network of bars is quite limited. The percentage of reduction finally chosen means that the membrane shows some wrinkles, but at the same time it can be assembled manually.

Assembly

The assembly consists of joining the bars from the upper hexagon downwards. Around this hexagon, the bars are positioned from the vertices of the hexagon, and then it is lifted and the joints are completed. When two more crowns have been lifted from this hexagon and the network of bars has maintained a convex shape, the membrane is anchored so that all the elements are balanced in the planned position. The base has been assembled beforehand, leaving the visible strip, without yet placing the decking, which can be left for the end. The bars that coincide with the seven anchoring points to the base are placed on the base. The assembled part of the bars and membrane is moved onto the base and the joints between the two parts are completed. The handmodel is a good reference to be used during the assembly process.

eme3 competition

With this solution, the Membrane House is taken to the BAM BioBui(L)t -Espai Txema, a space next to the MACBA that is assigned from the eme3 competition, held in November 2016, to be exhibited in Barcelona. This assembly is carried out without unforeseen events according to the conclusions drawn from the previous assembly tests. The prototype is assembled by six people in 4 hours, with all the necessary materials and tools at their disposal. The MH was the winner of the competition together with the REme prototype from Fab Lab Alicante.

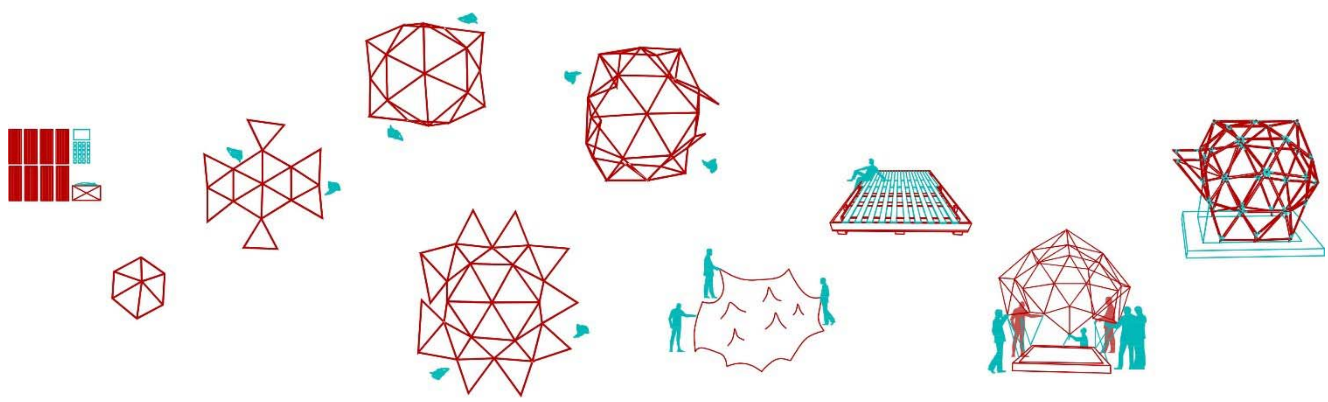


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Figure 11. Manuel for assembling the MH © Beatriz Arnaiz Barrio / LHRC Architecture Collective

Figure 12a/b/c. Erection of the MH at the BAM BioBui(L)t -Espai Txema © Beatriz Arnaiz Barrio / LHRC Architecture Collective

After the event, the Membrane House remained on display for 5 months at the BAM BioBui(L)t -Espai Txema. The MH has subsequently been mounted at various events. In each of the assemblies of the prototype, we have learnt and thought of possible improvements that would make the system polish the faults until a more optimised solution was found.

It is necessary to acknowledge the whole team of architects of the architecture collective LHRC, to which I belong, and from which we have carried out the whole process of design, construction, assembly and dissemination of the Membrane House, and we have continued to be involved in different ways in research and action on social space. In June 2019 our paths separated and we stopped generating new projects and activities from this collective . We have shared a way of doing architecture based on responsibility, low cost and efficiency of materials. From my specialisation in textile architecture we have explored the field of light architecture on the premise of the search for intelligent and unconventional forms .

FUTURE LINES OF RESEARCH

A clear future line of research would be to continue developing emergency prototype solutions for contingency situations. Emergency architecture is an architectural typology that is directly relevant to textile architecture and which still has a long way to go to be able to offer constructions that resolve the worrying situations of temporary shelter that many people find themselves in. A possible related research of great interest for the development of architecture in the face of the current paradigm would be a study that covers temporality related to architecture. Temporality related to its construction system, its function, its impact, among other aspects and beyond the distinction of ephemeral architecture that is recognised today. This would provide a scale of importance of the temporary quality associated with design.

CONCLUSIONS

A structural-constructive system has been developed that works in a stable integral tension equilibrium, combining tensile elements with compressed elements. The prototype works, demonstrating its stability in different locations and for different periods of time. Lessons were learned from the first manufactured structure leading to the manufacture of a new slimmer support structure (wooden bars) which enhances the position of the membrane. The scale of the prototype, the limited means for its assembly and the arrangement of the external structure with respect to the membrane do not allow the membrane to be correctly tensioned, resulting in wrinkles that affect the result of the prototype. The details designed fulfil their function and are coherent with respect to the whole. Although they have a lower durability than the bars and the membrane, they are perfectly replaceable. There are more structurally optimal solutions, as explained in the MH 2.0 section, but due to the means and the intention to develop a low-tech, low-cost prototype, they have not been developed. The potential of the prototype has been demonstrated through the interest shown by various entities, such as organisers of recreational events, NGOs and military institutions. These entities have not been able to provide the necessary funding for the generation of a final product from the MH 1.0 prototype.

The Membrane House has been recognised as a prototype suitable for the demands of contingency architecture as well as ephemeral architecture that gives rise to innovative social spaces that solve current needs in a coherent and sustainable way.

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Beatriz Arnaiz Barrio graduated in July 2021. Her promotor was Ramon Sastre and her tutor Xavier Gimferrer. She did her PhD at the Universitat Politècnica de Catalunya (Escuela Técnica Superior de Arquitectura del Vallès), She did as well many practical experiences together with the Colectivo LHRC, until these activities ended in 2019.

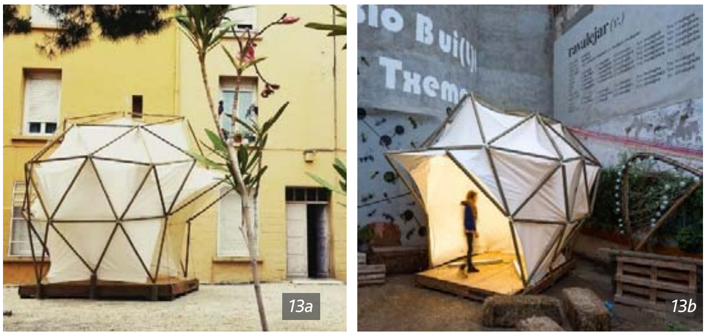

Figure 13a/b. MH set up in the urban context
13a. at Cerbere (France)
13b. at Barcelona (BAM BioBui(L)t -Espai Txema).
© Simon Garcia ArqFoto

Name of the project:	MEMBRANE HOUSE
Location address:	Barcelona (Spain), Girona (Spain), Cerbère (France), León (Spain), Madrid (Spain)
Client (investor):	Verkami, eme3 Competition "Contingency and Praxis" (2016)
Function of building:	Shelter
Type of application of the membrane:	Structural coverage
Year of construction:	Barcelona (Spain) 2016-2017 / Girona (Spain) 2017 / Cerbere (Frace) 2017/ León (Spain) 2018 / Madrid (Spain) 2021
Architects:	Beatriz Arnaiz - LHRC Architecture Collective
Consulting engineer for the membrane:	Ramon Sastre,
Contractor for the membrane (Tensile membrane contractor):	TP Arquitectura Textil
Supplier of the membrane material:	Serge Ferrari (donation)
Manufacture and installation:	LHRC Architecture Collective
Material:	
Structure streched:	Fabric; Membrane Precontraint 502 Satin (570g/m^2); Serge Ferrari
Structure compressed:	Wood; Timber sections 36x36; Vivre en Bois.
Nodes:	stainless steel; eyebolts, bolts, screws, nuts, cables, tensioners; any hardware store, not a specifc brand.
Flooring:	Wood; floorboards and support structure; Vivre en Bois.
Covered surface (roofed area):	12m^2

ADVANCED BUILDING SKINS

16TH ADVANCED BUILDING SKINS CONFERENCE & EXPO

The TensiNet Association will be represented at the 16th Advanced Building Skins Conference & Expo. The first evening, the "TensiNet and friends" meeting with a focus on the activities of the WG Eurocode and the WG sustainability & comfort (18.00-18.45) is scheduled, followed by the Permanent Members meeting (18.45-19.15). The second day, two TensiNet sessions on Membrane Architecture will be held chaired by Katja Bernert and Carl Maywald.

21-22 OCTOBER 2021, BERN, SWITZERLAND

International event on innovative building envelopes for architects, engineers, scientists and the construction industry

KEYNOTE LECTURE

Net Zero Carbon Buildings

the critical role of the envelope

Andrew Whalley, Chairman at Grimshaw Architects, is this year's keynote speaker. One of his well-known projects is the Eden Project in Cornwall, UK, which opened in 2000. He wanted the building to be future-proof, sustainable, energy-efficient, and constructed with minimal waste. The transparent building enclosure is made of three layers of ETFE, a material that provides freedom to form design. In 2001 Andrew Whalley opened the Grimshaw Architects office in New York City and in the same year won the international design competition for the Experimental, Media and Performing Arts Center. More recently Andrew Whalley was instrumental in Grimshaw's work on the Dubai Expo Sustainability Pavilion, which will open on 1st October 2021. His keynote lecture will focus on the urgent need for all new buildings to be Net Zero Carbon Ready. Using recently completed projects, the presentation will explore the influence of Climate and Geography on the Building envelope as part of a net-zero strategy and explore some of the analytical design tools Grimshaw developed.

Figure 1. Eden Project (Garden of Eden), St. Austell, UK, architects: Sir Nicolas Grimshaw & Partners, structural engineer: Anthony Hunt & Associates, execution (ETFE-Foil cushion structure): Vector Foiltec © Vector Foiltec

TENSINET SESSIONS

1 Skins from fabrics and foils Chair: Dipl.-Ing. Architect Katja Bernert

In the session **Skins from fabrics and foils** *Marijke Mollaert* will give an introduction input on contemporary tensile structures in Europe. *Carol Monticelli* will deepen the insight by showing the focal points of TensiNet's working group Sustainability and Comfort. *Katja Bernert* gives an overview on the state-of-the-art of fabric façade architecture, evaluate the industry's advances in sustainability and give a brief insight on what future building skins might look like. More case studies are presented by *Fevzi Dansik* and *Gerd Schmid*. *Allan Hurdle* finds an answer on the question "why limited combustible membranes are important". *Claudia Lüling* finishes the session by showing results from research about textile based, lightweight construction at Frankfurt University of Applied Sciences.

Figure 2a-b. Batumi Stadium, Batumi, Georgia, architect: Bahadir Kul Architect, main contractor: ANAGI LLC, execution: AG (ASMA GERME) © ANAGI LLC (2a), © AG (ASMA GERME) (2b)

2 Building Membrane Cladding Systems Chair: Dr. Carl Maywald

The session **Building Membrane Cladding Systems** starts with a presentation by *Ben Runhaar* on Low haze ETFE film for façade solutions. *Bernd Stimpfle* questioning if technical specifications are needed for building with foils and fabrics. *Carl Maywald* shows ETFE applications along with an outlook on the durability of foils commonly used in tensile architecture. One of today's major functions of tensile building envelopes is highlighted in the presentation of *Monika Rychtáriková* from Leuven University. She talks about researches in the acoustical effects of fabric façades. The insight in engineering ETFE façades is deepened by a presentation of *Felix Surholt*. *Maxime Durka* shows the possibilities of frame-supported membrane structures and Jürgen Holl gives an insight in calculating and form finding of tensile structures.

WE LOOK FORWARD TO WELCOMING YOU AT THE TENSINET BOOTH DESIGNED BY OUR ASSOCIATE PARTNER POLIMI.
MORE INFO: **HTTPS://ABS.GREEN/HOME/**