TensiNews

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NEWSLETTER OF THE EUROPEAN BASED NETWORK FOR THE DESIGN AND REALISATION OF TENSILE STRUCTURES

RESEARCH

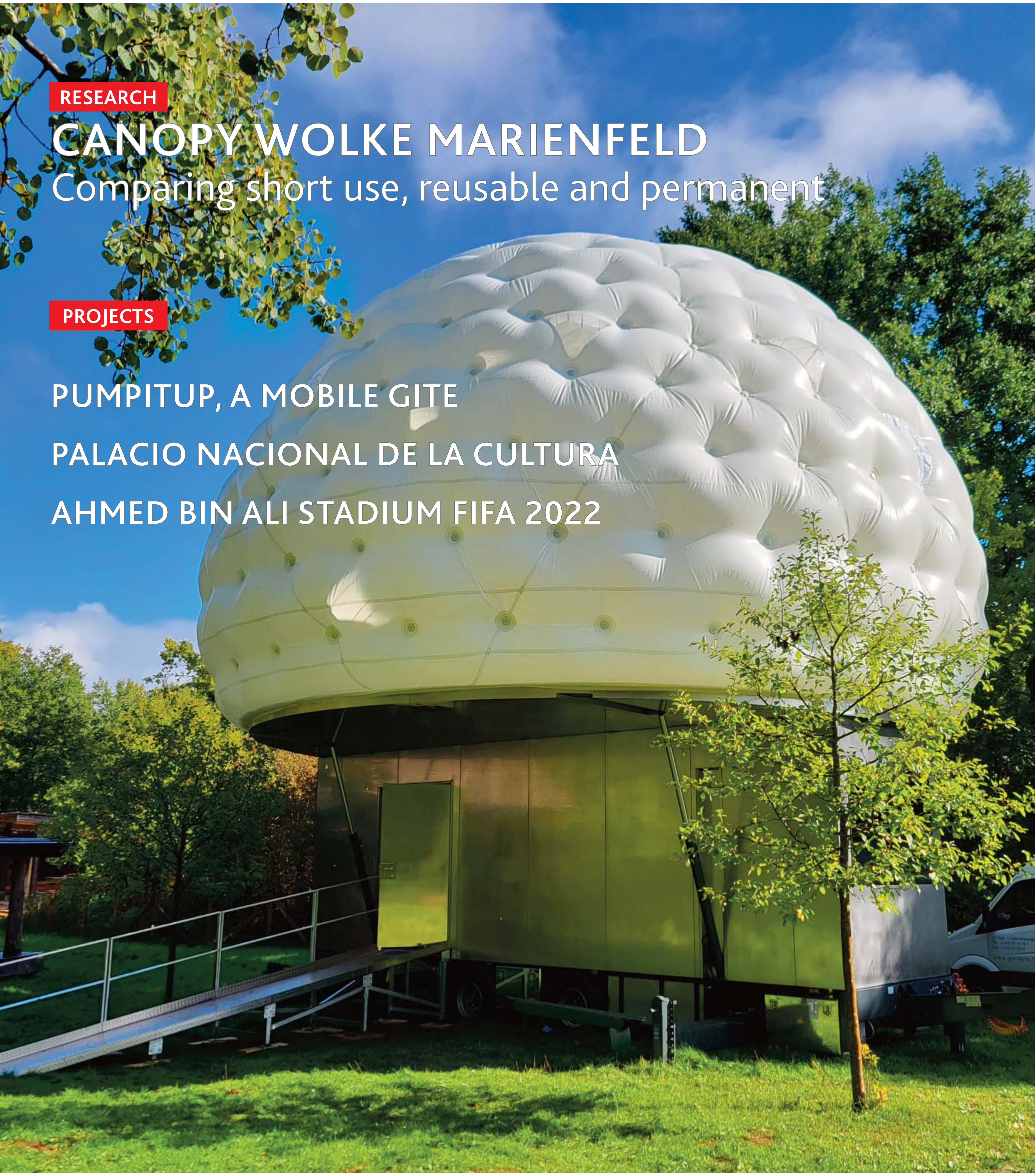
CANOPY WOLKE MARIENFELD
Comparing short use, reusable and permanent

PROJECTS

PUMPITUP, A MOBILE GITE

PALACIO NACIONAL DE LA CULTURA

AHMED BIN ALI STADIUM FIFA 2022

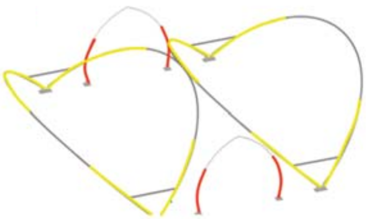


PumpItUp © formTL

contents

Tensinet 2023 partners

PAGE



TENSINANTES2023

MEMBRANE ARCHITECTURE: THE SEVENTH ESTABLISHED BUILDING MATERIAL.
DESIGNING RELIABLE AND SUSTAINABLE STRUCTURES FOR THE URBAN ENVIRONMENT.

WEDNESDAY 7TH JUNE

08.30-09.15	Registration
09.15-09.30	Welcome & Introduction
09.30-10.30	Keynote lecture **Bouncing Bridge: ephemeral, autonomous and self-supporting pneumatic temporary structure** Grégoire Zündel and Ramon Sastre
10.30-10.50	Coffee break
10.50-12.55	Lectures
13.00-14.00	Lunch break
14.00-16.05	Lectures
16.05-16.25	Coffee break
16.25-17.05	Lectures
17.05-18.05	Keynote lecture **Architecture in motion** Louis Ratajczak
18.05-20.00	**Cocktail drink**

THURSDAY 8TH JUNE

09.00-10.00	Keynote lecture **The Pathways to Zero Carbon for Tensioned Membrane Architecture: ongoing actions and next steps** Bruce Danziger and Carol Monticelli
10.00-10.20	Coffee break
10.20-12.25	Lectures
12.30-13.30	Lunch break
13.30-15.35	Lectures
15.40-16.00	Coffee break
16.00-17.00	Keynote lecture **Textile Architecture with or versus today challenges in built environment** Rosemarie Wagner
17.00-19.00	**Walk the green line.** Guided walk to the venue of the Gallerie des Machines
19.00-23.00	**Conference dinner** at Gallerie des Machines

FRIDAY 9TH JUNE

08.30-10.00	**General Assembly TensiNet association**
10.00-11.00	Keynote lecture **Milestones of ETFE construction methods and starting points for further developments** Karsten Moritz and Jean-Christophe Thomas
11.00-11.20	Coffee break
11.20-13.00	Lectures
13.00-14.00	Lunch break
14.00-15.40	Lectures
15.40-16.00	Outlooks & Thanks
16.00-17.30	**Working Group Sustainability & Comfort** Meeting with invited guest Bruce Danziger

TensiNews INFO

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Edito

Dear Reader

Only a few months from now, second week of June, our next TensiNet Symposium TENSINANTES 2023 "Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment" will take place at Nantes Université. Our organizers and the scientific committee have collected a wide range of interesting topics. You find more information in this TensiNews, on the conference website and of course on our TensiNet website. If you have not yet signed in, please take a look to our topics and program. It is worth to join, so don't hesitate. We will have our General Assembly during the symposium in Nantes, and our Sustainability and Comfort working group will also meet there.

This issue of TensiNews is again full of inspiring projects and contributions. Two research projects are presented, a floating membrane roof for storage tanks, and an LCA study about the environmental performance of a temporary structure partially made of reusable steel elements for short term use. You find here also articles about three membrane projects mechanically and pneumatically tensioned. The colleagues of University Duisburg-Essen were so kind to hand in a summary of the fifth Essener Membranbau Symposium, which took place last autumn.

The future Technical Specification for membrane structures prCEN/TS 19102 is now in translation in the different member states in order to be published soon for final voting. We are sure this milestone of standardisation work helps all of us. Please encourage the relevant people in your country to vote positive, or if you are in charge please vote for it.

Please enjoy this issue of TensiNews and I hope to meet you soon in Nantes, or on other occasions this year.

Yours sincerely,
Bernd Stimpfle

TensiNet

Forthcoming Events

The Fiber Society's 2023 Spring Conference I *Fibers for a sustainable world* I *15-17/05/2023* I
DITF, Denkendorf, Germany
www.thefibersociety.org

TENSINANTES 2023 — TensiNet — Nantes Université — GeM

TENSINANTES2023 – TensiNet symposium at Nantes Université I *Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment.* I
7-9/06/2023 I Nantes, France
https://tensinantes2023.sciencesconf.org/

ITMA 2023 I *Transforming the World of Textiles* I
8-14/06/2023 I Milan, Italy
https://itma.com/

IASS 2023 I *Integration of Design and Fabrication* I
10-14/07/2023 I Melbourne, Australia
https://www.iass2023.org.au/

STRUCTURAL MEMBRANES 2023 I
2-4/10/2023 I Valencia, Spain
https://structuralmembranes2023.cimne.com

Advanced Building Skins Conference & Expo 2023 I *30-31/10/2023* I Bern, Switzerland
https://abs.green/home

TENSINET SYMPOSIUM 2023 AT NANTES UNIVERSITÉ FROM 7TH TILL 9TH JUNE 2023

3 MAIN TOPICS

STRUCTURAL MEMBRANE
contemporary, innovative, adaptive daring and impactful solutions

TENSIONED MEMBRANE STRUCTURES
the seventh building material

STRUCTURAL MEMBRANE
an answer to issues of the 21st century

FILM Christo and Jeanne-Claude
"L'Arc de Triomphe, Wrapped" backstage - engineering for a work of art
by büro für leichtbau, Tritthardt+Richter

8 KEYNOTE SPEAKERS

Bruce Danziger - Danziger Engineering Collaborative, Inc. (US)
Carol Monticelli - Polytechnic of Milan (Italy)
Karsten Moritz - IMS Bauhaus® Archineer® Institutes e.V. (Germany)
Louis Ratajczak - DVVD (France)
Ramon Sastre - Universitat Politècnica Catalunya (Spain)
Jean-Christophe Thomas -Nantes Université (France)
Rosemarie Wagner - Building technology Faculty of Architecture KIT (Germany)
Grégoire Zündel - Atelier Zündel Cristea (France)

5 KEYNOTE LECTURES

- **Bouncing Bridge: ephemeral, autonomous and self-supporting pneumatic temporary structure**
- **Architecture in motion**
- **The Pathways to Zero Carbon for Tensioned Membrane Architecture: ongoing actions and next steps**
- **Textile Architecture with or versus today challenges in built environment**
- **Milestones of ETFE construction methods and starting points for further developments**

3 SOCIAL EVENTS

Cocktail drink

Walk the green line Guided walk to the "Gallerie des Machines"

Conference dinner at the "Gallerie des Machines"

TensiNet General Assembly 2023

The **General Assembly** will take place on Friday 9 June at 08.30, before the start of the lectures.

TensiNet Working Group Sustainability & Comfort Meeting

Invited guest Bruce Danziger
Friday 9 June at 16.00

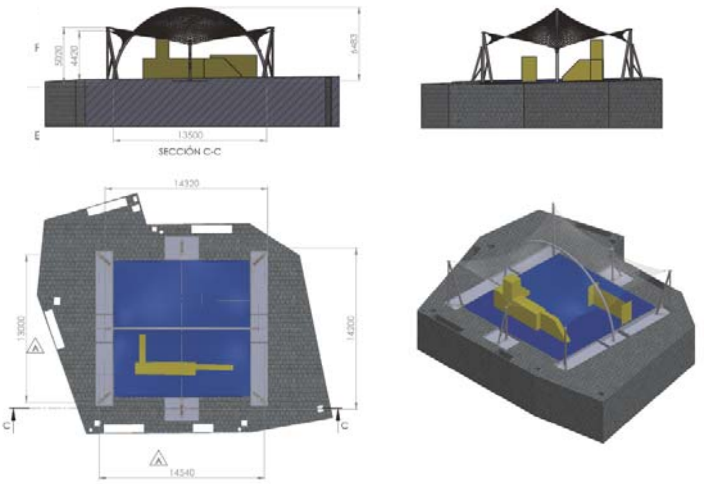
https://tensinantes2023.sciencesconf.org/

Tensile Cover for playgrounds

Combining curvy and straight geometry

Pamplona, Spain

During the summer of 2021, following the success of two tensile covers designed and built by Carpas Zaragoza the year before, the Pamplona City Council opened a call for tenders for the design and erection of more covers in selected playgrounds within the city. Despite the challenge of the short deadline for the preliminary design, the Carpas Zaragoza design team came up with a proposal which was awarded with four out of six of the new installations. The City Council required PES/PVC membranes supported on galvanised steel structures, with a design which would minimize the use of inner supports and vandal resistant.



Design

The playgrounds were both fairly square, with 12mx12m in Azpilagaña and 17mx18m in Buztintxuri , The driving idea behind the design was the combination between curvy and straight geometry, evoking the outline of a white dove. This idea was adjusted to the layout, shapes and height of the existing elements in each playground.
The shape in the smaller installation at Azpilagaña was solved with the use of a 13,5m span central arch and six twin legged masts, oriented according to the direction of the forces on the corner.

The philosophy behind the Buztintxuri cover was the same, but given the dimensions, a twin arch arrangement was chosen, where each arc opened to the outside as it gains in height. The supporting structure was completed with six masts, as in its smaller sister.
Each cover was given a white LED lightning installation to enhance the nocturnal aesthetics and increase the availability of the playground during the winter.

Once the preliminary design was approved by the City Council, the Design Team worked on the detail design to release the workshop drawings.

While the civil works were completed on site, manufacturing of the steel structure and the membranes were done in the Carpas Zaragoza facilities, as well as the details assembly (corner plates, etc…), final inspection, folding and packaging. The erection and final touch-ups were carried out by Carpas Zaragoza own personnel.

Figure 1. The tensile cover for the playground in Azpilagaña

Figure 2. The tensile cover for the playground in Buztintxuri

Carlos Angulo
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www.carpaszaragoza.com/

Name of the project:	Tensile Cover for playgrounds
Location address:	Azpilagaña and Buztintxuri neighbourhoods (Pamplona)
Client (investor):	Pamplona City Council
Function of building:	Protection from rain, snow and sunlight
Type of application of the membrane:	canopy
Year of construction:	2022
Design team:	Alex Moliner and Iñaki Ibero
Multi-disciplinary engineering, structural engineer and consulting engineer for the membrane:	Carlos Angulo
Main contractor, manufacture and installation:	Carpas Zaragoza, S.L.
Supplier of the membrane material:	Serge Ferrari
Material:	Serge Ferrari Flexlight Advanced 902 S2
Covered surface (roofed area):	150m² (Azpilagaña) + 280m² (Buztintxuri)

FLOATING MEMBRANE ROOF for large zootechnic and industrial storage tanks

1

The biogas sector had a rapid development in the last decade with several new industrial plants realized all over Europe and Worldwide. The intrinsic efficiency of membrane structures provided a cost-effective solution to cover digesters, bio-filters, lagoons and gas holders through different concepts such as floating membranes, anticlastic geometries and pneumatic structures.

The most challenging applications for biogas plants are the membrane roof for large lagoons and storage tanks designed to store the sewage after it has been treated. The most common shape is circular but elliptical and rectangular plans are also adopted in specific situations. For this application, the membrane roof protects the tank from rainwater and prevents the release of gas and smell in the atmosphere. In recent years, local environmental regulations became more stringent regarding the emissions released into the atmosphere and the current membrane structures do not always meet the new criteria.

In 2021 Maco Technology srl secured financial support (POR FESR 2014-2020: ASSE I – AZIONE I.1.B.1.2. BANDO "TECH FAST LOMBARDIA") for the development of a prototype able to address the limits of the current products and investigate the technical and financial viability of a new type of roof for zootechnic and industrial large storage tanks. The pilot project was carried out in collaboration with the University of Nottingham and Acqua e Sole srl and a 1:1 scale prototype was installed in the North of Italy in a circular metal storage tank 64m in diameter and 18m high.

The new, patent-pending, concept is based on a floating roof made of modular PET cubes and rectangular cuboids commonly used for floating pontoons cladded with an airtight membrane. The forces are transferred to the tank through low-friction wheels connected to the floating deck by means of rigid steel reinforcements designed to spread the load across multiple PET floating units. The membrane roof is manufactured in one single piece using a PVC-coated polyester fabric optimized for biogas applications. The membrane is connected to the floating deck by means of a tubular edge ring connected to the PET modules by means of a polyester webbing system tensioned through removable ratchets. The edge ring provides a barrier for the rainwater which is conveyed in dedicated areas for drainage by means of water pumps. The effective drainage of the rainwater avoids the dilution of the stored liquid and the consequent associated costs.

The airtightness of the membrane cladding is achieved by means of a hermetic clamping to the steel reinforcements and thanks to an immersed membrane flap which prevents the passage of the gas. The gas is drained from two points connected to a low-pressure blower. The design of the PET modules provides adequate space for the unleashing of the gas from the liquid and circulation under the membrane cladding. In tanks covered by fixed roofs, the volume and the pressure of the gas trapped between the liquid and the roof varies according to the level of the liquid. This creates the risk of oxygen infiltrations (due to the negative pressure due to a decreasing liquid level) which, combined with the large volumes of gas accumulated, could result in a high risk of explosions. In the proposed new concept, the floating deck creates a limited volume for the accumulation of gas between the membrane and the liquid which remain constant despite the variation in the liquid level. The result is a safe and effective way to prevent the release of gas into the atmosphere and 10% increase in the total gas output of the biogas plant. The structure has been successfully monitored for 12 months, the level of purity of the methane gas is over 90% and the air infiltrations are negligible despite the size of the membrane roof. The positive results achieved confirmed the technical and financial viability of the idea and lead to the commercialisation of the new, patent-pending, product on the market.

2

3

4

Figure 1. The aerial view of the biogas plant
Figure 2. The floating deck under construction
Figure 3. Detail of the steel reinforcement
Figure 4. The positioning of the membrane roof
Figure 5. The membrane roof ready to be deployed
Figure 6. The detail of the tensioning system and the protective layers around the perimeter of the floating deck
Figure 7. The tensioned membrane roof

5

6

7

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Acknowledgements: The pilot project was financially supported by the funding scheme POR FESR 2014-2020: ASSE I – AZIONE I.1.B.1.2. BANDO "TECH FAST LOMBARDIA"

AHMED BIN ALI STADIUM
An impressive venue for the 2022 FIFA World Cup

Al Rayyan, Qatar

The city Al Rayyan is known as the 'gateway to the desert' and for its strong connection to the country's traditional culture and heritage. The Ahmad Bin Ali Stadium, named after the Sheikh, is one of the venues for the 2022 FIFA World Cup and was awarded to the architectural firm Pattern Design by the Al Balagh-L&T construction joint venture. The London-based firm is lead designer and architect for the stadium, the training facilities and the master plan. The conceptual theme for the site is the Desert translated into a masterplan concept of a caravan or journey in the desert landscape. Dunn lightweight has been involved from the engineering phase, together with büro für leichtbau, until the installation phase of the inner roof, the wind net and the inner facade of the stadium.

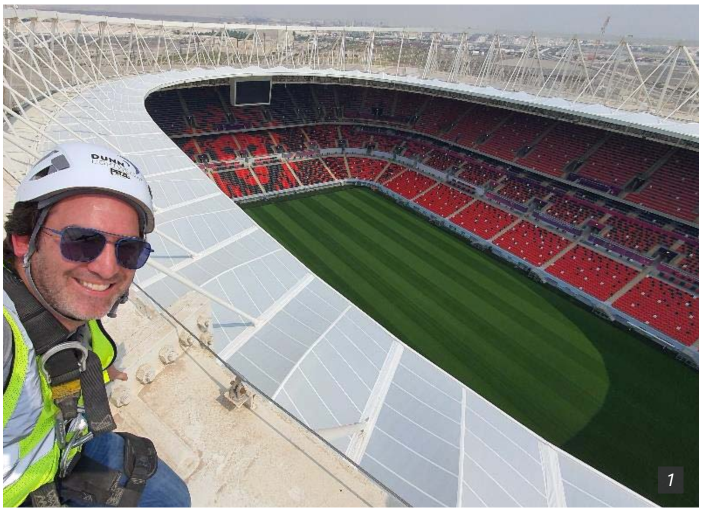
The stadium project was granted to Dunn lightweight, due to its attention and ability to design, supply, manufacture and install with their own team. History has been made since they stepped into the ring as a new player with other major players. As part of their task, Dunn lightweight developed a fully functional system for 3 main areas: inner roof (1), wind net (2) and inner facade (3).

Inner Roof

One of the biggest challenges was manufacturing the fabric panels in Mexico and the logistics of shipping 9 containers with the 48 rolled pieces. The material chosen was Verseidag's laminated fiberglass B18901, taken into account its properties of being very hard to fold or manipulate without damaging it. In addition, the entire structure was surveyed, and the cutting patterns were done for each individual panel. Together with Jorg Tritthardt, the compensation was resolved which was precise to the millimetre, and any deviation would substantially increase the prestress. In the end, the developed details and installation methods were very successful since we installed all panels without tears or damages. For installation, we used combined teams of technicians from our in-house crew, all IRATA certified, and a team managed by Marcelino Gonzalez, Manuel Garcia, Gabriel Rodriguez and Victor Garcia with turkish experts. A very straight policy for QC/QA was followed by our confection and installation team, as strict procedures of all kinds of tests were demanded and all were safely complied.

Fabrication:
Once we finished the patterns after research, we developed 12 different wooden geometries to follow the shape of the fabric and to be able to weld correctly. On figure 3 you can see two sections of the fabric are being connected to the wooden frame.

Figure 3. Fabrication process showing two sections of fabric being connected to the wooden frame.



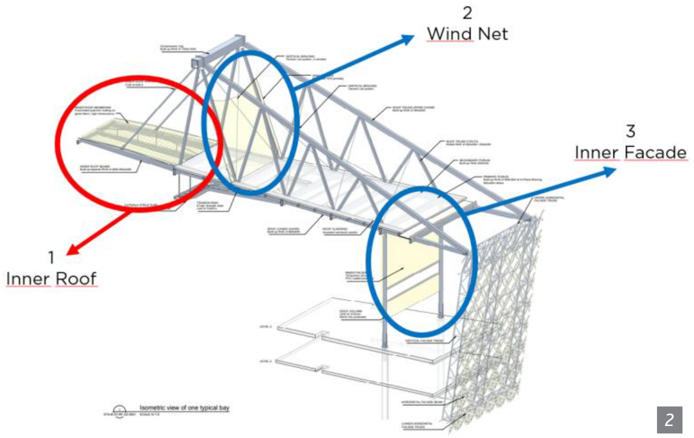


Figure 1. Installation of the inner roof of the Ahmad Bin Ali Stadium.
Figure 2. Fragment of the steel structure indicating the inner roof (1), wind net (2) and inner façade (3).

Transportation and Installation:
After carefully preparing the containers, each of which had to be subdivided in two levels, to store 3 panels at the top and 3 at the bottom, to avoid any damage per folding, all panels were fan folded, and reinforced on the fold with a tube to avoid kinks (Fig. 4). The installation was quite simple. The panels were offloaded from the containers, lifted with a crane to the metallic roof (Fig. 5) and deployed over the safety nets and precisely installed (Fig. 6).

Wind net

Once all simulations of the models, including wind/air-conditioned studies where done, the project needed a "wind breaker" in order to release the hot air from the central opening of the stadium. For this purpose, we were asked for a rope net of 3x3cm in order to break/deviate the wind and allow the hot air to come out. This special product was supplied by Manfred Huck GmbH and strictly designed and tested by Jörg Tritthardt to define the connection system, the compensation and the long-term behaviour

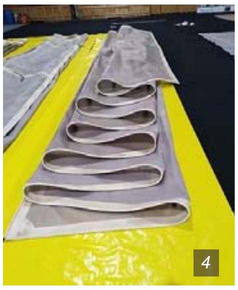
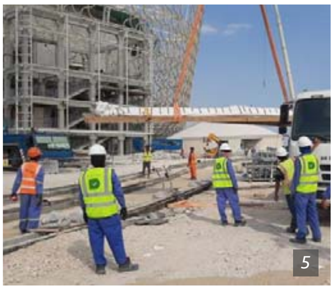



Figure 4. Carefully folding the panels for transport.
Figure 5. Offloading the packed panels.
Figure 6. Unfolding the panels above the safety nets.
Figure 7. Inner roof installed.

for this product during the foreseen lifespan of 5 years. All fabrication was done in Austria. At the top the fabric was laced over a stainless-steel cable in order to transfer the loads to the structure. The installation was carried out by a team of IRATA, that was fully suspended into the air. Also, a ratchet system was developed to slowly stretch the fabric and get it into the system geometry, 4 special nets were fabricated with a manhole to have access to the inner façade.

Fabrication:
After multiple visits, conversations and research, the system geometry was defined, and all 48 wind nets produced according to the data.

Transportation and Installation:
The wind nets were collected in small boxes consisting of different levels (Fig. 8). The installation was done following a previously accepted procedure, using rope access, connecting first the top cable to the structure and then pulling it with ratchet belts to the corners and bottom profile (Fig. 9).

Inner Façade

The stadium was designed to change its capacity from 40.000 spectators to 20.000, which is the standard for local club attendance. At that time all air conditioner systems will be removed. Therefore, a façade was designed to fully close the gap between the high seats and those that remain. The façade is removable using a lashing system. 2 special panels were fabricated to allow all communication and television systems to pass through.

Fabrication:
All panels were fabricated using HF machinery for seams, al QC/QA procedures were followed in order to comply with the contractual policies.

Transportation and Installation:
Transport was done in a single container, as all pieces of PVC fabric could be stacked. The fabrication was done using scaffolding, all 48 panels were fastened form the top to the bottom, after which cover flaps, to make the façade air tight, were welded to the struc-tural top and bottom elements and lateral from panel to panel (Fig 10).

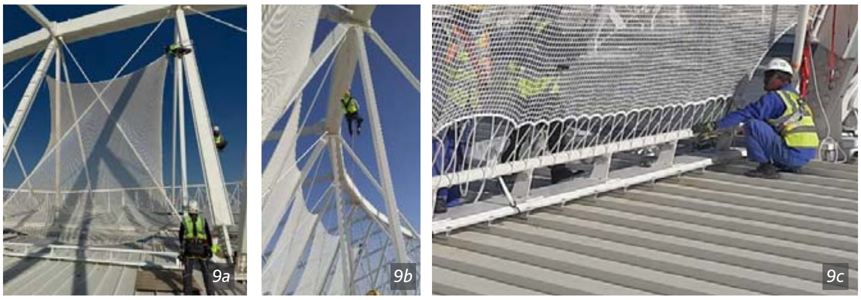



Figure 8. Small wooden boxes collecting the wind nets.
Figure 9 a/b/c. Connecting the wind nets to the steel structure.

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www.dunn-lwa.com
© Dunn lightweight


Figure 10. Folding and stacking of the PVC fabric for transport.
Figure 11. Installation of the removable inner façade between the seats to change the sitting capacity of the stadium.

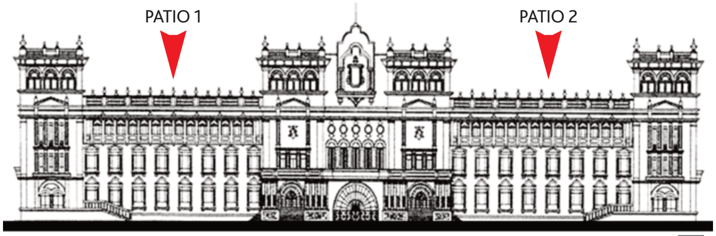
Name of the project:	Ahmed Bin Ali Stadium
Location address:	Al Rayyan, Qatar
Client (investor):	The Supreme Committee for Delivery & Legacy
Function of building:	Stadium
Type of application of the membrane:	Laminated fiberglass for inner roof PVC fabric inner removable facade and Huck Net for windbreak at the top of the roof.
Year of construction:	2018-2022
Architects:	Pattern Design
Multi-disciplinary engineering:	Dunn lightweight LLC / Jörg Tritthardt - büro für leichtbau
Structural engineers:	Dunn lightweight LLC / Jörg Tritthardt - büro für leichtbau
Consulting engineer for the membrane:	Dunn lightweight LLC / Jörg Tritthardt - büro für leichtbau
Main contractor:	Al Balagh-L&T
Contractor for the membrane (Tensile membrane contractor):	Dunn lightweight LLC
Supplier of the membrane material:	Verseidag / Serge Ferrari / Manfred Huck GmbH
Manufacture and installation:	Dunn lightweight LLC
Material:	Laminated fiberglass B18901; PVC fabric 932 S2 and Huck Net PP-filament yarn
Covered surface (roofed area):	Laminated fiberglass 5680m^2; PVC fabric 7590m^2 and Huck Net 4190m^2

Palacio Nacional de la Cultura

Guatemala, Central América

The building served as government headquarters from 1943 (year of completion) until 1998, when it became officially known as "Palacio Nacional de la Cultura". The building has a symmetrical design showing a central body from which two lateral bodies can be seen, each one has three levels and a central patio. The general style is very eclectic, however a neoplateresque design is predominant, its general lines are inspired by the Palacio of Monterrey of Salamanca (Fig. 2).

1



2

In 2004 a membrane cover was placed above 2 inner patios as rain cover, in 2010 however one of the roofs materials was torn due to poor design and the other one began to suffer both in material and structure (Fig. 3). Even though a morphological box proposing a variety of new designs taking into consideration form, function, stress forces, weight, impact were presented, according to national conservation laws, removing the structure and putting into place a new design was prohibited.

3a

3b

Project

A new plan was put into place consisting of three main aspects:

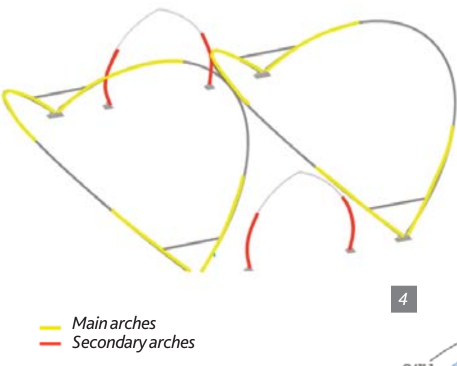
- Conduct a topographic survey in order to analyze both general and specifics points of the existing structure such as general dimensions, diameters of primary and secondary arches, anchorages, etc.
- Make a structural analysis using a virtual wind tunnel which determined that the structure was sub designed 2.5 times compared to what it needed, so structural reinforcements were designed and put into place all along the structures of both patios
- Add two lateral wings to each cover for better protection of sun and rain and adding extra stability to the structural system itself.

Reinforcement

Reinforcement is needed as shown in the following drawings:

The main arches were reinforced in their first 10.20 linear meters, they have three longitudinal sections in order to achieve contact between both surfaces as shown in figure 5.

The secondary arches were reinforced in their first 4.80 linear meters. Additional structure was put into place on the secondary arches (Fig. 6).



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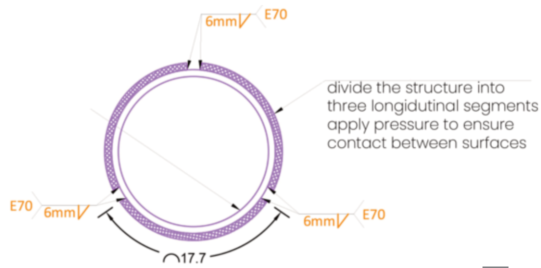
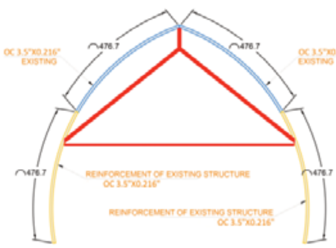
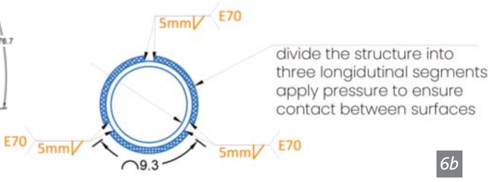


5

Figure 1. New membrane structure covers the patio
Figure 2. Façade Palacio National de la Cultura
Figure 3 a/b. The old structure and cover in bad condition.
Figure 4. Reinforcements in the arches
Figure 5. Reinforcements in the main arches
Figure 6 a/b. Reinforcement in the secondairy arches.



6a



6b

Installation

The mounting process was difficult since it´s a heritage building, the use of a mechanical crane was not an option: everything, from the materials to the structure and the membrane was uplifted by hand.

The final project was highly satisfying for both the client and the contractor. Achieving a successful project is always gratifying: this especially had a different sense of challenge being an historical landmark of the country. Therefore, it demanded nothing but the best from the material provided by Sattler PRO-TEX (Austria), up to the intervention on the building and its surroundings including the inner facades of the patios and the decorative elements.

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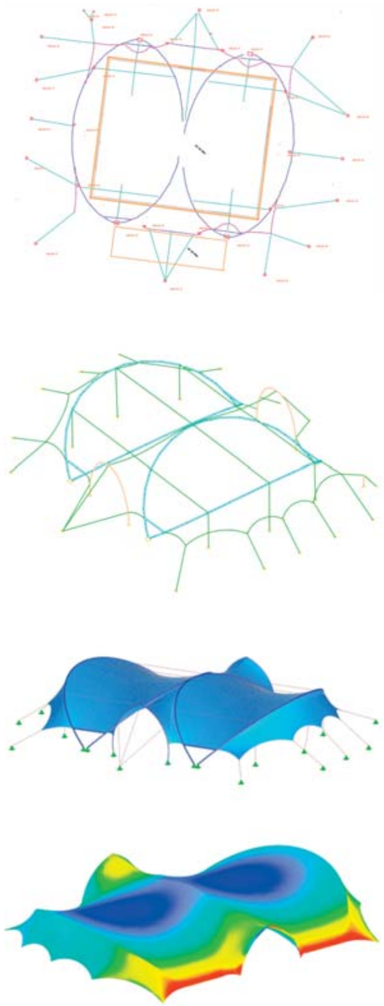

Figure 7a/b. Reinforcement in main and secondary arches.
Figure 8. Mounting of the first half of the membrane cover of one of the inner patios.
Figure 9. Architect Carlos Armendariz supervising the project.
Figure 10 a/b. Bird view with the new covered patio's.

Name of the project:	Palacio Nacional de la Cultura
Location address:	Guatemala, C.A.
Client:	Ministry of Culture, Guatemala
Function of building:	Government Offices
Type of application of the membrane:	Membrane Roof
Year of construction:	2021
Architect:	Arch. Carlos Armendariz, Arch. Ericka Escobar (crearquitectura, s.a.)
Structural engineers:	technotense mx
Engineering:	crearquitectura, s.a.
Main contractor and contractor for the membrane:	crearquitectura, s.a.
Supplier of the membrane material:	Sattler PRO-TEX
Material	ATLAS Architecture Type II TFL (art. 739)
Manufacture and installation:	technotense mx, crearquitectura, s.a.
Covered surface (roofed area):	1200m² per patio or 2400m² in total

CANOPY WOLKE MARIENFELD

Comparing the environmental performance of a short use, a reusable and a permanent membrane structure

Figure 1. Canopy Wolke Marienfeld. 1a/d ©Tom Bilsen, Stageco; 1b/c © form TL

Research context

The following research has been done in the context of the PhD of Zehra Eryuruk, under the supervision of Marijke Mollaert and Lars De Laet. The PhD research concerns the environmental impact of membrane structures.

Membrane structures are made of tensioned membranes with the major advantages of being lightweight and structurally optimized, but the End of Life (EOL) scenario and Life Cycle Assessment (LCA) are currently not fully resolved. There are many tools, studies and reference cases for LCA, but the context for tensile structures is very specific. In particular, the lifespan can vary from a few days to 40 years or more.

In more conventional construction sectors the considered life span for LCA simulations is 50- to 70-years. For short use or reusable membrane structures, the approach should be verified. Generating an LCA for these temporary lightweight structures requires more simulations with different input and EOL options. In this paper, we evaluate the environmental performance of a temporary membrane structure considering different simulations.

General description

The canopy Wolke Marienfeld (Fig. 1) is a pneumatic structure that served as the Pope's stage roof for the world youth day in 2005 (Cologne). The design represents a big white cloud placed on 4 steel columns (trusses).

Form TL provided the conceptual design along with the tender documents. The support structure was designed and built by Stageco, the Belgian company known for its worldwide temporary event structures. IF did the detailed design of the additional steelwork and the membrane, and Canobbio fabricated the membrane.

The dimensions of the roof are 30m x 32m. The grid, a standard structure, consists of trusses (1.8m or 1.3m high). These trusses are taken from Stageco's warehouse and returned after use (Fig. 3). The rectangular perimeter of the truss grid is extended with an elliptical ring to attach the top and side cushions to create the Cloud (Fig. 2). The five individual cushions are made of PVC-coated polyester. The top cushion (39m by 32m) is attached on top of the grid, and four smaller cushions (22m or 27m by 6m or 6.5m) form the border, which is attached to the perimeter of the grid. The total weight is about 120kg/m², and the covered area is 960m². Compared to more regular membrane constructions, this is a

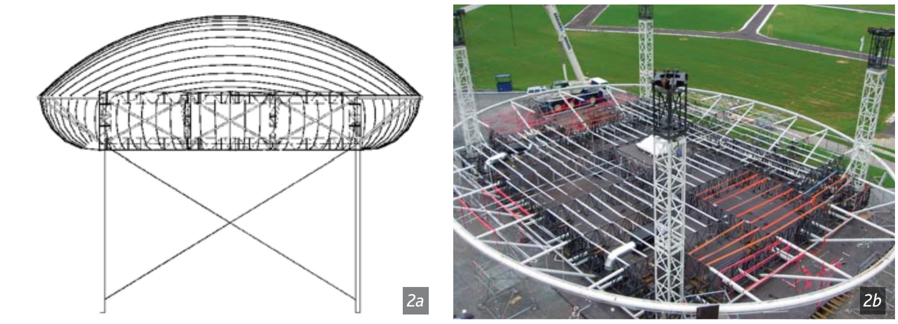

Figure 2. Structural system supporting the Cloud, 1a © form TL, 1b ©Tom Bilsen, Stageco
Figure 3. Stageco warehouse with standard steel columns and beams,
www.hln.be/economie/interview-podiumbouwer-hedwig-de-meyer-van-stageco-na-2-verloren-jaren-opnieuw-volop-aan-de-slag-in-de-vs-de-echte-test-komt-er-pas-volgend-jaar~a58c4dea/

fairly heavy construction. For example, the Dancing Tent designed by Frei Otto, has a weight of about 5kg/m².

Input data for the LCA

The simplified LCA simulations, based on rough quantity estimates, are performed using the OneClickLCA tool. The LCA process starts from raw material extraction, through production, transport, consumer use, and finally disposal and recycling. For this assessment, the following stages of the LCA are considered: the impact of construction materials (A1-A3), the construction and installation process (A5), the energy consumption for inflation (B6), the end of life (C1-C4) and the benefits and loads beyond the system boundaries (D). The Global Warming Potential (GWP) results are evaluated.

Three structural entities are considered in the LCA simulations: the standard steel trusses, the special steel components, and the membrane. For transport and other parameters, default settings are kept.

The total weight of the steel structure is about 105.000kg. 80% corresponds to reusable standard steel components. The towers and beams are reusable components from Stageco's warehouse, and the 'reused material' option is used in OneClickLCA. At the End of Life (EOL), the components are disassembled, stored and ready to be used for the next erection. For this purpose, the 'reuse as material' option is selected in the tool. The remaining 20% corresponds to recyclable special steel components and will be recycled at the EOL; for this process, the 'steel recycling' option was selected in the tool. The service life of steel is set at 70 years. Since no information is available, a steel with low recovered content was selected in the LCA tool: 'structural hollow steel sections (HSS), cold rolled, generic, 10 % recycled content, circular, square and rectangular profiles, S235, S275 and S355'.

The total amount of used PVC-coated polyester membrane is about 10.000m² with a wastage range of 20%. Two scenarios of EOL are possible for the membrane. The first is incineration and the second is, if reuse is applicable, 'reuse as material'. The service life of PVC-coated polyester is set at 25 years. For the inflation of the cushions, the operational energy is estimated to be 0,25kWh per year and per m².

The LCA parameter 'End of Life calculation method' is set to 'market scenario, user adjustable'. This means the EOL scenario is based on standard market practices. For example, if the considered country has highly regulated taxes and recycling rates (e.g., most of Europe), recyclable materials are recycled by default. In markets that lack regulations and landfill taxes (e.g., the Middle East), most materials are landfilled by default.

The service life of the structure must be specified in an LCA. For Wolke Marienfeld, which was dismantled after 2 weeks of use, the calculation period is set at 0.04 years.

LCA simulations

Different simulations are needed to understand the LCA of a short use canopy, a reusable structure and a permanent structure. Each simulation reflects a scenario.

Canopy Wolke Marienfeld (simulation 0) is considered as the reference. Newly made special steel components and a new membrane are installed, while standard steel trusses are reused from the warehouse. At the EOL, the standard steel components will be stored for reuse, the special steel components will be recycled and the membrane skin will be incinerated. The canopy is installed for 2 weeks.

As alternative, 3 scenarios of a reusable structure are analysed: a scenario where the structure is installed for the first time (simulation 1 - first), a scenario where the stored structure is reused and stored again (simulation 2 - intermediate), and a scenario where the structure is installed for a last time (simulation 3 - last). A duration of 2 weeks is considered for each set-up. The first installation is the scenario where new components are made to create the structure and where all materials are reused for another installation at the EOL. An intermediate installation is the situation where existing components are reused to build the structure and where at the EOL all materials are stored for a future installation. The last installation corresponds to the scenario where the materials are worn out and where all existing components and materials are used for the last time to build the structure. At the EOL, the standard steel trusses and special steel components are recycled, while the membrane is incinerated.

A final alternative design (simulation 4) considers a permanent membrane canopy where the canopy is used for 25 years. The installation is done with new standard steel elements, new special steel components and a new membrane. At the EOL, the standard steel trusses and special steel components are recycled, while the membrane is incinerated. The disadvantage of short use can be verified by comparing simulation 1 with simulation 4.

TABLE 1. GWP RESULTS FOR SIMULATIONS 0, 1, 2, 3 AND 4

Simulation	0	1	2	3	4
	Wolke Marienfeld	Reusable structure			Permanent
Installation	Once	First	Inter-mediate	Last	Once
Standard steel structure	Reused	Newly made	Reused	Reused	Newly made
Special steel components	Newly made	Newly made	Reused	Reused	Newly made
Coated fabric	Newly made	Newly made	Reused	Reused	Newly made
EOL: Steel	Recycling	Reuse as material	Reuse as material	Recycling	Recycling
EOL: Coated fabric	Incineration	Reuse as material	Reuse as material	Incineration	Incineration
Service life	2 weeks	2 weeks	2 weeks	2 weeks	25 years
Units	kgCO_2e	kgCO_2e	kgCO_2e	kgCO_2e	kgCO_2e
A1-A3 Construction Materials	131.000	443.000	0	0	443.000
A5 Construction and installation process	17.700	23.600	0	0	28.100
B6 Energy consumption for inflation	57	57	57	57	35.900
C1-C4 End of life	22.600	0	0	26.000	26.000
D External impacts	-356.000	-461.000	-438.000	-213.000	-221.000
Total	**173.000**	**469.000**	**1.720**	**27.700**	**535.000**
Per floor area m2 per year	4.510	12.200	44,7	721	22,3

A1-A3 Construction Materials and D External impacts

Global Warming Potential (GWP) results

The 5 simulations are evaluated based on the GWP indicator.

A1-A3 Construction Materials and D External impacts

The reference simulation (simulation 0, Table 1) assumes reused standard steel components, which will be stored after dismantling, newly made special steel components which will be recycled, and a newly made membrane, which will be incinerated after use.

The GWP of the modules A1-A3 (partly reused materials) is low (131.000kgCO_2e), and the GWP of module D is high (-356.000kgCO_2e). The GWP of module D contains firstly the benefit of the material (-354.000kgCO_2e), which is the sum of the following contributions: the reuse of the standard steel structure (-84.000 * 3,66 = -308.000kgCO_2e), the recycling of the specially designed steel components (-21.000 * 2,2 = -41.700kgCO_2e) and the incineration of the technical textile (-10.000 * 0,4927 = -4.930kgCO_2e) and secondly the benefit of the material wastage on the construction site (module A5), which is -2.360kgCO_2e. In these calculations, the coefficient for the reusing steel is 3,66kgCO_2e/kg, for recycling steel is 2,2kgCO_2e/kg, which is lower, while the coefficient for the burning technical textile is 0,4927kgCO_2e/m².

The first simulation (simulation 1, Table 1) corresponds to the scenario where the canopy is constructed with newly made materials and all materials are reused at EOL. The GWP of the modules A1-A3 is high (443.000kgCO_2e). The higher value, compared to simulation 0, is because the steel components and the membrane are newly fabricated. The GWP of module D (-461.000kgCO_2e) is of the same order of magnitude as modules A1-A3, which means that the GWP of the benefits beyond the system boundaries balance the GWP of production and manufacturing of the construction materials. The higher value of module D, compared to simulation 0, is because the reuse of all materials gives a higher result for the GWP of this module. Module D in this case, contains the reuse of the standard steel structure (-84.000 * 3,66 = -308.000kgCO_2e), the reuse of the specially designed steel components (-21.000 * 3,66 = -76.900kgCO_2e), the reuse of the technical textile (-10.000 * 5,34 = -53.400kgCO_2e) and the benefit of the material wastage on the construction site, which is -23.400kgCO_2e.

The intermediate installation (simulation 2, Table 1) corresponds to the scenario where the canopy is constructed with existing materials, and where all materials are reused at EOL. The GWP of modules A1-A3 is 0 because all materials of simulation 1 were reused in this simulation. The GWP of module D is high (-438.000kgCO_2e) due to reuse at EOL, and there is no material wastage considered at the construction site.

The third simulation (simulation 3, Table 1) reflects the situation where all steel components are made of reused materials and are recycled at the EOL. The membrane is also reused and will be incinerated at the EOL. The GWP of modules A1-A3 is 0 because all components are reused components. The GWP of module D (-213.000kgCO_2e) contains benefits and loads beyond the system boun-daries for recycled steel and incinerated membrane. This result is lower compared to simulation 2 or 3, where all materials were reused at the EOL.

The final alternative assumes a newly fabricated steel structure and membrane, with steel recycling and membrane incineration at the EOL (simulation 4, Table 1). The GWP of modules A1-A3 is high (443.000kgCO_2e) as for simulation 1, and the GWP of module D is comparable to the value for simulation 3 (-221.000kgCO_2e).

The total GWP

The total GWP for the canopy Wolke Marienfeld is low (173.000kgCO_2e) thanks to the reuse of standard steel components (80%).

For the alternative case of a reusable similar structure, the total GWP for the 3 simulations is very different:
first installation (469.000kgCO_2e), intermediate installation (1.720kgCO_2e) and last installation (27.700kgCO_2e).
One way to take into account the first and the last set-up for reusable structures could be to add a part of it to the GWP of the intermediate installation. For instance, consider n intermediate installations, which means n+2 total installations, the average GWP for each installation becomes:

$$\frac{(GWP\ simulation\ 1) + (GWP\ simulation\ 2)\ x\ n + (GWP\ simulation\ 3)}{n+2} \quad [1]$$

Using this formula, the total GWP for an intermediate installation varies, for example, between 166.140kgCO_2e for n=1 and 19.989 kgCO_2e for n=25.

The total GWP for the permanent canopy installed for 25 years is 535.000kgCO_2e. The total GWP increases by only 12% for a much longer service life of the structure, 25 years instead of 2 weeks (comparison of simulations 1 and 4).

An important note is that for short-use structures the total GWP should be given per floor area and per year of use. The comparison of simulations 1, with a lifetime of 2 weeks, and 4, with a lifetime of 25 years, shows that the total GWP value decreases from 12.200 to 22,3kgCO_2e/m²/year.

The total GWP per element

The GWP results for the primary structure (Fig. 4) show that the canopy Wolke Marienfeld (simulation 0) benefits from the reuse of standard steel components.
The GWP of the primary structure for the first simulation of a reusable structure is as high as for a permanent similar structure (simulation 4). Considering the GWP results for the

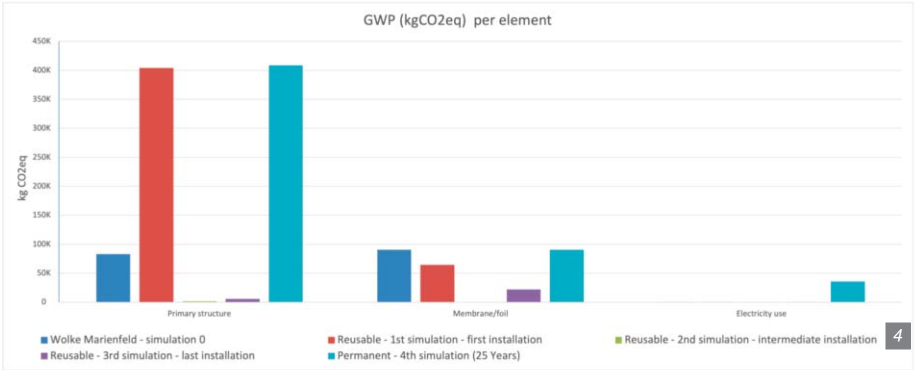

Figure 4. Life-cycle assessment - Global warming results per element (primary structure, membrane and electricity use) for simulations 0, 1, 2, 3 and 4

membrane, the GWP results for Wolke Marienfeld and a permanent similar structure are comparable, as they both use a new membrane which will be incinerated at the EOL. Moreover, the sum of the GWP of the membrane for simulation 1 and 3 has the same order of magnitude as the result for simulation 0 and 4, as one can expect.

The GWP for the energy consumption for inflation (module B6) increases from 57kgCO_2e (simulations 0, 1, 2 and 3) to 35.900kgCO_2e (simulation 4) and becomes of the same order of magnitude as the GWP for the construction and installation process (module A5).

Circularity score

OneClickLCA allows to estimate a circularity score for a scenario. It takes in account and averages both the input material and the end-of-life processes. The material used as input for the LCA can contain a certain percentage of reused content or be an existing component. The options for the EOL are recycling, downcycling, reusing as same material. The circularity score is the average of the fraction of recovered and recycled material.
Downcycling is considered for only 50%.

Comparing simulation 1, 2 and 3 shows well that the circularity score is higher if the components and material are reused. The highest values (83%, 100% and 97%) are obtained if the set-up reuses at least part of the materials. Note that the circularity score of simulation 3 is still reasonable high, while the complete steel structure will be recycled and the membrane incinerated. This is because in the circularity tool reuse and recycling are accounted for 100%. It must be mentioned again that components need to be made, need to be maintained and at a certain time, their use comes to an end. As proposed in the formula [1] above, making and maintenance could be divided among the subsequent installations.

Conclusions

The canopy Wolke Marienfeld was designed to be used for a short time. Environmental indicators must be calculated per year to reflect the impact of the period of use. In this case, the GWP (simulation 0) is 12.200kgCO_2e/year/m², while the GWP of simulation 4 is 22,3kgCO_2e/year/m².
For shorter periods of use, reuse and recycling are utmost important.
The considered case study is mainly a steel structure. For lighter constructions with less steel components and for which the coated fabric thus contributes more, recycling of coated fabrics will be needed to obtain an overall good environmental performance.

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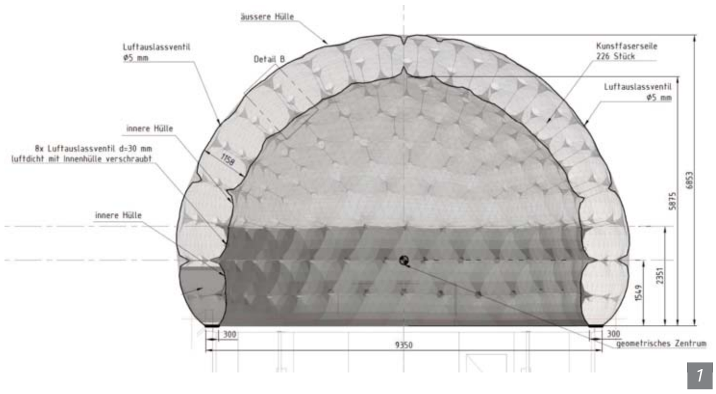
TABLE 2. CIRCULARITY SCORE FOR THE 5 SIMULATIONS

Simulation	0	1	2	3	4
Service life	2 weeks	2 weeks	2 weeks	2 weeks	25 years
Circularity score	83%	50%	100%	97%	47%

PumpItUp

Gite mobile for the European cultural capital

Esch-sur-Alzette, Luxembourg



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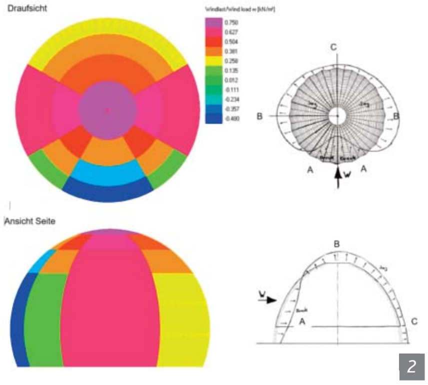

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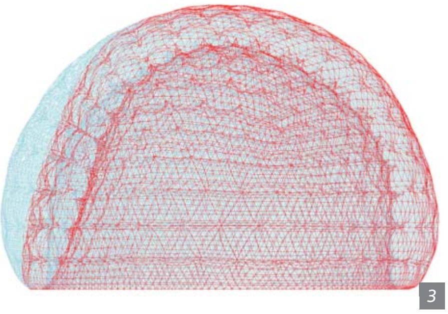

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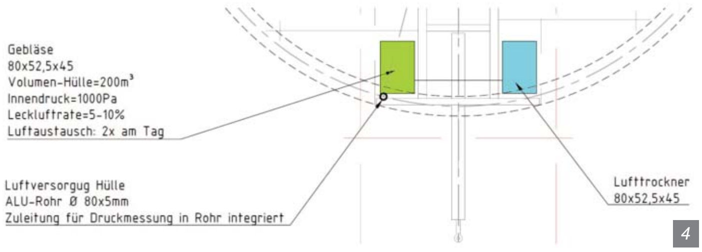

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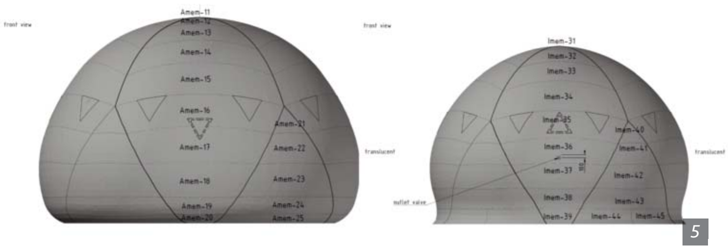

5

Figure 1: Section through the formfinding shape
Figure 2: Applied wind load distribution
Figure 3: Deformation under maximum wind
Figure 4: Integration of the blower unit in the chassis
Figure 5: Smooth patterning model Outside and Inside

Esch-sur-Alzette in Luxembourg was Capital of Culture 2022, together with Novi Sad in Serbia and Kaunas in Lithuania. Under the motto "Remix Culture", the city wants to present the cultural mix of the region and also combine the old industrial culture with the new. For one of the projects alongside with Esch 2022, a pneumatic mobile shelter has been built on a trailer with foldable wings.

The pneumatic envelope forms a sphere made from two layers of membrane. Both layers are made of high translucent PVC coated polyester membrane. Ten transparent bulls' eyes allow the view to the sky. Outer and inner membranes are coupled with synthetic fibre ropes. The envelope is connected to the platform is made with zips and aluminium clamping strips along the perimeter. In order to allow natural ventilation, two ventilations tunnels connect inner and outer membrane, closed with an open mesh on the outside, and a removable cover on the inside.

The mobile hut (gite mobile) is a temporary structure according to EN 13782. The Luxembourg national application document for Eurocode 1 part 1-4, gives a reference wind speed of 24m/s, thus the wind load table from EN 13782 can be applied. Snow load was not considered as the use in winter is not foreseen. The wind load is distributed according to EN 1994-1-4 for a hemisphere (Figs 2-3).

The support air unit is fabricated as a special design. The blower and the dryer are housed in two separate cases, installed in the chassis of the trailer left and right. It provides an internal pressure of 1000Pa in order to provide the pneumatic prestress (Fig. 4).

The shape of the structure is locally heavy curved, which would require a very high effort for the fabrication. For an optimal manufacturing process, the patterning model was generated as an averaged rotational surface, with an almost identical overall surface. A comparing analysis with this model under inner pressure led back to the original membrane geometry, which confirmed the feasibility of this cutting method (Fig. 5).

Client:	Ville d'Esch-sur-Alzette
Architecture:	2001 territories, buildings, spaces & ideas, Luxemburg
Interior design:	NJOY_architecture inside, Luxemburg
Structural design pneumatic envelop:	formTL ingenieure für tragwerk und leichtbau gmbh, Germany
Execution pneumatic envelop:	Canobbio Textile Engineering srl, Italy
Air supply:	Elnic, Germany
Surface area outer membrane:	251m^2
Surface area inner membrane:	168m^2
Covered area:	93m^2
Membrane material:	Sattler Polyplan 684 C
Foil material bulls eye:	Cristal Plus 500µm

Directly after completion of the envelope, a test assembly was carried out to test the inflation and folding of the membrane (Fig. 6). With the increase of the internal pressure, the envelope is lifted up. The outer membrane pulls the inner membrane via the connecting ropes. The assembly of the PumpITup project on the trailer took place in an old industrial hall in Schifflange. The chassis came from Belgium, the body from France and the membrane envelope from Italy.

The first outside installation was then realised in the natural reserve Ellergronn. As it is a mobile hut, shortly after this installation, it has been taken to the fair Home Expo in Luxemburg-Kirchberg to be presented to the public as a future concept.

Figure 6: Test inflation of the finalised translucent envelope © Canobbio
Figure 7: Inner view
Figure 8: Final project at night © 2001

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ESSENER MEMBRANBAU SYMPOSIUM

After a break due to the Covid 19-pandemic, the Institute of Metal and Lightweight Structures (IML) of the University of Duisburg-Essen, Germany invited to the Essener Membranbau Symposium 2022 for the fifth time on 23.09.2022. Professor Natalie Stranghöner, head of the institute, and Dr.-Ing. Jörg Uhlemann, head of the affiliated Essen Laboratory for Lightweight Structures (ELLF), moderated the format and began by presenting the institute's current research and standardization work in the field of membrane structures. Felix Surholt M.Sc. complemented the presentations with a view on the mechanical behaviour of the foil material ETFE.

Dr.-Ing. Patrick Beck of the IngenieurGruppe Bauen followed on thematically from the previous speaker and presented his results on the load-bearing behaviour of ETFE foils under continuous loading. Another presentation on the subject of material behaviour was given by Dipl.-Ing. Katja Bernert, Mehler Texnologies GmbH. In her presentation, she shared the research results obtained together with the IML on the material behaviour of the new load-bearing fabric made of recycled PET fibers.

The construction and the associated safety of technical membranes in biogas technology is a delicate and deficiently considered topic. Dipl.-Ing. Martin Paproth can look back on years of experience as an expert in this field and presented the current status of this application of membranes. The lack of well-founded regulations for the execution was emphasized. The topic of regulation of membrane structures was taken up again by Dipl.-Ing. Steffen Schneider of the Landesstelle Bautechnik in Tübingen in his presentation "ZiE/vBG in membrane structures from the point of view of building authorities". He illustrated how to get to a "single case approval" for membrane structures.

Following the tradition of the symposium, two prestigious and unique membrane projects were presented by partners involved in the construction. The "EXPO Dubai Shades" features a currently unique construction method: a membrane structure without prestressing. Dipl.-Ing. (FH) Marc Gabriel of Werner Sobek Design GmbH gave a detailed and interesting insight into the development and realization process of the 52.500m² covering fiber scrim. Another prestigious project represents the currently tallest textile-cladded building in the world. Professor Karsten Moritz from Taiyo Europe GmbH presented the challenges and innovative solutions for the cladding of the 246m high and multiple award-winning TK-Elevator test tower in Rottweil.

Figure 1. Professor Natalie Stranghöner and Dr.-Ing. Jörg Uhlemann moderated and started the event with the current status of the research and standardization work of the Institute of Metal and Lightweight Structures in the field of membrane structures © UDE/IML
Figure 2. Speakers at the symposium (from left to right): Katja Bernert, Felix Surholt, Steffen Schneider, Professor Natalie Stranghöner, Martin Paproth, Dr.-Ing. Patrick Beck, Marc Gabriel, Professor Karsten Moritz & Dr.-Ing. Jörg Uhlemann © UDE/IML

Traditionally, the end of the day took place at the Essen Laboratory for Lightweight Structures (ELLF), where the test facilities could be visited and the opportunity for further exchange was actively used.

The conference proceedings can be purchased from Shaker Verlag after the symposium: Natalie Stranghöner, Jörg Uhlemann (Eds.), 5. Essener Membranbau Symposium, Shaker Verlag, Aachen, 2022.

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Felix Surholt, M.Sc.
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Thanks to the great interest in the symposium, the IML and the affiliated ELLF are pleased to announce the sixth Essener Membranbau Symposium, which will take place at 20.09.2024 at University of Duisburg-Essen.

TENSINANTES2023

TensiNet symposium 2023 at Nantes Université

Membrane architecture: the seventh established building material. Designing reliable and sustainable structures for the urban environment.

TENSINANTES 2023 focuses on the significance and potential of fabrics and foils as established building materials and promotes the use of tensile structures in a world of constant change and adaptation. The optimal use of materials, the realisation of a Eurocode, sustainability and reuse are some of the topics that will be covered, ranging from research over practical experiences to realisations. The diversity and complementarity within the TensiNet community: suppliers, manufacturers, installers, engineers, architects, researchers & academics, inspired and fed the idea of putting together duos of speakers who will give keynote lectures around the 3 main themes:

- **STRUCTURAL MEMBRANE:** contemporary, innovative, adaptive daring and impactful solutions
- **TENSIONED MEMBRANE STRUCTURES**: the seventh building material
- **STRUCTURAL MEMBRANE:** an answer to issues of the 21st century

KEYNOTE LECTURES

Bouncing Bridge: ephemeral, autonomous and self-supporting pneumatic temporary structure The lecture of Grégoire Zündel and Ramon Sastre covers a series of pneumatic temporary structures for public spaces such as the Bouncing Bridge, all designed by AZC and with Ramon Sastre as their consultant. The key topics of their lecture are Why this project; Tubular pneumatic; Use; Analysis and Fabrication.

Bouncing Bridge, prototype diameter 10m © Ramon Sastre

The Pathways to Zero Carbon for Tensioned Membrane Architecture: ongoing actions and next steps Bruce Danziger and Carol Monticelli will discuss on the one hand how to learn and share effective methods to quantify and reduce the embodied carbon of lightweight structures and on the other hand start the discourse on the advancements of the research on this topic in the on-going transfer to today's design practice.

Milestones of ETFE construction methods and starting points for further developments The lecture of Karsten Moritz and Jean-Christophe Thomas shows the possibilities of ETFE as an important building material by an overview of milestone projects over the latest 50 years. At the same time, the keynote speakers look ahead to future possibilities taken into account the further development and implementation of LCA's, EPD's and the Eurocode for membrane structures as well as the trend to teach this construction methods more and more at universities.

Finally, the keynote lectures by Louis Ratajczak and Rosemarie Wagner are confirmed. Louis Ratajczak's presentation **Architecture in motion** will show the process from design to realisation of the retractable roof of the Philippe Chatrier centre court at Roland Garros. With her broad academic background in teaching and research, the keynote lecture of Rosemarie Wagner **Textile Architecture with or versus today challenges in built environment** attempts to link textile construction to current topics such as reducing fossil raw materials and CO_2 emissions, circularity and energy technology in order to make construction more attractive.

Retractabe roof Philippe Catrier © DVVD Architectes

The retractable roof of the Philippe Chatrier centre court at Roland Garros by DVVD.

The renovation of the Centre Court provides the stadium with a retractable roof. The office DVVD developed a roof made up of light and independent elements, as close as possible to the court, superimposed on each other to allow for light gaps and good ventilation. Inspired by the biplane of the aviator Roland Garros, the elements have been worked like an aeroplane wing, in terms of their shape, their materials and their structure. The curvature and geometry of these "wings" allow them to be interlocked and contribute to the drainage of water and to the thermal and acoustic environment of the stadium.

Retractabe roof Philippe Catrier © DVVD Architectes

Louis Ratajczak will take you through the design process of this inspiring project during his keynote lecture **"Architecture in motion"** on Wednesday 7th June. The Paris based office DVVD combines the architectural and technical design and economic control of projects as DVVD ARCHITECTES and DVVD INGÉNIEURS are two sister companies that conceive architecture and engineering without barriers. www.dvvd.fr

REGISTRATION IS OPEN TensiNet members pay a reduced registration fee of 500€ and students of 300€. The registration includes attending the 3 days symposium, the cocktail drink, the guided tour Walk the green line and the Conference dinner at the Gallerie des Machines. Register with a few clicks https://tensinantes2023.sciencesconf.org/registration