

Case study

'TENSILE SURFACES STRUCTURES'
DESIGN PROCESS

RESEARCH

A SIMPLE NON-LINEAR MATERIAL MODEL
FOR PVC-COATED POLYESTER FABRICS

"Batsail"

IMS RESEARCH PROJECT

PROJECT

STADIA
South Africa



contents



PROJECTS

PAGE
4 & 5

Pakistan

TOLL PLAZA CANOPIES

Spain LA FACTORIA

Sun shading of the streets of the shopping mall

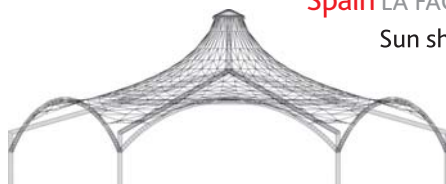
Turkey

WEDDING HOUSE CANOPY

A New Interpretation for the Wedding Gown

Turkey

SPORT FACILITIES



8 > 13

South Africa 4 STADIUM PROJECTS



Johannesburg Soccer City Stadium

Durban Moses Mabhida Stadium

Port Elizabeth Stadium of the "windy city"

Cape Town The new Cape Town Stadium



16 & 17

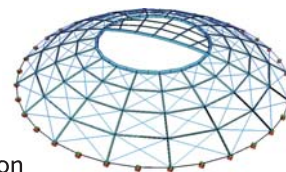
USA

LONE BUTTE CASINO Lights Up the Desert Sky

Spain

ETFE SINGLE SKIN

Aranda de Duero ROOF



22 **The Netherlands**

JINSO PAVILION Extension to a catering pavilion

RESEARCH

PAGE

6 & 7

A SIMPLE NON-LINEAR MATERIAL MODEL
for PVC-coated polyester fabrics

14 & 15

"BATSAIL" IMS Research Project

ARTICLE

15

FORMFINDER SOFTWARE

"One Click" Cost Estimation for the architectural design
of membrane structures

18

CASE STUDY 'Tensile surfaces structures' design process

MISC

PAGE

23

VIENNA UNIVERSITY OF TECHNOLOGY MASTER PROGRAM
MEMBRANE LIGHTWEIGHT STRUCTURES

ANHALT UNIVERSITY OF APPLIED SCIENCES

MASTER COURSE MEMBRANE STRUCTURES

LITERATURE SPANISH EDITION

European Design Guide for Tensile Surface Structures

THE TS ARCHI PROFILE PROFIL TENSION SYSTEM INNOVATION

24

SYMPOSIUM TENSILE ARCHITECTURE: Connecting Past & Future



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Symposium 2010

16-18th September 2010
UACG, Sofia, Bulgaria



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Every third year Tensinet organizes a Symposium. The field of Tensile Surface Structures is evolving: new materials and new realizations prove that the field of applications is steadily growing. The last two Symposia took place in Brussels (VUB) and in Milan (Politecnico di Milano) with increasing numbers of participants and speakers. These Symposia provide an opportunity for information transfer on the state of the art and new technologies, enabling delegates to share knowledge with a wider audience. On the other hand they advertise tensile surface structures and make them better known to potential clients as well as other professionals in the building industry.

As members of the Scientific Committee, Marijke Mollaert and myself, together with Evi Corne, have visited the UACG in Sofia. We had a warm welcome from the Principal and the Faculty who had given us the opportunity to visit the university facilities in preparation for the Symposium.

The Organizing Committee in Bulgaria has already prepared the website for registration. You can access all necessary information about our Symposium on the 16th-18th September at <http://tensinet2010.uacg.bg>.

The theme of the symposium "Tensile Architecture: connecting past and future" is well suited for the market situation in Bulgaria, since several archaeological sites could benefit from translucent, lightweight temporary covers. The Symposium will feature a number of stimulating (keynote) lectures by prominent experts such as Martin Glass (gmp architecten, DE), Françoise Fournier (FERRARI SA, FR), Jan Laperre (Centexbel, BE), Peter Gosling (Newcastle University, UK), Bernd Stimpfle and Gerd Schmid (form TL, DE), Markus Balz (schlaich bergemann und partner, DE) and many others.

A number of TensiNet meetings will also take place during the Symposium.

We invite you to attend our Symposium and ask you to inform colleagues about this event.

Currently TensiNet has more than 200 members from over 40 countries and 15 partners. We are happy to welcome a new partner within TensiNet: the German engineering and manufacturing company with a long history in the field of tensile fabric architecture: Hightex GmbH, Rimsting.

I hope you enjoy this current issue of TensiNews and I'm looking forward to seeing you in Sofia in September,

Dr. Balz

Forthcoming Meetings

TensiNet Meetings Verseidag, Krefeld, Germany 20/04/2010

Partner meeting 1 ☎ 11:00 - 12:30

Working Group ETFE ☎ 13:30 - 15:30

Working Group Analysis & Materials ☎ 13:30 - 15:30

Location: VERSEIDAG-INDUTEX GmbH
Industriestraße 56 - D-47803 Krefeld

TensiNet Meetings, UACG, Bulgaria TensiNet Symposium 2010 15/09/2010

Partner Meeting 2

Annual General Meeting

Working Group ETFE

Working Group Analysis & Materials

Working Group Standardisation & Eurocode

Forthcoming Events

International exhibition **ROOF INDIA 2010** Chennai Trade Centre, Chennai, India 23-25/04/2010 www.roofindia.com ● Workshop **Textile Roofs 2010** TUB, Berlin, Germany 03-05/06/2010 www.textile-roofs.com ●

1st International Conference on **Structures and Architecture (ICSA 2010)**

University of Minho, Guimarães, Portugal 21- 23/07/2010 www.icsa2010.com

● Symposium 2010 **Tensile Architecture: Connection Past and Future** University of Architecture, Civil Engineering and Geodesy

16 - 18/09/2010 <http://tensinet2010.uacg.bg/> ● International Symposium

on **Spatial structures - Temporary and Permanent IASS 2010**

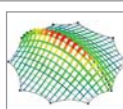
Shanghai, China 08-12/11/2010 www.iass2010.cn ● International trade Fair

& Symposium **Techtextil 2011** Frankfurt, Germany 24 -26/05/2011

<http://techtextil.messefrankfurt.com> ● International conference on

Structural Membranes 2011 Barcelona, Spain 05 -07/10/2011

<http://congress.cimne.com/membranes2011/frontal/Dates.asp>





Toll Plaza canopies

at Rawat & I.J. Principal Road
Islamabad, Pakistan

Tollink Pakistan, a subsidiary of Tollink South Africa, needed BOT-Toll (Build, Operate and Transfer) collection facilities in Islamabad and chose for their project a canopy that stood out different in its form and architectural apparition. The preliminary design from Isbah Hassan & Associates was much appreciated. The structural engineering was done by Amjad Niazi Associates whereas the membrane engineering was done in China by Covertex. Mehatop FR 1000 was used as membrane: a PVC coated polyester fabric with a PVDF top coating on both sides. It has a weight of 1050g/m² and a tensile strength of 120KN/m – 110KN/m in warp and weft direction.

The most challenging part of the project was giving the required shape to the 200mm diameter pipe, with 6mm wall thickness. For this project a pipe bending machine and the allied heat process had to be made. Once the pipes were bent they were welded on the ground and the whole frame was lifted up to be placed on the vertical structural elements. The very first project of tensile fabric structure in Pakistan got instant attention of the architects and was much appreciated.

 Kashif Ahmed, South Asia, Mehler Technologies GmbH
 www.mehler-technologies.com

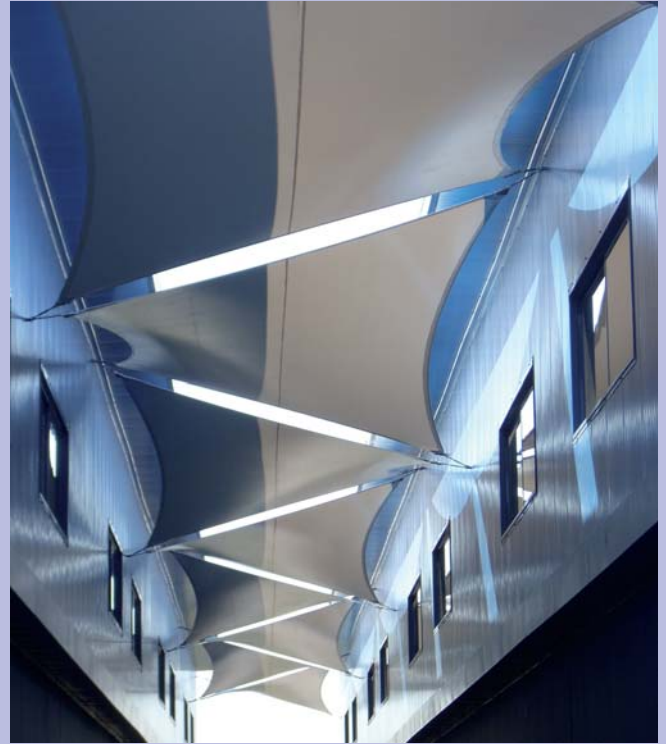


Name of the project:	Toll Plaza Canopies
Location address:	Rawat & I.J. Principal Road, Islamabad, Pakistan
Client (investor):	Tollink Pakistan
Function of building:	Toll collection facility
Type of application of the membrane:	Canopy Cover
Year of construction:	2009
Architects:	Isbah Hassan & Associates
Multi disciplinary engineering, Main contractor, manufacture and installation:	Ramcon
Structural engineers:	Amjad Niazi & Associates
Consulting engineer for the membrane:	Jason Wang, Covertex China
Tensile membrane contractor:	Covertex China
Supplier of the membrane material:	Mehler Technologies Germany
Material:	PVDF, Mehatop FR1000 Type III
Covered surface:	700m ²

Sun shading of the streets of the shopping mall

The first open-air commercial centre La Factoria is situated in the region of Huelva, Spain. During spring and summer

temperatures exceed 40°C and solar radiation hits directly and very intensively. The demand was to find and realize a possibility of



Wedding House Canopy

The Municipality of Karşıyaka needed an extension for the main wedding house. The ARCH-ART team designed a conical roof with a hexagonal plan, supported by six arch structures which as a whole represent a wedding gown. The after wedding cocktail receptions and the Turkish traditional jewelry ceremonies take place at this extended area. The main function of the roof is

to protect the guests from rain surprises but mostly from Izmir's hot sun. Also, by creating an optical highlight that can be seen from a large distance, especially from the ferries that constantly carry passengers between the two main zones of the bay; the roof creates an attraction point, enhancing the wedding house. The roof stands like a white flower blooming, representing the purity of the

La Factoria

Huelva, Spain

protecting the 8 streets of the commercial centre from the sun and give shadow to its visitors during their stay. On demand Carpatec designed, produced and installed a total of 64 hyperbolic paraboloids of 9.80m x 4.80m between the buildings of the centre and with a height of 9m, thus protecting the 8 streets and the façades of more than 200 shops. For the design the software programme Rhino Membrane was used, for the calculation of loads and form finding Forten 3000 was applied. Tensioning ropes and fittings are

of stainless steel 316. The membrane is Mehler Valmex FR 700 MEHATOP F – Type I. The welding was made at high frequency. Production and installation were made within only 21 days from receipt of order, thus assuring that the project was ready on the inauguration day of the centre in summer 2009.

 *Dagmar Anne Genten*
 *D.Genten@mehler-technologies.com*
 *www.mehler-technologies.com*

Name of the project:	La Factoria
Location address:	Huelva, Andalusia, Spain
Function of building:	Shopping Mall
Type of application of the membrane:	Sun shading of the streets of the shopping mall
Year of construction:	2009
Consulting engineer for the membrane:	Yago Gonzalez
Membrane design:	Gustavo Ramirez
Supplier of the membrane material:	MEHLER Technologies GmbH, Germany
Manufacture and installation:	CARPATEC, S.L., Madrid, Spain
Material:	VALMEX MEHATOP FR 700gr/m ² PVDF lacquered
Covered surface (roofed area):	3.100m ² (64 sails)

TENSAFORM MEMBRANE STRUCTURES INC



Sport facilities

Ipek Yolu (Silk Road) Rally, with a total racetrack of 4.500km from Russia to Turkmenistan, is one of the FIA (International Automotive Federation) approved activities. The finish line to host the competitors been set in the territory of Turkmenistan. The Turkmenistan authorities and the contractor Polimeks Inc. specified a monumental welcoming structure to honour the competitors. Architect Tolga Cetin and his team designed a huge covering system of 1.875m² remarkable from long distances in the large steppes of the region. With 10 high points and monumental lines, the structure appeared as the symbol of this sport event. The designing, manufacturing and erection phases have been completed in a very short time of 15 days to reach the activity date. The structure itself was so impressive that after the completion of the rally, the authorities decided to move the artefact to different location for prestigious events. Structured with 10 poles to form conical shapes, the coverings highest point is 14m and span-width 27m. Due to the stretch forming of the corners by steel ropes, the total weight of steel has been extremely minimized.

 *Mehmet Yilmaz, Tensaform Membrane Structures Inc.*
 *info@tensaform.com*
 *www.tensaform.com*

Name of the project:	TURKMENISTAN IPEKYOLU RALLY
Location:	Turkmenbasi, Turkmenistan
Client:	Polimeks Inc.
Function of Building:	Entertainment & Recreation
Year of Construction:	2009
Architect:	Tolga Cetin
Engineering, Manufacturing and Installation:	Tensaform Membrane Structures Inc
Material:	Mehler Haku Valmex FR 1000
Covered Area:	1875m ²

A New Interpretation for the Wedding Gown

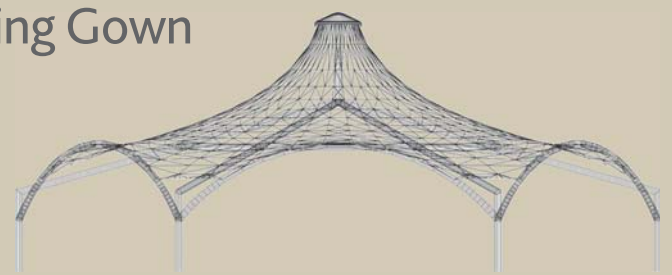
Karşıyaka, Izmir, Turkey



wedding gown, with the background of blue sea, creates beautiful scenes at any time of the day. The main target of the design is to highlight the membrane with a simple construction. A frame structure was chosen as

construction system to avoid using cables that may limit the area usage.

 *Ozgur Demirbas*
 *info@arch-art.com.tr*
 *www.arch-art.com.tr*



Name of the project:	Canopy for Karşıyaka Wedding House
Location address:	Karşıyaka, Izmir, Turkey
Client (investor):	Municipality of Karşıyaka
Function of building:	Celebration ceremony and entrance canopy
Year of construction:	2008
Architects and Structural engineers:	ARCH-ART
Consulting architect for the membrane:	İsmail SARIAY
Manufacture for membrane:	ARCH-ART
Manufacture for steel and installation:	OBA
Supplier of the membrane material:	Mehler Technologies
Material:	Valmex 7211 FR900 Mehato
Covered surface:	180m ²

A simple non-linear material model for PVC-coated polyester fabrics

Introduction

The design and analysis of tensioned and inflatable structures made of coated-fabrics rely on numerical calculations whose accuracy strongly depends on the accuracy of the material models. Coated woven fabrics are non-isotropic materials and have a non-linear behaviour, mainly due to the strong interaction between the warp and the fill yarns. Whereas they consist of orthogonal fibres, their elastic properties do not comply with plane stress orthotropic theory, as it has been emphasized by Gosling^[1]. In the last decade, complex models have been developed in order to take these effects into account. Among them are micro-mechanical models^[2,3], where the fabric behaviour is derived from a model of its microstructure. The other approach is to describe the fabric behaviour directly from experimentally determined stress-strain relationships^[4,5]. However, these elaborated models are too involved and too demanding regarding computation times to be used in engineering. We propose a new simple and computationally efficient non-linear material model based on an extensive experimental study of PVC-coated polyester fabric behaviour.

Experiments

Cruciform specimens were loaded on our biaxial test machine^[6] (Fig. 1). The central square of the specimen was 500mm wide. In each cruciform arm four slits were made leading to five strips. Each strip was loaded independently by an electromechanical drive mounted on linear bearings allowing free movement of the drive transverse to the loading direction. Tests were load-controlled by the use of 10kN load cells fixed between every pair of drive and grip. Strains were measured by the use of two needle-extensometers placed in the warp and fill direction and bolted on the test specimen using small diameter screws. Specimens were first loaded at pre-stress and then from pre-stress up to maximum test stress using five different load ratios (5:1, 2:1, 1:1, 1:2 and 1:5). For every load ratio, the loading/unloading cycle was repeated five times in order to remove the residual strains. Only the last loading curve was used to determine the material properties.

An almost linear relationship was experimentally found between elastic moduli E_f and E_w (subscripts w and f represent the warp and fill directions) and load ratios in their normalized form γ_w and γ_f (Fig. 2), defined as

$$\gamma_w = \frac{\sigma_w}{\sqrt{\sigma_w^2 + \sigma_f^2}} \quad \gamma_f = \frac{\sigma_f}{\sqrt{\sigma_w^2 + \sigma_f^2}}$$

The Poisson's ratio ν_{wf} did not significantly vary as a function of γ_w and γ_f .

Proposed model

A simple material model is proposed based on the experimental results^[7]. The material behaviour is assumed to be linear elastic, plane stress orthotropic for a given load ratio. In this case, the yarn-parallel mechanical behaviour is described by

$$\begin{bmatrix} \varepsilon_w \\ \varepsilon_f \end{bmatrix} = \begin{bmatrix} \frac{1}{E_w(\gamma_w)} & \frac{-\nu_{wf}}{E_w(\gamma_w)} \\ \frac{-\nu_{wf}}{E_w(\gamma_w)} & \frac{1}{E_f(\gamma_f)} \end{bmatrix} \begin{bmatrix} \sigma_w \\ \sigma_f \end{bmatrix}$$

where the Young's moduli can be formulated as linear functions of the normalized load ratios (Fig. 2):

$$E_w(\gamma_w) = \Delta E_w \left(\gamma_w - \frac{1}{\sqrt{2}} \right) + E_w^{1:1}$$

$$E_f(\gamma_f) = \Delta E_f \left(\gamma_f - \frac{1}{\sqrt{2}} \right) + E_f^{1:1}$$

The material model has five parameters: $E_w^{1:1}$ and $E_f^{1:1}$ are the reference values of warp and fill Young's moduli given for the 1:1 load ratio, ΔE_w and ΔE_f represent the variation of warp and fill Young's moduli on the whole range of load ratios, and the Poisson's ratio ν_{wf} . All five parameters are estimated so that the difference between experimental and modelled data is minimized.

The corresponding values are given in Table 1 for all tested materials.

The new model is represented by three dimensional stress-stress-strain surfaces in Figure 3, where it is superimposed with experimental data. The model non-linearity is here clearly visible: curved surfaces enable a better representation of the material behaviour.

Finite element analysis

The model is finally included in the commercial finite element software ANSYS with a USERMAT routine. Its predictions are compared to those of a standard plane stress orthotropic material and to biaxial test experimental results. The model accuracy was assessed by estimating the difference between measured and predicted strains for all data points. The results are presented in Figure 4 for all tested materials with the root mean square (RMS) of the strain difference and the maximum absolute strain difference. The difference between experiments and the proposed model was reduced by more than a factor 2 compared to the standard orthotropic material model for most fabrics.

Only for the Ferrari membranes no significant improvement was observed. These materials have indeed a special manufacturing process where the fabric is pre-stressed during the coating. As a result the material is less

MANUFACTURER & REFERENCE (polyester type)	$E_w^{1:1}$ (kN/m)	$E_f^{1:1}$ (kN/m)	ΔE_w (kN/m)	ΔE_f (kN/m)	ν_{wf}
MEHLER TECHNOLOGIES VALMEX FR700 (I)	653.2	444.5	521.2	403.7	0.327
MEHLER TECHNOLOGIES VALMEX FR900 (II)	882.0	679.6	803.8	437.6	0.263
MEHLER TECHNOLOGIES VALMEX FR1000 (III)	1200.0	881.7	941.2	782.5	0.318
MEHLER TECHNOLOGIES VALMEX FR1400 (IV)	1374.1	1003.4	1204.7	981.7	0.314
FERRARI PRÉCONTRAIT 702 (I)	635.3	661.9	295.0	168.5	0.196
FERRARI PRÉCONTRAIT 1002 (II)	830.2	976.0	766.7	123.9	0.213
VERSEIDAG INDUTEX B1617 (II)	865.8	707.5	662.9	662.5	0.308

Table 1. Estimated parameters for the proposed non-linear material model.

sensitive to crimp interchange and its behaviour is similar to a standard linear orthotropic material. The second important result is that the computation time did not significantly increase. An average increase of less than 3% was observed during the analyses.

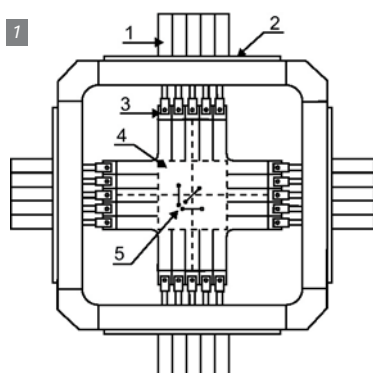
Conclusion

A simple non-linear material model to describe the yarn parallel behaviour of PVC-coated polyester fabrics under biaxial tension has been proposed. The model is based on a

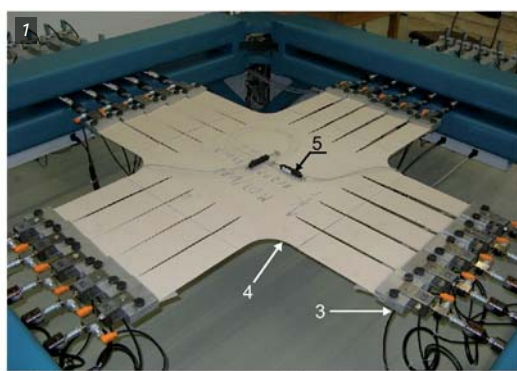
standard plane stress orthotropic material model with a constant Poisson's ratio but with Young's moduli that are linear functions of the normalized load ratios. The material response can be accurately described with five parameters, namely the warp and fill Young's moduli for a 1:1 load ratio, the change in warp and fill Young's moduli and the Poisson's ratio. Only five different load ratios have to be measured in order to obtain reliable parameters. The new model has been included in ANSYS with a USERMAT routine. It has already successfully been applied for the finite

element analysis of Tensairity® inflated structures developed in our centre^[8]. The model is also suitable for the design of tensile fabric structures, where it could help improving the accuracy of numerical predictions.

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(Center for Synergetic Structures)



1 Electromechanical actuators
4 Cruciform specimen



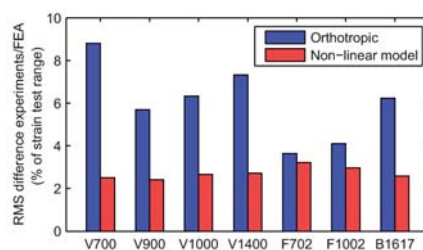
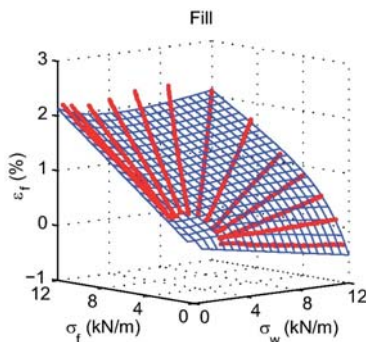
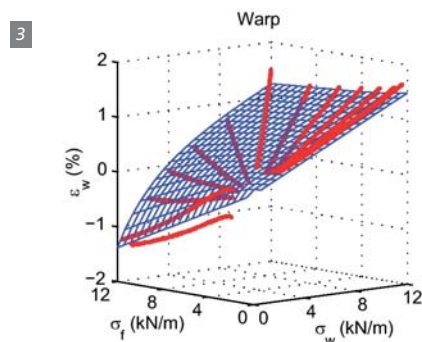
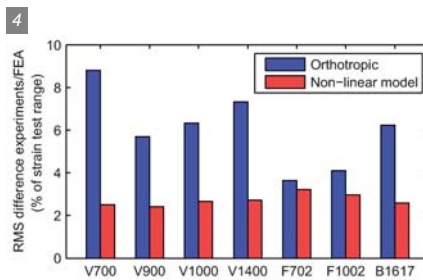
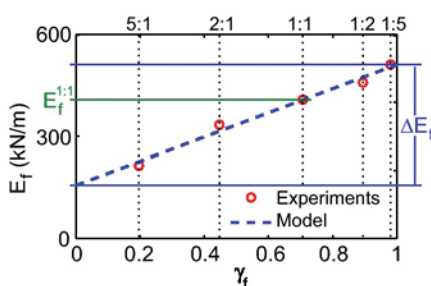
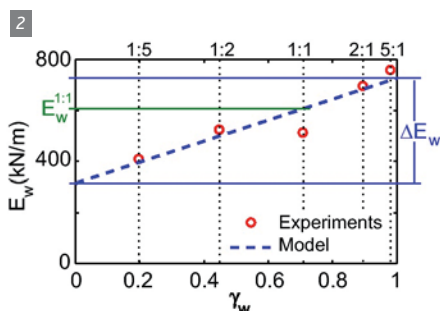
2 Linear bearings
3 Aluminium grips
5 Needle extensometers

Figure 1. Biaxial testing machine.

Figure 2. Linear relationship between Young's moduli and normalized load ratios.

Figure 3. Stress-strain representation of experimental data (red lines) and prediction of the proposed non-linear model (blue grid).

Figure 4. Comparison between the proposed non-linear model with a linear elastic orthotropic material model: difference between FEA predictions and experimental results.



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4 South African

Johannesburg

Durban

Port Elizabeth

Cape Town

South Africa's successful application for hosting the World Cup has resulted in the construction of several new stadia. The construction or modernization of these new arenas coincides with novel ideas for the design. In all cases the roofs play the major role when it comes to the question of unique design and easy recognition. The roof is the most important element to create the stadium look.



Johannesburg

Soccer City Stadium

The earth coloured 'African Pot', the traditional calabash, as a melting pot of cultures can be seen as the unique Pan-African symbol (Fig. 1). This was the main idea of the architects for the design of the biggest stadium on the African continent.

The stadium can accommodate 94.000 spectators. The three tier levels can be reached via curved inner and outer ramps. The Stadium is located in close neighbourhood to Soweto. Historical parts of the upper tier level of the old stadium (built in 1987), where Nelson Mandela was present during important events have been retained and conserved, whereas the whole rest of the stadium has been newly built. Specially arranged coloured façade-panels with 6 colours and 3 textures on the surface changing from darker to lighter colours on the top as well as the light coloured upper membrane blend into the natural surroundings of the typical local 'mine-dumps'. Starting from the architects images and ideas, **schlaich bergemann und partner** designed and developed the optimised structure for the huge roof and the façade structure in close corporation with the structural engineers of the concrete tiers structure, PDNA of Johannesburg. The overall shell geometry (roof and façade) derives from a torus with an outer diameter of 300m which was defined in section with varying radiuses (Fig. 2).

As the opening of the roof and the surrounding spatial ring truss (the most important structural element) follow the rectangular shape of the field and the arrangement of the tiers, both geometries combined create an impressing 3-dimensional curved structure.

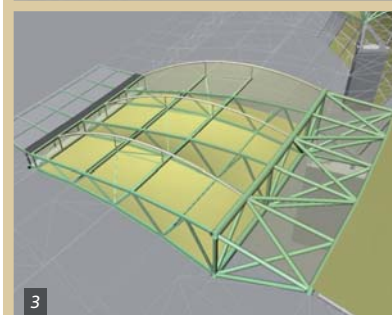
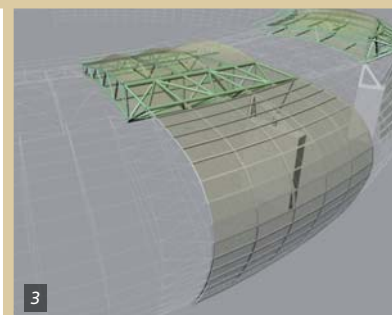
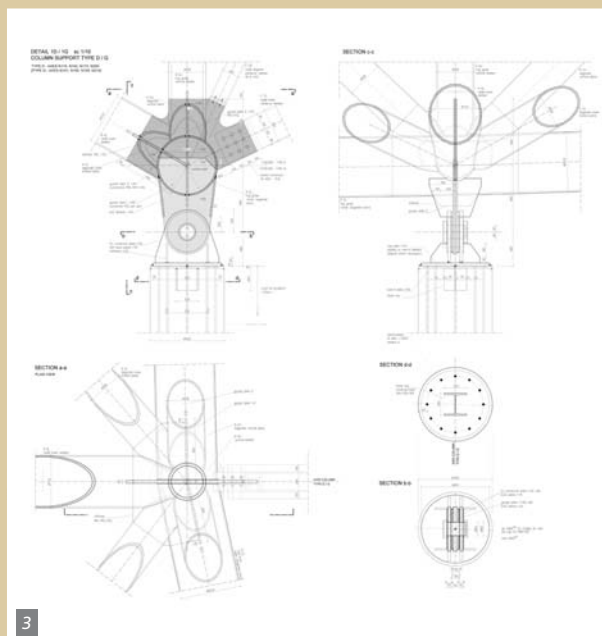
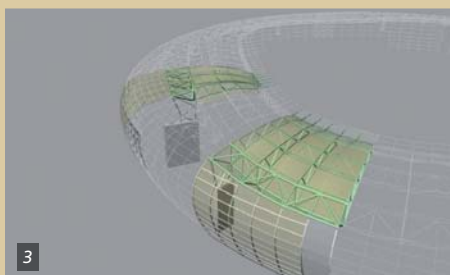


Figure 1:
Aerial view of the stadium.

Figure 2:
Plan.

Figure 3:
Construction details.

Figure 4:
Erection of the roof.

Figure 5:
Erection of the façade.

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Stadium Projects

Since the cable net structures for the Olympic Stadium roof in Munich, we use all our knowledge and creativity to make the roof of a stadium the star of the event. This can easily be observed in South Africa. The stadium roofs in Johannesburg (Soccer City), Durban, Port Elizabeth and Cape Town were designed by structural consulting engineers **schlaich bergmann und partner** under the lead of Knut Göppert, already widely known for their special designs.

Roof structures for enormous spans had to be developed, often with a depth of more than 50 m. Spatial load transfer structures are state of the art when it comes to efficient and sustainable engineering solutions. Fabrication and erection aspects influence the early design ideas and lead to unique installation processes. The authors present the four projects in detail and provide a view into the future of stadium roof design.

The 800m long spatial ring truss with its 3 chords (circular sections) is clad with polycarbonate panels. It is supported by 12 concrete shafts and 16 columns only. The roof cantilever truss (open sections) length over the tiers is 38m. The cantilevers are clad with arch supported PTFE membrane on the top side and an open mesh Glass/PTFE membrane on the bottom side. For the cladding of the inner edge of the roof also polycarbonate panels were used. Different from many arch supported membrane roofs for stadia, the soccer city stadium uses a radial arch arrangement. This considers the comparative small panel size as well as the architectural idea of the "finger formed clay pot" (Fig. 3 & 4).

The slim shell structure of the façade, designed as curved steel beam is supported on inclined concrete columns and fixed on the top to the spatial ring truss. The glass-fibre reinforced 13mm thick concrete façade panels 1,2m x 3,6m have been fabricated with natural colours and different textures and arranged exactly according to the architects special patterning design (Fig. 5).

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Name of the project:	Soccer City Stadium Johannesburg
Location address:	Johannesburg, South Africa
Client:	City of Johannesburg
Function:	Multifunctional arena, Stadium
Year of construction:	April 2006 – February 2010
Structural Engineers Roof and Façade:	schlaich bergmann und partner, Stuttgart
Structural Engineers Concrete Structure:	PDNA, Johannesburg
Architects:	Boogertman, Urban Edge and Partners (Bob van Bebbier / Piet Boer), Johannesburg
Wind Engineering:	Wacker Ingenieure, Birkenfeld
Main contractor:	GLTA/Interbeton, South Africa / Netherlands (Joint Venture)
Main contractor roof:	Cimolai, Pordenone / Italy
Fibre concrete subcontractor:	Rieder, Austria
Membrane manufacture and installation:	Hightex, Rimsting / Germany
Supplier of the membrane material:	Verseidag-Indutex, Krefeld, Germany
Capacity:	94.000 seats
Steelwork:	9.000 tonne
Roof area: Upper membrane:	23.000m ² PTFE/Glass (glass fiber fabric coated with Dyneon PTFE and Dyneon Fluorothermoplastics)
Lower mesh membrane:	25.000m ² PTFE/Glass (glass fiber fabric coated with Dyneon PTFE and Dyneon Fluorothermoplastics)
Vertical mesh membrane:	2.000 PES/PVC
Glazing:	12.000m ² Polycarbonate, t=12mm
Façade area:	35.000m ² fibre reinforced concrete, t=13mm



2

Durban

Moses Mabhida Stadium

As part of the City of Durban's redevelopment program the projected World Cup stadium was chosen to create an icon for the KwaZulu Natal region and Durban, being the 2nd largest city in South Africa. The ambitious plan to gain international attention enabled the lead Architects von Gerkan Marg und Partner, Berlin, the lead structural engineers **schlaich bergemann und partner**, Stuttgart and BKS, Durban to design an outstanding stadium of unprecedented scale and beauty and therefore won the design competition. The scope of work for the structural engineers did also include all erection engineering, the checking of all workshop drawings and surveys, the site and fabrication supervision as well as the technical lead for the tender process and the implementation phase for the client.

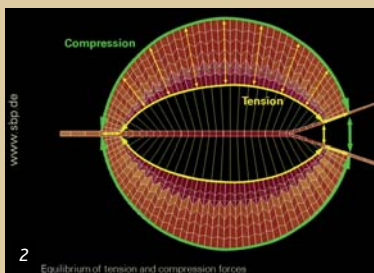
The multipurpose stadium with a possible capacity of 85.000 seats features a unique roof structure of 46.000m² of Glass/PTFE membrane being prestressed against a cable net. The cable net is tensioned against two steel compression rings along the perimeter of the stadium and a mayor arch structure with 103m height and 360m distance between its foundations (Fig. 2-3). Governed by the high wind loads in close proximity to Durban's coastline the membrane structure required a rather dense cable support structure to minimize the membrane stresses. To achieve a global safety factor greater than 5, as stipulated in the European design guide for tensile surface structures, the distance in plan between ridge and valley cables needed to be reduced to a maximum distance of only 8m at the outside

perimeter (compression ring). Often the installation procedures reduce the material strength remarkably, especially when effective quality control is missing. To achieve the required safety factor in reality, a detailed investigation into the strength deterioration due to, manufacturing, handling, packing and installation was undertaken, to overcome the critical strength reduction due to folding of the glass/PTFE material. In order to not accept mishandling of the material the braking strength of the virgin material and the handled material was compared in several stages, even by taking out installed sub panels for testing. The form found and most effective structural shape of the stadium roof drains 75% of the rain water directly towards the gutter located at the compression ring.

The remaining water is firstly running towards the tension ring, before it can be redirected naturally towards the compression ring in the areas underneath to the arches. To achieve this the membrane shape and the gutter located on the tension ring had to be form found in a specific manner. All membrane connections close to the gutter were connected using continuous cables and cable clamps requiring local membrane cut outs with unsupported membrane edges. These locations were designed and tested using bias cut and straight cut membranes. The installation of the membrane panels was following structural design criteria that were derived using the local wind data of prevailing winds. Due to the open shape of the partly installed roof the wind loads during construction and therefore membrane stresses were higher than for the final building, even though reduced wind pressures for construction stages were used. Several construction stages, also for the membrane installation, had to be assessed in the wind tunnel.

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Figure 1. Aerial view of the stadium.
 Figure 2. Equilibrium of tension and compression forces.
 Figure 3. Erection of the mayor arch structure and final interior view.



Name of the project:	Moses Mabhida Stadium, Durban
Location address:	Durban, South Africa
Client:	City of Durban - eThekweni Municipality
Function:	stadium
Year of construction:	March 2006 – November 2009
Structural Engineers Roof:	schlaich bergemann und partner , Stuttgart
Structural Engineers Concrete Structure:	BKS Durban, South Africa
Architects:	gmp Architekten, Berlin
Consulting engineer for the membrane:	Birdair, Buffalo
Wind Engineering:	Wacker Ingenieure, Birkenfeld
Main contractor:	JV WBHO / Group 5
Main contractor Roof:	Pfeifer Seil- und Hebeteknik, Memmingen
Membrane subcontractor:	Birdair, Buffalo
Supplier of the membrane material:	Saint Gobain, Merrimack, NH
Capacity:	70.000 World Cup mode; 54.000 legacy temporary seats will be substituted by conference facilities; 85.000 Olympic mode
Steel work:	2.860 tonne main arch, 2.700 tonne compression ring and columns
Cable structure:	550 tonne
Membrane surface:	46.000m ²
Roof area:	39.000m ² (vertical projection)

3 Stadium of the “windy city”



Port Elizabeth, one of the South African cities selected to host the games of 2010 Fifa World Cup had the special challenge of building a world class sports arena. A German design team started in 2005 the planning of the stadium, aiming to design a signature landmark that could be at the same time a structurally and economically meaningful building.

Contractors from South Africa, USA, Australia, Japan and Kuwait worked during 42 months in its construction, until its completion in April 2009. Particular boundary conditions, as the frequent wind and an extremely corrosive environment, due to high temperatures combined with a high degree of humidity and salt content of the air required individual solutions from the very initial design of the roof until its final completion.

The architectural planning team was inspired by the privileged site, an elevated platform next to the North End Lake, to create a building that could be remarkable and visible from afar.

Roof and facade had a fundamental role in the planning process – integrated in an interesting interplay of concave and convexes forms, both created not only the stadium identification, but functionally they also provided a wind shelter for the internal stands. In addition to the wind tunnel tests to determine the wind loads acting onto the roof, a wind comfort study for the stands and the field was performed to provide the maximal comfort to the spectators as well as the owner's confidence in the project. Again, **schlaich bergemann und partner's** approach to control all stages of a project, from first design ideas until the last bolt being placed, was a fundamental contribution to the success of the project. Thirty-six triple chord steel girders of spatial tubular framework, cantilevering over the grandstands, carry the roof and simultaneously articulate the unique outer appearance of the stadium like petals of a flower growing on top of monumental facade columns and tapering off towards the centre of the

stadium, all together forming a calyx in a ridge and valley shape (Fig. 2). The girders, clad with aluminium standing seam sheeting, form the ridges. Fabric panels of PTFE coated glass fibre membrane, spanning between the girders, form the valleys and dewater the roof. The alternation of translucent and opaque material is visible as a series of illuminated surfaces: at day from inside - at night from outside. A ring beam connecting the top points of the girders forms the inner edge of the membrane bays and carries a circular walkway integrating the flood light system (Fig. 3). Polysiloxane based corrosion protection with high UV resistance has been chosen for the structural steelwork; movable and accessible parts are duplex coated. All relevant details of connections of the membrane and the aluminium sheeting had to pass a long term salt spray test to demonstrate their applicability. Port Elizabeth stadium construction performed an interesting experience in the coordination of international suppliers and contractors, in a complex but successful example of globalisation. The steel framework girders were prefabricated in Kuwait and shipped to Port Elizabeth in parts. Next to the bowl, the girders were assembled on false-work templates considering tight tolerances. After surveying, the 45m long 25m wide curved 55 tonne trusses were lifted in position on top of the R/C structure by a crawler crane. Due to a maximum wind speed for the crane activity, most lifts had to be done in the early morning hours and had to be finished before the wind frequently started to increase. The membrane panels, fabricated in Japan, were unfurled on a temporary net spanning between the girders and pre-tensioned in steps. A big part of the aluminium sheeting has been installed by climbers sheet by sheet since only the area next to the facade was accessible by a movable shoring tower. Besides accommodating sports events like a 2010 quarter final, the stadium also houses conference rooms, offices, gastronomy and corporate boxes. The major legacy of Port Elizabeth stadium is, therefore, its remarkable contribution to the revitalization of the quarters around North End Lake, transforming the area with its architectural presence and opening its doors for the public, even beyond the final whistle of the 3rd place playoff match in South Africa this year.

Knut Göppert

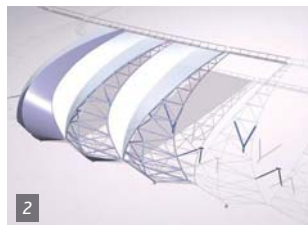
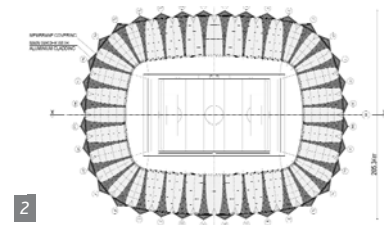
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Lorenz Haspel

Figure 1. Aerial view of the stadium. © GLTA

Figure 2. Plan.

Figure 3. Erection of the roof.



Name of the project:	The roof for the new 2010 WorldCup Stadium, Port Elizabeth
Location address:	Port Elizabeth, South Africa
Client:	Nelson Mandela Bay Metropolitan Municipality
Function:	stadium with conference rooms, offices, etc
Year of construction:	November 2005 - April 2009
Architects:	von Gerkan Marg und Partner, Berlin
Design Team Structural Engineers Roof:	schlaich bergemann & partner , Stuttgart
Engineers for local coordination:	Iliso Consulting, Port Elizabeth
Design Team Roof wind engineering:	Wacker Ingenieure, Birkenfeld
Consulting engineer for the membrane:	Birdair, Buffalo
General Contractor:	Grinaker-LTA / Interbeton (Joint Venture)
Contractor Steel and Membrane structure:	Taiyo Membrane Corporation Birdair, Australia/USA
Contractor Aluminium Cladding:	CC George Roofing, Cape Town, South Africa
Contractor Steel manufacture:	ABJ, Kuwait
Steel Structure:	2300 tonne
Aluminium Cladding:	22.500m ²
Material:	Glass-PTFE membrane
Capacity:	48.600 seats, thereof 45.940 permanent
Membrane surface:	22.000m ²
Covered area:	30.000m ²
Costs Roof:	ca. 22mio €



Cape Town

4

The new Cape Town Stadium

The new Stadium in Cape Town is set into the spectacular scenery of the Table Mountain, Lions Head, City Bowl and Atlantic Ocean. Although the location within the Greenpoint Common Area was controversial at the beginning – set in-between a golf course, cricket grounds, tennis courts, etc. – the completed building shows a respectful integration into its environment and surroundings. The design was driven by two main criteria: first, the city set forth specific criteria, which limited the maximum height of the building. The second parameter was the dominating impression of the horizontal silhouette of the Table Mountain. A simple spoke-wheel roof, as has been done many times before for other stadiums, was not possible due to the required height of the columns, which would have exceeded the limit by far. Even a cantilevered roof would have required a construction height at the outer edge that would have exceeded the set limit. Furthermore, to create a counterpoint to the Table Mountain, the eaves of the building should have an intentional curvature to their shape.

The final result is a roof design consisting of a strongly undulating compression ring, a suspended cable net and an elevated truss girder structure. The latter one stabilizes the "soft" cable net in case of unbalanced loads and lifts up the actual roof surface to an elevation that allows for natural dewatering to the outside. Since the suspension roof requires additional weight to bear uplift forces, the entire cladding system of the roof was designed as glazing, a first for any stadium roof.

A mesh membrane, located underneath the truss girders and spanning between the radial cables, closes the roof void from below and positively influences the visual appearance, acoustic behaviour and wind exposure level. Only the cantilevering part of the structure, from the ring cable to the inner roof edge remains uncovered from below (Fig. 2). The glazing above this area is clear, whereas on the rear part of the glazing (with the membrane underneath) a layer of white print was applied to its lower surface. Great importance was also attached to the design and appearance of the roof surface, since it is visible from many highly frequented observation points as well as from the higher situated properties of Greenpoint, and therefore acts as a "facade" (Fig. 3). The lateral facade consists of an off-set steel structure made of vertical and horizontal beams, which are connected to the concrete structure behind by diagonal struts. The horizontal beams, curved in plane, are arranged in front of the facade surface and therefore form a visible horizontal division of 14 strips. The steel structure is covered with a silver coloured mesh membrane. Its doubly-curved single panels form an almost chameleon-like skin, which intriguingly changes the appearance of the stadium in colour and translucence depending on the exterior lighting conditions. Due to the seaside location and typically extreme wind conditions in Cape Town the wind loading was, of course, the governing aspect of the design of the structure. A particularity for the design was that not only the pressure values according to the standards

DYNEON

Coated membranes for the Soccer City Stadium and the Cape Town Stadium

The First National Bank Stadium (Soccer City Stadium) in Johannesburg is being completely renovated. The design of the new exterior facade is based on a typical African vessel, the calabash. It has been possible to create the new roof shape, which encircles the stadium, through the use of PTFE/glass fiber membranes coated using Dyneon™ PTFE and Dyneon™ Fluorothermoplastic dispersions. A further highlight for the 2010 World Cup will be created directly at the foot of Table Mountain in Cape Town,

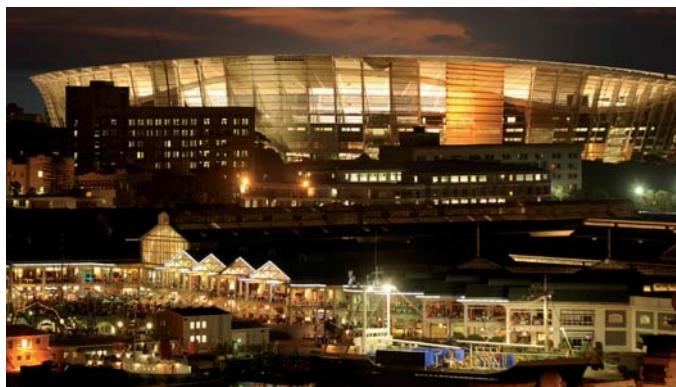


Fig. 1 Translucent façade of the Cape Town Stadium

where the Green Point Stadium will be replaced by a new and larger stadium. A multifunctional

arena is to take shape here under the name of "Cape Town Stadium". The flowing facade of

the stadium consists of an abstract, light membrane structure composed of concave elements having a large surface area. The translucent surface absorbs and reflects daylight in a unique fashion. At sunset the stadium shimmers red, blue on a summer's day and gray if the weather is bad. The wave-shaped roof will be coated with laminated safety glass and covered on the inside with a translucent membrane. Technical elements for acoustics and lighting can be integrated between the

had to be taken into account, but also the specific topographic conditions at that particular location between Table Mountain, Signal Hill and the close sea. The final wind loads acting on the structure had to be investigated by two different wind tunnel tests. The first one used a topographic model to determine the specific local wind and gust conditions, while the second one applied these first results to the model of the stadium building.

Another challenge specific to this structure was the interaction between cladding (glazing) and deformation. Despite the stiffening effect of the truss girders, the resulting deformations of the structure are not negligible; this means that there is significant amount of warping and bias/distortion in the substructure of the glazing. To allow for this, numerous tests had to be conducted to develop the bearing details for the glazing, which allow for the required relative movement between the glass panes and sub structure.

A perfect interplay between design architects and the structural engineers from **schlaich bergemann und partner** as well as the smooth cooperation between the engineers of the roof and façade structure with our colleagues responsible for the reinforced concrete structure formed a strong base for the successful completion of the project. Again, it has been proven that it is fundamental for projects of this complexity to have design, erection engineering, site and fabrication supervision as well as the checking of all workshop drawings concentrated in the hands of the lead structural engineers of the roof.

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Figure 1. Aerial view of the stadium.
Figure 2. Roof acting as facade.
Figure 3. Visualisation.

glass and the membrane. The company Verseidag Indutec GmbH in Krefeld, which specializes in textile architecture, is supplying the textile support structure of duraskin® membranes. Use of different coating techniques on the different support and cover materials ensures optimum protection, as in a "second skin". The duraskin® membranes consist of coated glass fiber fabric, which offers tensile strengths of more than one tonne per meter width and only weighs 0,5 kg per square meter. The coating with Dyneon PTFE and Fluorothermoplastic materials provides the membrane with the special characteristics needed for the tough task within the stadium construction. The surface of the coating is very smooth and

offers permanent resistance to the most varied weather conditions, as demonstrated by many years experience in different climatic zones. Dyneon PTFE features resistance to almost all chemicals along with good mechanical properties. An important advantage of PTFE coatings is that they require neither plasticizers nor stabilizers, which evaporate over time, leading to embrittlement. The membrane coated with Dyneon PTFE and Dyneon Fluorothermoplastic remains smooth and elastic. After several years

Fig. 2 Detail of wave-shaved roof of the Cape Town Stadium.



service there will be no cracks which could allow bacteria and mould to become established. Even under conditions of limited rainfall a shower is sufficient in order to clean the roof. The transparency of the fabric guarantees optimum light conditions for fans and players during daylight.

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Name of the project:	The new Cape Town Stadium
Location address:	Green Point Common, Cape Town, South Africa
Client:	City of Cape Town
Function:	Multifunctional arena, Stadium
Year of construction:	2007-2010
Structural Engineers Roof and Facade:	schlaich bergemann und partner , Stuttgart
Structural Engineers Concrete Structure:	BKS Bellville, South Africa
Architects:	Stadiumarchitects (gmp Berlin, Louis Karol, Point Architects both Cape Town)
Consulting engineer for the membrane:	Birdair, Buffalo
Wind Engineering:	Wacker Ingenieure, Birkenfeld
Main contractor:	Murray & Roberts / WBHO (Joint Venture)
Contractor Roof:	Pfeifer / Birdair (Joint Venture)
Contractor Facade:	Hightex / Mostostal (Joint Venture)
Start design - Completion	April 2006 – December 2009
Capacity:	68.000 World Cup mode, 55.000 afterwards (temporary seats will be substituted by lounges)
Roof area Glazing:	ca. 37.000m ² , ca. 9000 single panes (2x8mm TVG)
Roof area Lower membrane:	ca. 35.000m ² mesh fabric PES/PVC
Facade area membrane:	ca. 27.000m ² mesh fabric PTFE/Glass (glass fiber fabric coated with Dyneon PTFE and Dyneon Fluorothermoplastics)

Images, where not noted different, by **schlaich bergemann und partner**
schlaich bergemann und partner - Structural Consulting Engineers
STUTTGART . BERLIN . NEW YORK . SAO PAULO - www.sbp.de

Contractor of the membranes Birdair, Inc

For the stadia in Cape Town, Durban and Port Elizabeth Birdair, Inc was involved as contractor for the membranes. Birdair, Inc. is a leading specialty contractor of lightweight long-span roofing systems and tensile structures throughout the world, providing design-build solutions for architects and clients in all aspects of project design, engineering, installation and maintenance. Lightweight long-span roofing systems and cable structures can be attached to any building envelope and offer aesthetic and functional options to complement any exterior design. Birdair, based in Buffalo, NY, is a member of the Taiyo Kogyo Group, with operations serving North and South America and other international locations. (www.birdair.com)

IMS Research Project "Batsail"

Initial Experiment

As a first step a Batsail membrane with 5 fibre rods under compression was exposed to several load cases at different positions of the membrane surface to test the deformation of the structure compared to a simple 4-point sail. The results were as expected: the higher the pre-compression in the glass fibre bats, the more homogeneous the behaviour with less deformation over the whole surface of the membrane could be noticed (Fig. 1).

As the first experimental Batsail was too complex as a structure with too many possible influencing factors, it appeared impossible to simulate the behaviour within a computational model. Therefore it was decided to initiate a smaller second advanced experiment with one single glass fibre bat anchored at the edge cable without cantilevering effect.

Second Experiment

Within a scaffold cube of 3m edge length a 4-point shallow hypar was erected. At each corner point spring balances were adjusted to measure the tension forces of the Batsail. A single glass fiber bat was fixed below the membrane by stitching to exclude the influence of a pocket. The compression was introduced by a simple screw shortening the space within the anchoring steel tube. The membrane was

Hyperbolic membrane structures can be a very charming and aesthetic way to cover smaller areas such as carports or shading sails. Technologies and detail points for this type of membrane construction are well developed, with one big challenge: the inwards curved edge cables narrow the spanned-over space, so only a small area can actually be covered.

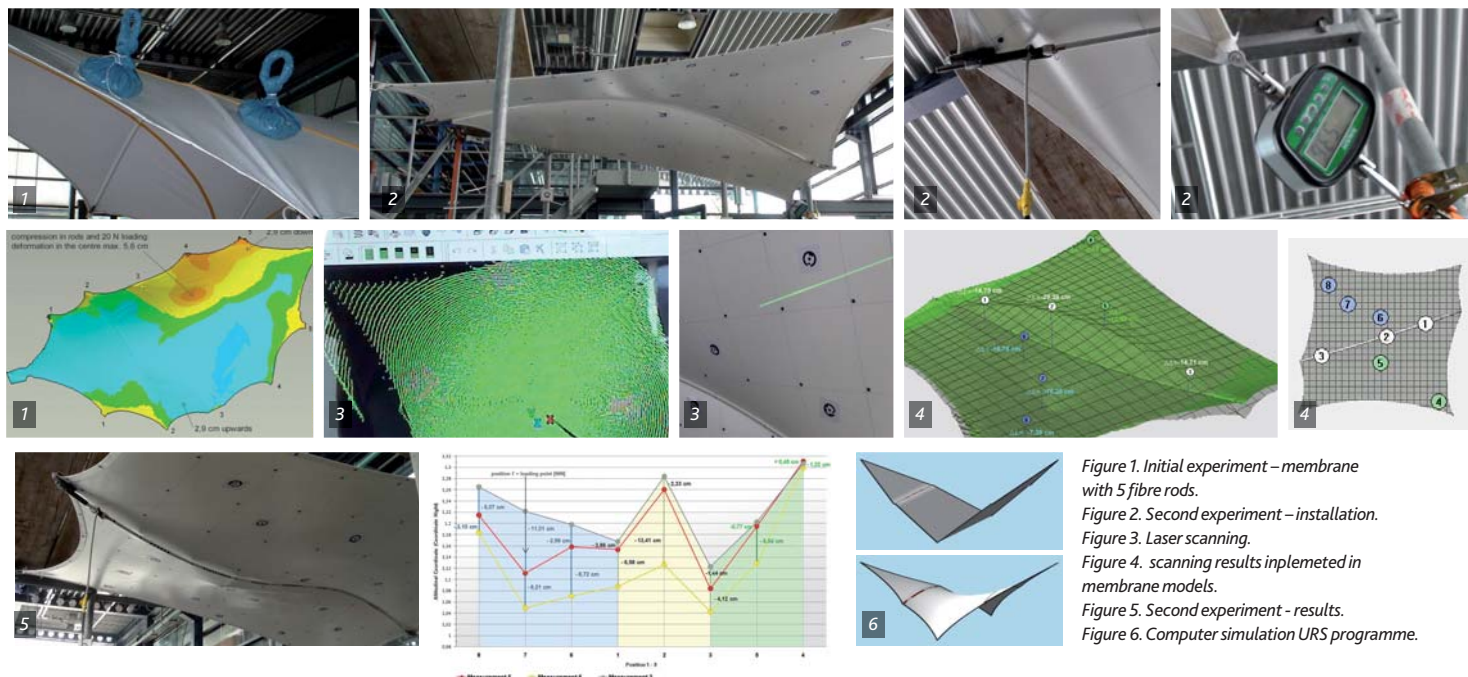
To address this problem and to generally widen the possibilities of membrane structures one of the IMS research projects is the "Batsail" project, a membrane reinforced with flexible reinforcement fibre rods, able to take compression forces under buckling state secured and anchored within the membrane surface itself. In addition the compressed rods can extend over the edge cables like wings of a bat. They stiffen the membrane edges and maximize the covered space. The structural behaviour and promising possibilities of this hybrid and form-adaptive structure were content of research at the IMS and University Anhalt, Germany.



made of one piece to also exclude the influence of seams (Fig. 2). Before starting to tension the rod and putting loads onto the membrane, a laser scan was done. Each step of change that occurred to the membrane by putting loads onto it or removing it, was laser scanned - up to the point of failure of the glass fibre rod (Fig. 3).

The scans of each measurement case were used to create the membrane's surface as computer model. Projecting a system of grid lines (the same for each case) on each of the membrane models provided the possibility to compare - additionally to the comparison of the measured forces in the rod and spring balances - the different scans to each other, at defined positions: 5 in the field and 3 on the rod itself (Fig. 4). Inserting a load at any position to a membrane

without uncompressed flexible fibre rod, the membrane's deformation, especially in the area of the loading's placement, will be high, depending on the load value. Even in uncompressed condition the fibre glass rod's compression force was activated by applying a vertical load on the membrane's surface. The bat absorbed a part of the additional stress in the structure caused by the load. The deformation of a membrane without anchored bat will be much higher. For the tensioned membrane with uncompressed fibre glass rod and a load of 90N a downward deformation of 2,6% (over all positions 1-8) of the maximum diagonal length of the membrane was monitored. After pre-compressing the bat, the deformation was reduced to only 0,9%! So with the help of a compressed flexible fibre glass bat a significant reduction of



deformation can be achieved. The introduction of compression force into the rod anchored at the edge cables automatically increases the stress over the whole structure including the corner points. Thus with the help of the rod the whole structure can be pretensioned. While introducing single vertical loads on the membrane (position 7) the precompression and pretension is reduced at the bat and the corners. Less force is transferred to the supporting structure, even applying additional load to the surface, while at the same time the deflection with a load of 20N is only 0,3% and with 90N only 0,9% (% referring to the diagonal length of flat membrane). Just load case 5 (membrane under tension, rod compressed, load of 90N) is applying additional compression on the bat and additional tension at the highpoints. So up to the point where the introduced prestress and precompression is "used up", the deflection is within a comparatively small range compared to the span. Applying more load, the compression in the rod increases again as well as the high point's stress level. This goes up to 13% of increase of compression in the rod, then the snap through point is reached. Before the rod failed, stresses were increasing everywhere. A big difference between the forces in the low points (degreased) and the high points (increased) was to be noticed. After snap through all load is hanging on the two high points with an increase of 15% tension force and an average deflection of 3,8%. The snap through incident is clearly predictable by these indicators (Fig.5).

Summary

Structures like the Batsail - with flexible fibre rods anchored to a membrane - allow us to enlarge the covered area by "pushing the edge cables" outside. The main unexpected advantage is the possibility to significantly reduce the deflection under load without having to increase the prestress level of the membrane by higher anchoring forces. This enables larger spans with less deflection, smaller mast dimensions and foundations. The next step of reliable structural calculation has yet to be proven in order to introduce the Batsail into everyday structures. Therefore the results were sent to Prof. Dr. Kai-Uwe Bletzinger, at the Technical University Munich to simulate the experimental Batsail within his URS (Updated Reference Strategy) programme. A first simulation already shows that a Batsail structure can be accurately modelled (Fig. 6).

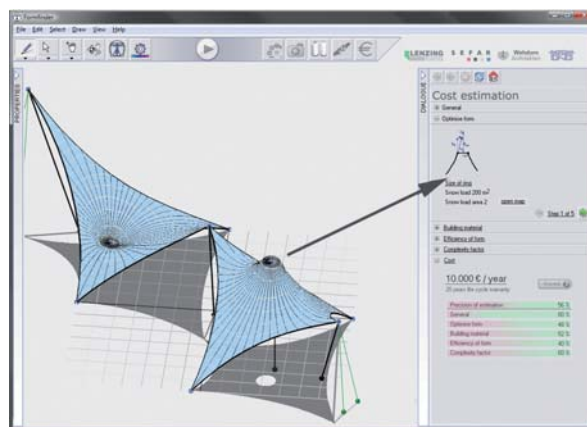
✍ Prof. Dr. Robert Off, Director IMS, Germany, Anhalt University. (article)

✉ robert.off@ims-institute.org

✍ Prof. Dr. Heinz Runne, Anhalt University, Germany (surveying)

✉ heinz.runne@ims-institute.org

🌐 www.ims-institute.org



FORMFINDER Software "One Click" Cost Estimation for the architectural design of membrane structures



Who knows the price? At each step of the design someone might ask this question. Especially membrane structures are rarely documented and analyzed with respect to these (cost) factors. Due to the vast number of different shapes a comparison was not possible up to now.

The solution introduced here is based on the Formfinder software and opens a completely new way on the evaluation of different cost factors. The first part of the solution is a new logical database that contains specific expert's knowledge generously provided by Mr. Horst Dürr at "Ingenieursgemeinschaft IF". The second part is an incorporating self-learning calculation algorithm that connects specific geometric components of the design with the so called design "values".

Each design "value" represents a specific view on the intended design. It is important that each value is refined with the number of matchable data available and is not only measured in Euros. Also values like uniqueness, complexity factors or geographical values are part of the consideration. A creation of a sample set of these "values" and a closer investigation how they influence the cost estimation is a subject of the PhD thesis by Mr. Nikolay Kim who is working in the Formfinder Software Development Team. The intention of the self-learning calculation process is to support the designer at each step of the design and to increase the architectural quality of membrane structures. The integrated design tool also includes "values" like the shaded area, rain-protected area or simple projects that have been built already. Especially with respect to the project database the intended cooperation with Tensinet will also provide more information to the designer.

✍ Robert Wehdorn-Roithmayr, Formfinder Software GmbH Wien

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🌐 www.formfinder.at

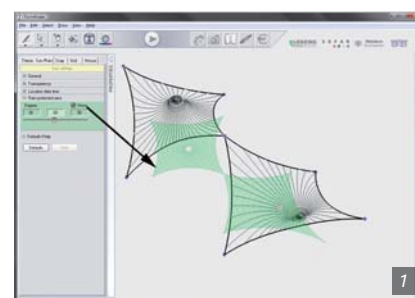
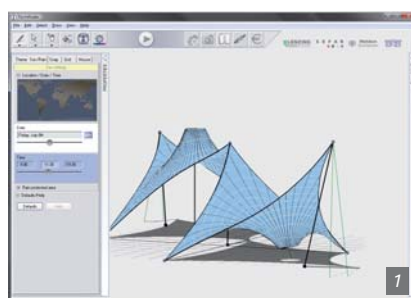


Figure 1. Display of the sun-shape area (left) and rain-protected area (right).

Figure 2 (above) The Formfinder ProjectFinder is also available for any mobile device e.g. iPhone

Lone Butte Casino Lights Up the Desert Sky

Chandler, Arizona, USA



The newly constructed Lone Butte Casino is located south of Phoenix in Chandler, Arizona and is owned and operated by the Gila River Indian Community. Visitors to the casino are greeted by a spectacular fabric structure at the main entrance built by FabriTec Structures. FabriTec, in conjunction with Group West Architects and General Contractor JE Dunn, have created a custom framed tensile structure made of Teflon-coated Fiberglass (PTFE) fabric. The 5-tiered, wrapped panels form the canopy for the main entrance and peak at a height of 13,7m. The panels range in sizes from as much as 21,3m long to widths of up to 9m. The casino also features two smaller side-entry structures as well as an interior fabric structure for the central court of the building.

The 3 entrances to the building were given equal importance and were designed with matching features both outside and in the immediate indoor entry areas.

The design of the fabric structure is unique in that the fabric cladding is on the underside of the structural steel elements thus concealing the steel from view below (Fig. 1). The cumulative effect of this design is that the structure looks like layers of clouds floating above the entryway. To add to the dramatic appearance, the structure has been built with colorful custom up-lighting which automatically changes and can be controlled for various degrees of evening light and for time of year. FabriTec Structures won at the 2009 International Achievement Award (IAA) with this project the Outstanding Achievement award.

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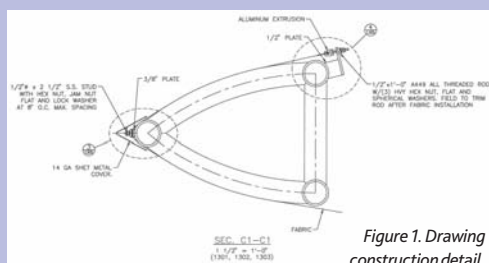


Figure 1. Drawing construction detail.



ARQUITEXTIL FHECOR

ETFE single skin

Architectural concept

Aranda de Duero is a town in Castille (Spain). A new Arena was constructed in this town. The building consists of a circular grandstand and a global roof. The roof is partially retractable in order to adapt the configuration of the building to different events. The Arena has a circular shape in plan with a diameter of 80,14m. The roof

was designed as a shell structure. Half of the central part of the roof is retractable and has a shape of spherical sector of 32,90m of diameter in plan. (Fig 1)

Steel structure – fixed roof
The main structure has a Schwelder configuration. A spherical shape supported only in the perimeter by



Name of the project:	ETFE SINGLE SKIN ARANDA DE DUERO ROOF
Location:	Aranda de Duero, Spain
Client:	Victoriano del Rio
Function of the building:	Concerts, sports and bullfighting Arena
Type of application of the membrane:	Protection against environmental hazards and light transmission
Year of construction:	2006
Architectural Design:	José Romo (FHECOR Ingenieros Consultores) José María Lastra (Comercial Marítima L&Z)
Structural Engineers:	José Romo (FHECOR Ingenieros Consultores)
Consulting engineer for the membrane:	José Romo (FHECOR Ingenieros Consultores) & José María Lastra (Comercial Marítima L&Z)
Tensile membrane contractor:	Comercial Marítima L&Z
Supplier:	Nowofol GmbH
Manufacture and installation:	Comercial Marítima L&Z
Material:	Nowofol ET 6235 300 µm ETFE
Cover surface:	1.400m ²

Location address:	Chandler, Arizona, USA
Client:	Gila River Indian Community
Function of building:	main entrance Casino
Type of application of the membrane:	canopy
Year of Construction:	2009
Architects:	Paul Hamel (Group West Architects)
Engineering:	FabriTec Structures
Contractor:	JE Dunn Construction
Supplier of the membrane material:	Saint-Gobain & MultiKnit
Manufacture and Installation:	FabriTec Structures



Spain Aranda de Duero Roof

neoprene bearings of 300x400x121mm located over 36 concrete pillars. The maximum relative level of the fixed roof is 9,64m. This gives a ratio height/span of 1/8,3. The structure conformed by HEB280 profiles as meridian and parallel beams. The diagonals of steel bars 32mm give the shell behavior of the structure. Diagonals were prestressed to ensure efficiency of the system.

The structure has an outer beam. This element of 0,60m depth and 0,90m width was made in reinforced concrete working in tension. The central oculus has in the perimeter a steel hollow beam of 745mm width, 700mm depth and 12mm of thickness. This beam is working mainly in compression. The structure is considerably light. Its slenderness ratio (depth/span) is 1/285 meanwhile the egg shell is 1/100. (Fig 2)

Steel structure – retractable roof
Half of the oculus follows the geometry of the main roof and it is also fixed while the other half is movable. (Fig 3 - 4)

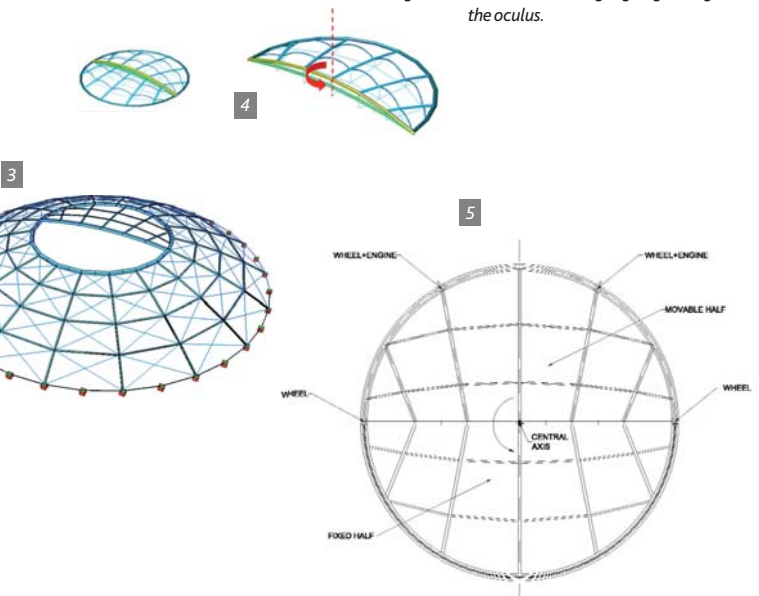
In order to unify the global design of the roof, the retractable part has the same radius of curvature as the fixed roof. To have a more clean view, the structure of the oculus

does not follow the structural system of the fixed roof. The movable half spins around the central vertical axis. (Fig 5)

The movable part is supported in the central axis and in four wheels. Two of them are in both edges of the beam, and the other two at 60 and 120 degrees. Two engines move the central wheels. The movable structure is composed by HEB steel profiles. Both circular beam and the one in the diameter have steel hollow section. (Fig 6) Movable upper half bearing on fixed bottom half.

ETFE membrane
ETFE has been used as the oculus roof material to obtain maximum transparency. Even though Aranda has snow winter conditions, the membrane was design as a single layer. ETFE has a thickness of 300µm. The membrane has a negative Gaussian curvature, to resist snow loads as well as wind suction. Steel arches give shape to the membrane. Twelve radial sectors configure the ETFE membrane.

Each of them was fixed to the meridian beams, and stressed by elevating the steel arches. Longitudinal inox 8mm cables were used to help the membrane resist snow loads. (Fig 7)



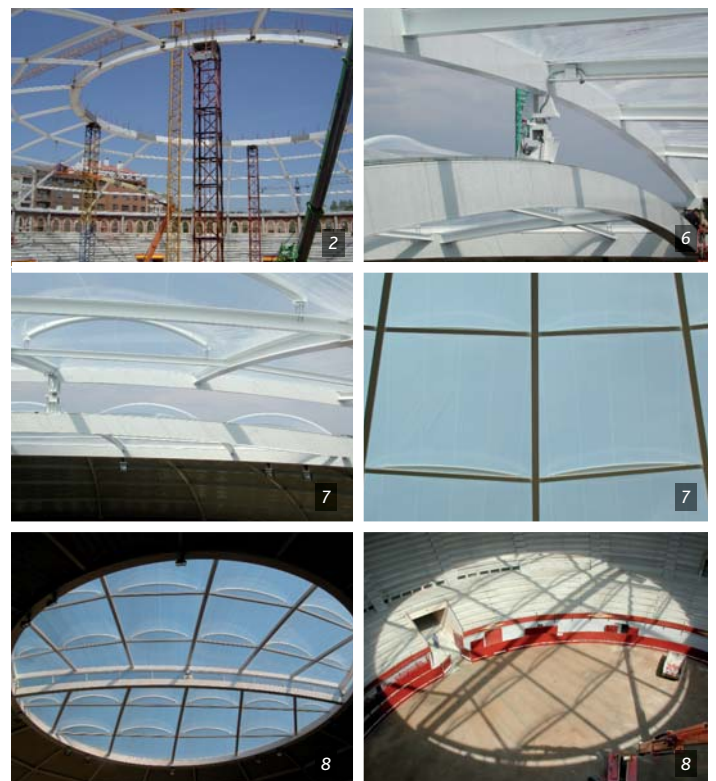
Conclusions

Light ETFE has allowed to build a slender movable roof which could not be possible with heavier materials such as glass. Single skin gives a high level of transparency which was one of the client's requirements. One of the main goals of this design was the successful combination of ETFE with a movable structure. (Fig 8)

Figure 1. Air views of the roof.
Figure 2. Fixed roof during construction.
Figure 3. Model view of the fixed elements.
Figure 4. Retractable roof in opened and closed positions schemes.
Figure 5. Top view of the closed oculus.
Figure 6. Movable upper half bearing on fixed bottom half.
Figure 7. Membrane bottom view.
Figure 8. Interior view and light going through the oculus.

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Case study 'Tensile surfaces

The present case study – a membrane roof model – took form during a Mastering Research at the University of Ouro Preto, Brazil and aims to explore the characteristics of the roof construction system when applied to a particular situation and to analyze the joint work of Engineering and Architecture on the development of tensile surface structures. It was studied through a particular method of work – which involves flexible, physical and computational models and from which the qualitative and structural solutions are derived. In 2007, the model built for this study was awarded the First Prize at Valmex Structure 2007's competition, organized by Mehler Technologies in Brazil.

1. Introduction

Tensile surface structures are three-dimensional systems composed by the association of membranes and a supporting system (cables, masts, arches, trusses, etc. normally in steel) under a tensile state. Having minimal weight when comparing with the supported load, these structures are very flexible, a result of the substitution of the material mass by the appropriate form to achieve stability. They introduce a unique structural approach, in which the form derives from the flow of forces in the structure. Thus, the stability, performance and efficiency of the system are dependent on the geometry, the pre-stress state and the continuous and integrated work of all the structural components.

This approach represents a major challenge to architects and engineers: the structural solution needs an accurate design, the knowledge on the system's conditions and parameters and, besides that, it must incorporate the structural analysis to the conception of the project. Therefore, the design process in this case is different from the traditional one, as it should concentrate the efforts of a multidisciplinary team (architects, engineers, manufacturers etc), becoming the result of this team's interaction since the beginning. Consequently, the quality of the spatial and structural solution and the production of accurate information for the partially industrialized building process are a result of the dialogue among the members of the team and the integration of their work actions.

2. Method of work

In this case study, the particular method of work used comprises the conception of the project as well as the design process. The conception aims to set up the project's guidelines or, in other words, to understand and define the use, activities and the identity of the object that will be built, such as the building site's qualities and its characteristics (views, topography, influence of the wind/sun, neighbourhood, relation with the landscape and city, and the local laws). The design process includes physical and computational modelling and permits the development of the system's equilibrium configuration, gradually exploring the benefits of having Architecture and Engineering working together.

The physical modelling can be accurately carried out and allows the investigation of the geometry and the behaviour of the components under a tensile stress field. However, the method of using flexible physical models was indirect in this case study. That means it was based on the identification and mapping of the most important characteristics of the constructive system (geometry and integrated work of the components under a tensile state) for later observations and qualitative analysis of the system's behaviour. The dimensions and parameters involved on the physical model and the ones of the real structure are the same, but there is no geometric factor to establish a relation between the material's properties (unit weight and load), a fact that could turn evaluation into a

simplified representation of the reality. The computational models comprise the engineering of the structure, including the selection of the materials and the analysis and design of the system. The Density Force Method and the Finite Element Method were used when studying this roof. They made possible the modelling of the initial surfaces (form finding) and the preliminary non-linear analysis of all the structure, refining the research on the equilibrium configuration of the proposed model.

2.1 Conception of the design or guidelines of the project

The site chosen to reveal the proposed covering model is the amphitheatre square of the Federal University of Ouro Preto, which is a large strategic area, situated in the centre of the main campus (Figure 1). Within this academic context, the proposed project intends to give visibility and a purpose to the place, stimulating the local use under different weather conditions – a cultural, academic or ephemeral use. The proposed configuration occupies an area of 2212m² and is composed by two surfaces: a permanent one (external) and a retractable one (internal). This creates an appropriate solution: it protects from rain or sun, provides the experience of open and close spaces, permits occasional changes and offers flexibility towards the most different uses. It also explores the possibilities for natural lighting and ventilation of the large free space as well as the openings to the nice views and relation with the landscape. A frequent use will improve the safety of the place.

2.2 Design process

The first stage of the design process comprised the insertion of the structural project on the local physical context using physical models. The initial models, with scale of 1:500 (Figures 2, 3), explores different structural configurations and allows the intuitive understanding of the global system. The models on scales 1:200 (Figure 4) and 1:100 (Figures 12, 13) provide a more detailed comprehension. The 1:500 and 1:200 models were built with nails, fishhooks, cotton thread, nylon fabric from woman's stocking and cardboard for their bases. For the 1:100 model, paper, cotton, steel thread and hardboard for the base were employed.

The first proposed configuration - **Study 1** (a 17x18x5cm flexible model built on a 1:500 scale) presents the system's support and the



Figure 1. Amphitheatre square of the Federal University of Ouro Preto

structures' design process

permanent external roof (Figure 2). A three-dimensional system supports the top of this roof. It is supported by four tall rigid masts and rigid bar elements, with no continuity, inserted in a continuous net of tensile cables and defining a stable and articulated spatial system (Tensegrity's Principle). The system is associated to two rigid rings: the inner ring, connected to cables, and the outer ring, connected to the rigid bars. This association brings more stability and stiffness to the system.

On the second proposal - Study 2

(a 17x18x5cm flexible model built on a 1/500 scale) the top of the roof is also supported by the three-dimensional system and the basis is still sustained by the same tall masts (Figure 3). The main difference is that the basis is now at a higher position in reference to the ground due to shorter masts added to the model. Another difference resides in the fact that the spatial system is supported by three tall independent masts that are no longer rigid but present a hinge and tensile cables. The three-dimensional pin-ended mast's configuration is a stable shape in space that avoids the flexural moment. The compressed mast and the two tensile cables also enable the reduction of the structure's weight, increasing its efficiency. The Study 2 was chosen to give continuity to the research on the geometry and behavior of the roof due to the simplicity and the challenging balance situation of the supporting system in addition to the search for the integration of the proposed tensile membrane structure with the landscape.

Hence, a new flexible model was created (scale 1/200, 50x50x10cm) in order to study the complete roof. This **Study 2 (1st adjustment)** revealed the necessity of some modifications on the supporting system (Figure 4). Thus, the spatial system received a central flying mast and the rigid bar elements were connected to two rigid rings. The central flying mast's role is to support the high points of the convertible surface and by doing so it becomes the central element of the spatial supporting system. The two rigid rings have different diameters and are set on different planes in order to permit the overlapping and the support of the roofs. The complete roof also has different arrangement and behaviour, being now composed by two anticlastic surfaces (double curvature in opposite directions). The external permanent surface is a cone shape, with its top supported by the internal ring and its basis by the small

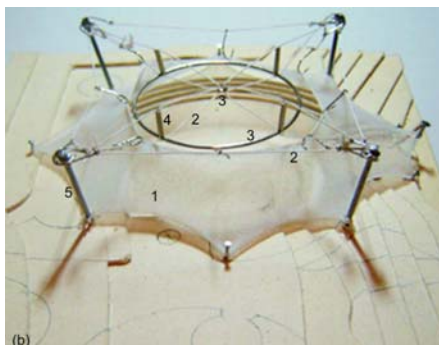


Figure 2. View flexible model : three-dimensional of flexible model – Study 1, scale 1/500 - 1. Permanent covering: Support system: 2. cables- 3. rigid rings - 4. bars - 5. tall masts

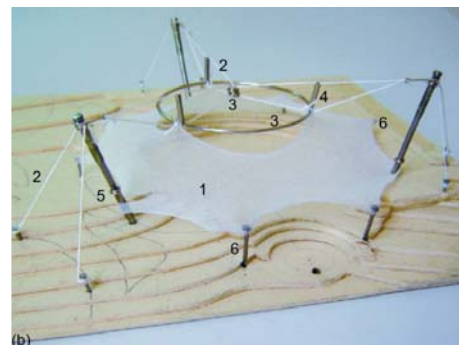


Figure 3. View flexible model : three-dimensional of flexible model – Study 2, scale 1/500 - 1. Permanent covering: Support system: 2. cables- 3. rigid rings - 4. bars - 5. tall masts - 6. small masts

and tall masts. The internal convertible roof presents a radial array of nine modules of saddle-shaped form. The top of the flying mast supports the roof's centre and cables anchored to nine points of both external rings supporting the roof's basis. When closed, the centrally retractable surface is protected by a glass roof. The mechanisms responsible for the movement of the internal roof are activated by sliding engines (tractors) that connect the membrane's edges to the cables. These tractors, driven by synchronized electric engines, move freely along the cables (which are supported by the top floating mast and the rings) opening and tensioning or closing the membrane roof. However, to make the opening and tensioning of this surface possible, the flying mast may have a retractile mechanism that allows the height adjustment of the system.

The second stage of this process included the registration and the computational modelling of the developed proposed system: Study 2 (1st adjustment). It involves the initial surfaces' modelling (form finding) and the system's preliminary analysis.

Initially, the surfaces were modelled through the Force Density Method using Densalfa, software developed by Vinicius de Oliveira (OLIVEIRA, 2003). The force density is an initial tensile force based in a constant relation between force and the length of each bar element, allowing an internal equilibrium of pre-stress forces. In this mathematical approximation, the equilibrium form of the surface relates the geometry and an internal tensile stress field. Thus, the membrane surface was discretised as a cable net by the definition of a net mesh composed by radial and circum-

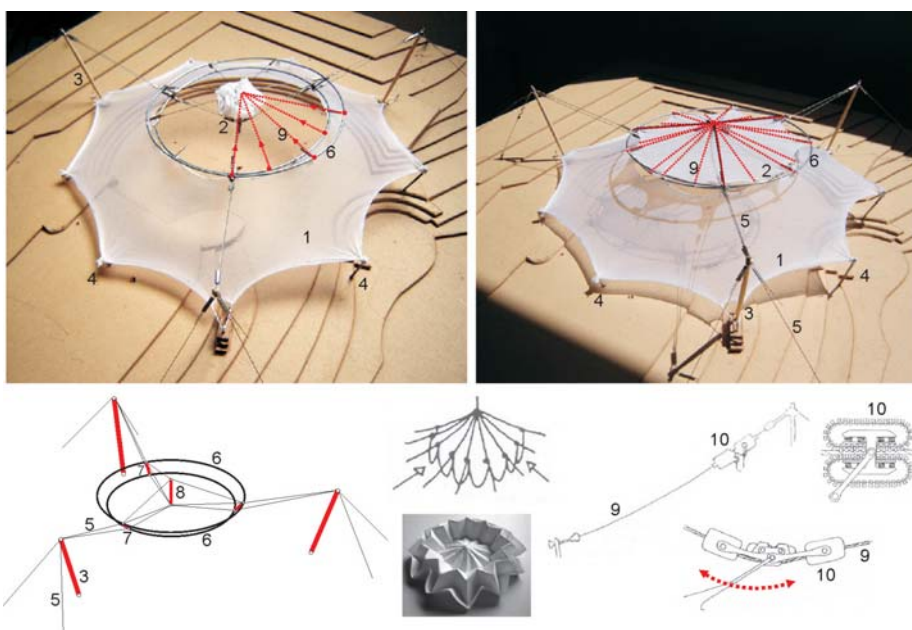


Figure 4. Views flexible model: Study 2 (1st adjustment), scale 1/200; Mechanisms responsible for the movement of the internal roof 1. Permanent covering - 2. Convertible covering; Support system: 3. tall masts - 4. small masts - 5. cables - 6. rigid rings - 7. rigid bars - 8. flying mast - 9. cables that support sliding tractors - 10. tractors

ferential cable elements and the spatial coordinates of the anchoring points. Then, the force density was applied to the cable elements in both directions. In this method, the simplified equations do not have parameters that refer to the net material. However, it describes the spatial form and allows the understanding of its behaviour and the parameters that govern the surface's equilibrium shape: the double curvature, the curved edge and the pre-stress forces. Since the form follows the stress flow, on *Figure 5*, it is possible to observe the series of adjustments made on the curvatures of the permanent surface that resulted from changes in the applied pre-stress present in the net's internal field and edge cables. If the tensile force applied to the edge cable is higher than the one on the net's inner tensile field, the inner surface will present a smoother curvature, becoming less warped. However, if the level of this tensile force decreases, the inner surface will suffer a contraction modifying its form and increasing the warping of the surface and the edge cable's sag. The final configuration and the surfaces' tensile stress field were defined by the comparison and overlapping of the surfaces developed through the Force Density Method and the images of the physical model (Study 2 - 1st adjustment) (*Figure 6*). The final three-dimensional surfaces were exported to another software, which permitted their association to the system's support axis, and then exported to Ansys® for the preliminary analysis (*Figure 7*). The supporting system received more adjustments to improve the efficiency of the structural complex. In Study 2 (2nd adjustment), the two rigid rings became a trussed ring (a truss is a binary of tensile and compression in equilibrium that does not develop flexible stresses and allows the use of slender elements). The tall masts and flying masts' heights were also changed, increasing the slope and reducing the tensile force's horizontal component of the cables that support the spatial system (*Figure 8*). After that, a non-linear computational modelling was carried out by using the Finite Element Method and the Ansys software for structural simulation, and that modeling permitted a preliminary three-dimensional analysis of the whole structure considering the properties of the materials used. This model was developed at the State University of São Paulo/USP during Lightweight Systems lectures, taught by Professor Ruy Marcelo Pauletti in a joint work with Engineer Elivaldo Silva, as a way of connecting the aspects of the Architecture and Engineering for the development of the tensile structures.

The preliminary analysis of Study 2 (2nd adjustment) was defined in small and consecutive load steps guaranteeing a gradual

change in stress in a search for the equilibrium shape of the structure under pre-stress combined with others loads. In the 4th loading step (*Figure 9*), considering the structure's self weight, it is possible to observe that the highest stresses are concentrated on the connections of the external surface to the trussed ring and on the top of the internal surface, near the connections to the flying mast. These points coincide with the areas of maximum displacements of the initial form (*Figure 10*). Although these displacements may be considered small, they show evidence that these surfaces are subjected to big movements due to loading actions. As deformations and flexibility are part of this structure's behaviour, it is necessary to adjust the curvatures and the pre-tension level in order to equilibrate these displacements. For further analysis, it is important to consider the wind load, as it is the most important load on the system at the site where the roof is placed, due to the system's minimal structural mass.

To investigate the adjustments that had been done on the supporting system and the patterning of the spatial surfaces another flexible model on a 1/100 scale and 80x90x19cm wide was built: Study 2 – 2nd adjustment (*Figure 13*). Initially, the three-dimensional surfaces, composed by radial and circumferential cable elements and generated by the Force Density Method, were converted into a triangular mesh using a graphic software. Then, this mesh was patterned into strips, following the geodesic lines or, in this case, the radial lines. Then, the spatial strips were flattened through mesh's triangulation (determining the relative positions of the mesh's points in space by measuring of each element's length distances and its angles), forming two-dimensional panels (*Figure 11*). Later, the two dimensional panels were printed, cut out and received extra border-sides to allow the lateral overlapping and fixing of the panels and to form the loose edge pockets through which the cables (cotton threads) passed.

By doing so, it was possible to produce the three dimensional geometry, pre-stress the surface and connect it to the supporting system. For this procedure, it was very important to align the panel patterning to the fabric's directions (warp and weft) and to the main curvatures of the surface in order to minimize the strains and distribute the stress in the surface uniformly.

This flexible model was built on a flat surface to facilitate its mobility and considered the top level of the amphitheatre as reference. All components (masts, trussed ring and surfaces) were produced at once. Their assembly was done in consecutive stages. First, the supporting system was installed: placement of the

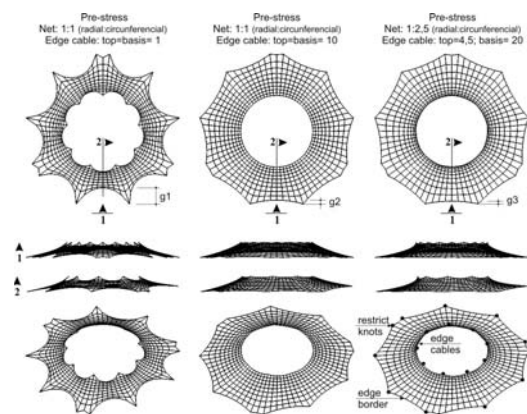


Figure 5. Changes in the pre-stress on the external surface.

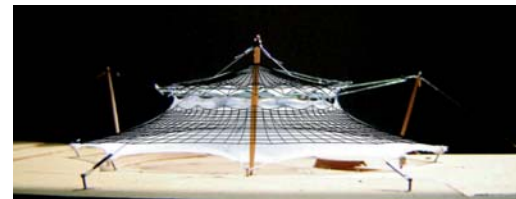


Figure 6. Comparison and overlapping of the surfaces developed through the Force Density Method and the images of the physical model (Study 2 - 1st adjustment).

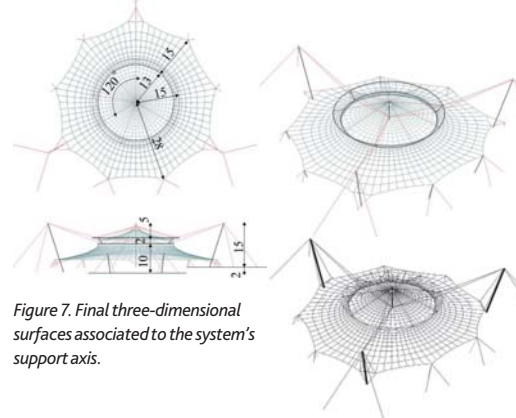


Figure 7. Final three-dimensional surfaces associated to the system's support axis.

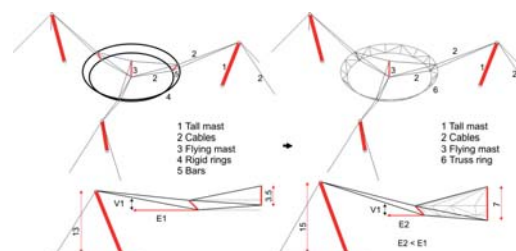


Figure 8. Supporting system adjustments: the two rigid rings became a trussed ring; tall masts and flying masts' heights changes.

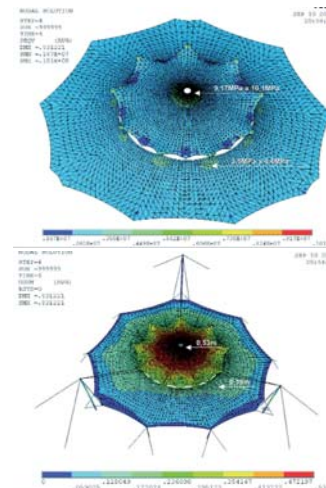


Figure 9. 4th loading step: stress on the structure's self weight.

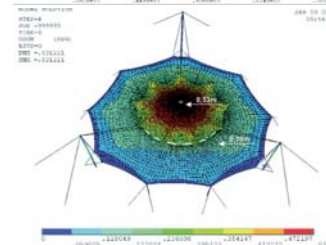


Figure 10. 4th loading step: displacements on the structure's self weight.

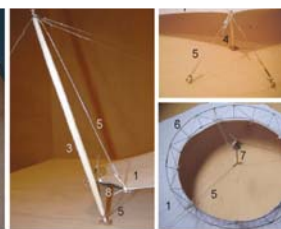
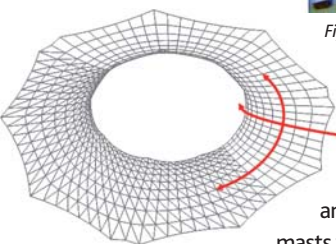


Figure 13. View flexible model: Study 2 - 2nd adjustment, scale 1/100.

Coverings: 1. Permanent - 2. convertible Support system: 3. tall masts - 4. small masts - 5. cables - 6. truss ring.



temporary support and lifting of the trussed ring. Then, an initial pre-tension was applied to guarantee a partial three-dimensional stability (*Figure 12*). In this stage, it was observed that the supporting system separately suffers large displacements. The surfaces were hoisted and connected to the supporting system and, later on, the pre-tension was applied to all the components (*Figure 13*). As a result, a significant increase in the stiffness and stability of the whole system was observed. The development of this model gave possibility to verify that not only the supporting system sustains the membrane's surface, but also the membrane brings stability and stiffness to the supporting system. These observations provide evidence and demonstrate the continual, integrated and global work of all components.

When working with tensile surface structures, there is a particular vocabulary related to the elements (membranes, supporting system and connections). Because of that, in the final stage of this research, a study on the geometry of the supporting system's components was done using a three-dimensional modelling of the structure (*Figures 14, 15, 16*). It was noticed that the form and performance of each element are closely linked to its structural behaviour and to the system's pre-tension state, making clear why both of them have to be analyzed and developed together with all systems aspects. An example of this necessity is the choice of the

Another point to emphasize is how these structures were pre-tensioned. It was observed that the connections have a significant performance and represent the articulation between components. As the membrane structures do not support compressive and flexural stresses, they may be subjected to large movements when under loading actions. As a result, the connections become essential to the system, for they should allow rotations and displacements and provide the means of reaching the structure's taut state.

The mast-cable proposed connections (*Figure 14*) were done by flat steel plates, eyed or not, allowing the insertion of steel cable terminals (shackles, swages, spelters) that permit length adjustments and the articulation and angular changes of the cable in different directions as well. The masts and cables basis, with ball hinges, were articulated and permitted rotation and their adjustment. For the trussed ring, the connections between the truss tubular bars and the ring were done by flat steel plates, allowing the connection of other eyed plates. These new-eyed plates allowed the anchoring of the

support cables. The flying mast (*Figure 15*) was supported by tubular rings located on its base and top. The top rings received the cables of the supporting system, the convertible roof and its transparent protection.

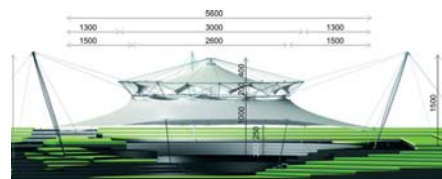


Figure 16. Three-dimensional modelling of the structure.

The proposed model made possible the investigation and experimentation of the system's form and behaviour in a particular situation, and provided understanding on what makes tensile surface structures unique: the search for the minimal quantity of energy focusing quality when designing and constructing. In other words, the system's basic development principle resides on how the system organizes itself to support and equilibrate the load, in an attempt to optimize the form of all the components (weight, size, etc), their material (cost), the stress distribution and the man-work (designing, manufacturing and assembly).

As an integrated system, it introduces a complete interrelation between form and forces, which means between the constructed form and the spatial proposal. It can be affirmed that during the design the search for the membrane's equilibrium shape is quite associated to the choice of the supporting

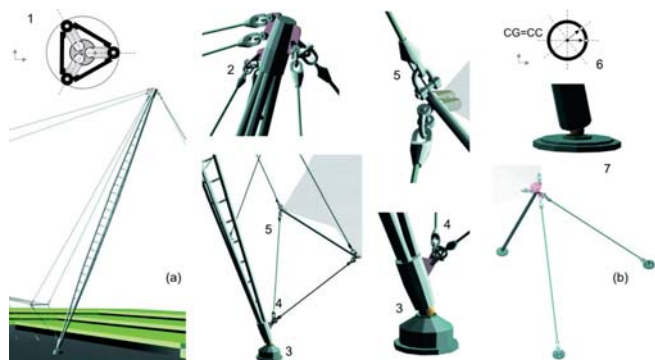


Figure 14. Masts details. a. tall mast: 1. section; connections - 2. top: cable - 3. basis/ball hinge - 4. basis: cable - 5. membrane-cable-bar - b. small mast: 6. section: connections - 7. mast basis/ball hinge

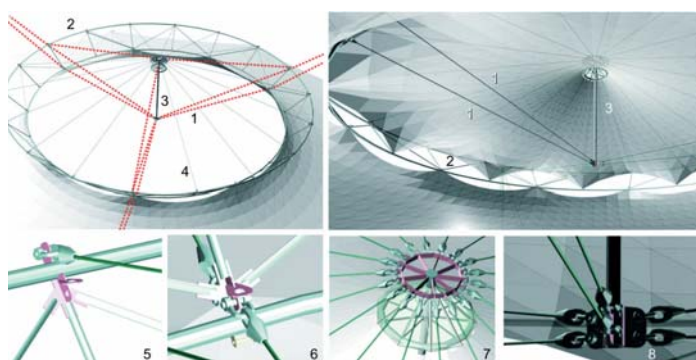


Figure 15. Supporting system details. - Spatial supporting system: 1. cables - 2. truss ring - 3. flying mast - 4. sliding tractors's supporting cables. Connections: 5. 6. truss ring - 7. 8. top and basis of the flying mast

system, consequently they need to be elaborated together for simplicity, quality and efficiency. In this context, the development of the global and the three-dimensional view of the whole system are essential, as well as the knowledge on the design and building processes, as all the decisions affect the system's form, behaviour and building process.

This particular process of work also permitted verifying that each stage of the designing process generates different types of additive information and integrates Architecture and Engineering to the constructive process. The physical models permitted the qualitative exploration, investigation and analysis of the behaviour (flexible and non-linear) of the system, the boundary conditions, the form and geometry of the components in a tensile equilibrium state, which would not be possible to be experienced in a two-dimensional field. They also made possible the understanding of the manufacturing of the components and their assembling process, just as a global view of the system, bringing the study closer to reality. The computational modelling of the surfaces by the Force Density Method allowed the comparison between the physical model and the preliminary analysis. It also permitted the representation of the proposed shape in the first stages of the designing through the control of the geometry and pre-stress, the so-called Form Finding Procedure. In other words, the computational modelling considered only the parameters that control the equilibrium shape of the surface and left out the material stiffness. The preliminary analysis carried out through the Finite Element Method allowed checking the viability of the equilibrium configuration of the whole structure considering its self weight as well as experiencing the complexity and efficiency of numerical analysis. Besides, the brief research on the structural components confirms the importance of the study of the form of each element associated to its behaviour, seeking the simplicity of the system and of the building process. It points out new possibilities of study like patterning of components and connections, focusing on interchangeable connections to simplify and ease the adjustment among components, reducing the time of assembly and the cost. The initial designing procedure also stimulates the spontaneous development of the structural complex and the elaboration of viable configurations to be studied. The research added accuracy and efficiency. Therefore, it is interesting to emphasize that all actions taken by architects and engineers converged to the improvement, refinement and synthesis of the initial proposal. This dialogue, besides adding quality, amplifies the chances of a complete understanding of the structural problem and reveals expressive structural solutions.

Acknowledgments

To Vinicius Maia Barreto de Oliveira, for the cession of DENSALFA program developed during his PhD at COPPE/ UFRJ, 2003, and to Elivaldo Silva (Doctorate Student at State University of São Paulo/ USP) for the computational modelling and the helpful suggestions.

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Extension to a catering pavilion on the Arena Boulevard Amsterdam, The Netherlands

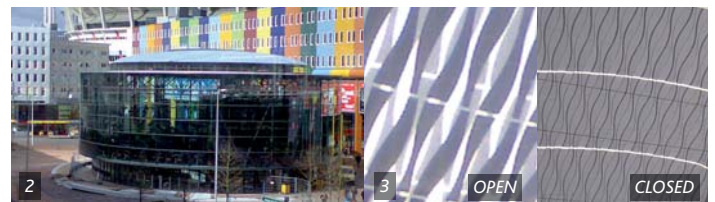
The pavilion was designed by cepezed in the 1990s. Due to the scale enlargement of the entire area during the last decade, the Municipality of Amsterdam requested the owner and operator to invest in high-quality expansion. The original building consists of an elongated, two-storey box measuring 20x10m. In the initial designs, the extension involved a skin of ETFE cushions that constituted a roofed-over winter garden, stretching over the pavilion as a kind of rotation figure. As a result of various regulations and a refinement of the programme by the client, the concept eventually evolved into a transparent glass oval, more than 12m high and measuring 43 by 30m in length and width, accommodating wholly climatized bar and restaurant functions. On the ground floor, the main volume has a 2m constriction, while the first floor has a gallery more than 4m wide. The façade and the roof are particularly striking. The façade consists of cold-bent insulation glass, which was bent and placed by means of suckers on the site itself. On the ground floor, the façade can be opened over more than three quarters of its length by means of a faceted folding wall in which every separate part has a different radius (Fig 1-2). The façade accommodates three stability crosses, of which two are situated at the heads of the oval. These locations are also used for the organization of the stairs. The roof is more than 2.5m high and comprises eight large pneumatic cushions mounted on a refined detailed steel construction of faceted delta-beams. Each of the cushions consists of four layers of ETFE with three air chambers in each cushion. The ETFE bears a pattern through which the sun and light transmittance can be regulated by a change in pressure in the innermost chamber (Fig 3). The air supply for the cushions is integrated in the construction. A cooling "patio" has been integrated in the roof for the building-related installations that must have contact with the outside air. The paving of the boulevard continues on into the pavilion. Embedded in large plant pots that were cast in the floor at the time of construction, the greenery appears natural and self-evident.

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Figure 1. Internal view.
Figure 2. External view.
Figure 3. Pattern regulating light transmittance.



Name of the project:	JinSo Pavillion
Location address:	Arena Boulevard, Amsterdam, The Netherlands
Client (investor):	Sojin Holding BV
Function of building:	Restaurant
Type of application of the membrane:	Roof
Year of construction:	2008/ 2009
Architects:	Cepezed, Delft, The Netherlands
Consulting engineer for the membrane:	Tentech BV, Utrecht
Engineering of the controlling mechanism:	Buitink Technology
Contractor for the membrane (Tensile membrane contractor):	Buitink Technology,
Supplier of the membrane material:	Nowofol, Germany
Manufacture and installation:	Buitink Technology
Material:	ETFE Film
Covered surface (roofed area):	600m ²

MASTER PROGRAM MEMBRANE LIGHTWEIGHT STRUCTURES VIENNA UNIVERSITY OF TECHNOLOGY

In November 2010 the first University Master Program in "Membrane Lightweight Structures" will start at the Vienna University of Technology. The world's leading experts will share the latest technologies and tools in textile architecture. The 4 semester part-time Program contains modules from "Fundamentals in membrane architecture and engineering" up to state of the art "Detailing / Workshop drawings" and "Software tools". The major target group is the individuals working in architects and engineers offices in the private or the public sector, who aim



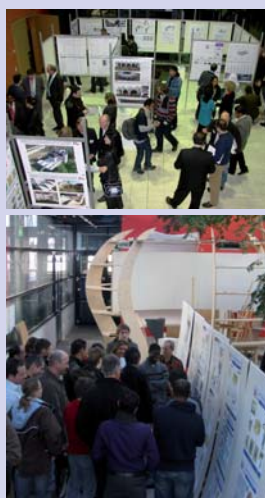
to enhance their professional career and prepare themselves for an exciting, interdisciplinary, and innovative professional future. Graduate students in related disciplines are also of great value to this program. Visionary concepts and top class lectures are designed to accentuate the entire creative process from the first sketch up to the realization.

Application latest: June 12th 2010
For further information look at

✍ Robert Wehdorn-Roithmayr
✉ mail@formfinder.at
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🌐 <http://mls.tuwien.ac.at>
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MASTER COURSE MEMBRANE STRUCTURES ANHALT UNIVERSITY OF APPLIED SCIENCES

This March, it was the 5th time that the Institute for Membrane and Shell Technologies started with its Master Course in Membrane Structures at the Anhalt University of Applied Sciences. The course is accredited as an international master course by the accreditation board AQAS. Over the past 5 years there were 111 students from 37 countries. About one third of the students are architects, one third of the students are civil engineers while the others have another background like tensile surface structures fabricator or university professor. 27 students had already successfully finished the course, with 14 extra graduating this year. The Grand Opening event with the handover of the Master Degree Certificates to the alumni and the exhibition of master-theses took place on Sunday 7th March. For further information look at www.membranestructures.de



LITERATURE



Spanish edition European Design Guide for Tensile Surface Structures ARQUITECTURA TEXTIL Guía Europea de Diseño de las Estructuras Superficiales Tensadas

Author: Brian Forster, Marijke Mollaert

In 2004 TENSINET (initially the *European Network of Tensile Structures*, later re-named the *Tensinet Association*) completed a project in which its members had engaged for over two years: the formulation of the first design guide for this type of structures, published that same year. The guide immediately became an international reference for the design and engineering of tensioned membrane structures, particularly any involving woven fabric. It contains a full description of the options available in this type of structures, as well as the aspects relevant to both architectural design and structural and service engineering. It is, in short, a complete guide for designers involved in this type of construction. Shortly after the international association was founded, the establishment of regional chapters was seen to be a desirable corollary. That idea materialized with the creation of the **Iberian Section (Tensinet Ibérica)**, which groups the Tensinet members headquartered in Spain or Portugal, and possibly in the future, in Latin America. The Iberian Section was instituted at a meeting of its members held at Guimarães, Portugal, in October 2006. One of the Section's first tasks was to translate the Tensinet design guide, both as an aid for its present and future members and as a contribution to the construction industry's expertise. The aim was to furnish more complete information on tensioned membrane technology and tensile architecture in general, making such formally and operationally attractive solutions more readily accessible to designers. The contributions of many Tensinet Ibérica members were instrumental to its publication.

■ EDITORIAL MUNILLA-LERIA ■ TRANSLATION CARMEN O. MENÉNDEZ ■ COORDINATION SPANISH EDITION JUAN MONJO CARRIO ■ ISBN-978-84-89150-82-9 ■ PAGES 326, SOFT COVER ■ PUBLISHED 2009 ■



Fig1. Las Rozas Business Center,
BAT - Buro Arquitectura Textil

PROFIL TENSION SYSTEM INNOVATION: THE TS ARCHI PROFILE

PROFIL TS has recently registered a new patent: the TS ARCHI profile. PROFIL TS is specialised in tensioning system solutions for all kind of PVC and textile materials. Used with the TS range, TS ARCHI system perfectly completes PROFIL TS existing tensioning solution and offers a tension recovery of the fabric and prevents from slackening.

In 2010, a new TS Range aluminium profiles was introduced onto the façade textile market in combination with PROFIL TS traditional system + TS ARCHI system.

Additionally to its effects on materials expansion, the new European patent allows to offer wider and bigger textile tiles and is able to face climatic changes, giving guarantee on the whole mesh life.

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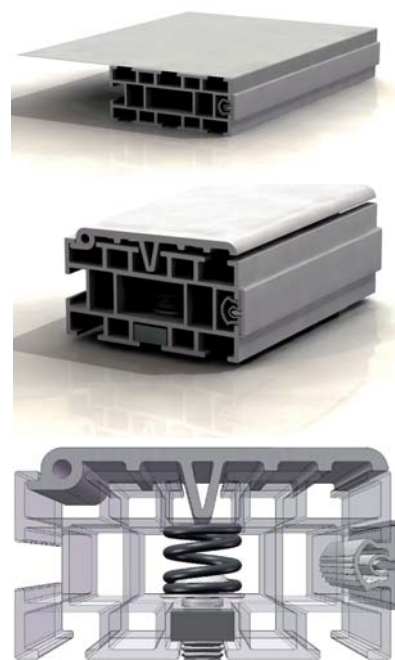


Fig 2. Traditionnal Tension with TS RANGE profiles + Gripp + TS KEY (top) and Mesh Expansion Recovery with TS ARCHI TENSION OPTIMIZATION With TS RANGE PROFILES 2010 + TS ARCHI system (middle & under)

Introduction

The **focus** of the TensiNet Symposium 2010 will be the adaptability of structural systems with tensioned surfaces for various service conditions and their ability to impart a new appearance to existing buildings or to enclose them in a common volume. Within the main **topics** key themes will be modular assembled and disassembled tension structures with textile membranes (or foils) for emergency shelter, protection of architectural monuments, as well as those reconciling different functions by incorporating sound and thermal insulation systems, photovoltaic components etc.

The **aim** of the symposium will be to integrate the efforts of architects, designers, researchers, manufacturers and builders for the further development of tensile surface architectural-structural systems meeting new challenges and striving for the preservation of ecological balance.

Textile design systems with membranes and foils will promote the search for appropriate architectural forms, new organisation of interior spaces, smooth connections to existing volumes and modernisation of historic complexes.

THURSDAY 16TH AND FRIDAY 17TH SEPTEMBER 2010

A two-day symposium organised around the topics:

- SUSTAINABLE DESIGN
- ANALYSIS AND NEW MATERIAL TECHNOLOGIES
- ETFE APPLICATIONS
- TECHNOLOGY, FABRICATION, ERECTION AND MAINTENANCE
- REALIZATION, RECENT PROJECTS

This event will be attended by leading figures from organisations working worldwide in the field of architecture and engineering of textile structures, including those innovating in the field of membrane architecture design and textile suppliers and manufacturers engaged in the development of the newest textile and foil materials applicable to the construction sector.

Representatives from Architecture and Engineering offices such as form TL and Buro Happold fabric suppliers and manufacturers such as Ceno-Tec, Canobbio and Dyneon, as well as Universities and Research Centres working in the field have already confirmed their presence at the TensiNet Symposium 2010.

The **Scientific Committee** has invited prominent experts in the membrane architecture and engineering world to introduce each topic with a stimulating keynote lecture to be followed by presentation of the related papers.

SATURDAY 18 SEPTEMBER 2010

A one-day trip will be organised to the city of Plovdiv, including a visit to the Bachkovo monastery.

WEDNESDAY 15TH SEPTEMBER

The TensiNet Association organises several meetings such as the Partner Meeting, the Annual General Meeting and different Working Group Meetings.

CALL POSTER EXHIBITION

An accompanying event will be an exhibition of posters, in the foyer, showing work by PhD and graduated students.

Deadline poster submission is Monday 31st May 2010.

Registration fee

Member TensiNet 200€ - Non member 250€ - PhD students 30€

The book of proceedings, containing all presented papers, is included in the TensiNet member and non-member registration fees. PhD students registering at the reduced fee will have to pay 25 € extra to receive a copy of the proceedings.

Further information is available at <http://tensinet2010.uacg.bg/>

CALL FOR ABSTRACTS ANNOUNCEMENT V CONFERENCE ON TEXTILE COMPOSITES AND INFLATABLE STRUCTURES STRUCTURAL MEMBRANES 2011 BARCELONA, SPAIN, 5 – 7TH OCTOBER 2011

The previous conferences of these series were held in Barcelona (Spain) in 2003, in Stuttgart (Germany) in 2005, in Barcelona in 2007 and in Stuttgart in 2009.

The **objectives** of Structural Membranes 2011 are to collect and disseminate state-of-the-art research and technology for design, analysis, construction and maintenance of textile and inflatable structures. The conference will address both the theoretical bases for structural analysis and the numerical algorithms necessary for efficient and robust computer implementation. A significant part of the conference will be devoted to discuss advances in new textile composites for applications in membrane and inflatable structures, as well as in innovative design, construction and maintenance procedures.

In summary, Structural Membranes 2011 **aims** to be a forum for discussing recent progress and identifying future research directions in the field of textile composites and inflatable structures.

Deadline for presenting a one page abstract:

13th February 2011

Further information is available at <http://congress.cimne.com/membranes2011/frontal/Dates.asp>



CALL MILANO CAMPING DESIGN COMPETITION

The **Milano Camping Design** Competition is organised by the Milan city council, Department of production, labour policy and employment, by the INDACO department of Politecnico di

Milano and by Triennale di Milano, with the patronage of the ADI, the Italian industrial design association, and the European Association TensiNet, in collaboration with Material Connexion Milano and with support from Ferrino.

The Competition, focused on the theme of **innovative low-cost accommodation**, is aimed at young designers, project architects and visitors who are to come to Milan in future years for the occasion of the many events organised throughout the year, culminating in Expo 2015, an event of international magnitude.

The Competition calls for the design of a new concept of city campsite, understood to be the place where various accommodation facilities for visitors are grouped together and equipped with all amenities, which can in part be adapted by the users themselves. These new forms of housing add to the value of flexibility of use and promote temporary forms of housing which can easily be prepared on the occasion of a specific event and dismantled and repositioned on the basis of needs that change in time. These new models of housing cannot however escape the idea of environmental sustainability, forcing the project architects to choose materials and technologies with low environmental impact and high efficiency.

The Competition is structured in different phases whose overall objective is to promote a new concept in low-cost city accommodation and produce the actual campsite in stages, by selecting the best ideas and the best construction solutions.

First phase - concept design: deadline 17th May 2010

Second phase - feasible design: deadline 21st June 2010

Further information is available at www.designcamping.it/