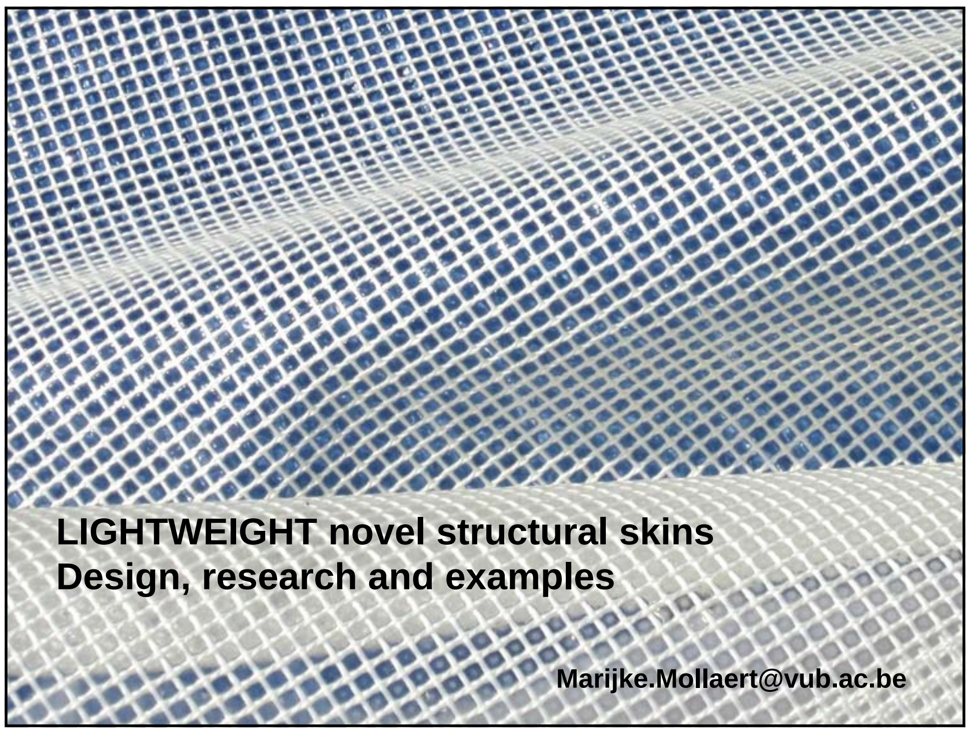


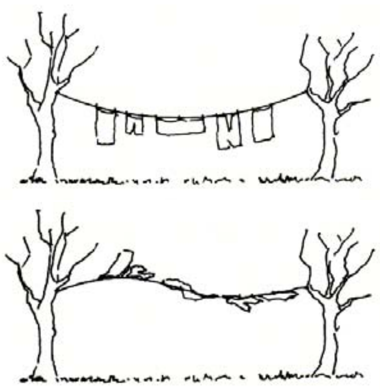
LIGHTWEIGHT novel structural skins
Design, research and examples

Marijke.Mollaert@vub.ac.be

Tensile surface structures, materials
Eurocode
Research: material characterisation, wind load estimation, partial factor calibration, kine(ma)tic structures, bending active systems
Examples

Tensile Surface Structures

Form-active structures =
Form
depends on the external load
Large deflections can occur



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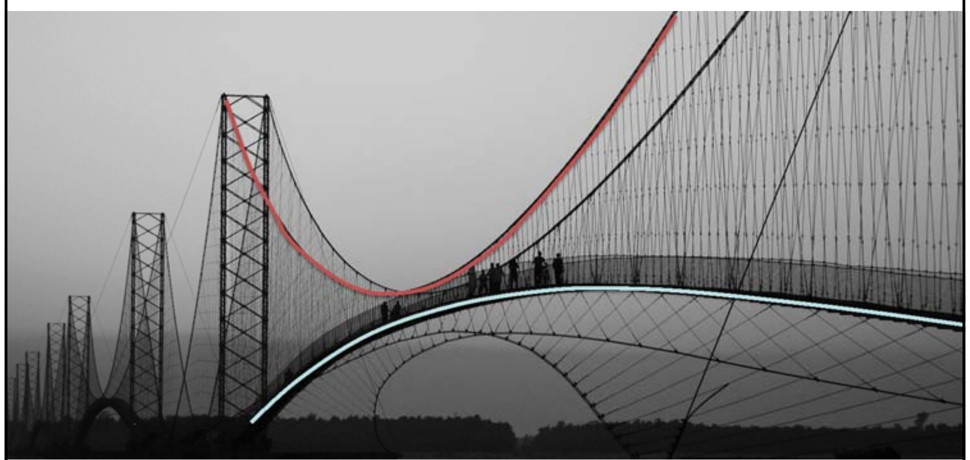
Tensile Surface Structures

Hanging cables + arching cables = stable construction



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Tensile Surface Structures

5

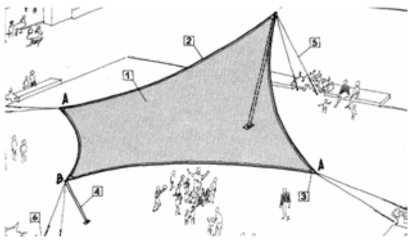
Tensile Surface Structures

6

Tensile Surface Structures

Typical anticlastic shapes

- Saddle



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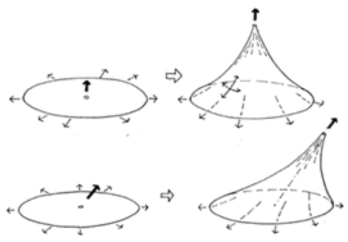
Tensile Surface Structures

Typical anticlastic shapes

- Saddle
- Conical with high or low points in the surface



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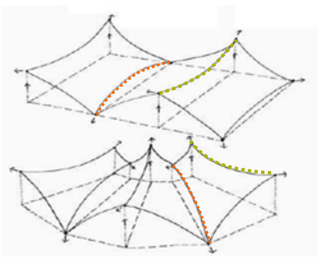
Tensile Surface Structures

Typical anticlastic shapes
- Saddle
- Conical with high or low points in the surface
- Wave form



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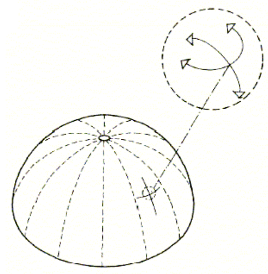
Tensile Surface Structures

Typical anticlastic shapes
- Saddle
- Conical with high or low points in the surface
- Wave form
- Inflated



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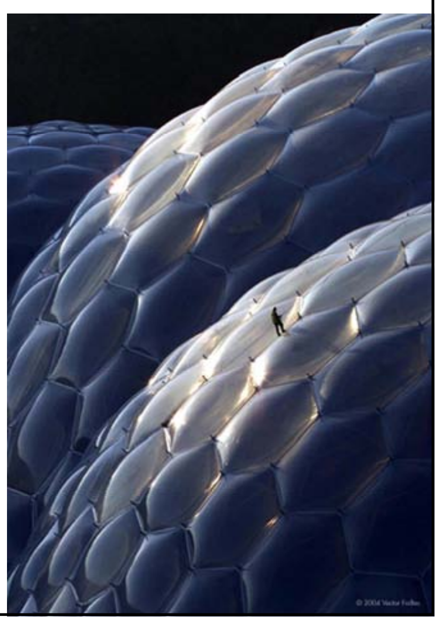
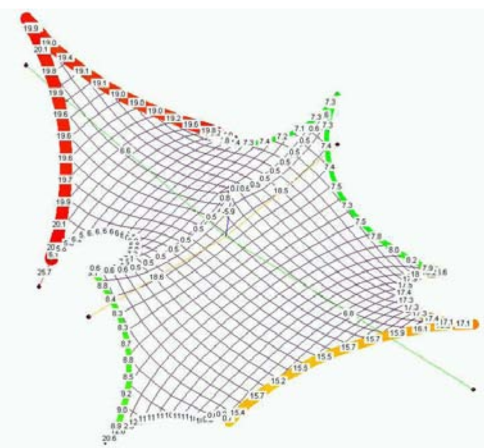


Tensile Surface Structures



Formfinding

Geometry
of the equilibrium form
+
Internal forces
in this equilibrium form

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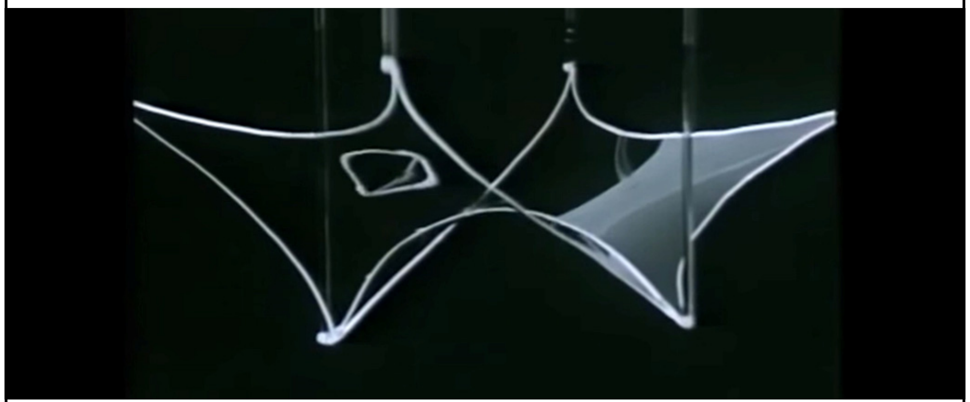
Formfinding: physical models



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Formfinding: physical models

20

Formfinding: physical models

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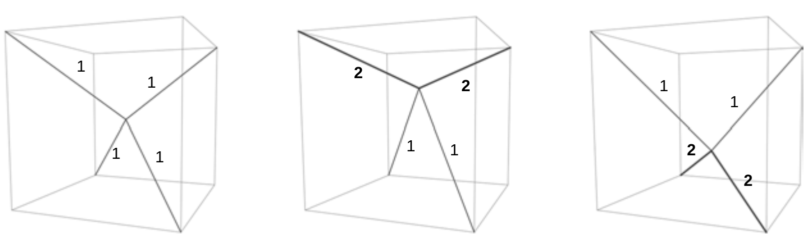
Formfinding: physical models

22

Formfinding: numerical



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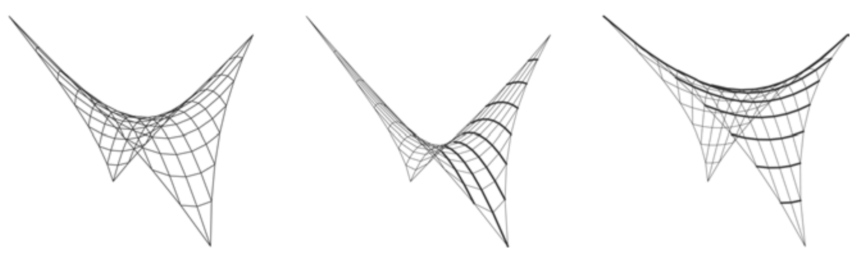
Formfinding: numerical



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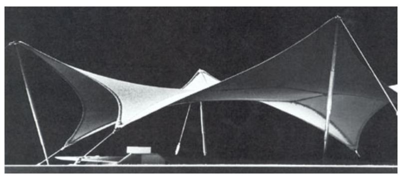
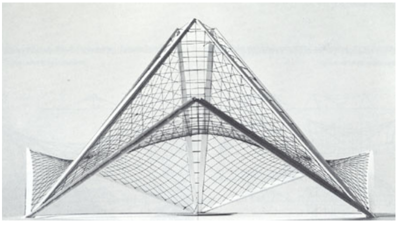
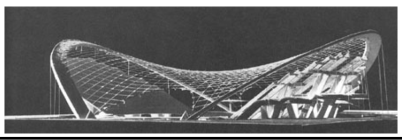
Tensile Surface Structures

Primary structure

- Transfers loads and pretension to the foundations
- Can consist of
  - Struts + tie down cables
  - Beams
  - Arches…

Tensile Surface Structures

Consist of

- supporting structure
- curved tensioned surface
- connections
- anchorage

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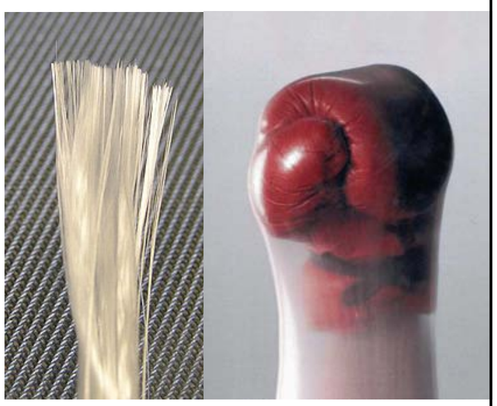
Structural membranes

Structural membranes consists of:

- Fibres:
  high E-modulus
- Coating
  low E-modulus



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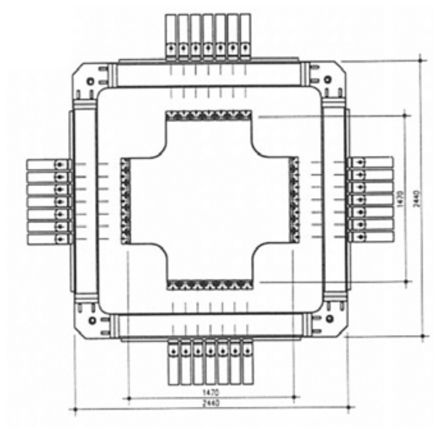
Structural membranes

Tension in 2 directions
The elongation depends on the ratio
of the applied forces F_2/F_1



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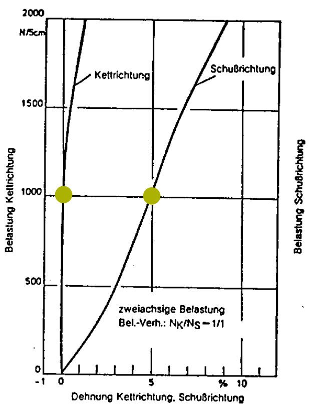
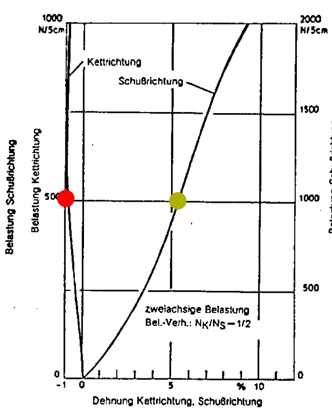
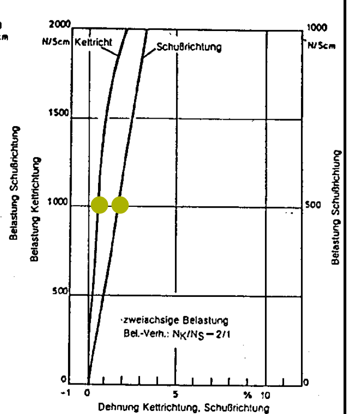
Structural membranes







Warp/weft 1/1 1/2 2/1

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Structural membranes

External loading
Snow

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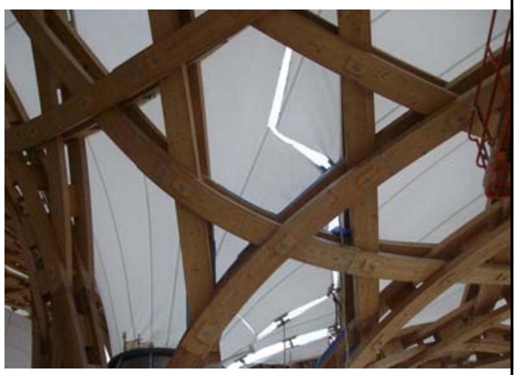
Structural membranes

Two tears in two weeks



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Structural membranes

Wind pressure
+ pressure of rain water
accumulated in pockets

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Structural membranes

Cables were not able to
withstand the wind pressure
+ pressure of rain water

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Tensile surface structures, materials
Eurocode
Research: material characterisation, wind load estimation, partial factor calibration, kine(ma)tic structures, bending active systems
Examples

EUROCODE

- 1989: agreement for a mandate for 20 years
- Responsible for the development: CEN TC 250
- First Eurocodes established
- 2010: withdrawal of contradictory national standards
- 2012: New mandate:
  - Maintenance
  - Harmonisation
  - Develop new parts, like for membrane structures

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EUROCODE

EN 1990 – 1.5 Terms and definitions (1)

1.5.2.17
reliability
ability of a structure or a structural member to fulfil the specified requirements, including the design working life, for which it has been designed. Reliability is usually expressed in probabilistic terms

NOTE Reliability covers safety, serviceability and durability of a structure.

1.5.2.18
reliability differentiation
measures intended for the socio-economic optimisation of the resources to be used to build construction works, taking into account all the expected consequences of failures and the cost of the construction works

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EN 1990 – 1.5 Terms and definitions (2)

1.5.2.8
design working life
assumed period for which a structure or part of it is to be used for its intended purpose with anticipated maintenance but without major repair being necessary

1.5.2.12
limit states
states beyond which the structure no longer fulfils the relevant design criteria

1.5.2.13
ultimate limit states
states associated with collapse or with other similar forms of structural failure

NOTE They generally correspond to the maximum load-carrying resistance of a structure or structural member.

1.5.2.14
serviceability limit states
states that correspond to conditions beyond which specified service requirements for a structure or structural member are no longer met

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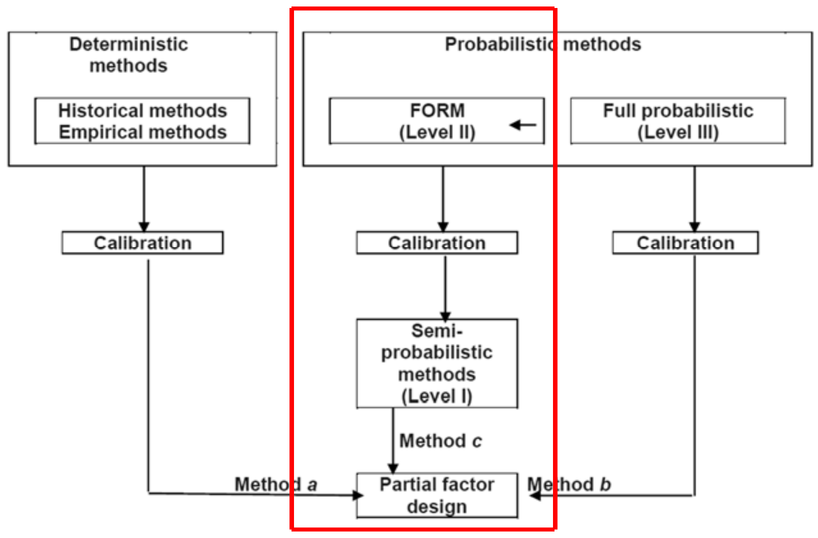
EUROCODE

Overview of reliability methods (EN 1990 – Annex C)



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The probabilistic approach of structural safety:

- Identify limit states
- Evaluate the risks
- Design in such a way that the probability of the mentioned risks is low

What is low?

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Semi-probabilistic verification:

- Adopt representative values for actions, resistances…
- Apply partial factors γ to actions, resistances…
- Introduce safety margins in the models of actions, action effects…

EUROCODE

Actions F_k

Design value

$F_d = \gamma_f . F_k$

Design value of geometric data a_d

Effects of actions

$E(F_d, a_d)$

Design value of effects of actions

$E_d = \gamma_{Ed} . E(F_d, a_d)$

$E_d = \gamma_F . E_k$

Material property X_k

Design value

$X_d = (\eta / \gamma_m) . X_k$

Design value of geometric data a_d

Resistances

$R(X_d, a_d)$

Design value of resistances

$R_d = (1/\gamma_{Rd}) . R(X_d, a_d)$

$R_d = (1/\gamma_M) . R_k$

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Verification ULS

$E_d < R_d$

R_d design value for the correspondent resistance

Verification SLS

$E_d < C_d$

C_d limiting design value for the serviceability criterion

- Specific combinations of actions
- Recommended values for the partial factors γ

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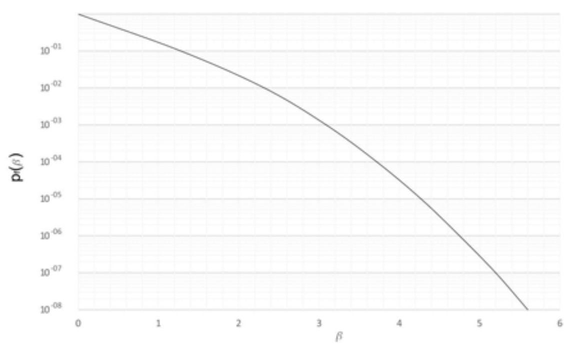
EUROCODE

Level II procedure

The reliability is defined by the reliability index β

P_f = probability of failure

$P_f = \Phi(-\beta)$



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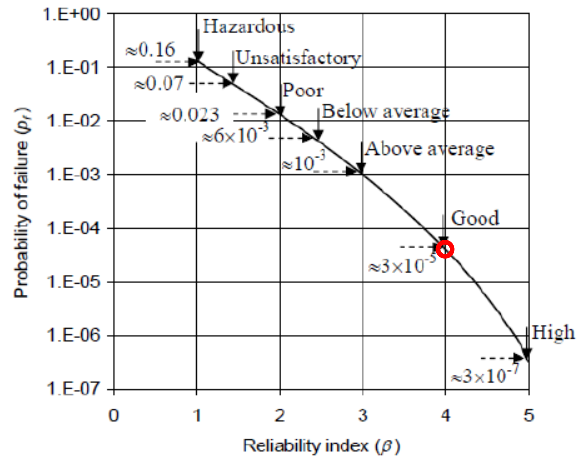
EUROCODE



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Definition of consequences classes and associated reliability classes

Consequences Class	Description	Examples of buildings and civil engineering works	Reliability class	Recommended minimum value for the reliability index: 1 year reference period	50 years reference period
CC3	High consequence for loss of human life, or economic, social or environmental consequences very great	Grandstands, public buildings where consequences of failure are high (e.g. a concert hall)	RC3	5,2	4,3 (= 3,8 + 0,5)
CC2	**Medium consequence for loss of human life, economic, social or environmental consequences considerable**	**Residential and office buildings, public buildings where consequences of failure are medium (e.g. an office building)**	RC2	4,7	3,8
CC1	Low consequence for loss of human life, and economic, social or environmental consequences small or negligible	Agricultural buildings where people do not normally enter (e.g. storage buildings), greenhouses	RC1	4,2	3,3 (= 3,8 – 0,5)

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The target value $\beta_{50} = 3.8$ corresponds to the 'acceptable' probability of failure $P_{f\,50} = 7.2\ 10^{-5}$

The β-value is a formal number to develop consistent design rules

It does not give a real indication of the structural failure frequency

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EUROCODE

Basis for Partial Factor Design and Reliability Analysis

Target reliability index β for Class RC2 structural members [1)]

Limit state	Target reliability index: 1 year	50 years
Ultimate	4,7	3,8
Fatigue		1,5 to 3,8 [2)]
Serviceability (irreversible)	2,9	1,5

[1)] See Annex B

[2)] Depends on degree of inspectability, reparability and damage tolerance.

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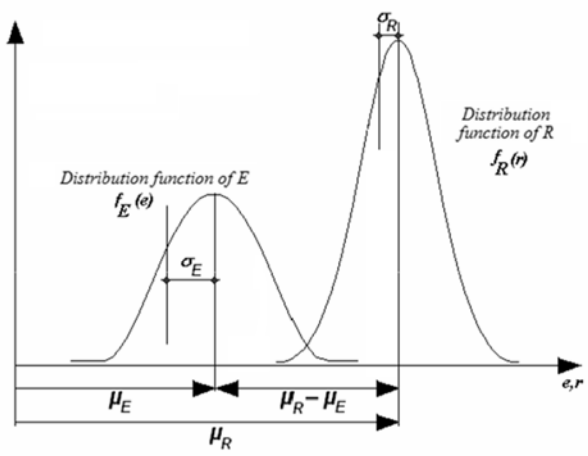

Central safety factor $\bar{\gamma} = \dfrac{\mu_R}{\mu_E}$

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E and R are independently Normally distributed with parameters (μ_E, σ_E) and (μ_R, σ_R)

For a reliable design Z = (R_d - E_d) > 0

Z also follows a Normal distribution

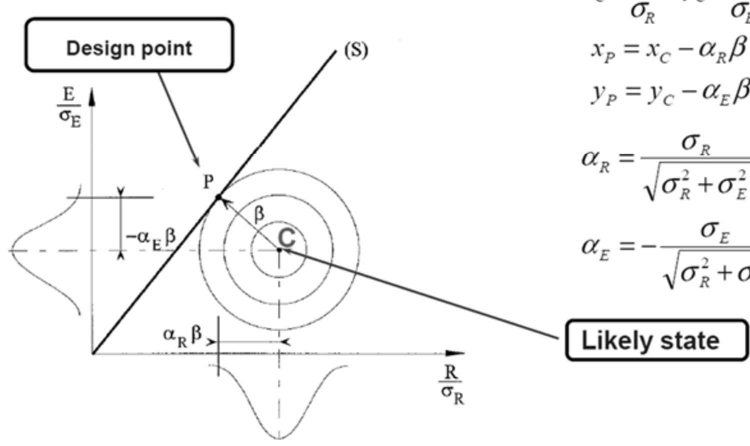
The reliability index $\beta = \mu_Z / \sigma_Z$

The target reliability index is β_0

For a reliable design $\beta > \beta_0$

EUROCODE

Geometrical interpretation
Standardized coordinates



$$x = \frac{r}{\sigma_R} \quad y = \frac{e}{\sigma_E}$$

$$x_C = \frac{\mu_R}{\sigma_R} \quad y_C = \frac{\mu_E}{\sigma_E}$$

$$x_P = x_C - \alpha_R \beta$$

$$y_P = y_C - \alpha_E \beta$$

$$\alpha_R = \frac{\sigma_R}{\sqrt{\sigma_R^2 + \sigma_E^2}}$$

$$\alpha_E = -\frac{\sigma_E}{\sqrt{\sigma_R^2 + \sigma_E^2}}$$

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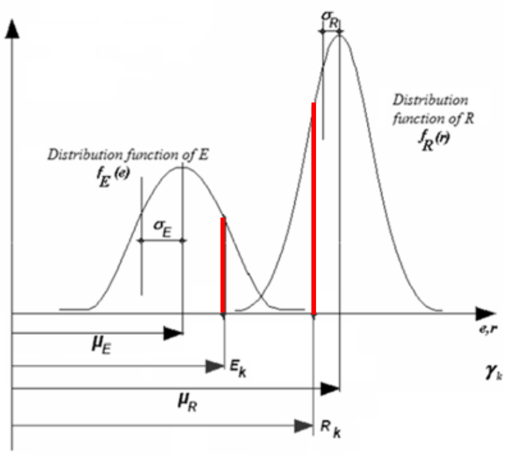

Coefficients of variation

$$V_R = \frac{\sigma_R}{\mu_R} \quad V_E = \frac{\sigma_E}{\mu_E}$$

$$E_k = \mu_E + k_E \sigma_E$$

$$R_k = \mu_R - k_R \sigma_R$$

Characteristic safety factor

$$\gamma_k = \frac{R_k}{E_k} = \frac{\mu_R - k_R \sigma_R}{\mu_E + k_E \sigma_E} = \bar{\gamma} \times \frac{1 - k_R V_R}{1 + k_E V_E}$$

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EUROCODE

The partial safety factors are function of the target reliability index β (design point)

Verification with the partial factors

$\gamma_F \cdot E_k < (1/\gamma_M) \cdot R_k$

Or

$\gamma_F \cdot \gamma_M < \gamma_k$

EUROCODE

Interpretation of partial factors for material strength: interpretation based on reliability methods

$$\gamma_M = \frac{R_k}{R_d} = \frac{\mu \exp(-k V_f)}{\mu \exp(-\alpha_R \beta V_R)}$$

$$k = 1{,}645 \quad \beta = 3{,}8 \quad \alpha_R = 0{,}8$$

V_m model uncertainty
V_G geometrical uncertainty
V_f uncertainty on the property (strength)

$$V_R = \sqrt{V_m^2 + V_G^2 + V_f^2}$$

$$\gamma_M = \frac{R_k}{R_d} = \eta \times \exp(3{,}04 V_R - 1{,}645 V_f)$$

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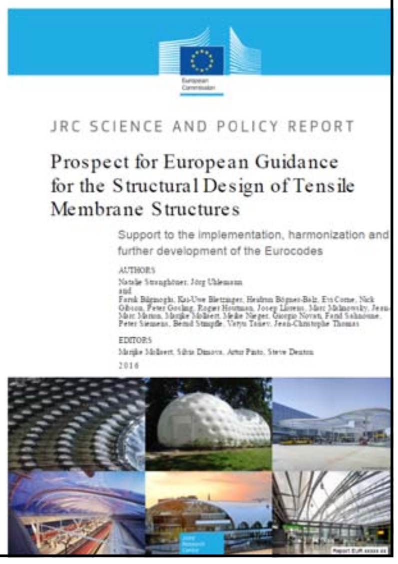
EUROCODE

The combinations of actions should be the same for all materials and types of structures

CEN/TC 250/WG 5 Membrane structures

JRC Science and Policy Report

Prospect for European Guidance for structural design of Tensile membrane structures



Tensile surface structures, materials

Eurocode

Research: material characterisation, wind load estimation, partial factor calibration, kine(ma)tic structures, bending active systems

Examples

Research

Material characterisation

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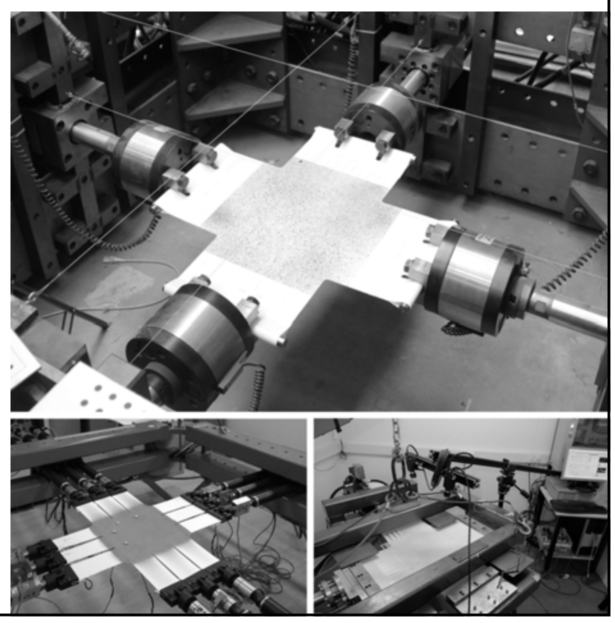
Currently, biaxial tests on fabrics are conducted using various setups and methods

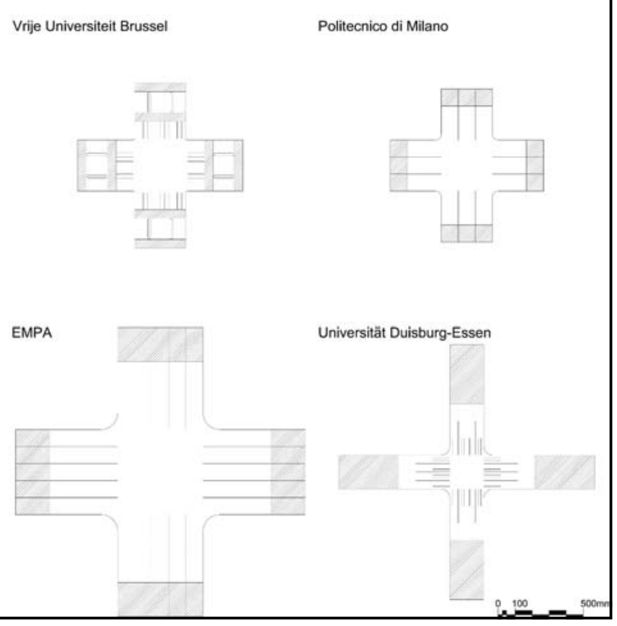
Different test environments



Currently, biaxial tests on fabrics are conducted using various setups and methods

Different test environments

Different sample geometries

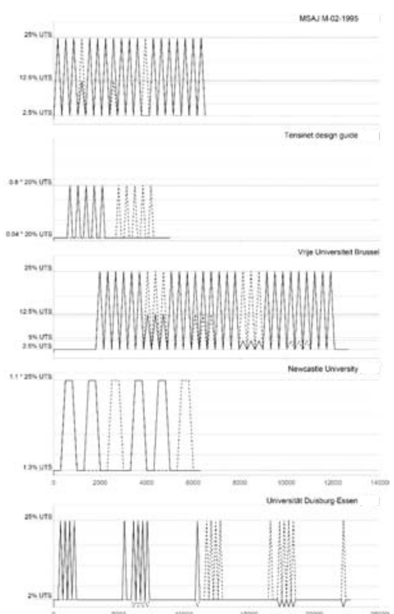


Currently, biaxial tests on fabrics are conducted using various setups and methods

Different test environments

Different sample geometries

Different load profiles



The aim is to assess the variations in derived material parameters and their impact on the design process

Test the same material using various biaxial load profiles

Derive linear elastic orthotropic parameters using various processing methods

Compare the various sets of material parameters

Characterise their variability through statistical analysis

Impose various selected sets of parameters into numerical models

The PVC-coated polyester fabric was tested using five different load profiles

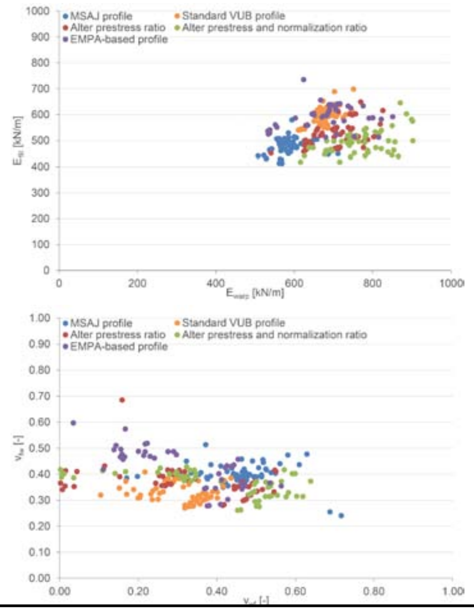
MSAJ-based profile

Standard VUB profile
1/0 and 0/1 ratios replaced by
5/1 and 1/5

Alter the prestress ratio
prestress ratio 1/1 replaced by 2/1

Alter the normalization ratio
Normalization ratio 2/1

EMPA-based profile
No normalization ratio,
more load ratios



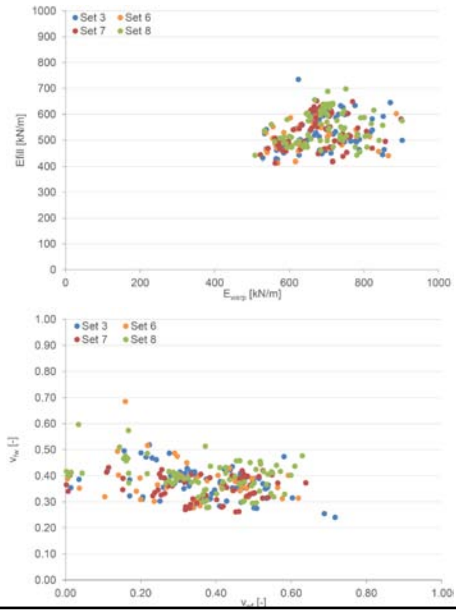
Four different methods of extracting stress-strain data has been used

All intermittent points (set 3)

Linearize the loading cycles (set 6)

Average subsequent load cycles
of the same ratio (set 7)

Average all load cycles
of the same ratio (set 8)



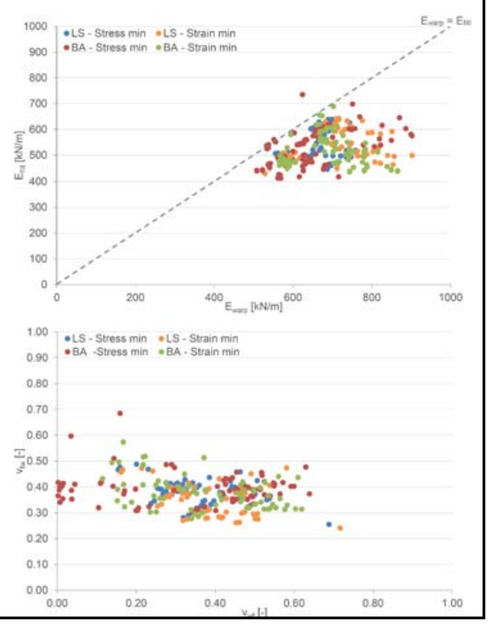
Four different derivation methods have been used, all of them with and without the reciprocal relation

Least-squares stress minimisation

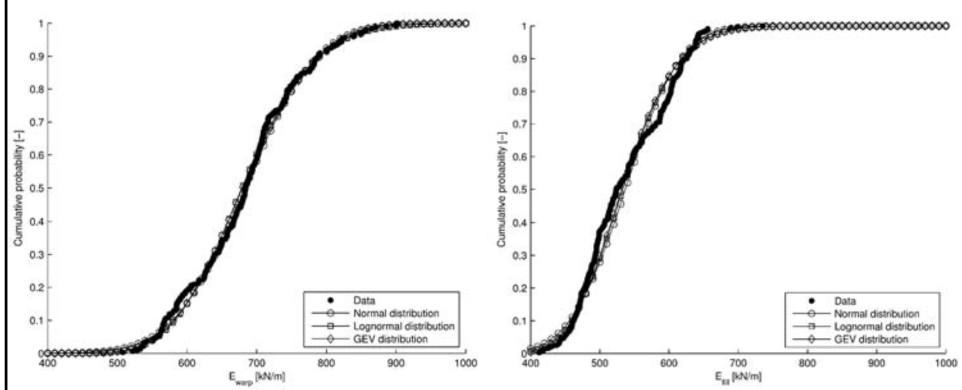
Least-squares strain minimisation

Best-approximation stress minimisation

Best-approximation strain minimisation



The variation in the material parameters has been characterised through testing various distributions



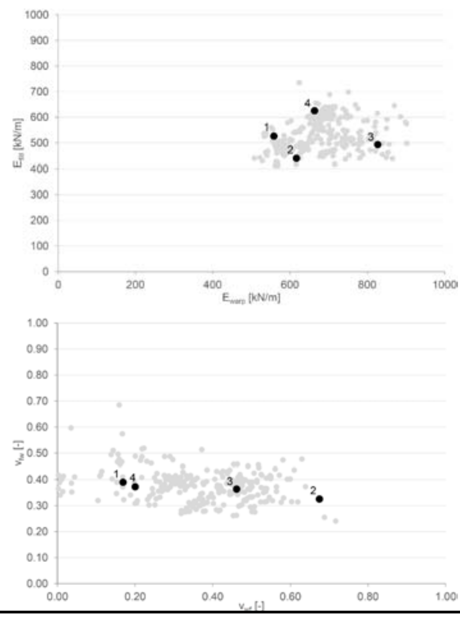
Comparison between Normal, Lognormal and
Generalized Extreme Value distributions

Both probabilities and correlations were used to derive least-favourable sets for each failure mode

Ponding and inversion (set 1 + set 2)
Small Young's moduli and Poisson's ratios
(intended)

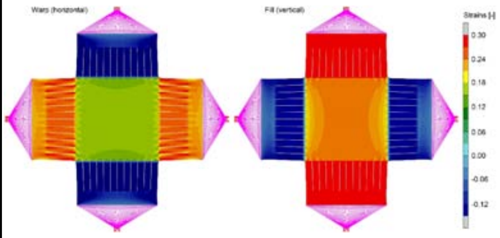
Wrinkling in the fill direction (set 3)
Large E_{warp} and small v_{wf}
(intended)

Wrinkling in the warp direction (set 4)
Large E_{fill} and small v_{fw}
(intended)

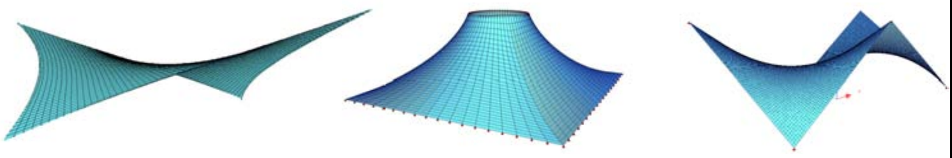


The next step consists of conducting various numerical simulations to assess the impact

Models of the biaxial sample



Models of various representative structures



Research

Wind load estimations

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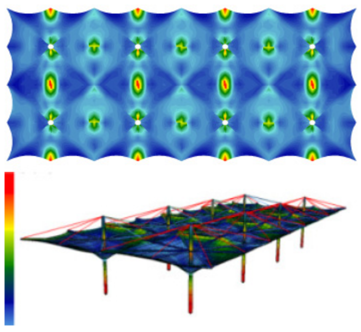
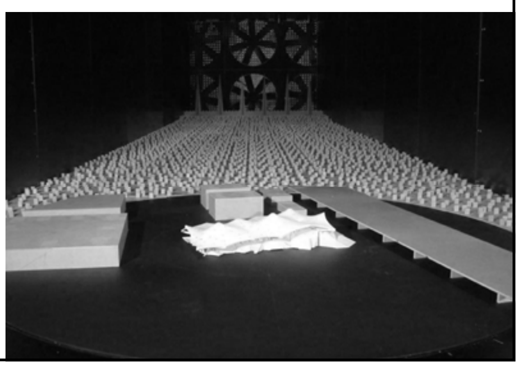
Wind Load Estimations

Approximations, based on codes





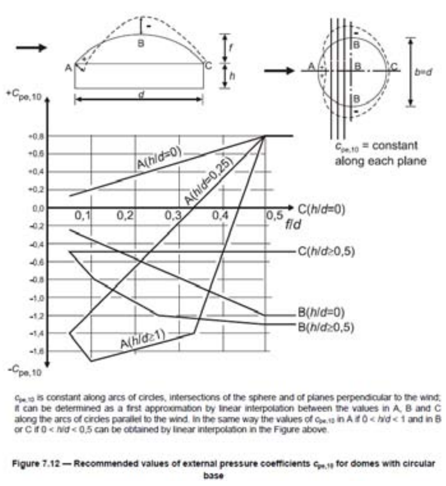
Wind Load Estimations

Accurate wind-pressure data
for membrane structures is needed

Wind Load Estimations

No Cp-distributions available for doubly curved basic shapes

- Conventional Standards
- Wind Tunnel testing
- Computational fluid dynamics



(CEN, 2005)

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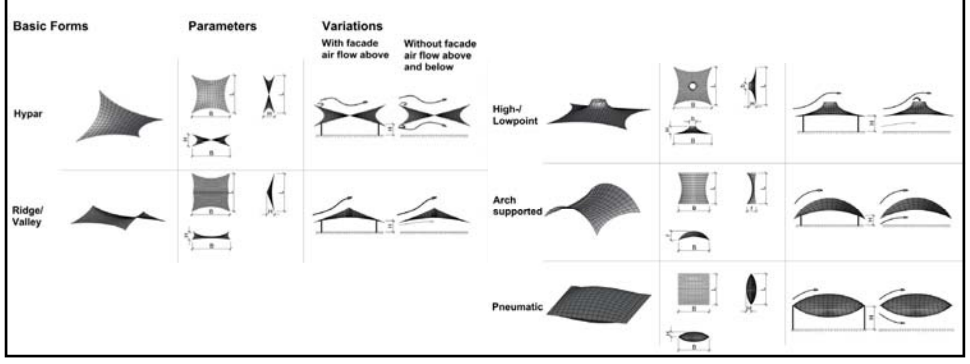
Wind Load Estimations

Even simple doubly curved shapes are not considered in the standards

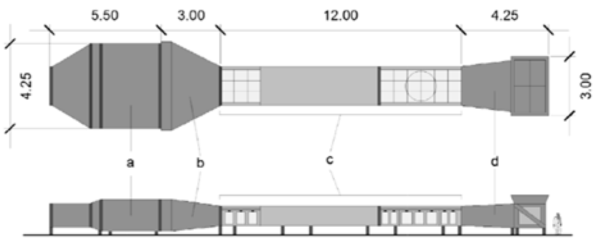


Wind Load Estimations

Round Robin Exercise 3, launched by TU1303

Collate wind data

- Relevant studies for hypar and conical shapes
- Different shape parameters
- Identify most critic wind orientations
- Draft simplified Cp-distributions



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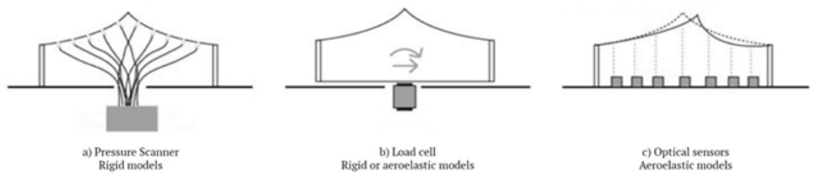
Wind Load Estimations

Extend the Eurocode section

- Standardised Cp-distributions
- Local and overall Cp-values
- For various shapes and shape parameters



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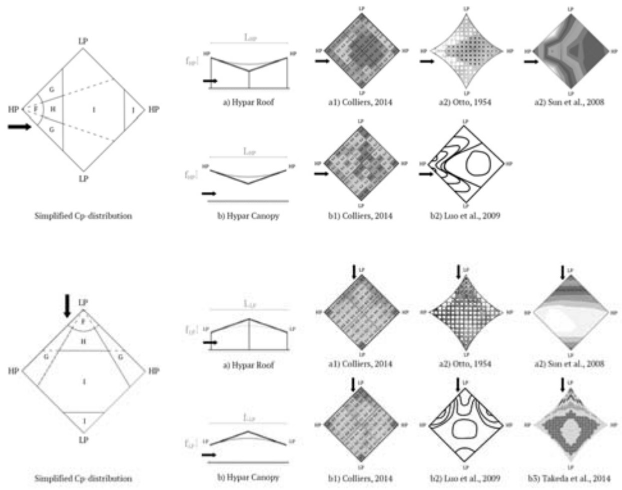
Wind Load Estimations

Hypar

$$SP_{Hypar,HP} = \frac{2\,f_{HP}}{L_{HP}}$$

$$SP_{Hypar,LP} = \frac{2\,f_{LP}}{L_{LP}}$$



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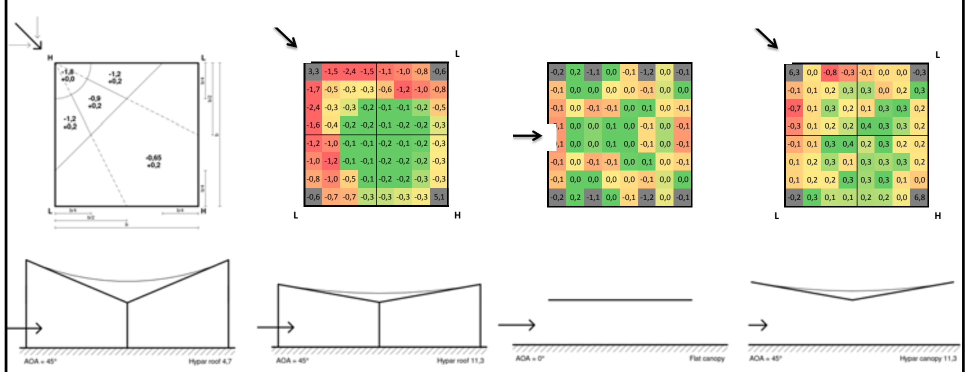
Wind Load Estimations

Wind tunnel test data from Round Robin Exercise 3

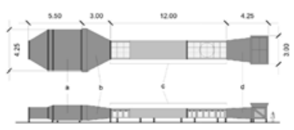


Wind Load Estimations

Wind Tunnel Testing (WTT): uncertainties

Flow → wind profile, turbulence profile…
Model → geometry, material, Reynolds similarity…
Measurement → calibration, precision…

Accuracy relation to full-scale reality?



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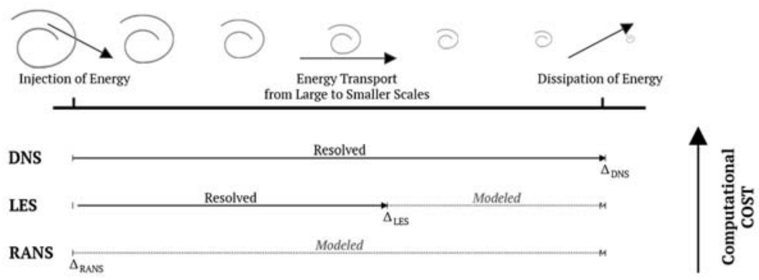
Wind Load Estimations

Most common Computational Fluid Dynamics approaches

- Reynolds-Averaged Navier-Stokes
- Large eddy Simulation
- Direct Numerical Simulation



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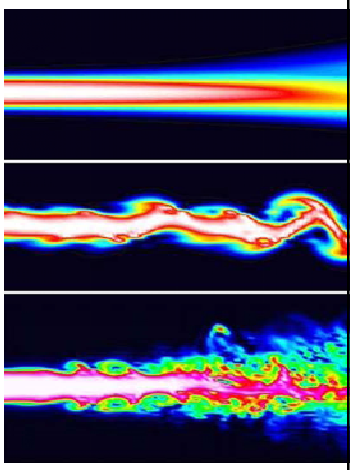
Wind Load Estimations

Reynolds-Averaged Navier-Stokes
- Statistical mean values (time-averaged)
- Good for ABL flows, not for unsteady separation flows

Large eddy Simulation
- Dominant turbulence scales are resolved
- Good for fundamental research in turbulence

Direct Numerical Simulation
- All turbulence scales are solved
- Unfeasible for most applications

RANS and hybrid RANS-LES for engineering applications



Maries et al., 2012

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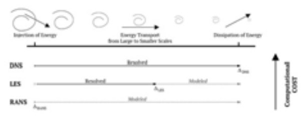
Wind Load Estimations

Computational Fluid Dynamics (CFD): uncertainties

Numerical → discretization, convergence criteria…
Modelling → boundary conditions, turbulence models, meshing…

Accuracy relation to full-scale reality?



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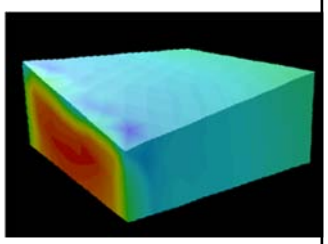
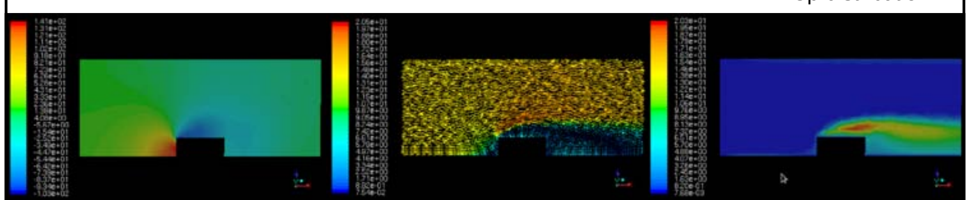
Wind Load Estimations

Computational Fluid Dynamics (CFD)
Post-processing



Cp-distribution



Static Pressure | Velocity Field | Turbulence

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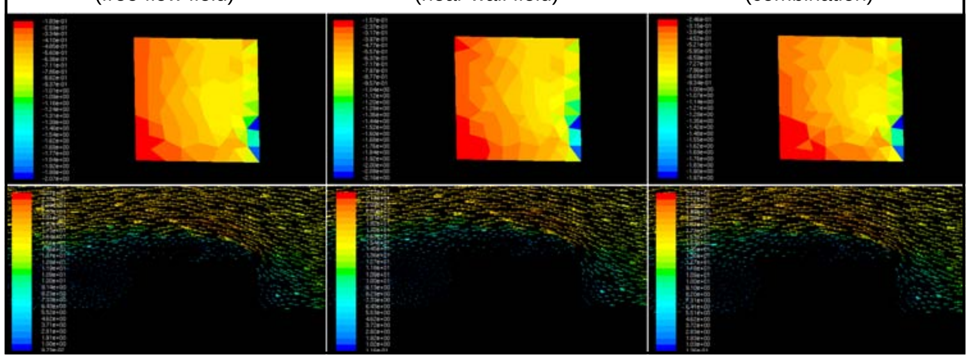
Wind Load Estimations

CFD
Turbulence models

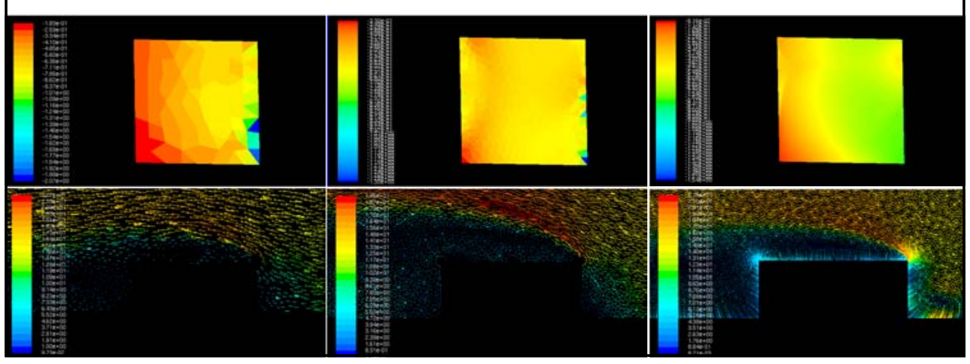
→ k-ε (free flow field) | → k-ϖ (near wall field) | → k-ϖSST (combination)



Wind Load Estimations

CFD
Meshing

→ 5,0 cm | → 2,5 cm | → 2,5cm + refinement + inflation



Research

Partial factor calibration

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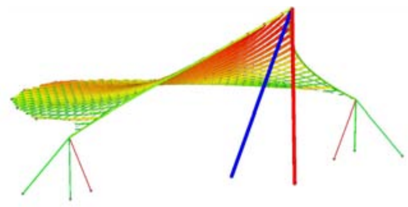
Development of a Eurocode design format for reliable and robust tensile surface structures

Development of a Eurocode design format for reliable and robust tensile surface structures

Quantify the uncertainties for strength, stiffness, pretension…
Determine the relevant parameters



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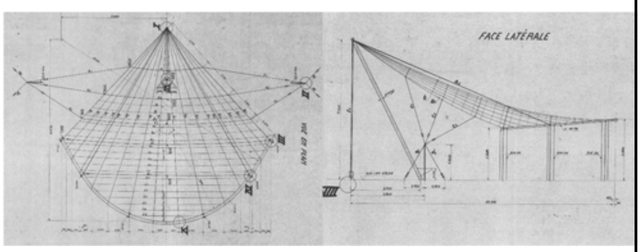
Development of a Eurocode design format for reliable and robust tensile surface structures

Analyse a simplified cable-net and membrane structure
The Band Stand: steel cable-net structure built at Expo '58
Effect of a partial factor for pre-tension 1 vs 1.35



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Development of a Eurocode design format for reliable and robust tensile surface structures

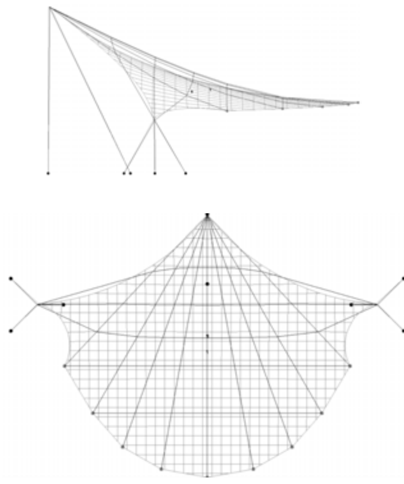
ULS

situation 1: **1** x pre-tension
1.5 x load
stiffness (EA)

situation 2: **1.35** x pre-tension
1.5 x load
stiffness (EA)

SLS

situation 1-2: ponding?
inversion of curvature?



Increase by 35% of the pre-tension results in an increase in weight for the cable-net of 5%

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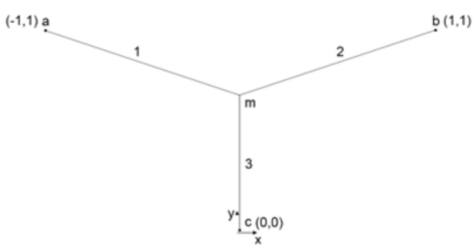
Development of a Eurocode design format for reliable and robust tensile surface structures

Y-structure



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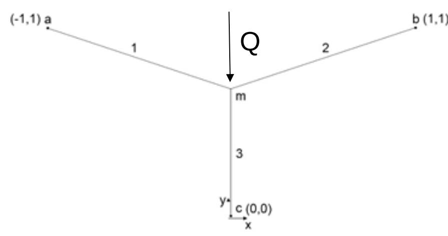
Development of a Eurocode design format for reliable and robust tensile surface structures

Step 1: design

situation 1: **1** x pre-tension
1.5 x load (Q)
$f_d = f_y/1,2$
stiffness (EA)

situation 2: **1.35** x pre-tension
1.5 x load (Q)
$f_d = f_y/1,2$
stiffness (EA)



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Development of a Eurocode design format
for reliable and robust tensile surface structures

Step 2: Latin Hypercube Sampling
6 variables: nominal values and standard deviations:
l_{01}
l_{02}
l_{03}
Q
f_y
EA
Consider {(4 x # of variables) + 1} sets = 25 sets

91

Development of a Eurocode design format
for reliable and robust tensile surface structures

Step 2: Latin Hypercube Sampling
6 variables: nominal values and standard deviations:
$\mathbf{l_{01}}$
$\mathbf{l_{02}}$
$\mathbf{l_{03}}$
Q
f_y
EA

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Development of a Eurocode design format
for reliable and robust tensile surface structures

Step 2: Latin Hypercube Sampling
6 variables: nominal values and standard deviations:
l_{01}
l_{02}
l_{03}
Q
$\mathbf{f_y}$
EA

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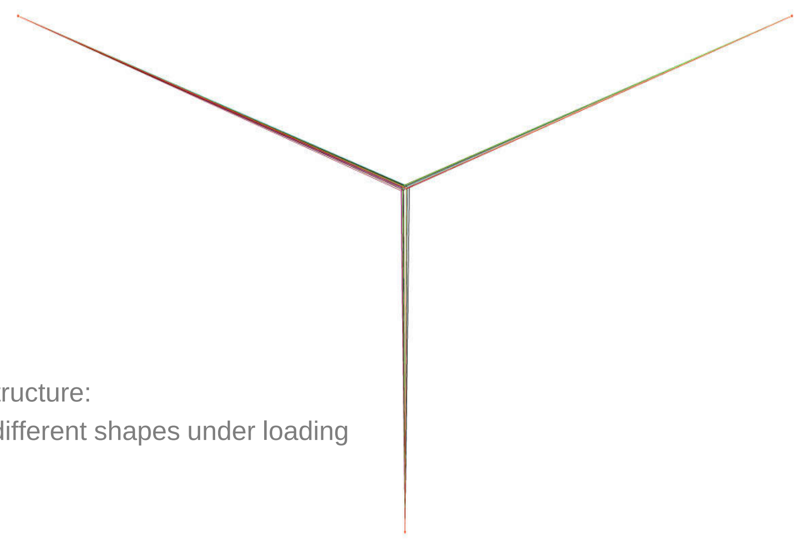
Development of a Eurocode design format
for reliable and robust tensile surface structures



Y-structure:
25 different shapes under loading

94

Development of a Eurocode design format
for reliable and robust tensile surface structures

Y-structure

Reliability in case of 1 x pre-tension: **2.27**
Reliability in case of 1.35 x pre-tension: **5.42**
The reliability index is about **two times higher**
in case a partial factor for pre-tension of 1.35 is used

Further research to calibrate the partial safety factors
for tensile surface structures is needed

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Research

Kine(ma)tic structures

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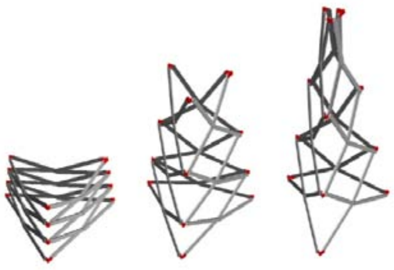
Research question

Context:
pre-tensioned fabrics +
kinematic principles



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Research question

Flexible/adaptable skins
contribute to
- Gain day-light
- Reduction of
  overheating/glare problems

Dynamic facade of the Kiefer technic showroom by Ernst Giselbrecht + Partner, photo by Paul Ott

98

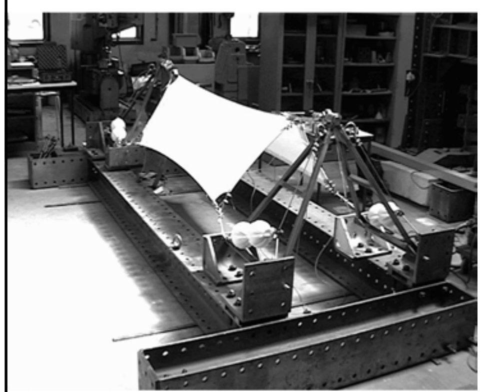
Research question

Also roofs
could be designed
to be adaptable

Study for a retractable small-span roof by Karni E., Pellegrino S

99

Research question



To what extent
is it possible to keep
the fabric tensioned?

Philippe Block, Tom Van Mele

100

Deployable dome structure

Can the system
structural membrane +
foldable frame
be tensioned
in different configurations?

101

Deployable dome structure

IASO has built
a demonstrator:
- Triangular panels

- PVC-coated polyester
- Pre-tension: 0.04kN/m

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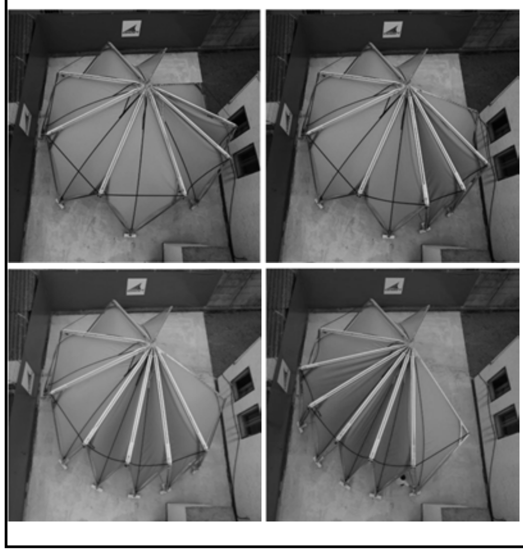
Deployable dome structure



The membrane was only slightly pre-tensioned

When folded there was no tension left > wrinkles

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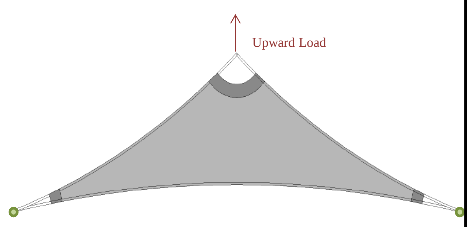
Deployable dome structure

Before further analysing the 3D configuration:

- a single panel was studied
- full scale experimental set-up
- force-controlled



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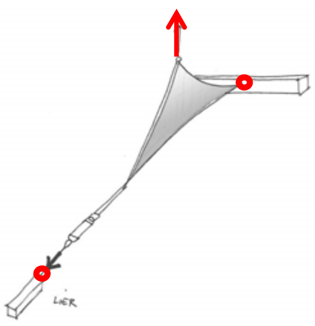
One single panel



The apex point is pulled up
Corresponds to the action on the membrane while unfolding a unit

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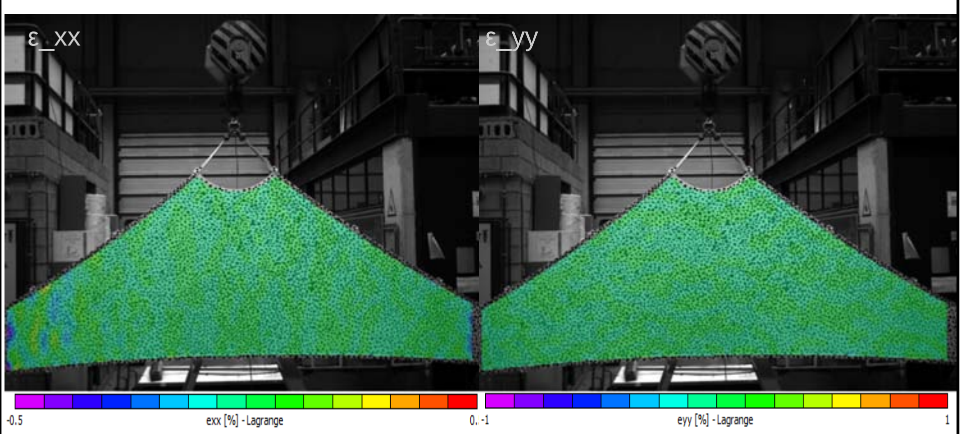
One single panel

Start configuration for the experimental set-up: ~0 strain



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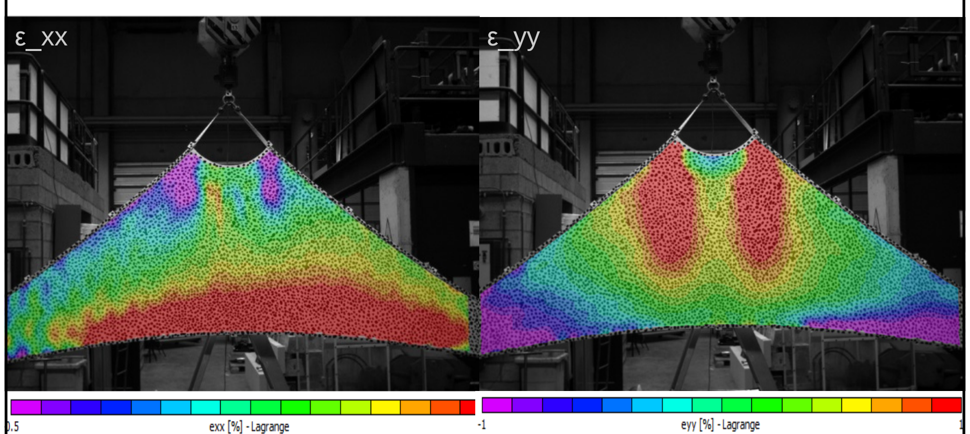
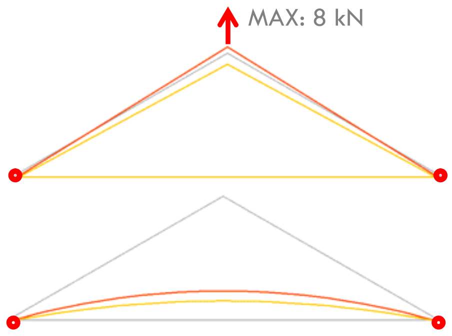
One single panel

First loading up to a vertical load of 8kN in the top
ε_xx: min. -1.3% max. 1.9%, ε_yy: min. -4.4% max. 4.8%



108

One single panel



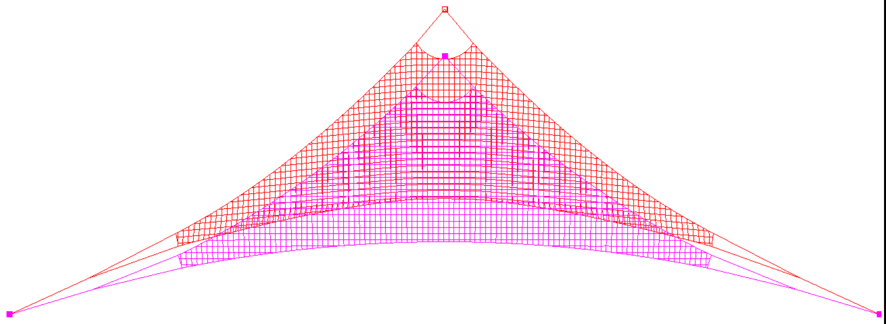
The circumscribed triangle highly deforms:
Displacement in the top
38cm (~7m span, ~5%)

The sag at the bottom
+ 35cm (high strain of the belt)

109

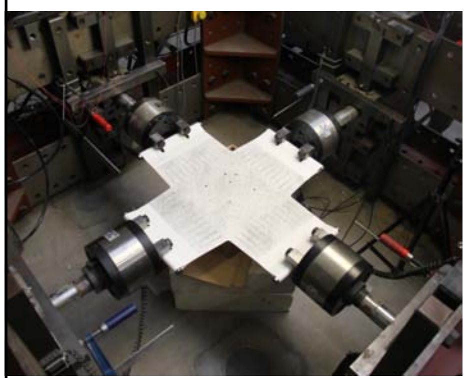
One single panel

Displacement in the top: 38cm
Increase of the bottom line sag:
35cm
Corresponds with the experiment



110

One single panel



The test protocols
to estimate the compensation
have to be in accordance
to the stresses
predicted in the model

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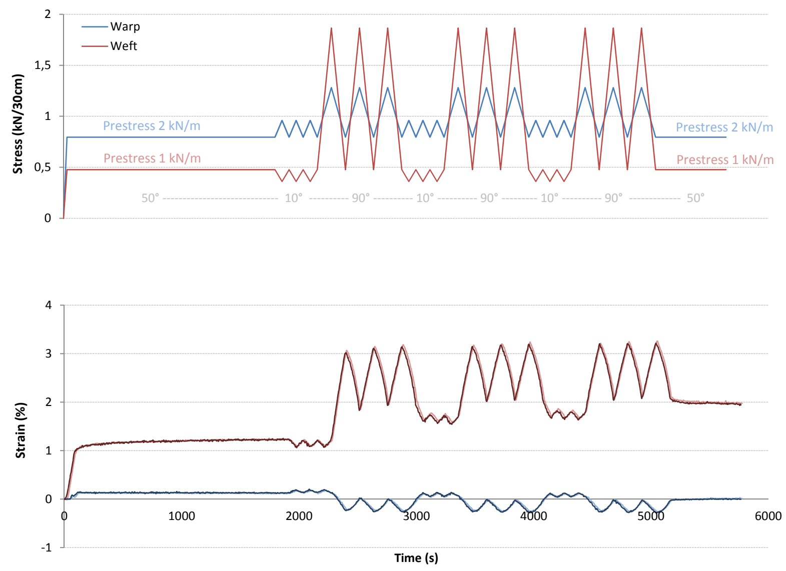

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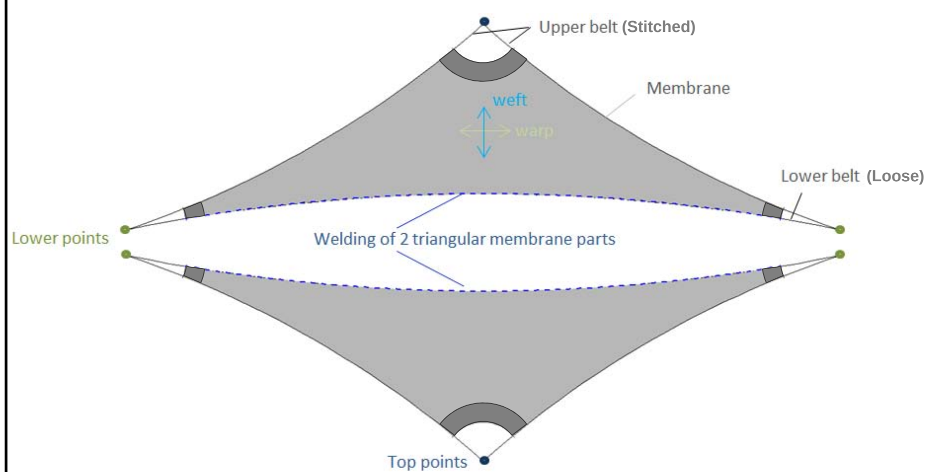
A single foldable unit

Two membrane triangles are joined along their base



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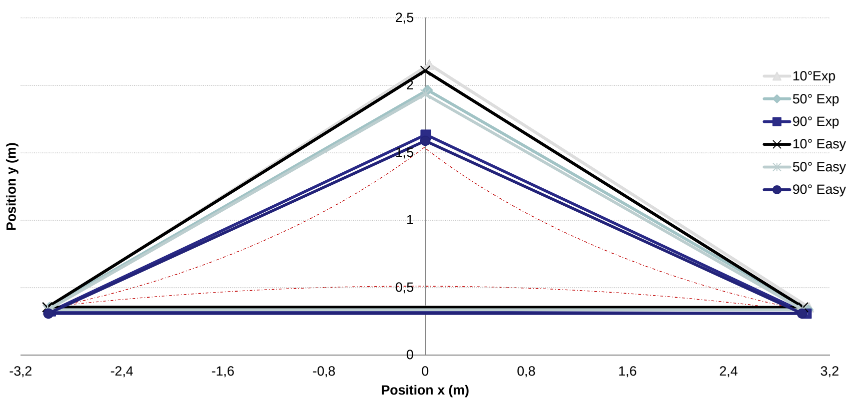
The circumscribed triangles are OK
The curvature of the boundaries is different



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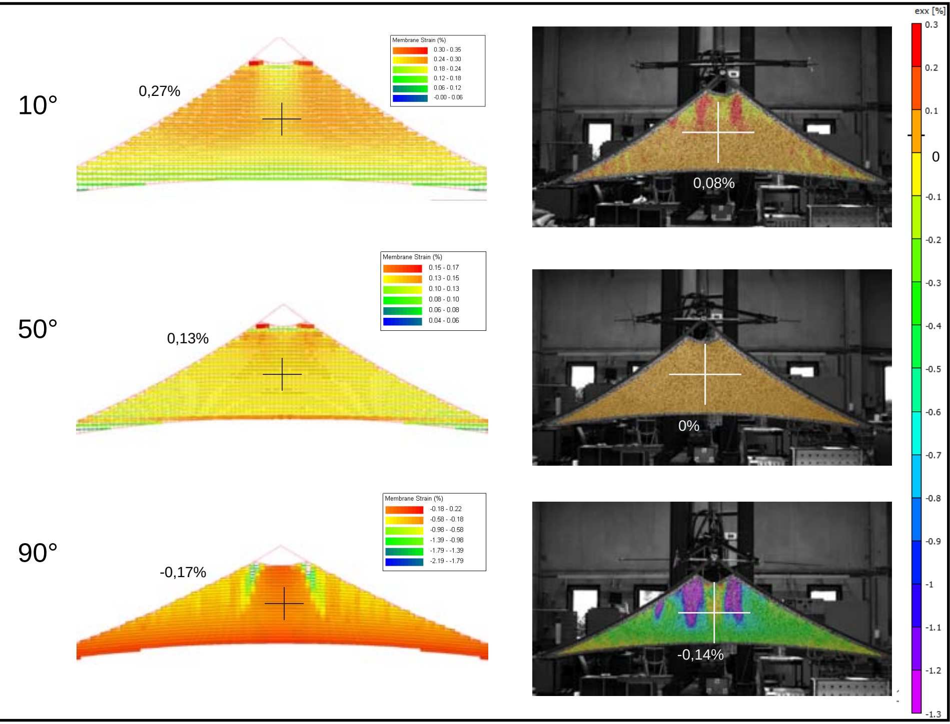
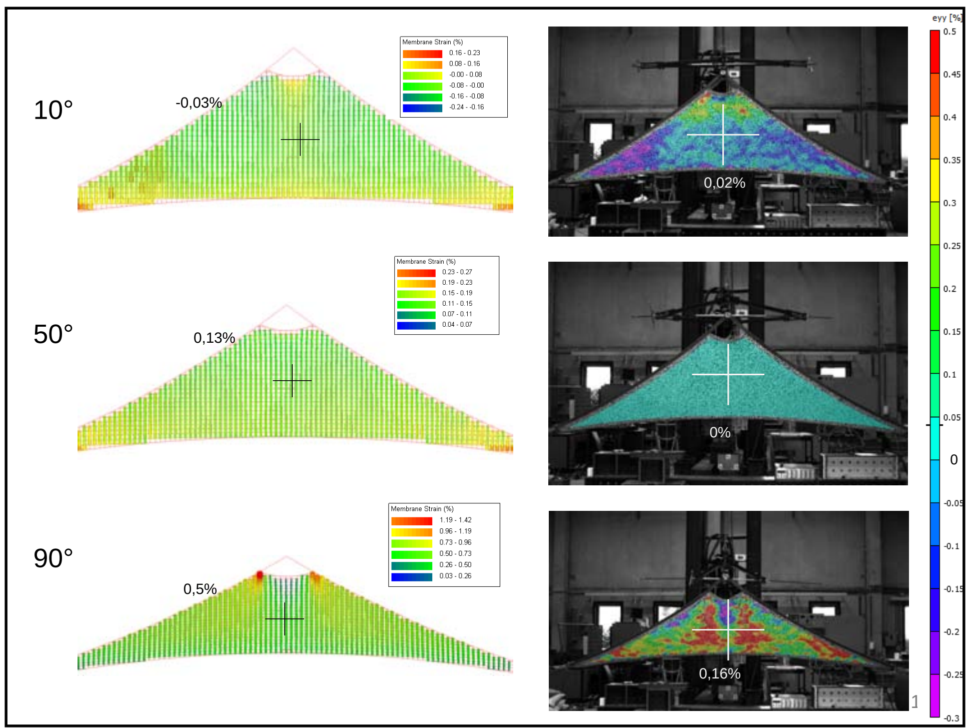
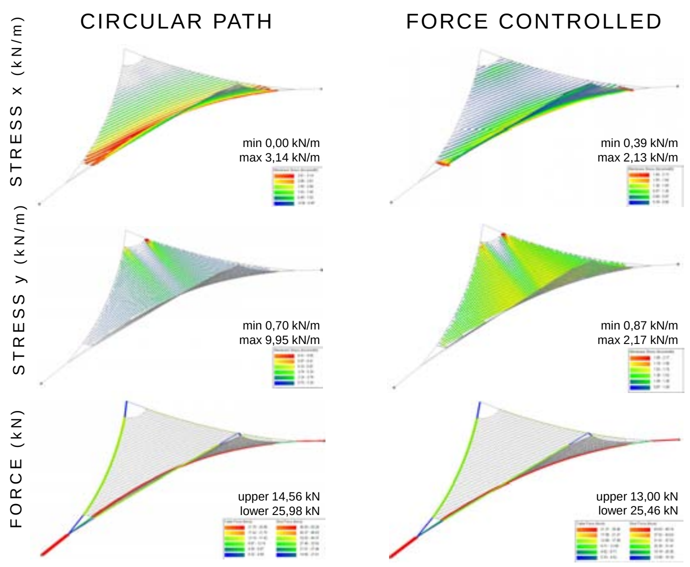




Uniform stress?



start = 50° - 2 kN/m and 1 kN/m prestress - 90° opening

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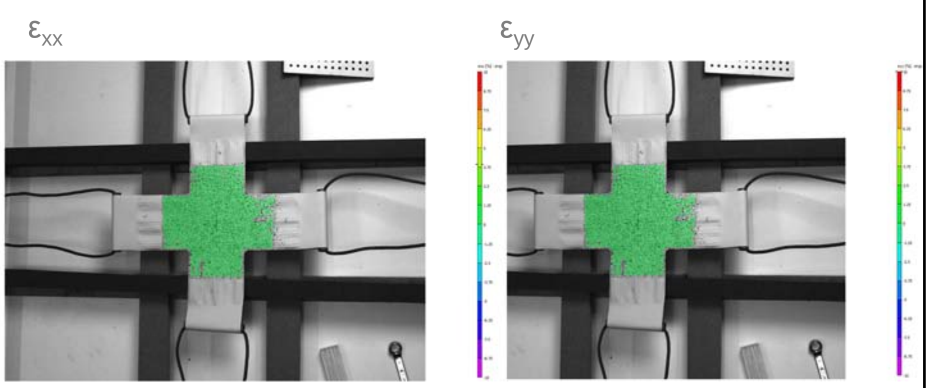
Stretchable material?



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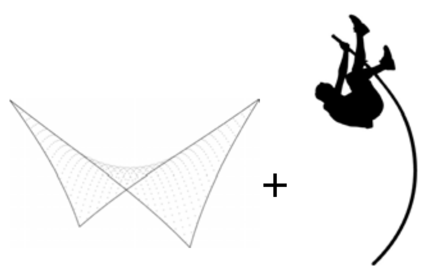
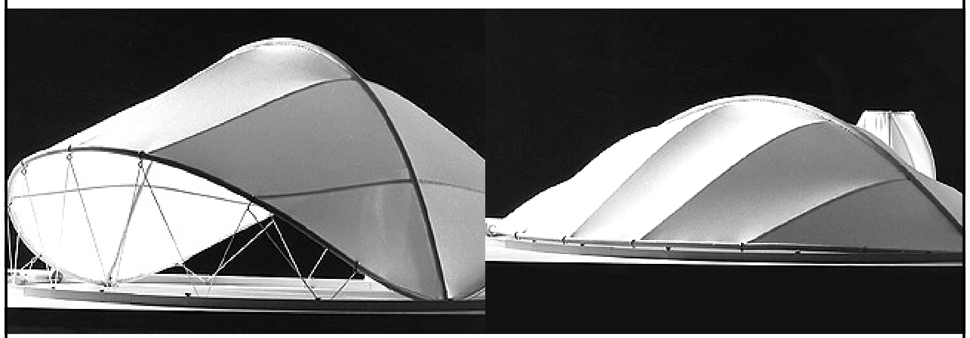
Research

Bending Active Systems



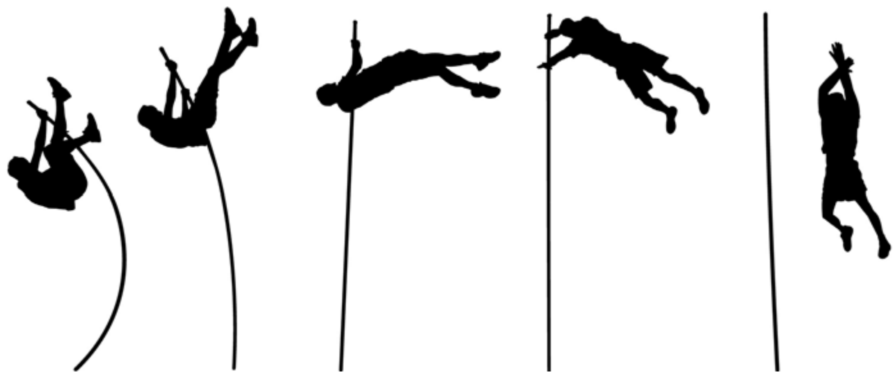
120

Bending active



121

Bending active

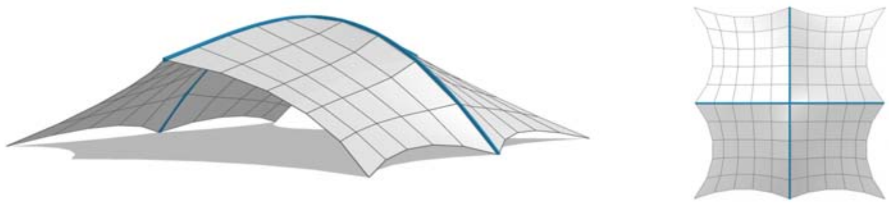


122

Bending active

123

Bending active



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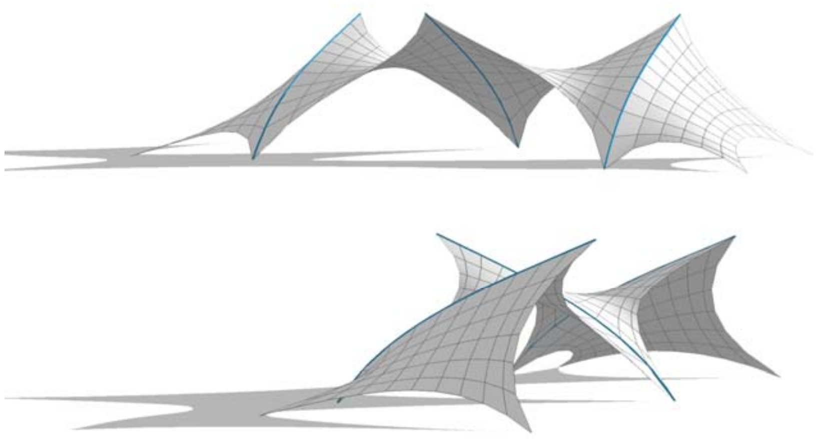

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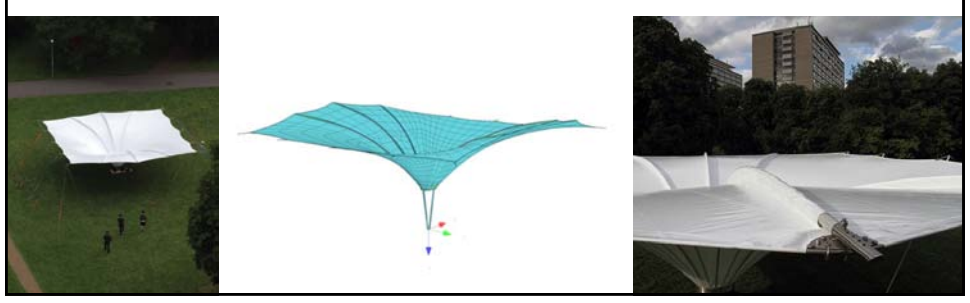
Bending active

Bending-active elements used as stiffening element for membrane structures



Bending active

ITKE - Institute of Building Structures and Structural Design
Julian Lienhard

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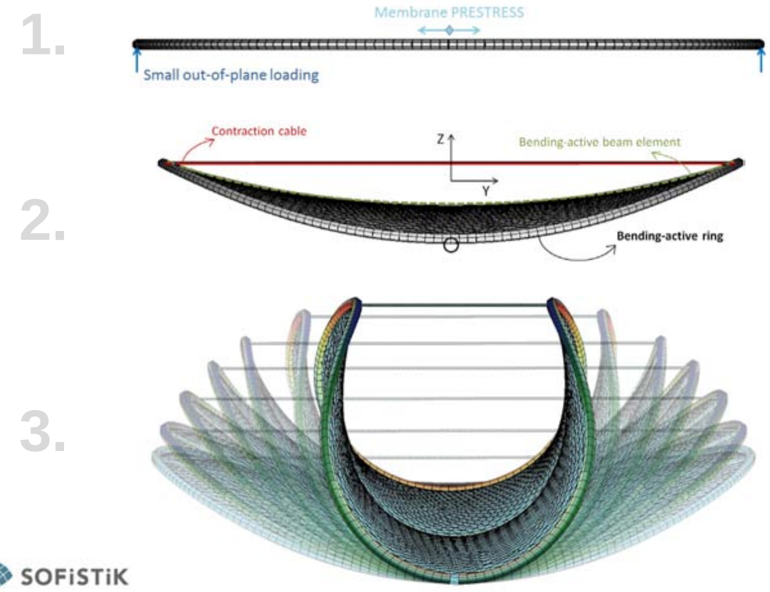
Kinematic Form-Active Structure in a Bending-Active ring



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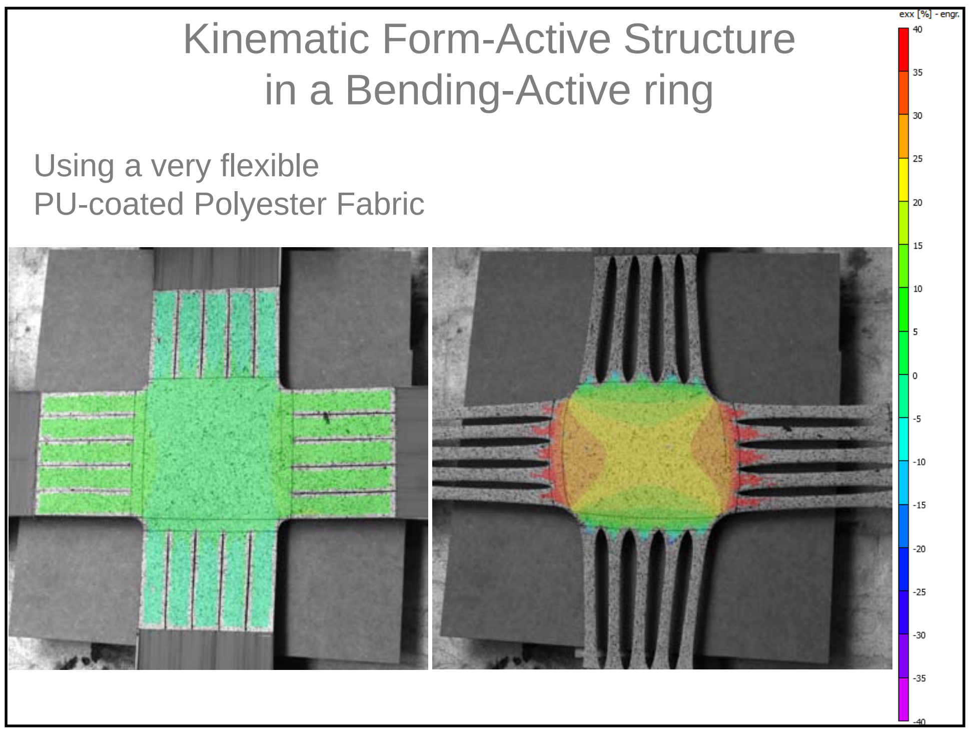
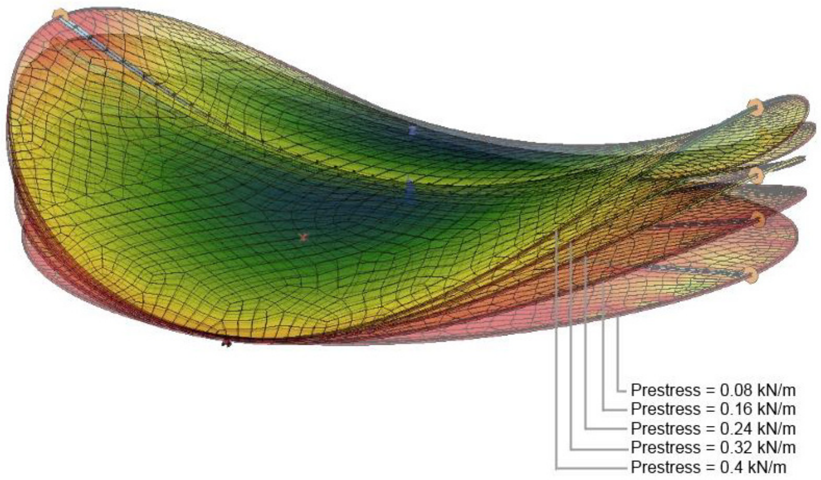
Kinematic Form-Active Structure in a Bending-Active ring

Using a very flexible
PU-coated Polyester Fabric



Kinematic Form-Active Structure in a Bending-Active ring

Adding the membrane pre-stress: complex interaction between membrane and bending-active elements



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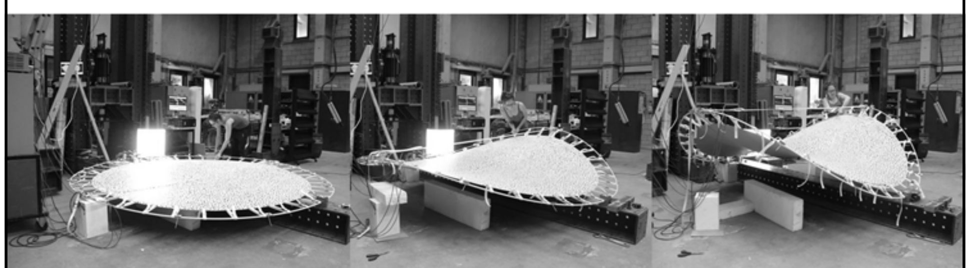
Kinematic Form-Active Structure in a Bending-Active ring

Experimental investigation of the structural behaviour



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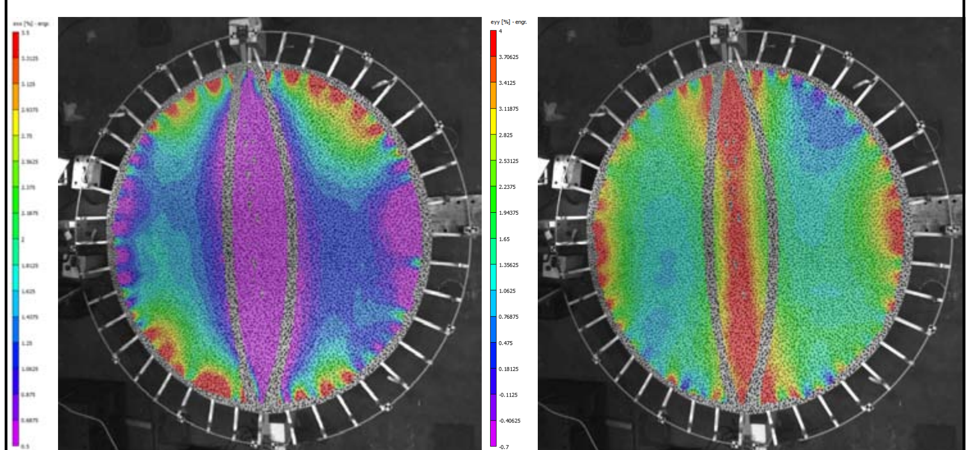
Kinematic Form-Active Structure in a Bending-Active ring

Experimental investigation of the structural behaviour



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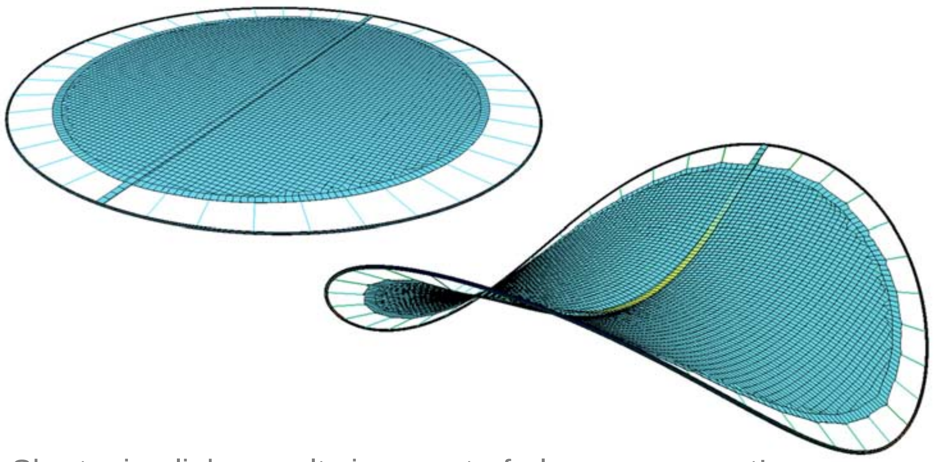
Kinematic Form-Active Structure in a Bending-Active ring

Numerical simulation of the experimental process



Shortening links results in an out-of-plane movement!

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Tensile surface structures, materials

Eurocode

Research: material characterisation, wind load estimation, partial factor calibration, kine(ma)tic structures, bending active systems

Examples

TensiNet Association

- is a platform for parties interested in tensioned membrane structures
- to exchange and share multidisciplinary knowledge about tensile structures in order to **increase quality**
- establish a Eurocode part
- www.tensinet.com

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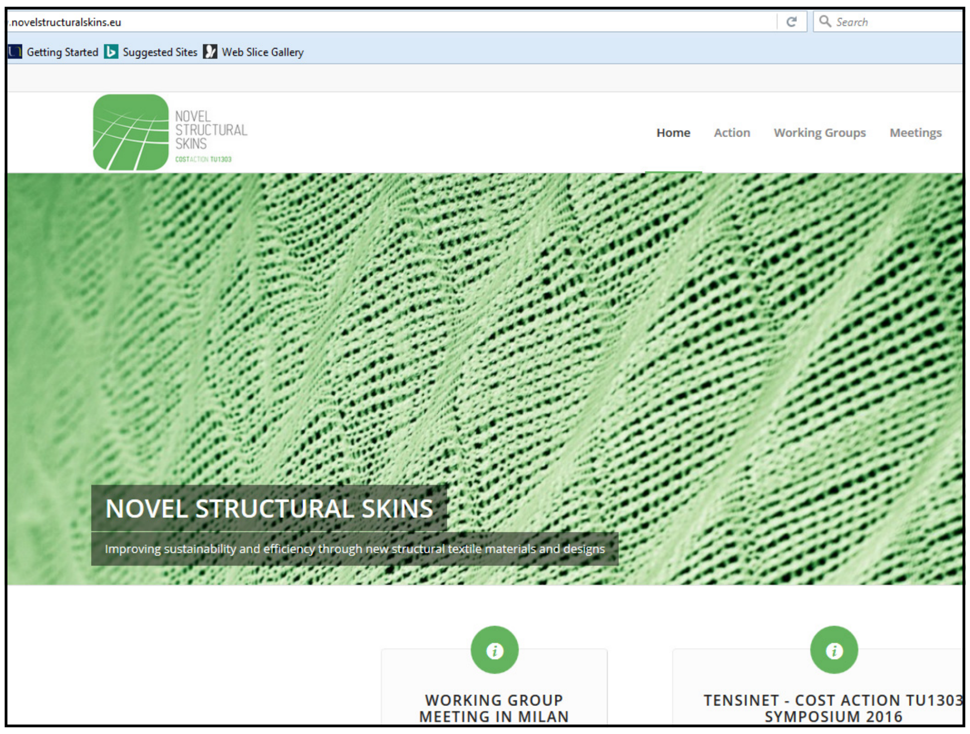

CANOPIES

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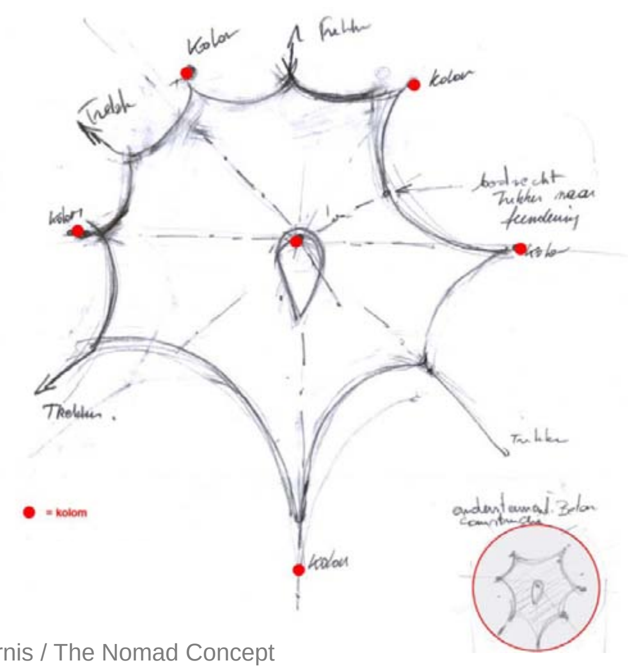

De Prettige Wildernis / The Nomad Concept

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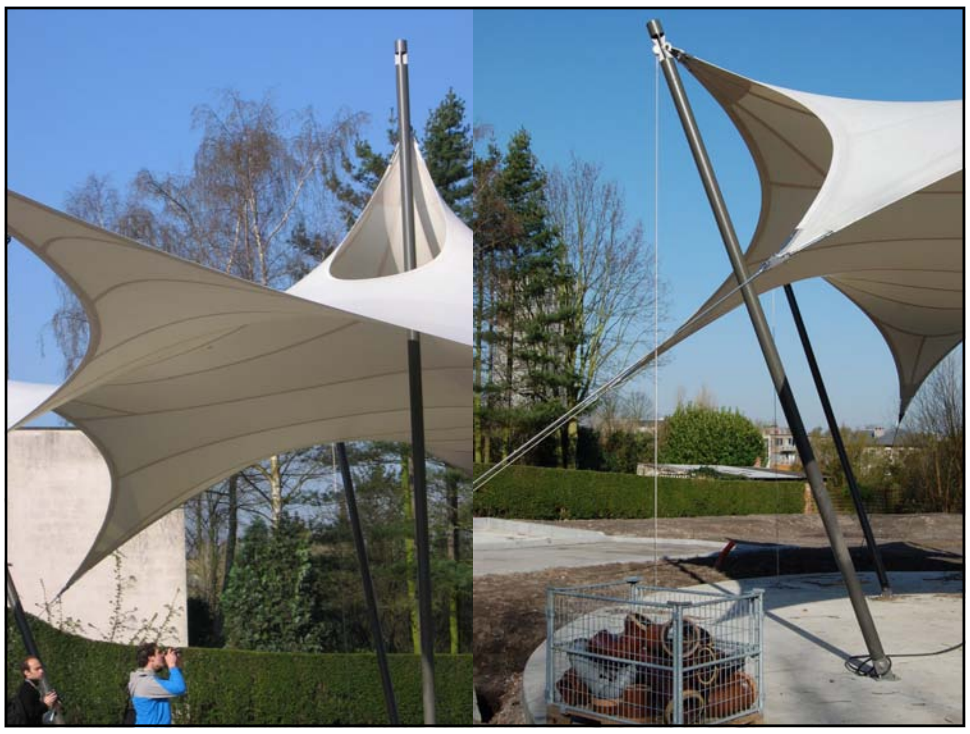

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Canopies

Expo Zaragoza 2008 : Felix Escrig & José Sanches / IASO © IASO

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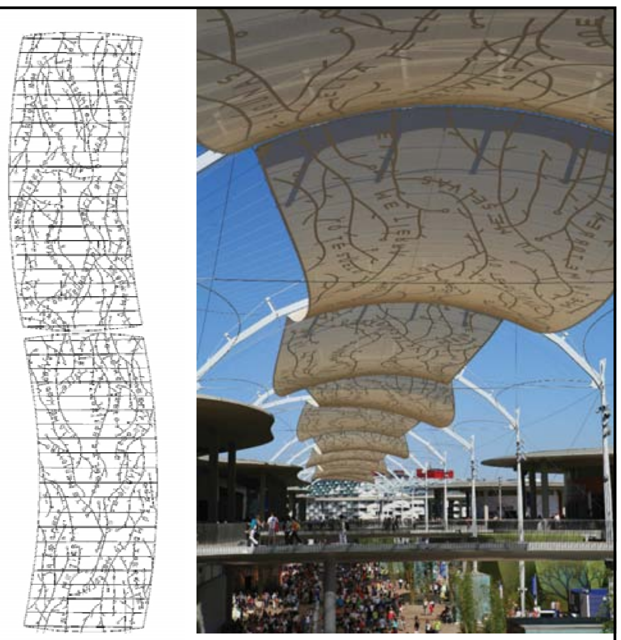

Expo Zaragoza 2008 : Felix Escrig & José Sanches / IASO © IASO

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Canopies

De Persgroep covered terrace / Amandus VanQuaille / The Nomad Concept © Amandus VanQuaille

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Canopies

Carré des Arts / AGWA – Ney & Partners / Ney & Partners / Veldeman Structure Solutions / Buitink Technology © FM PLISSART

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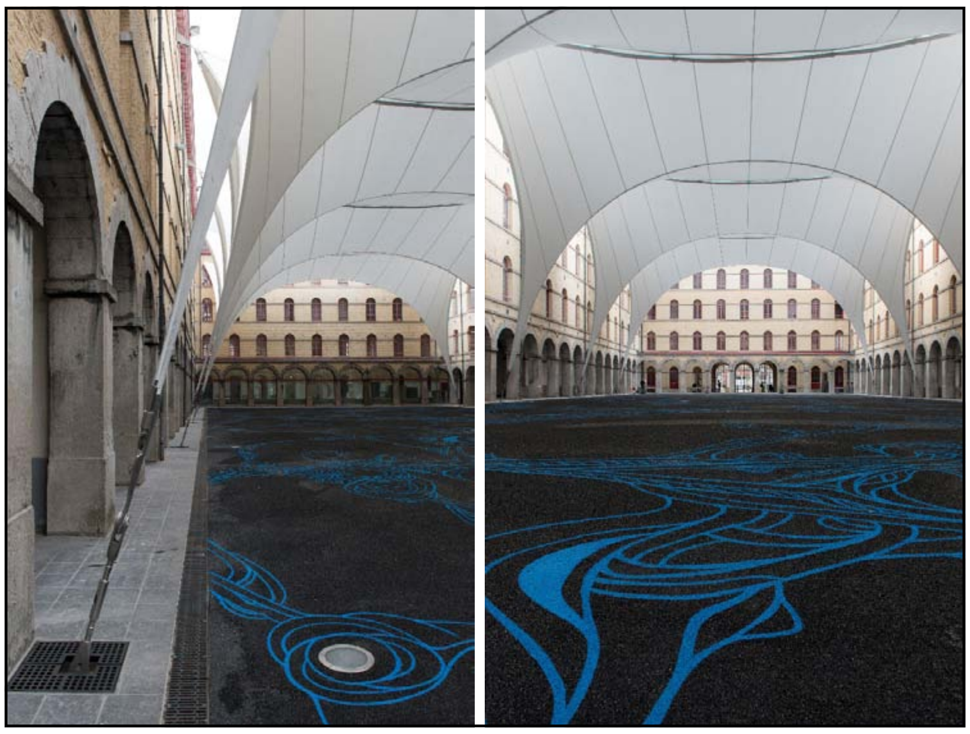

Canopies

Chapel of Rest / J. Desablens / Ney & Partners © J. Desablens

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Chapel of Rest / J. Desablens / Ney & Partners © J. Desablens

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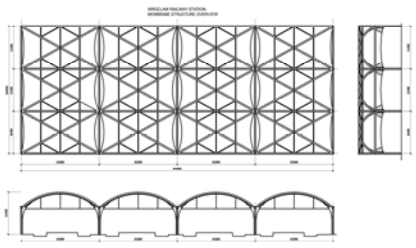
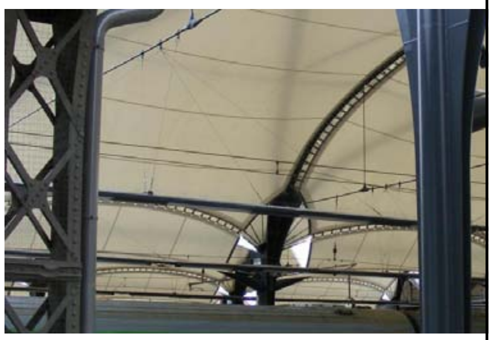
Canopies

Railway station Wroclaw / GRUPA 5 / k2 engineering

150

Canopies

Railway station Wroclaw / GRUPA 5 / k2 engineering

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Canopies


Hagar Qim & Mnajdra temples/ Hunziker & Kiefer architects/ form TL © form TL

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Canopies


Hagar Qim & Mnajdra temples/ Hunziker & Kiefer architects/ form TL © form TL

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MEMBRANE ROOFS

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Turin University / Architect Sir Norman Foster / form TL / Canobbio ©
Canobbio & Michele d´Ottavio

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Roofs

Turin University / Architect Sir Norman Foster / form TL / Canobbio ©
Canobbio & Michele d´Ottavio

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Roofs

Turin University / Architect Sir Norman Foster / form TL / Canobbio ©
Canobbio & Michele d´Ottavio

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RETRACTABLE ROOFS

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Retractable roofs

Mobile coverage for the central patio at the Great Mosque of Paris / A.T.I.C. /
AIA Ingénierie / Serge Ferrari © AIA

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Mobile coverage for the central patio at the Great Mosque of Paris / A.T.I.C. /
AIA Ingénierie / Serge Ferrari © AIA

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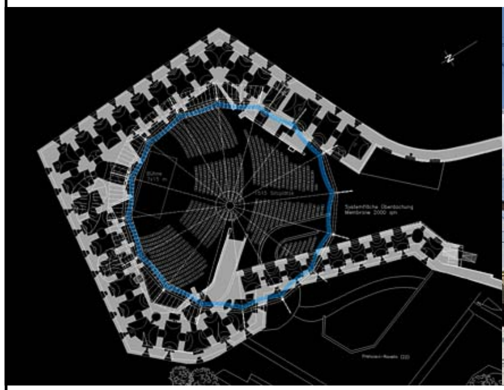
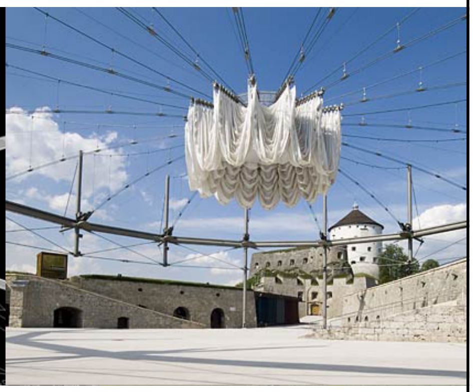
Retractable roofs





Retractable roof – Kufstein / Kugel + Rein Architects and Engineers / Hightex GmbH © Kugel + Rein Architects and Engineers

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Prophet´s Holy Mosque, Medina, SL-Rasch

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REMOVABLE & TEMPORARY

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Helicopter Hangar for navy / Ceris / Toile et structures / Ferrari

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Helicopter Hangar for navy / Ceris / Toile et structures / Ferrari

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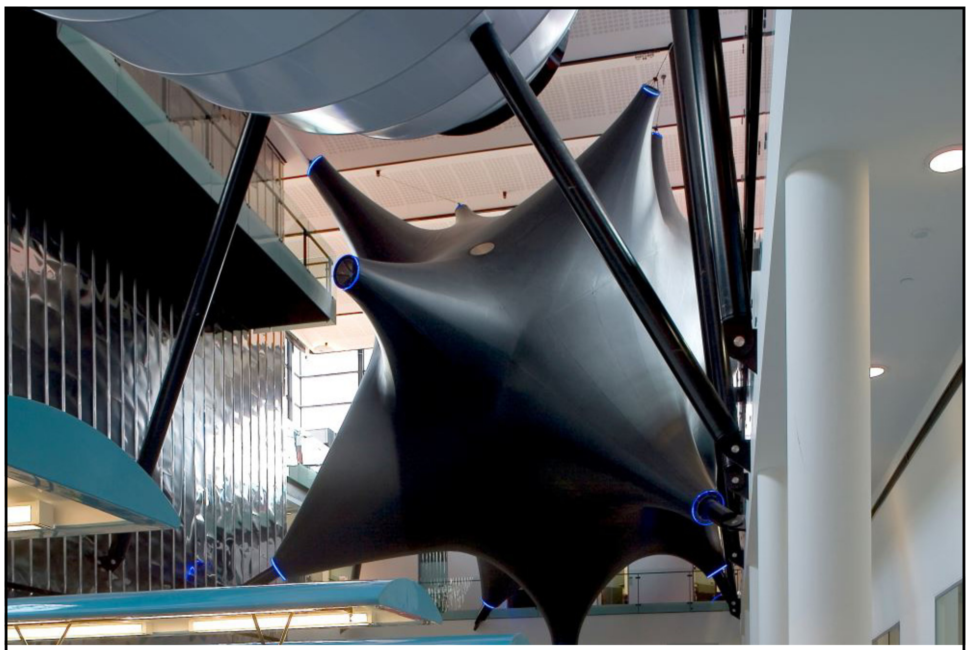

Spiky Pod, Queen Mary University / Alsop architects /McAlpine design Group
© Architect Landrell Associates

Removable & Temporary

Modern Teahouse / Kengo Kuma / form TL / Canobbio © form TL

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Modern Teahouse / Kengo Kuma / form TL / Canobbio © form TL

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Layers are
point-wisely joined
3-4 times per m²
which leads
to a golf ball shape
when air is blown in

Minimal assembly
and dismantling time

CANOBBIO

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Form finding, material selection
and structural analysis
were one
Details were evaluated
and optimized

CANOBBIO

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ETFE CUSHIONS

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ETFE Cushions

Tropical Islands (former CargoLifter Airship Hangar) / CL MAP / formTL / CenoTec

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ETFE Cushions

Tropical Islands (former CargoLifter Airship Hangar) / CL MAP / formTL / CenoTec

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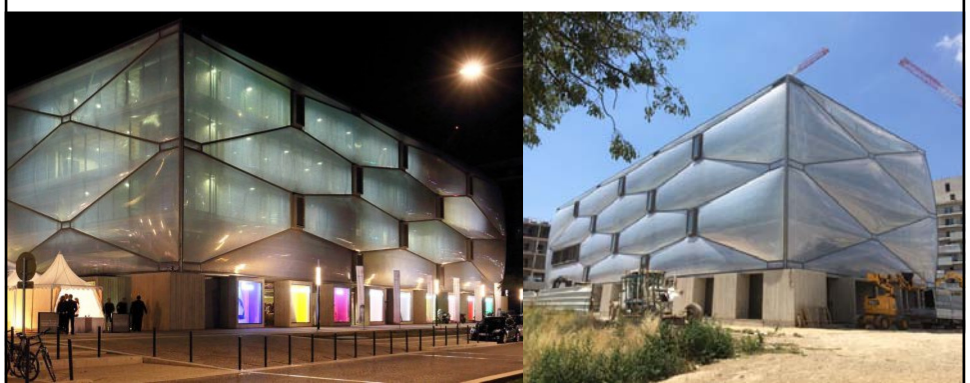
ETFE Cushions



Facade Sports and Wellness Centre, Le Nuage / Ph. Stark / C. Destenay / Abaca - Nicolas Pauli © Abaca - Nicolas Pauli

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ETFE Cushions

ETFE film cushions roof for carport / Ackermann und Partner Architekten BDA / Taiyo Europe / 3M Dyneon © Taiyo Europe

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ETFE Cushions

ETFE film cushions roof for carport / Ackermann und Partner Architekten BDA / Taiyo Europe / 3M Dyneon © Taiyo Europe

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ETFE Cushions

Canopy Bus Terminal Aarau / vehovar & jauslin / form TL / Arge Foliendach RUCH AG + Vector Foiltec

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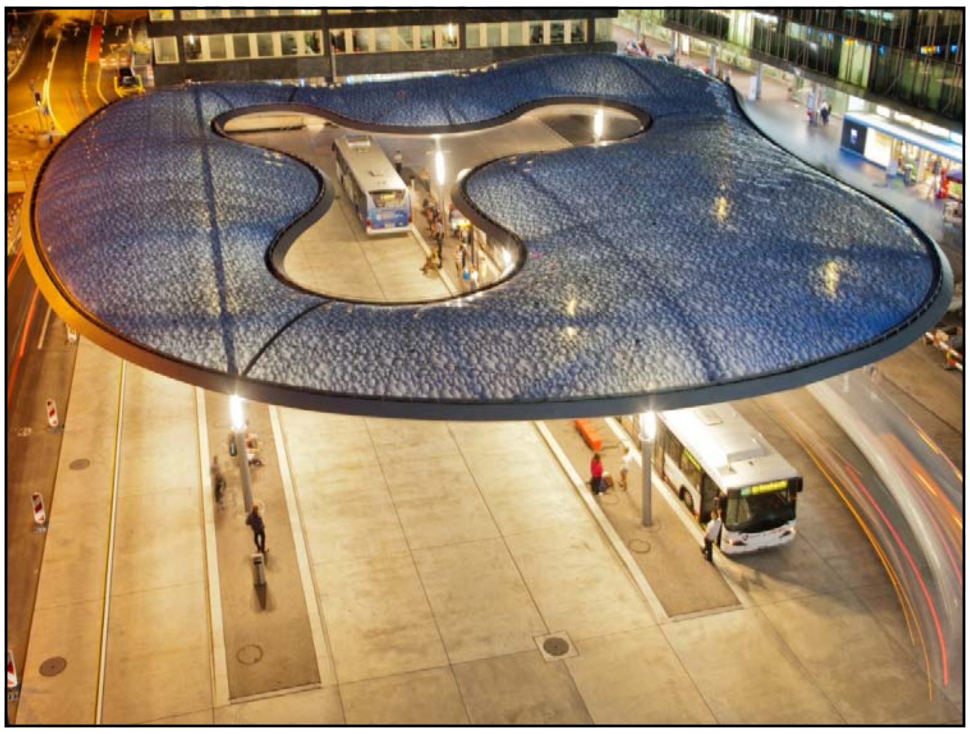

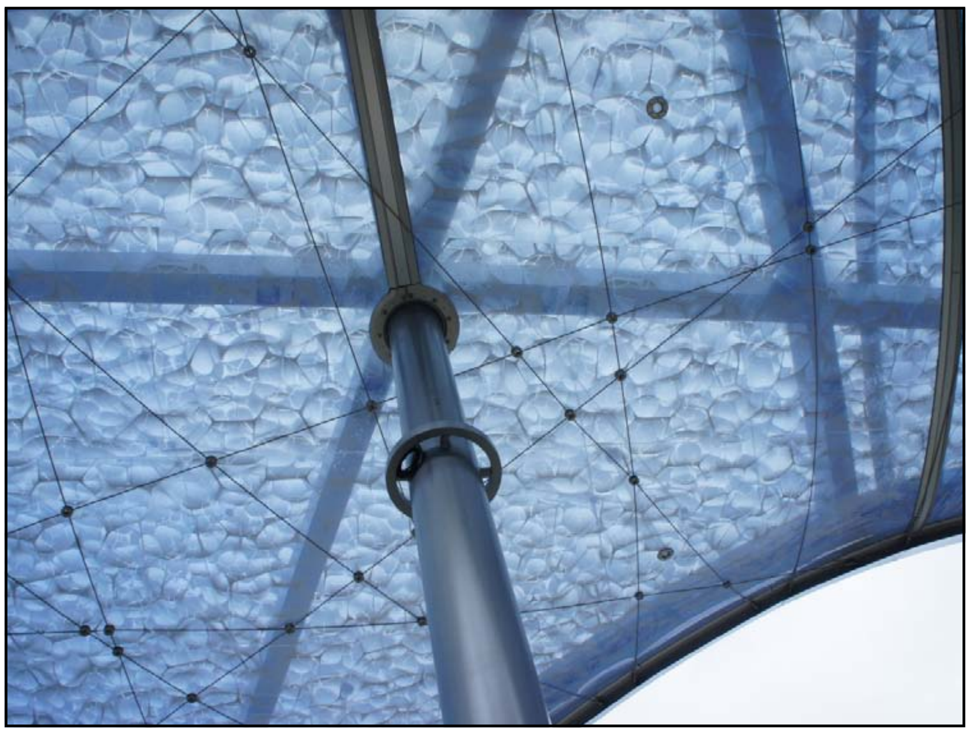

TENSAIRITY

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Tensairity Structures

Tensairity Structures


Inno-wave-tion / Silvain Dubuisson Architecte / Tentech / High Point Structures & Buitink Technology / Serge Ferrari © Tentech

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Tensairity Structures


Inno-wave-tion / Silvain Dubuisson Architecte / Tentech / High Point Structures & Buitink Technology / Serge Ferrari © Tentech

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SECOND SKIN

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Second skin


Foil façade Unilever Building / Behnisch Architekten / form TL / Vector Foiltec © formTL

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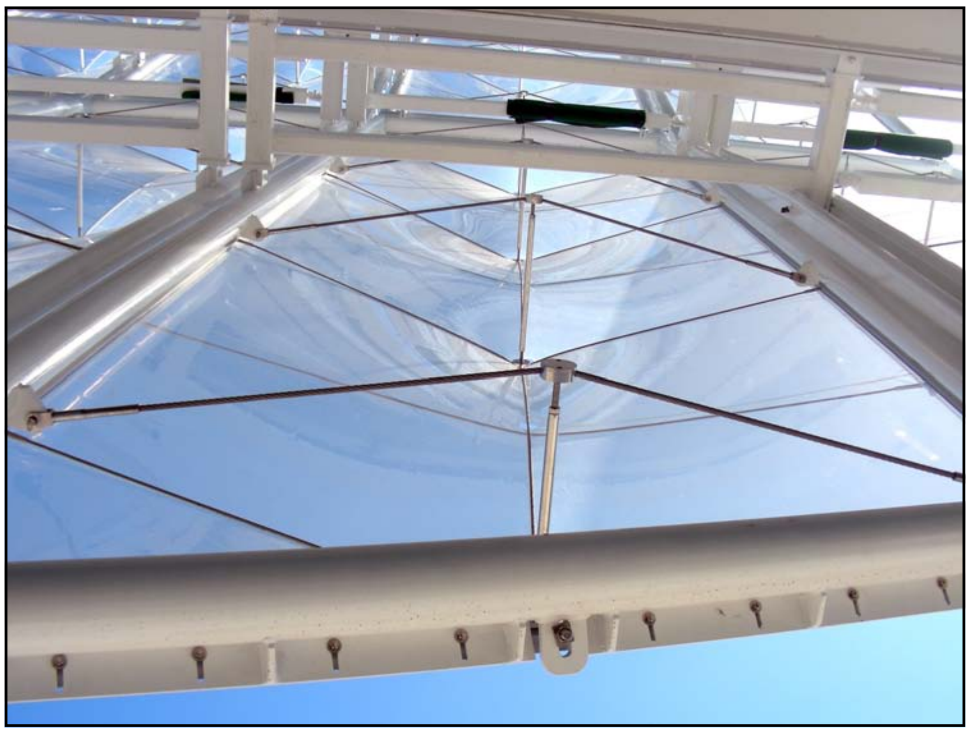

Second skin

South facade Santa Lucia Hospital / Francesc Pernas. Casa Consultors i Arquitectes, S.L. / IASO, S.A. © David Pernas

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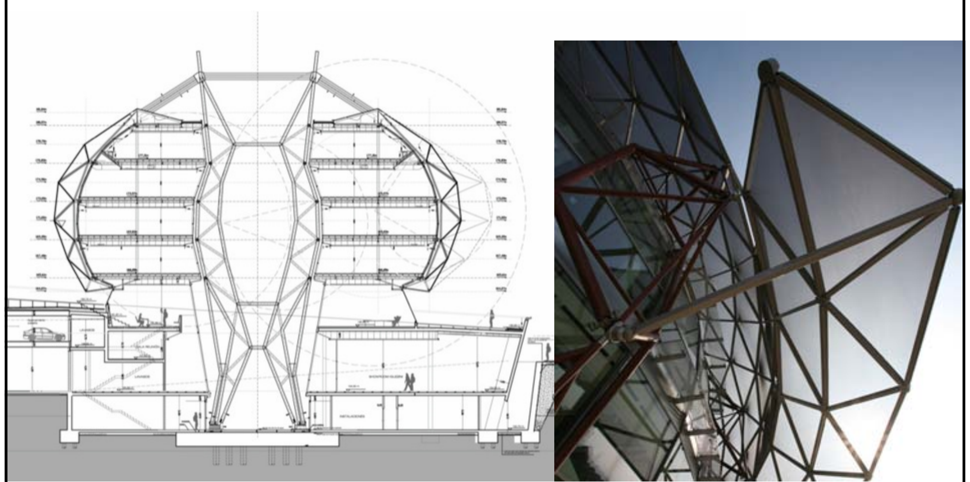
Second skin



New Iguzzini Headquarters / Miàs Arquitectes / LANIK, S.A. / IASO, S.A. © Adrià Goula

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MULTI LAYERED SKIN

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Multi-layered skin

Parkbad Velbert / IPL / form TL © KRIEGER Architekten | Ingenieure GmbH

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Multi-layered skin

Serpentine Sackler Gallery / Zaha Hadid Architects / ARUP © Luke Hayes

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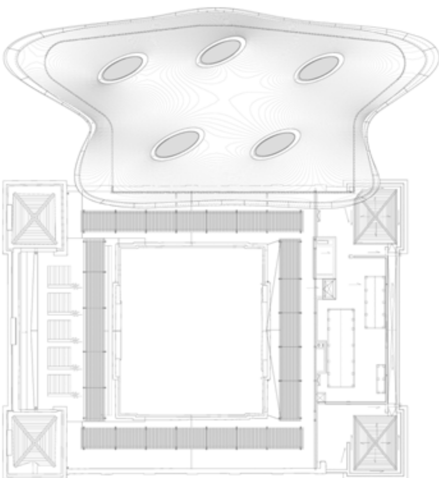
Multi-layered skin



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STADIA

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Stadia

Stade Allianz Riviera, Nice / Wilmotte & Associés SA / IASO, S.A. / Serge Ferrrari © Serge Demailly

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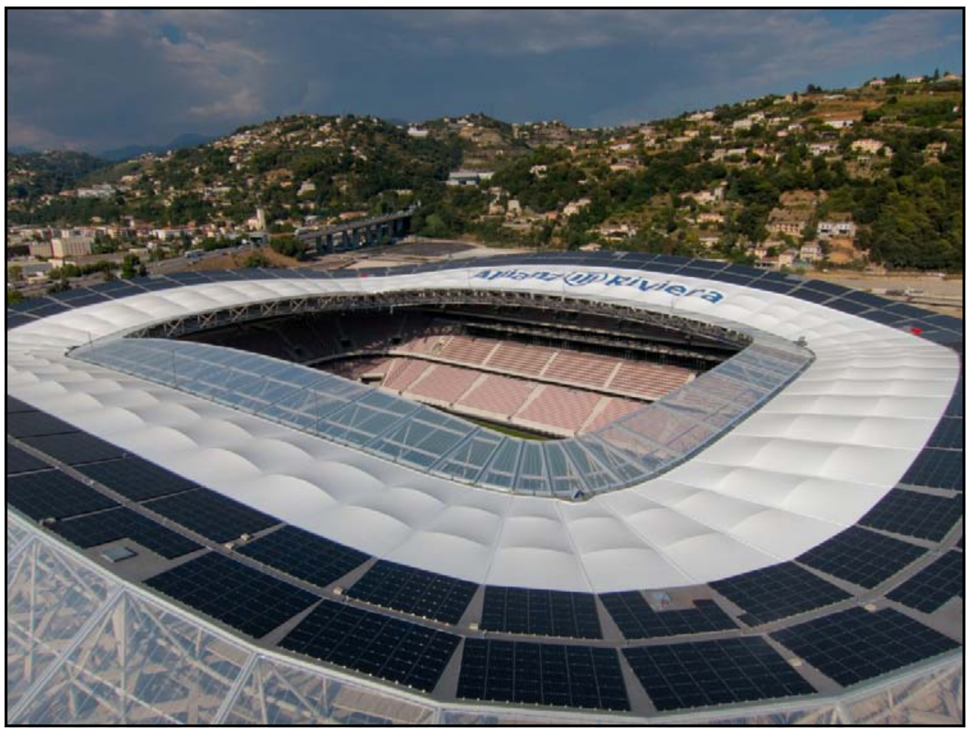

Stadia

National Sports Complex Olimpiyskiy in Kiev/ Architecten von gerkan, Marg und partner / form TL / Hightex ©

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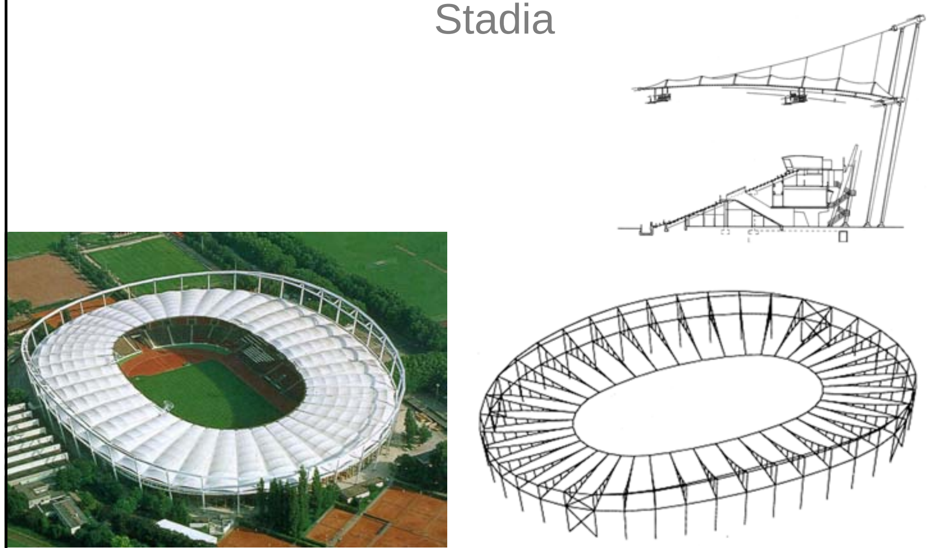
Stadia



Mercedes-Benz Arena / Weidleplan, Siegel & Partner, schlaich bergerman und partner © Herr Storck

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Stadia

Mercedes-Benz Arena / Weidleplan, Siegel & Partner, schlaich bergerman und partner © Herr Storck

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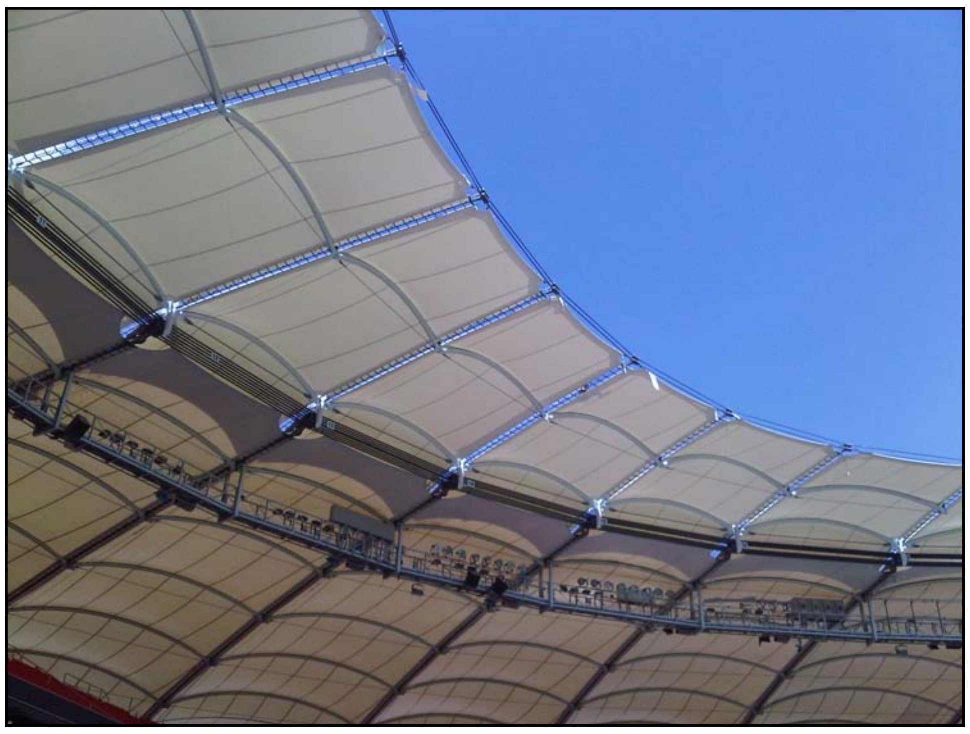

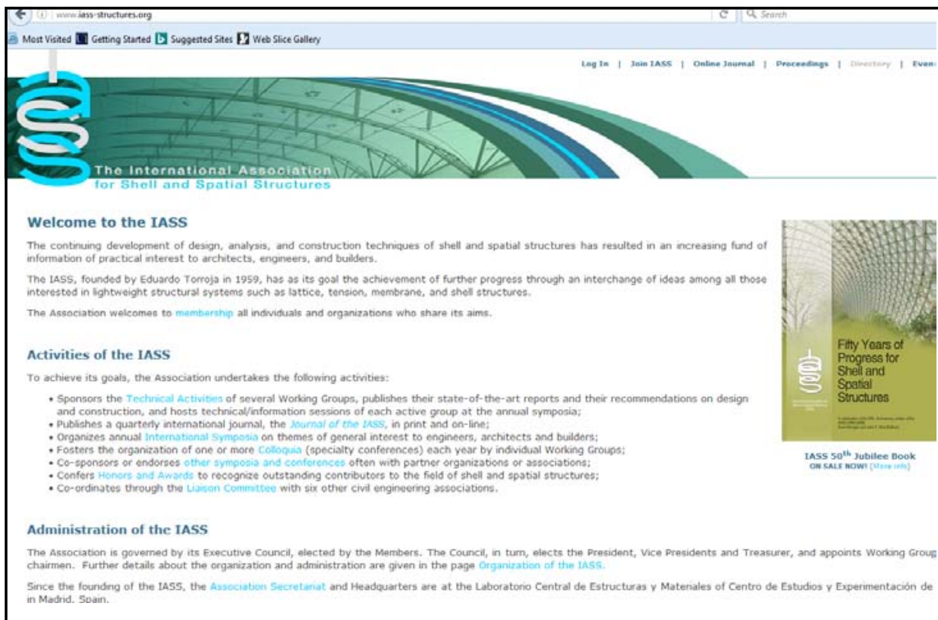
Log In | Join IASS | Online Journal | Proceedings | Directory | Even

The International Association for Shell and Spatial Structures

Welcome to the IASS

The continuing development of design, analysis, and construction techniques of shell and spatial structures has resulted in an increasing fund of information of practical interest to architects, engineers, and builders.

The IASS, founded by Eduardo Torroja in 1959, has as its goal the achievement of further progress through an interchange of ideas among all those interested in lightweight structural systems such as lattice, tension, membrane, and shell structures.

The Association welcomes to membership all individuals and organizations who share its aims.

Activities of the IASS

To achieve its goals, the Association undertakes the following activities:

- Sponsors the Technical Activities of several Working Groups, publishes their state-of-the-art reports and their recommendations on design and construction, and hosts technical/information sessions of each active group at the annual symposia;
- Publishes a quarterly international journal, the Journal of the IASS, in print and on-line;
- Organizes annual International Symposia on themes of general interest to engineers, architects and builders;
- Fosters the organization of one or more Colloquia (specialty conferences) each year by individual Working Groups;
- Co-sponsors or endorses other symposia and conferences often with partner organizations or associations;
- Confers Honors and Awards to recognize outstanding contributors to the field of shell and spatial structures;
- Co-ordinates through the Liaison Committee with six other civil engineering associations.

Fifty Years of Progress for Shell and Spatial Structures

IASS 50th Jubilee Book
ON SALE NOW! (More info)

Administration of the IASS

The Association is governed by its Executive Council, elected by the Members. The Council, in turn, elects the President, Vice Presidents and Treasurer, and appoints Working Group chairmen. Further details about the organization and administration are given in the page Organization of the IASS.

Since the founding of the IASS, the Association Secretariat and Headquarters are at the Laboratorio Central de Estructuras y Materiales of Centro de Estudios y Experimentación de in Madrid, Spain.

WG 6: Tension and Membrane Structures

WG chair: K. Kawaguchi, Co-chairs: R. Shaeffer, M. Mollaert

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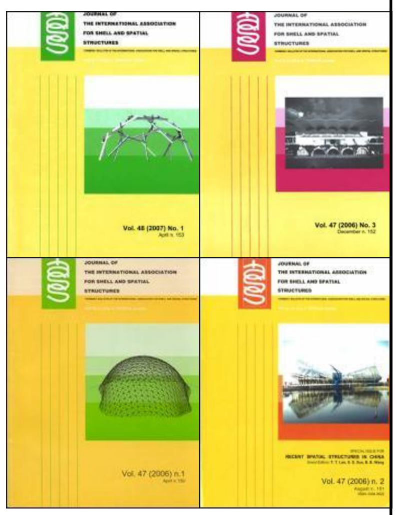
Current Objectives

- Organize sessions at IASS Symposia
- Discuss and share information about key trends, research and future issues



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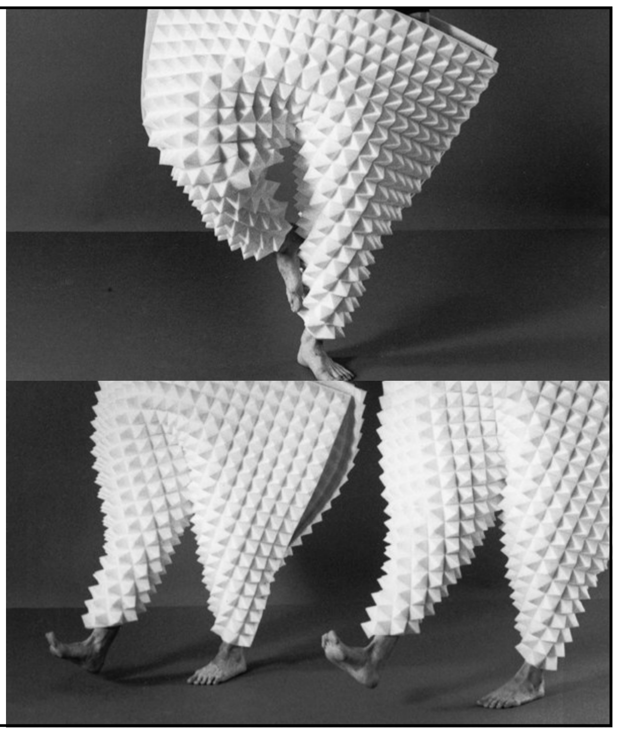
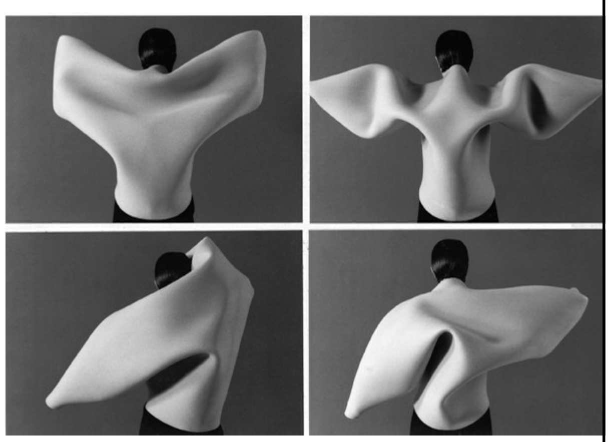
'… Embedded
in the material,
the form reveals itself



To experience
the freedom
…

To see
what emerges
from one form



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Inciting
the flow
of continuous creation

No waste,
no loss of energy,
alert and alive'
Maria Blaisse

http://www.mariablaisse.com/maria/home.html

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