PEF2602
Estruturas na Arquitetura I I - Sistemas Reticulados

EP-USP

FAU-USP

Tensoestruturas

Professores
Ruy Marcelo O. Pauletti , Leila Meneghetti Valverdes, Luís Bitencourt

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Estrutura Retesadas (‘Tensoestruturas’):

“aquelas que requerem que seus elementos estejam rete ***retesados***,
Ao invés de ***frouxos*** ou ***enrugados***, para funcionarem a contento”

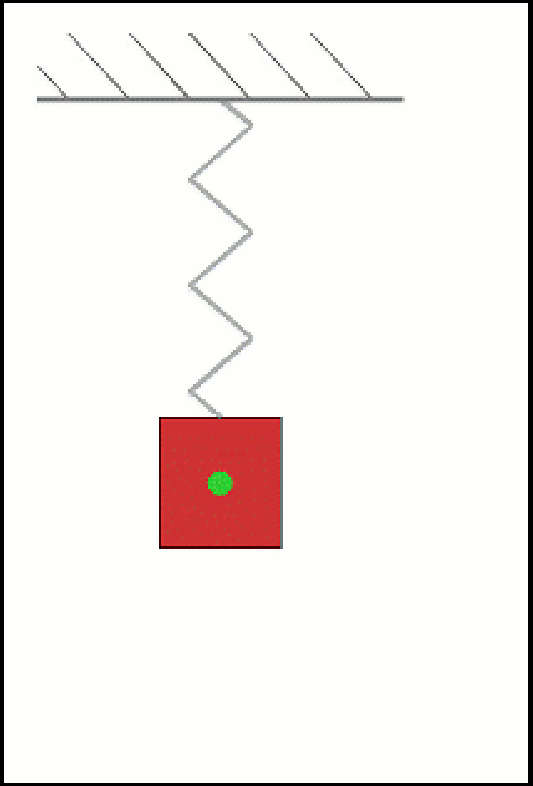
Estados de uma Tensoestrutura:

frouxo

enrugado

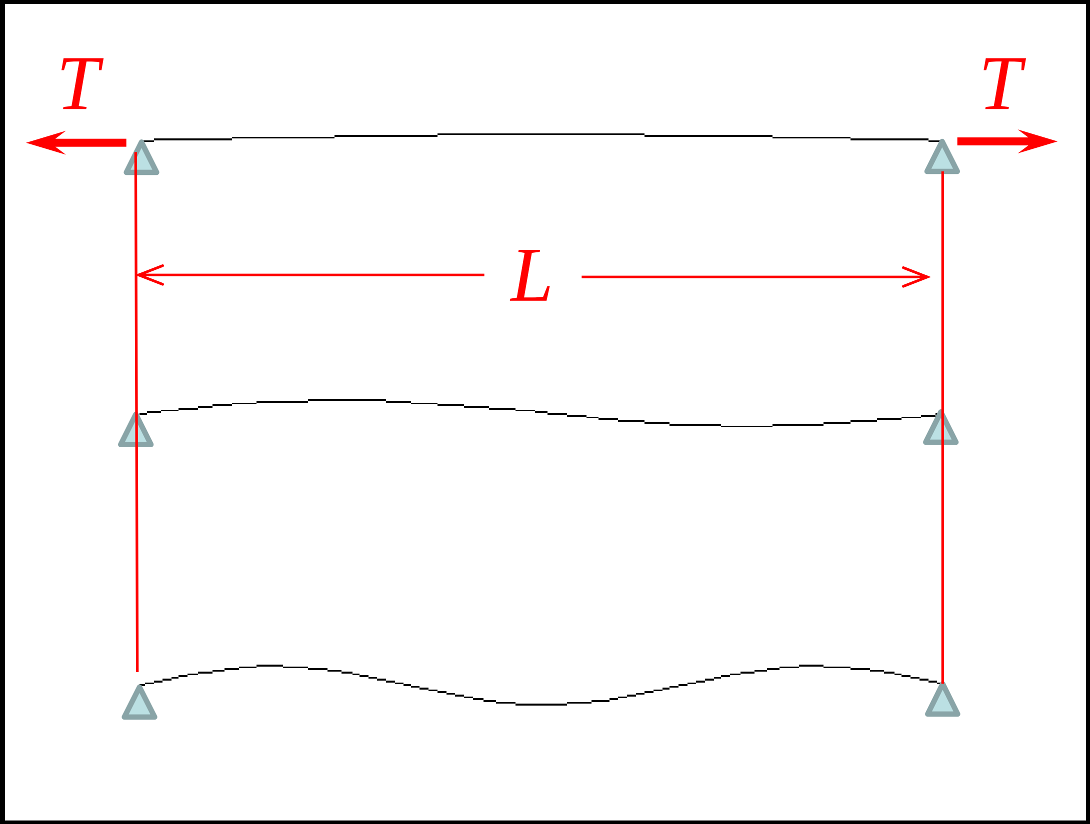
retesado

Um sistema massa-mola:



$$f = \frac{1}{2\pi}\sqrt{\frac{k}{m}}$$

Uma corda vibrando:

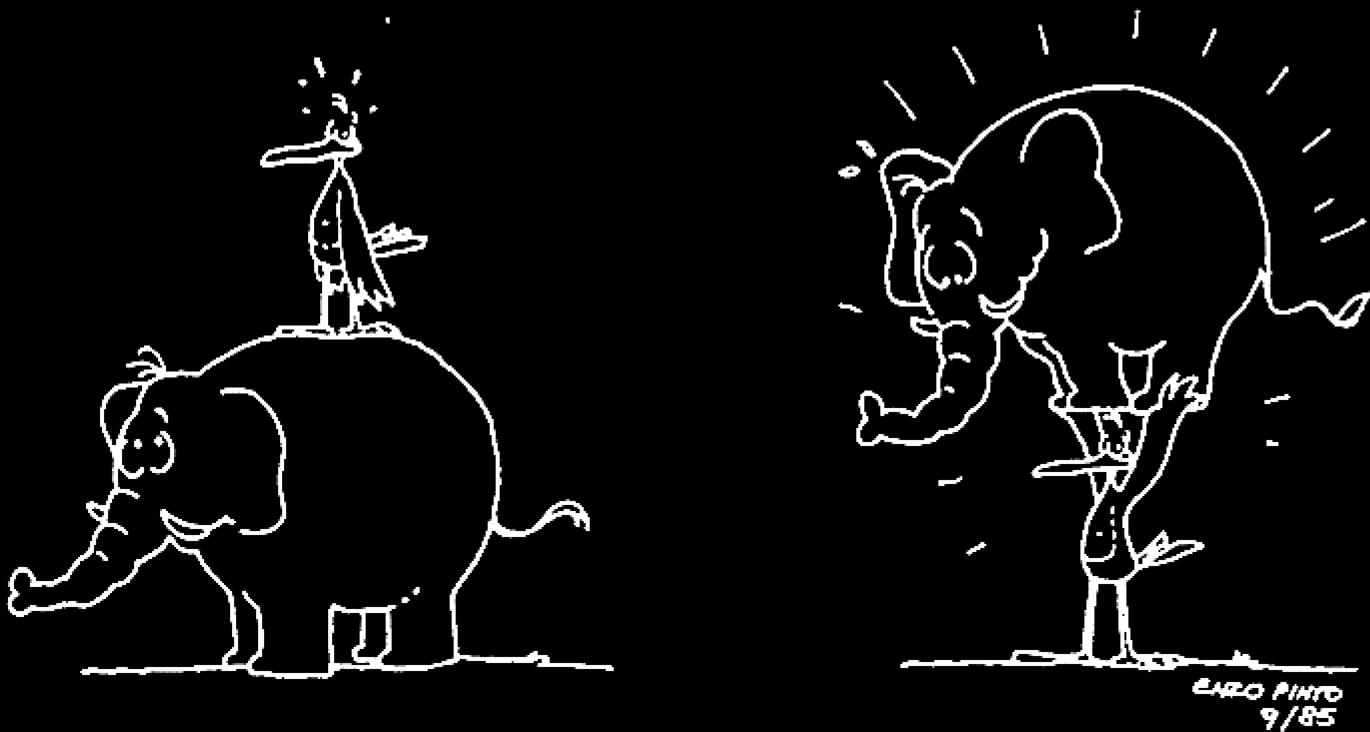


$$f = n\pi\sqrt{\frac{\left(\frac{T}{L}\right)}{m}}$$

‘rigidez geométrica’

$$k_g \sim \frac{T}{L}$$

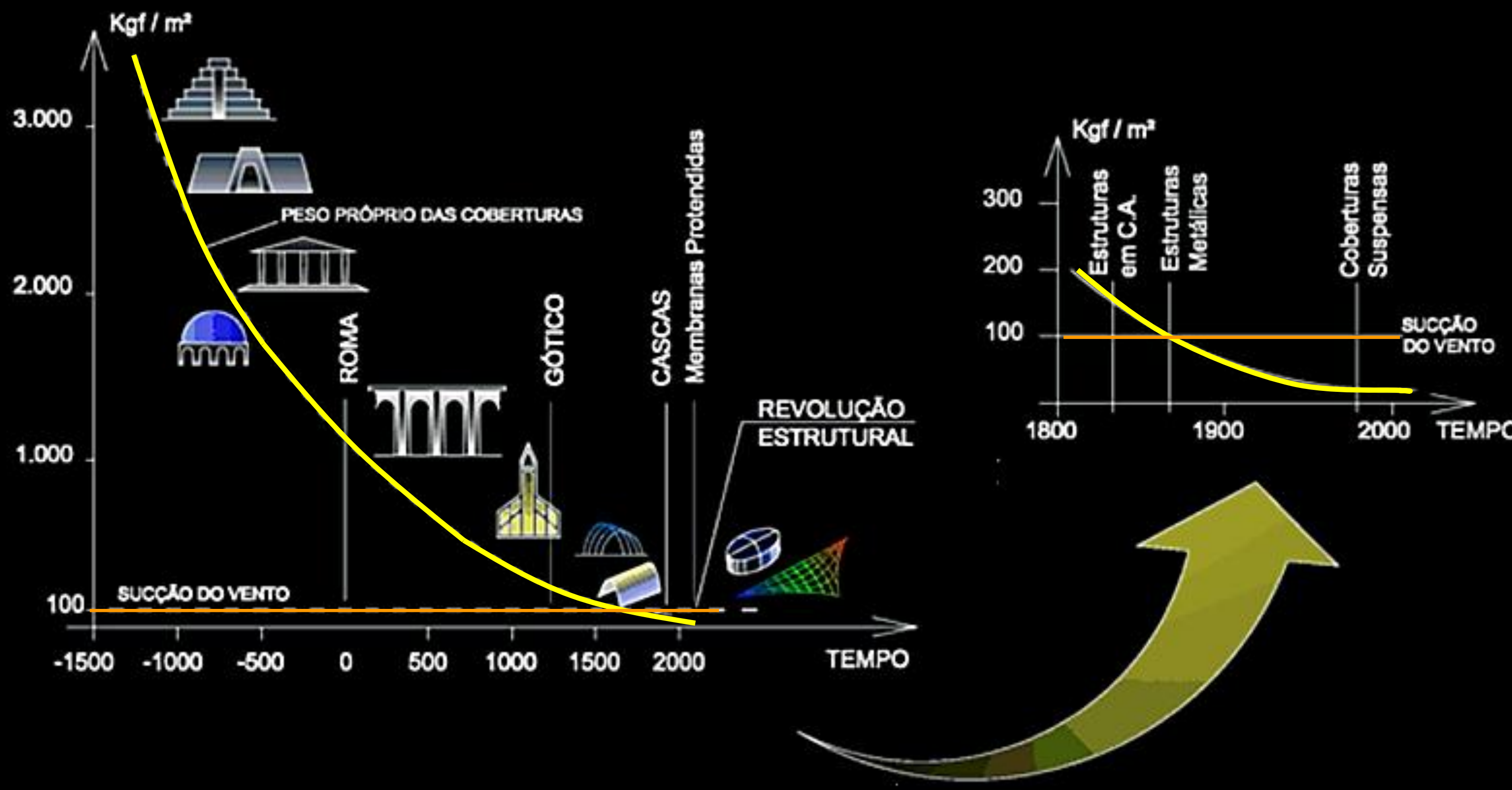
Estruturas Leves:



‘peso portante’ << ‘peso portado’

Desenho de Enzo Pinto, Nápoles, 1985.

Estruturas Leves:



Adapted from R. Serger, "Structures nouvelles in architecture", in Cahiers du centre d'estudes architecturales, n. 1, 1967, p. 42.

“Light structures, structures of light”

Horst Berger

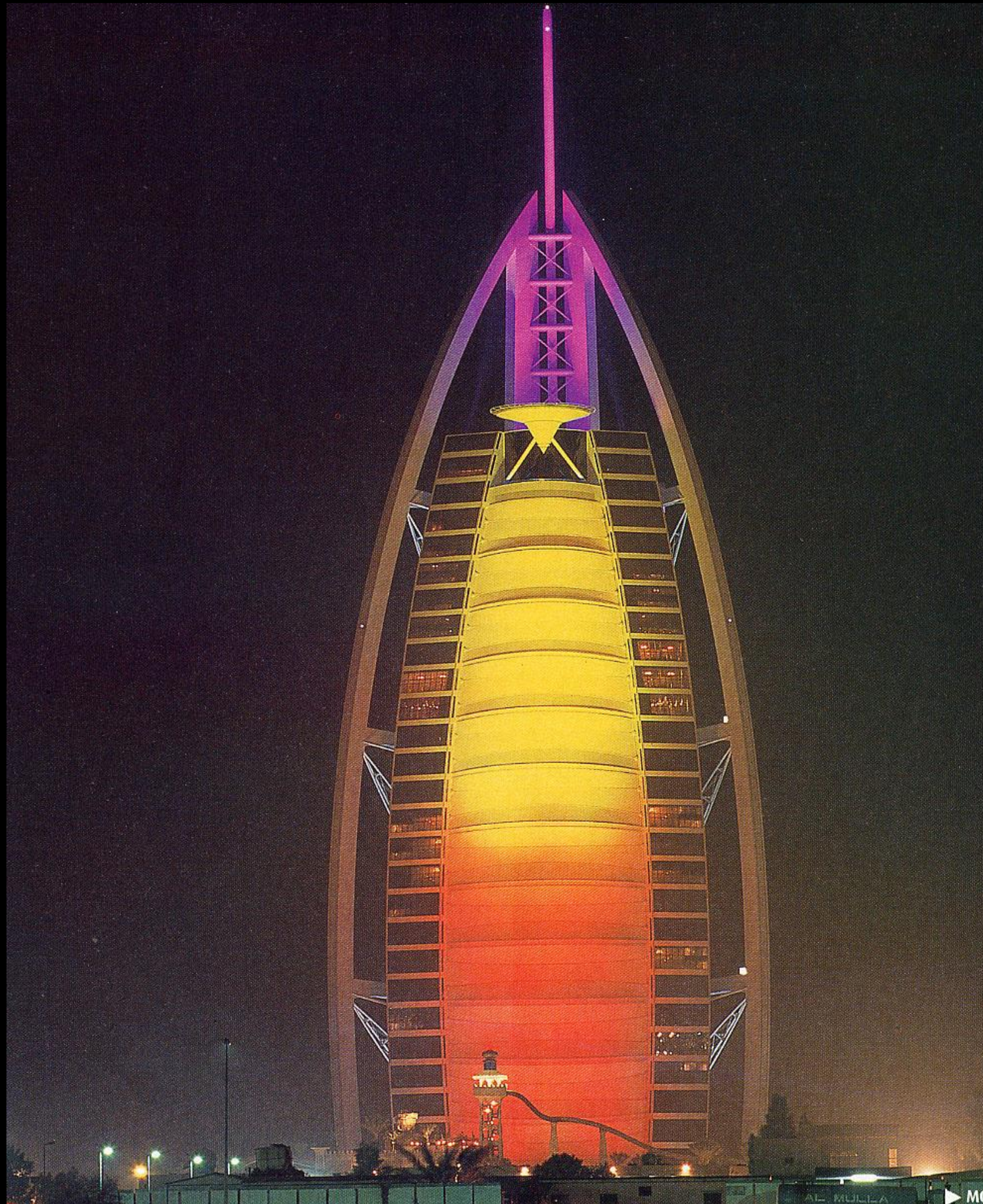
“Light structures, structures of light”

Horst Berger

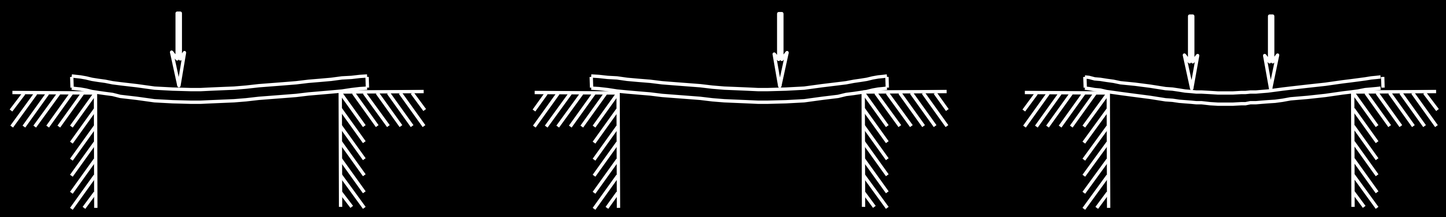
Suvarnabhumi Airport,
Bangkok, Thailand


Select Your Ultimate Home
from
CBRE

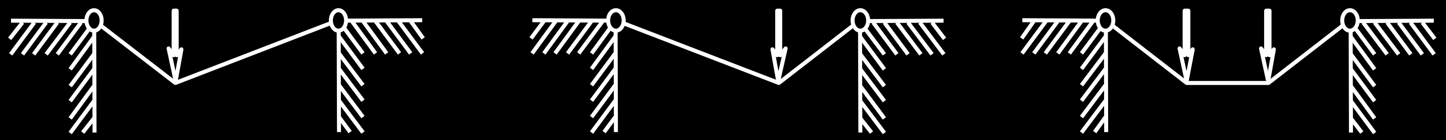
Photo by
Tim Nugent, 2009


AL MULLA

Estruturas Flexíveis:



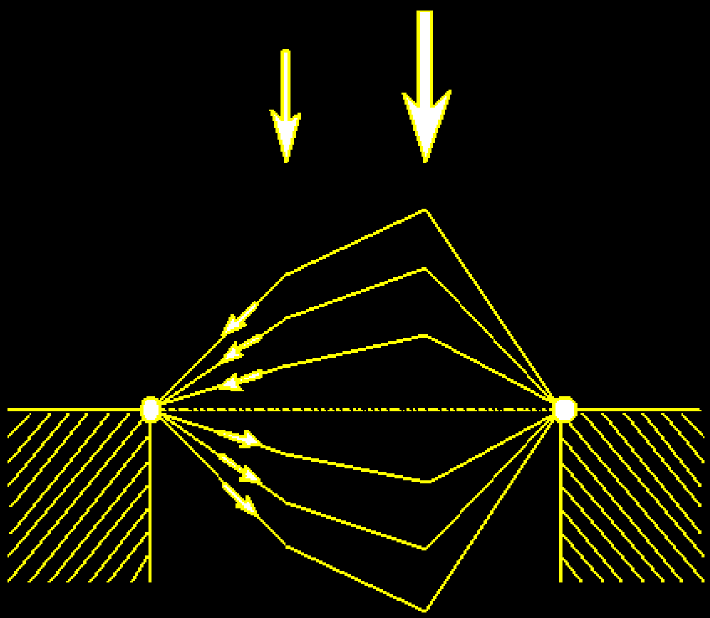
(a) Uma estrutura 'rígida' , como uma viga, não muda drasticamente de forma, quando o carregamento varia

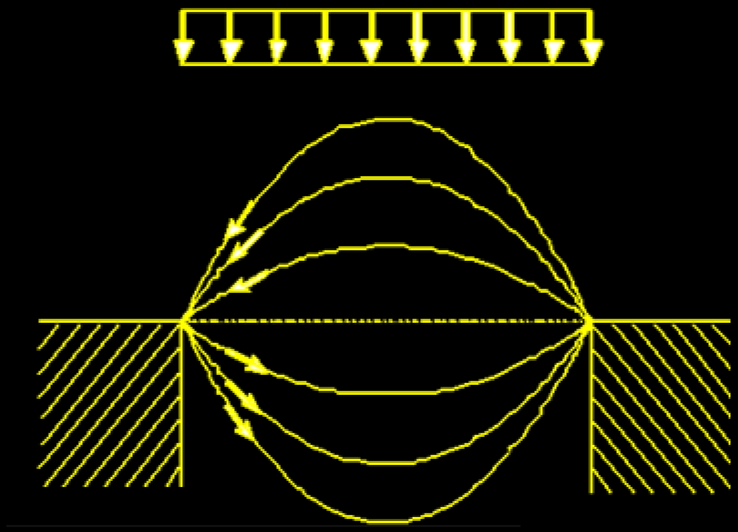


(b) Uma estrutura 'flexível', como um cabo, pode alterar drasticamente sua forma, quando o carregamento varia

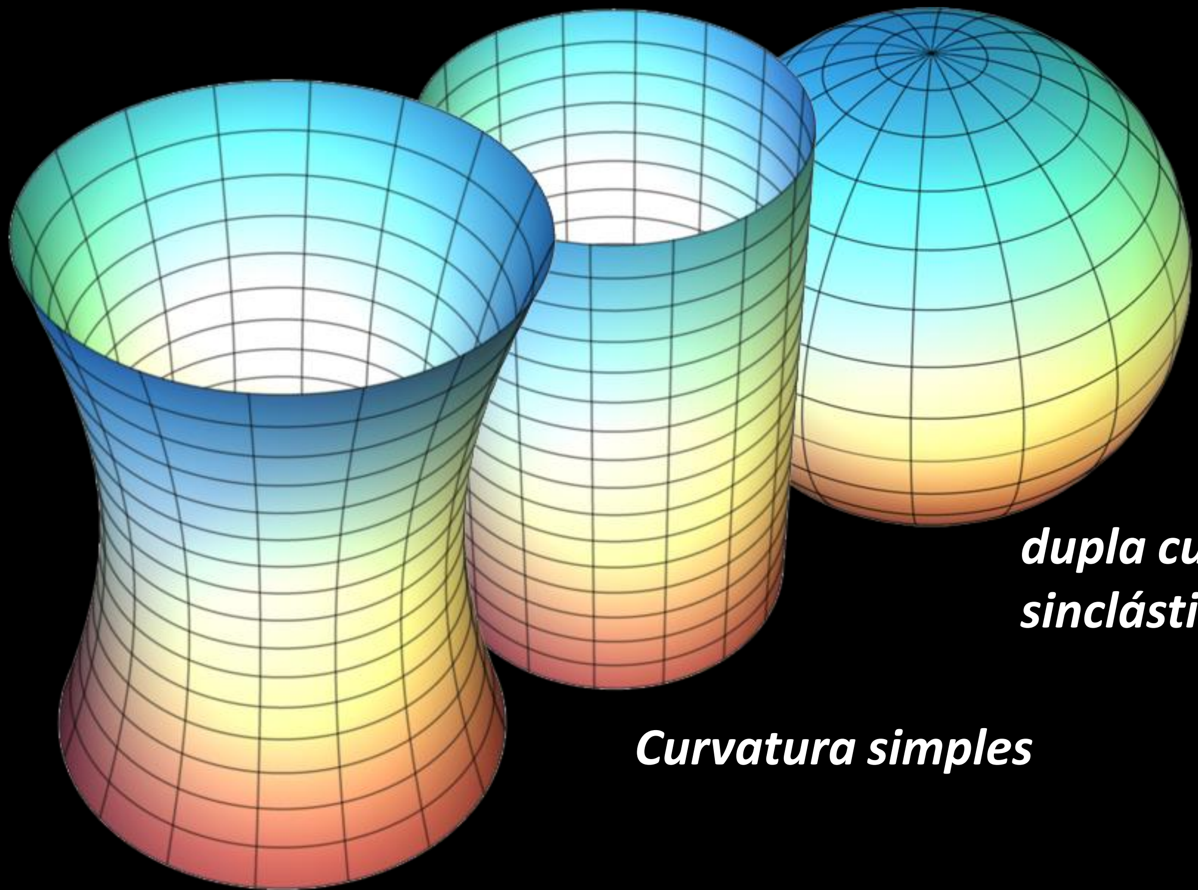

Estruturas flexíveis deve se conformar às formas funiculares:
‘aquelas que equilibram um conjunto de carregamentos, sem desenvolver esforços de flexão

Cada ‘padrão de carregamento’ tem associada a si uma ‘família de formas funiculares’:

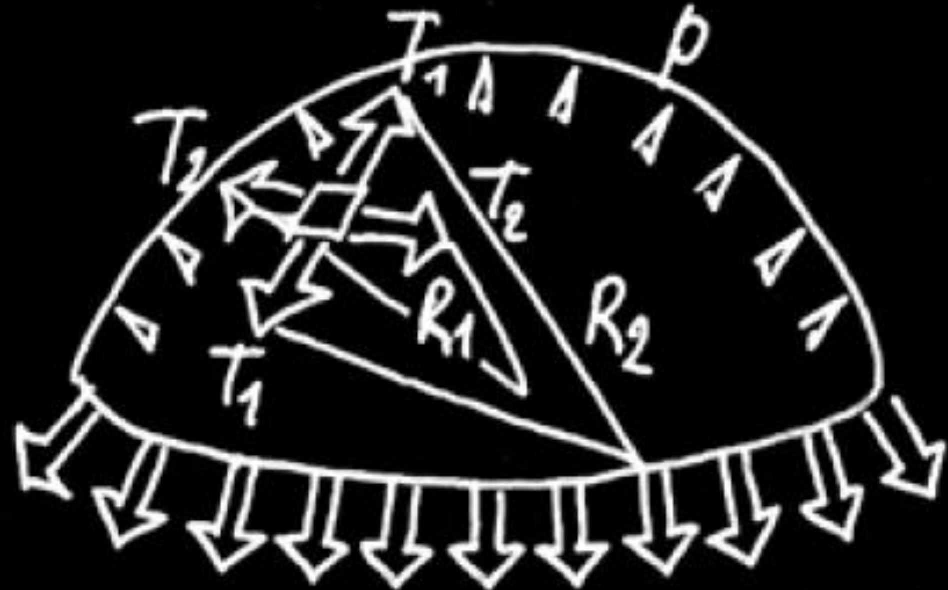




Membranas e redes de cabos usualmente constituem superfícies de curvatura simples ou dupla:

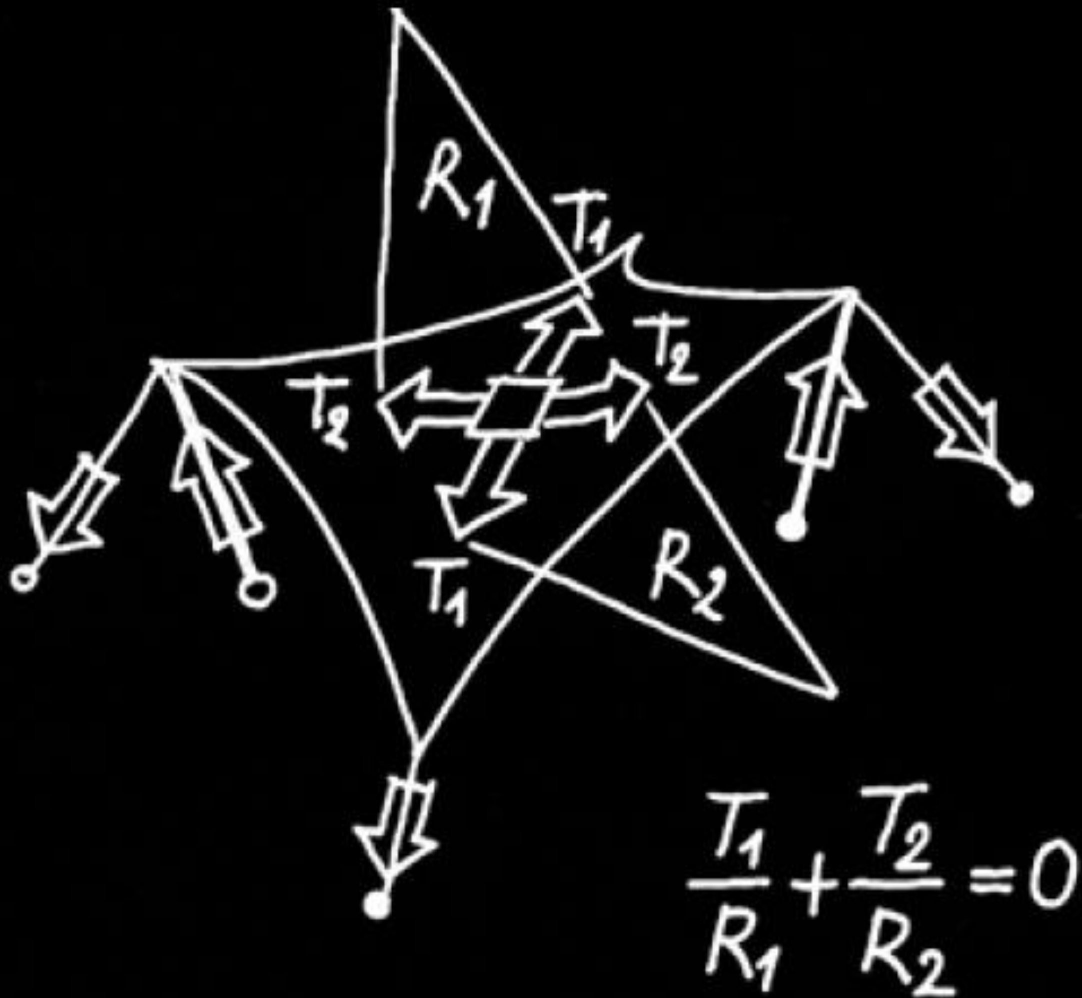


Membranas pneumáticas em geral são sinclásticas:

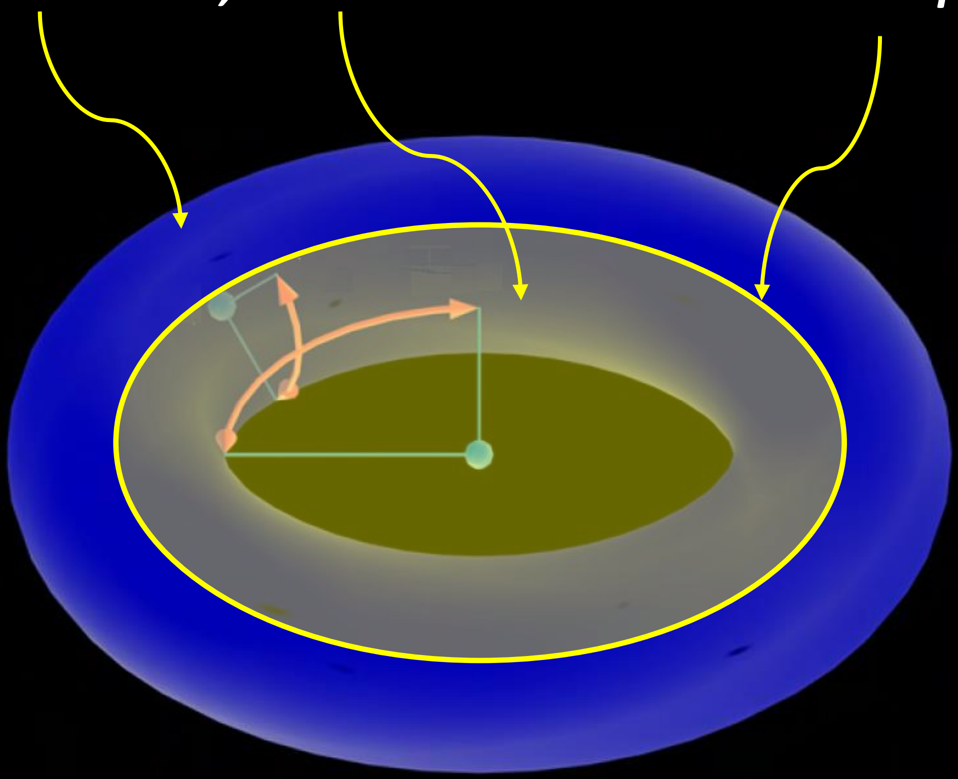


$$\frac{T_1}{R_1} + \frac{T_2}{R_2} = P$$

Porém tendas são sempre anticlásticas or planas!

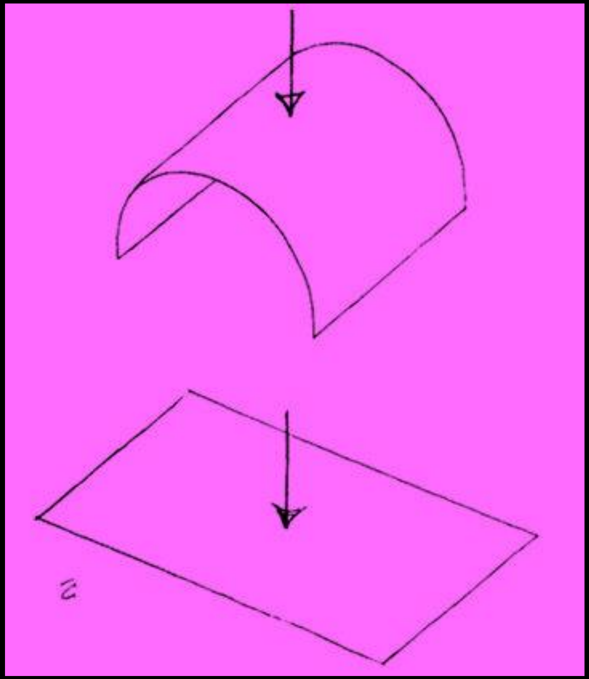


Estruturas pneumáticas podem apresentar zonas sinclásticas, anticlásticas e de curvature simples:

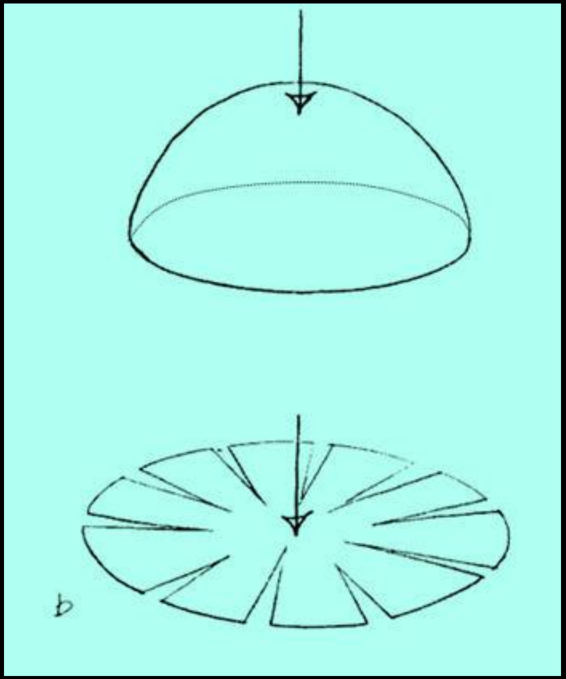



SAVE
THE
CLIMATE

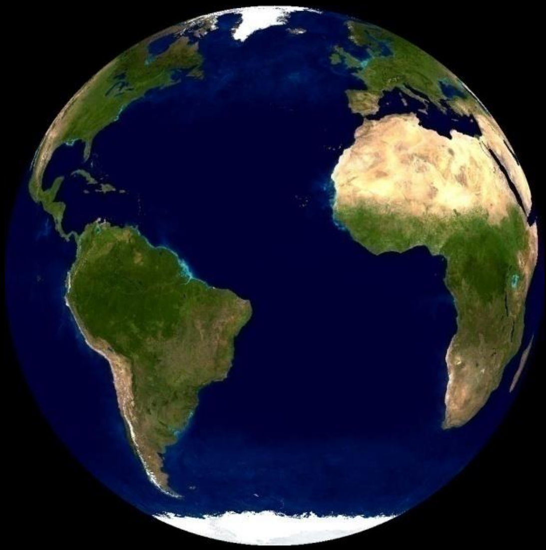
Planificação

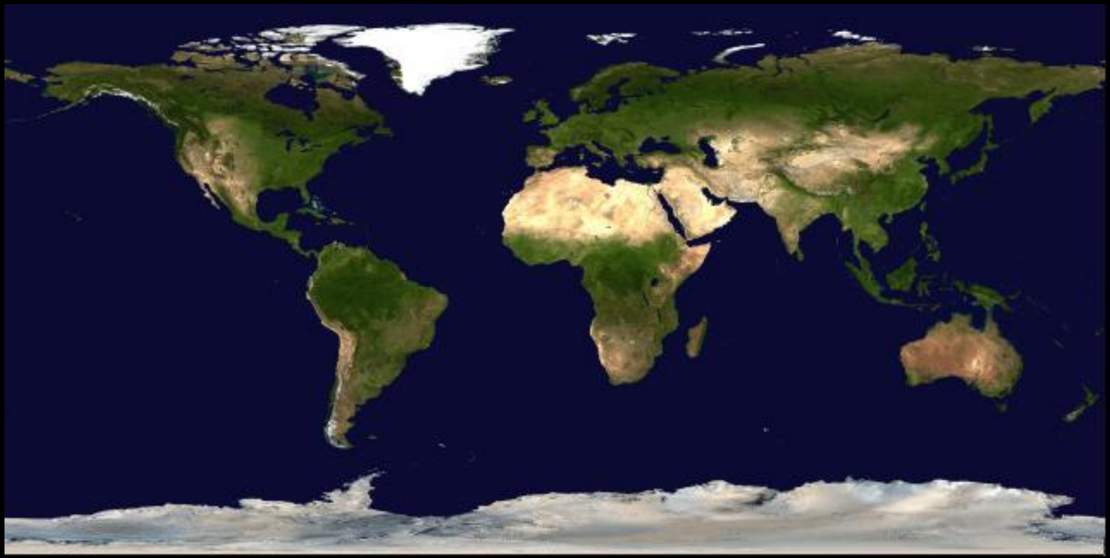


Superfícies de curvature simples
podem ser planificadas sem distorção

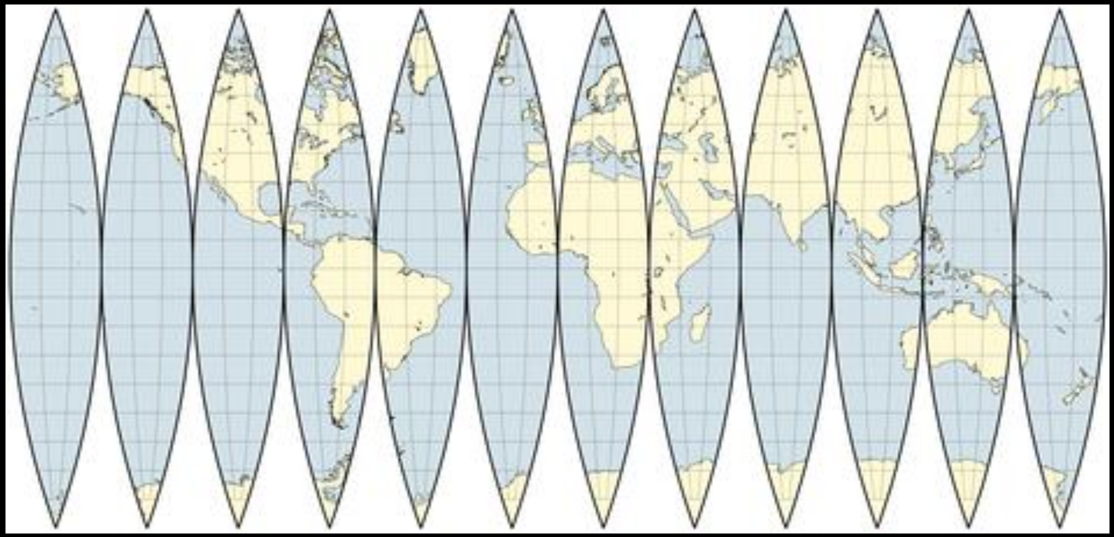


Superfícices de dupla curvature
sofrem distorção quando planificadas





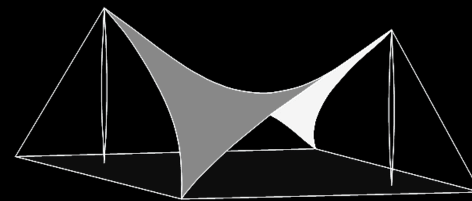
Mercator projection



A gore map using Apian's first projection.

O Processo de Projeto das Estruturas Retesadas

INTENÇÃO AEQUITETÔNICA:



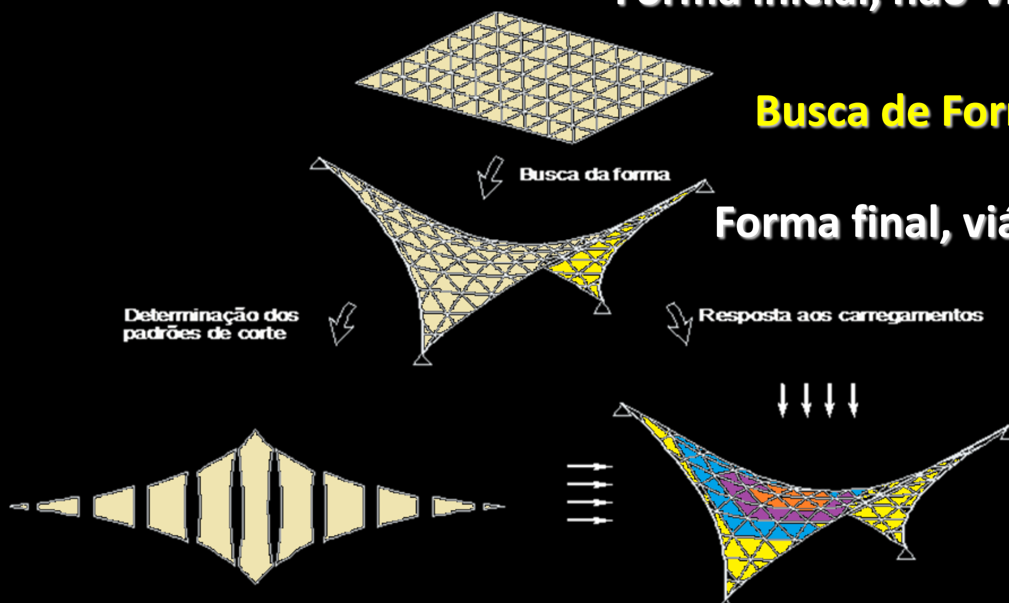
PROJETO / ANÁLISE:

Forma inicial, não-viável

Busca de Forma

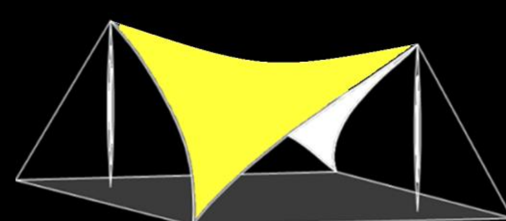
Forma final, viável

Padronagem:

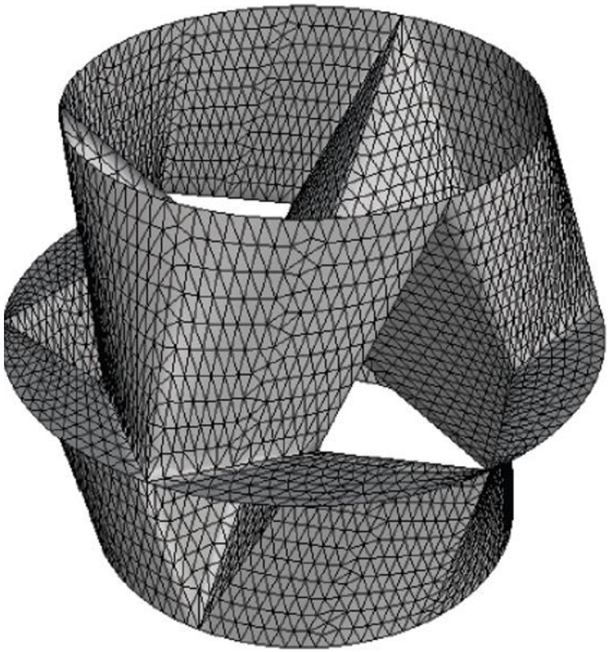


Análise de Carregamentos

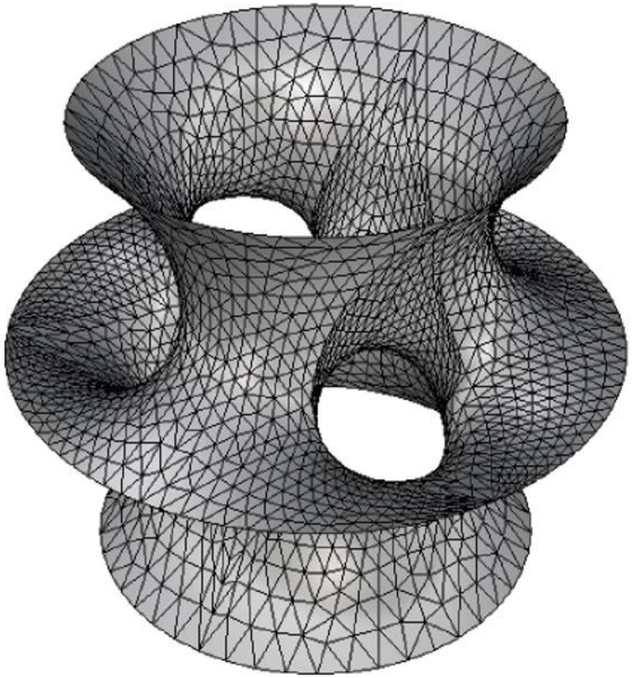
SOLUÇÃO DE PROJETO:



Uma escultura de membrana
(Princeton, 2017)

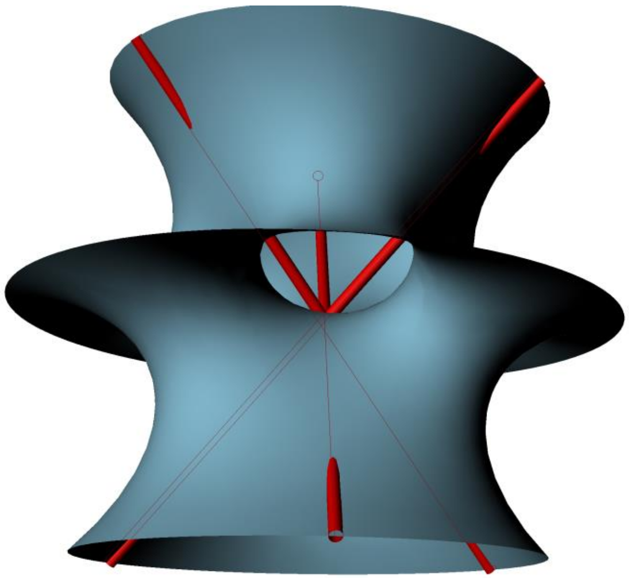


INITIAL MESH

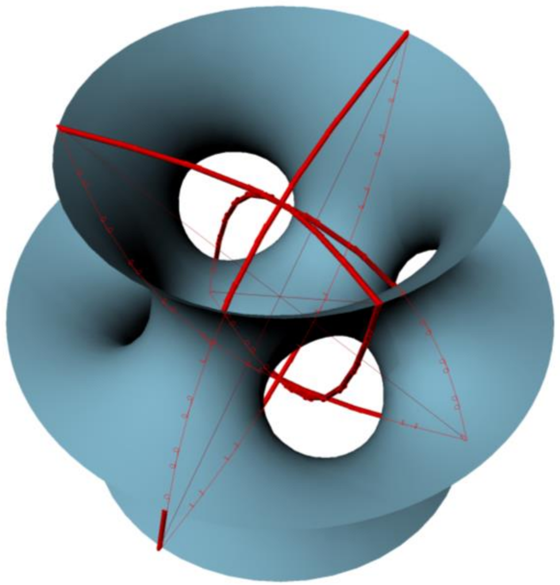


FINAL MESH

Sistema de retesamento de flexão ativa

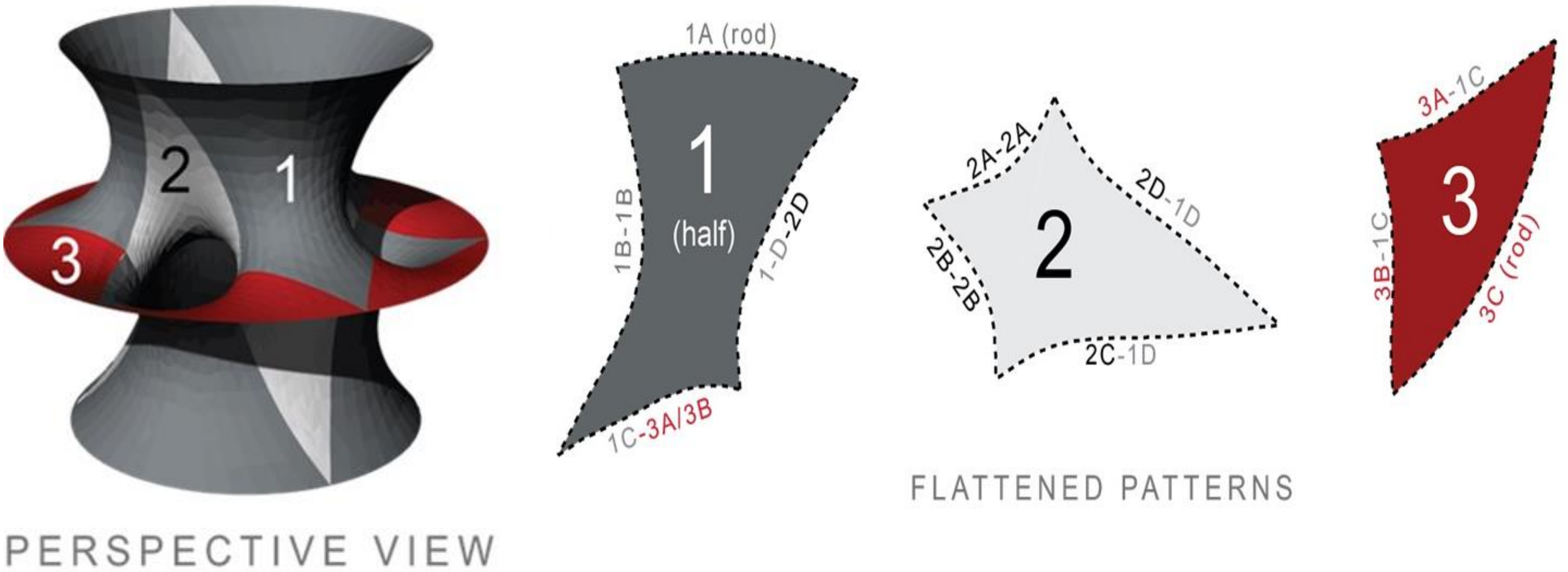


Barras retas interferem com a superfície da membrana



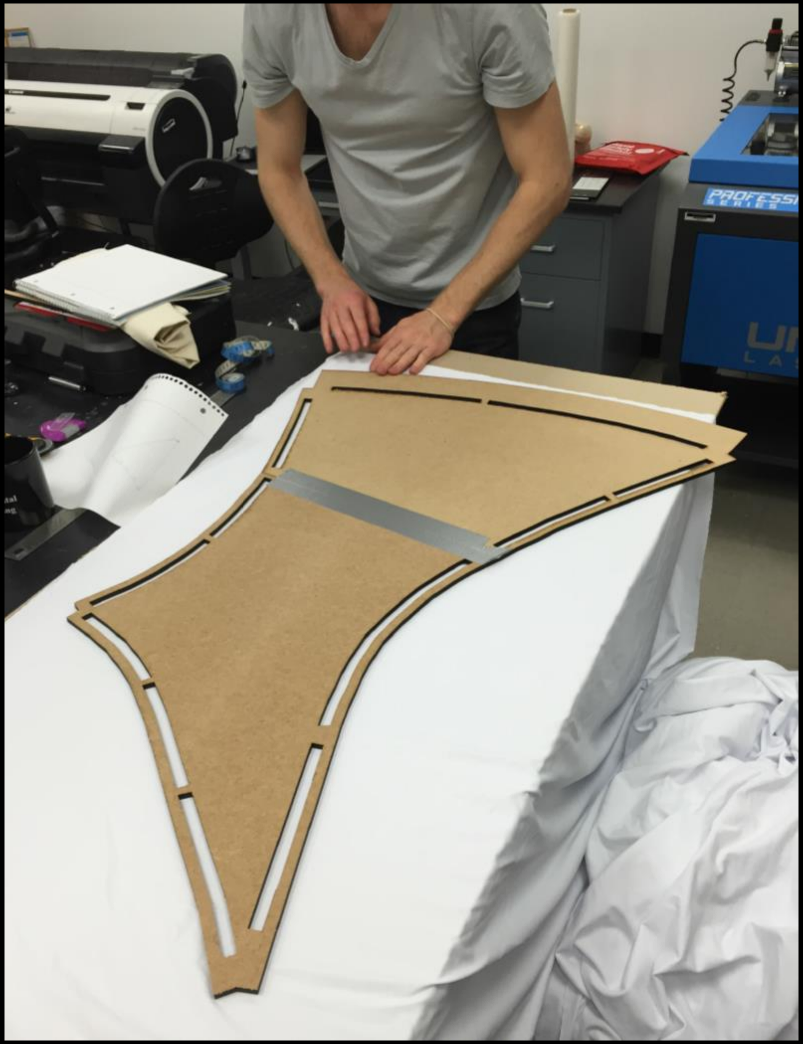
Barras fletidas podem sem acomodadaa e provêem um Sistema de ativação (retesamento) muito conveniente

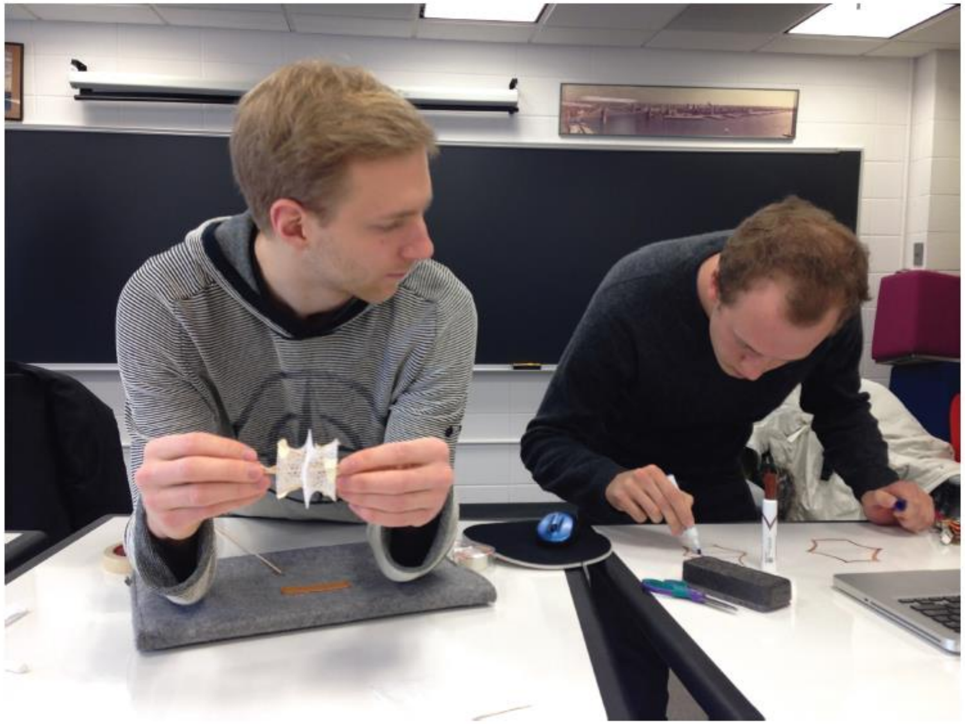
PADRONAGEM

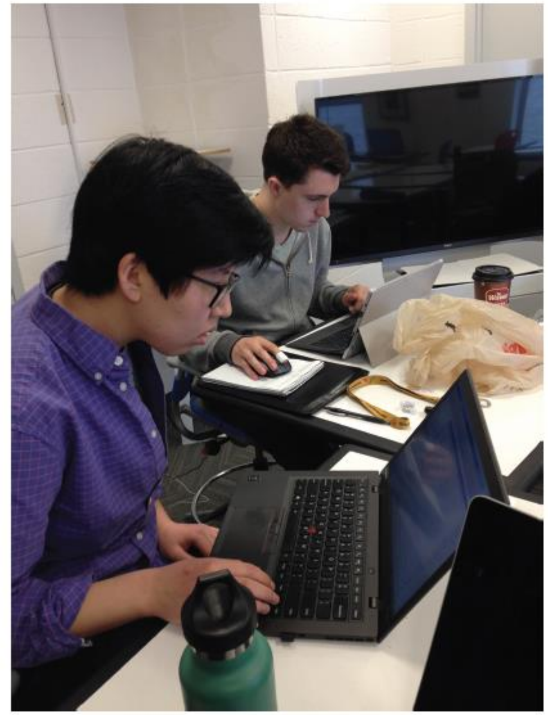


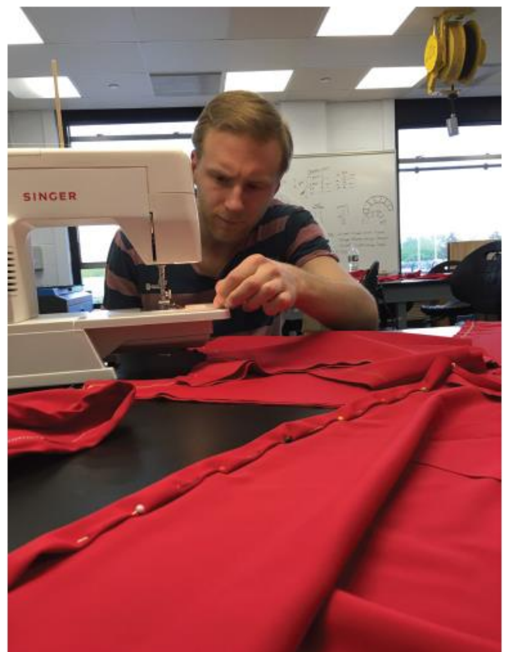
2
1
3
PERSPECTIVE VIEW
1A (rod)
1B-1B
1
(half)
1-D-2D
1C-3A/3B
2A-2A
2D-1D
2B-2B
2
2C-1D
3A-1C
3B-1C
3
3C (rod)
FLATTENED PATTERNS

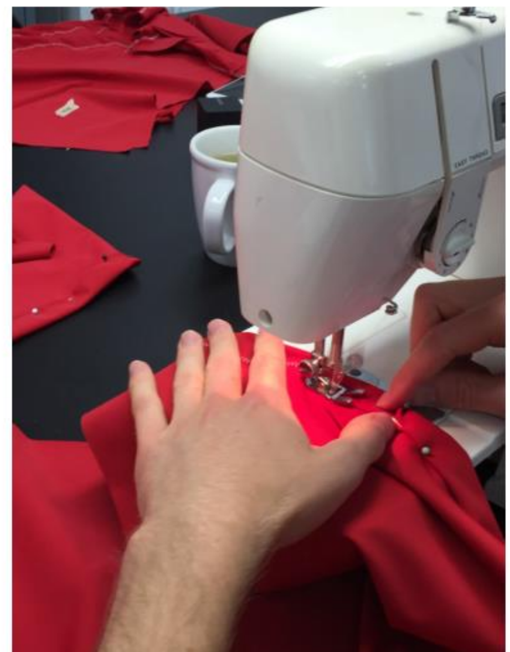
PRODUÇÃO

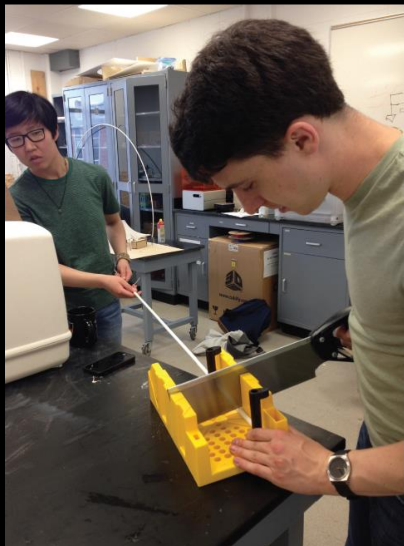


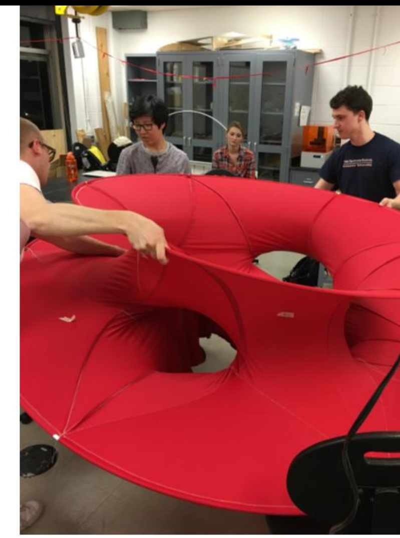


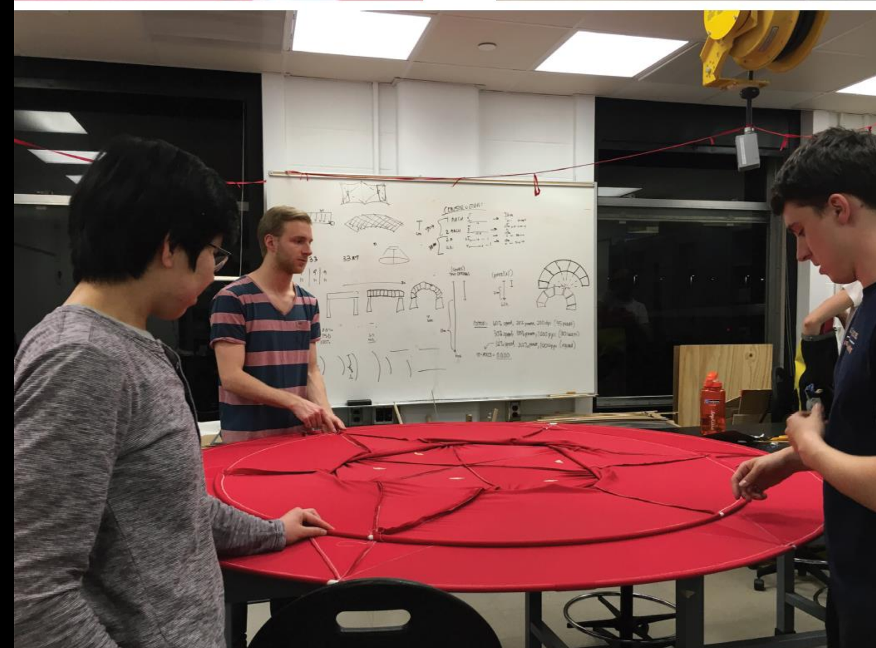


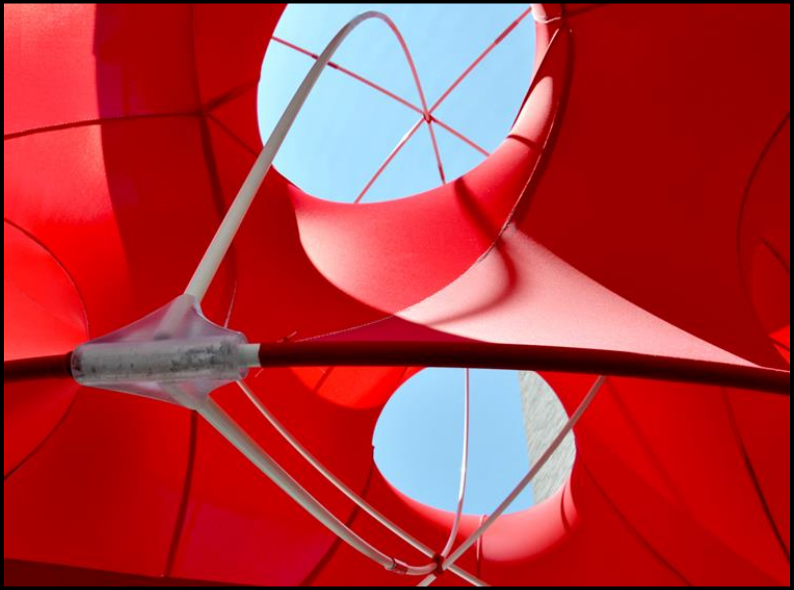

SINGER





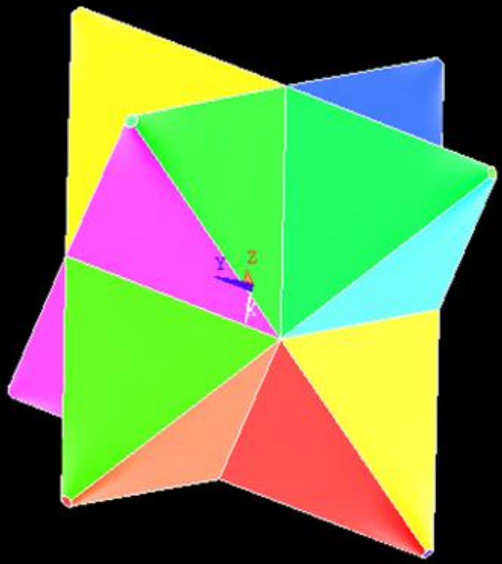



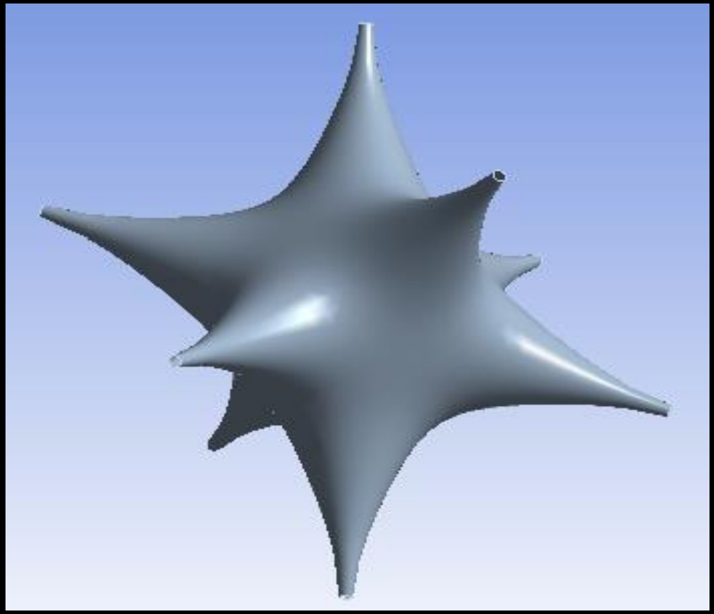


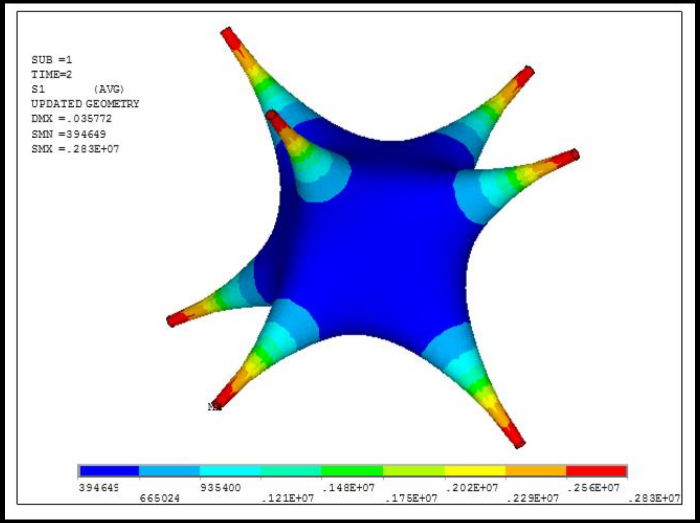


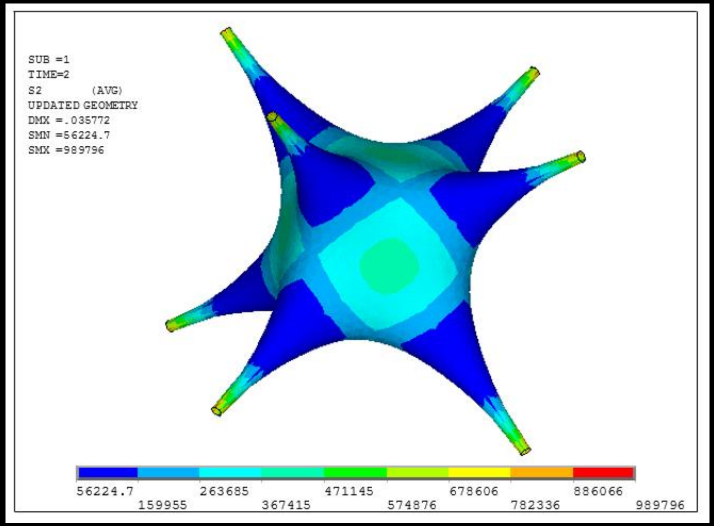
A escultura exibida no hall of Universidade de Hamburgo (2017)

The Octahedral cusped (São Paulo, 2017)

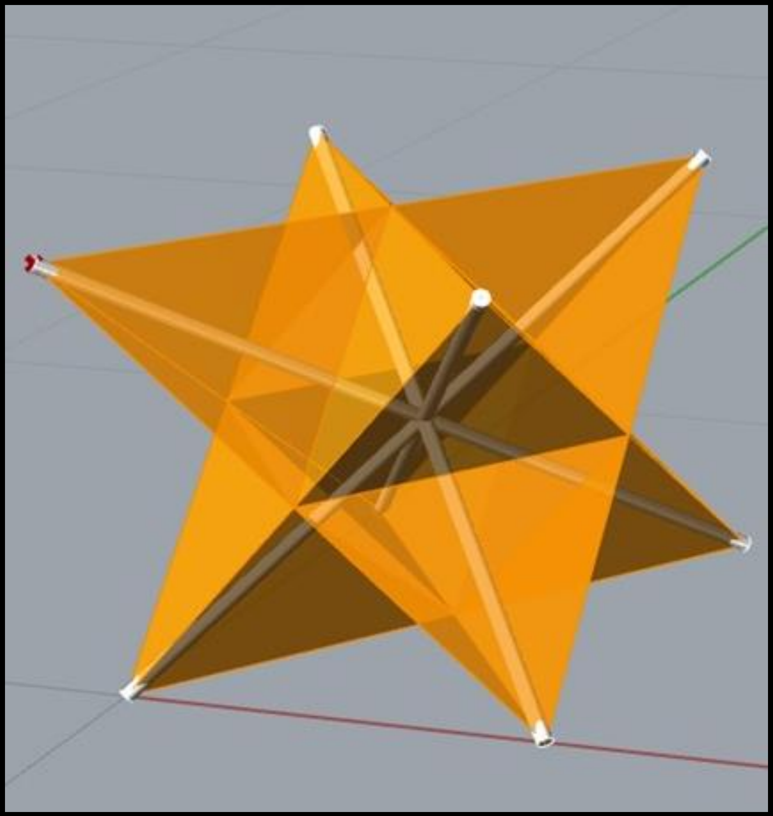


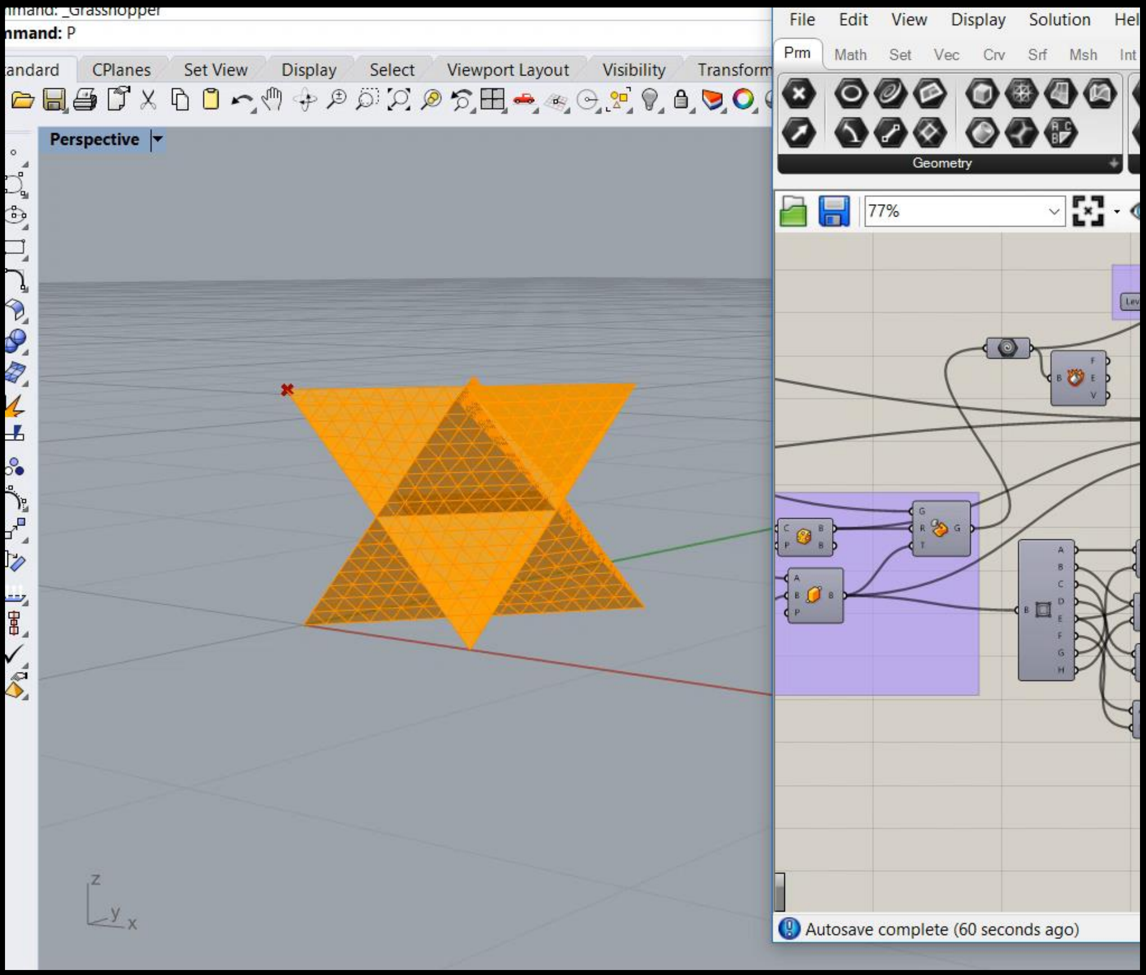


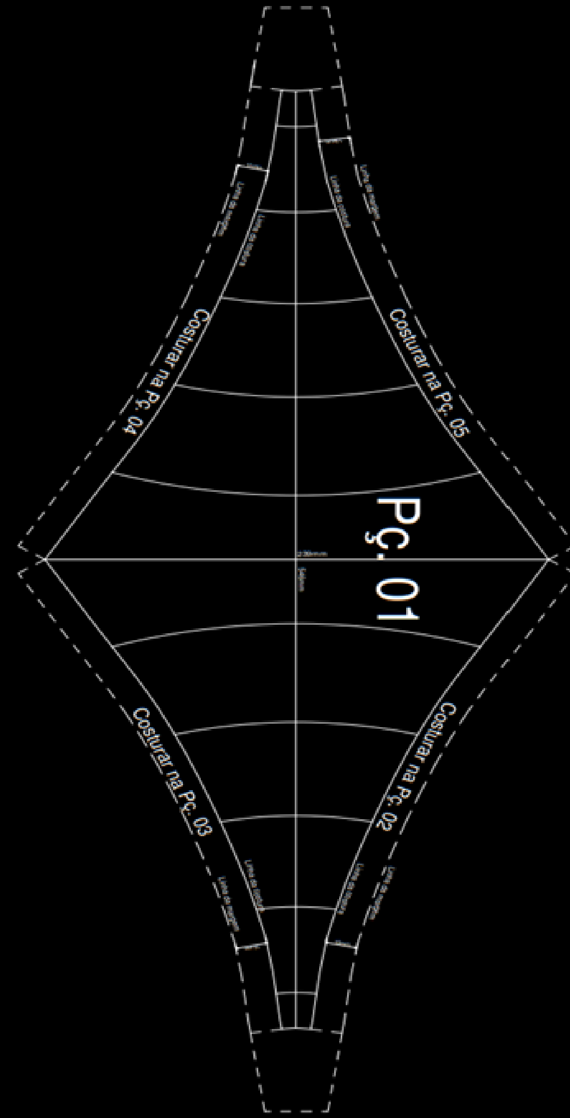




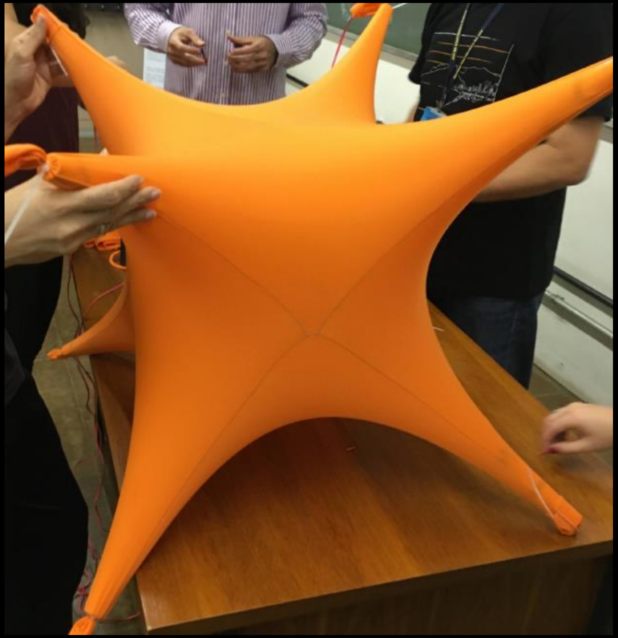
The Octahedral cusped (São Paulo, 2017)



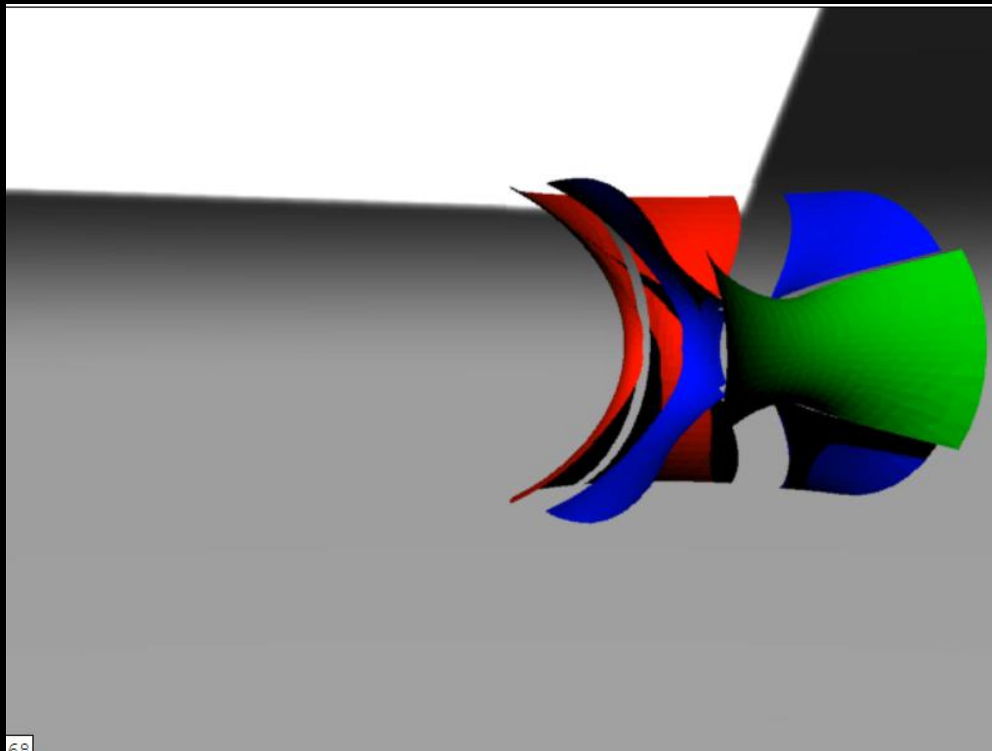


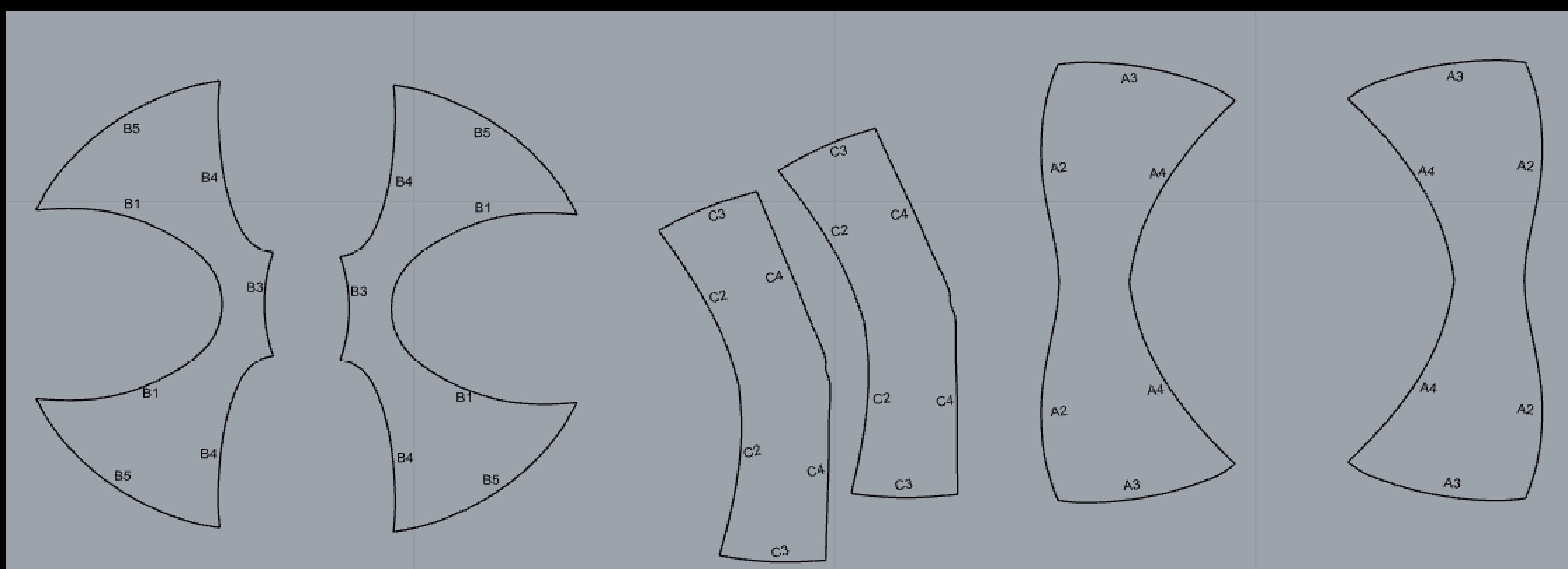

Costurar na Pç. 04
Costurar na Pç. 05
Pç. 01
Costurar na Pç. 03
Costurar na Pç. 02



An Enneper surface with a Handle (Padua, 2018)


68


B5
B4
B1
B3
B1
B4
B5
B5
B4
B1
B3
B1
B4
B5
C3
C4
C2
C2
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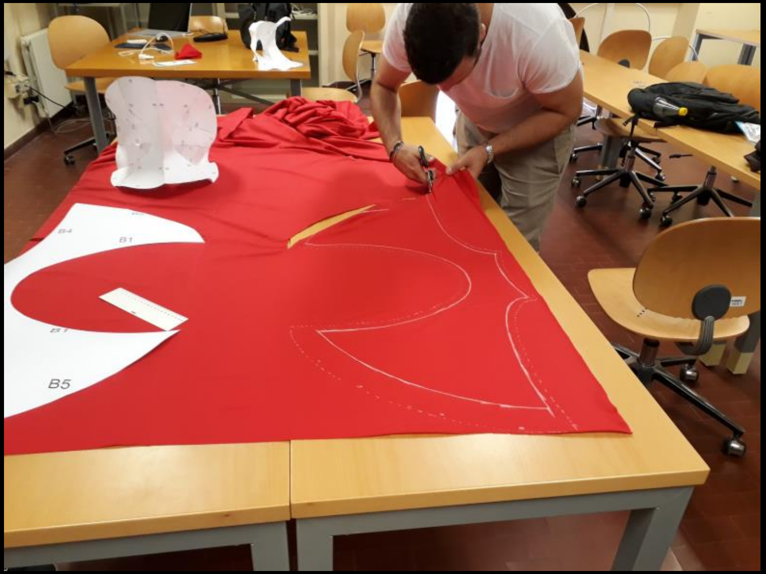
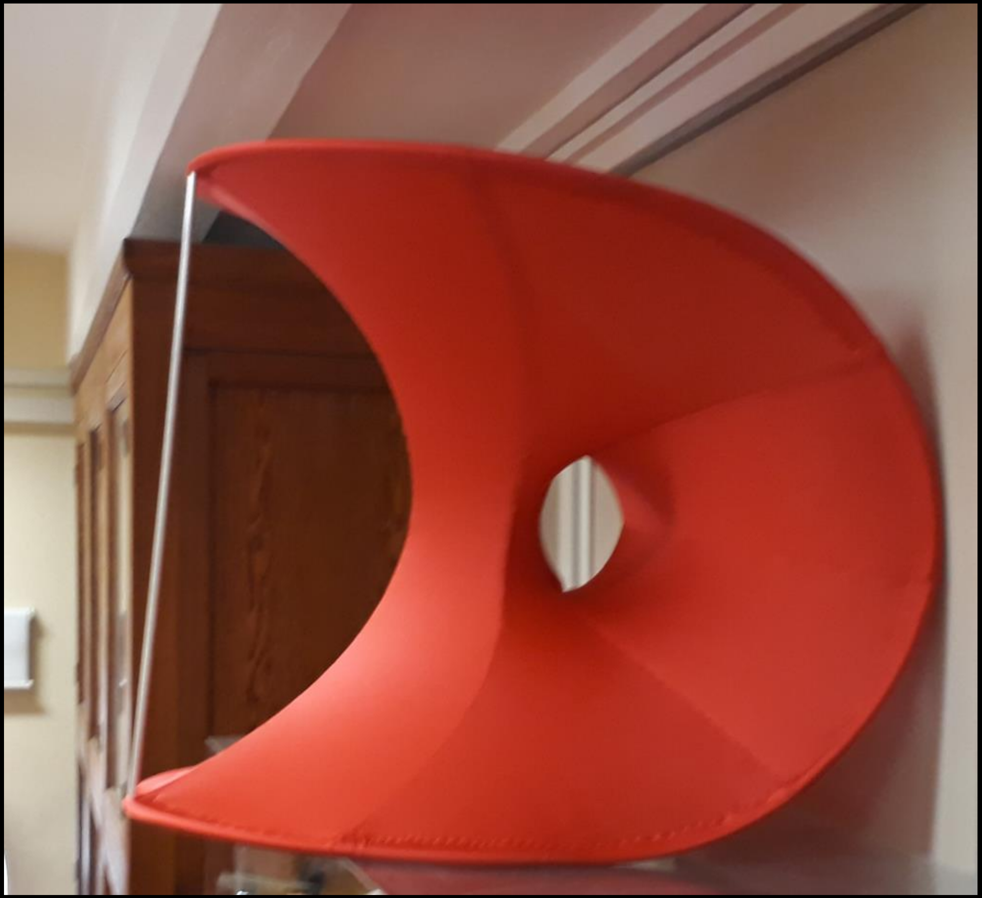
C2
C4
C3
A3
A2
A4
A4
A2
A3
A3
A4
A2
A4
A2
A3


C3
C4
C2
C3
C2
C4
C3
A2
A4


B4
B1
B5

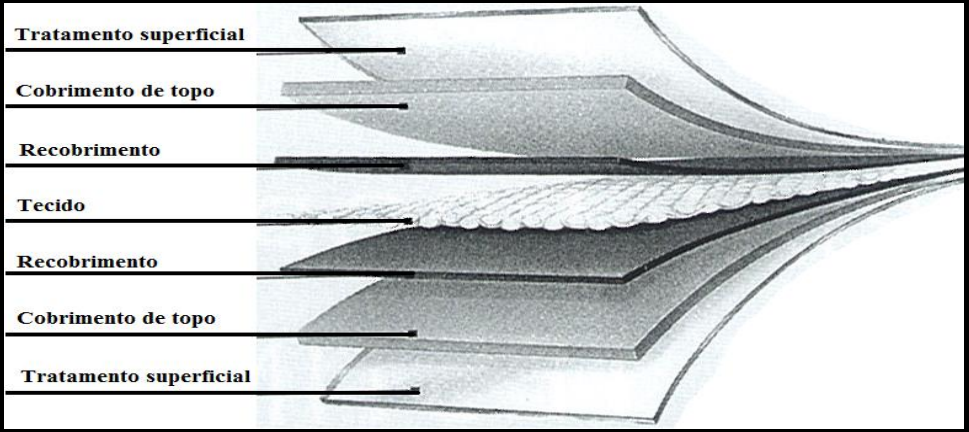

B5
B1
B5
B3



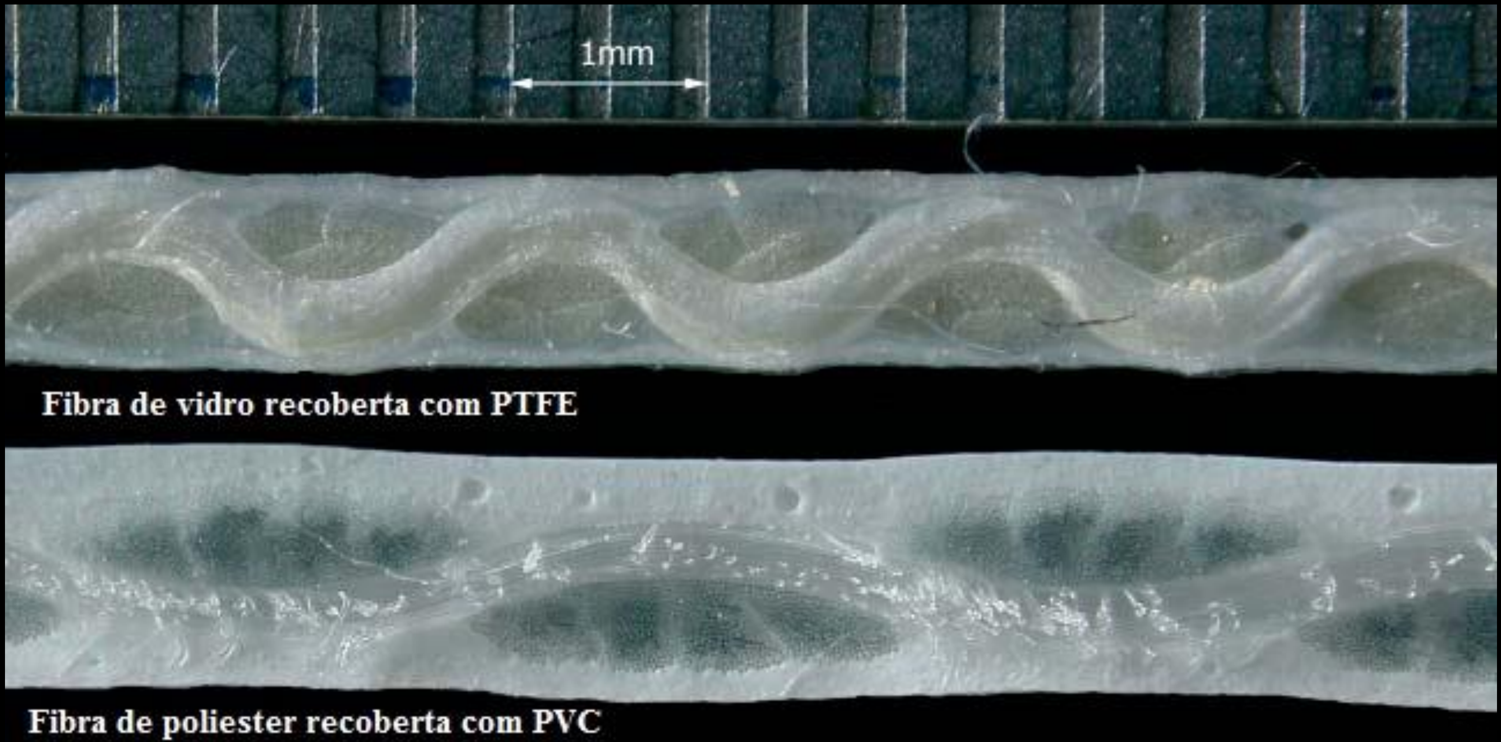
Tecidos técnicos

Produção de um tecido de fibra de vidro (Pudenz, 2004)

Recobrimento com PTFE (Pudenz, 2004)

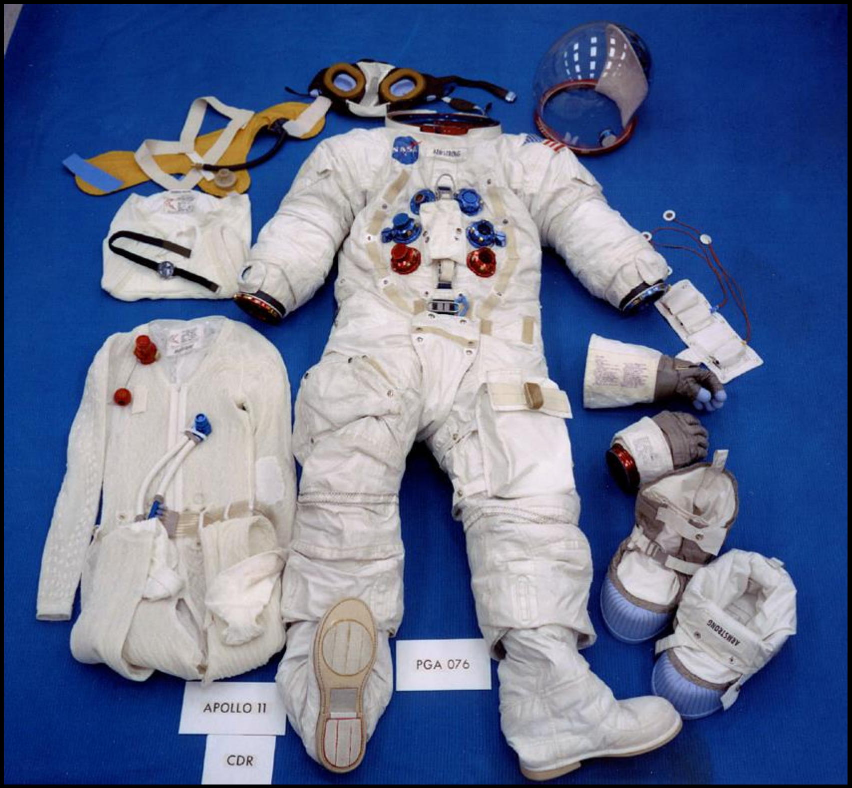


Diferentes camadas de um tecido técnico Blum *et al* (2004)

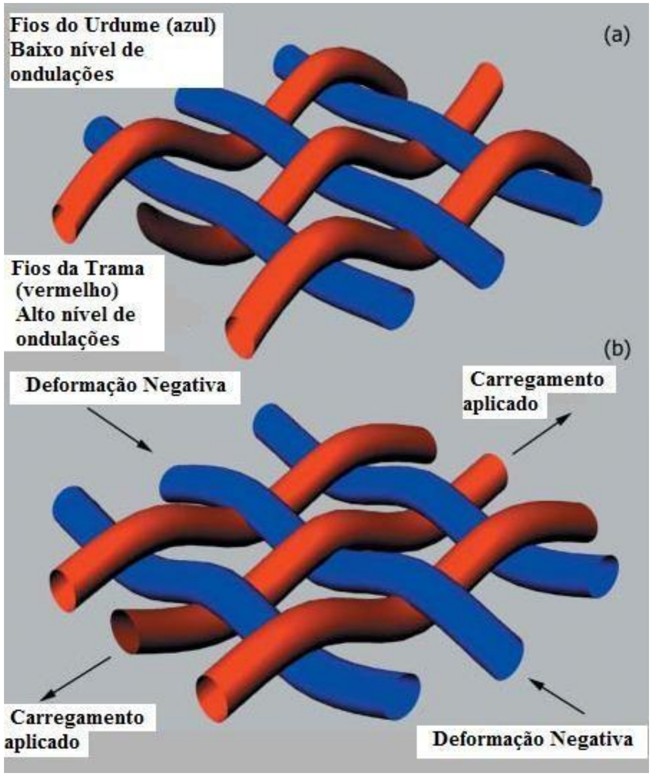


Seções transversais de tecidos de fibra de vidro e poliéster (BRIDGENS et al, 2004).

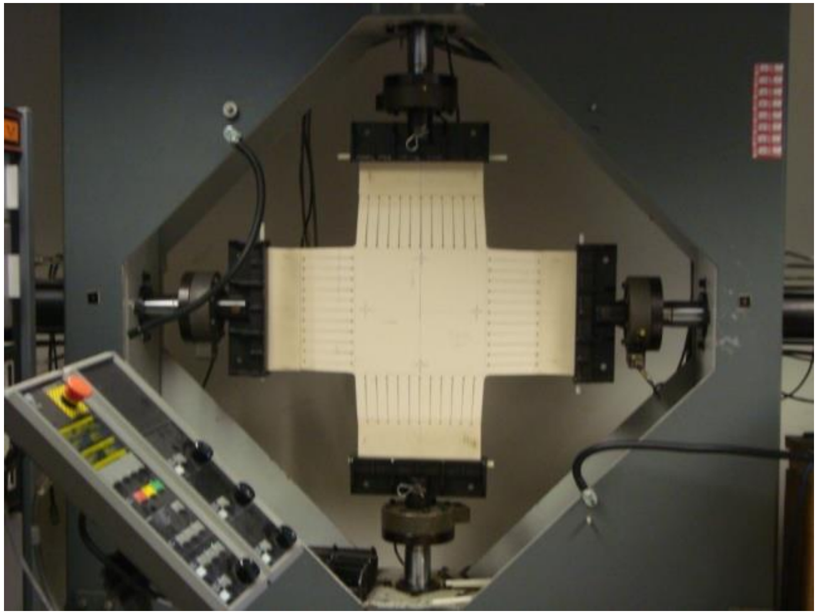
PTFE-covered fiberglass fabric (1969)
DuPont, Birdair, Chemfab & Owens-Corning



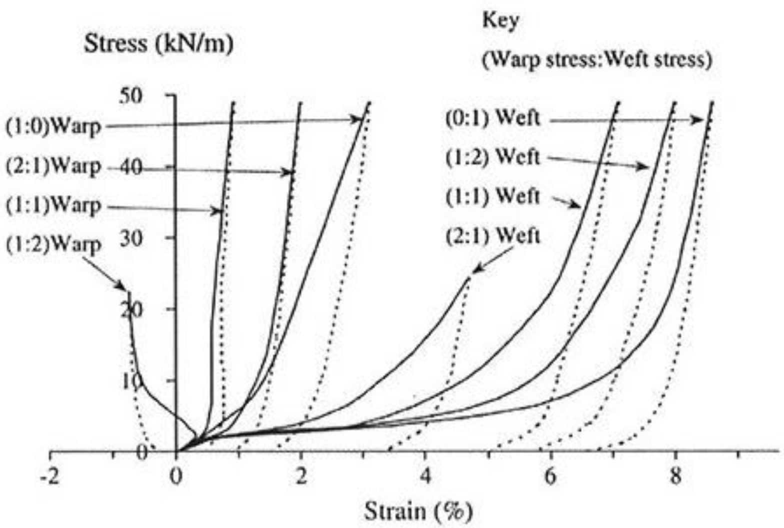
Neil Armstrong's Suit
Apollo 11 Project (1969)



Crimp Interchange,
Bridgens et al. (2004).



Biaxial test (Chivante, 2009)



σ-ε curves for a PTFE-fiberglass fabric
(warp = urdume; weft = trama), Kato *et al* (1999)

Comparison between different types of structural fabrics

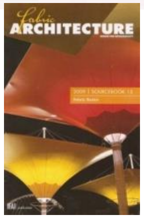
	PVC coated polyester fabrics	PTFE coated glass fabrics	Silicone coated glass fabrics	PTFE coated PTFE fabrics
Tensile strenghth warp/weft (kN/m)	115/102	124/100	107/105	84/80
Fabric weight (g/m²)	1200 (type 3)	1200 (type G5)	1100	830
Trapezoïdal tear warp/weft (N)	800/950	400/400	960/700	925/925
Visible light transmission (%)	10-15	10-20	< 80	19-38
Flexibility/crease recovery	high	low	high	high
Fire reaction	M2 (NFP 92 503) B1 (DIN 4102)	M1 (NFP 92 503) B1/A2 (DIN 4102)	A (ASTM E-108) no toxicity of smokes	
Cleaning	easier with top coats	self cleaning	self cleaning	self cleaning
How to make the seams	by high frequency	thermally	vulcanisation	stitching
Life span (years)	> 15-20	> 25	> 25	
Cost	low	high	high	

Comparação de usos e custos de diferentes tipos de tecido (incluindo elementos complementares)

Fabric type	Typical use	Cost comparison*
PTFE-coated fiberglass	Large scale permanent structures Class A ASTM E-108	\$75 – 100 per ft.^{2}
Silicone-coated fiberglass	Large scale permanent structures Class A ASTM E-108	\$75 – 100 per ft.^{2}
Vinyl-coated polyester	Temporary and permanent structures	\$50 – 75 per ft.^{2}
Woven PTFE	(More pliable than standard PTFE) Retract-able roofs, structures	\$85 – 125 per ft.^{2}
ETFE	High transparency (97%) Atria, indoor parks, biospheres, skylight applications	\$100 – 125 per ft.^{2}
HDPE (High Density Polyethylene)	Shade structures/systems	\$25 – 50 per ft.^{2}
Laminates	Tents, awnings & canopies	\$35 – 50 per ft.^{2}

*2008 dollars. Surface area X cost per ft^2 = Budget Plan area (length X width) X Shape factor (H) = Surface area

Fabric Architecture 2009 Sourcebook



Tecidos de poliéster recobertos com PVC

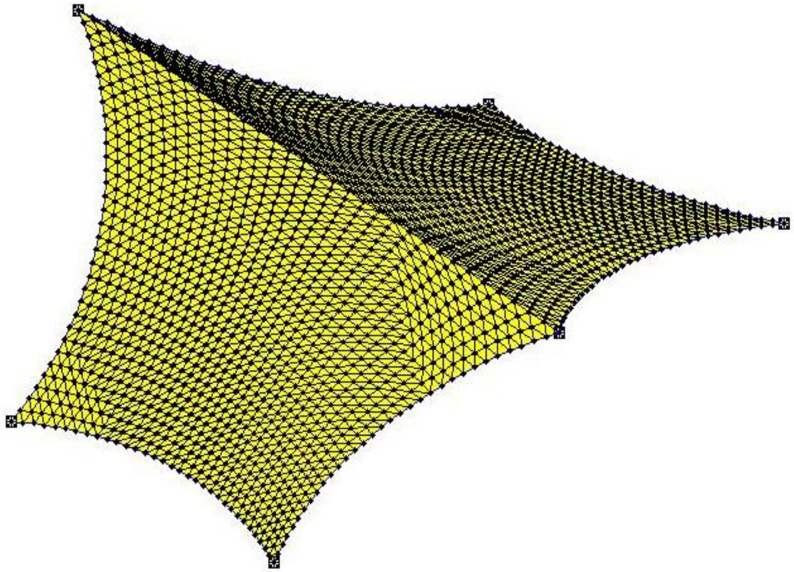
Type	1	2	3	4	5
Surface weight (g/m²)					
French design guide	720	1 000	1 200	1 400	2 000
WG Messe Frankfurt	800	900	1 050	1 300	1 450
Yarn linear density (dtex)					
French design guide					
WG Messe Frankfurt	1 100	1 100	1 670	1 670	2 200
Tensile strength warp/weft (kN/m)					
French design guide	60/60	84/80	110/104	120/130	160/170
WG Messe Frankfurt	60/60	88/79	115/102	149/128	196/166
Trapezoïdal test warp/weft (N)					
French design guide					
WG Messe Frankfurt	310/350	520/580	800/950	1 100/1 400	1 600/1 800
Yarn number per cm warp/weft					
French design guide					
WG Messe Frankfurt	9/9	12/12	10.5/10.5	14/14	14/14

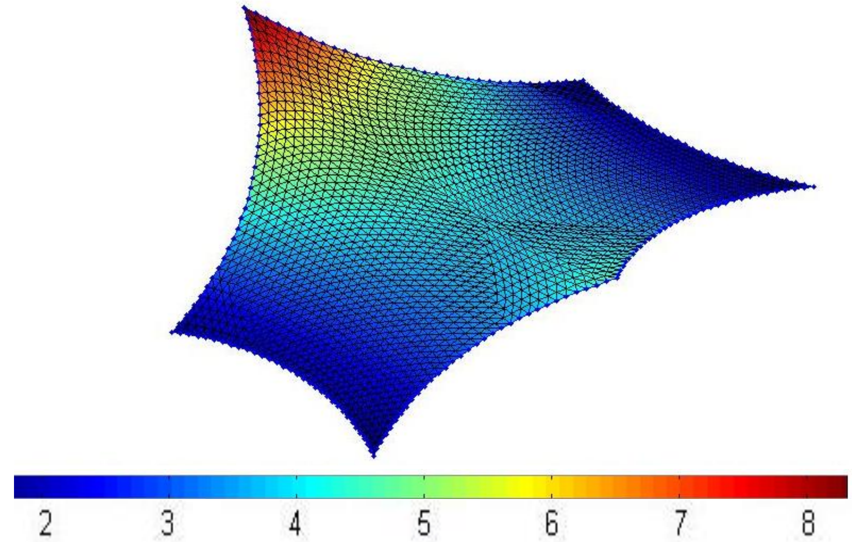
Tecidos Poliéster / PVC Resistência ao fogo – Incêndio Shopping Nova América, RJ - 2015

Tecidos Poliéster / PVC Resistência ao fogo – Incêndio Shopping Nova América, RJ - 2015

Tecidos Poliéster / PVC Resistência ao fogo – Incêndio Shopping Nova América, RJ - 2015

Membrana de cobertura do Memorial dos Povos de Belém do Pará (2006)

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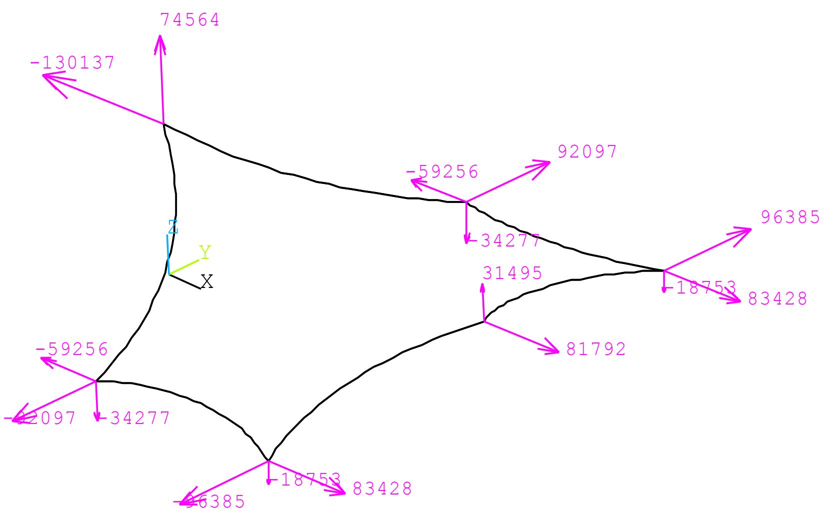
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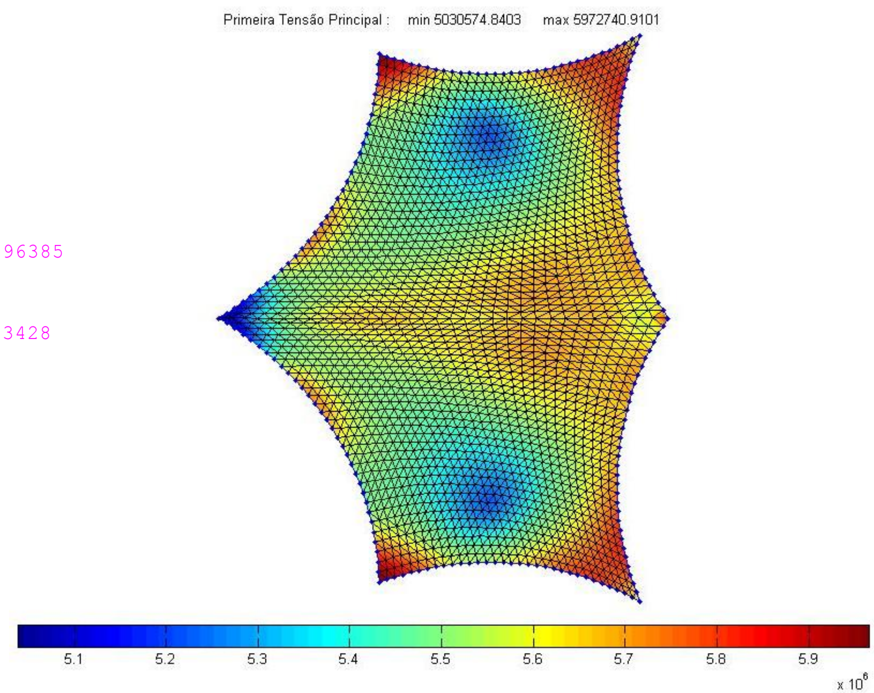
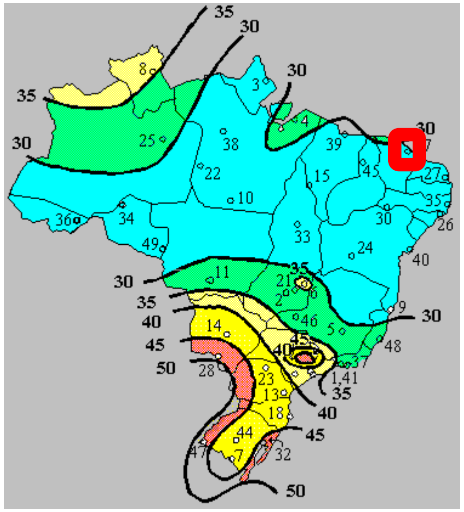
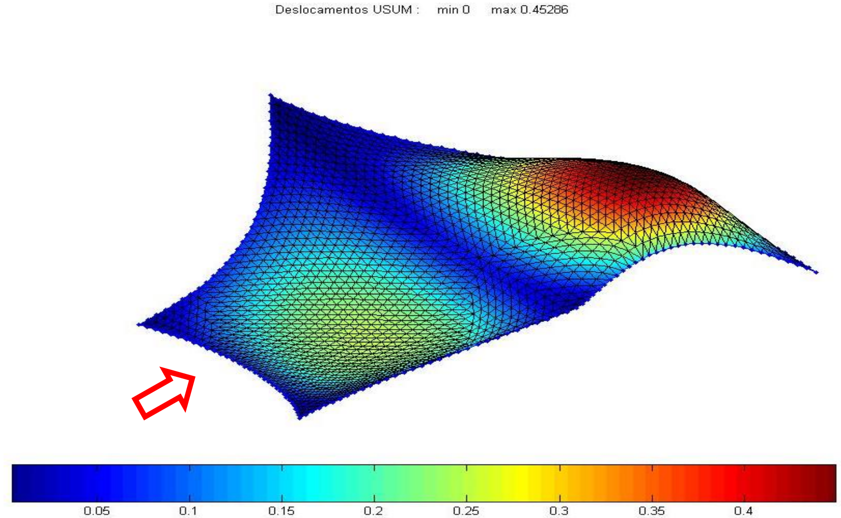
Z
Y
X

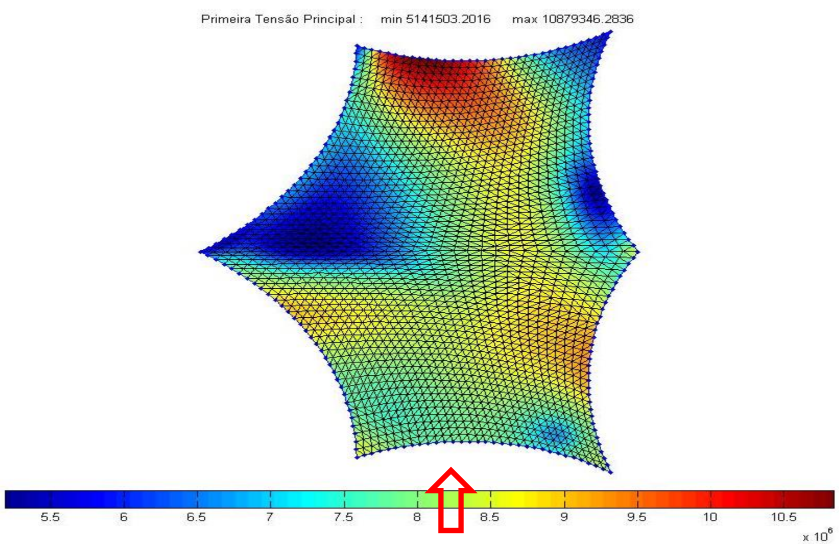

Primeira Tensão Principal : min 5030574.8403 max 5972740.9101
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
x 10^6

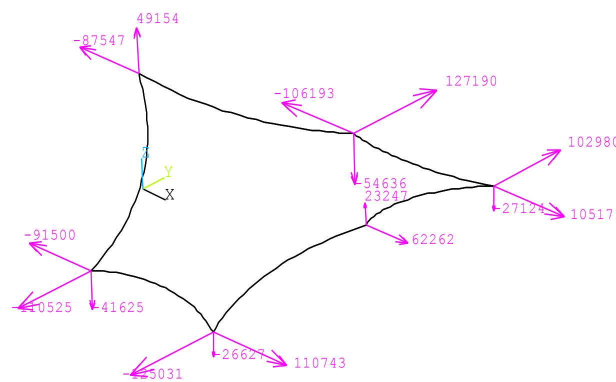
Resposta às cargas de ventos





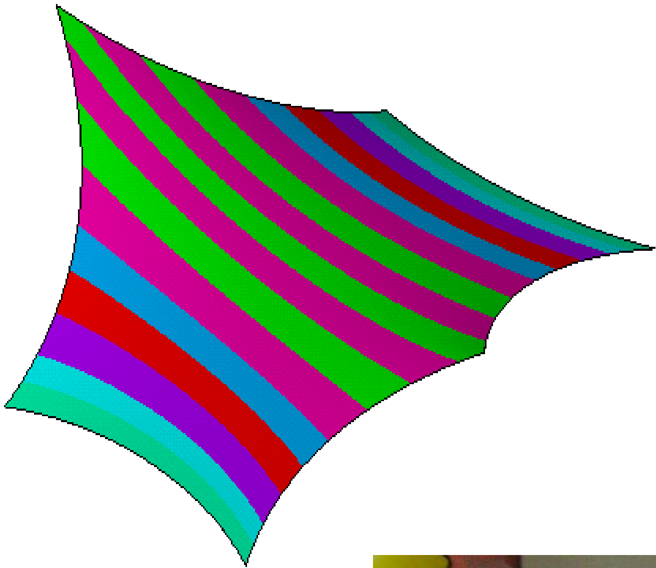
displacement norms,
for the Y-wind load case

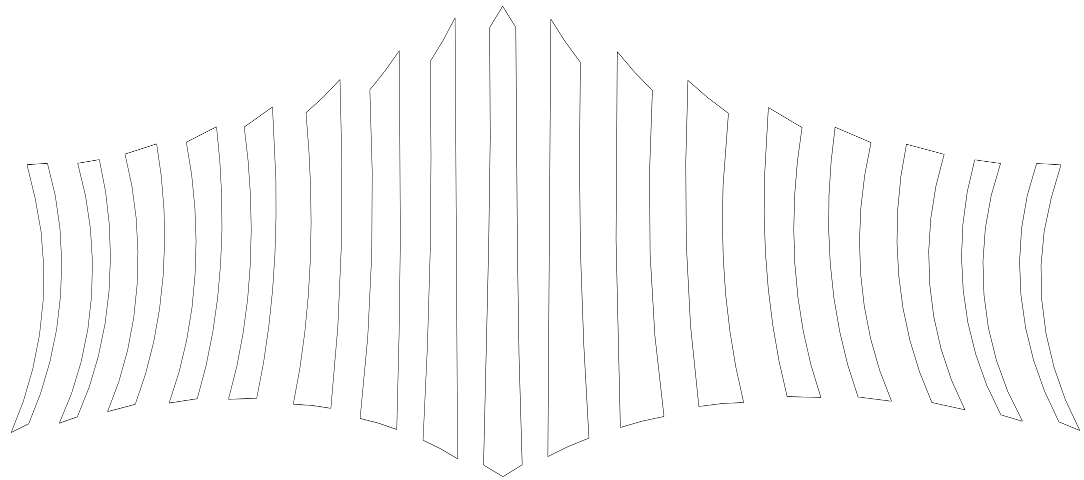




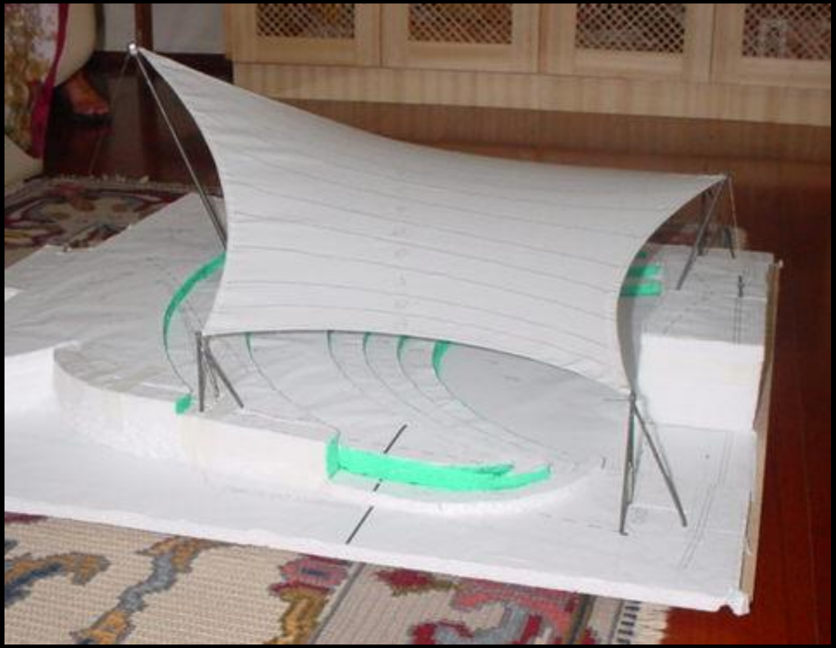
Maximum 1st principal stresses
(S1) for the Y-wind load case

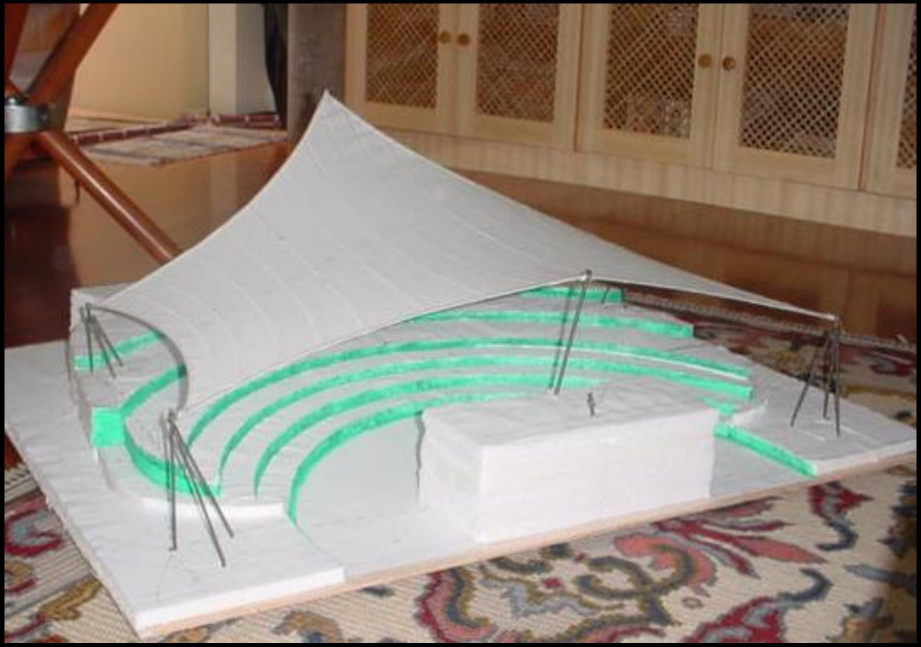
Padrões de corte





Maquete em tecido escala 1:50





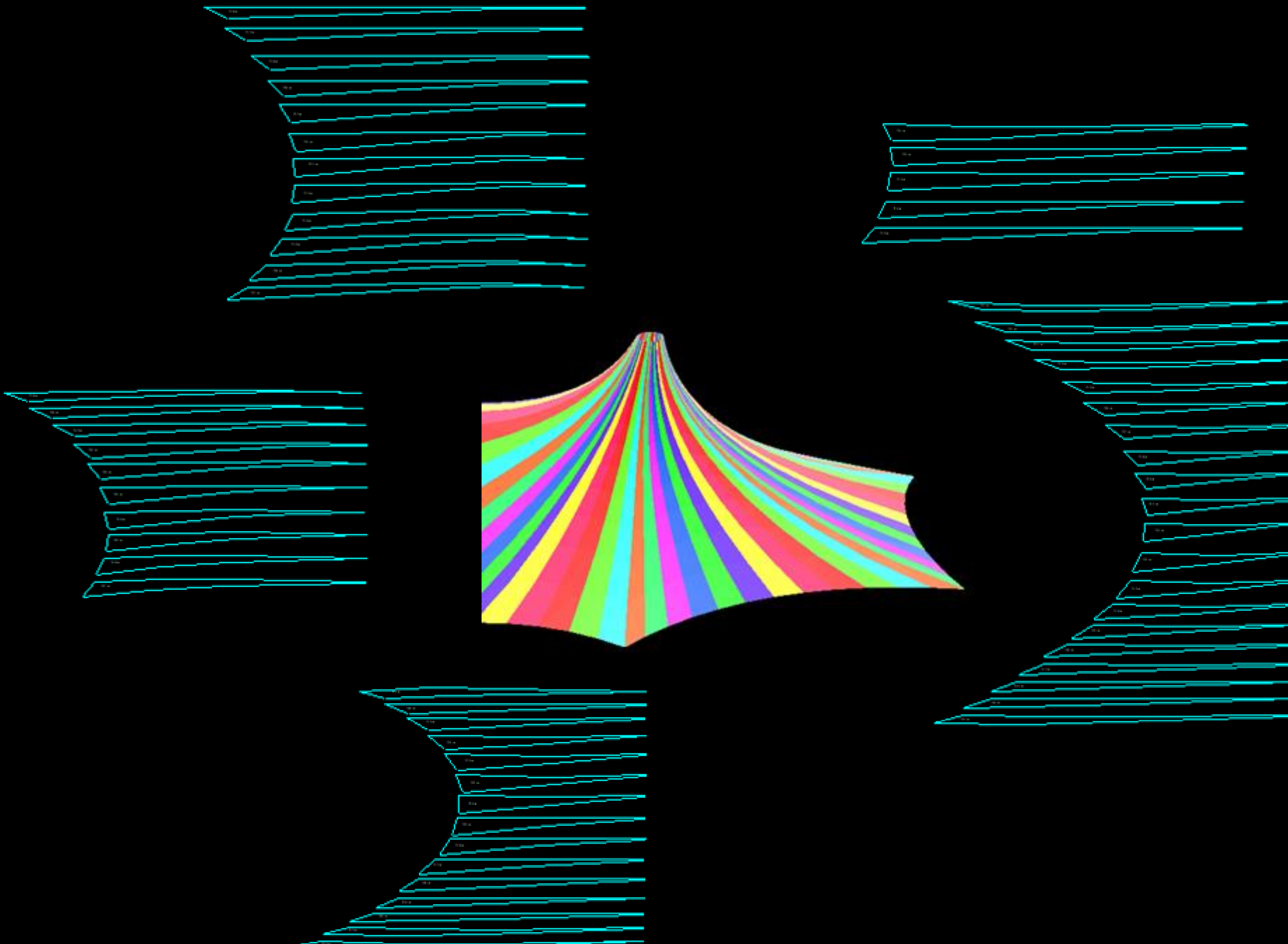
Modelo em tecido escala 1:10






Membrana de cobertura do Memorial dos Povos de Belém do Pará (2006)

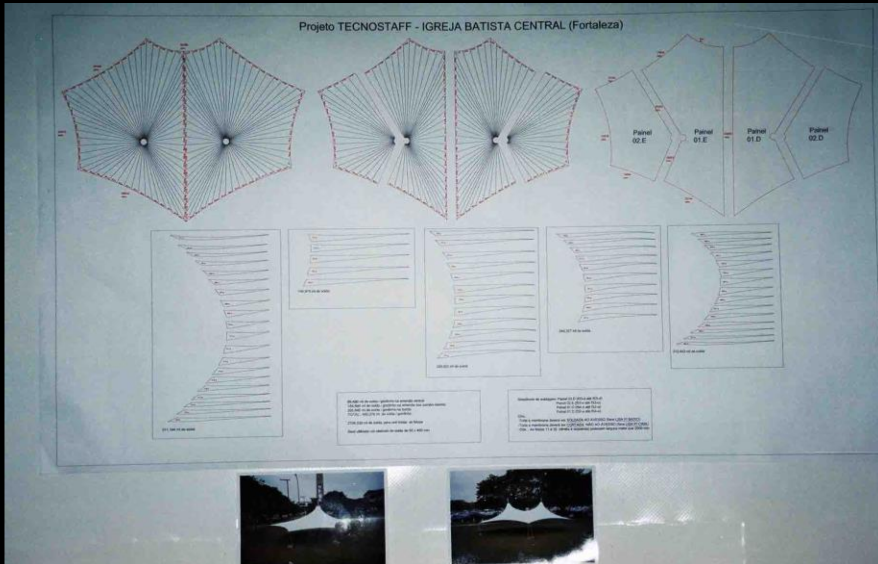
Igreja Batista de Fortaleza
durante a inauguração, 27 de Novembro, 2003







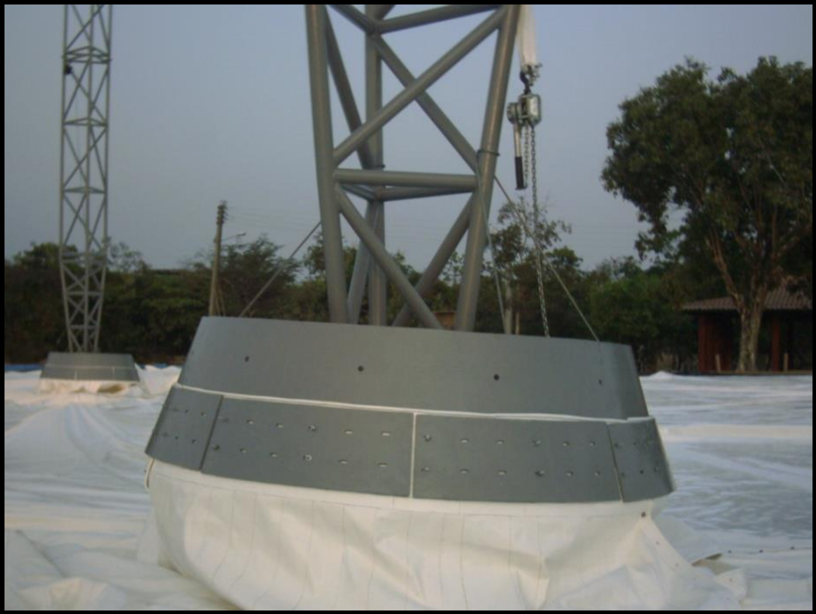
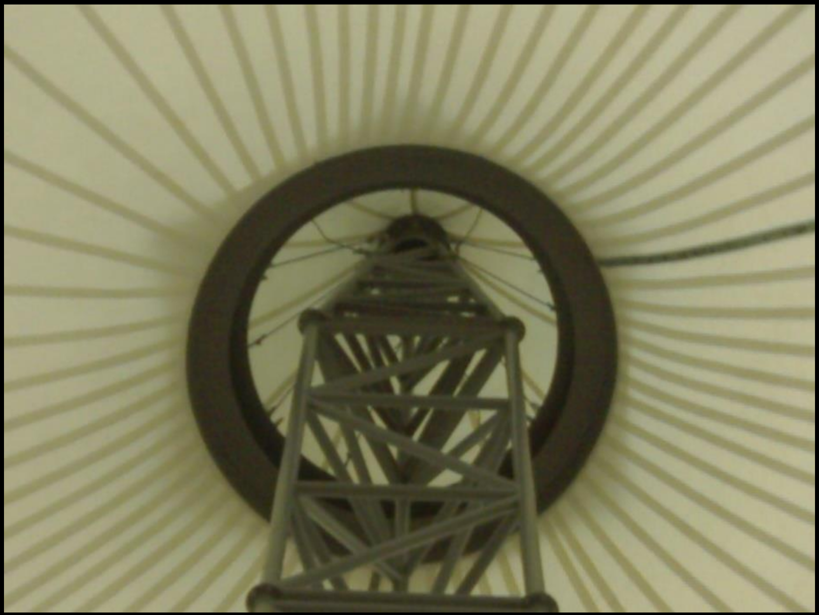



Projeto TECNOSTAFF - IGREJA BATISTA CENTRAL (Fortaleza)
Painel 02.E
Painel 01.E
Painel 01.D
Painel 02.D

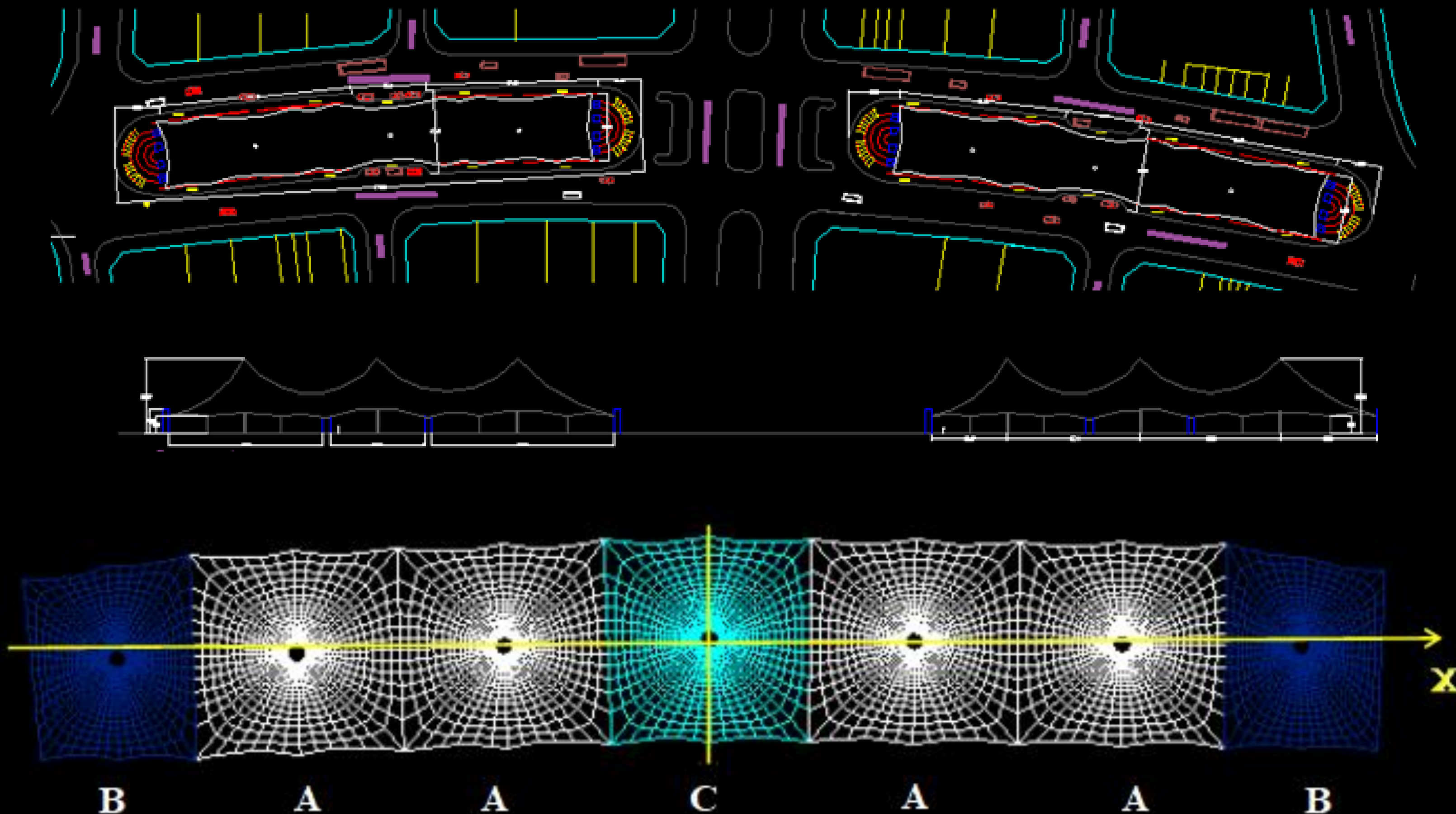

Formatto
Coberturas Especiais






Goiânia´s Open Market (2006)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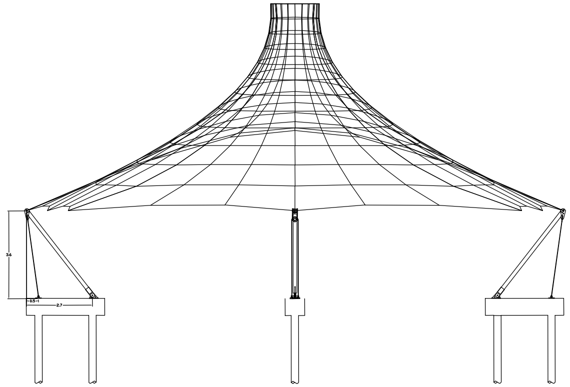
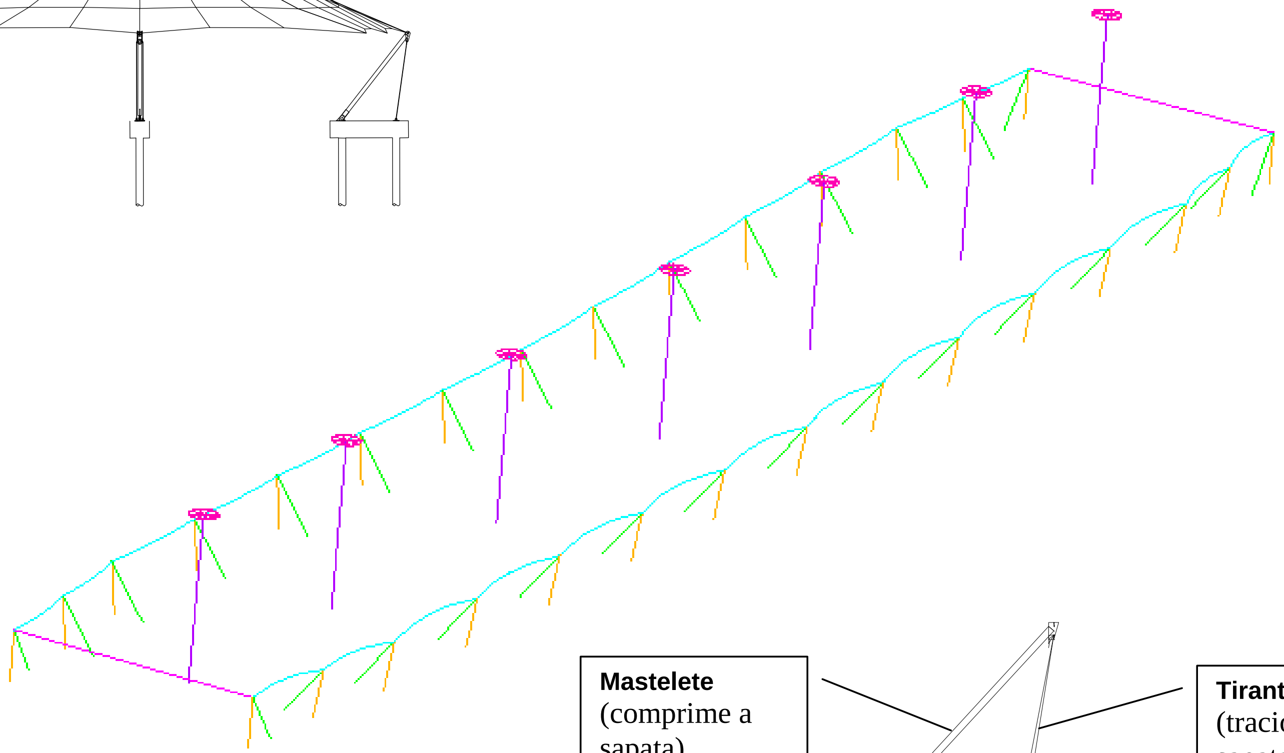
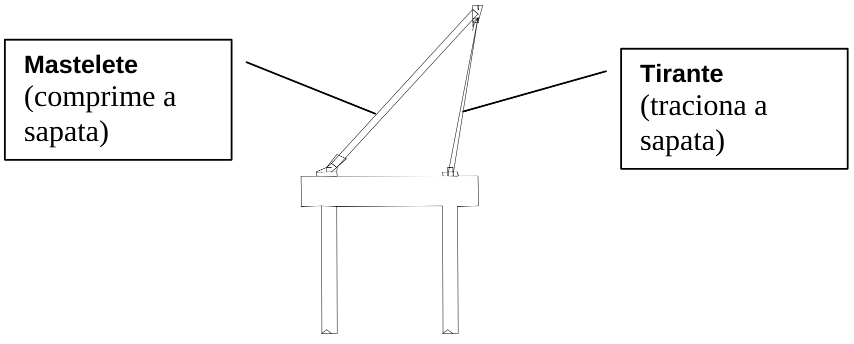
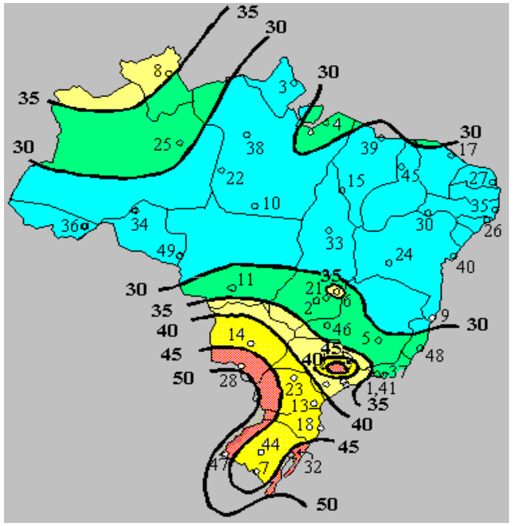
B
A
A
C
A
A
B






Mastelete
(comprime a sapata)
Tirante
(traciona a sapata)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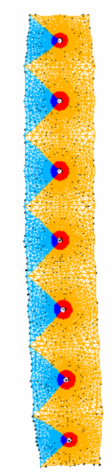

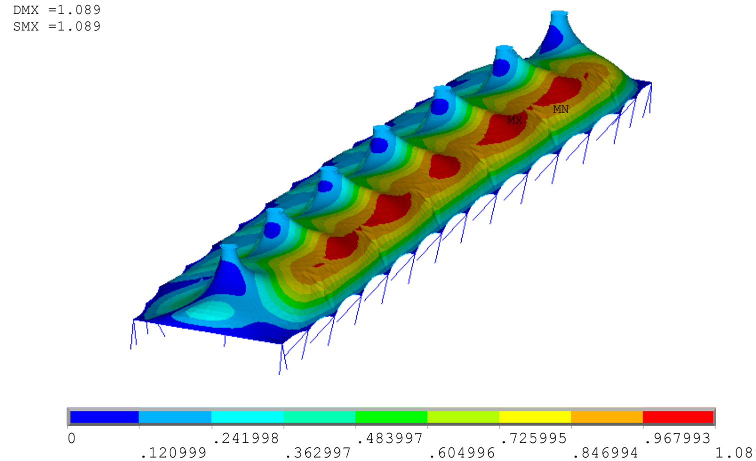
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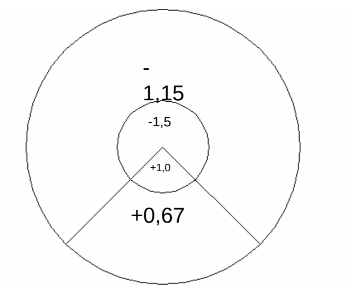
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1,15
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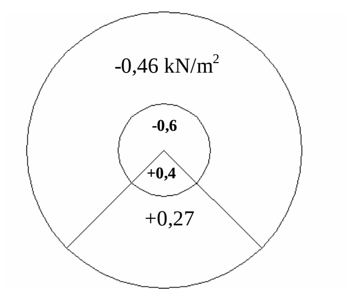
+1,0
+0,67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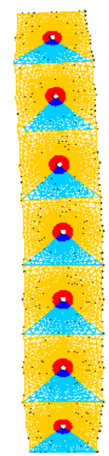
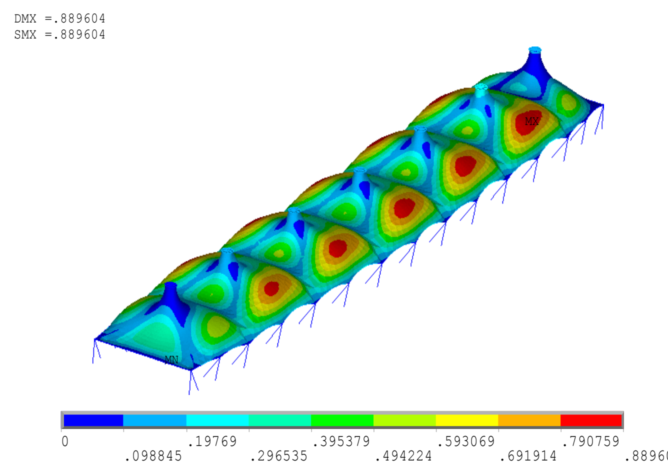
+0,27

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PEF5750
ESTRUTURAS
LEVES
28-08-2007

"Feira da Cidade de Ananindeua, PA (2006)
Arch. José Maria Coelho Bassalo and Flávio Campos do Nascimento

"Feira da Cidade de Ananindeua, PA (2006)
Arch. José Maria Coelho Bassalo and Flávio Campos do Nascimento

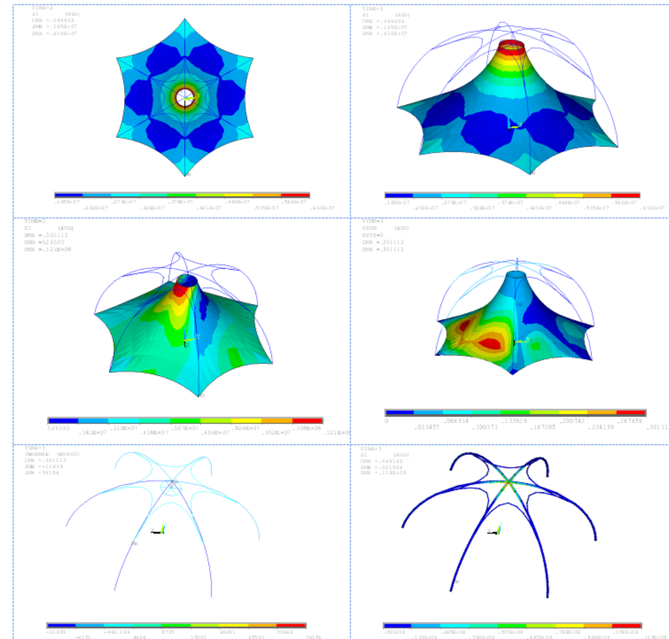
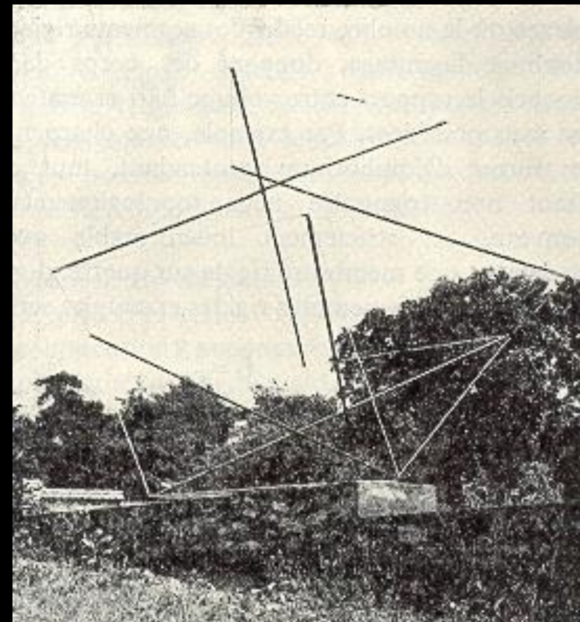


Figura 4 - Máximas tensões principais e deslocamentos nas tendas cônicas, para as cargas de retesamento (primeira linha) e de vento (segundo linha); tensões normais e máximas tensões principais nos elementos metálicos (terceira linha)

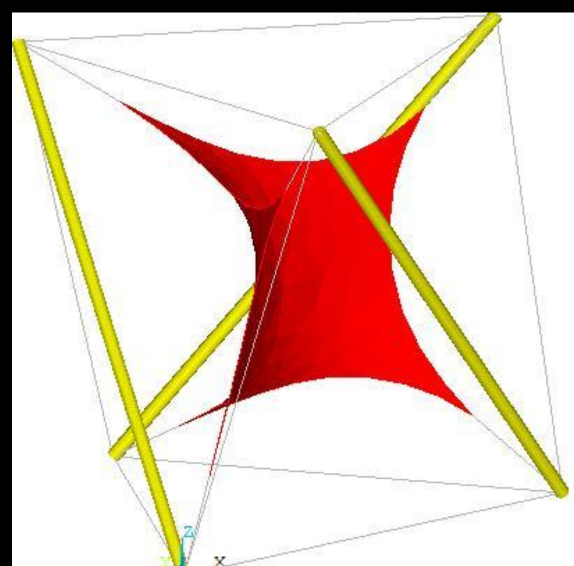
"Feira da Cidade de Ananindeua, PA (2006)
Arch. José Maria Coelho Bassalo and Flávio Campos do Nascimento

Tensegrities

Needle Tower,
K. Snelson, 1948

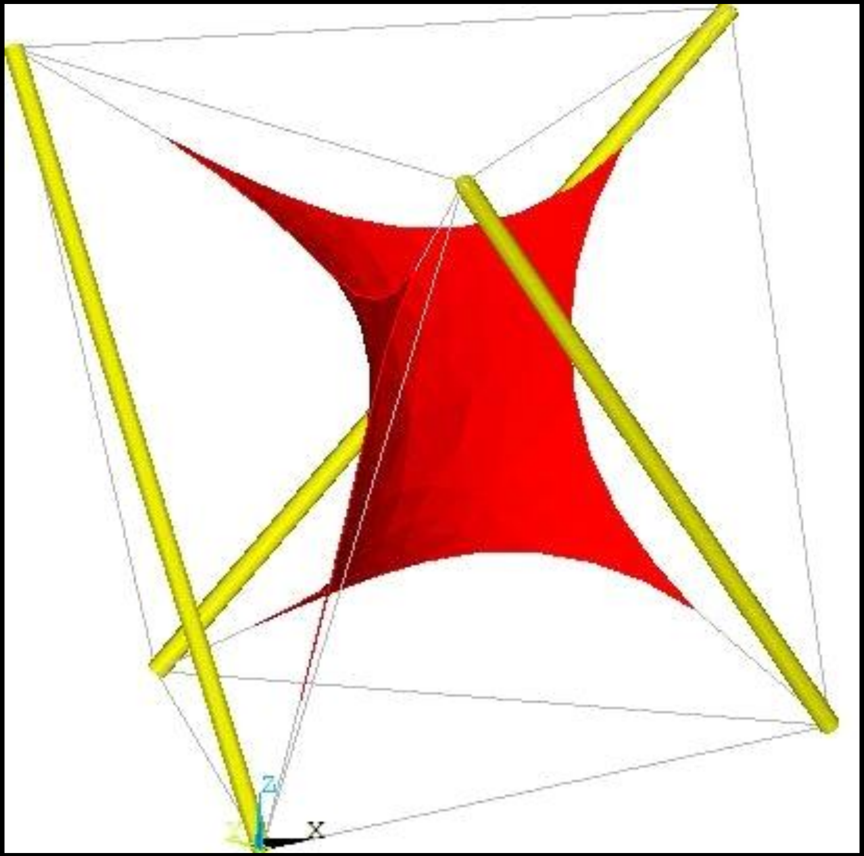


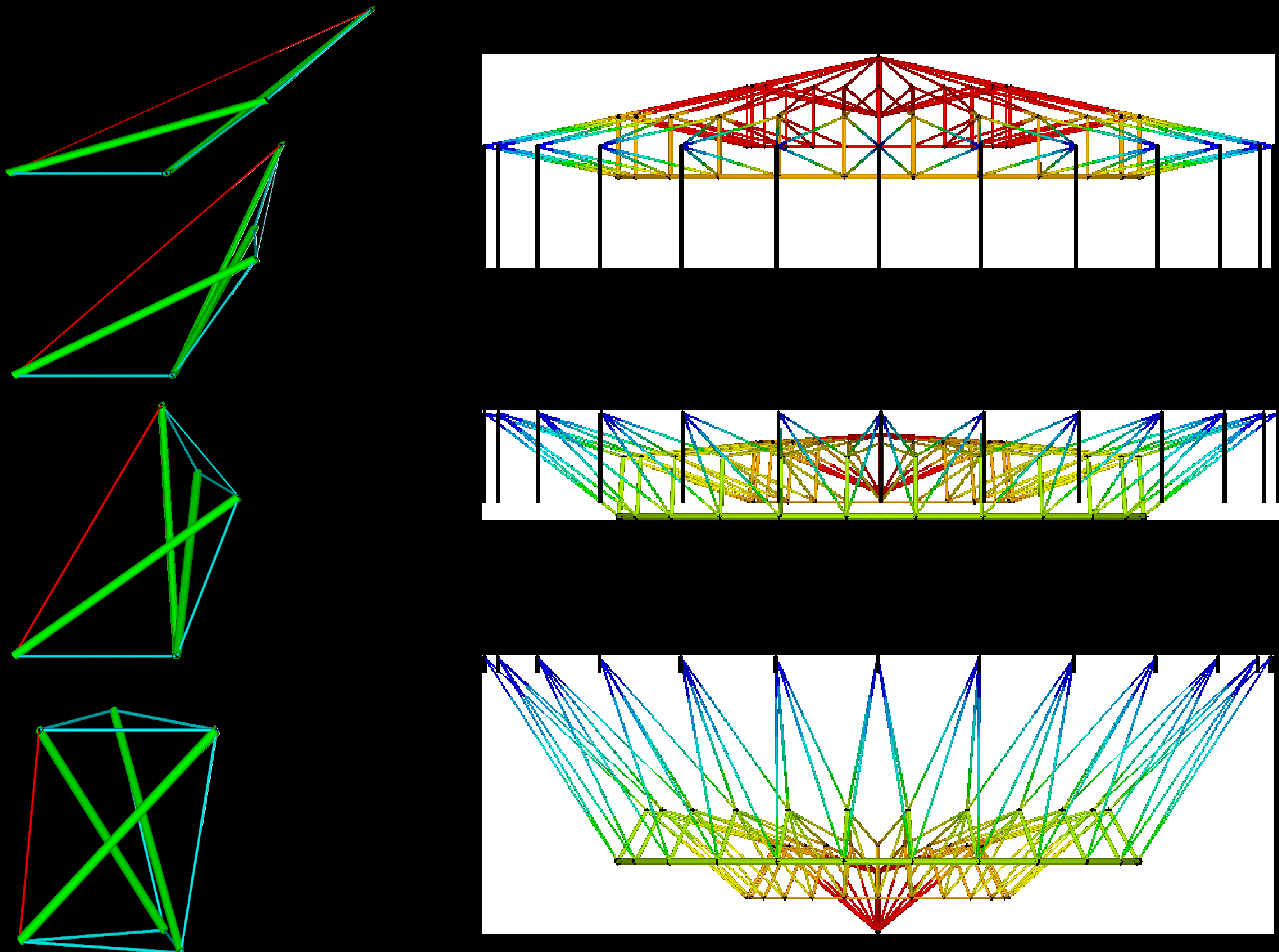
The Monument to
the Futile Form,
D. Emmerich, 1966

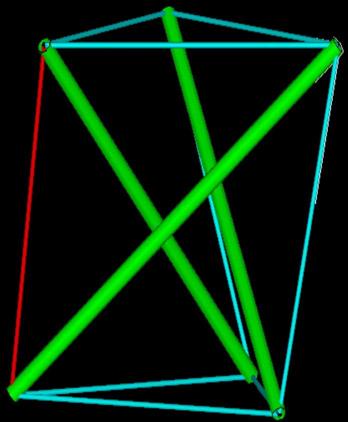


The Monument to the
Futile Form II
Titotto, Deifeld, Pauletti,
2003


Monument to the Futile Form II (2003)

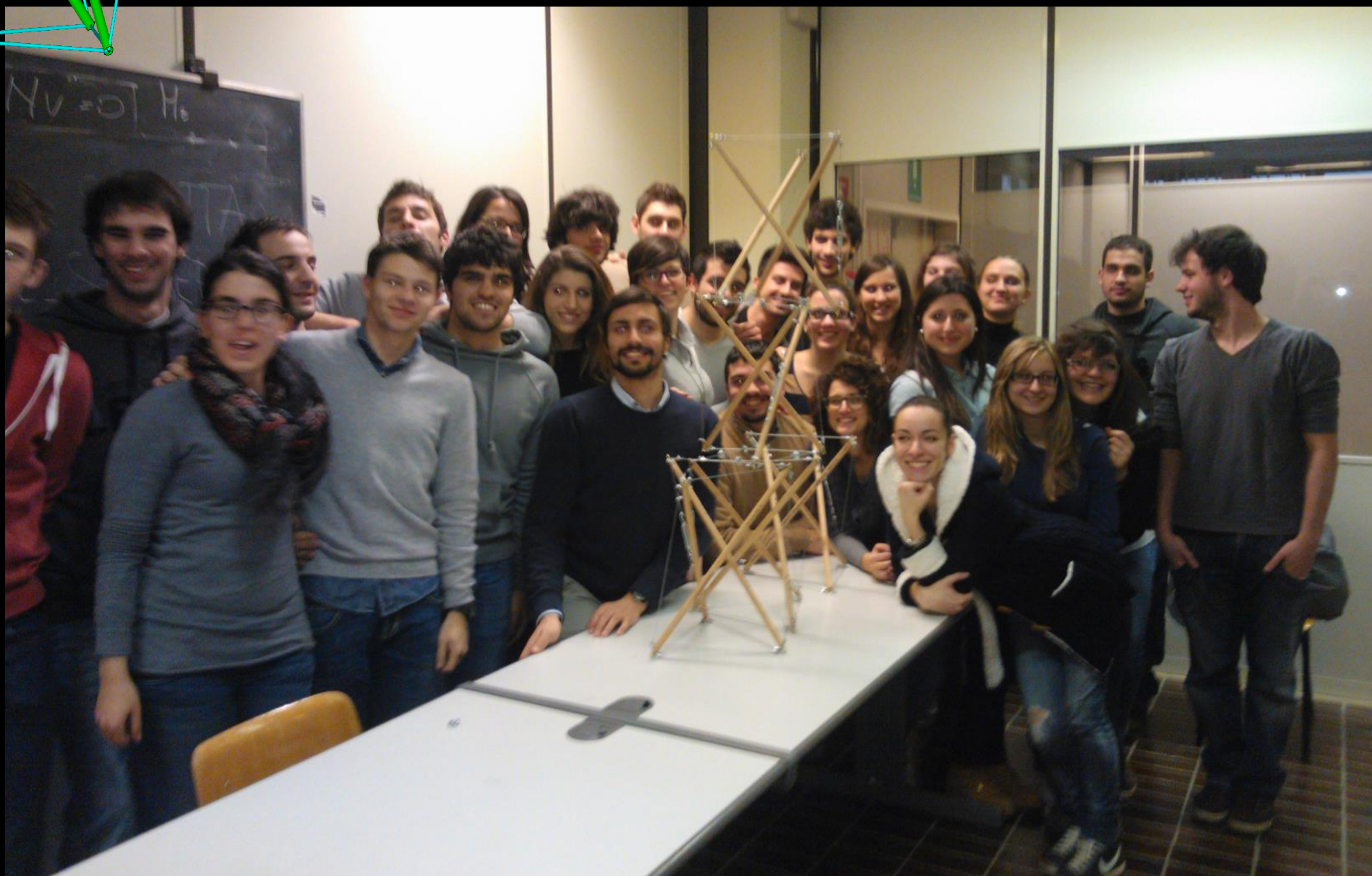






3 days workshop at Università delle Marche (Ancona) (2013)

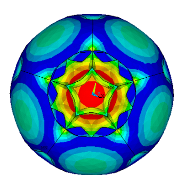
3 days workshop at Università delle Marche (Ancona) (2013)

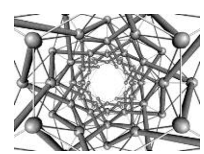


Ruy Marcelo de Oliveira Pauletti & Jung Yun Chi

Polytechnic School - University of São Paulo

Modeling and Construction of the 'Dodecoid', an Inflated, Double-Skin Dodecahedron



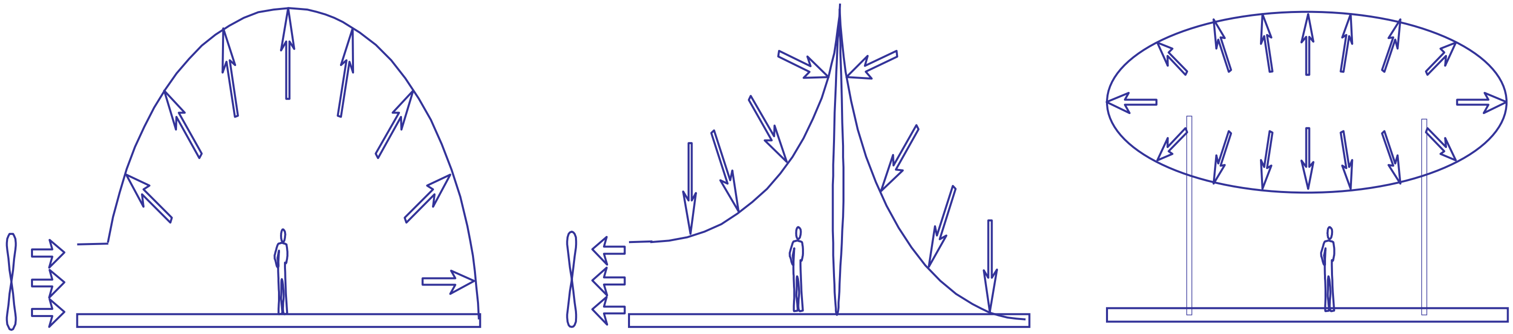


IASS-2004

Shell and Spatial Structures: from Models to Realization

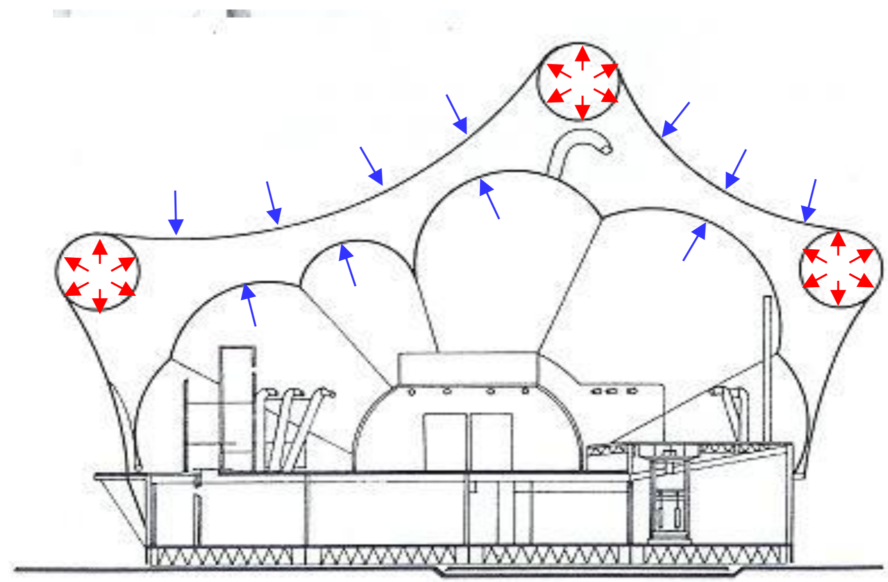
Montpellier, 20-24/09/2004

Pneumatic Structures



(a) Insufflated; (b) Aspirated; (c) Inflated

Tokyo "Big-Egg" Dome (1988)



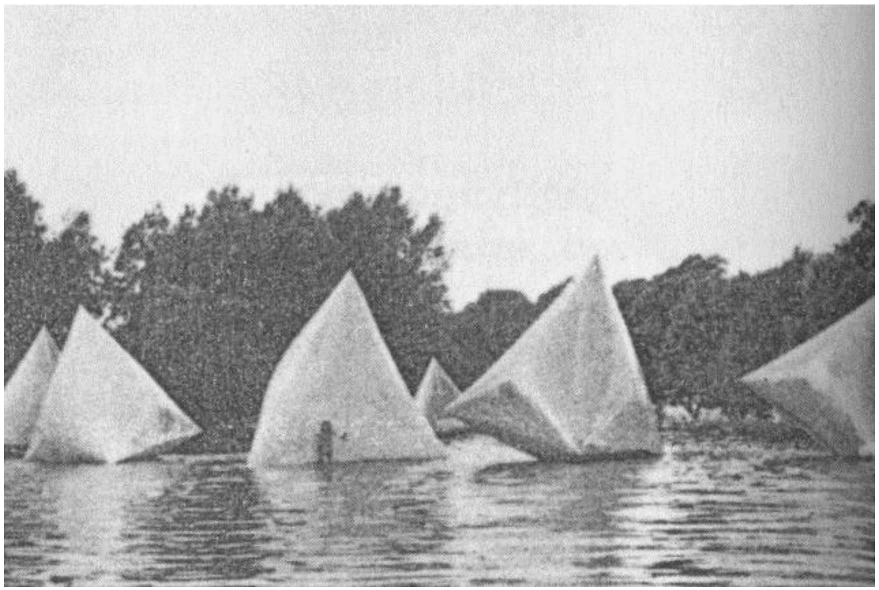
Floating Pavilion (Osaka, 1970)

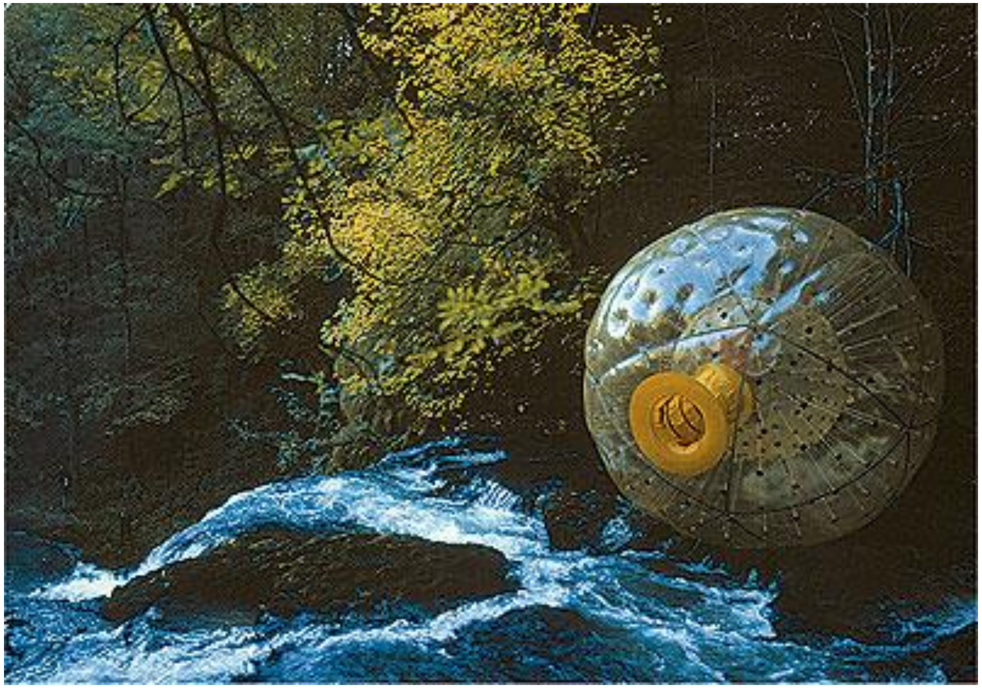


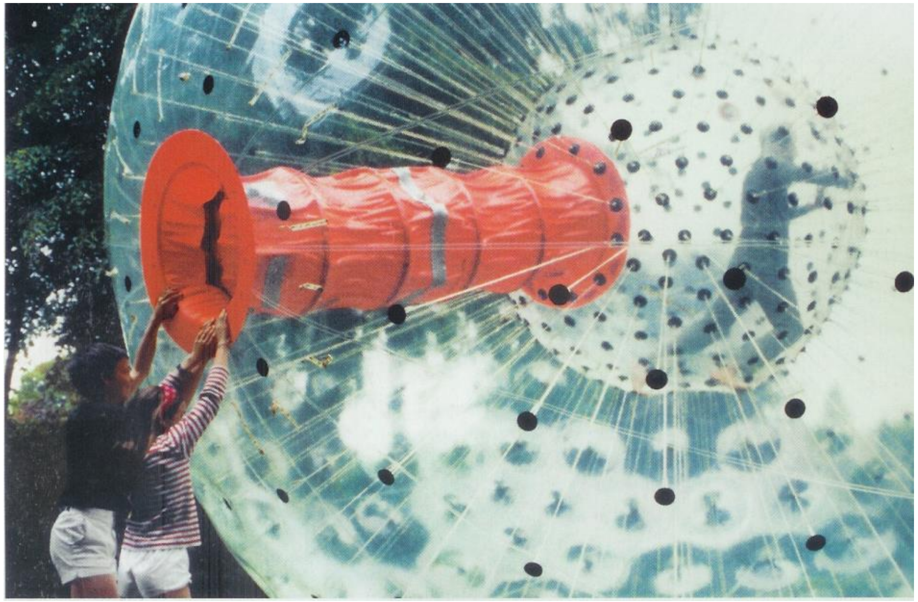

Inflated tetrahedron ‘walking machine’

Eventstructure Research Group, 1968.

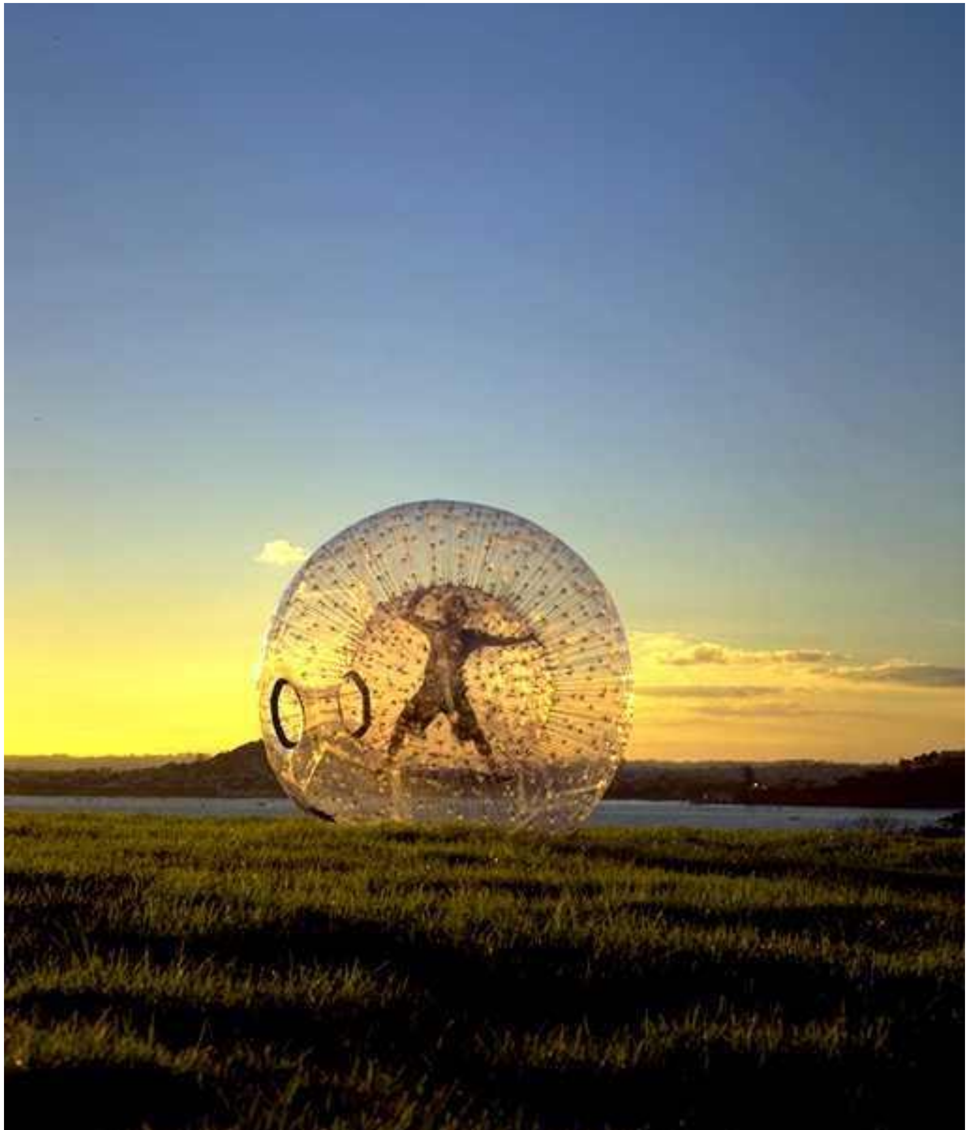
0.5 mm thick transparent or translucent PVC foils;
watertight zip fastened entrances.



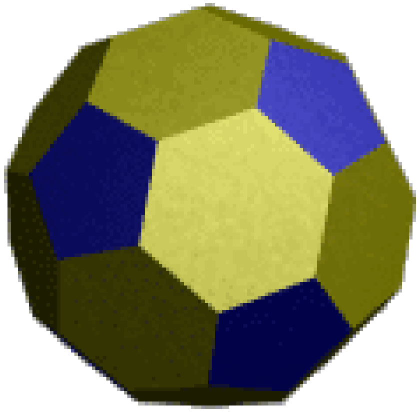




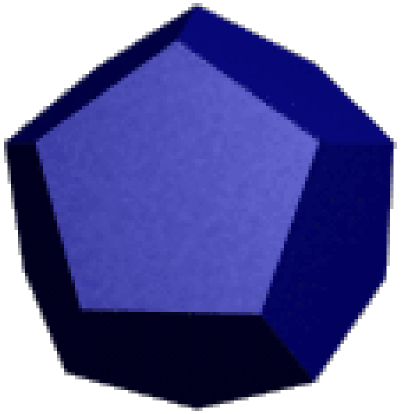
La Balulle -
Gilles Ebersolt, France
(1973 – 1985)



Icosahedron
Faces: 20
Edges: 30
Vertices: 12

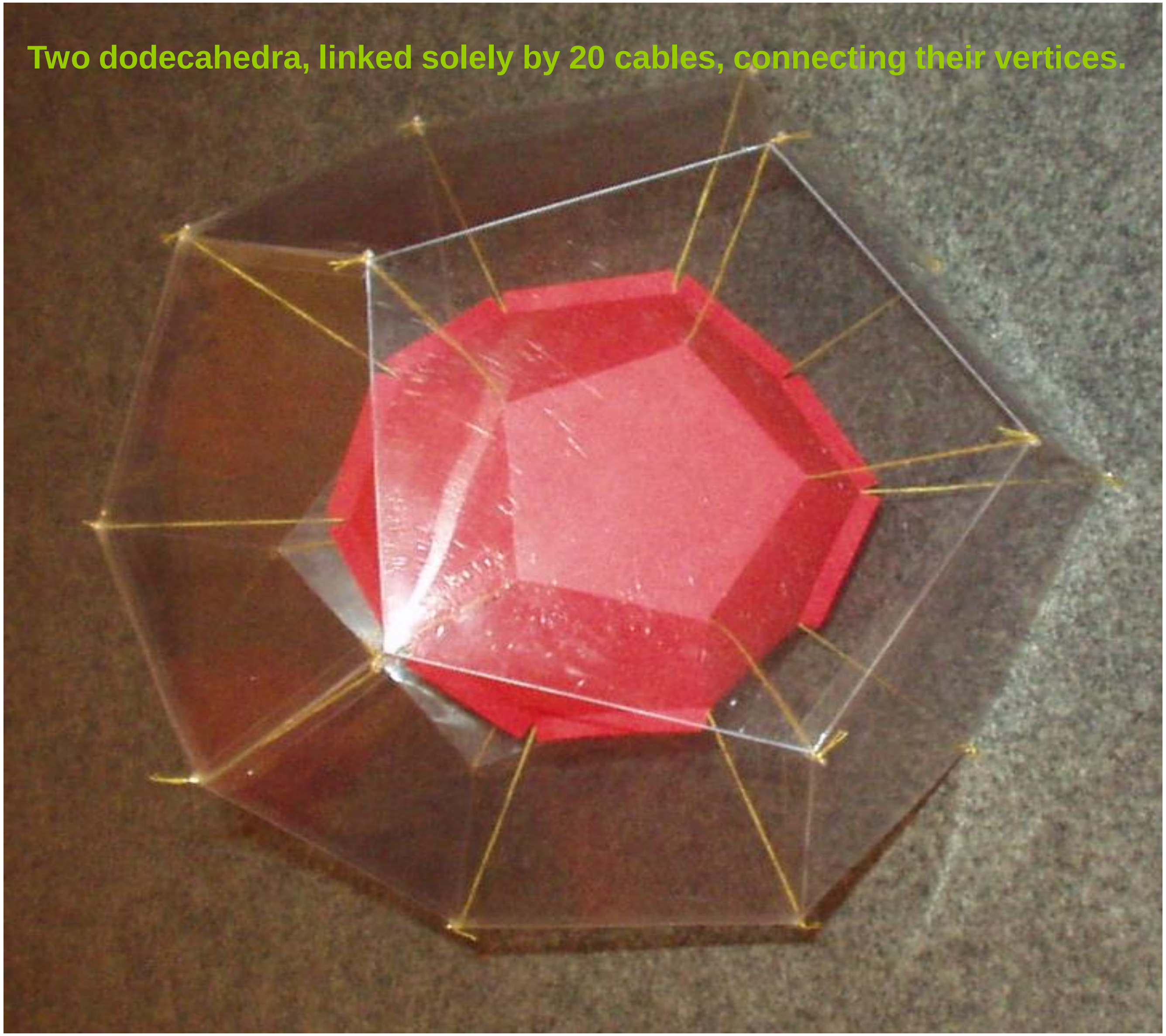


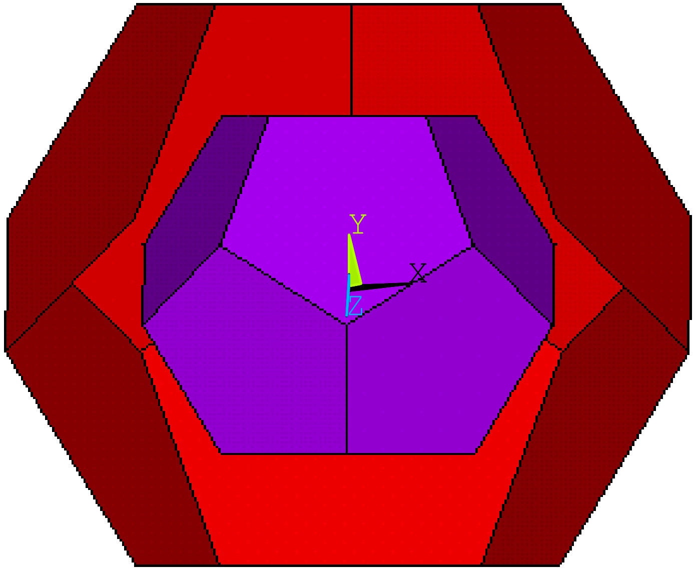
truncated icosahedron
Faces: 32
Edges: 90
Vertices: 60

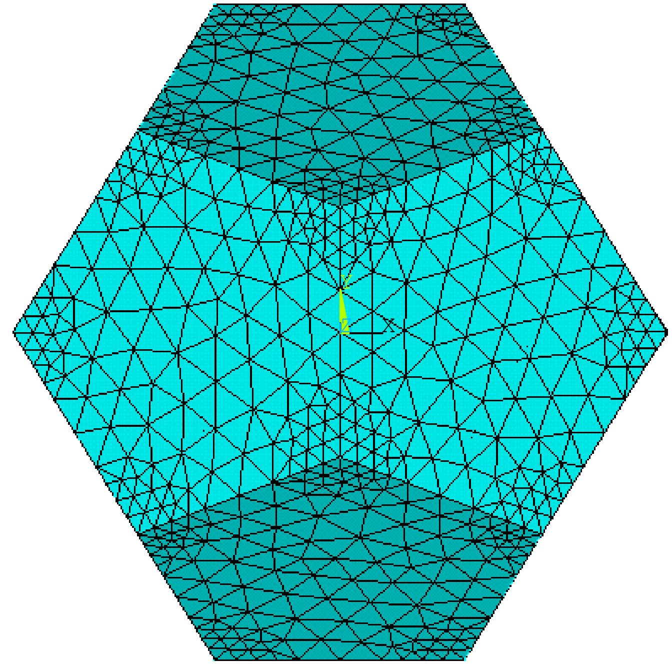


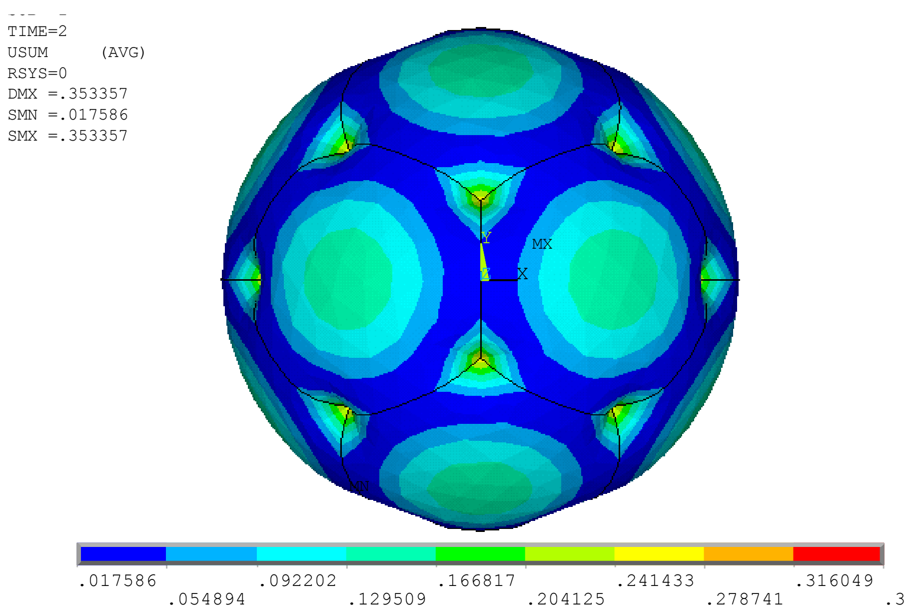
Dodecahedron
Faces: 12
Edges: 30
Vertices: 20

The “Dodecoid”




Y
X
Z

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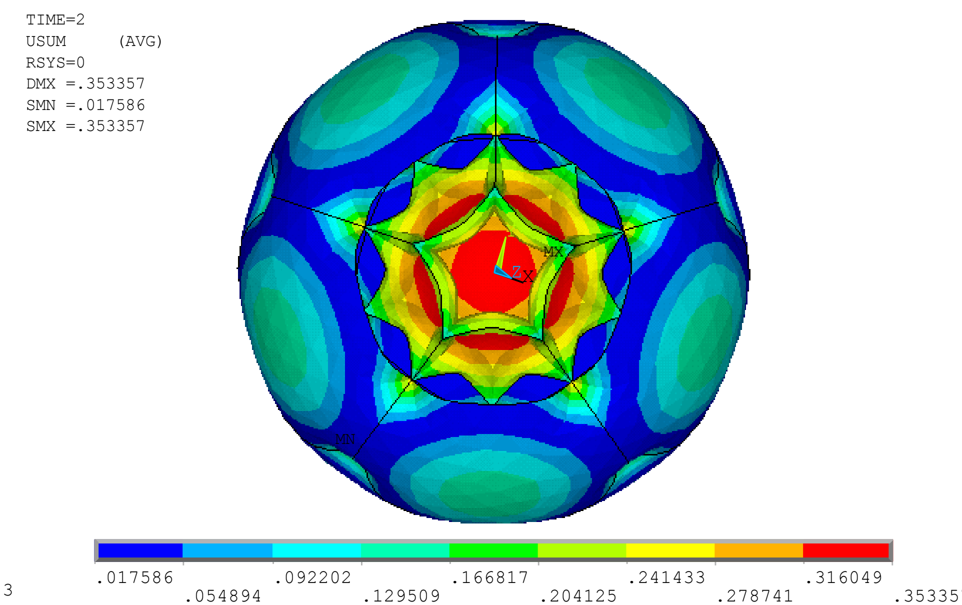
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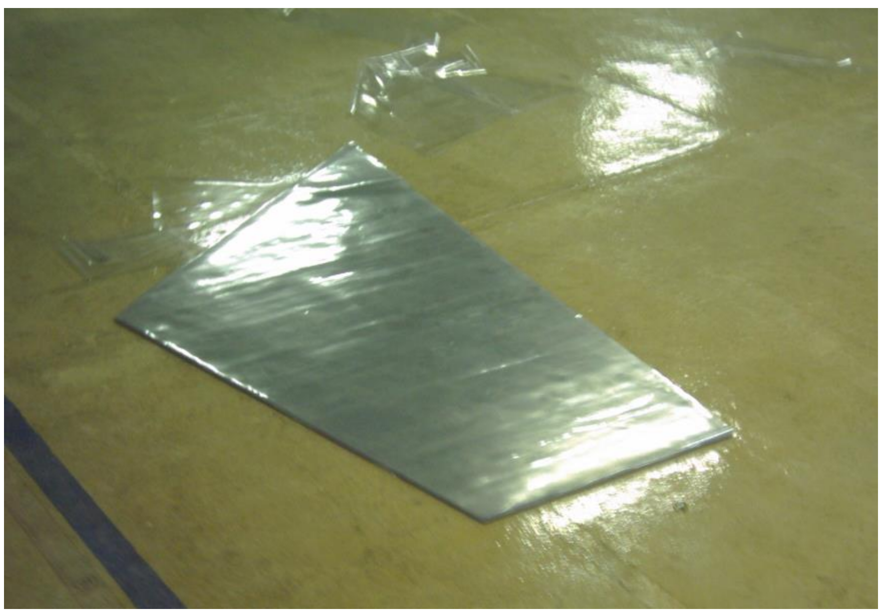
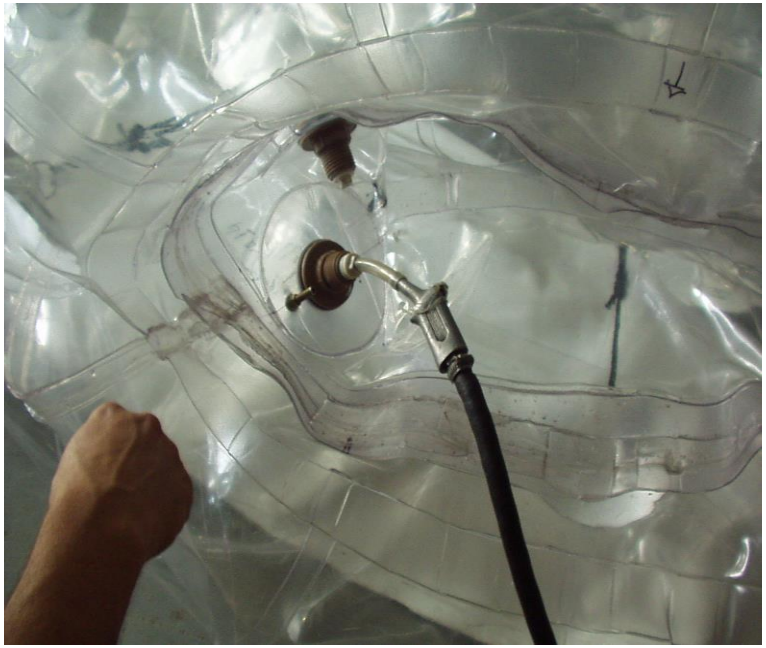
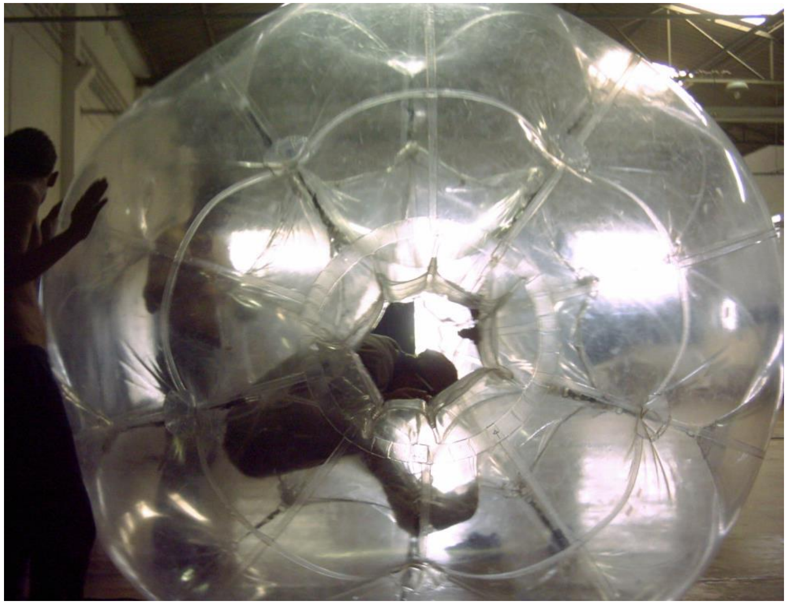




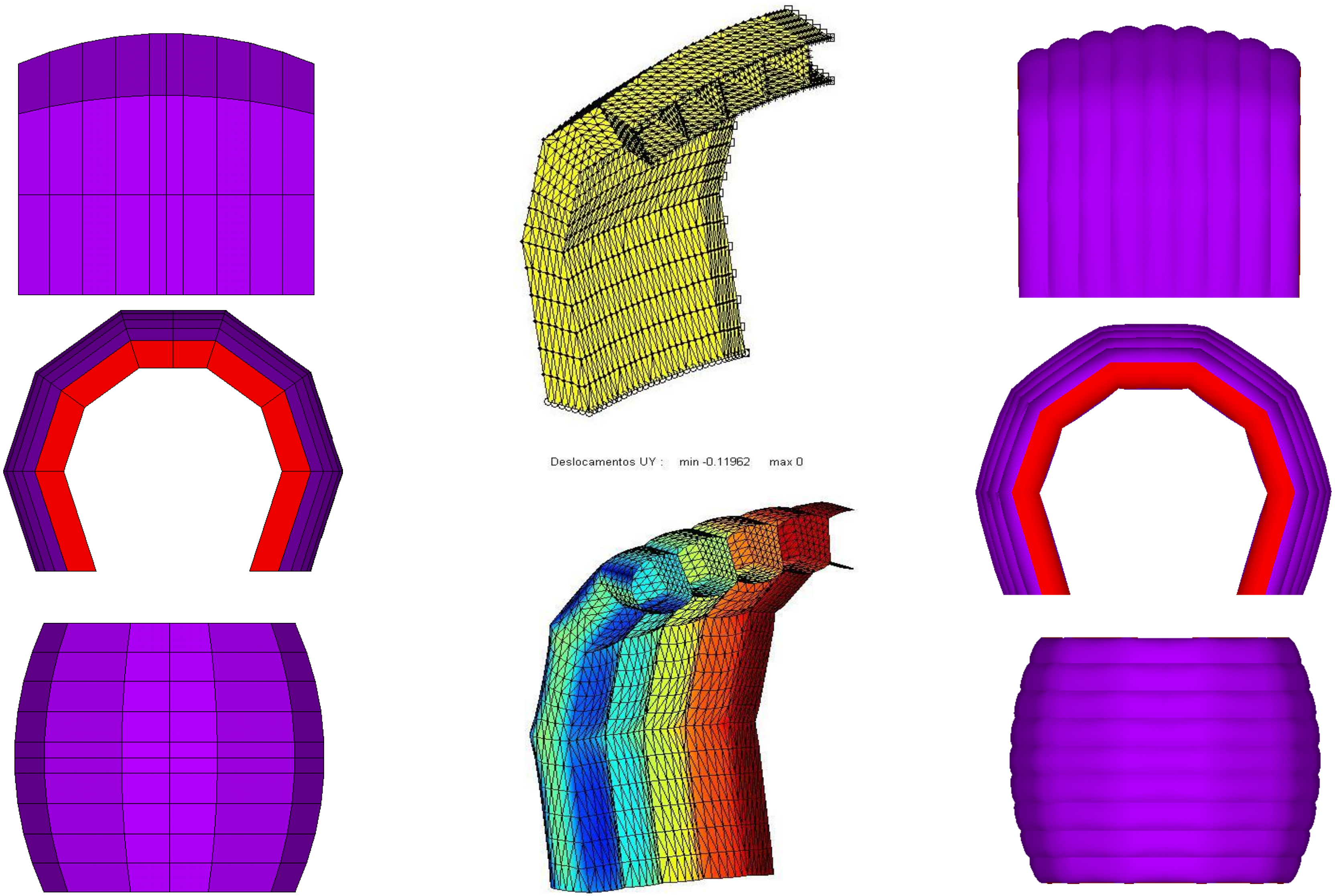


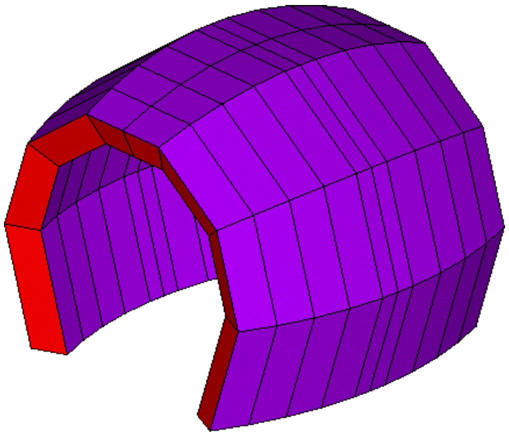


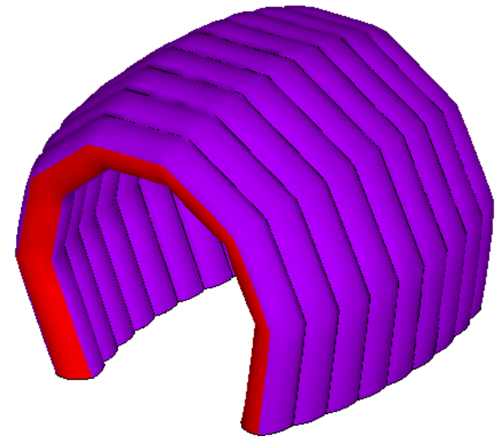






A pneumatic dome (2005)

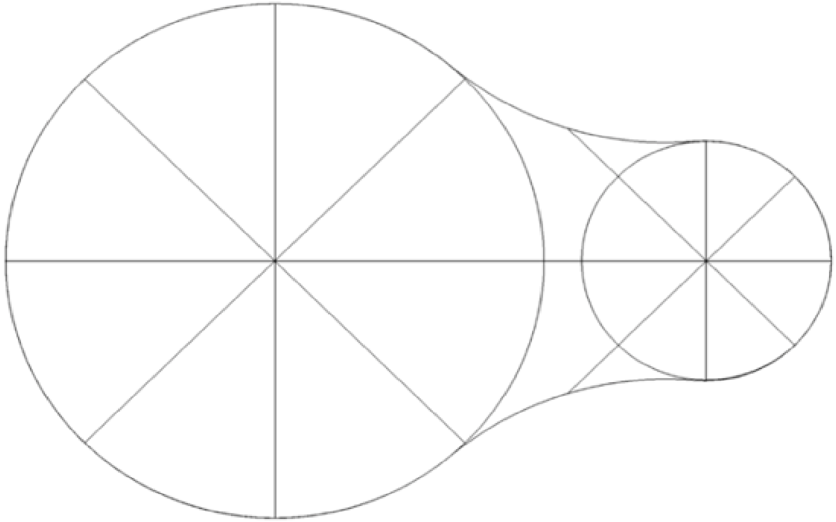


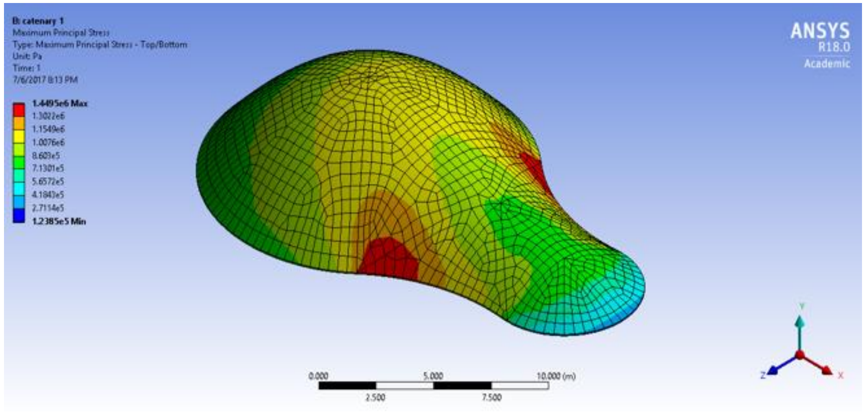


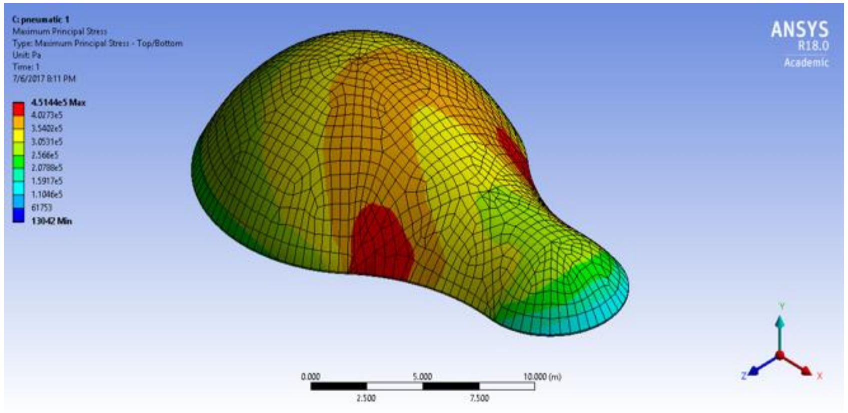


Pneumatic Formworks: Formfinding with ANSYS

(Nyema Watson, 2017)



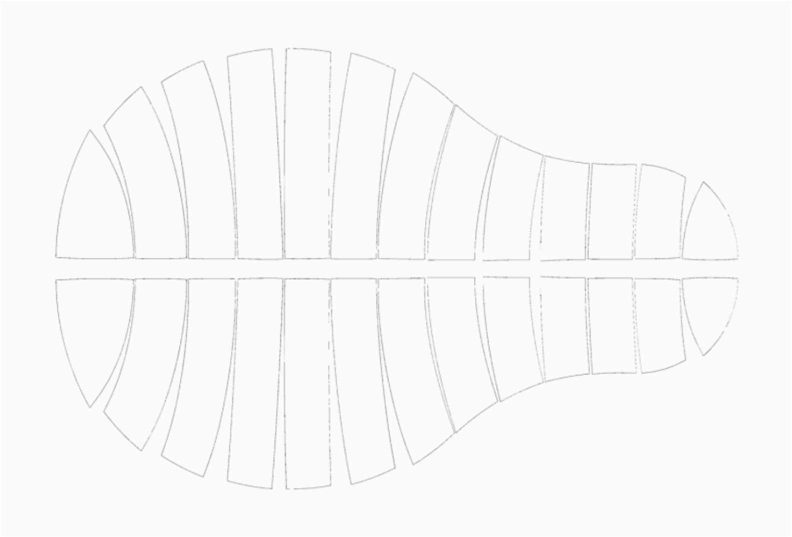


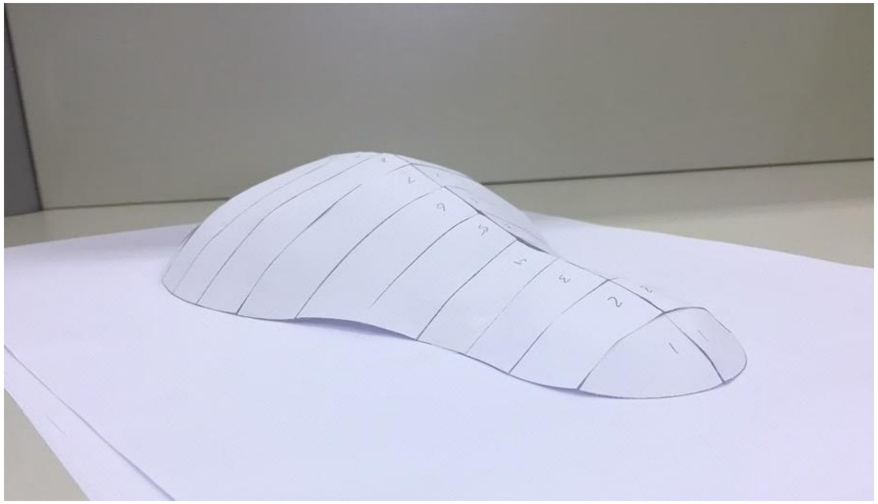


Physical Model

(Neyma Watson, Leila Meneghetti, Ruy Pauletti, 2017)

Patterning: making a 3D surface





Physical Model
(Neyma Watson, Leila Meneghetti, Ruy Pauletti, 2017)

Sliding Cables and Wrinkling

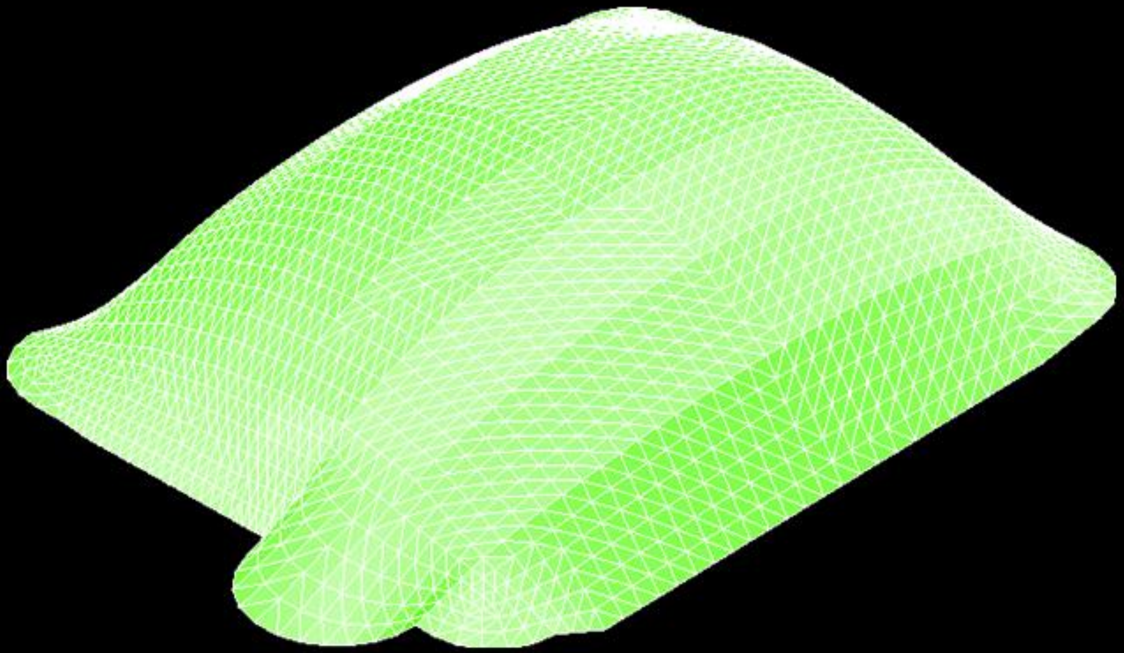
Pneumatic envelope for 'Angra III' ground preparation

(September 2009)

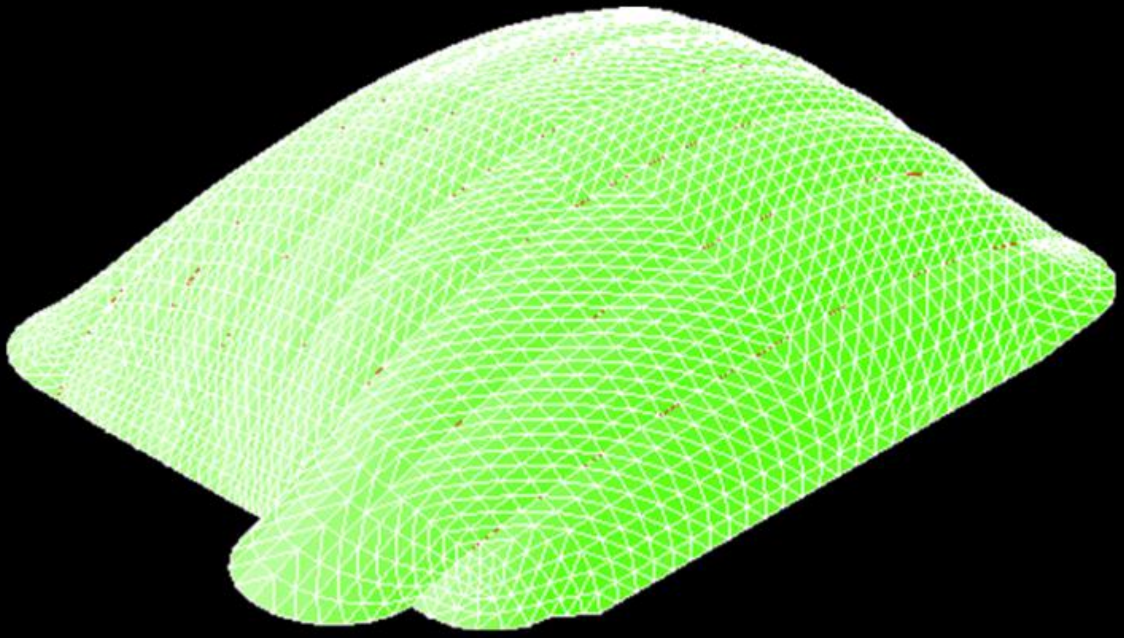
Sliding Cables and Wrinkling

Pneumatic envelope for 'Angra III' ground preparation

(September 2009)

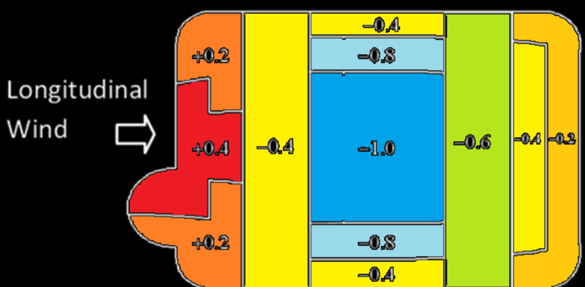


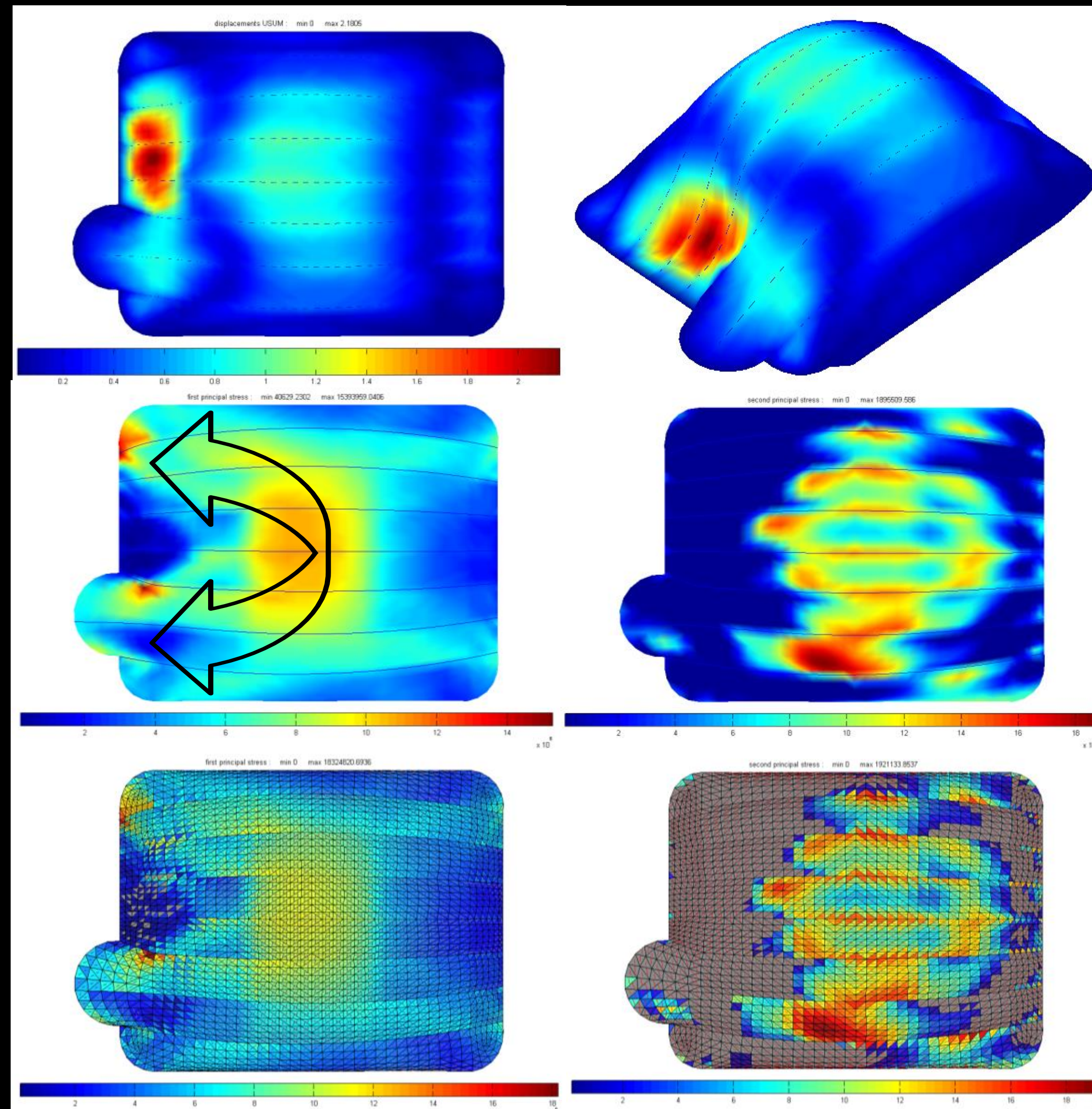
Initial mesh modeled in SATS



equilibrium geometry under internal pressure

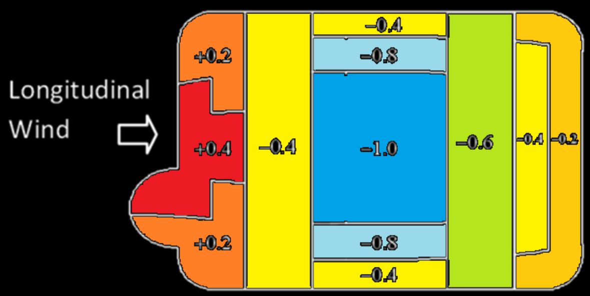
Longitudinal wind,
adherent cables

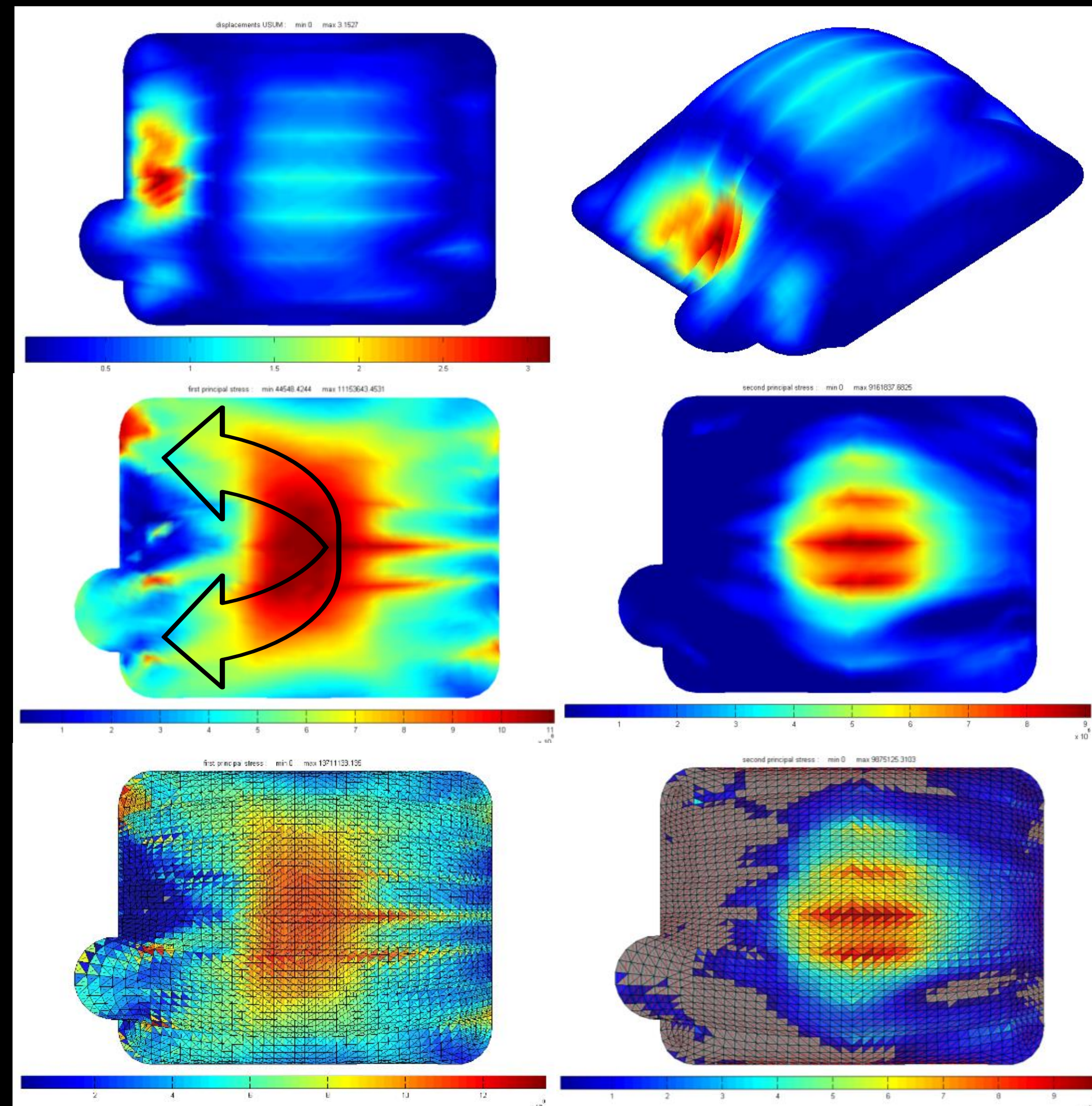




(a) field of displacement norms; *(b) idem*, isometric view; *(c)* stress field; *(d)* stress field.

Longitudinal wind, sliding cables





(a) field of displacement norms; *(b) idem*, isometric view; *(c)* stress field; *(d)* stress field.

CENPES II – Rio de Janeiro, 2010

Archs. Ziegbert Zenettini, Wagner Garcia

CENPES II

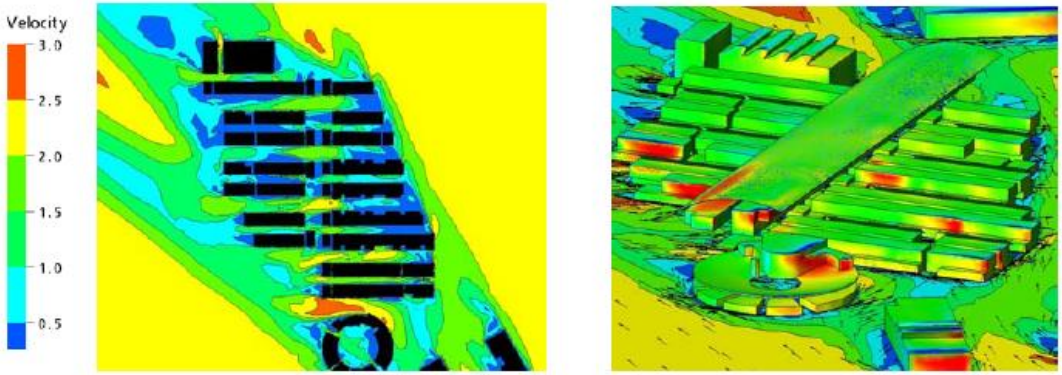
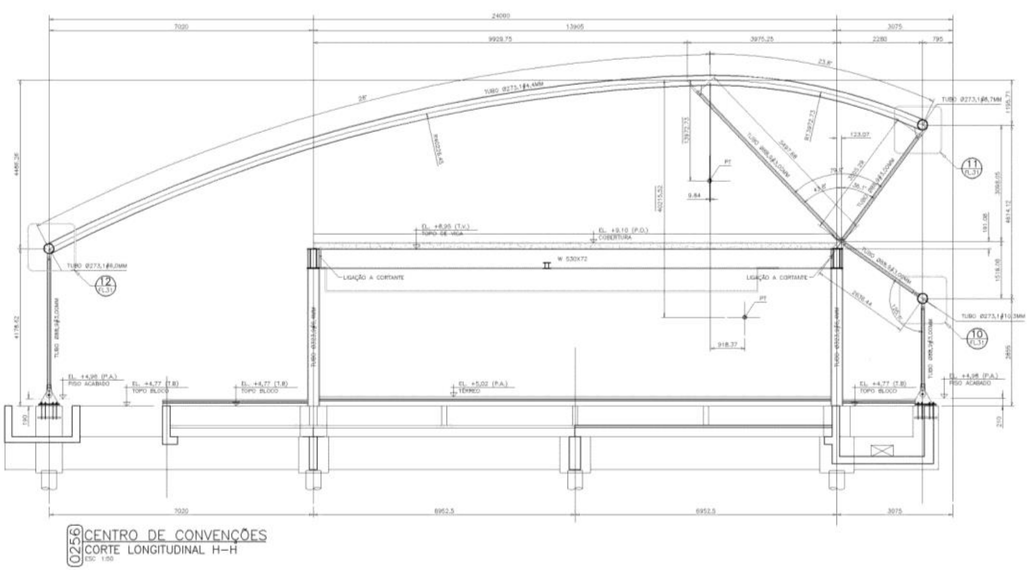
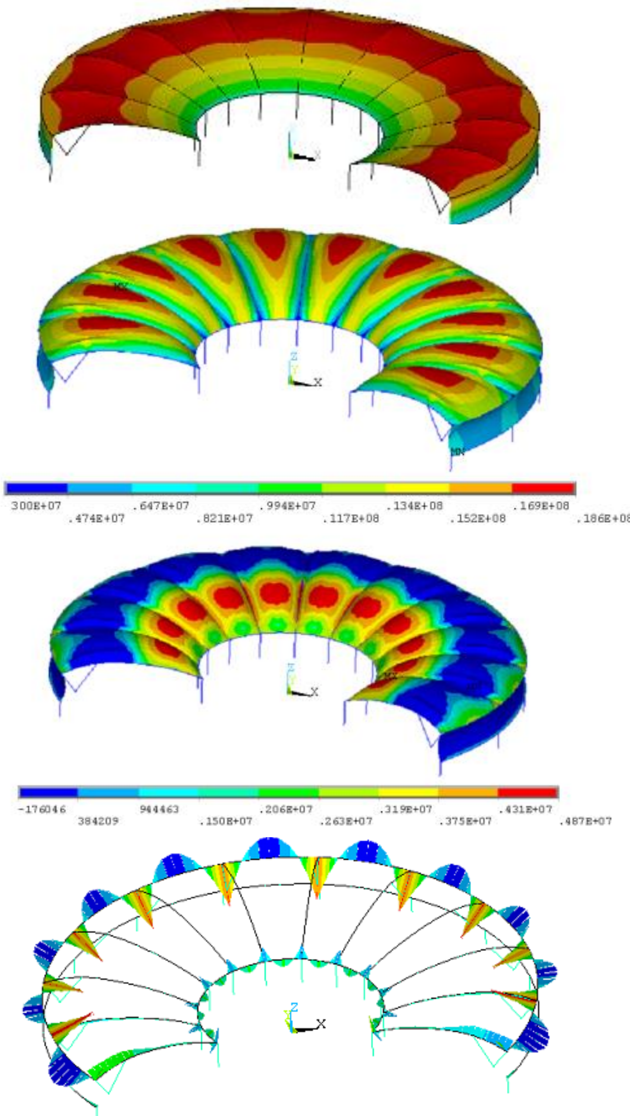
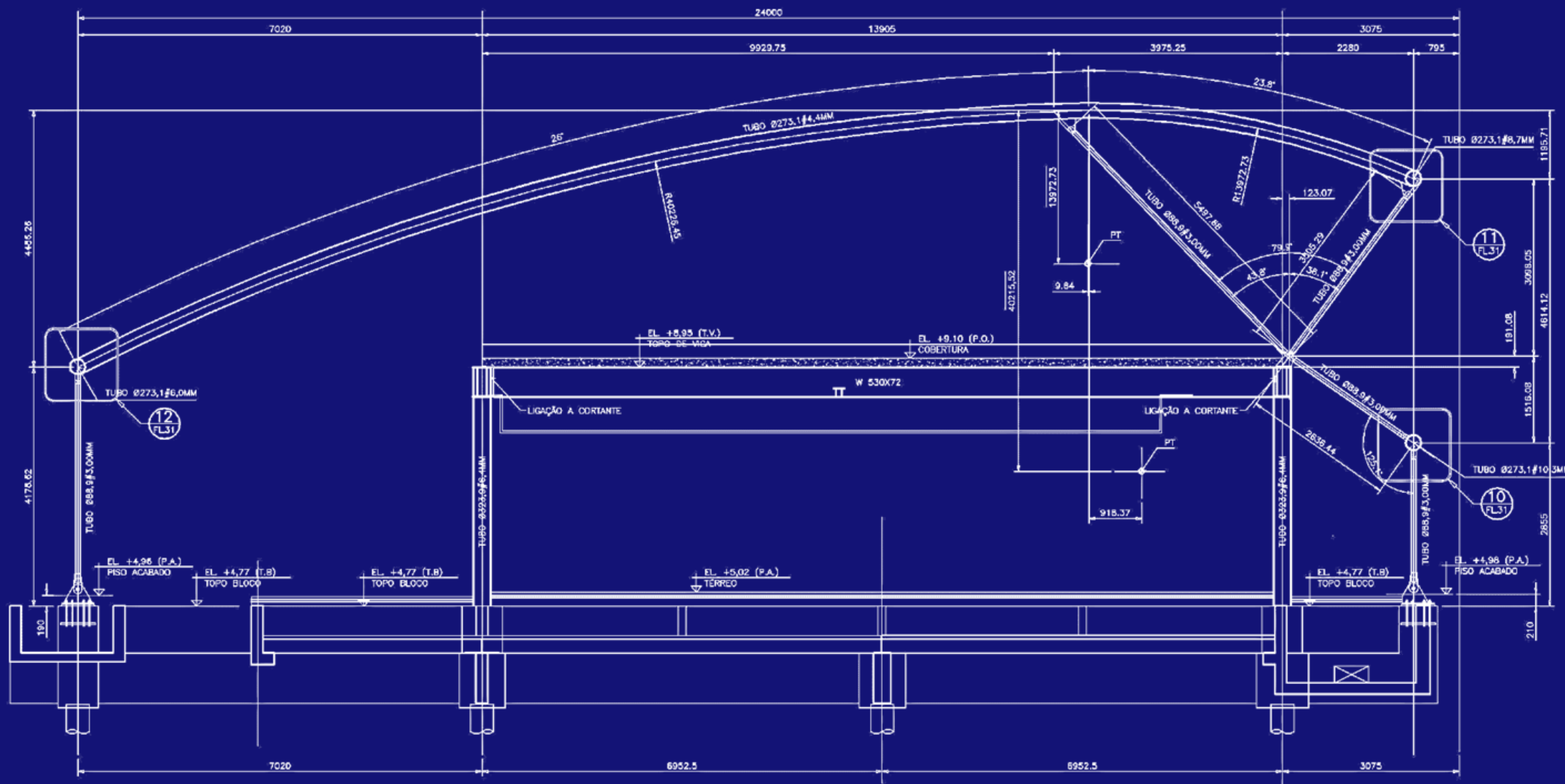


Figura 4 – À esquerda, distribuição da velocidade do vento no nível do pedestre, a 1,5m. Observar escala de velocidades de 0m/s a 3m/s. À direita, distribuição de pressões de vento sobre as envoltórias.







0256 CENTRO DE CONVENÇÕES

CORTE LONGITUDINAL H–H

ESC 1:50

Membranes on top of ‘Morro da Urca’, Rio de Janeiro, 2014

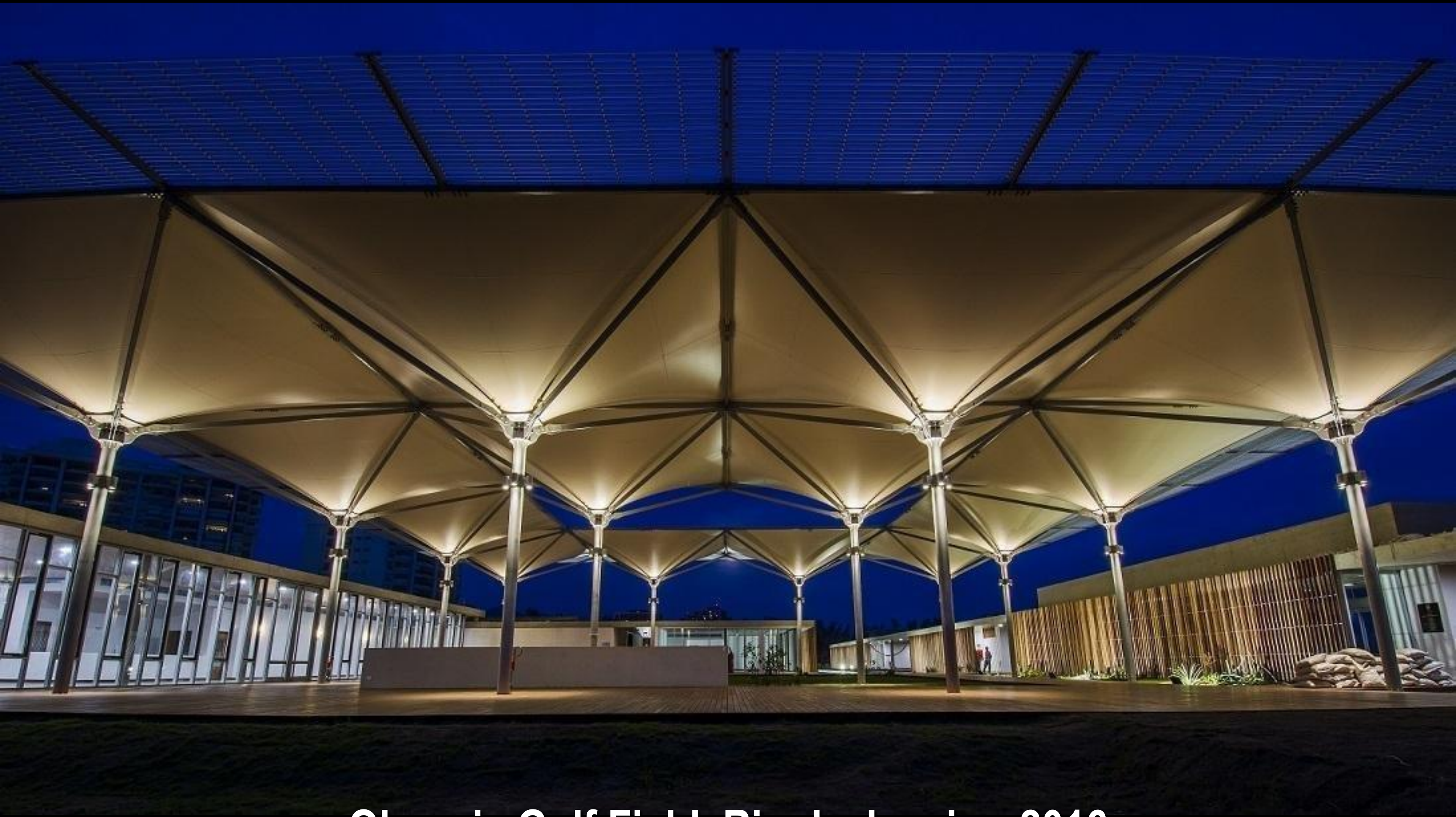
Designers:

(1) Nelson Fielder

(2) Pedro Marcelo Pain de Santana

Olympic Golf Field, Rio de Janeiro, 2016

Olympic Golf Field, Rio de Janeiro, 2016



Olympic Golf Field, Rio de Janeiro, 2016

PEF2602
Estruturas na Arquitetura II - Sistemas Reticulados

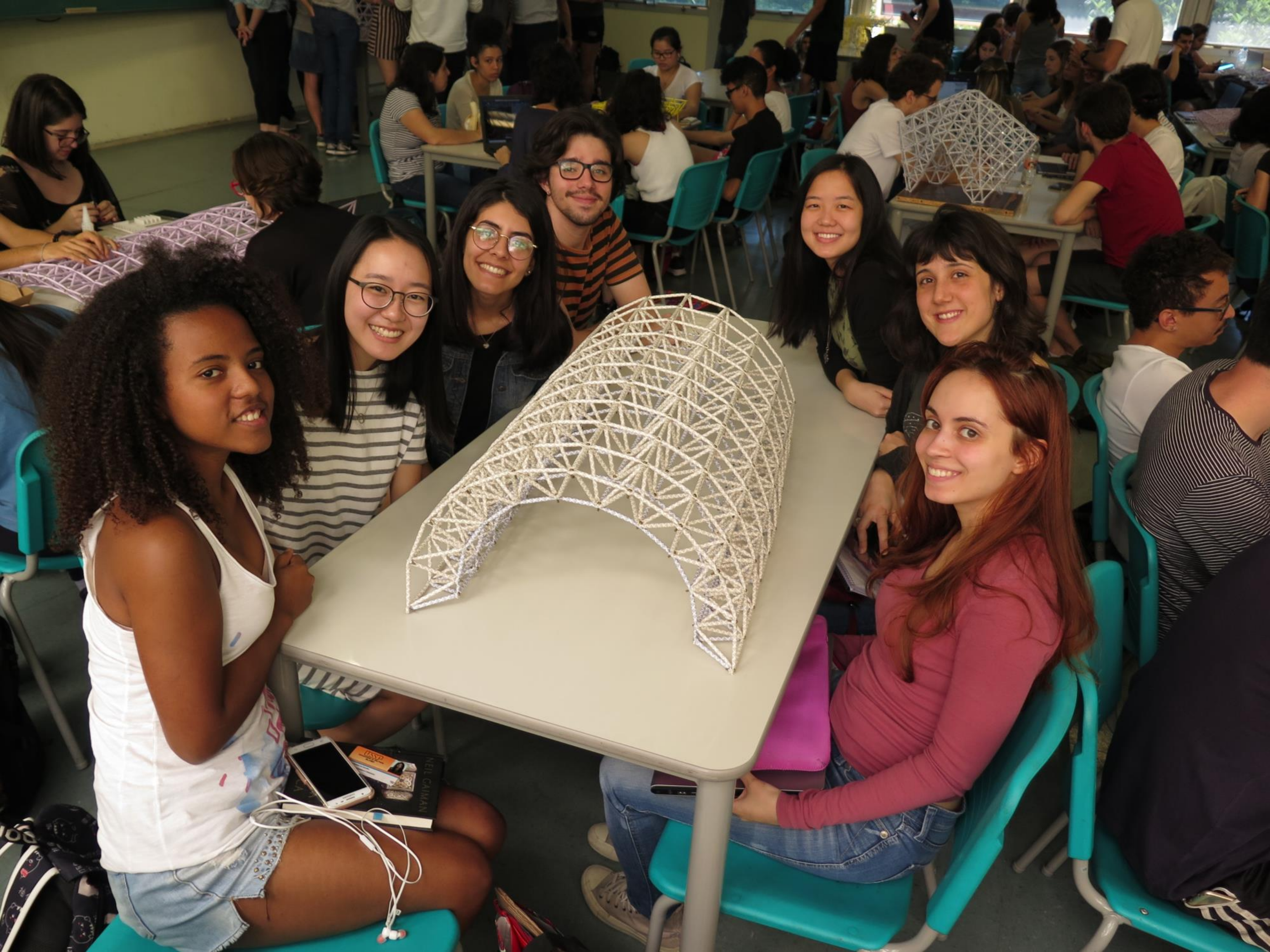
EP-USP

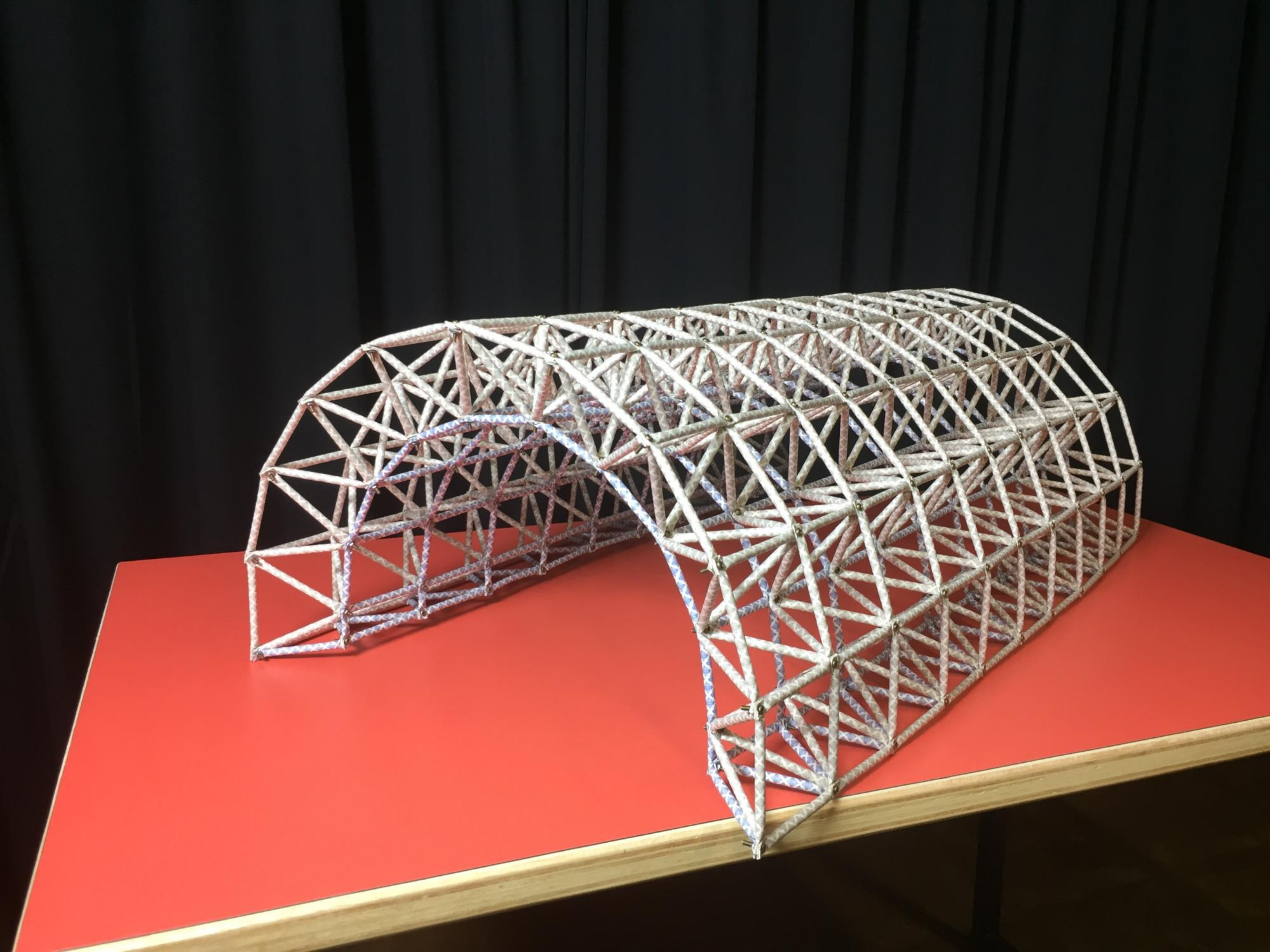
FAU-USP

2º Trabalho em Grupo

Professores
Ruy Marcelo O. Pauletti , Leila Meneghetti Valverdes, Luís Bitencourt

1º Semestre 2019


NEIL GAIMAN




DAD Project – University of Surrey , 2014
Prof. Alireza Behnejad


DAD Project – University of Surrey , 2014
Prof. Alireza Behnejad
No access for unauthorised persons
Foot protection must be worn
Head protection must be worn
Eye protection must be worn


DAD Project – University of Surrey , 2014
Prof. Alireza Behnejad