EP-USP

PEF2603
Estruturas na Arquitetura I I I
- Sistemas Reticulados e Laminares

FAU-USP

Tensoestruturas
(Redes da Cabos e Membranas)

Professores
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1º Semestre 2023

Estrutura Retesadas (‘Tensoestruturas’):

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

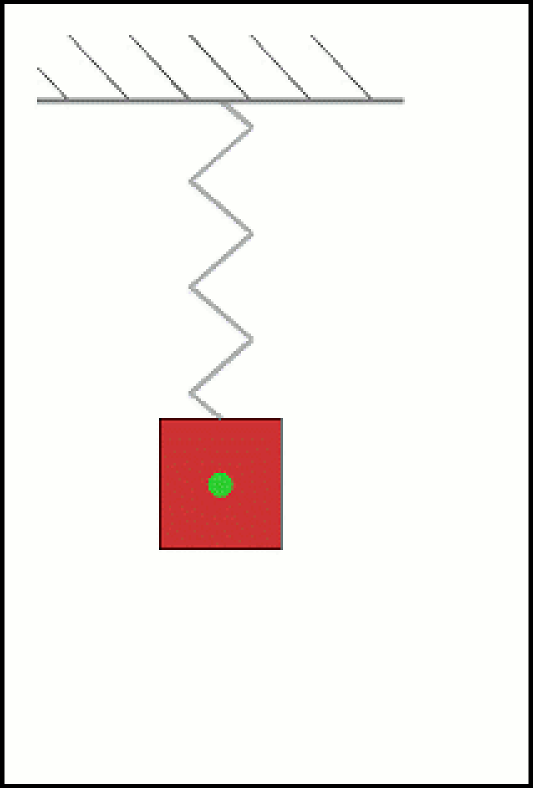
Estados de uma Tensoestruturas:

frouxo

enrugado

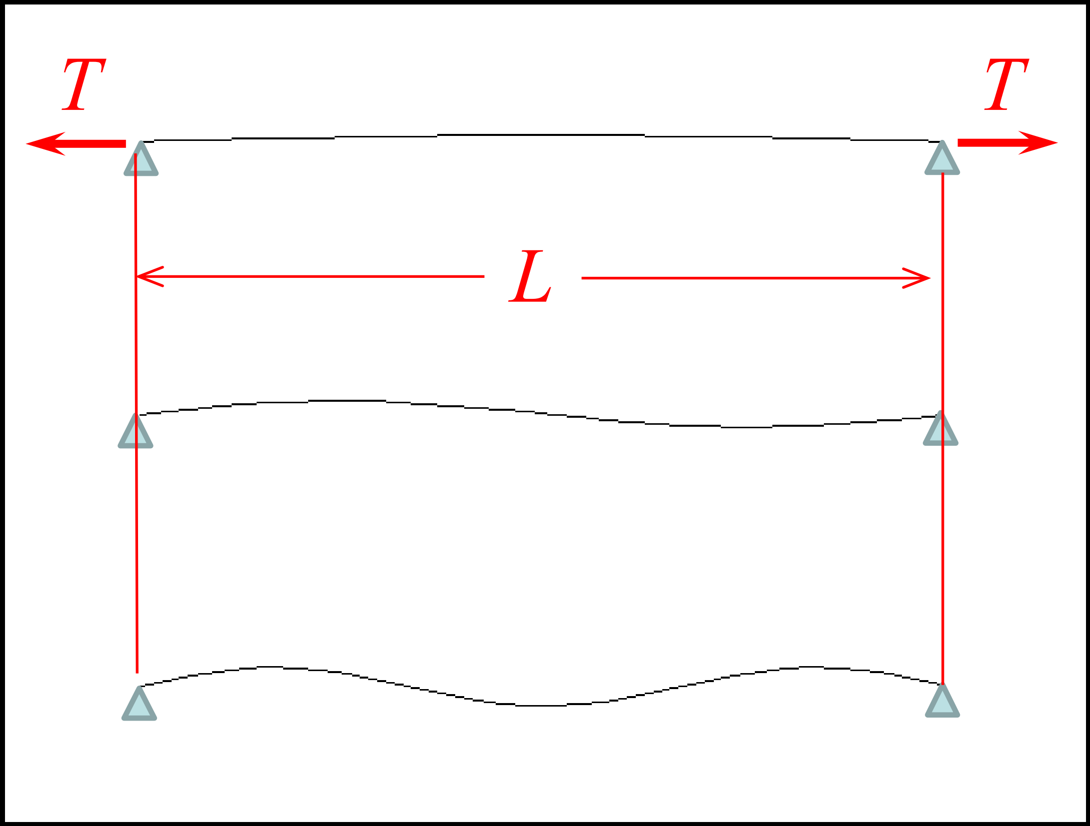
retesado

Um sistema massa-mola:



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

Uma corda vibrando:

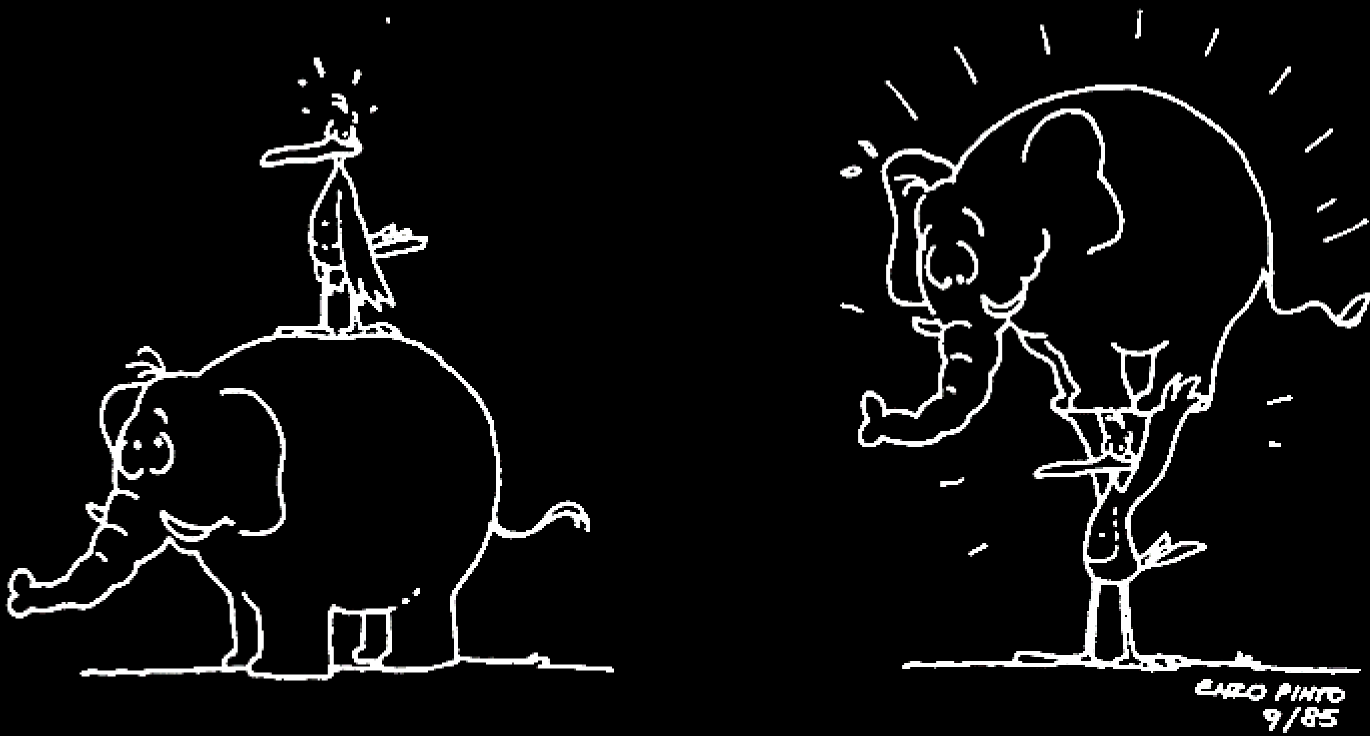


$$f = n\pi\sqrt{\frac{\left(\frac{T}{L}\right)}{m}}$$

'rigidez geométrica'

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

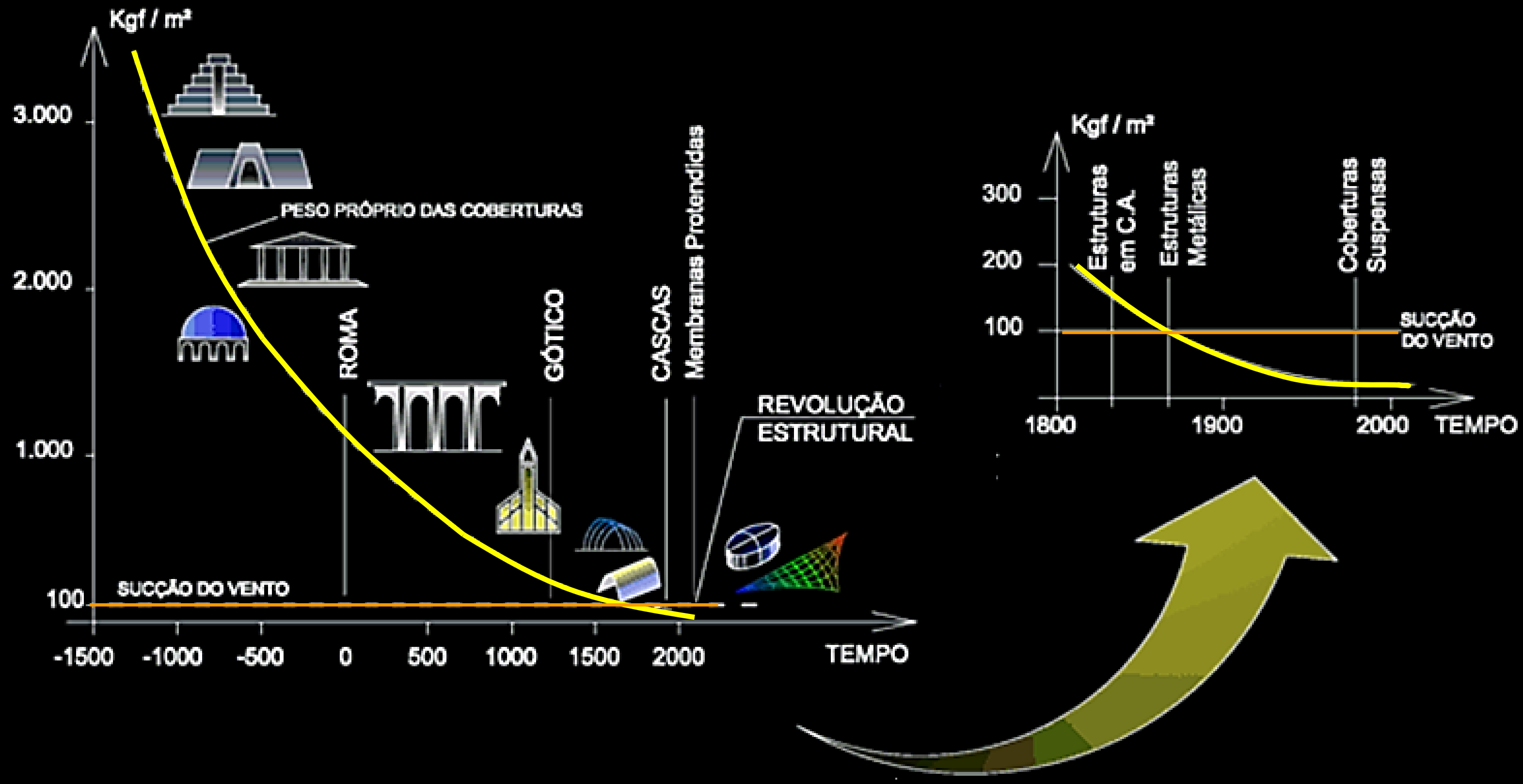
Estruturas Leves:



'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”

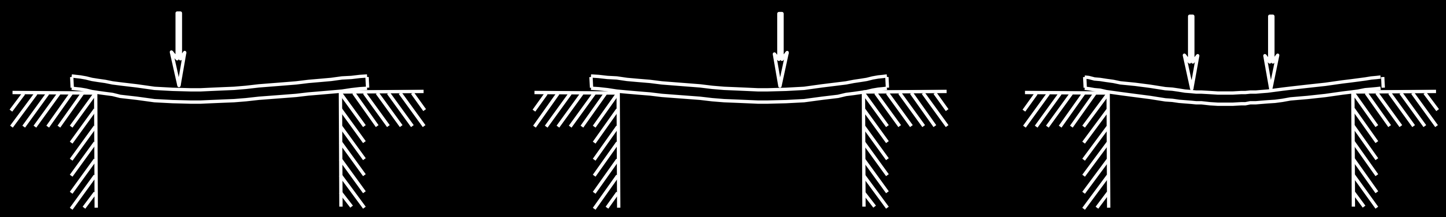
Horst Berger

Suvarnabhumi Airport,
Bangkok, Thailand

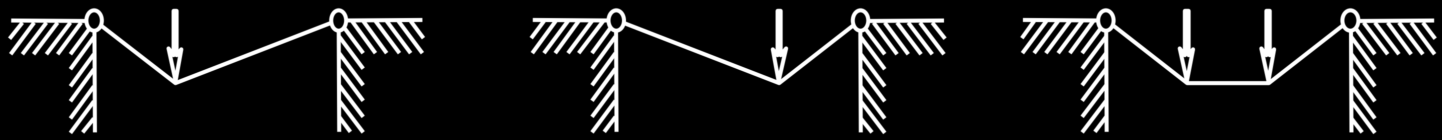

Select Your Ultimate Home
CBRE

Photo by
Tim Nugent, 2009

Estruturas Flexíveis:



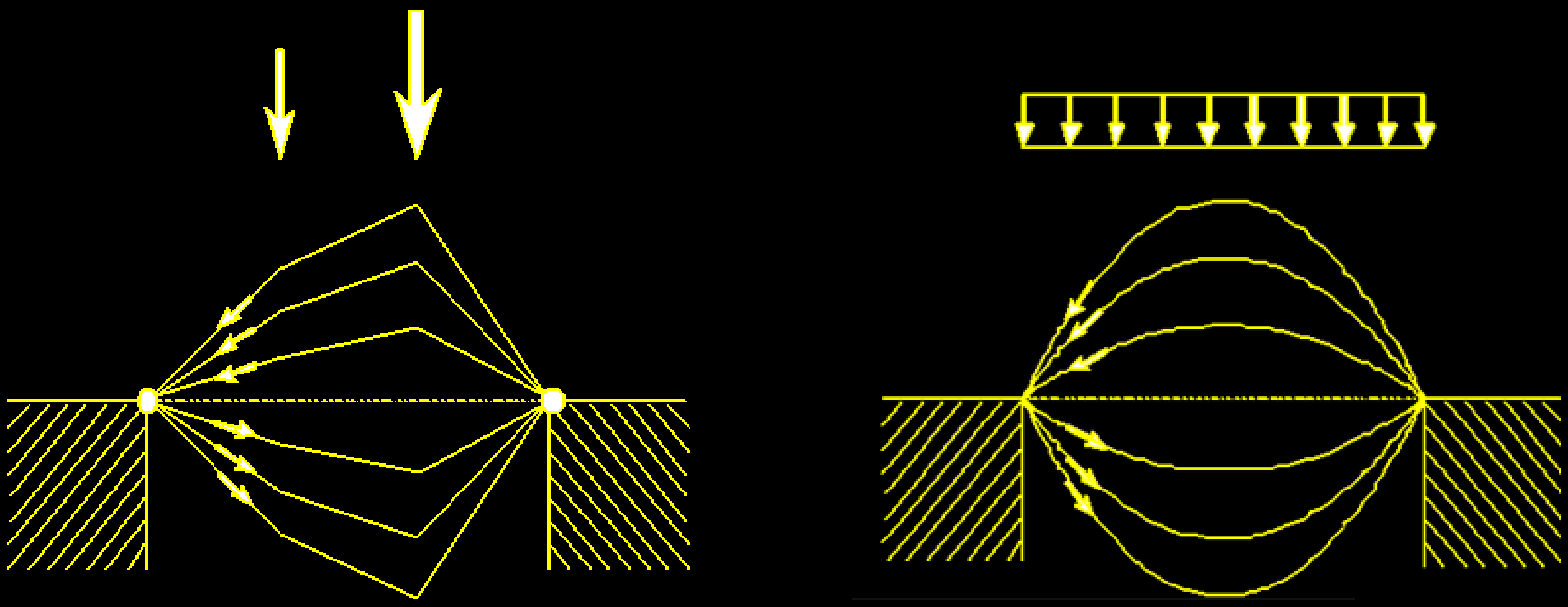
(a) Uma estrutura 'rígida' , como uma viga, não muda drasticamente de forma, quando o carregamento varia



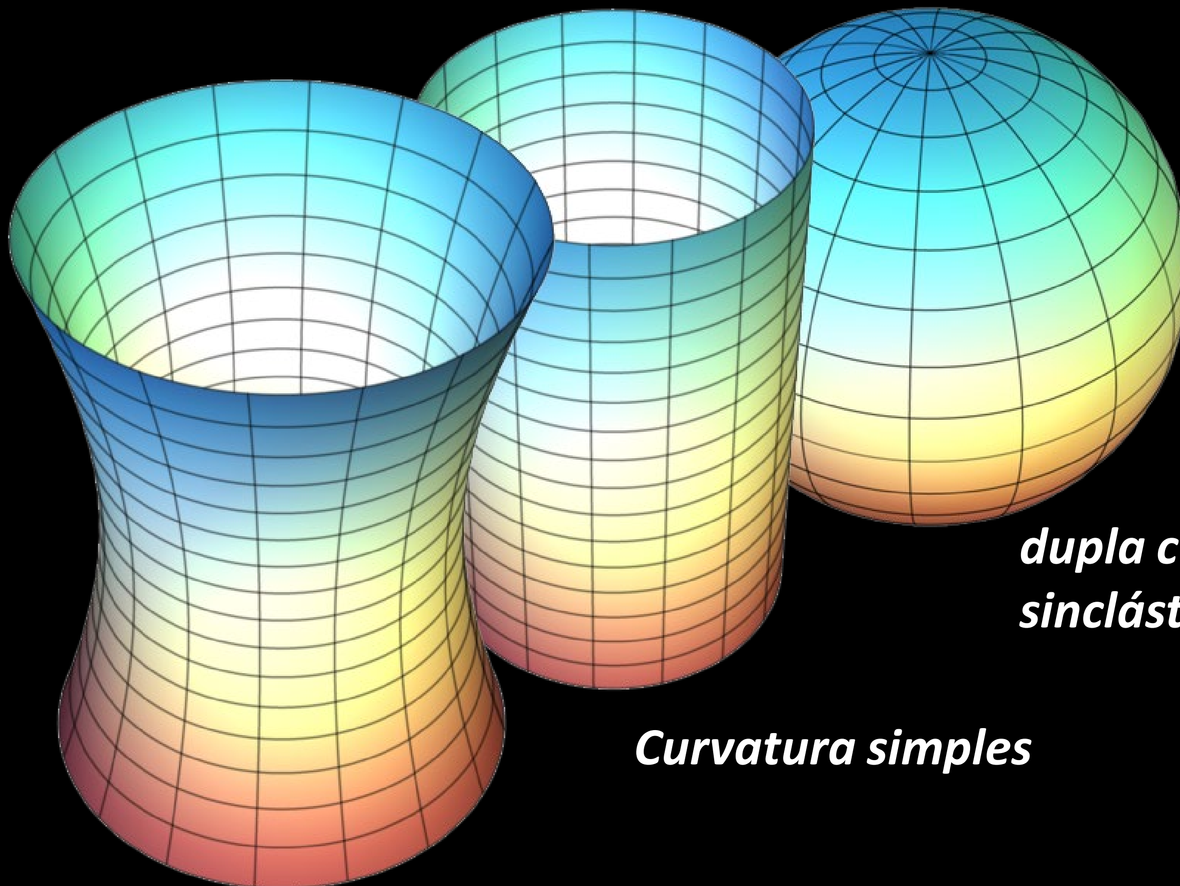
(b) Uma estrutura 'flexível', como um cabo, pode alterar drasticamente sua forma, quando o carregamento varia


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:

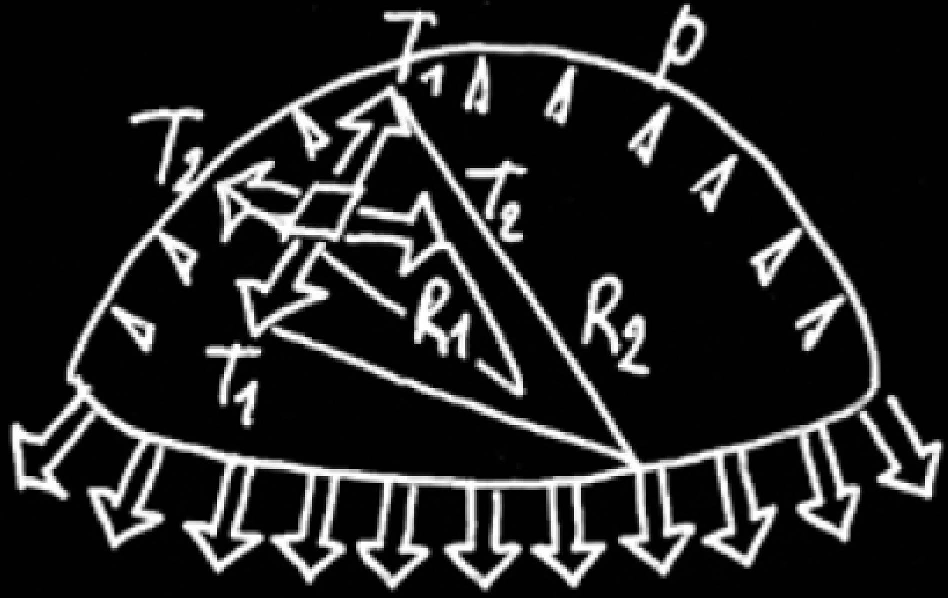


dupla curvatura, sinclástica

Curvatura simples

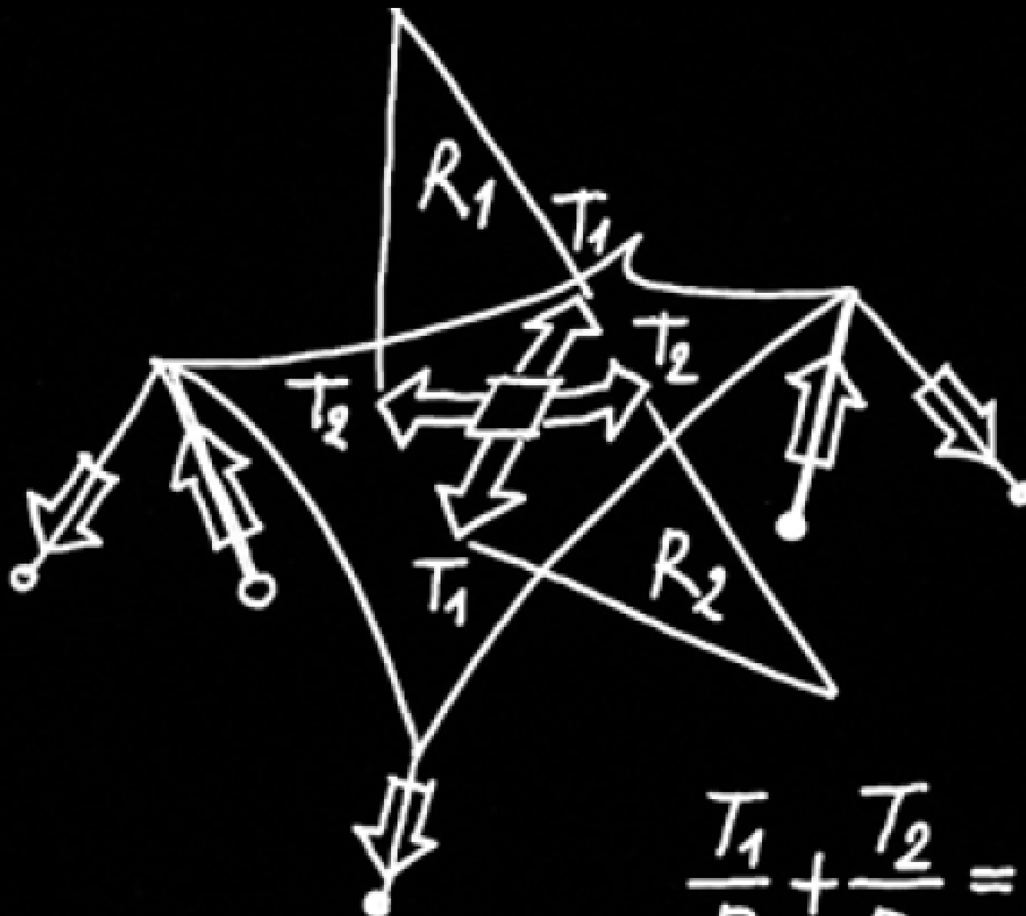
dupla curvatura, anticlastica

Membranas pneumáticas em geral são sinclásticas:



Equação de Laplace-Young: $$\frac{T_1}{R_1} + \frac{T_2}{R_2} = p$$

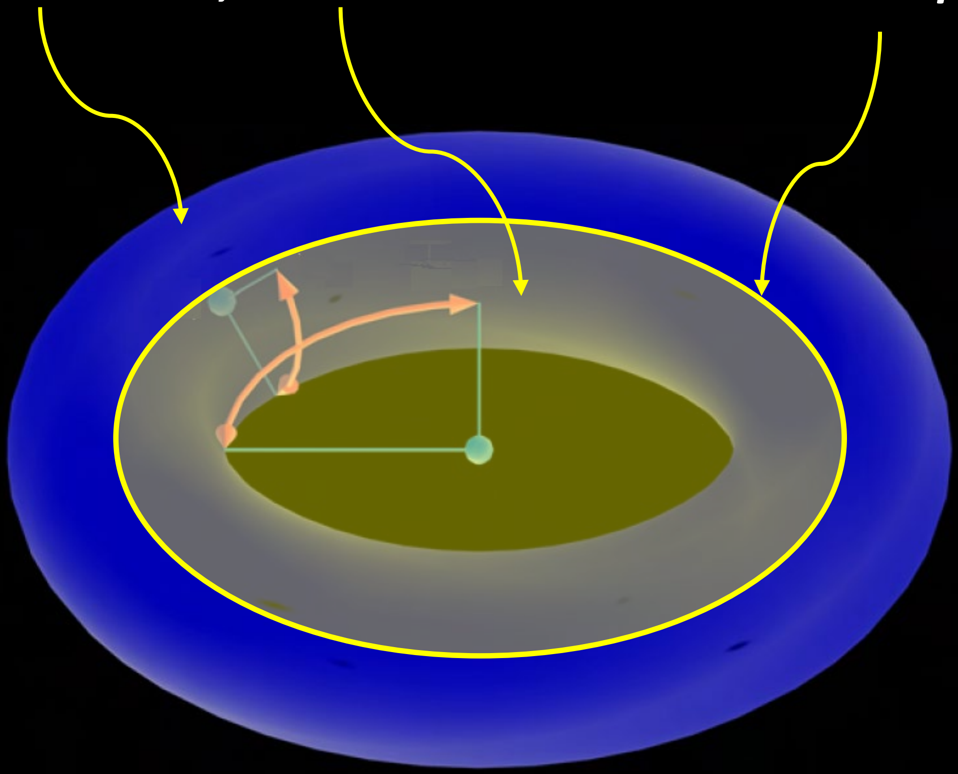
Porém tendas são sempre anticlásticas or planas!



$$\frac{T_1}{R_1}+\frac{T_2}{R_2}=0$$

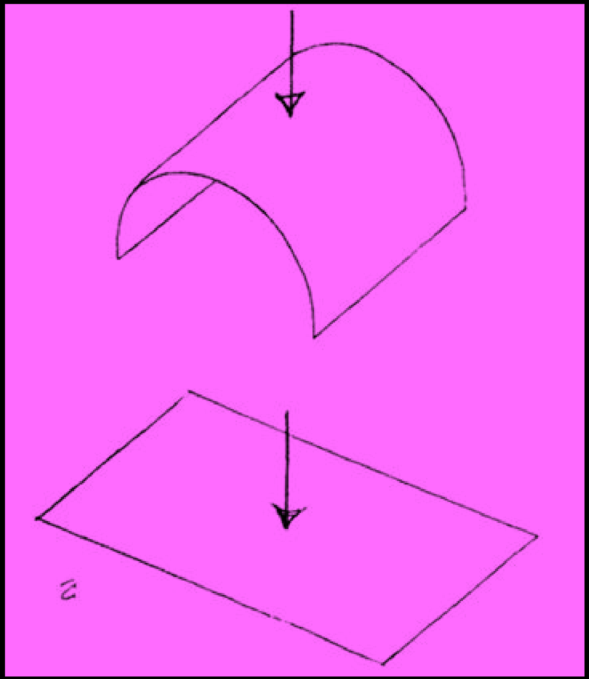
Equação de Laplace-Young:

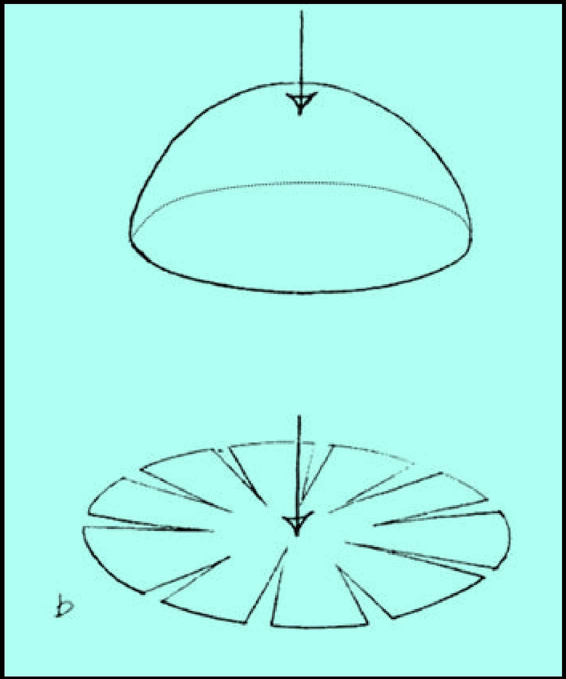
Estruturas pneumáticas podem apresentar zonas sinclásticas, anticlásticas e de curvature simples:




SAVE
THE
CLIMATE

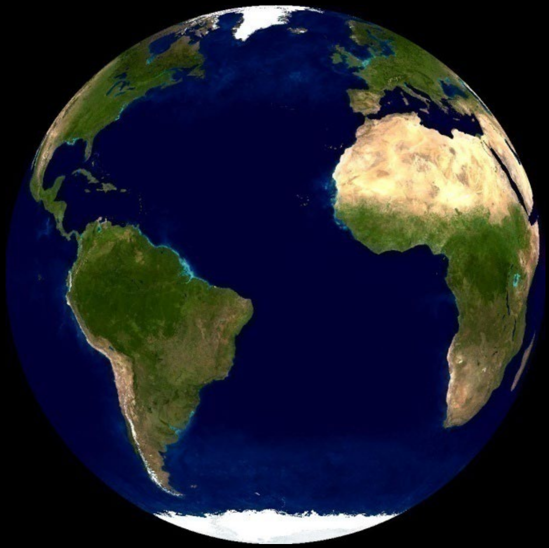
Planificação

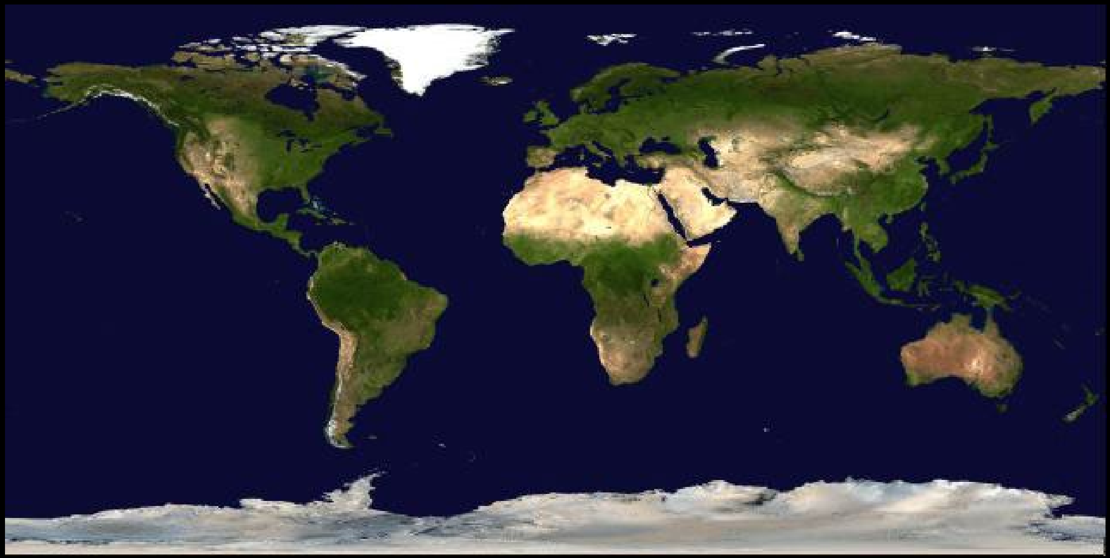




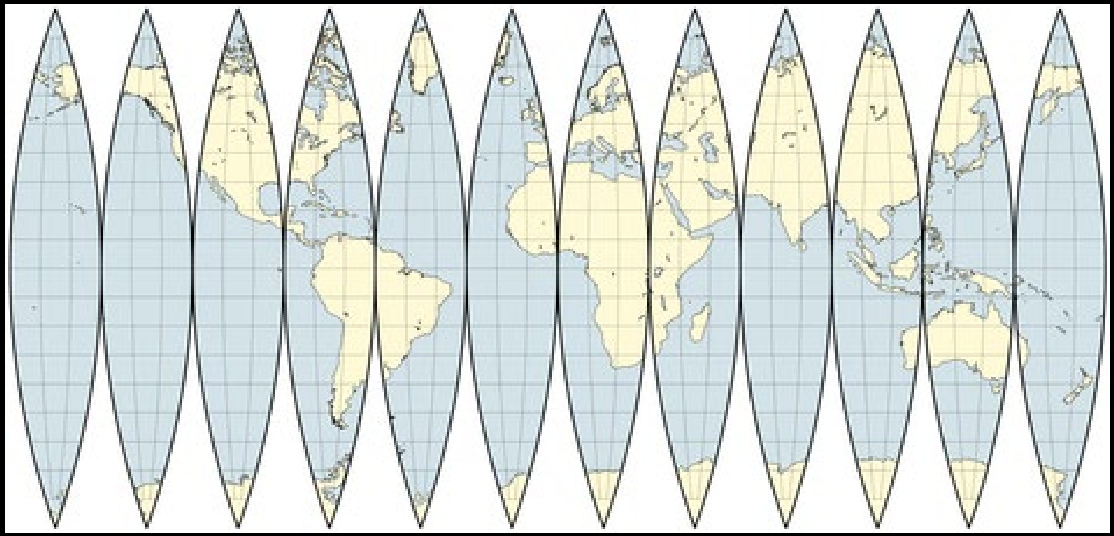
Superfícies de curvature simples podem ser planificadas sem distorção

Superfícices de dupla curvature sofrem distorção quando planificadas





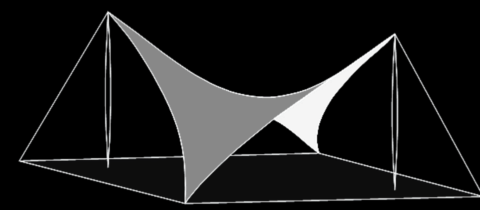
Mercator projection



A gore map using Apian's first projection.

O Processo de Projeto das Estruturas Retesadas

INTENÇÃO ARQUITETÔNICA:



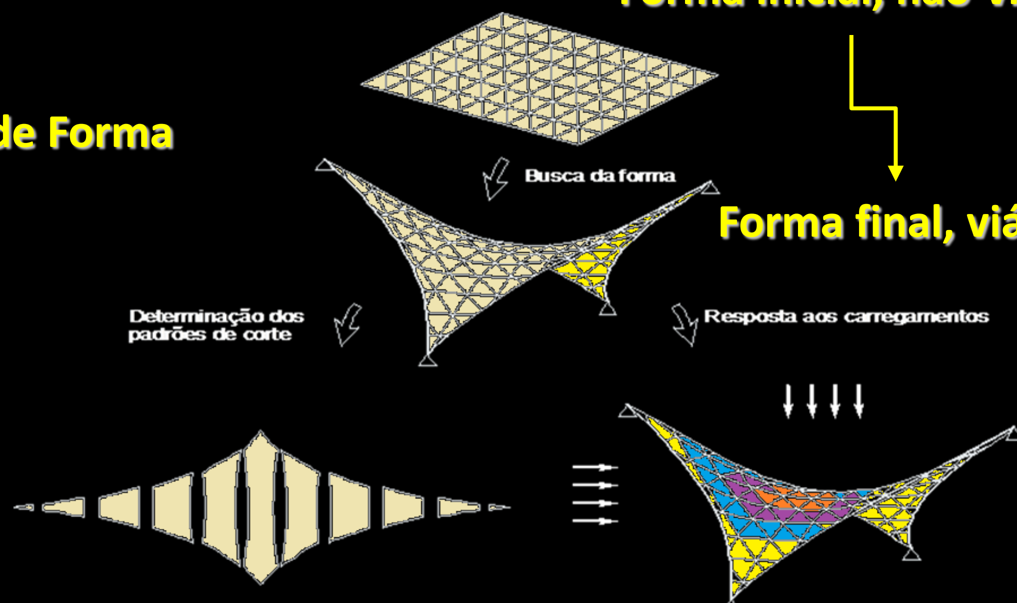
PROJETO / ANÁLISE:

Forma inicial, não-viável

Busca de Forma

Forma final, viável

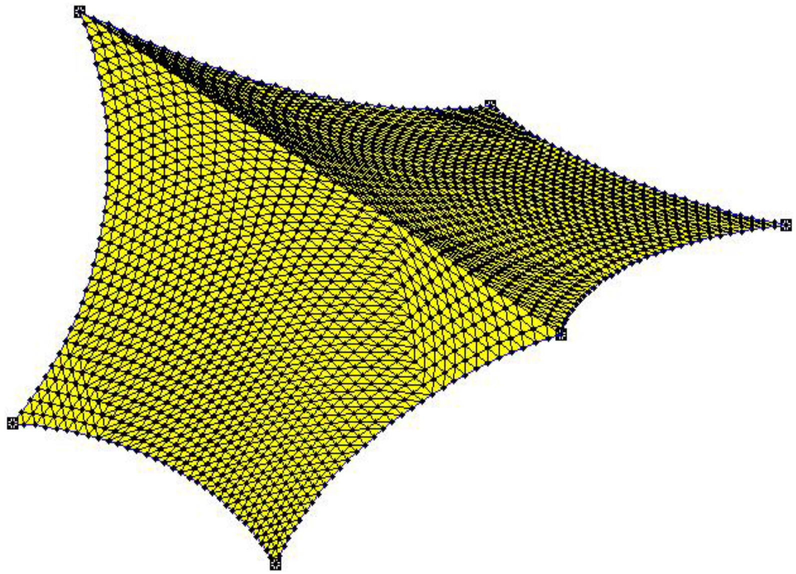
Padronagem:

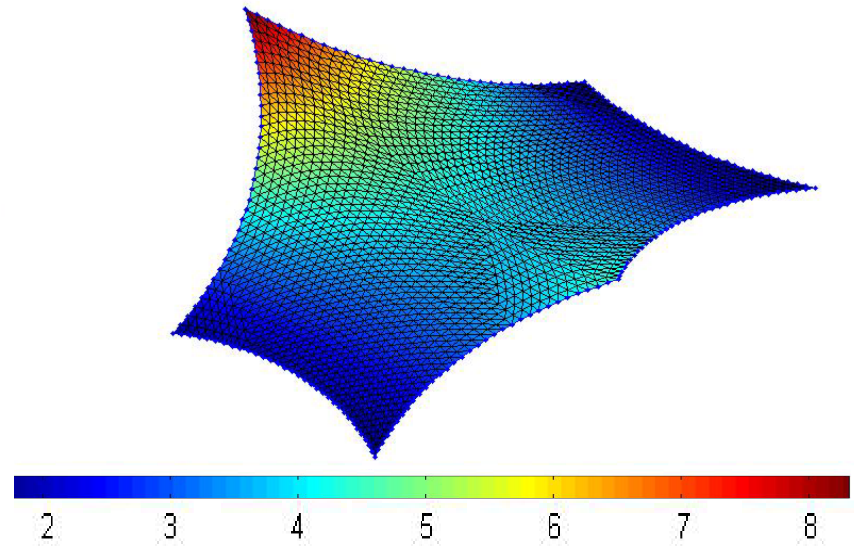


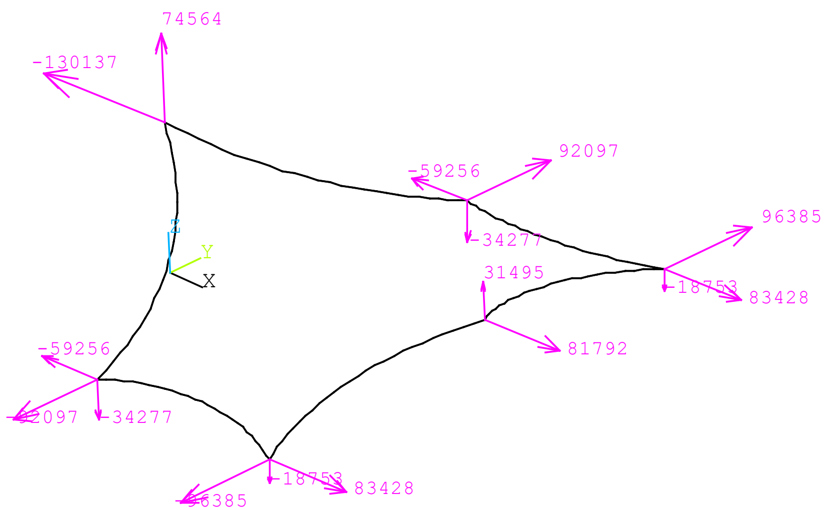
Análise de Carregamentos

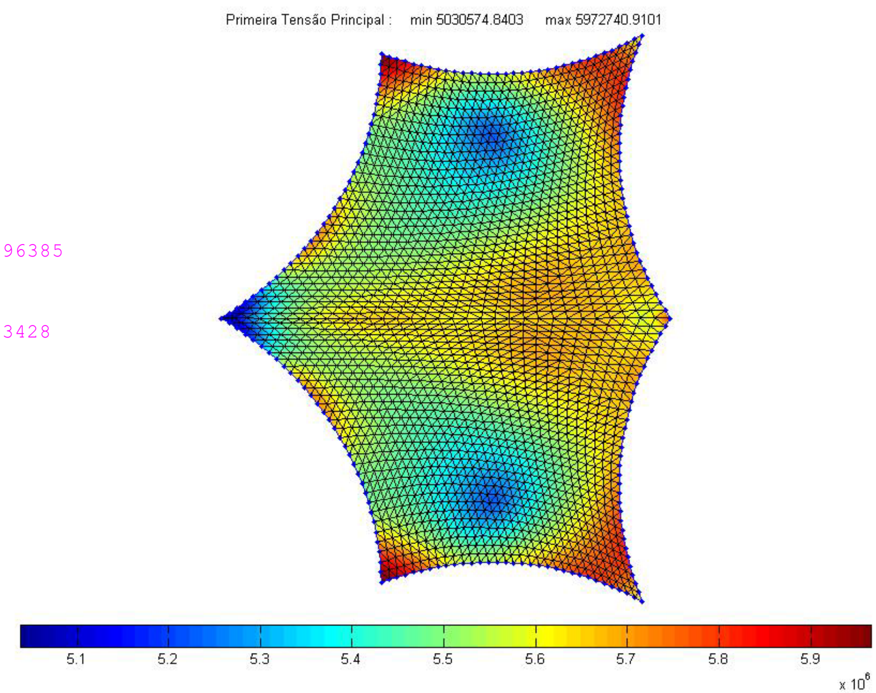
SOLUÇÃO DE PROJETO:

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

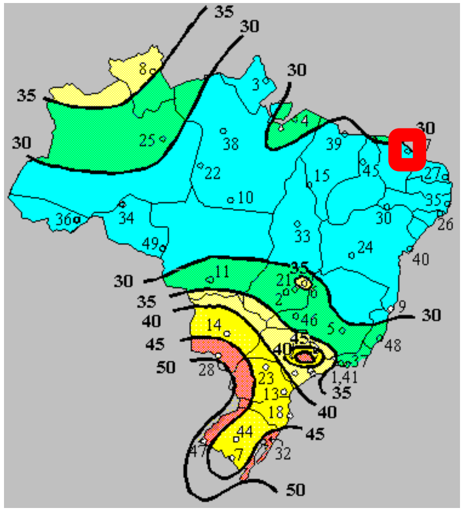


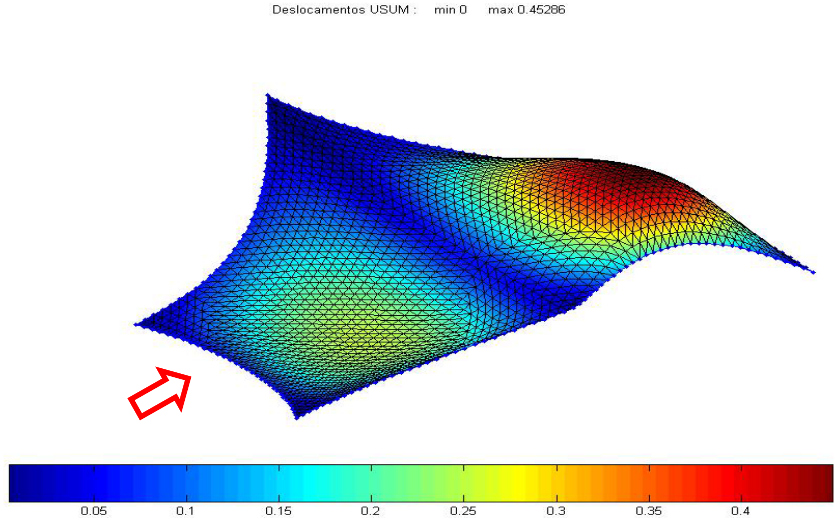

2
3
4
5
6
7
8


74564
-130137
92097
-59256
-34277
96385
31495
-18753
83428
81792
-59256
-34277
83428
Z
Y
X

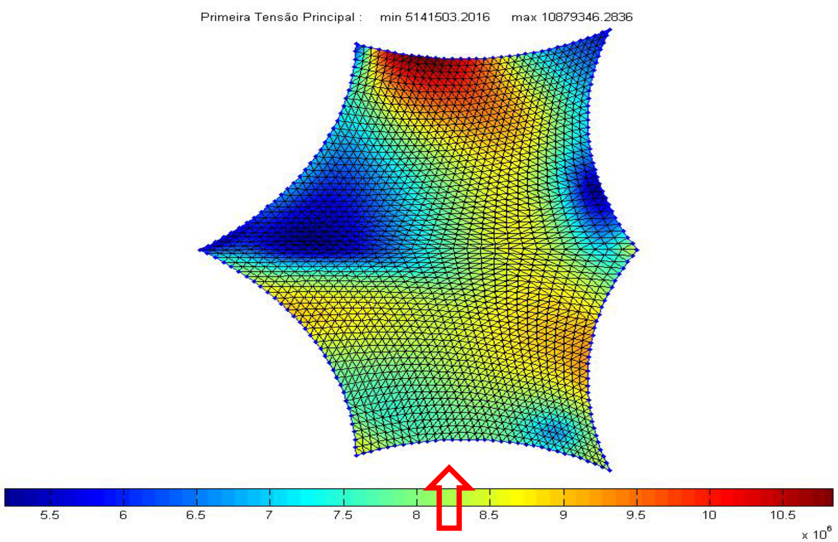

Primeira Tensão Principal : min 5030574.8403 max 5972740.9101
5.1
5.2
5.3
5.4
5.5
5.6
5.7
5.8
5.9
x 10^6

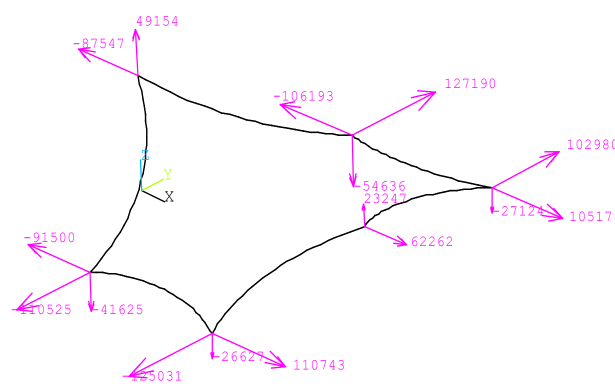
Resposta às cargas de ventos





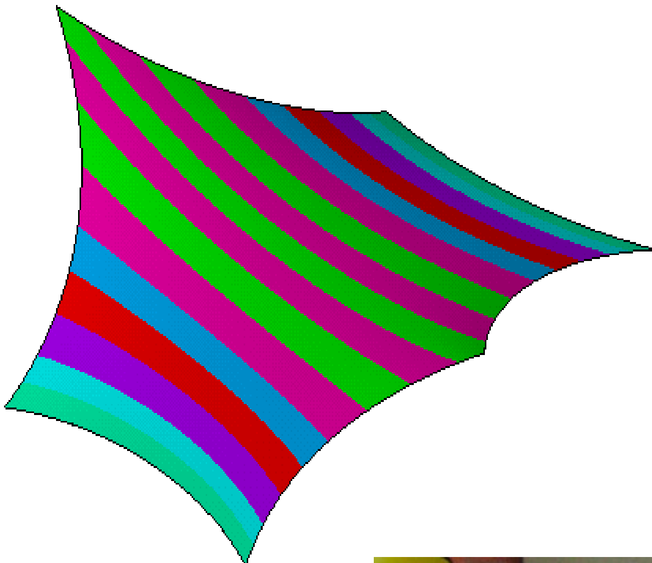
displacement norms,
for the Y-wind load case

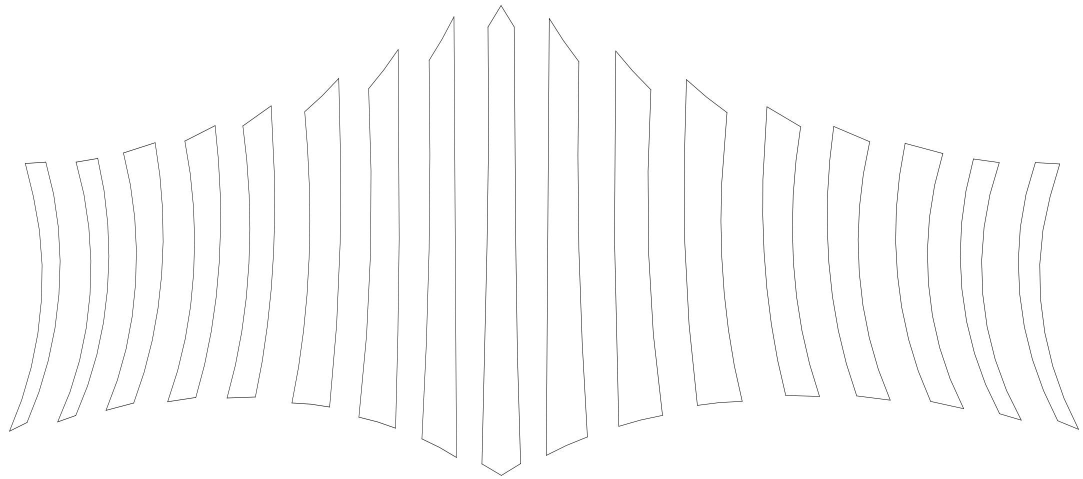


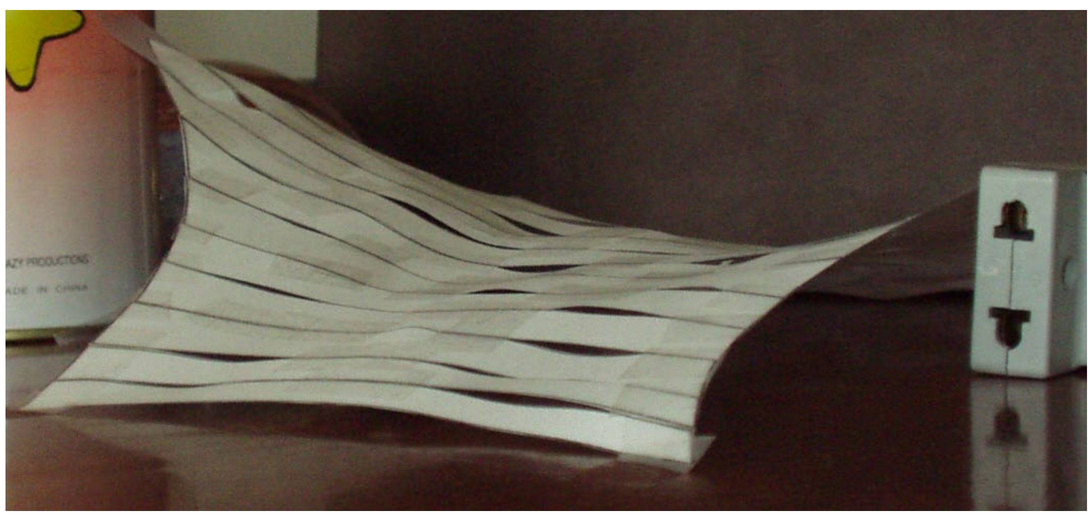


Maximum 1st principal stresses
(S1) for the Y-wind load case

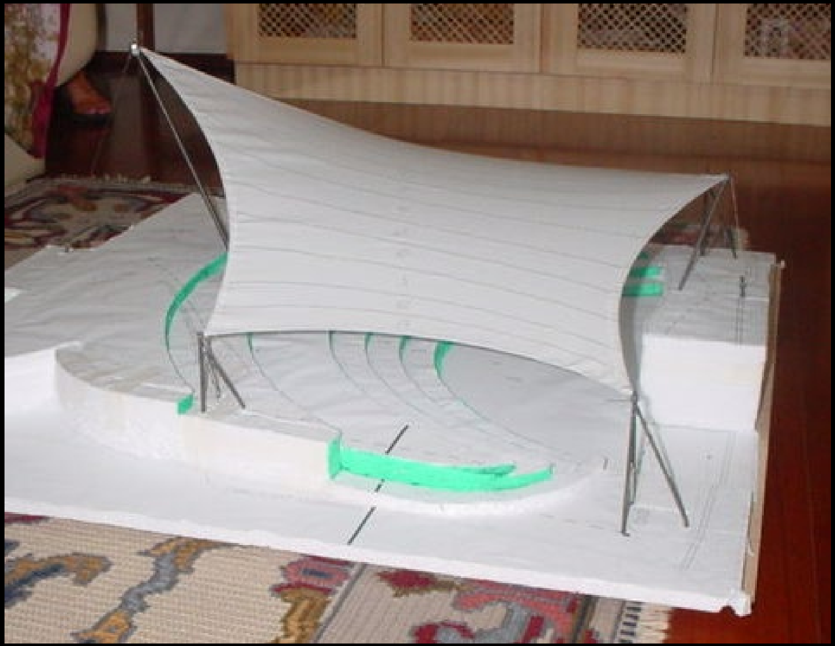
Padrões de corte

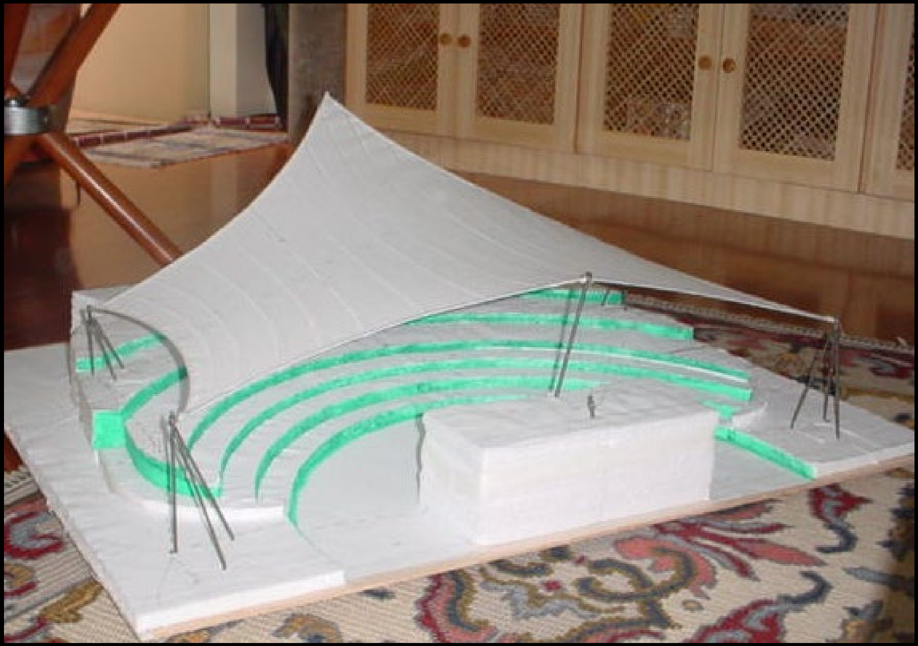






Maquete em tecido escala 1:50





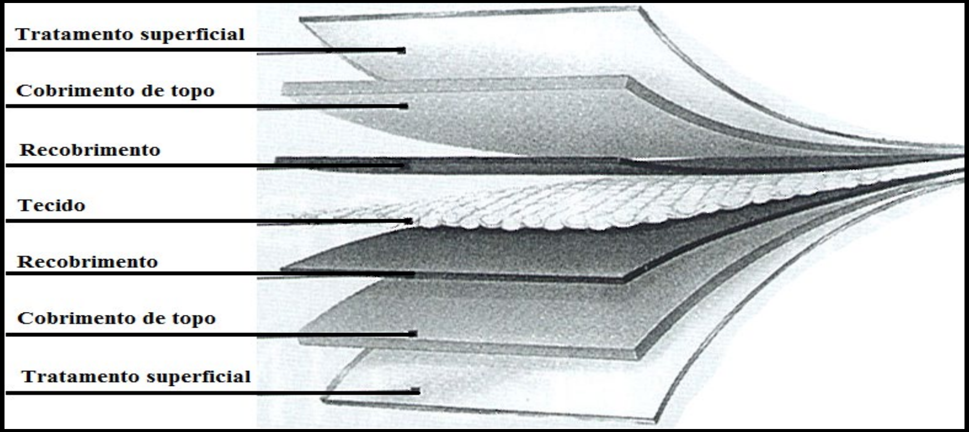
Modelo em tecido escala 1:10



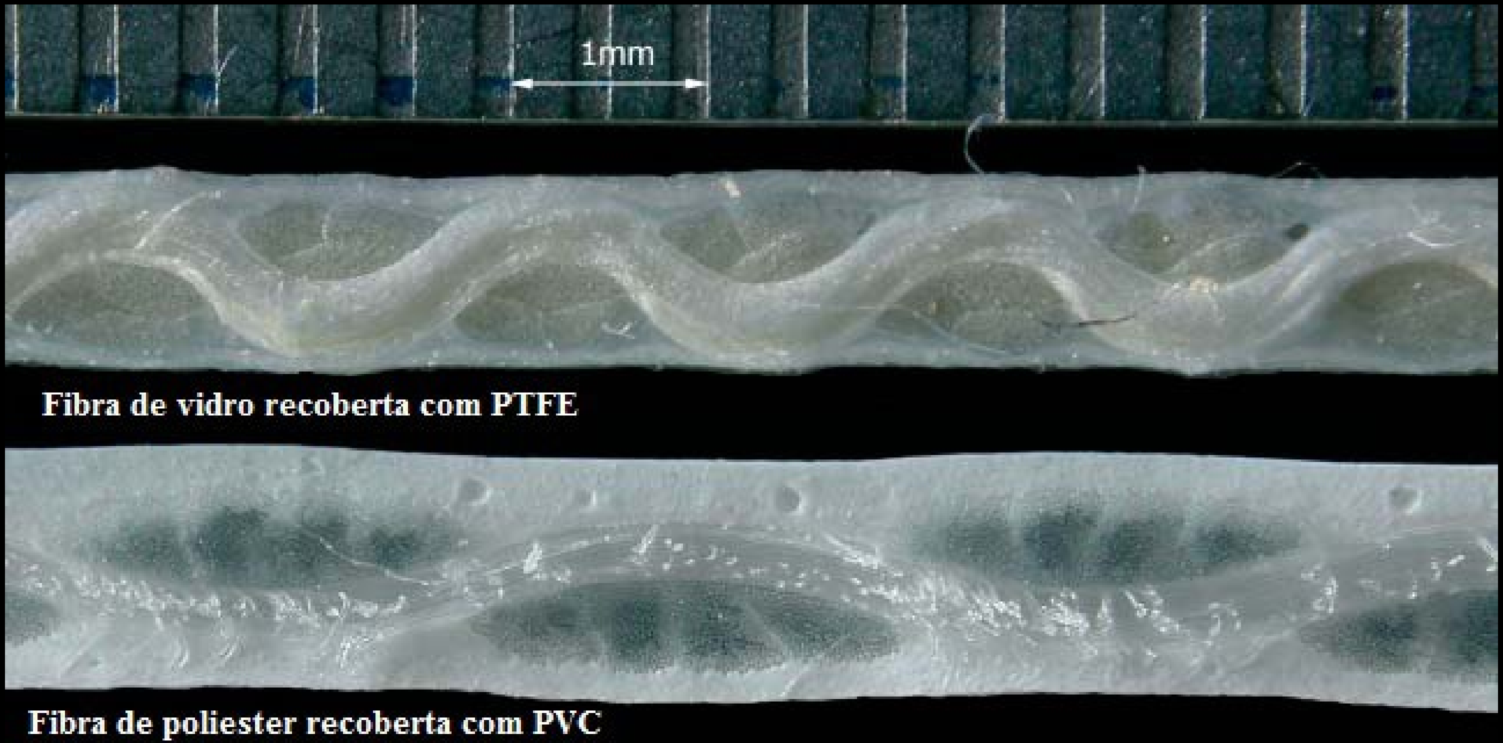
Tecidos técnicos

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

Recobrimento com PTFE (Pudenz, 2004)

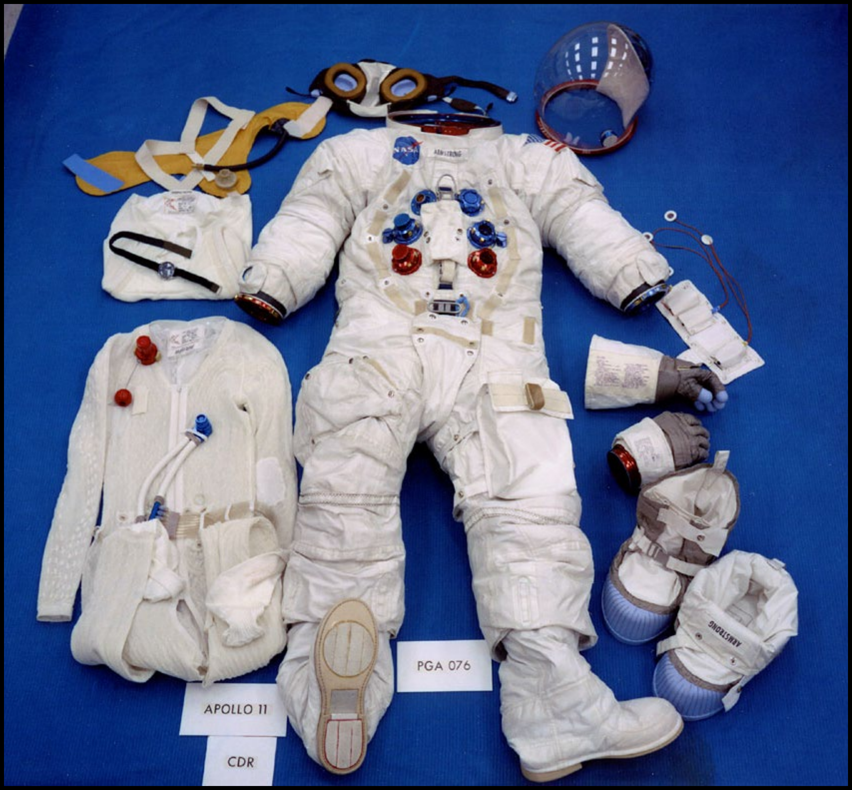


Diferentes camadas de um tecido técnico Blum *et al* (2004)

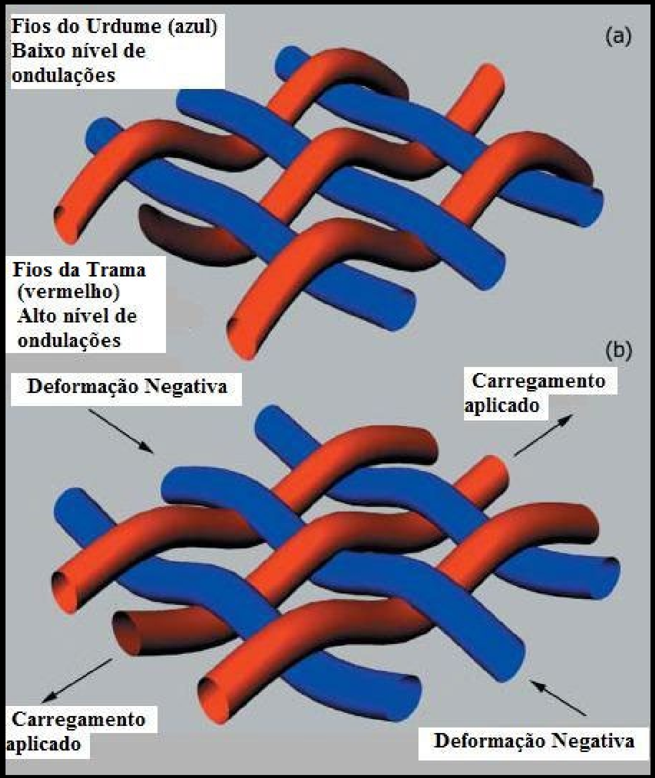


Seções transversais de tecidos de fibra de vidro e poliéster (BRIDGENS et al, 2004).

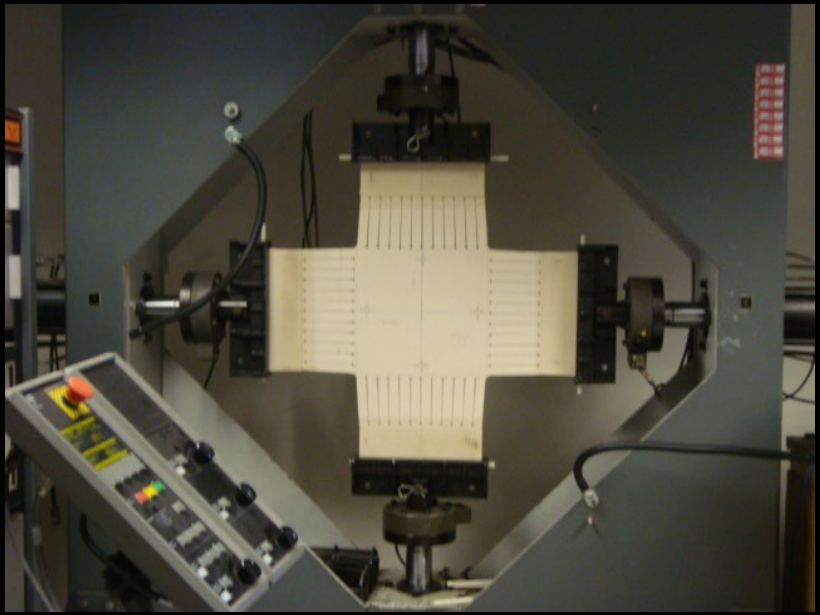
PTFE-covered fiberglass fabric (1969)
DuPont, Birdair, Chemfab & Owens-Corning



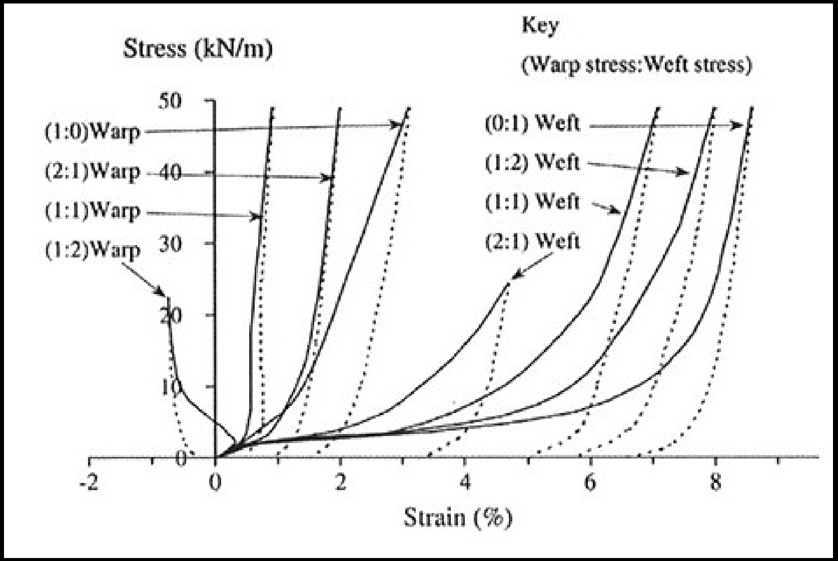
Neil Armstrong's Suit
Apollo 11 Project (1969)



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

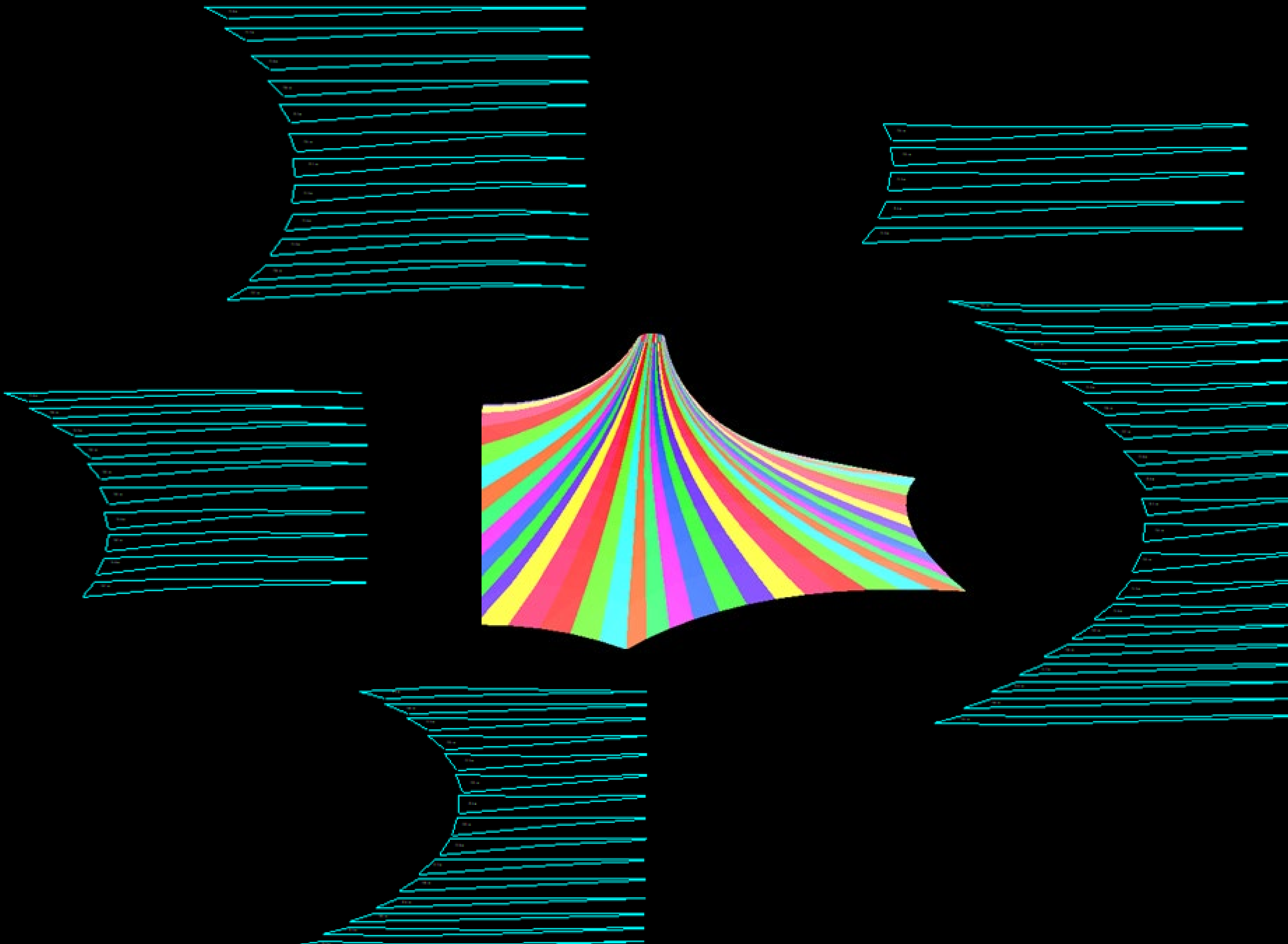
Fabric Architecture 2009 Sourcebook

Tecidos de poliéster recobertos com PVC

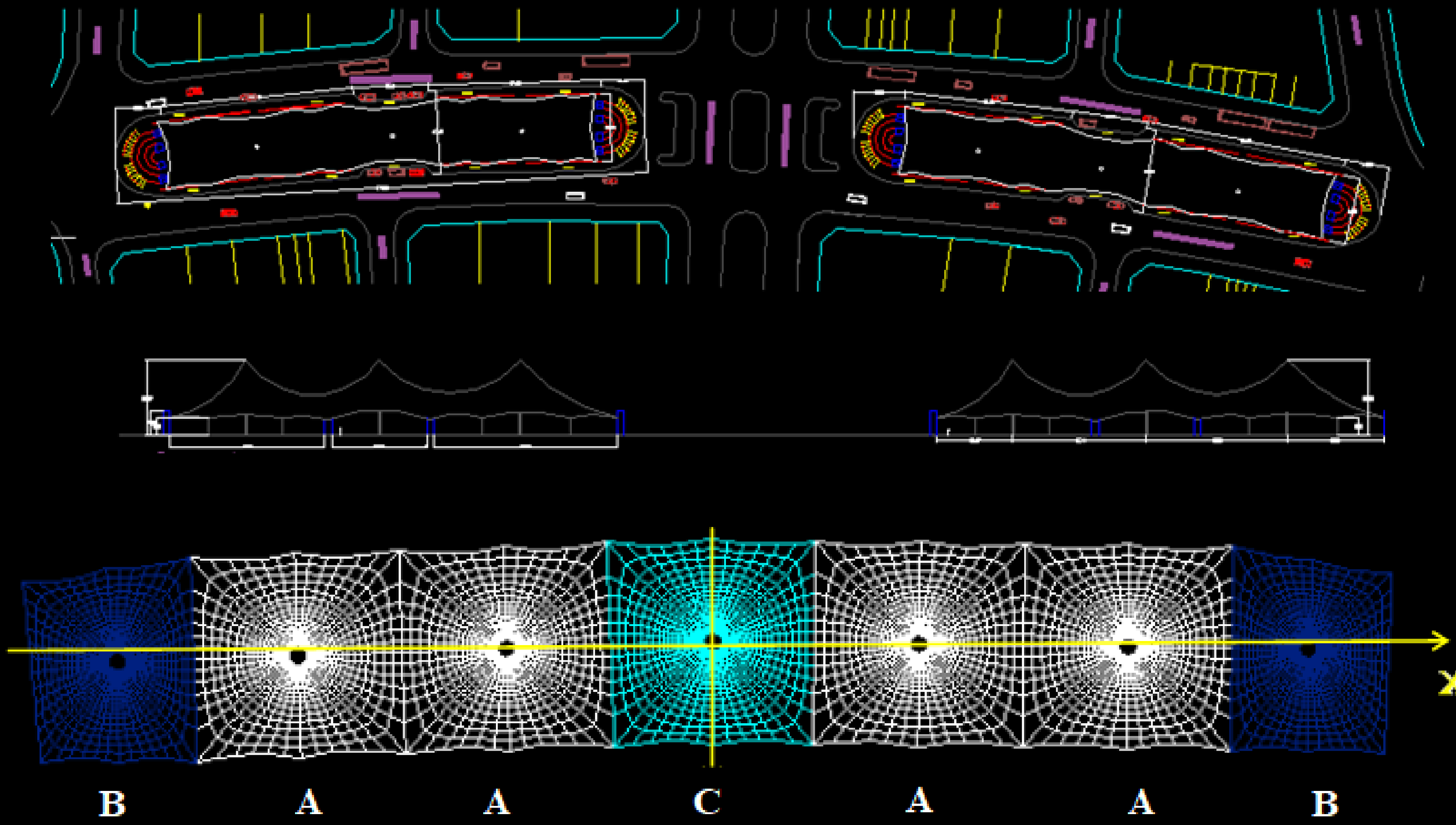
Type	1	2	3	4	5
Surface weight (g/m²)					
French design guide	720	1 000	1 200	1 400	2 000
WG Messe Frankfurt	800	900	1 050	1 300	1 450
Yarn linear density (dtex)					
French design guide					
WG Messe Frankfurt	1 100	1 100	1 670	1 670	2 200
Tensile strength warp/weft (kN/m)					
French design guide	60/60	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

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




Goiânia´s Open Market (2006)

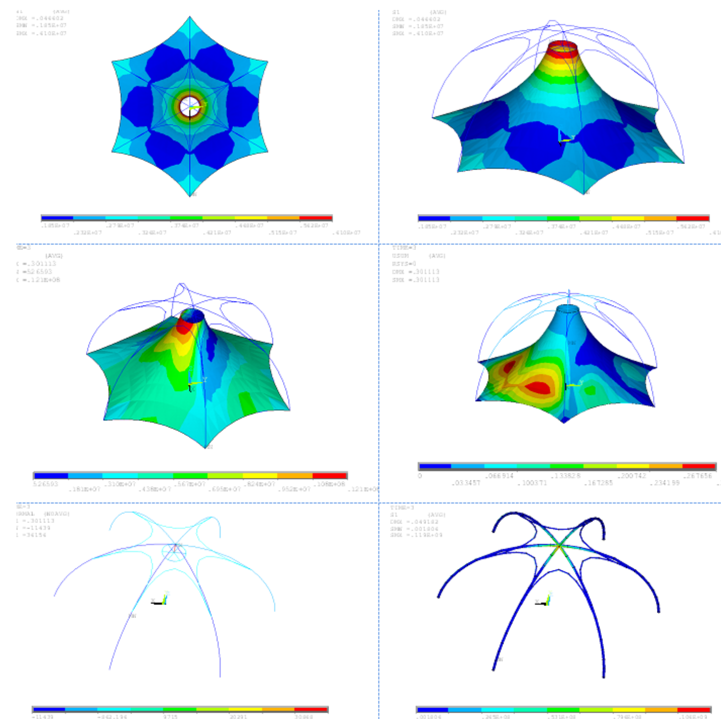

X
B
A
A
C
A
A
B





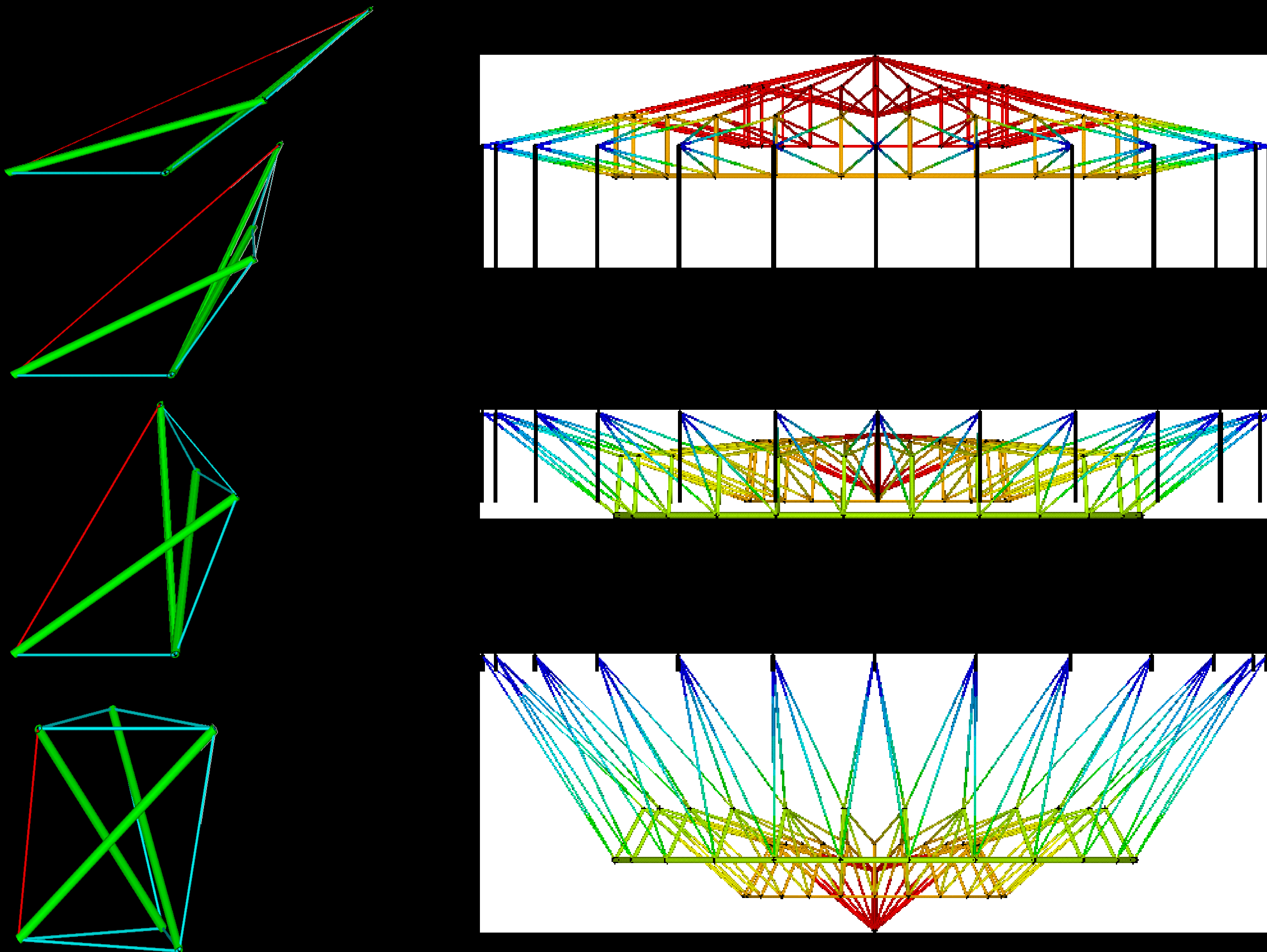
PEF5750
ESTRUTURAS
LEVES
28.08.2007

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

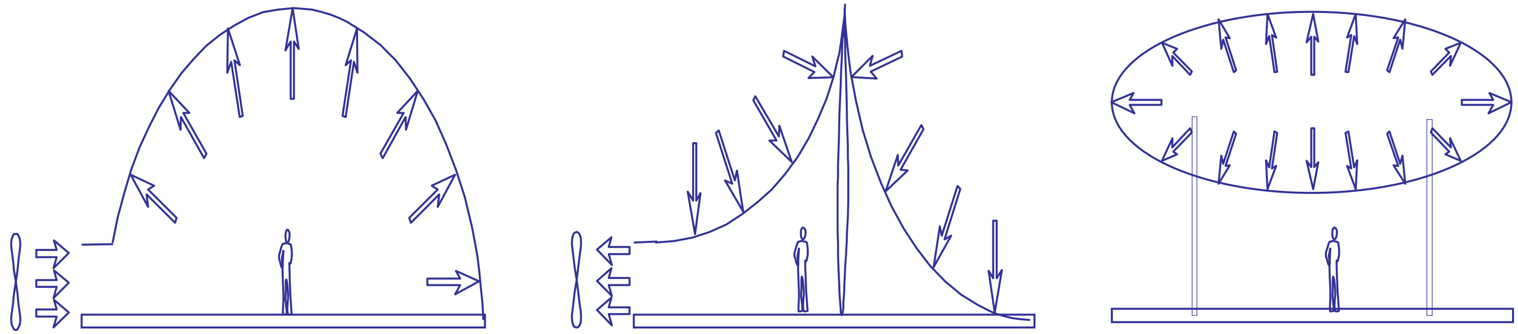


"Feira da Cidade de Ananindeua, PA (2006)
Arch. José Maria Coelho Bassalo and Flávio Campos do Nascimento

Monument to the Futile Form II (2003)

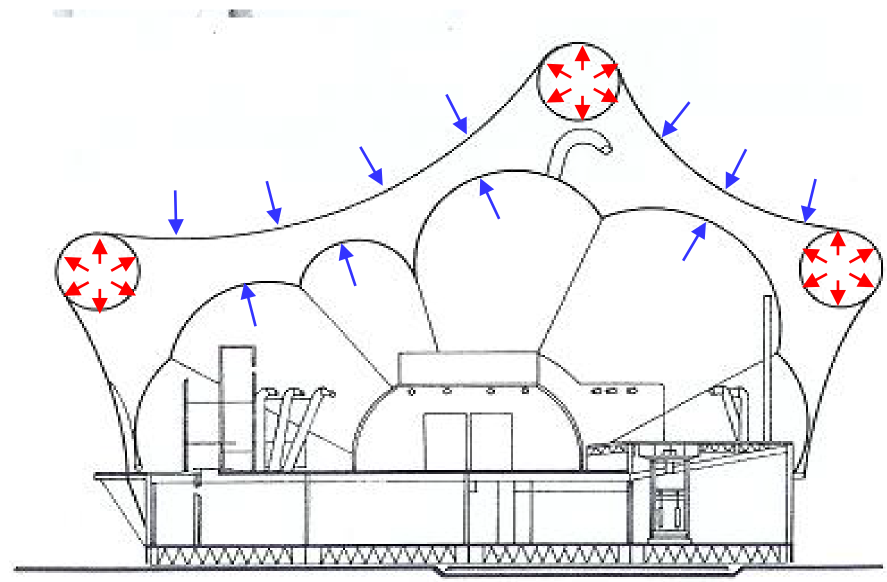


Pneumatic Structures



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

Tokyo "Big-Egg" Dome (1988)



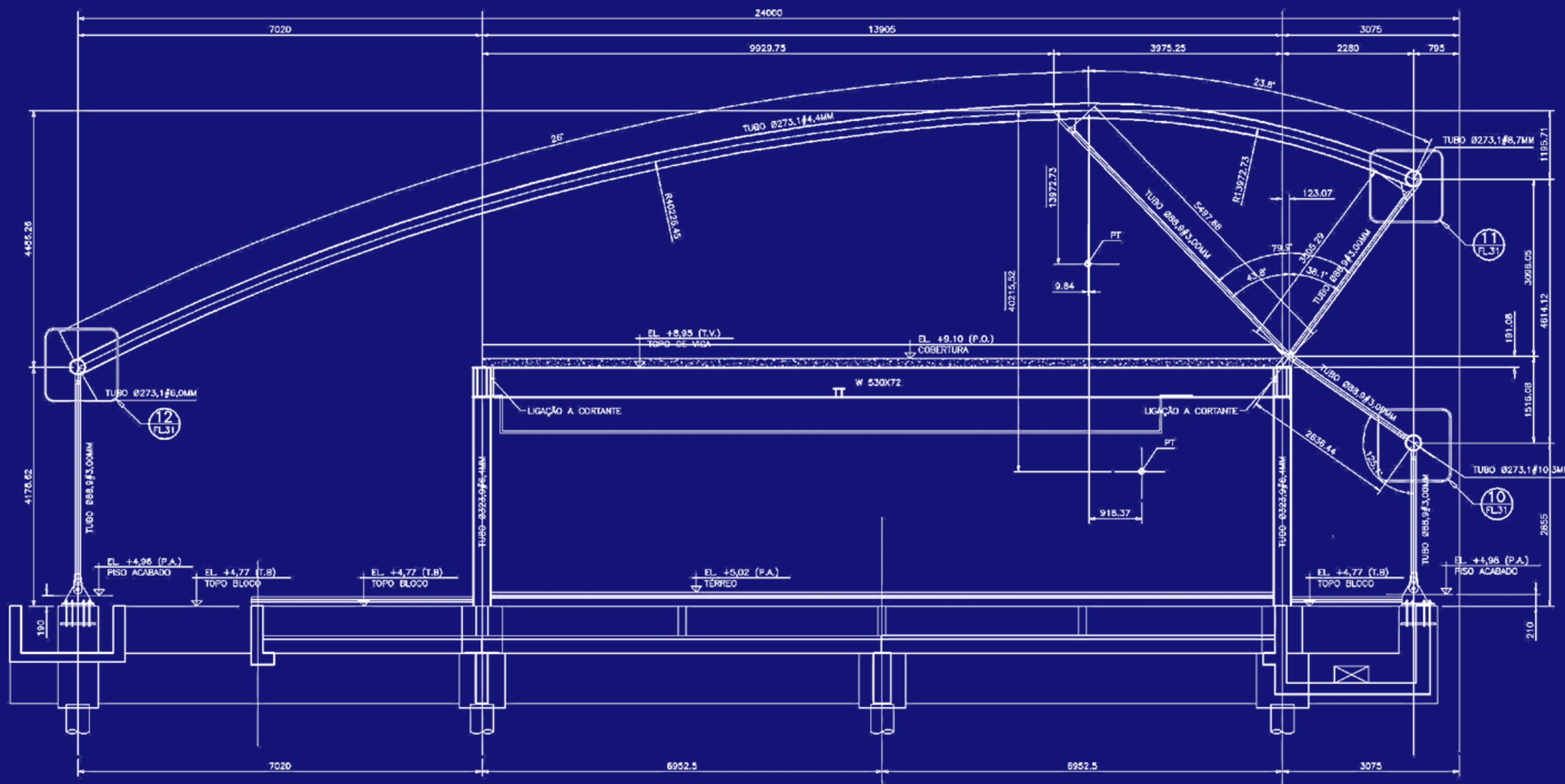
Floating Pavilion (Osaka, 1970)


blow
poltrona
gonfiabile


Sliding Cables and Wrinkling
Pneumatic envelope for ‘Angra III’ ground preparation
(September 2009)

CENPES II – Rio de Janeiro, 2010

Archs. Ziegbert Zenettini, Wagner Garcia



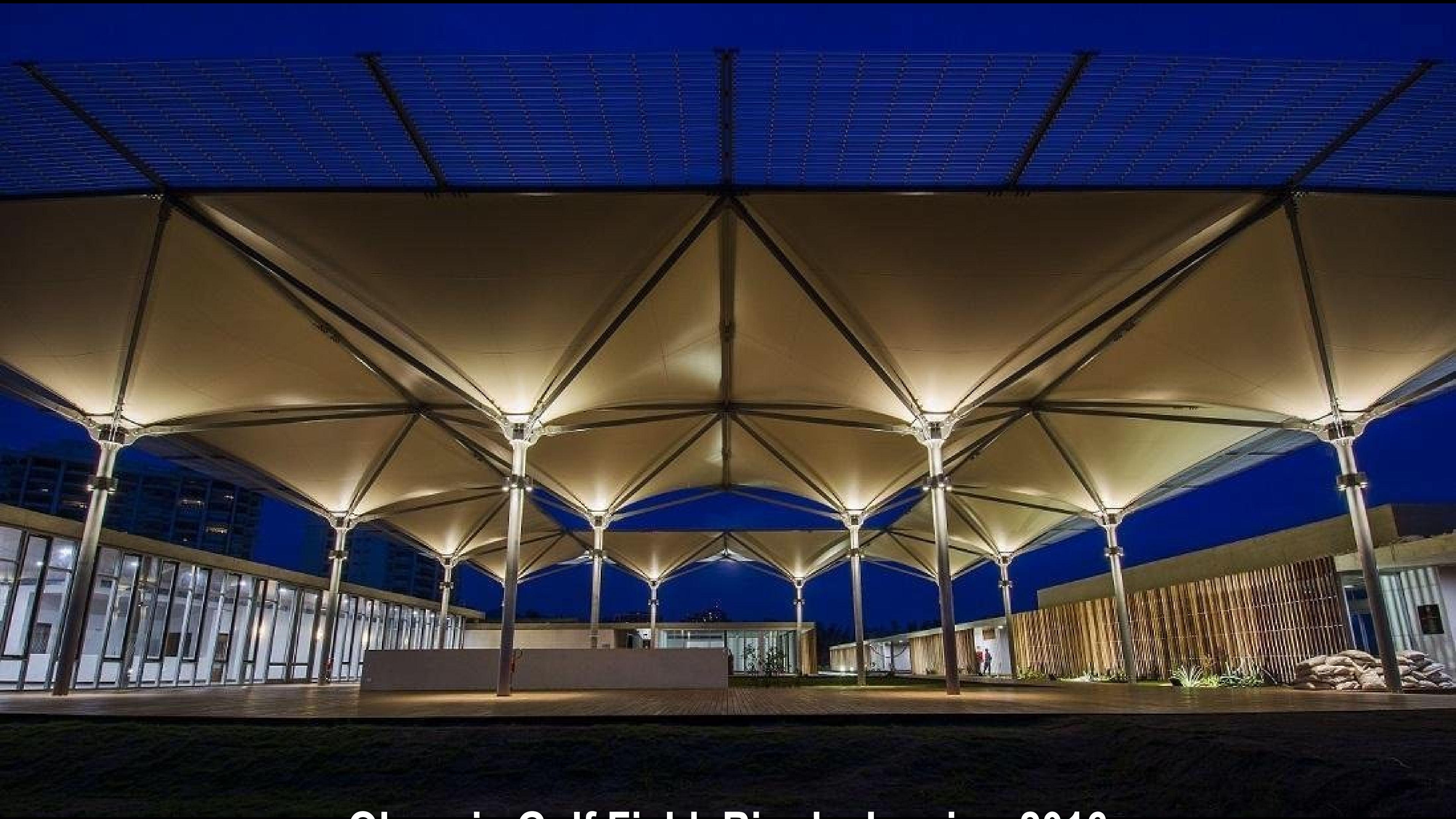
0256 CENTRO DE CONVENÇÕES

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