EP-USP

PEF2603
Estruturas na Arquitetura III - Sistemas Reticulados e Laminares

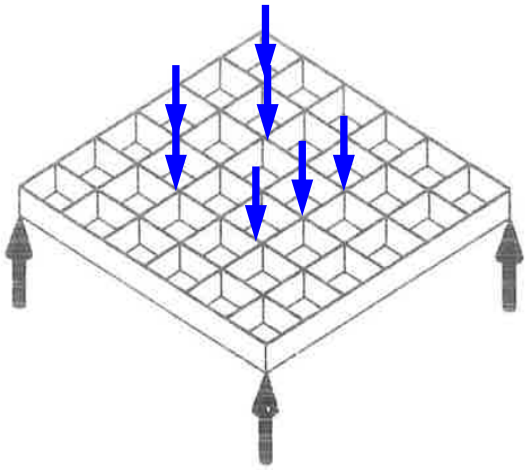
FAU-USP

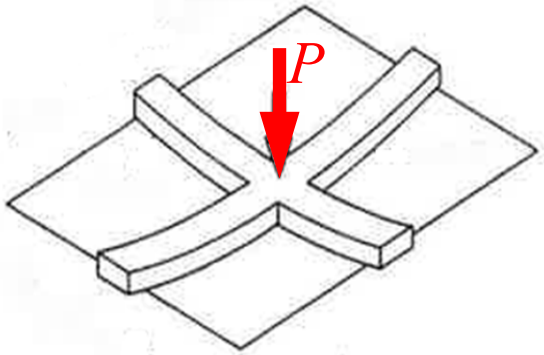
Cascas

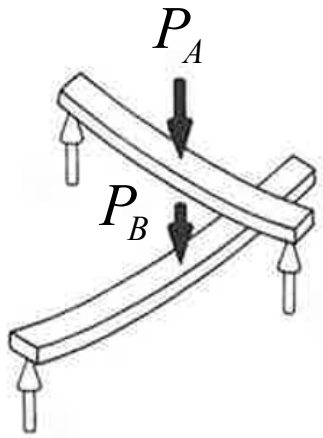
Uma Visão Geral

Professores
Ruy Marcelo O. Pauletti , Leila Cristina Meneghetti, Luís Bitencourt Jr.
19/06/2023

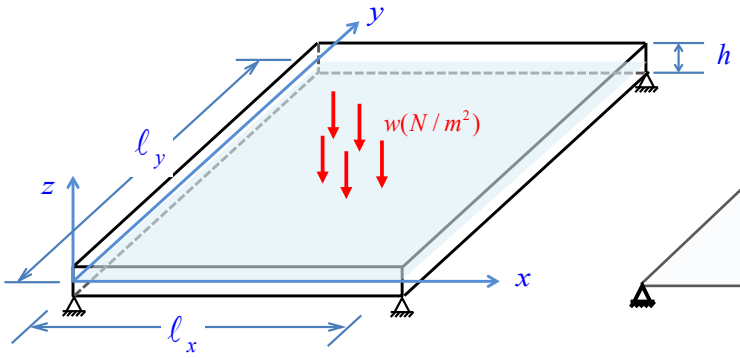
Anteriormente, vimos as grelhas...

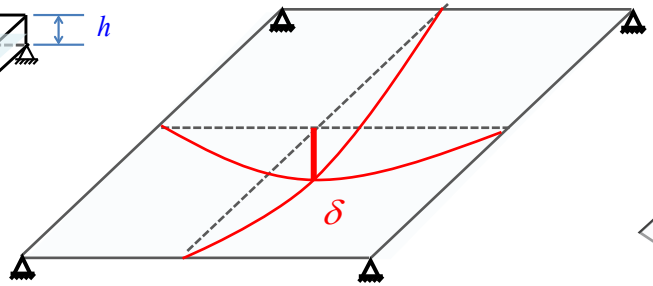


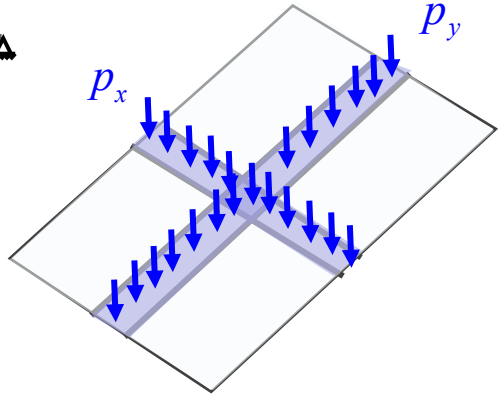




E as placas...

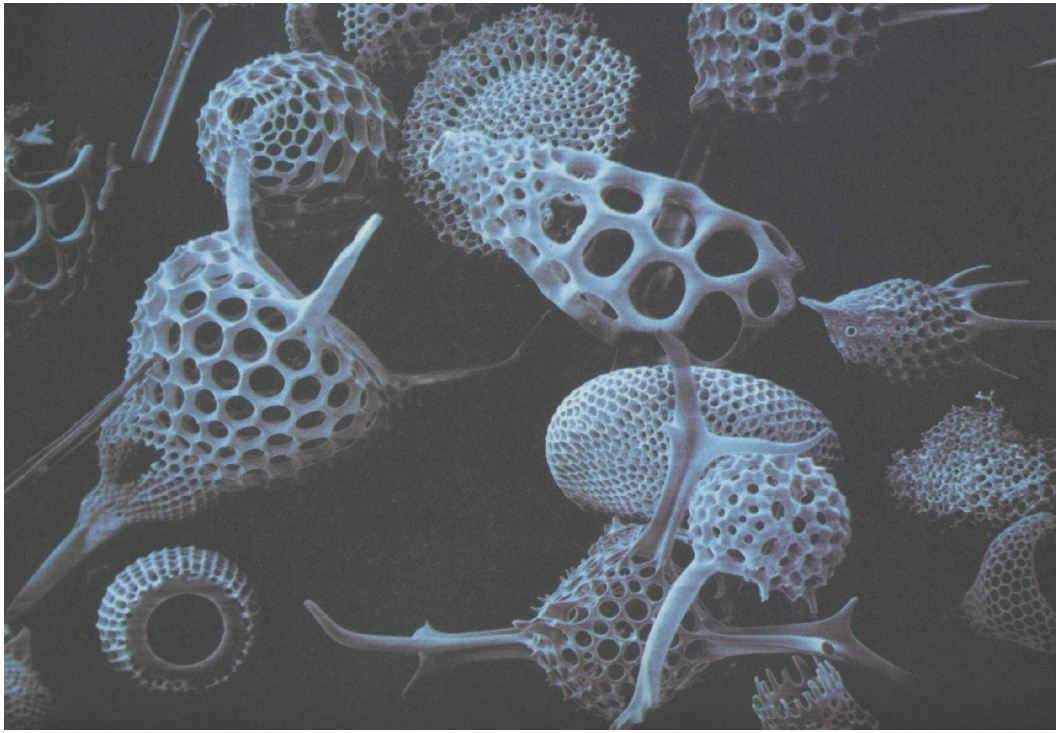






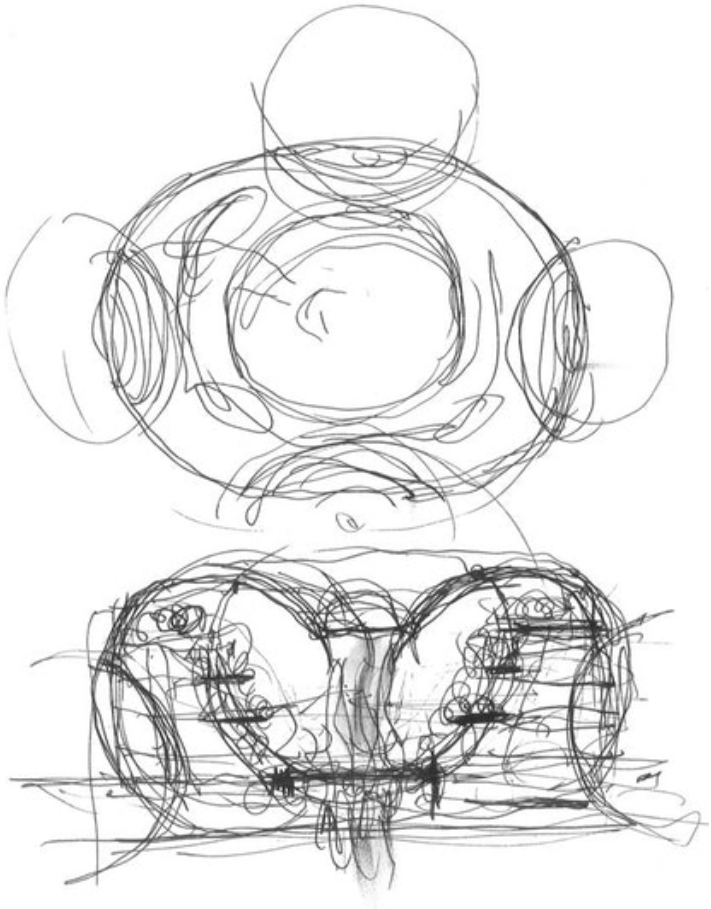
Sistemas geometricamente bem caracterizados por um plano médio, mas comportamento tridimensional...

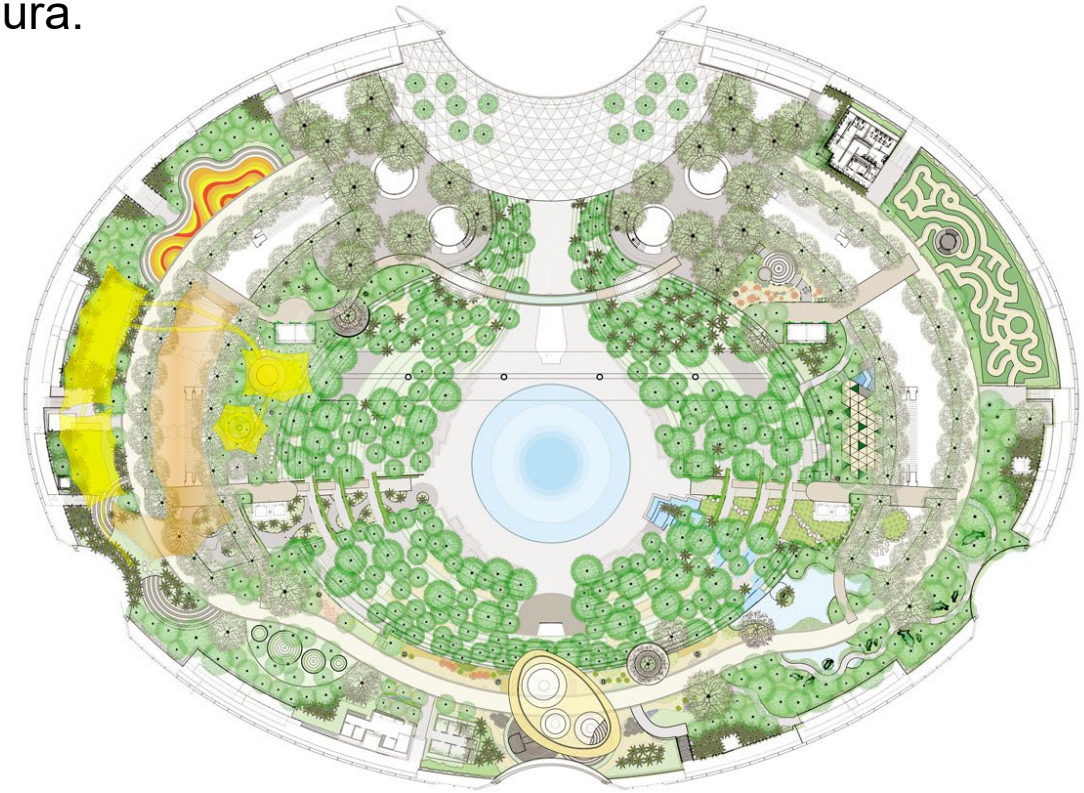
Cascas contínuas e reticuladas (shells & gridshells)

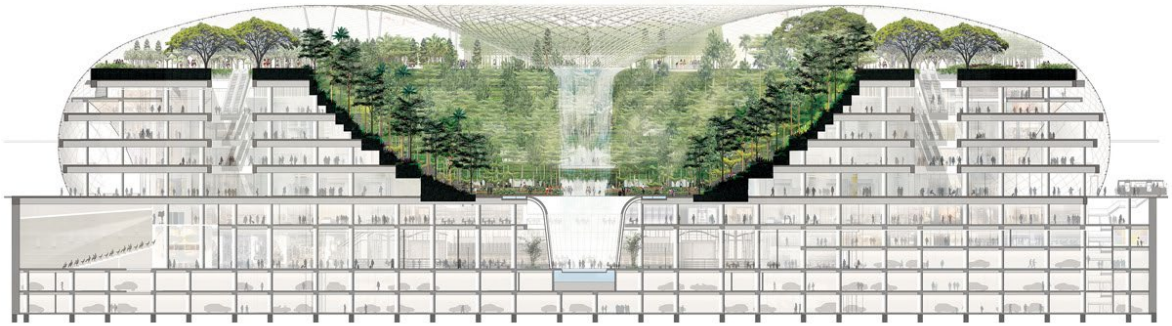


Estruturas de comportamento tridimensional, capazes de resistir à flexão e geometricamente descritas por superfícies curvas

Jewel Changi Airport, Singapura.
Arq. Moshe Safdie (2016)

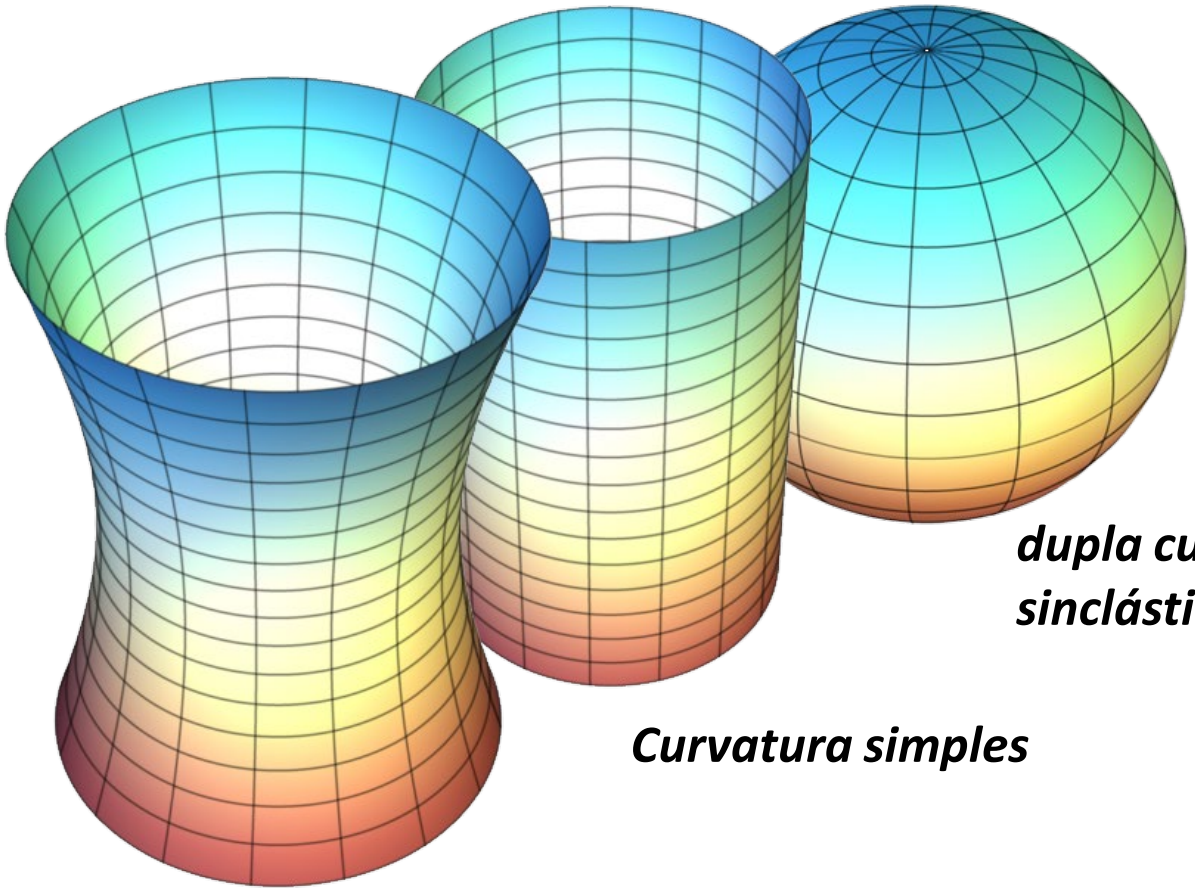







BOARDING GATE

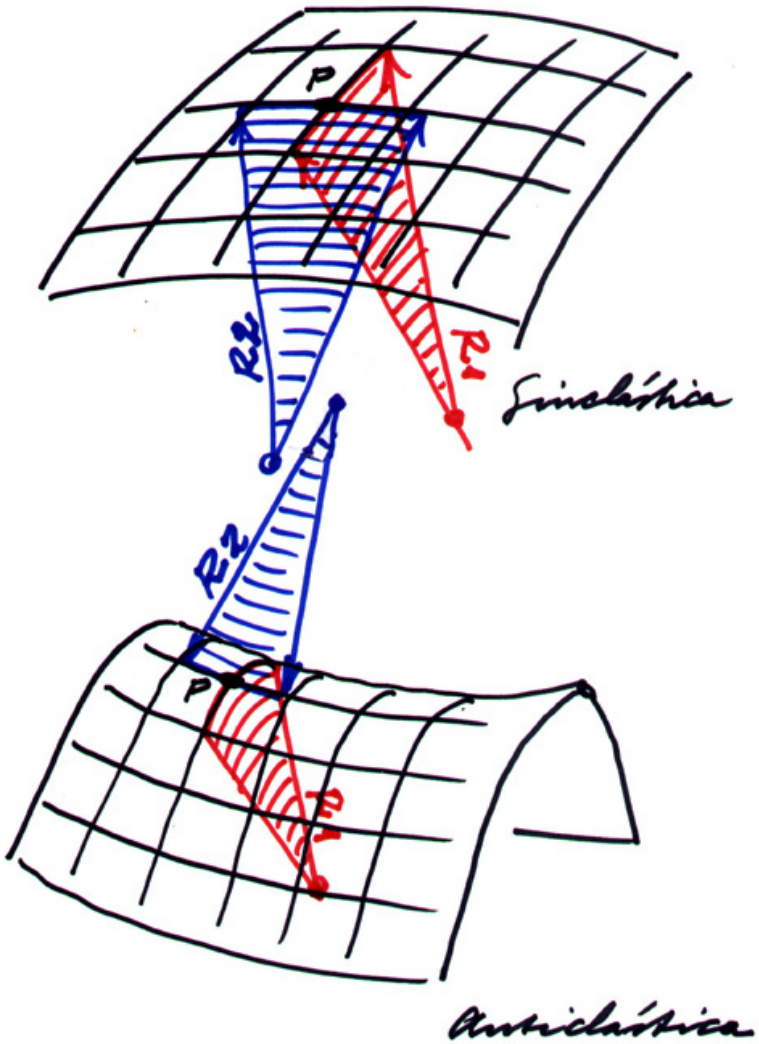
Superfícies de curvatura simples ou dupla:



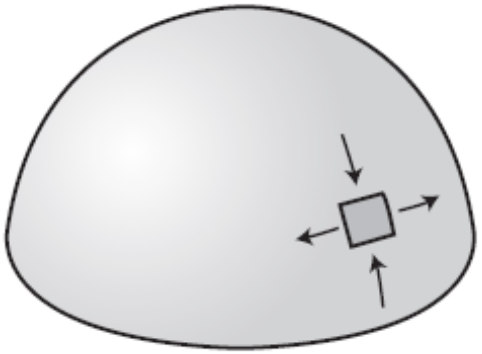
dupla curvatura, sinclástica

Curvatura simples

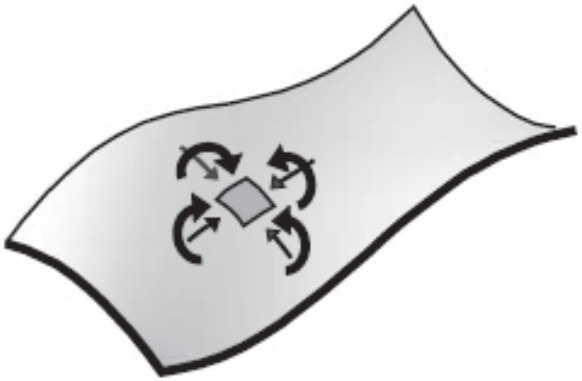
dupla curvatura, anticlastica



CURVATURAS

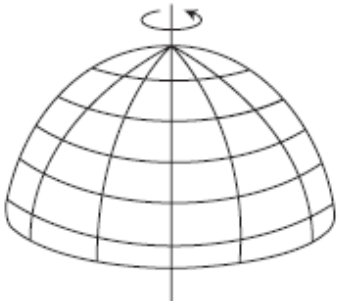


Casca Funicular: comportamento de membrana; somente esforços de tração e compressão

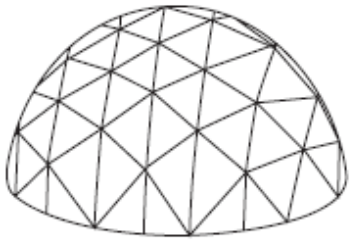


Formas complexas: presença de momento fletor;

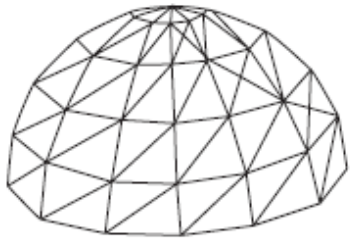
(Esquemas originais – Prof. Mário Franco)



Esfera

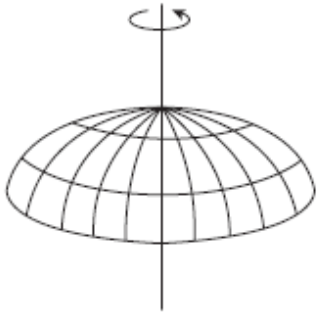


Domo Geodésico

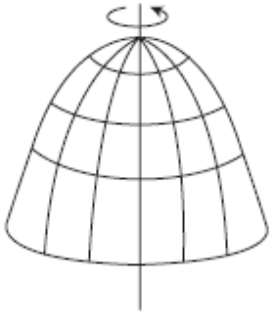


Domo de Schwedler

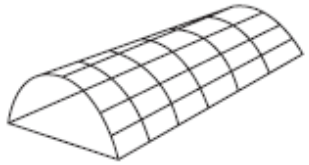
Domo Nervurado



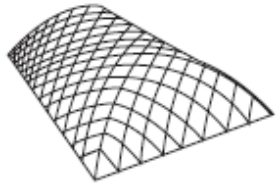
Elipsóide



Parabolóide

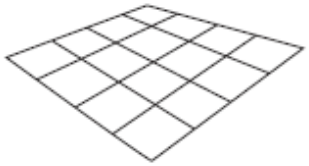


Cilindro Nervurado



Cilindro Lamelar

Casca funicular

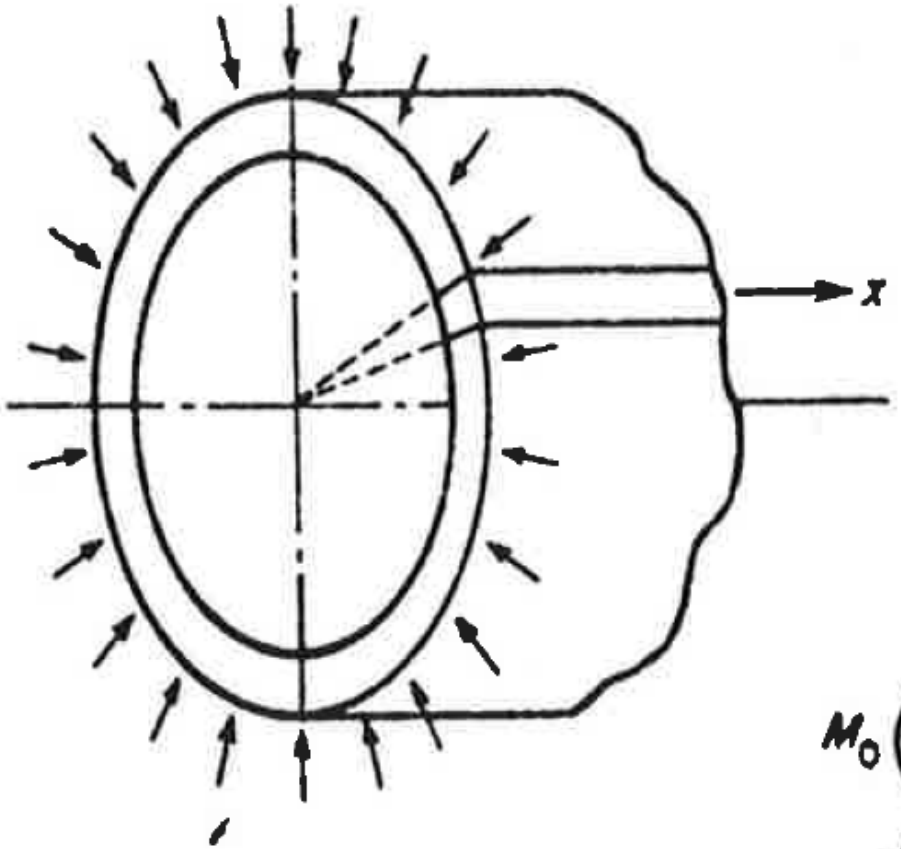


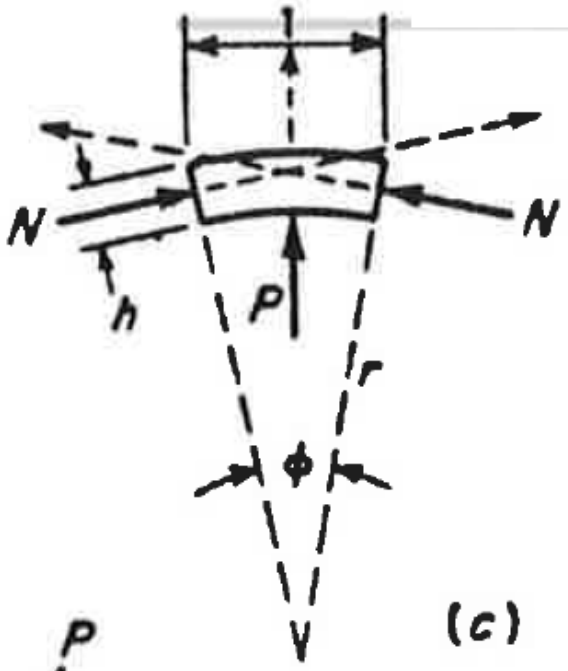
Parabolóide Hiperbólico

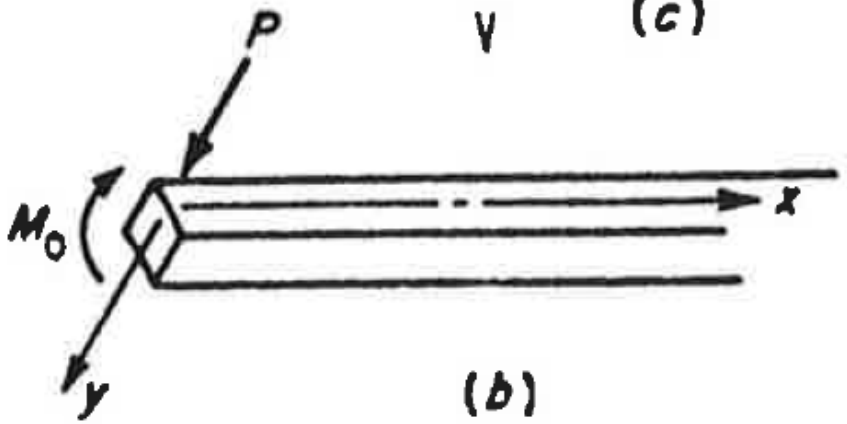
Parabolóide Hiperbólico

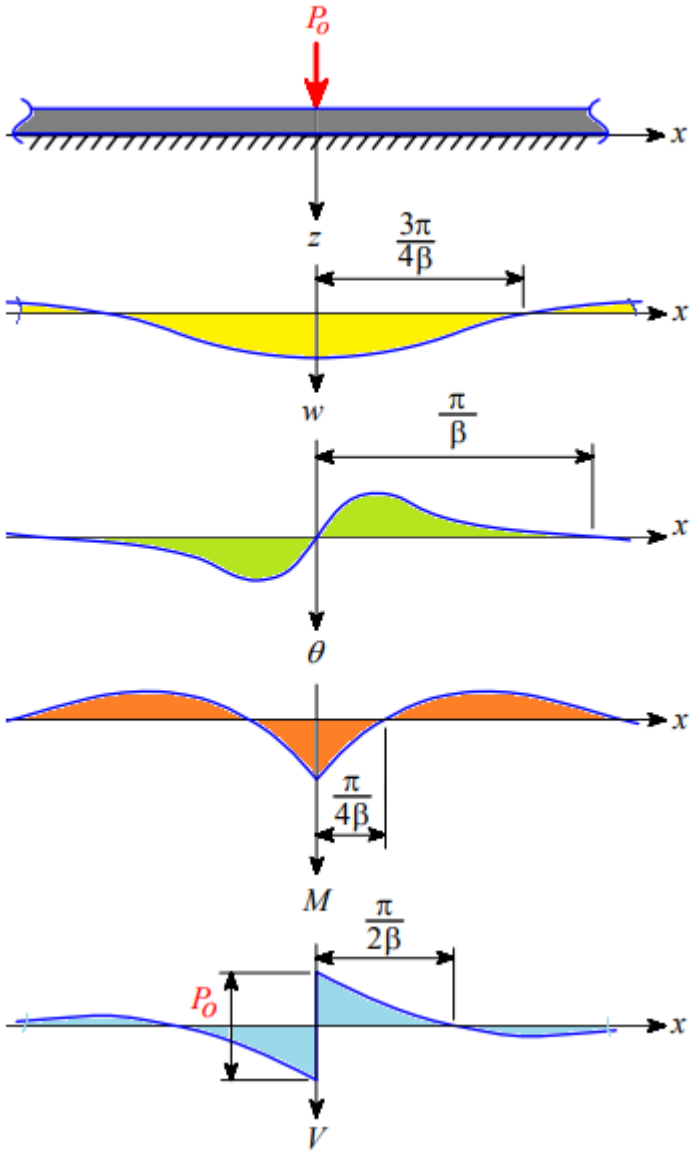
Superfície de forma livre

Cascas – Tubo de seção circular sobre carga anular








P_o
x
z
$\frac{3\pi}{4\beta}$
x
w
$\frac{\pi}{\beta}$
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x
$\frac{\pi}{4\beta}$
M
$\frac{\pi}{2\beta}$
P_o
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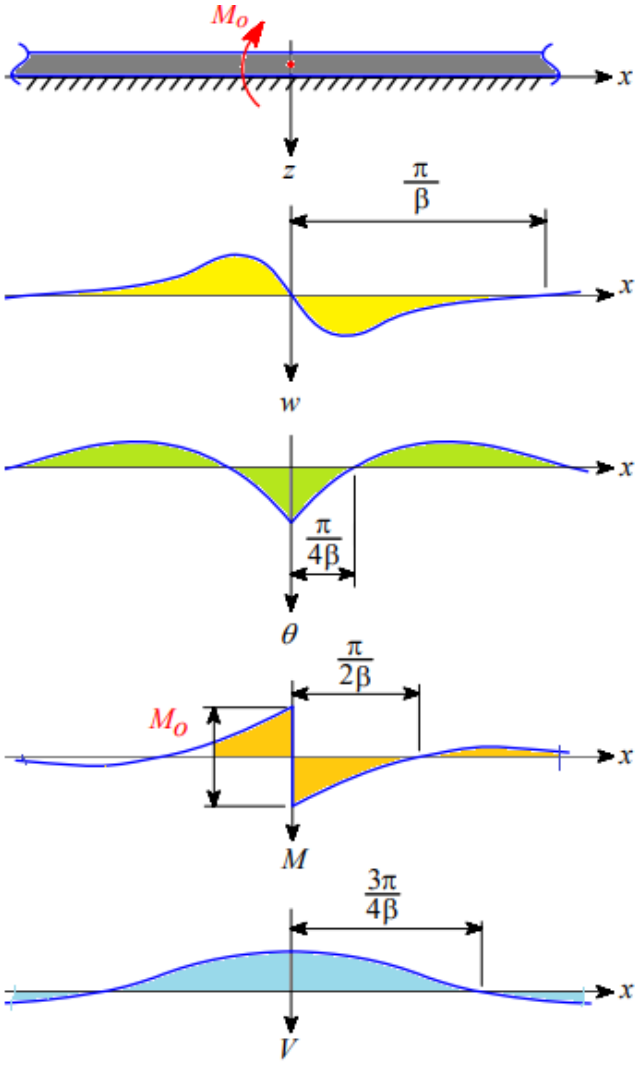
M_o
x
z
$\frac{\pi}{\beta}$
x
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$\frac{\pi}{2\beta}$
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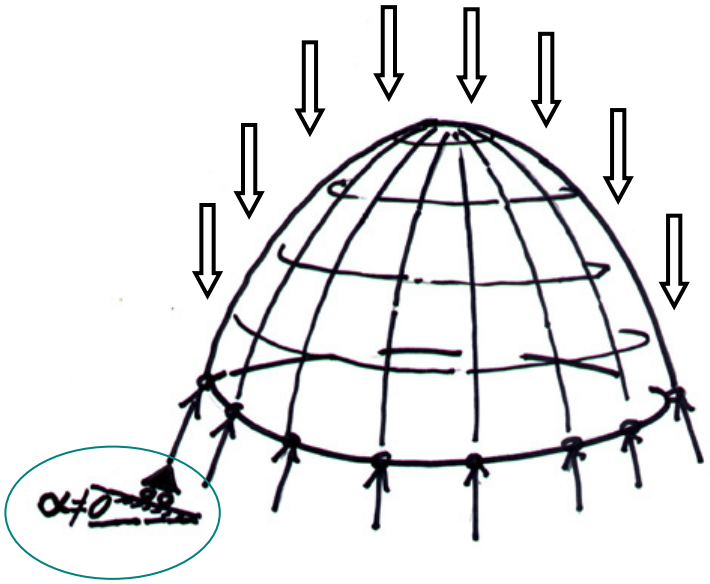
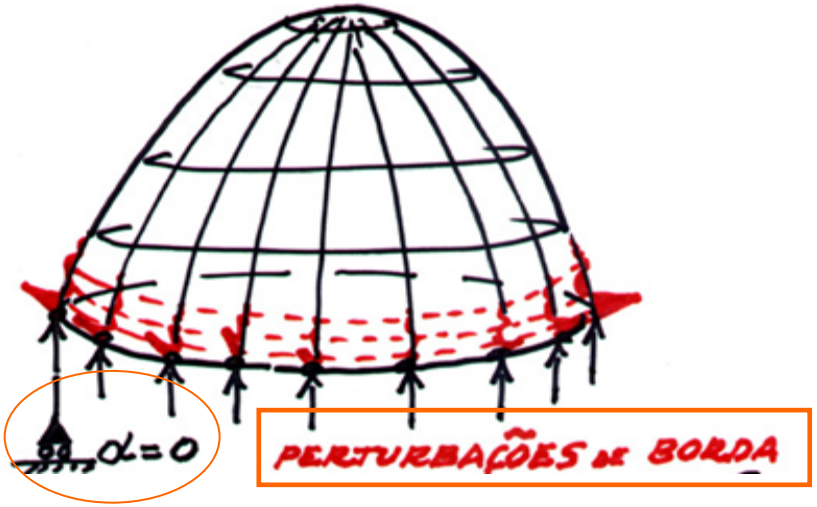
Cascas



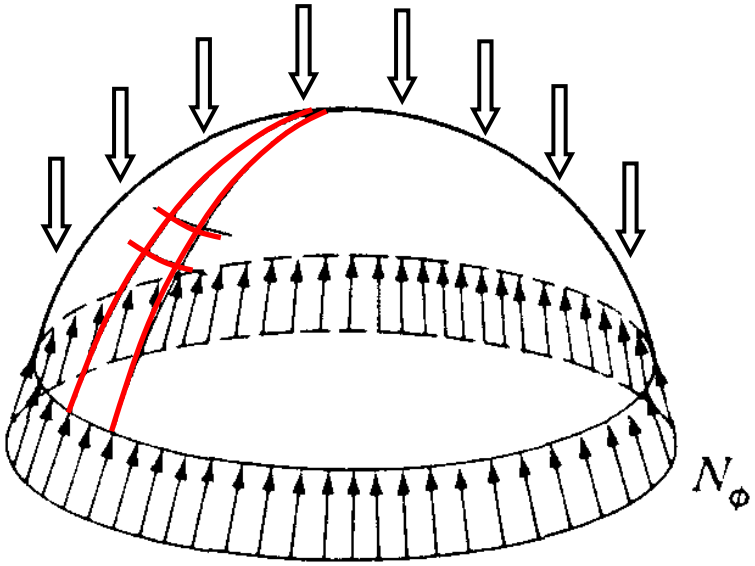
Casca Funicular
ao carregamento

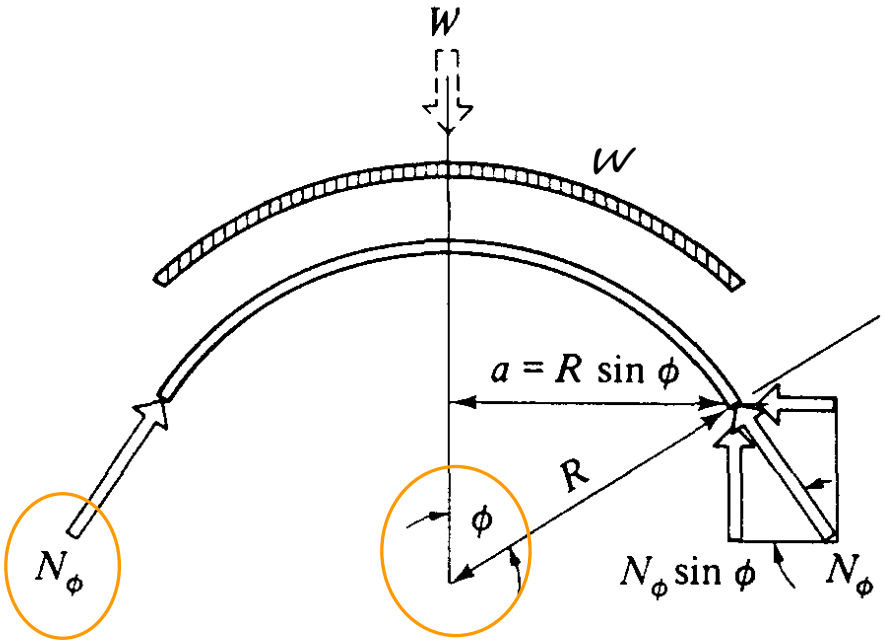


Esquemas originais – Prof. Mário Franco

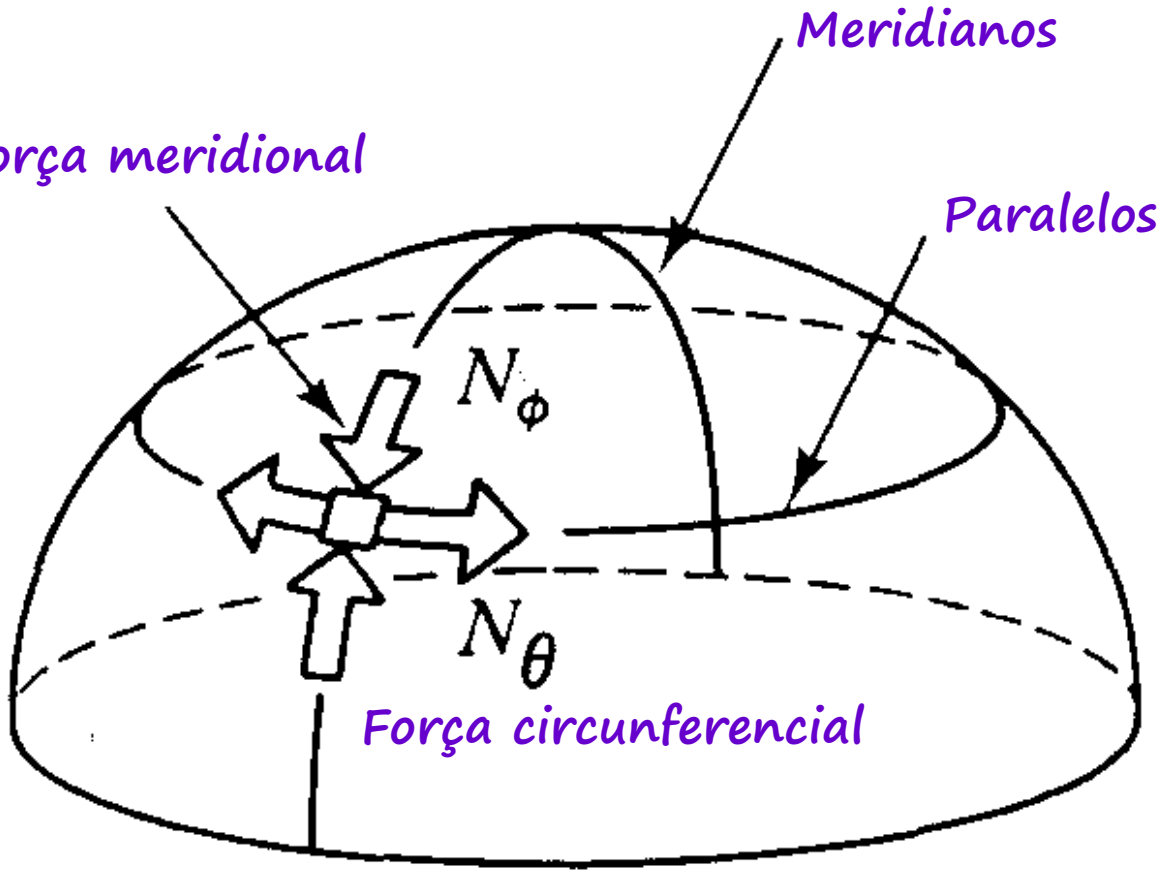
Casca esférica sujeita a cargas verticais

(Referência: Shodek, Structures)





Casca parabólica:

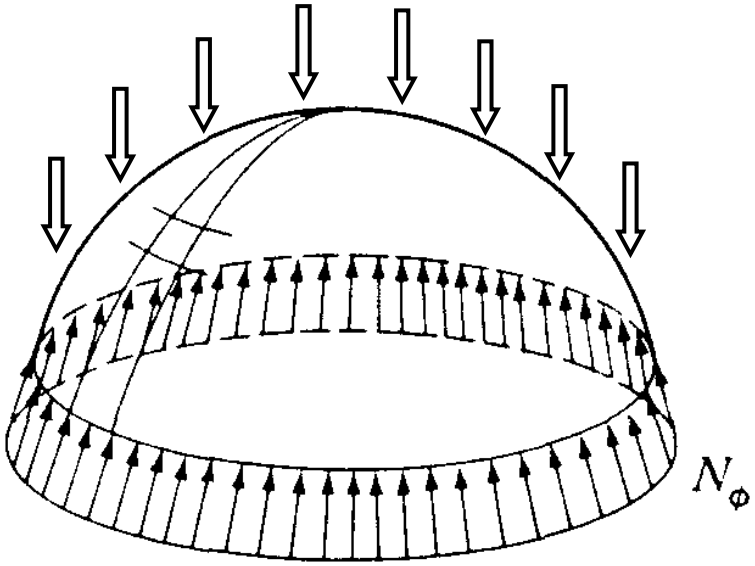


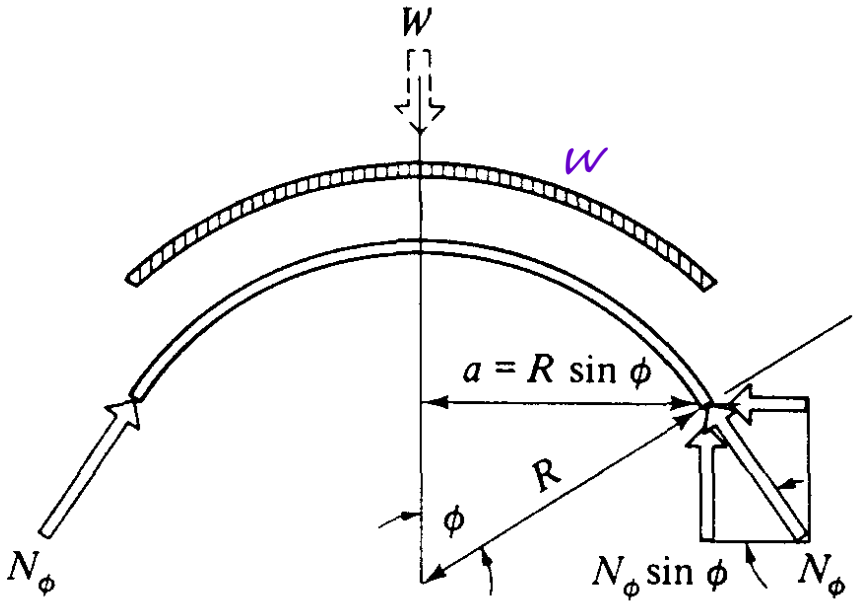
Do estudo das membranas, recorda-se a Equação de Laplace-Young:

$$\frac{N_\theta}{R_\theta} + \frac{N_\phi}{R_\phi} = p_r$$

Nota: nesta aula, as membranas serão vistas após as cascas!

Casca esférica sujeita a cargas verticais

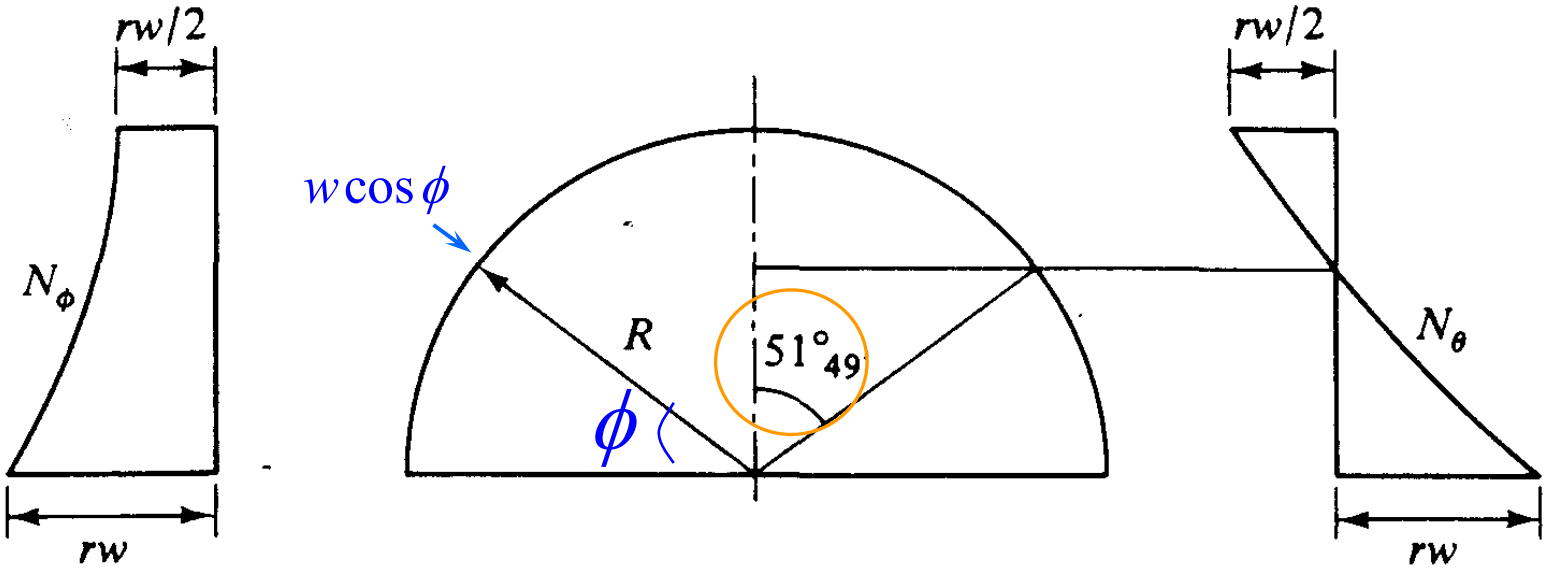




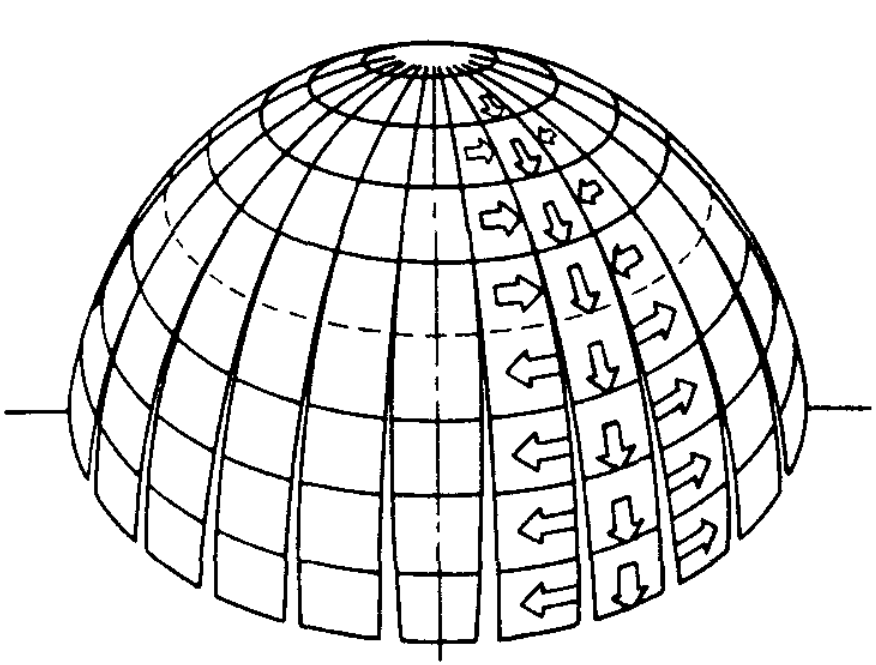
$$N_\phi = \frac{Rw}{1+\cos\phi}$$

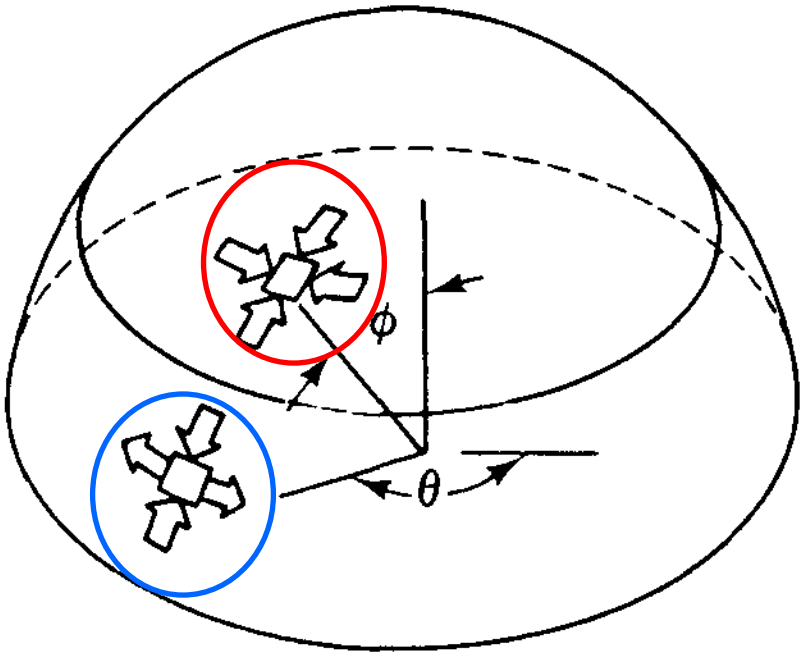
Eq. Laplace:

$$\frac{N_\theta + N_\phi}{R} = p_r = w\cos\phi$$



$$N_\theta = Rw\left(\cos\phi - \frac{1}{1+\cos\phi}\right)$$




ϕ
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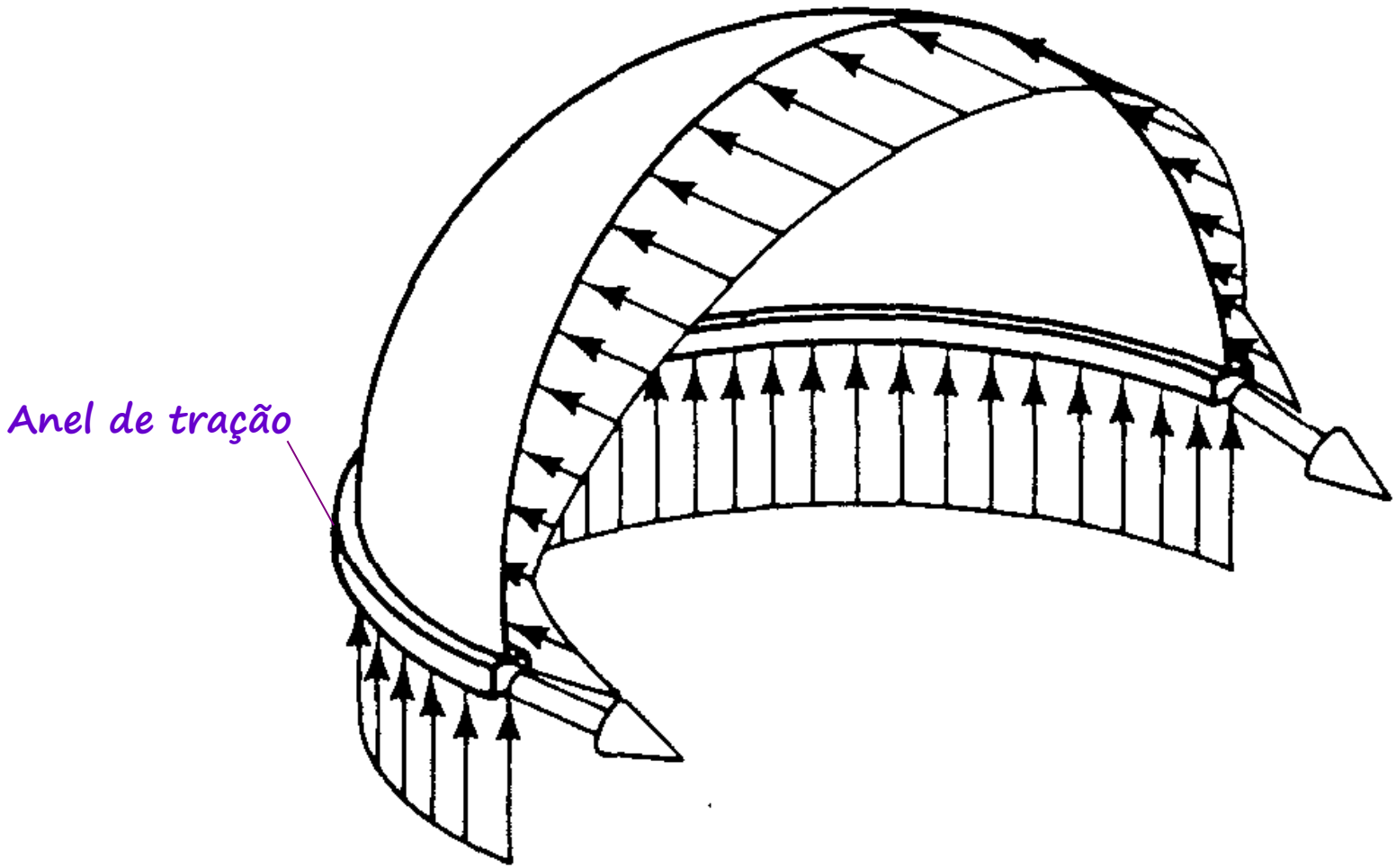
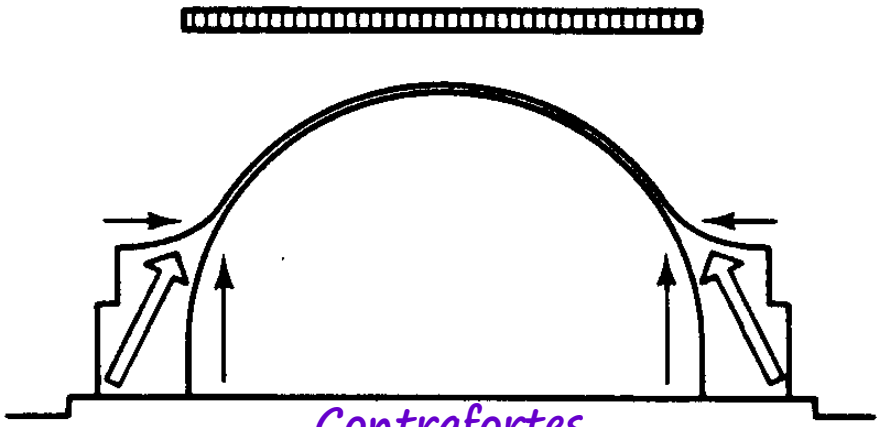
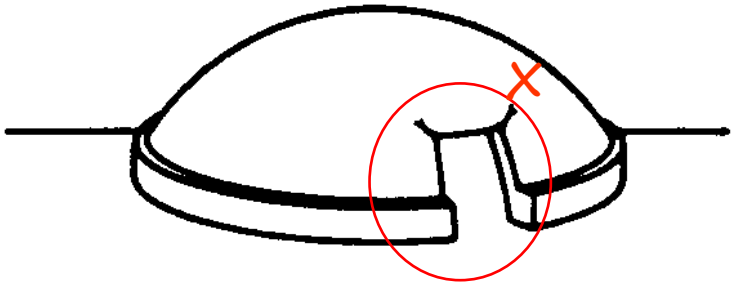
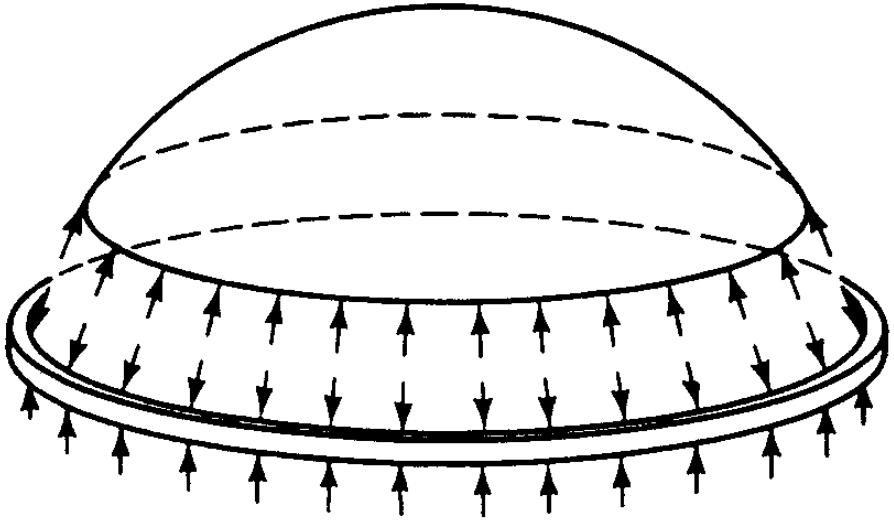

Anel de tração

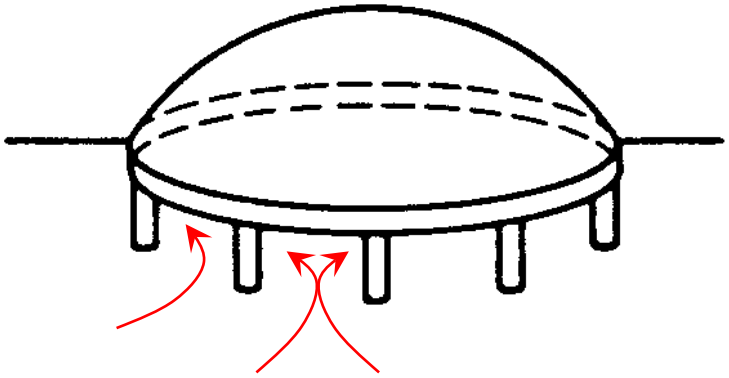


Contrafortes



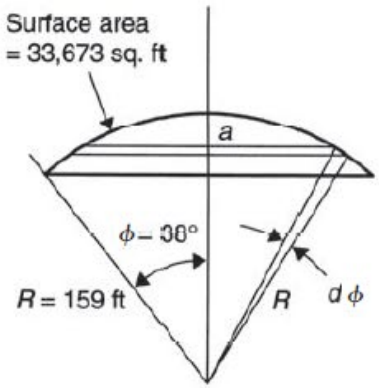


Anel de tração



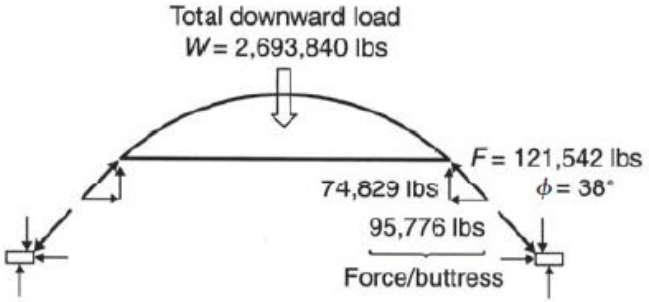
Palazzetto dello Sport – 1956 – 1957
Pier Luigi Nervi, Annibale Vitellozzi
1960 Olympics

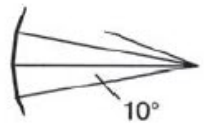

virtusroma.it
virtusroma.it



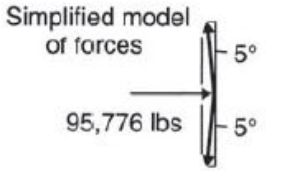
(a) Area calculations

(b) Dome during construction

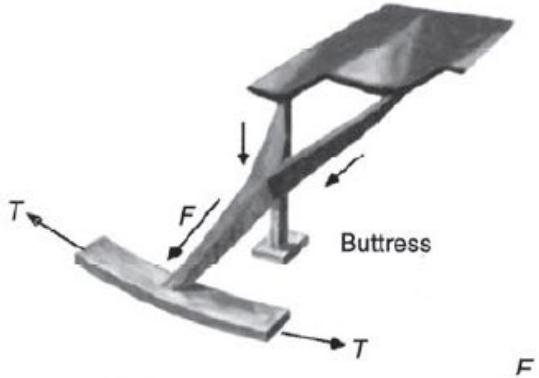


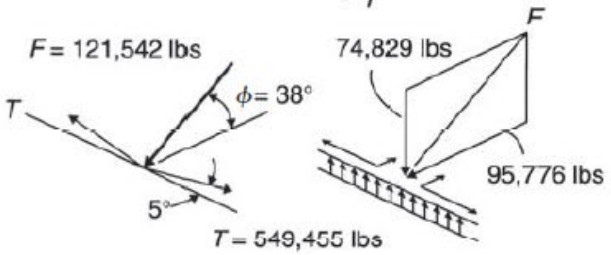


Angles subtended by
one of 36 buttresses

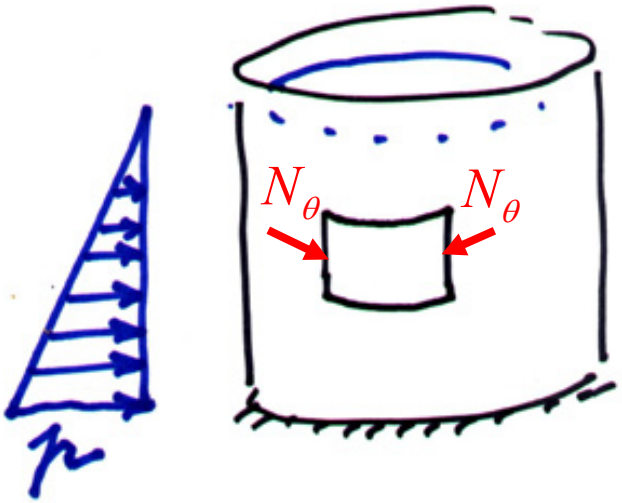


T = 549,455 lbs



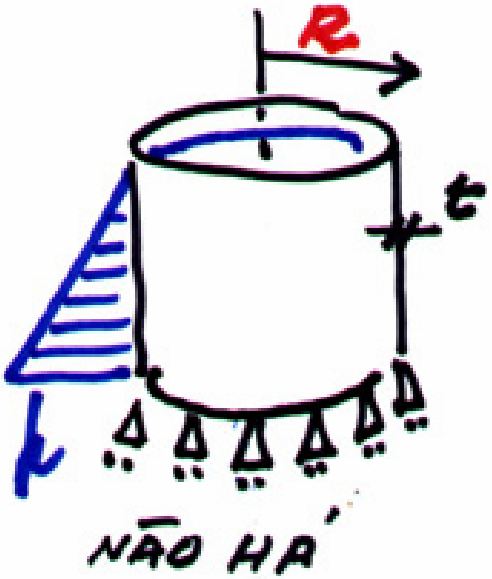


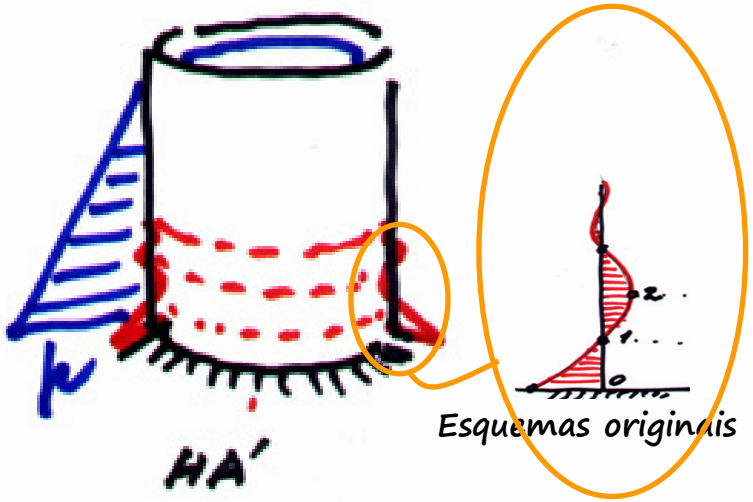
Reservatórios



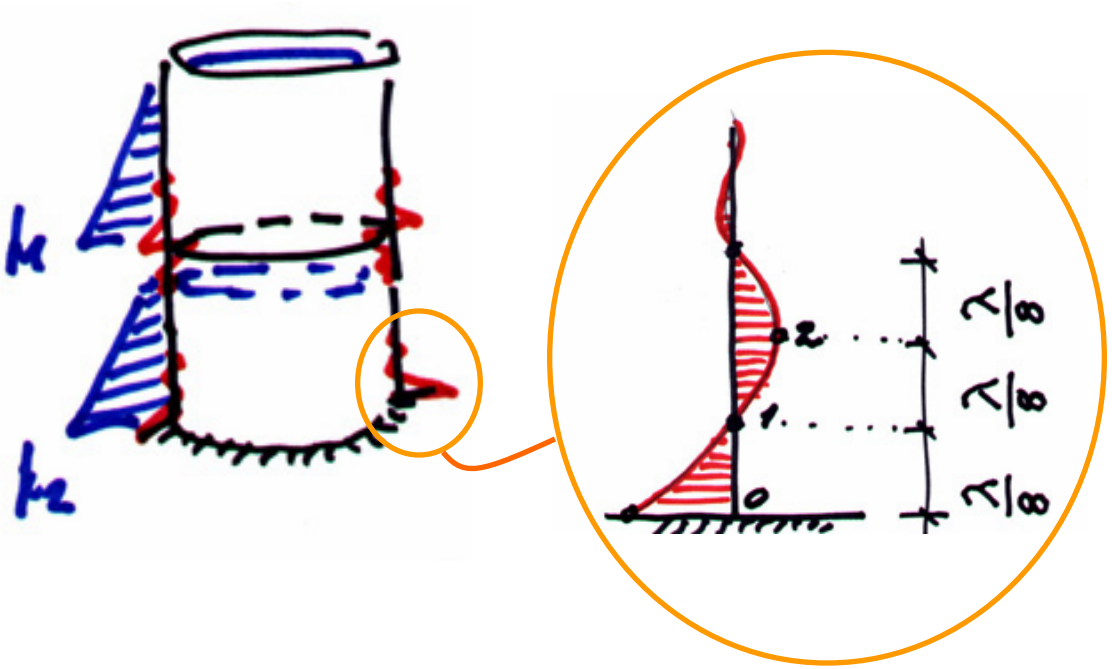
$$\frac{N_\theta}{R} = p_r$$

PERTURBAÇÕES DE BORDA





Esquemas originais – Prof. Mário Franco



$$\lambda = 4.83\sqrt{Rt}$$

$$M_0 = 0.294\,pRt$$

$$M_1 = 0$$

$$M_2 = -0.061\,pRt$$

Exemplo:

$$R = 4m, \quad t = 0.20m, \quad p = 150kN/m^2$$

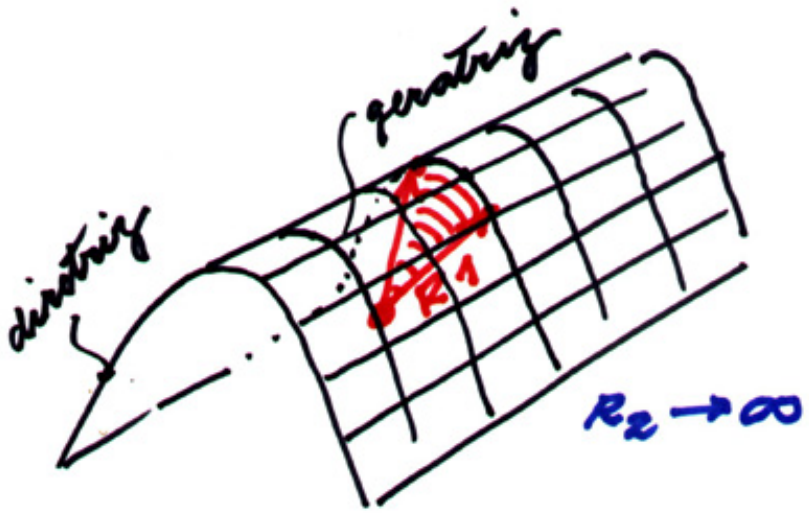
$$N_\theta = 600kN/m; \quad \lambda = 4.32m$$

$$M_0 = 35,3kNm/m \ (\phi 10 \text{ cada } 10\text{cm})$$

$$M_2 = -7,3kNm/m \ (\phi \text{ minimo})$$

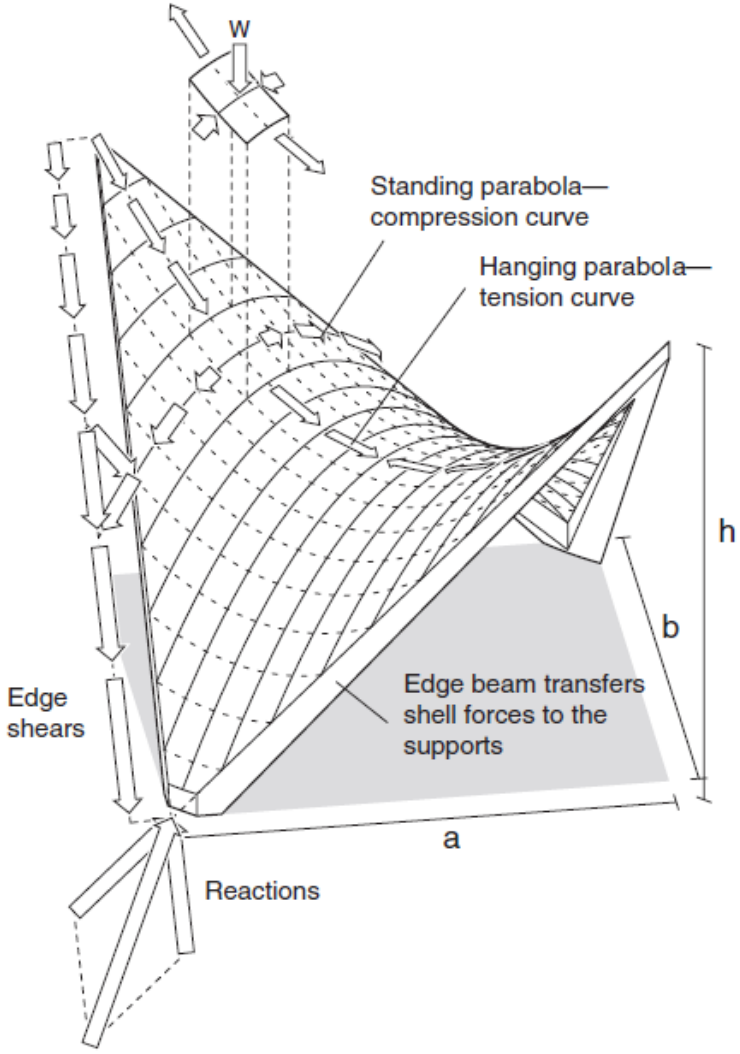
Esquemas originais – Prof. Mário Franco

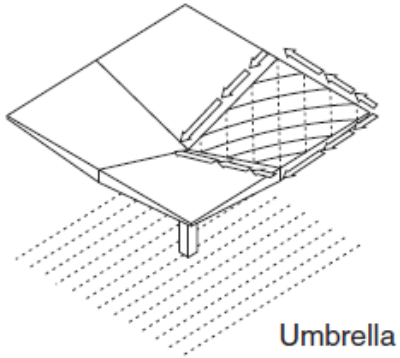
CASCA CILÍNDRICA



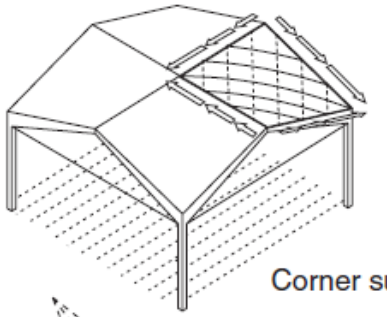
Esquemas originais – Prof. Mário Franco

Parabolóide hiperbólico

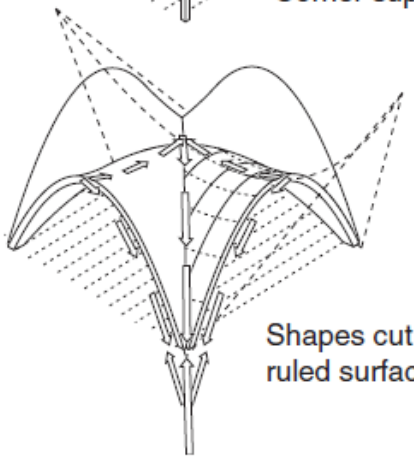




Umbrella shell



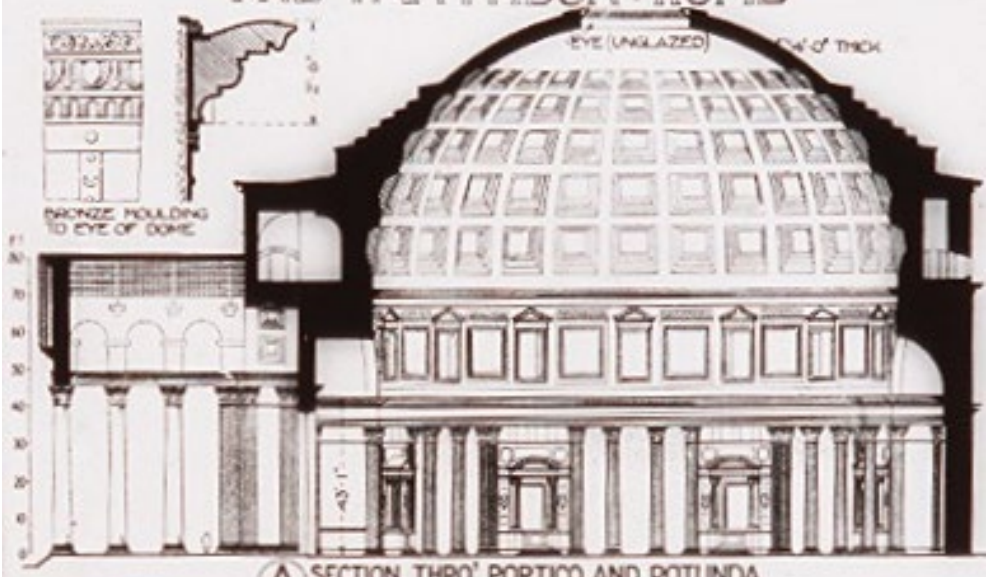
Corner supported



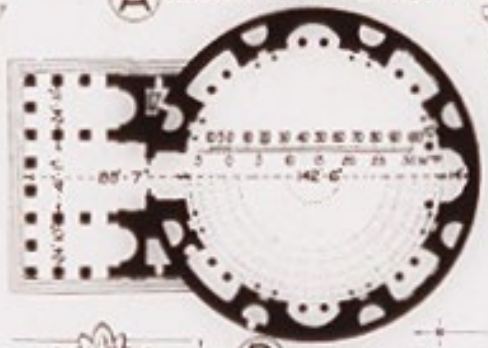
Shapes cut from
ruled surface

ROMAN ARCHITECTURE

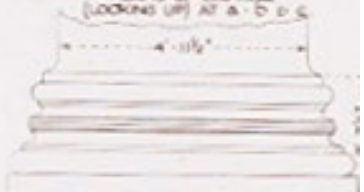
THE PANTHEON : ROME



A SECTION THRO' PORTICO AND ROTUNDA

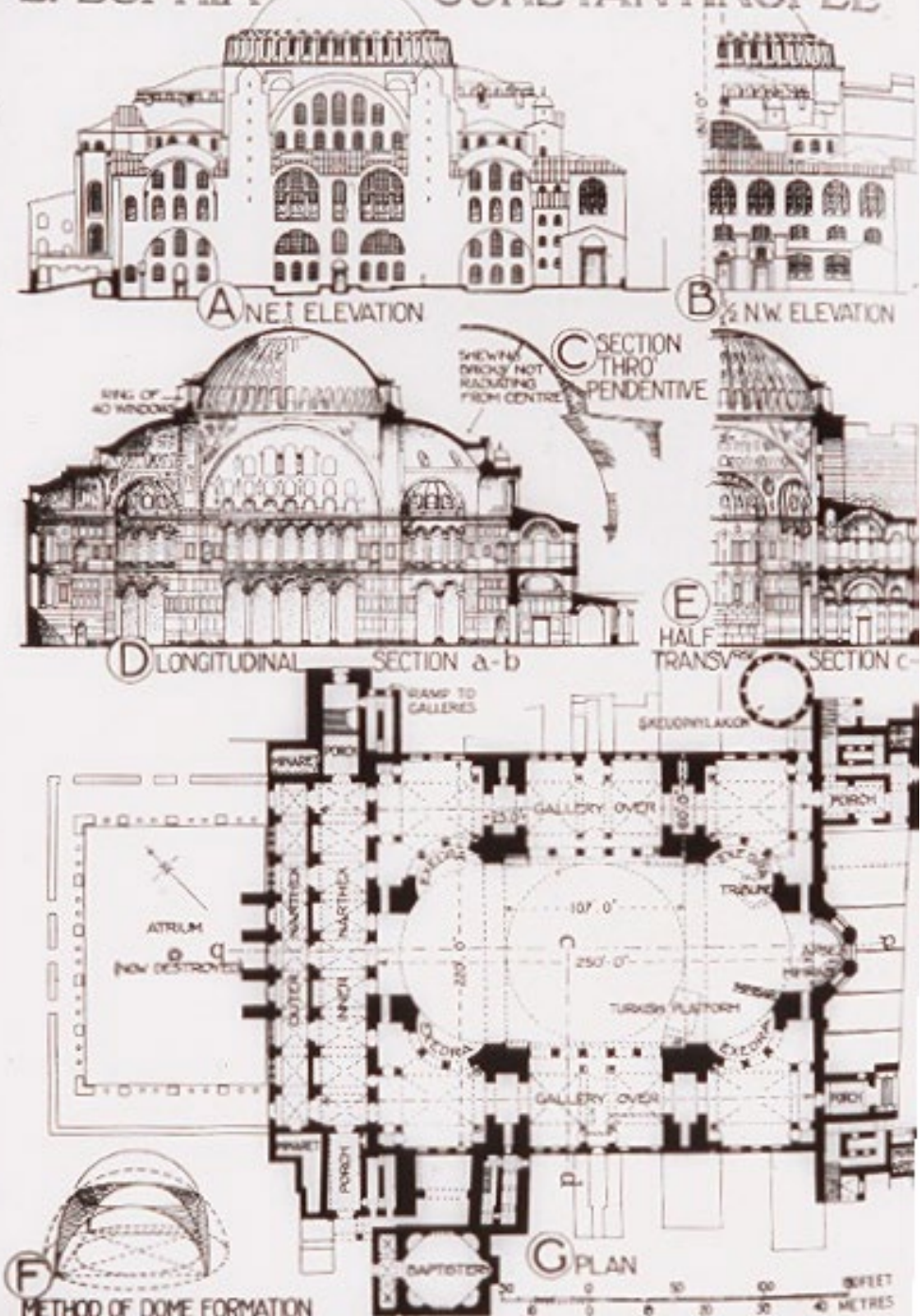


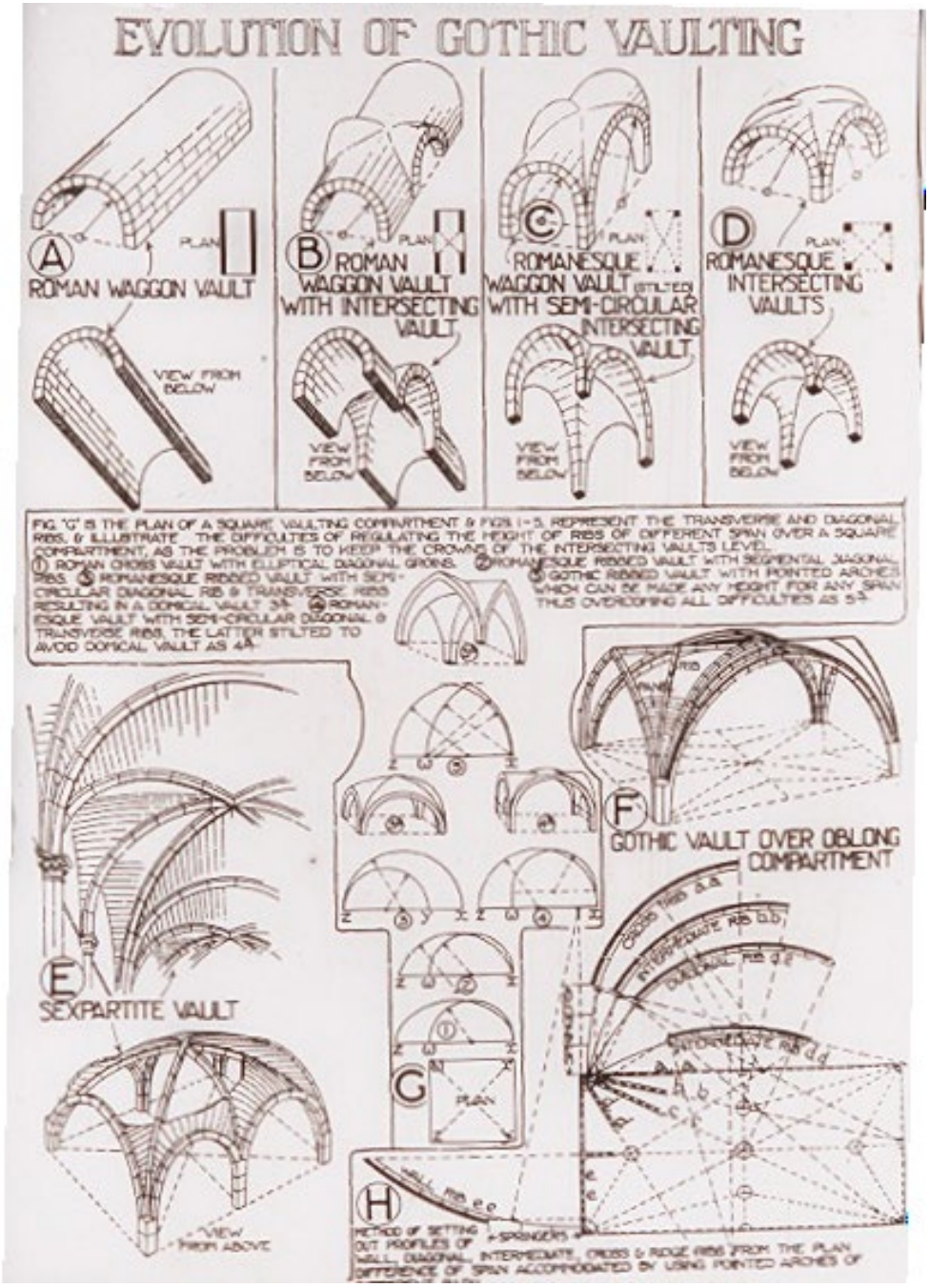
B PLAN

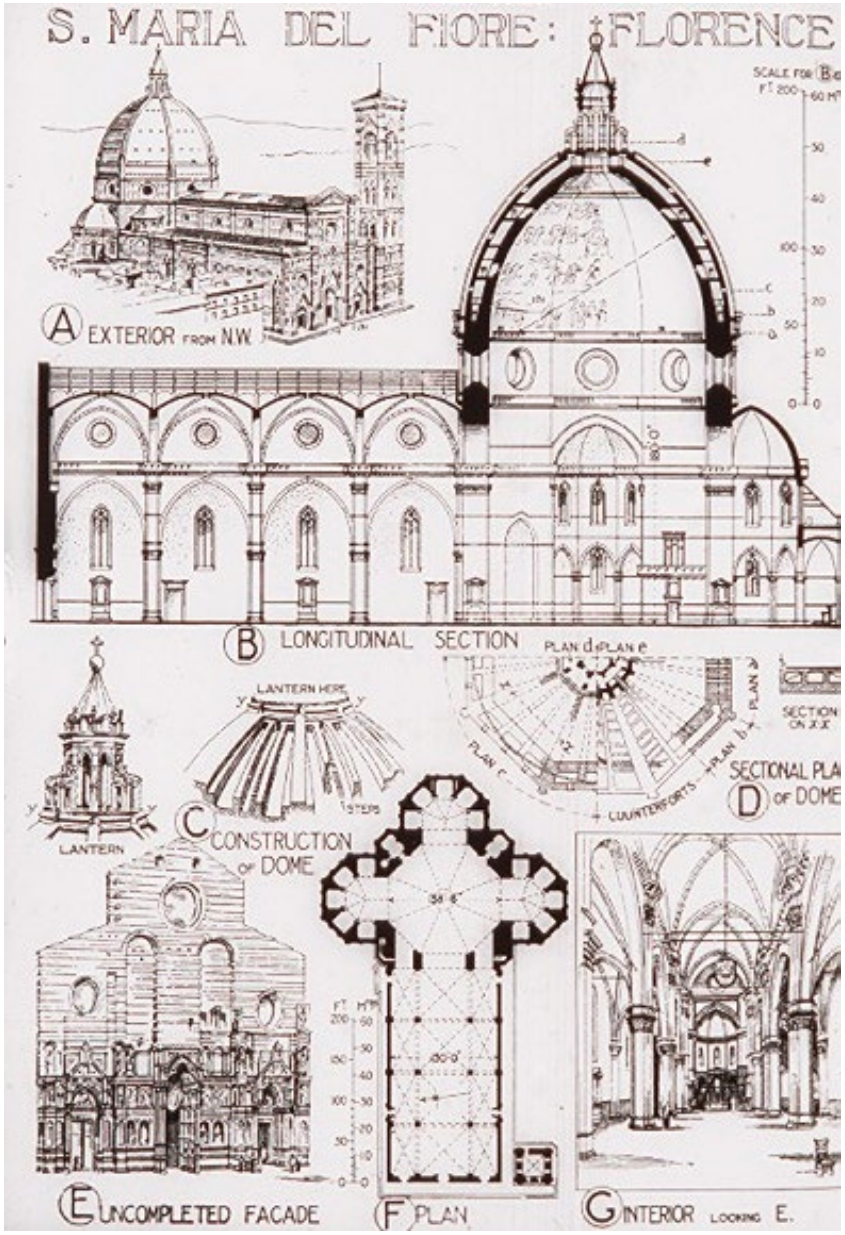



M·AGRIPPA·L·F·COS·TERTIVM·FECIT
Totocalcio

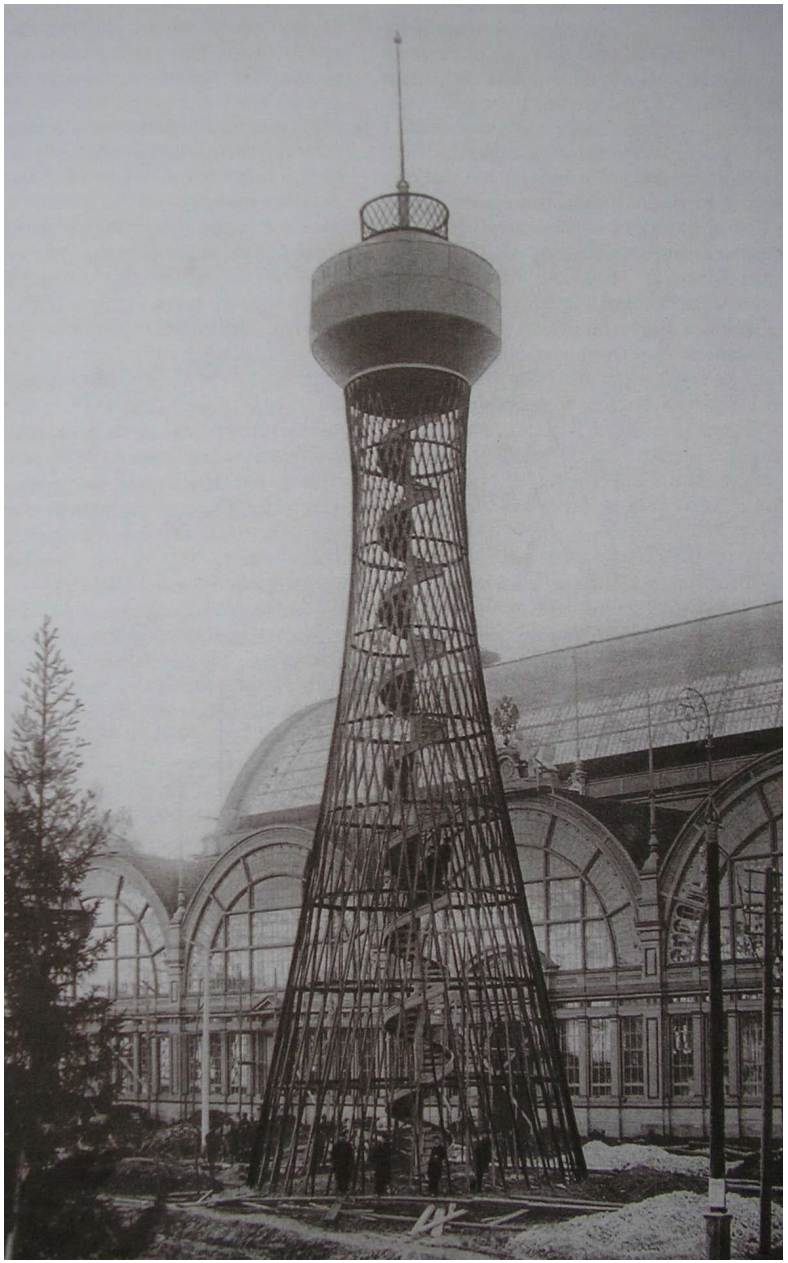
S. SOPHIA CONSTANTINOPLE




EVOLUTION OF GOTHIC VAULTING
A
ROMAN WAGGON VAULT
PLAN
VIEW FROM BELOW
B
ROMAN WAGGON VAULT WITH INTERSECTING VAULT
PLAN
VIEW FROM BELOW
C
ROMANESQUE WAGGON VAULT (STILTED) WITH SEMI-CIRCULAR INTERSECTING VAULT
PLAN
VIEW FROM BELOW
D
ROMANESQUE INTERSECTING VAULTS
PLAN
VIEW FROM BELOW
FIG 'G' IS THE PLAN OF A SQUARE VAULTING COMPARTMENT & FIGS 1-5 REPRESENT THE TRANSVERSE AND DIAGONAL RIBS, & ILLUSTRATE THE DIFFICULTIES OF REGULATING THE HEIGHT OF RIBS OF DIFFERENT SPAN OVER A SQUARE COMPARTMENT, AS THE PROBLEM IS TO KEEP THE CROWNS OF THE INTERSECTING VAULTS LEVEL.
1 ROMAN CROSS VAULT WITH ELLIPTICAL DIAGONAL GROINS.
2 ROMANESQUE RIBBED VAULT WITH SEGMENTAL DIAGONAL RIBS.
3 GOTHIC RIBBED VAULT WITH POINTED ARCHES WHICH CAN BE MADE ANY HEIGHT FOR ANY SPAN THUS OVERCOMING ALL DIFFICULTIES AS 5.
4 ROMANESQUE RIBBED VAULT WITH SEMI-CIRCULAR DIAGONAL RIB & TRANSVERSE RIBS RESULTING IN A DOMICAL VAULT.
5 ROMANESQUE VAULT WITH SEMI-CIRCULAR DIAGONAL & TRANSVERSE RIBS, THE LATTER STILTED TO AVOID DOMICAL VAULT AS 4.
F
GOTHIC VAULT OVER OBLONG COMPARTMENT
E
SEXPARTITE VAULT
G
PLAN
VIEW FROM ABOVE
H
METHOD OF SETTING OUT PROFILES OF WALL, DIAGONAL, INTERMEDIATE, CROSS & RIDGE RIBS FROM THE PLAN.
SPRINGERS


S. MARIA DEL FIORE: FLORENCE
A EXTERIOR FROM N.W.
B LONGITUDINAL SECTION
C CONSTRUCTION OF DOME
LANTERN
LANTERN HEIGHT
D SECTIONAL PLAN OF DOME
PLAN d
PLAN e
PLAN c
PLAN b
PLAN a
SECTION ON X-X
COUNTERFORTS
E UNCOMPLETED FACADE
F PLAN
G INTERIOR LOOKING E.


PETRVS ET SVPER HANC

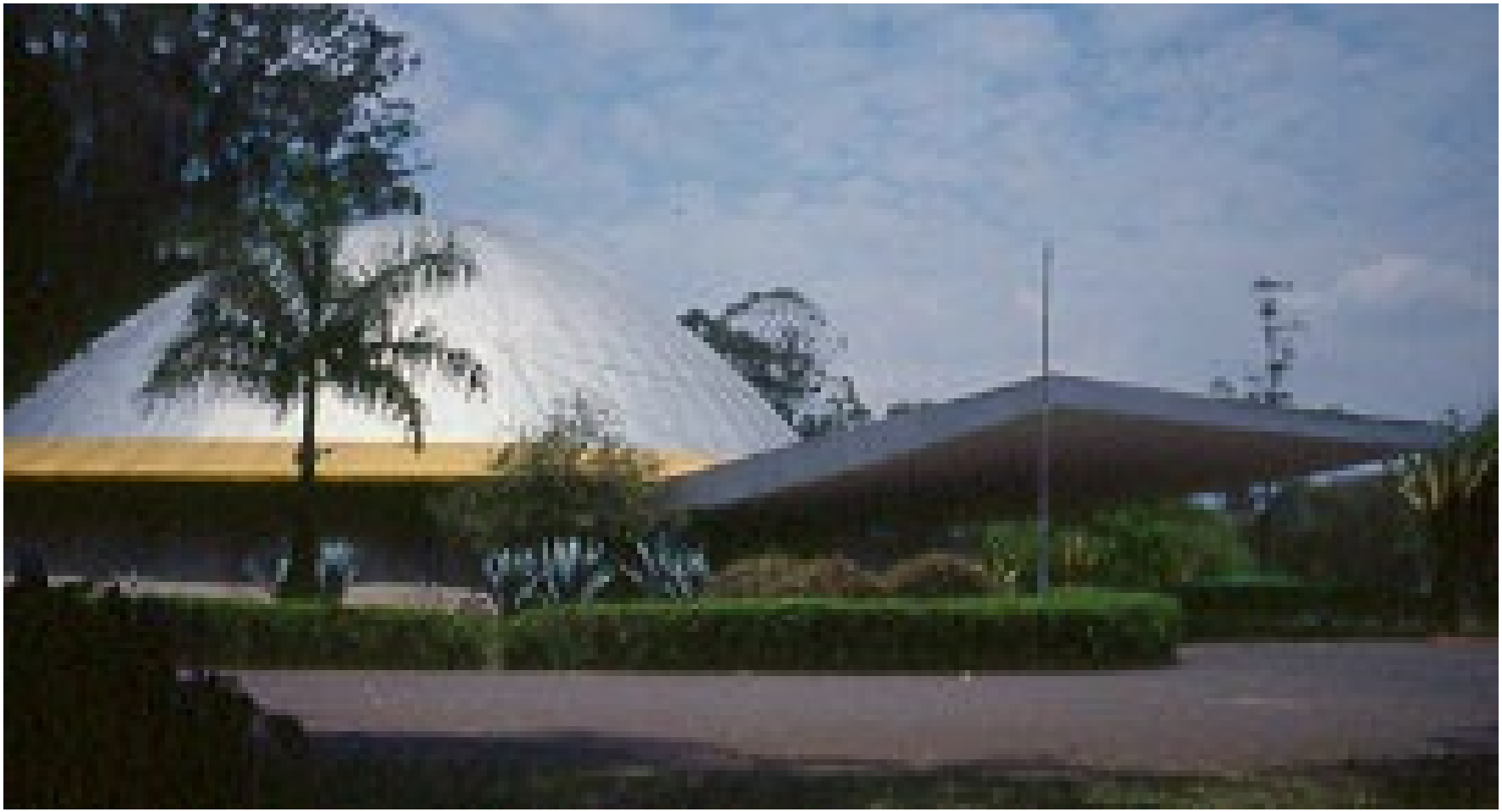


The world's first hyperboloid structure
Vladimir Shukhov, Nizhny Novgorod, 1896

Piscina Coberta Centro Esportivo Baby Barioni - SP - 1948
Ícaro de Castro Mello

Palácio das Artes – SP – 1951

Oscar Niemeyer, Zenon Lotufo, Hélio Uchôa, Eduardo K. de Mello



Planetário - SP - 1955

Eduardo Corona & Roberto José Goulart Tibau & Antônio Pitombo

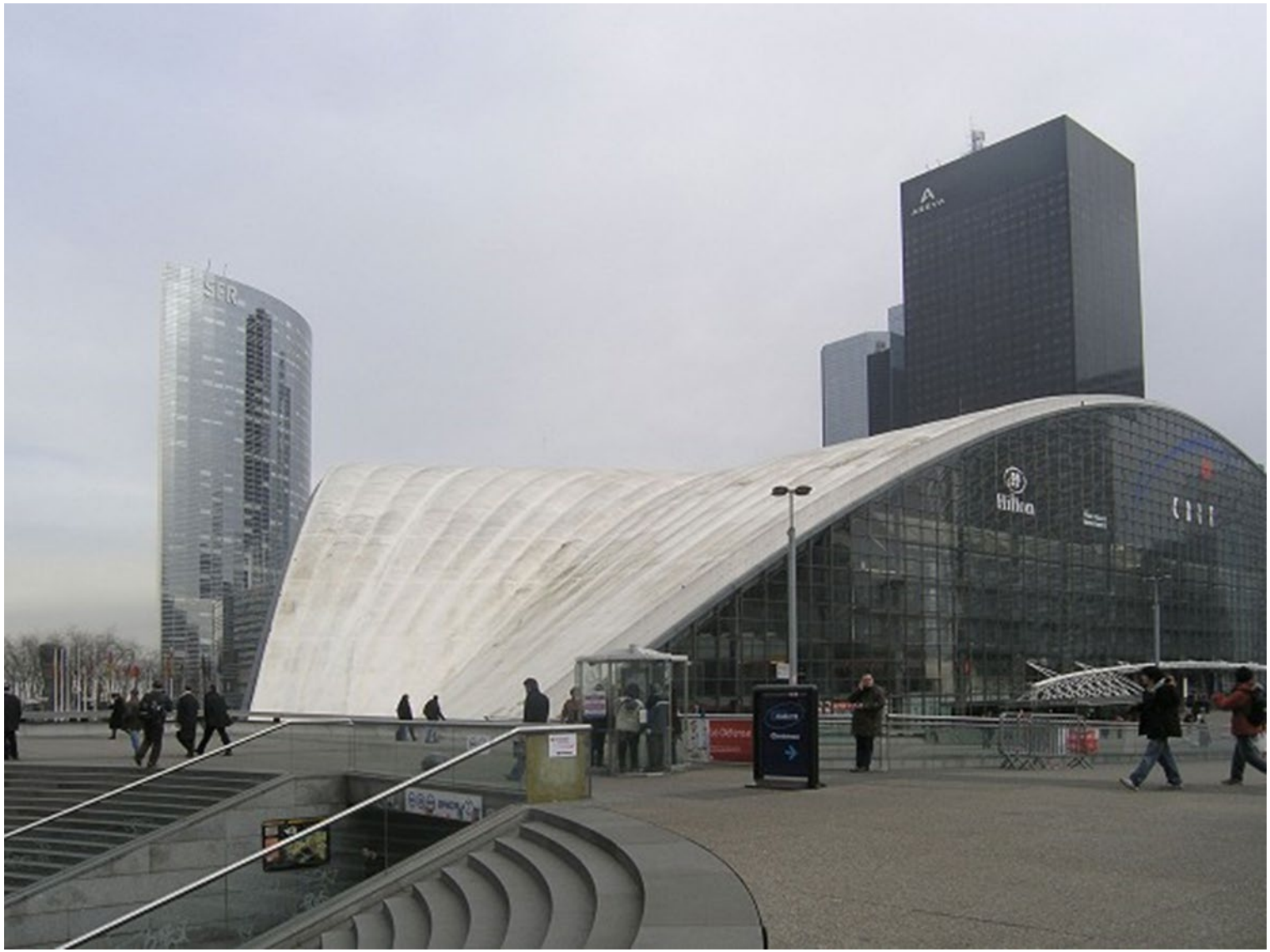
Xochimilco Restaurant Los Manantiales, Mexico, 1957/1958
Felix Candela (Eng), Fernando Alvarez Ordóñez; Joaquin Alvarez Ordóñez (Arqs)

CNIT

Centre des nouvelles industries et technologies,

Paris, 1956 - 1958

Architect	Robert Edouard Camelot
	Jean de Mailly
	Bernard Louis Zehrfuss
Engineer	Nicolas Esquillan
	Jean Prouvé
Consultant	Pier Luigi Nervi


SFR
Hilton


SFR
fnac
AIR FRANCE

TWA Terminal at JFK International Airport , New York, 1956-1963

Design engineer: Boyd G. Anderson

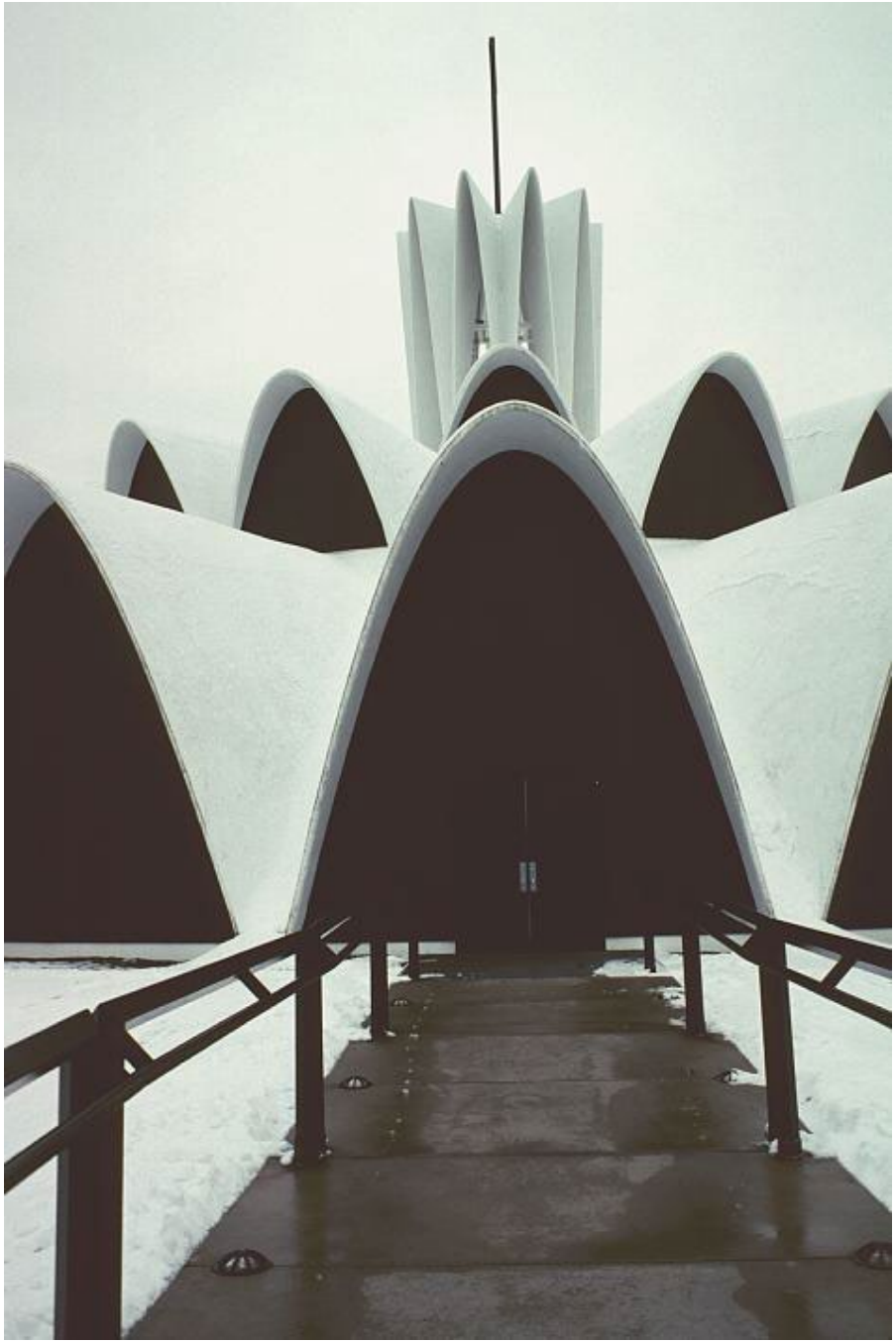
Architect: Eero Saarinen

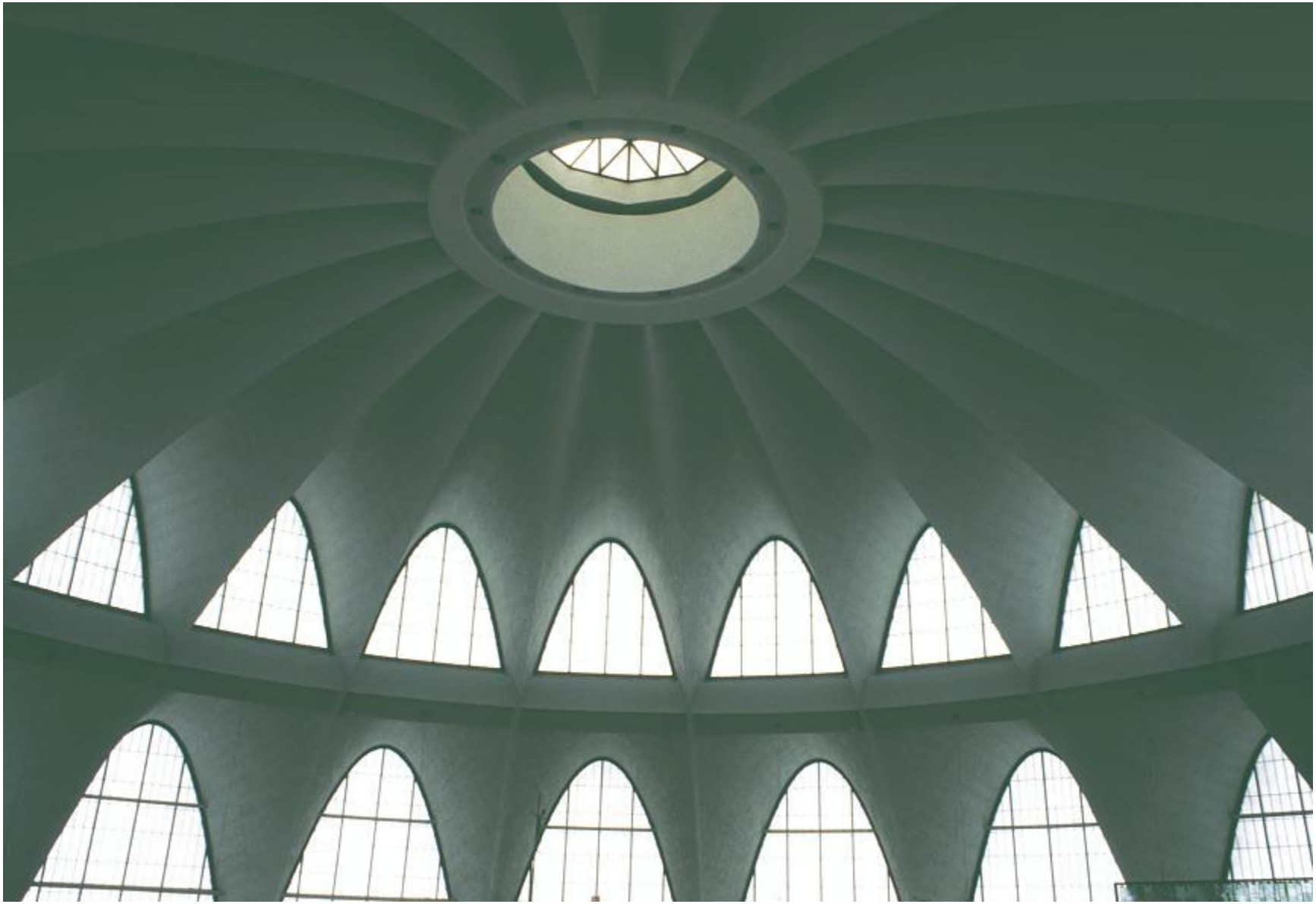

5
6


DEPARTURES
DEPARTURES


DEPARTURES

St. Louis Abbey (or the Priory Chapel)
Gyo Obata of Hellmuth, Obata & Kassabaum (HOK) with Pier Luigi Nervi, consultant
1962





H. Isler, Wyss Garden Center, Suíça, 1961

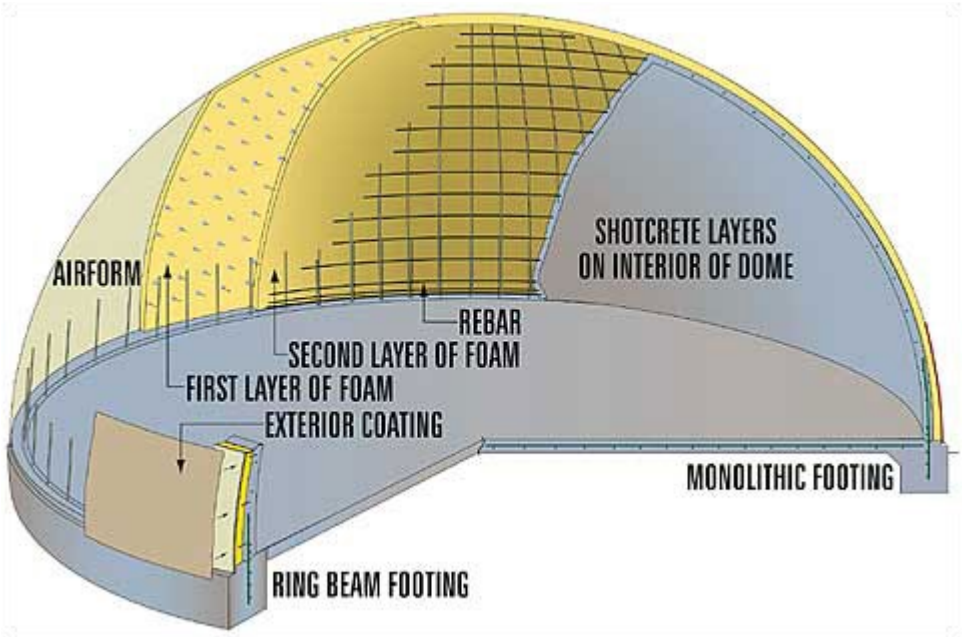
Heinz Isler – Bürgi Garden Center – Suíça, 1973

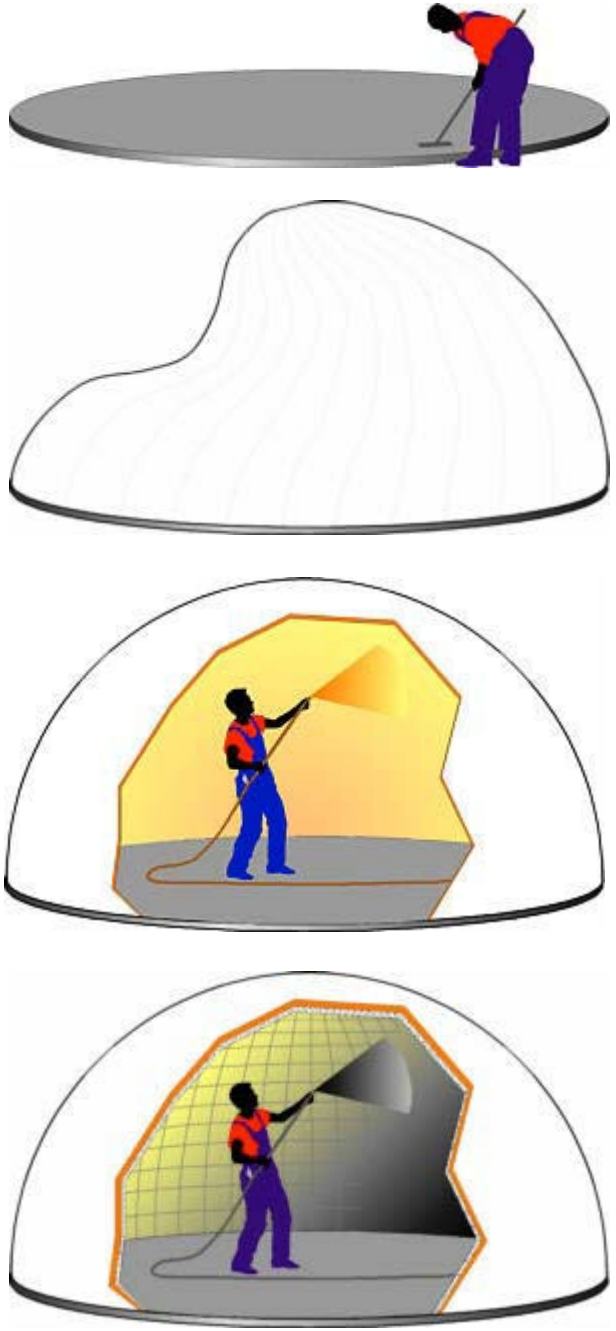
Heinz Isler – Bürgi Garden Center – Suíça, 1973

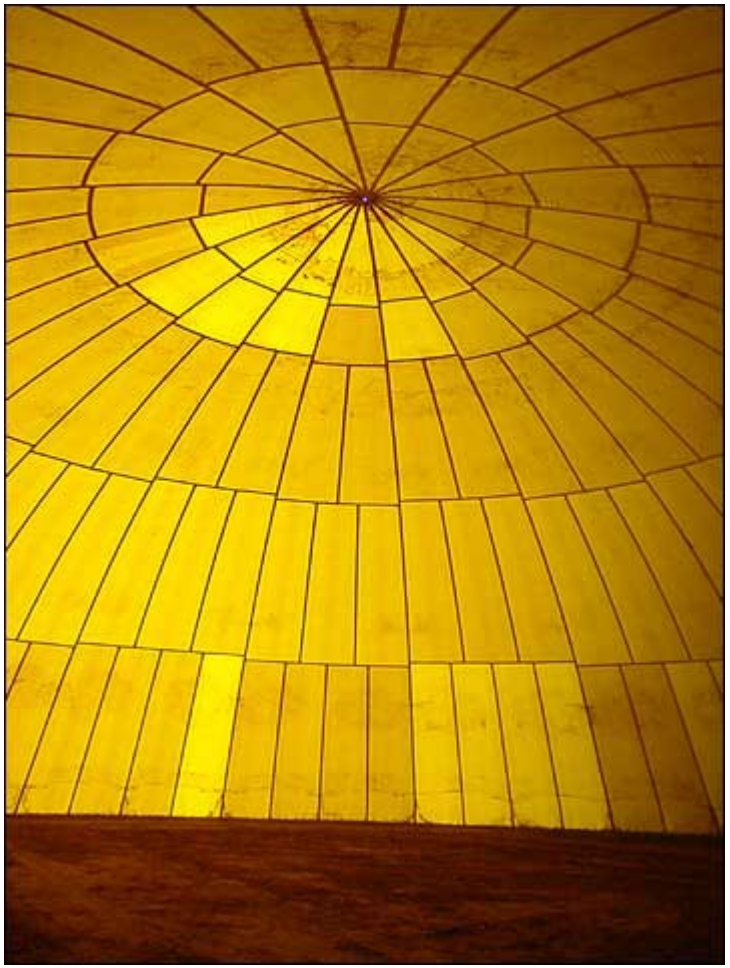
H. Isler, Brühl Sports Center , Suíça, 1982

Sistema Bini

The Kallangur Shopping Center, Queensland, Australia

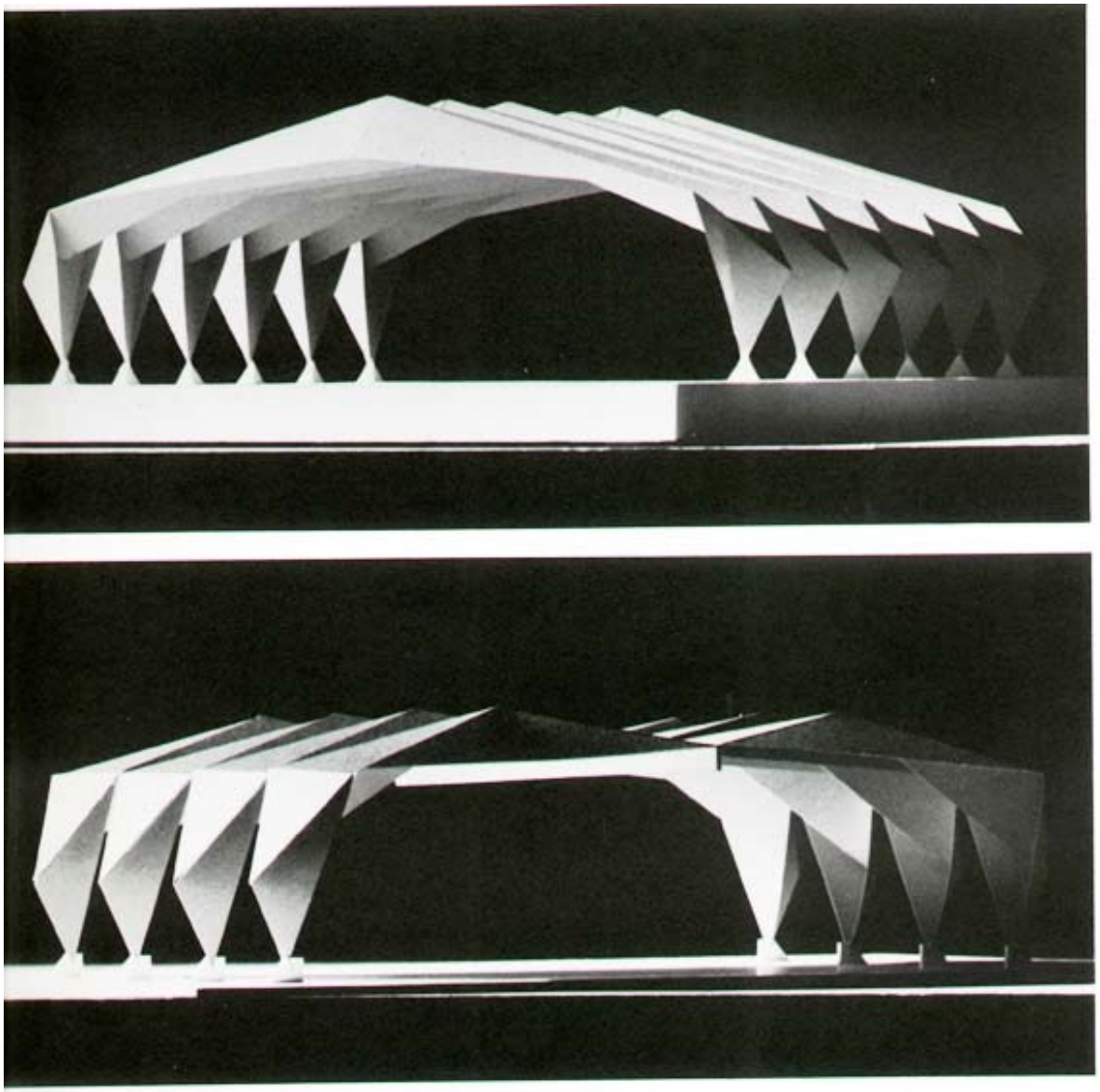

AIRFORM
SHOTCRETE LAYERS
ON INTERIOR OF DOME
REBAR
SECOND LAYER OF FOAM
FIRST LAYER OF FOAM
EXTERIOR COATING
MONOLITHIC FOOTING
RING BEAM FOOTING

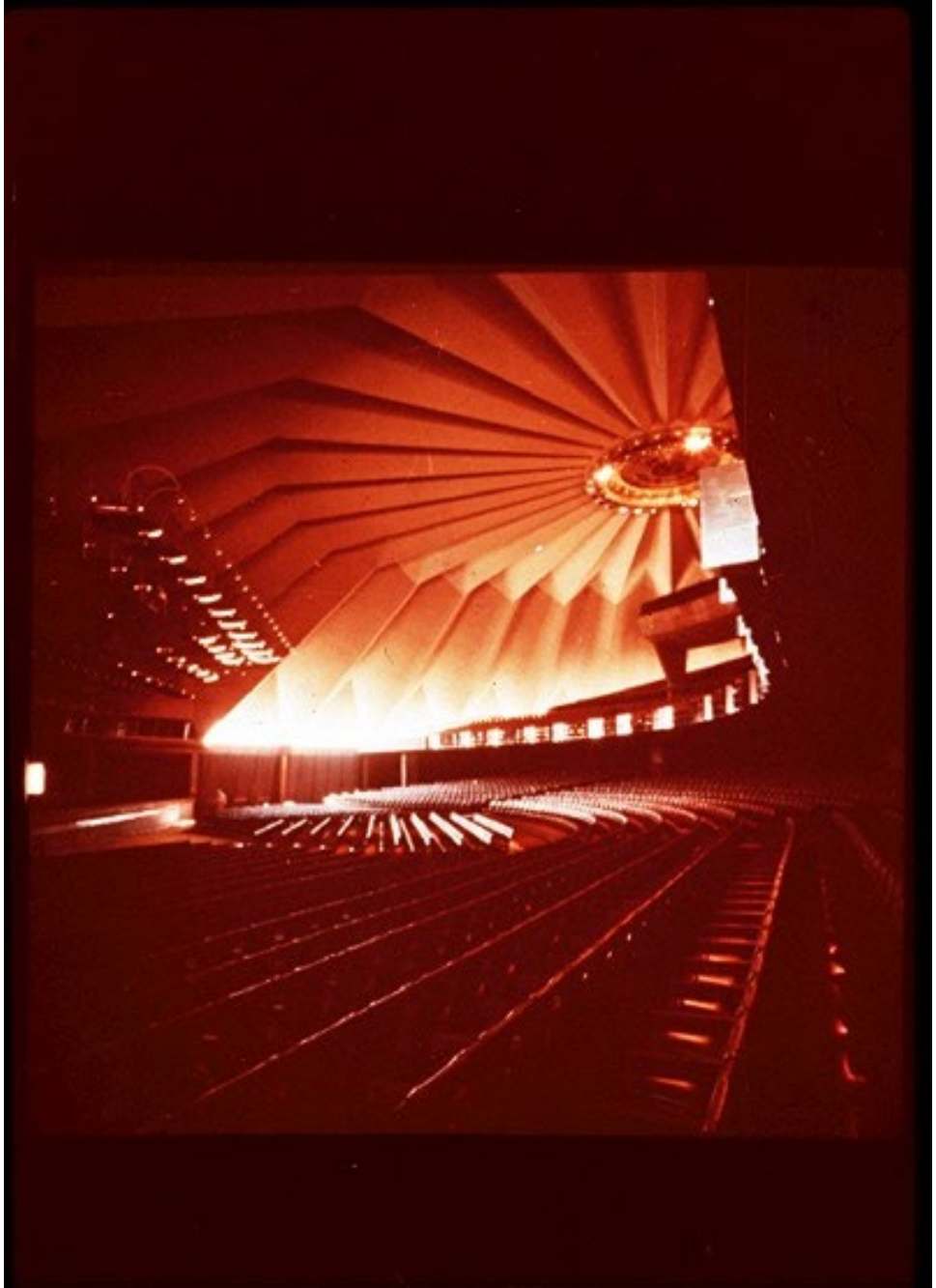


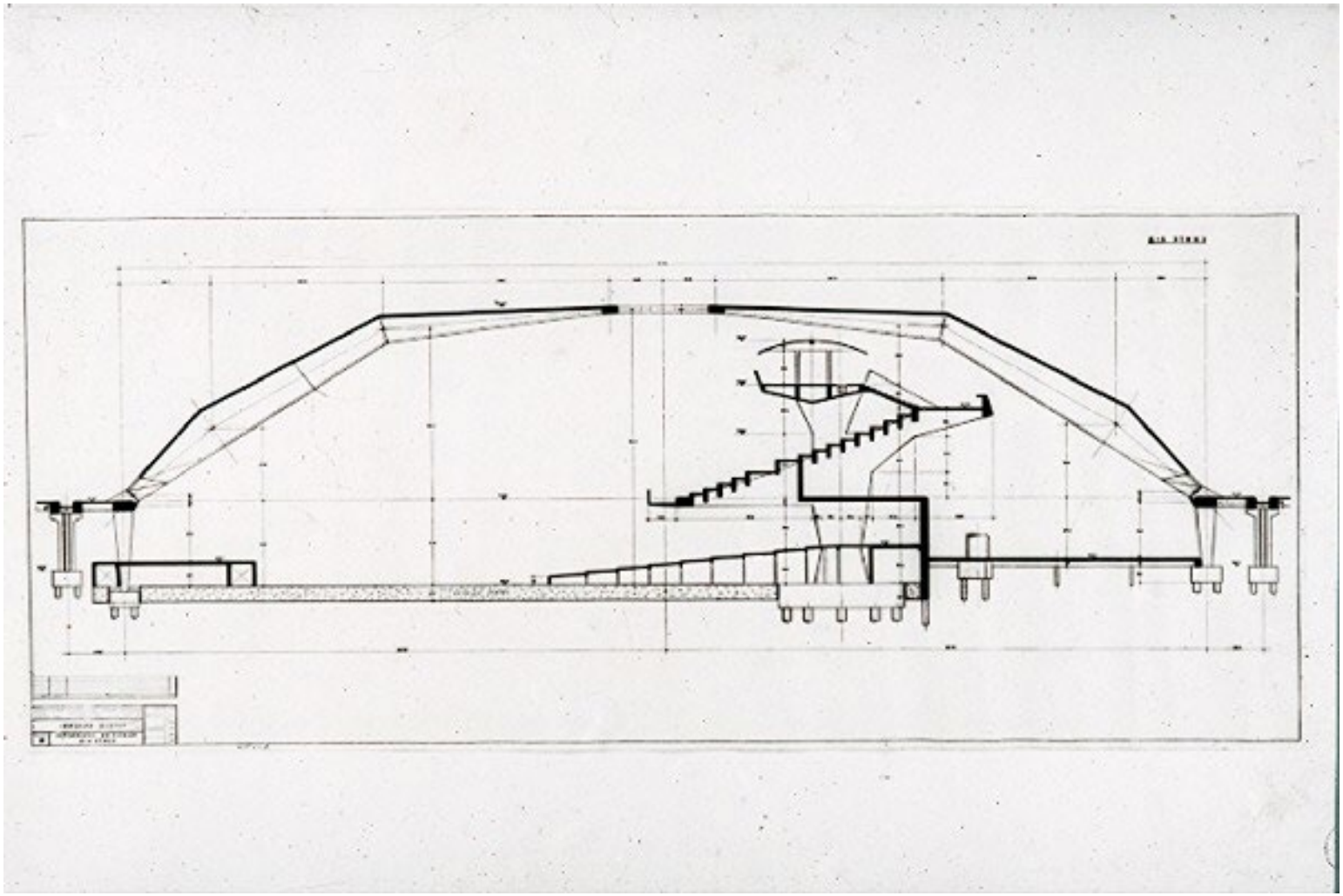


Palácio das Convenções - SP - 1967

Miguel Juliano e Silva, Jorge Wilheim





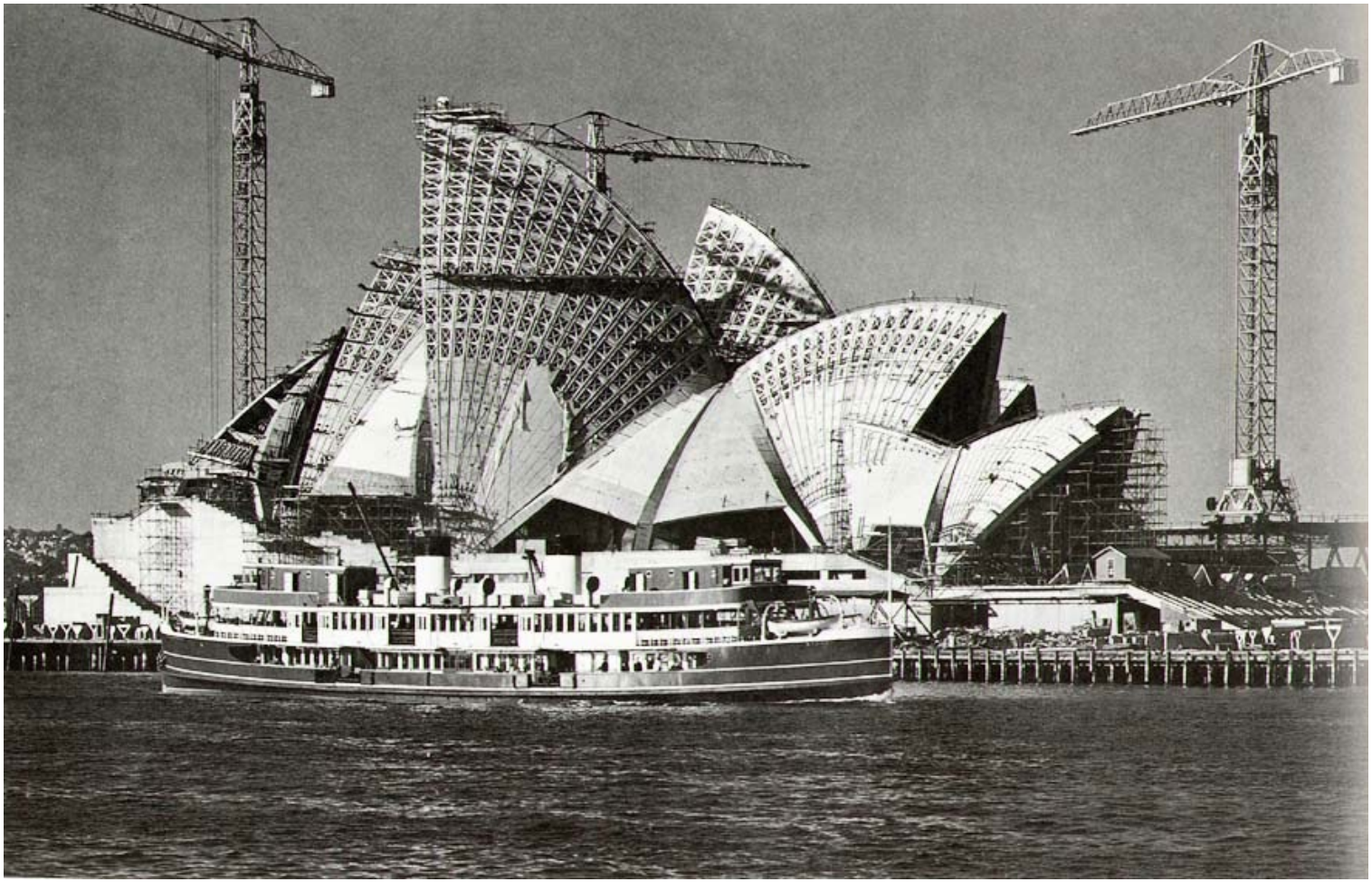


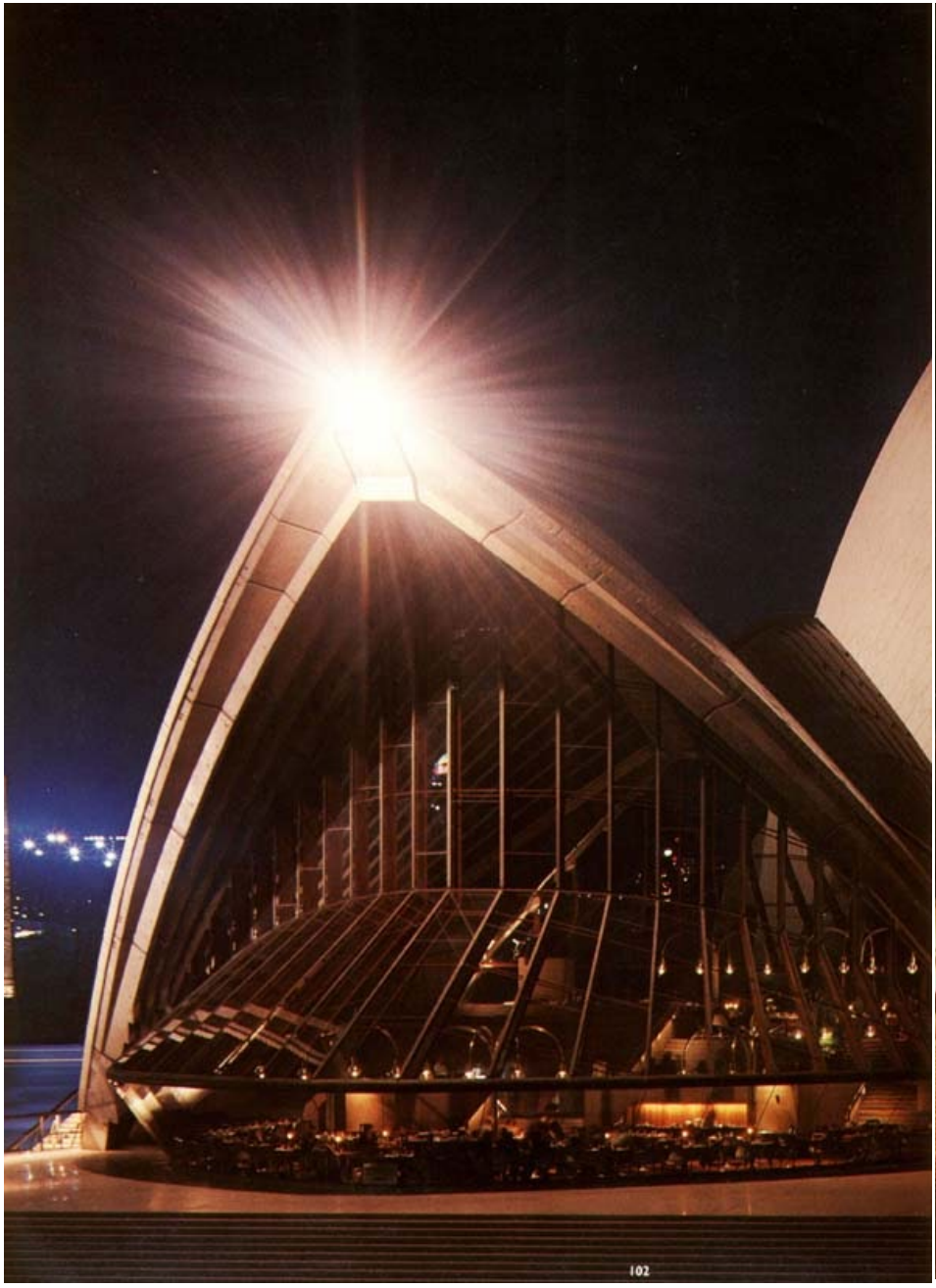
Posto Catacumba - RJ - 1968

Dilson Gestal Pereira, Waldyr Antunes Figueiredo, Paulo Roberto M. Souza, Alfredo Lemos

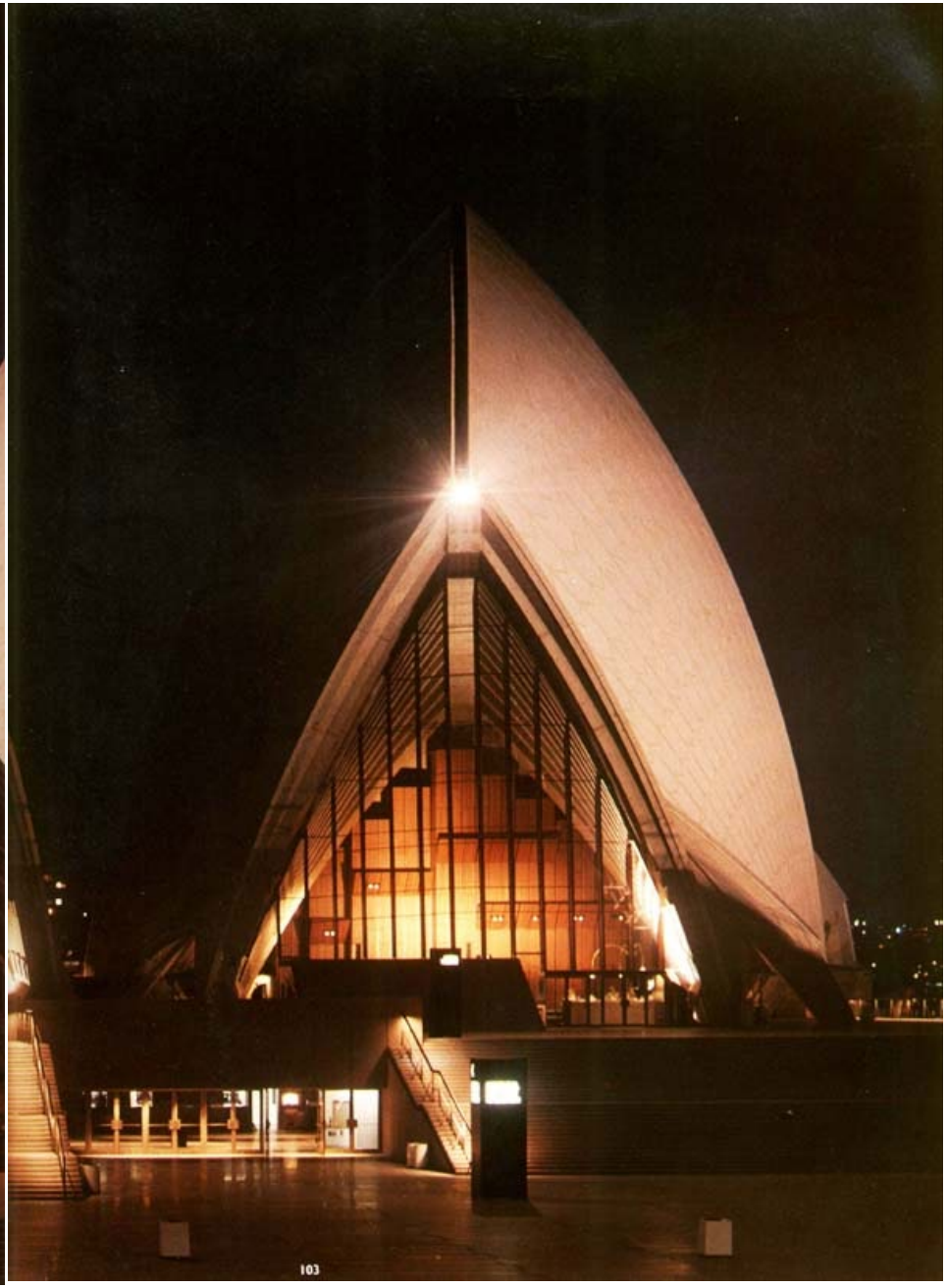
Sydney Opera House (1958 – 1973)

Double thin shell ribbed ; Concept designer Jørn Utzon; Architect E. H. Farmer , Peter Hall, David Littlemore, Lionel Todd ; Engineer: Ove Nyquist Arup



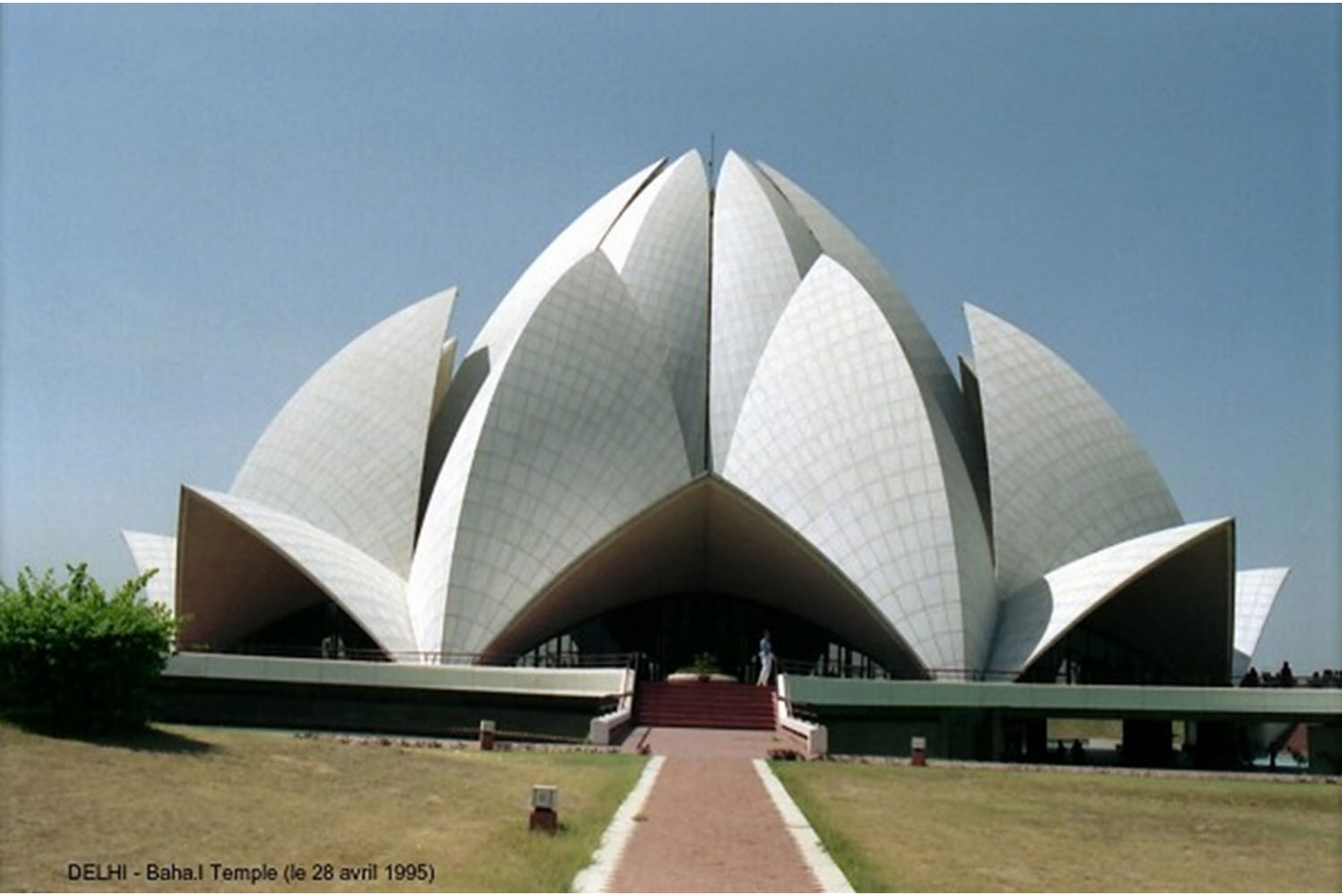


102

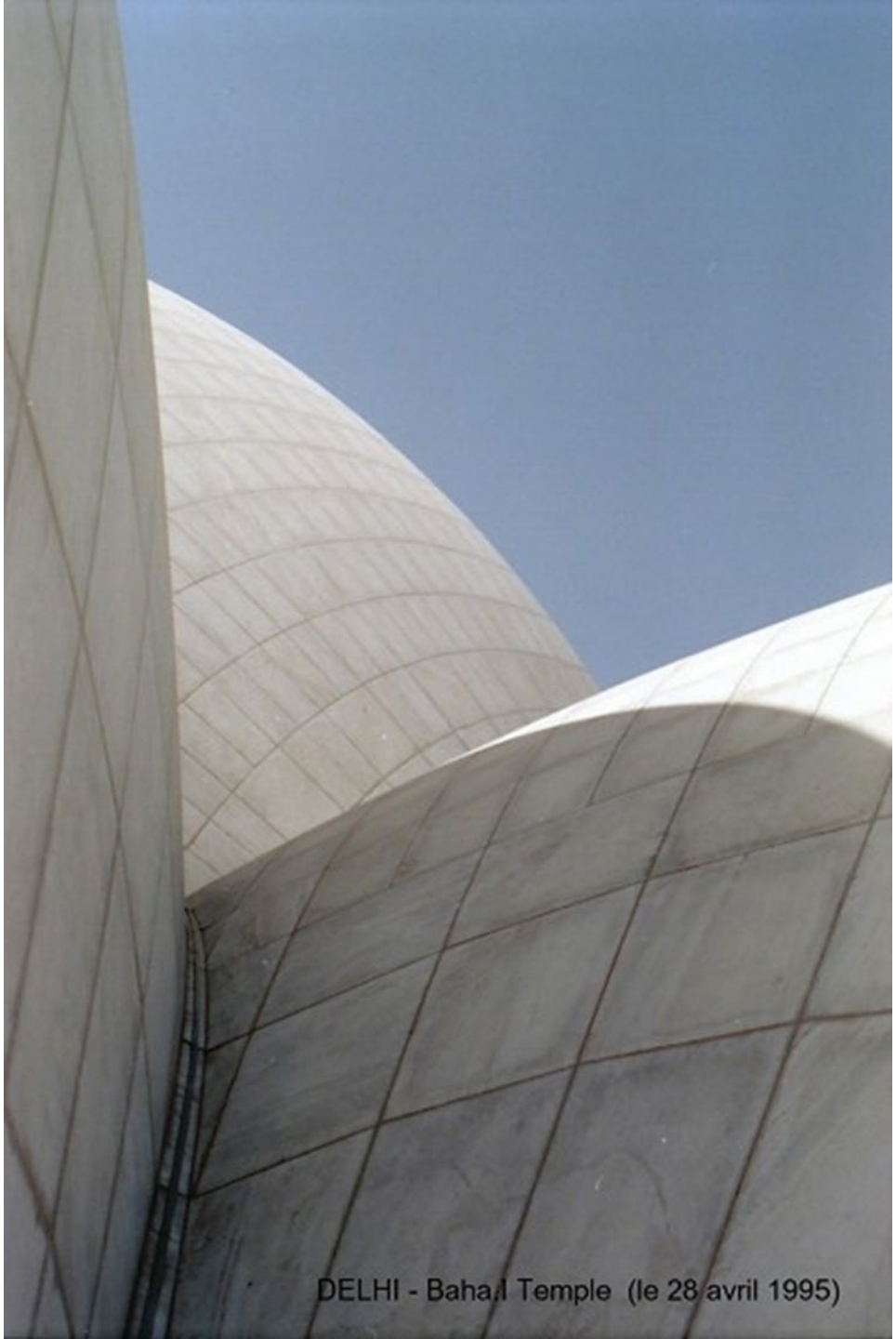


103

Fariborz Sahba (canadian architect)


DELHI - Baha.I Temple (le 28 avril 1995)

DELHI - Baha.I Temple (le 28 avril 1995)

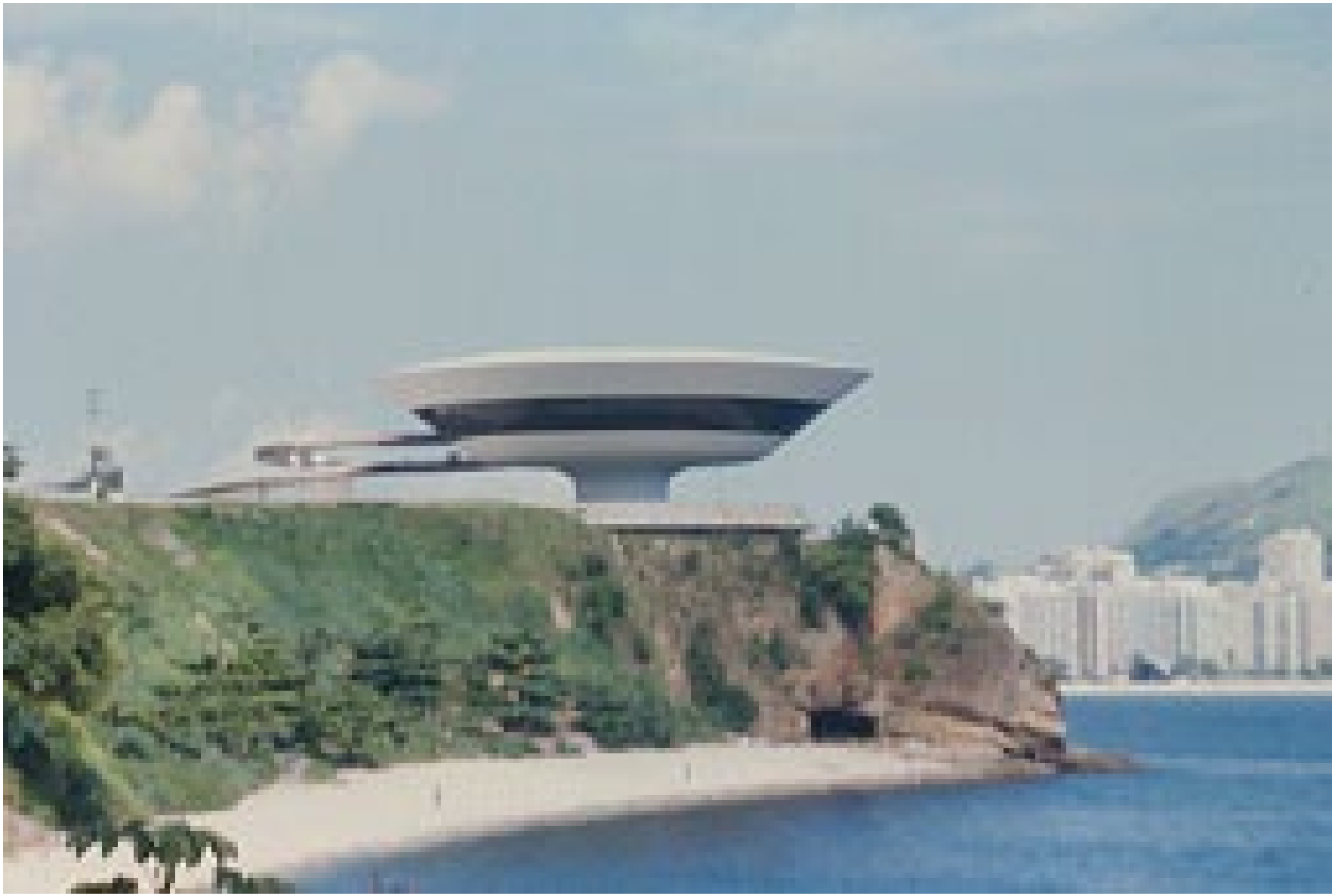

DELHI - Baha'I Temple (le 28 avril 1995)

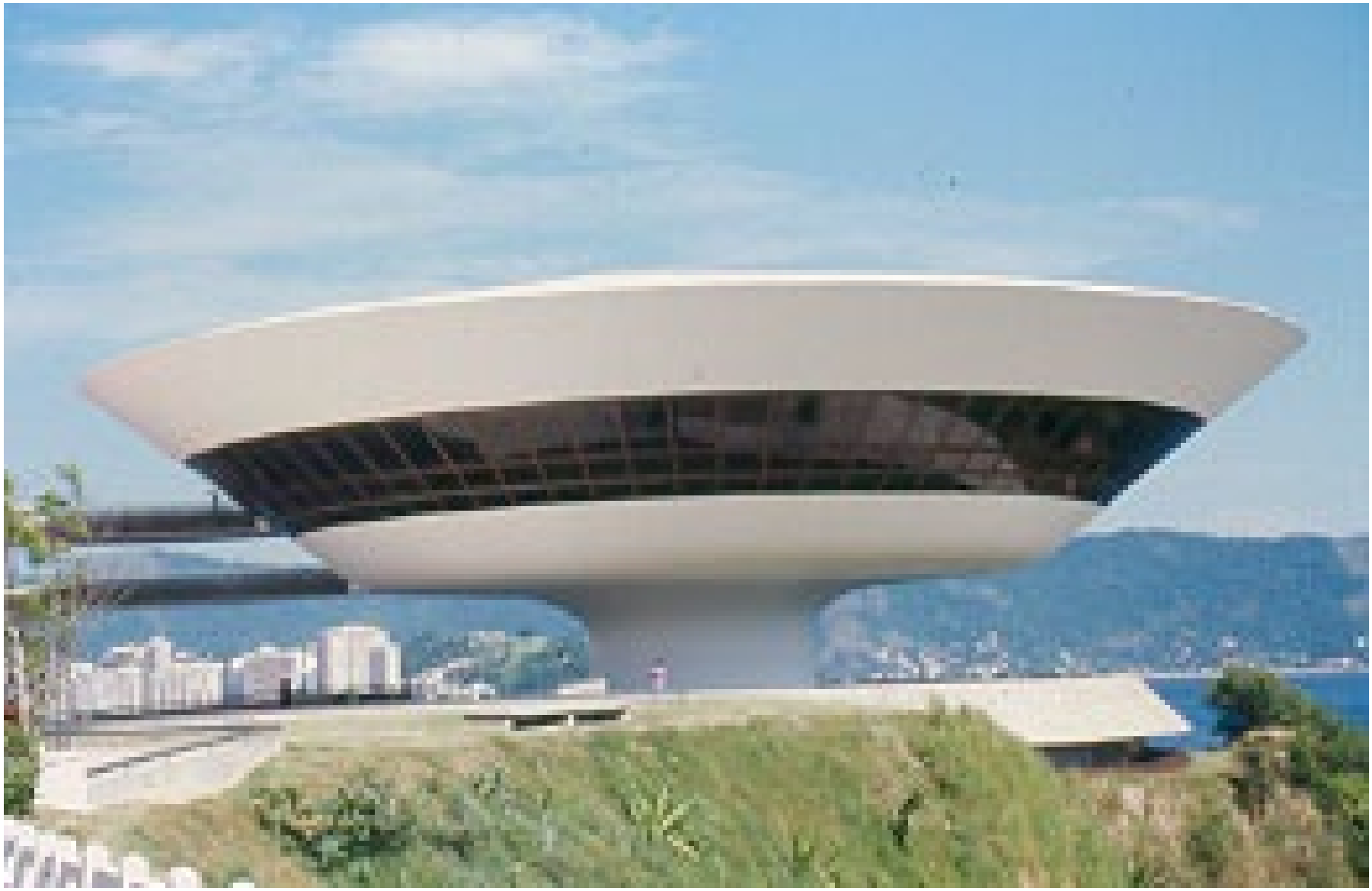
Memorial da América Latina - SP - 1987

Oscar Niemeyer

Museu de Arte Contemporânea - RJ - 1996

Oscar Niemeyer

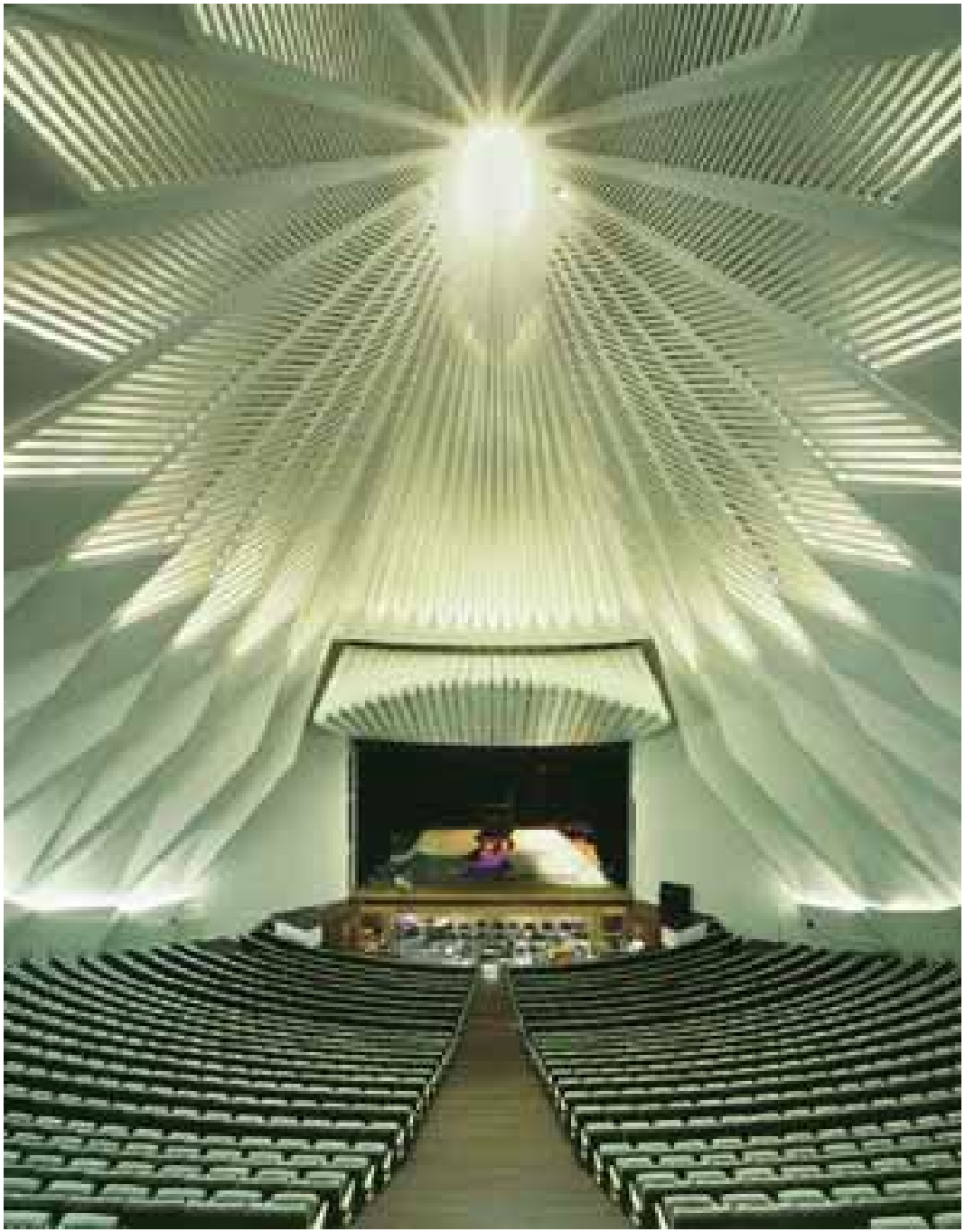




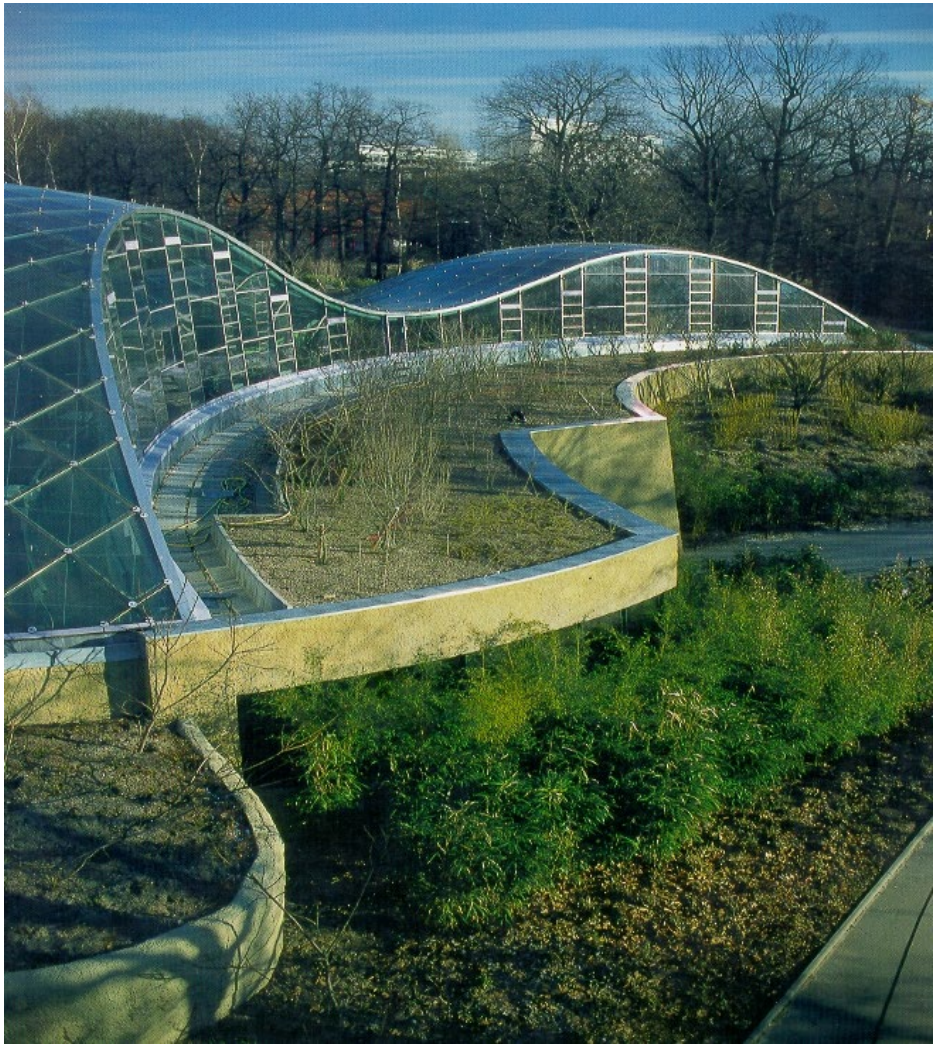
L'Oceanogràfic, Valencia , 2002
Félix Candela

Santiago Calatrava
Tenerife Concert Hall, 1996
Canary Islands, Spain

The all-concrete building is characterized by the dramatic sweep of its roof. Rising off the base like a crashing wave, the roof soars to a height of 58 meters over the main auditorium before curving downward and narrowing to a point. The building's plinth forms a public plaza covering the site and allows for changes in grade between the different levels of the adjacent roads.



Guggenheim Museum, Bilbao, 1997
Architect: Frank Owen Gehry

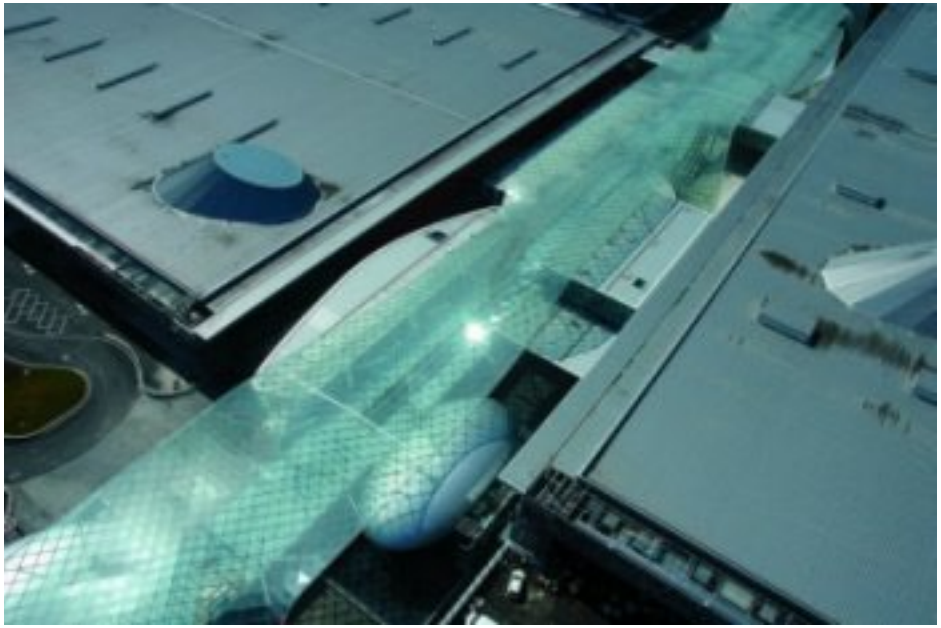


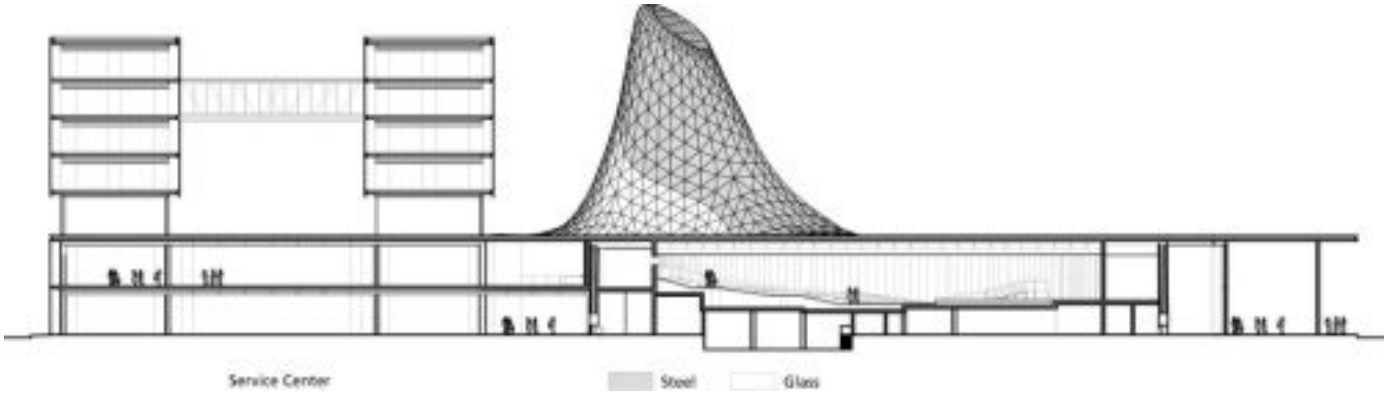
Viveiro dos hipopótamos do zoológico de Berlim
Arq. J. Griebl (1999)

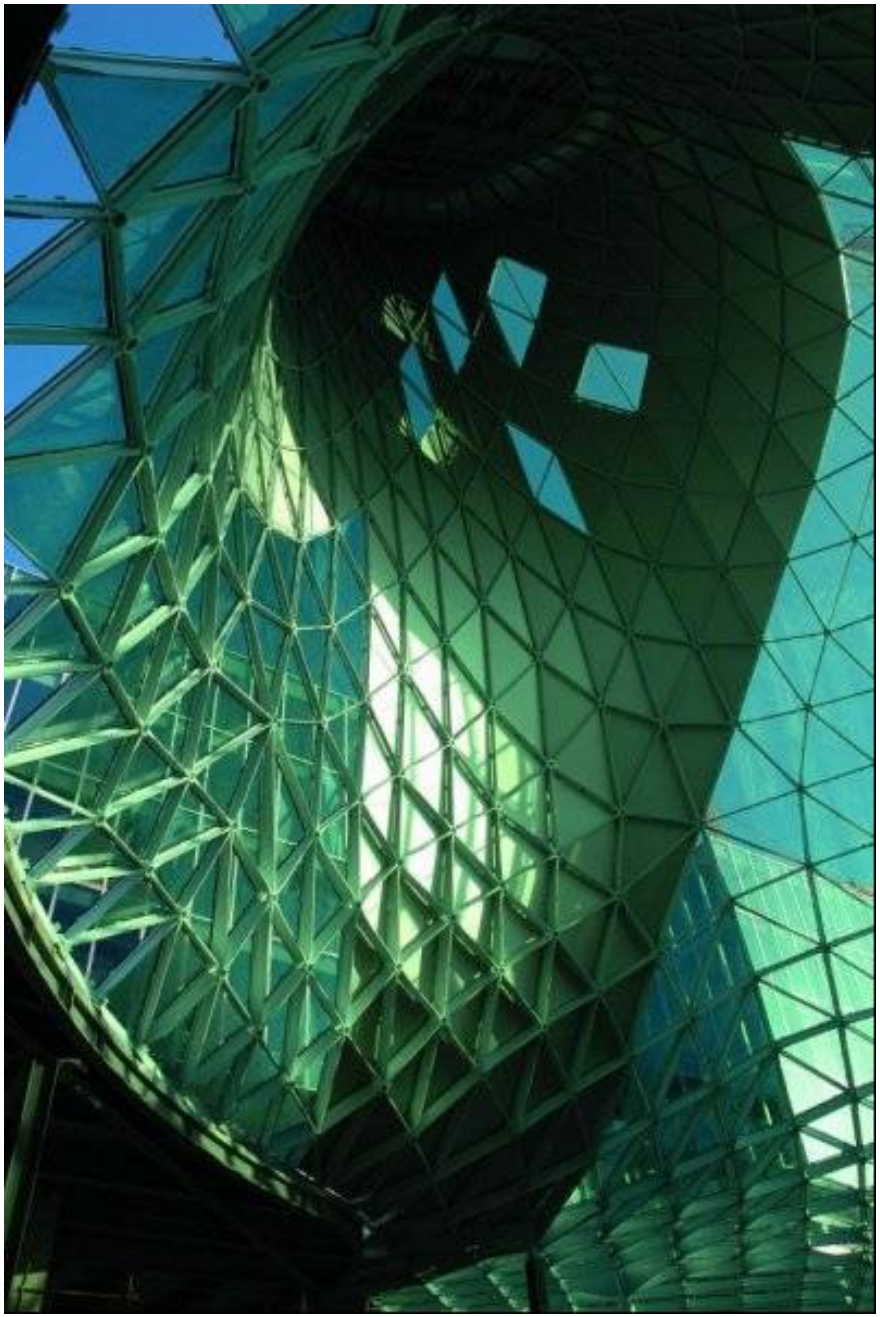
Desgin: Jorg Schlaich

Viveiro dos hipopótamos do zoológico de Berlim

Fiera di Milano Exhibition Centre, Milan, Italy
Massimiliano Fuksas, 2005




Service Center
Steel
Glass



Anaheim Regional Transportation Intermodal Center
Anaheim, California, 2015
HOK Architects

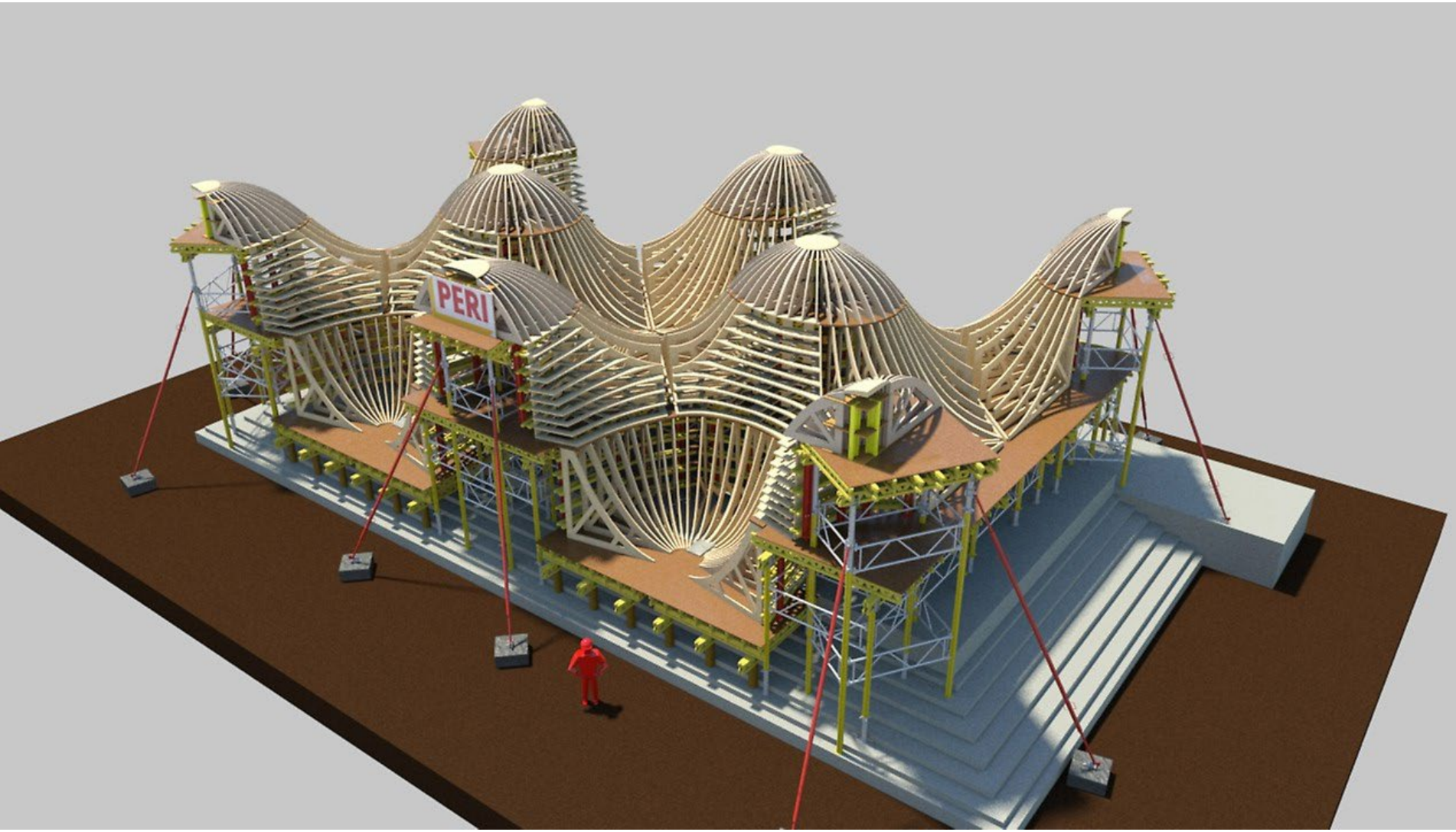

TICKETS & BAGGAGE CHECK-IN
BUS TICKETS & INFORMATION
COMING SOON
SPRING 2015

Metropol Parasol
Arq. Jürgen Mayer H. Architects (2011)

Centro Heydar Aliyev, Azerbaijão (2013)
Arqs. Zaha Hadid, Patrik Schumacher

Arnhem Central Station, the Netherlands, 2015
Architects: UNStudio

Bosjes Chapel, Witzenberg, South Africa, 2017
Steyn Studio (UK) & TV3 Architects (SA)


PERI