EP-USP

# PEF2603

## Estruturas na Arquitetura III - Sistemas Reticulados e Laminares

FAU-USP

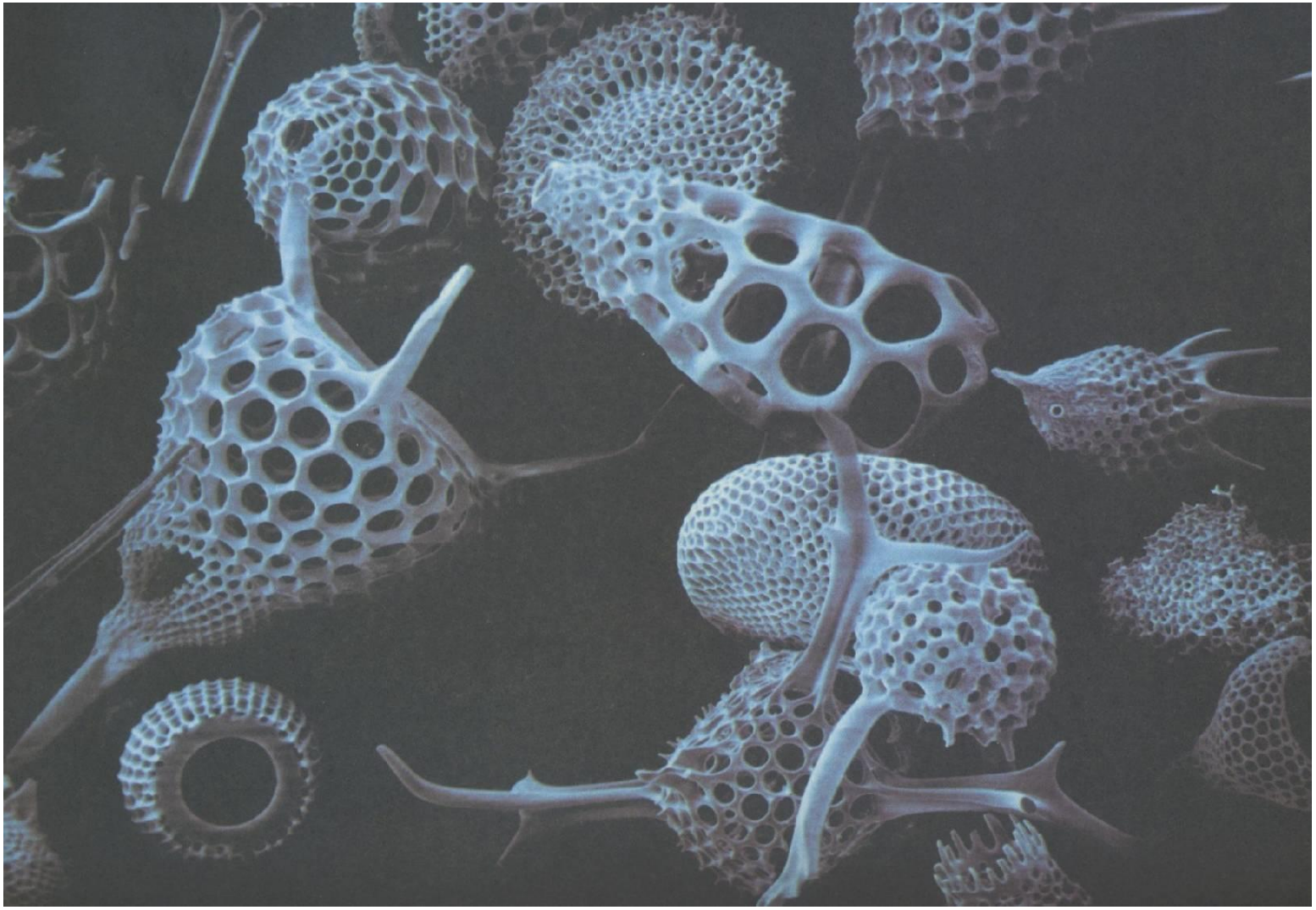
# Cascas

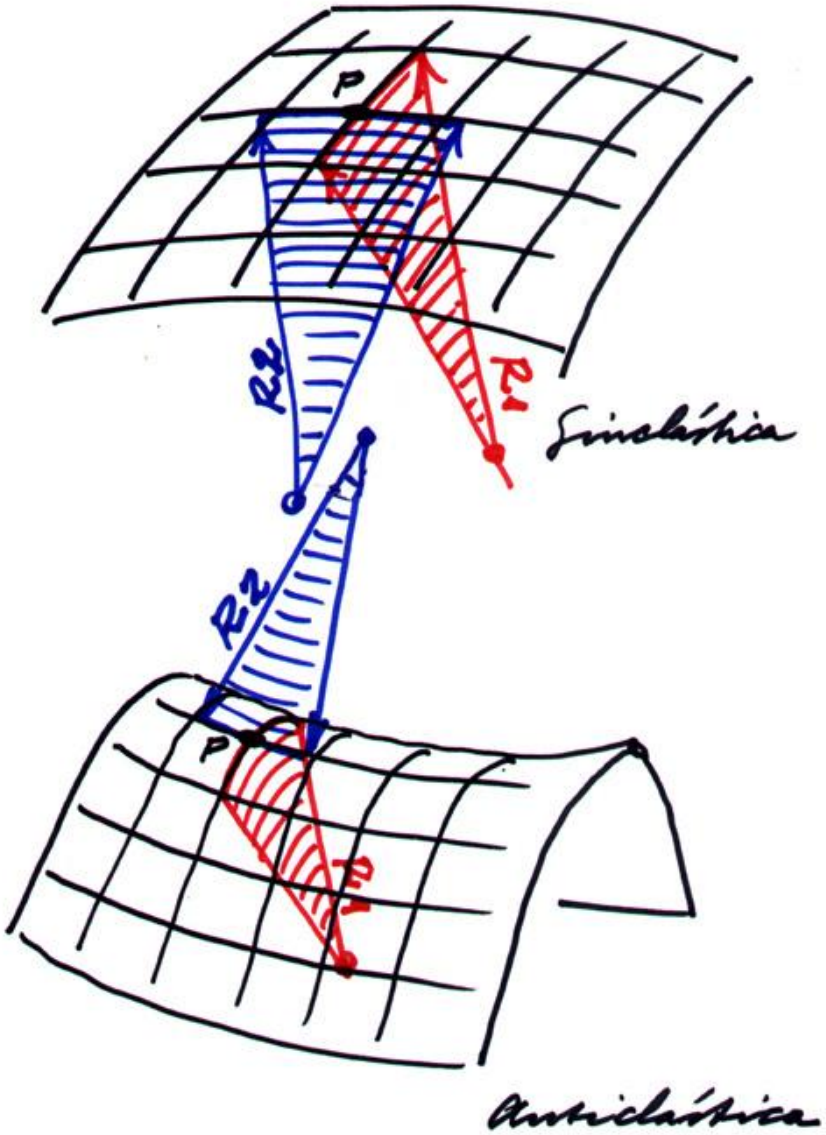
## Uma Visão Geral

(20/05/2019)

Professores
Ruy Marcelo O. Pauletti , Leila Cristina Meneghetti, Luís Bitencourt Jr.

1º Semestre 2019





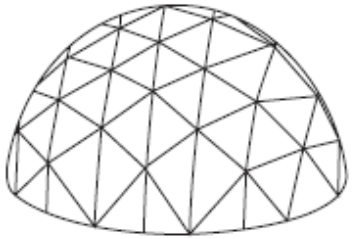

CURVATURAS



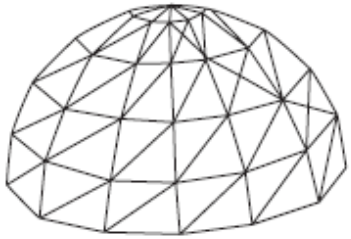
Esquemas originais
– Prof. Mário Franco

# Superfícies de Revolução

Esfera

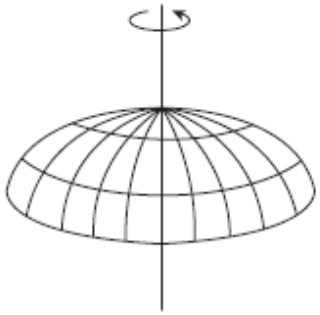


Domo Geodésico

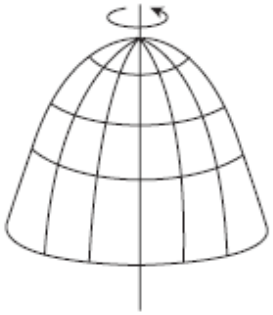


Domo de Schwedler

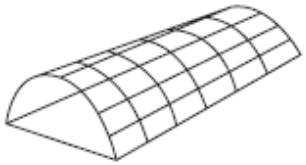
Domo Nervurado



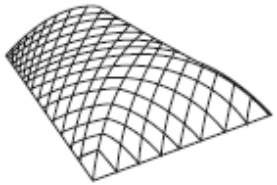
Elipsóide



Parabolóide

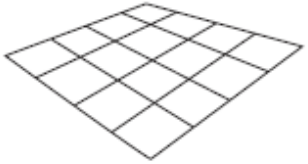


Cilindro Nervurado



Cilindro Lamelar

Casca funicular

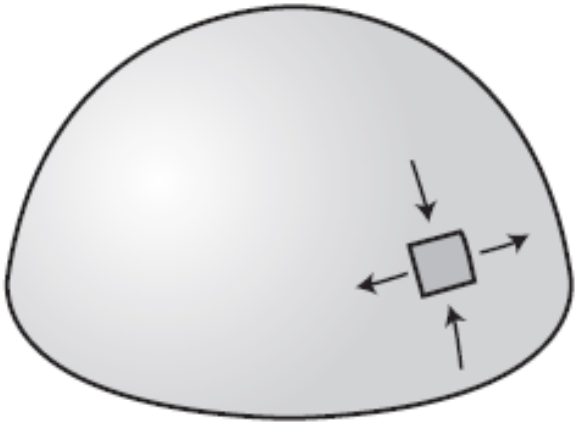


Parabolóide Hiperbólico

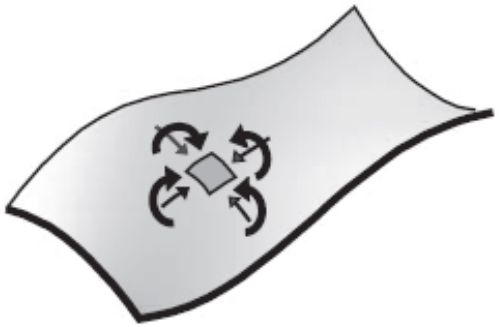
Parabolóide Hiperbólico

Superfície de forma livre

# Cascas x outras superfícies

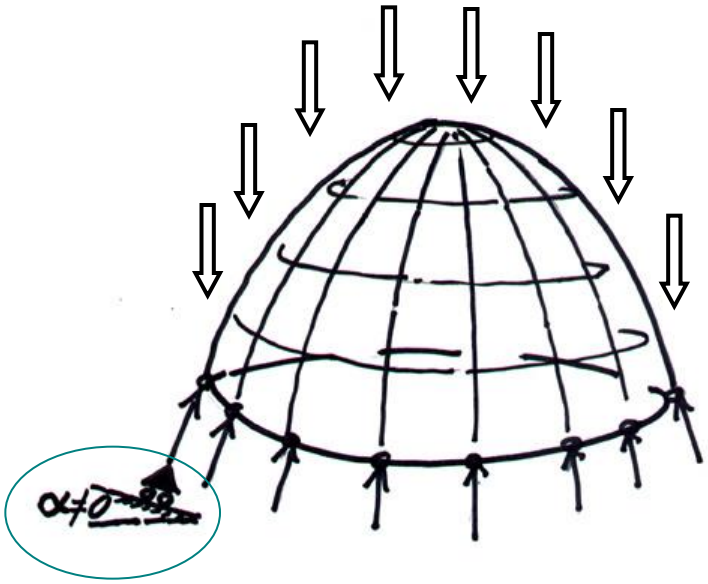


Casca Funicular:
comportamento de membrana
somente esforços de tração e compressão

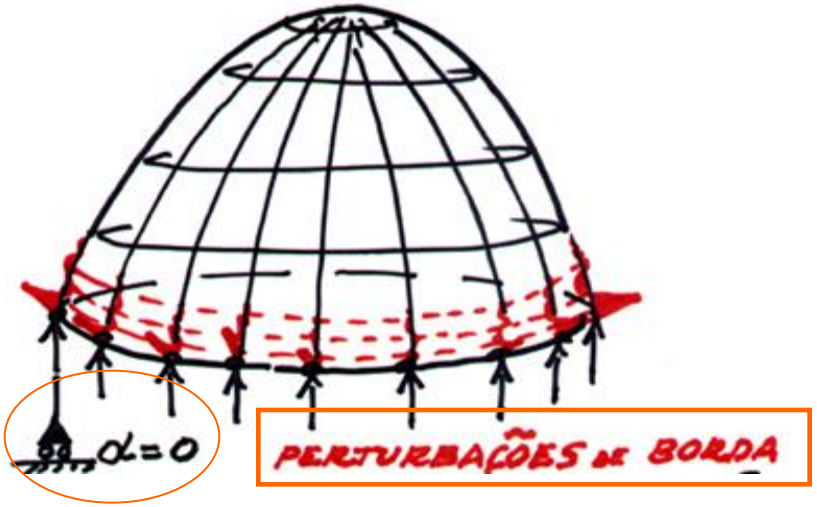


Formas complexas:
presença de momento fletor
aumento da espessura

# Cascas

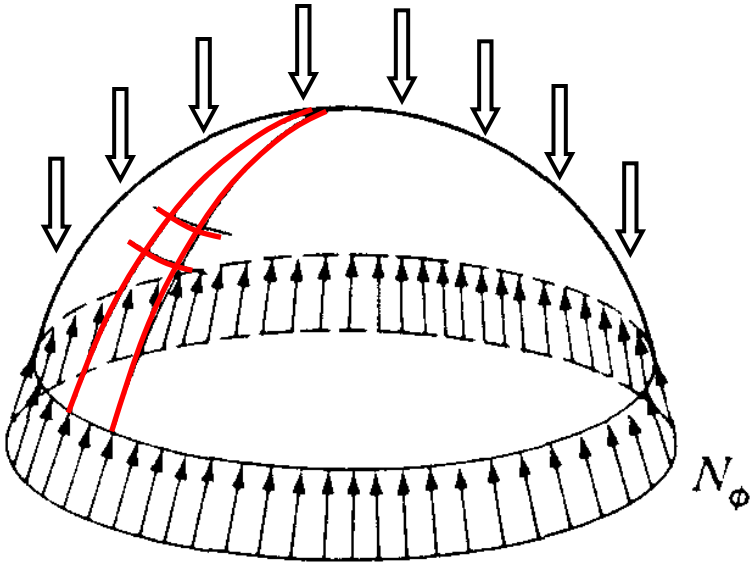


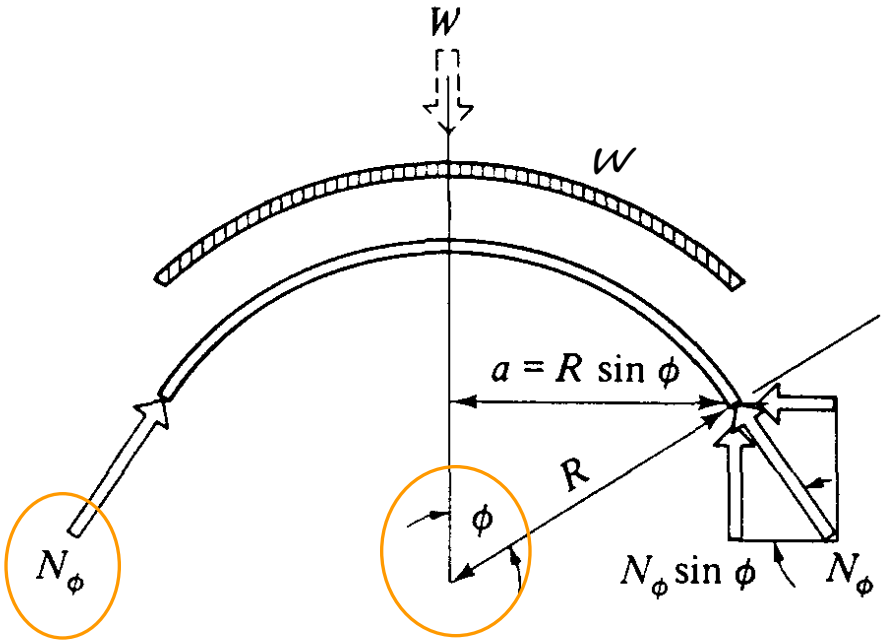
Casca Funicular
ao carregamento



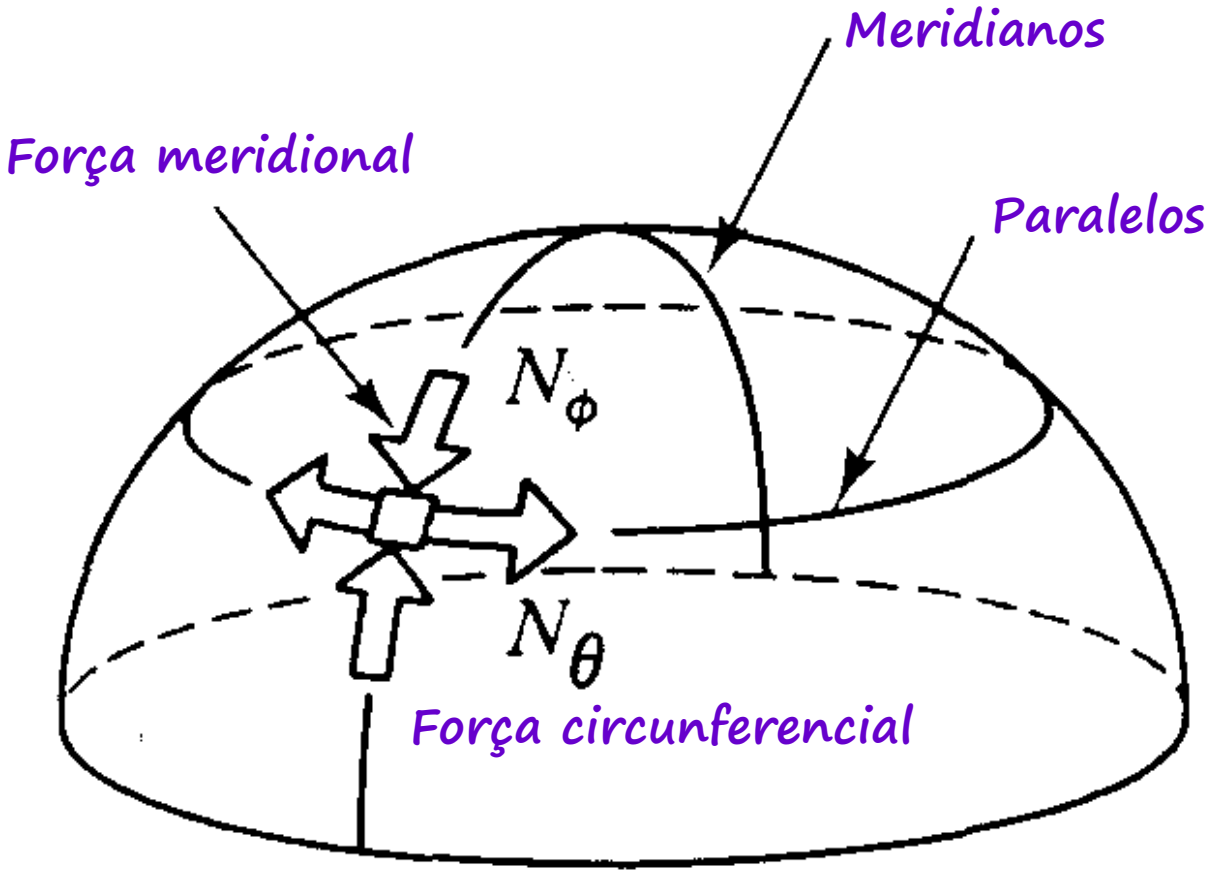

Esquemas originais – Prof. Mário Franco

# Casca esférica sujeita a cargas verticais



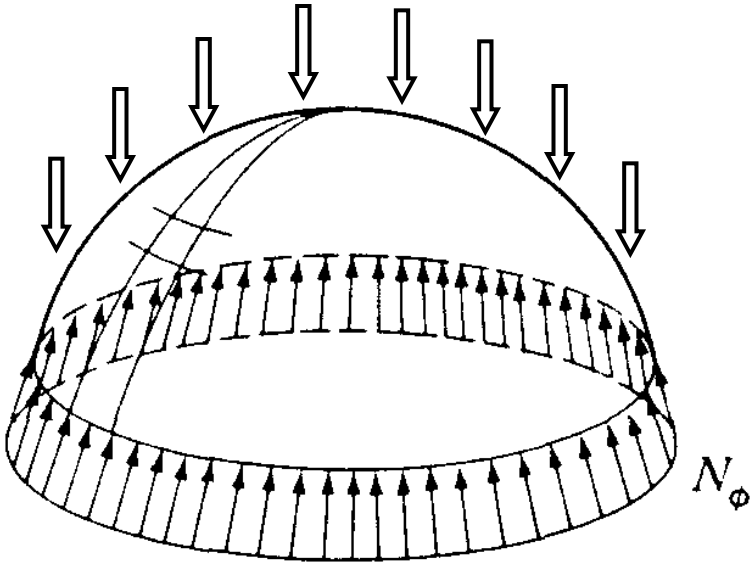
Casca parabólica:

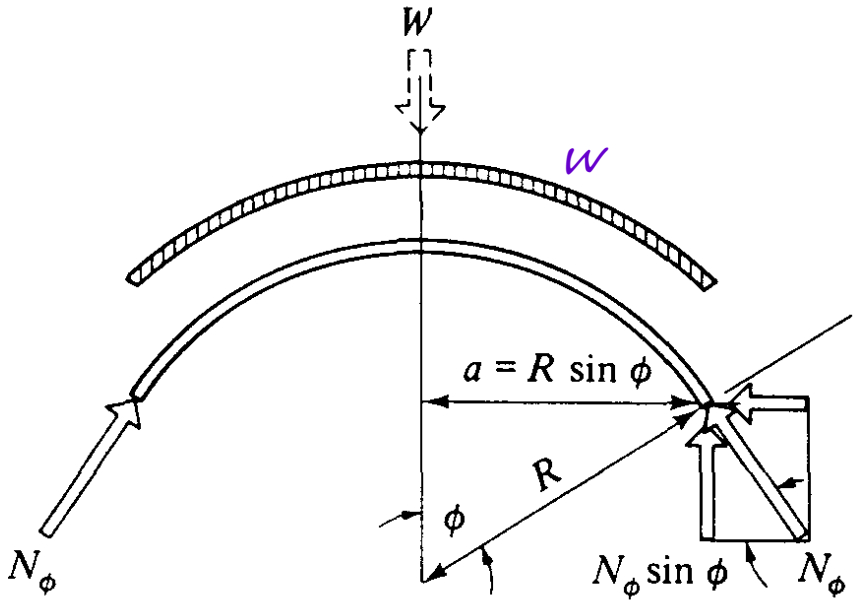



Recordando a Equação de Laplace-Young:

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

# Casca esférica sujeita a cargas verticais

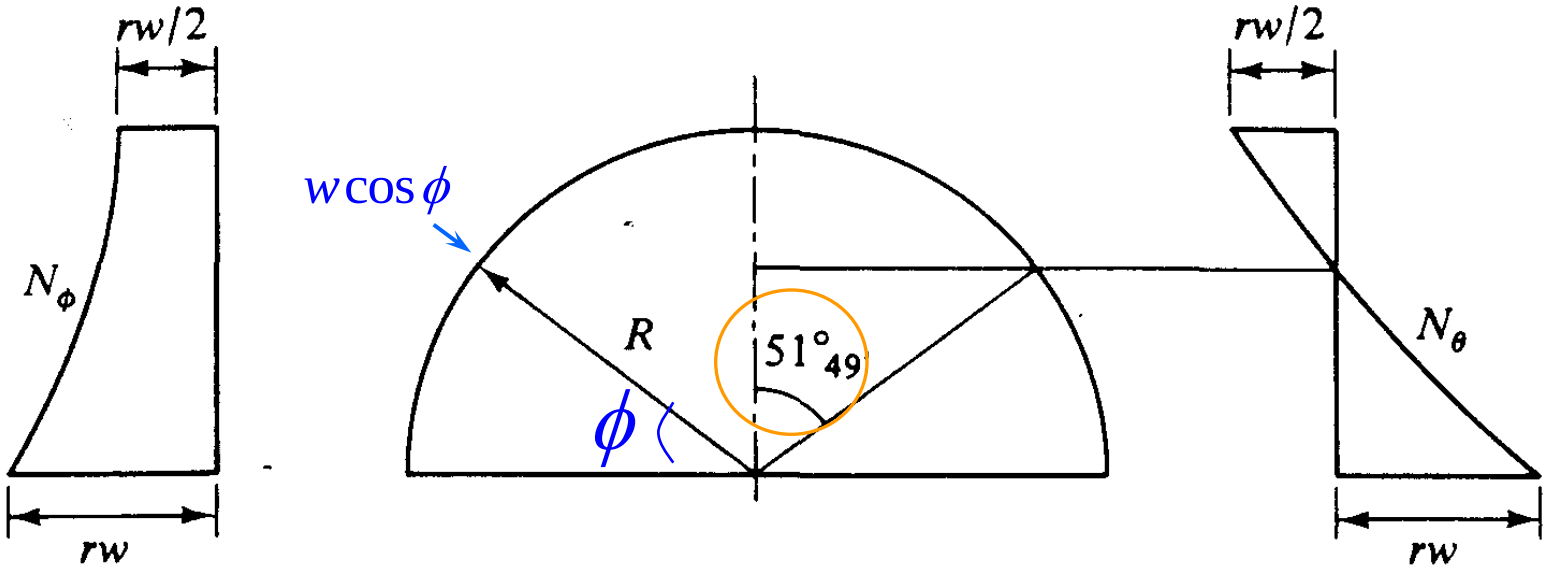



$$N_\phi = \frac{Rw}{1+\cos\phi}$$

Eq. Laplace:

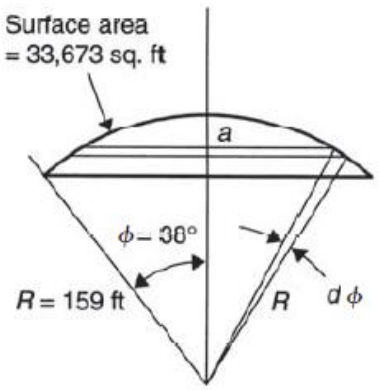
$$\frac{N_\theta + N_\phi}{R} = p_r = w\cos\phi$$




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

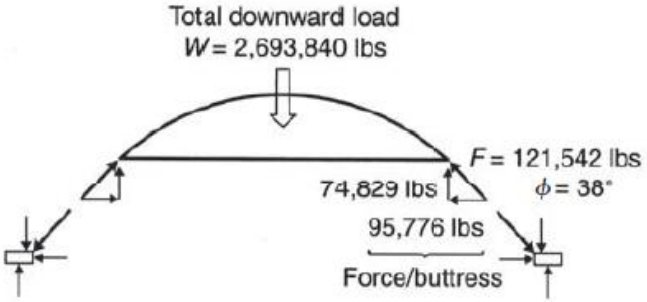
**Palazzetto dello Sport – 1956 – 1957**
**Pier Luigi Nervi, Annibale Vitellozzi**
**1960 Olympics**

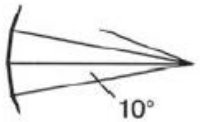

INGRESSO 1



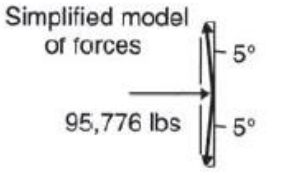

(a) Area calculations

(b) Dome during construction

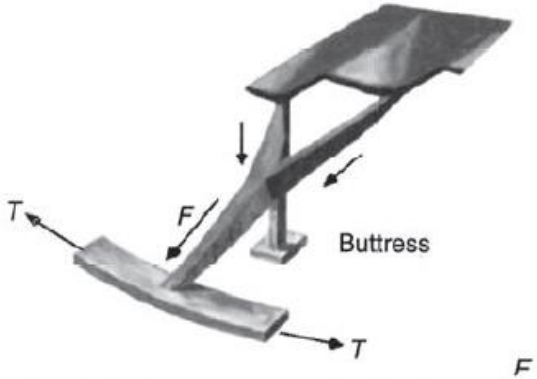


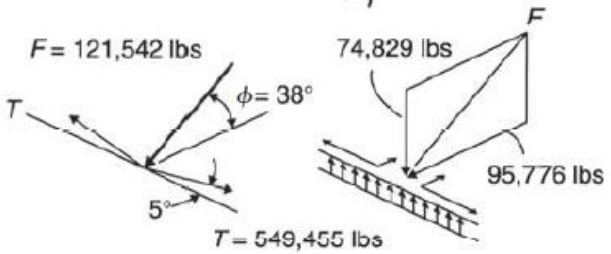




Angles subtended by
one of 36 buttresses

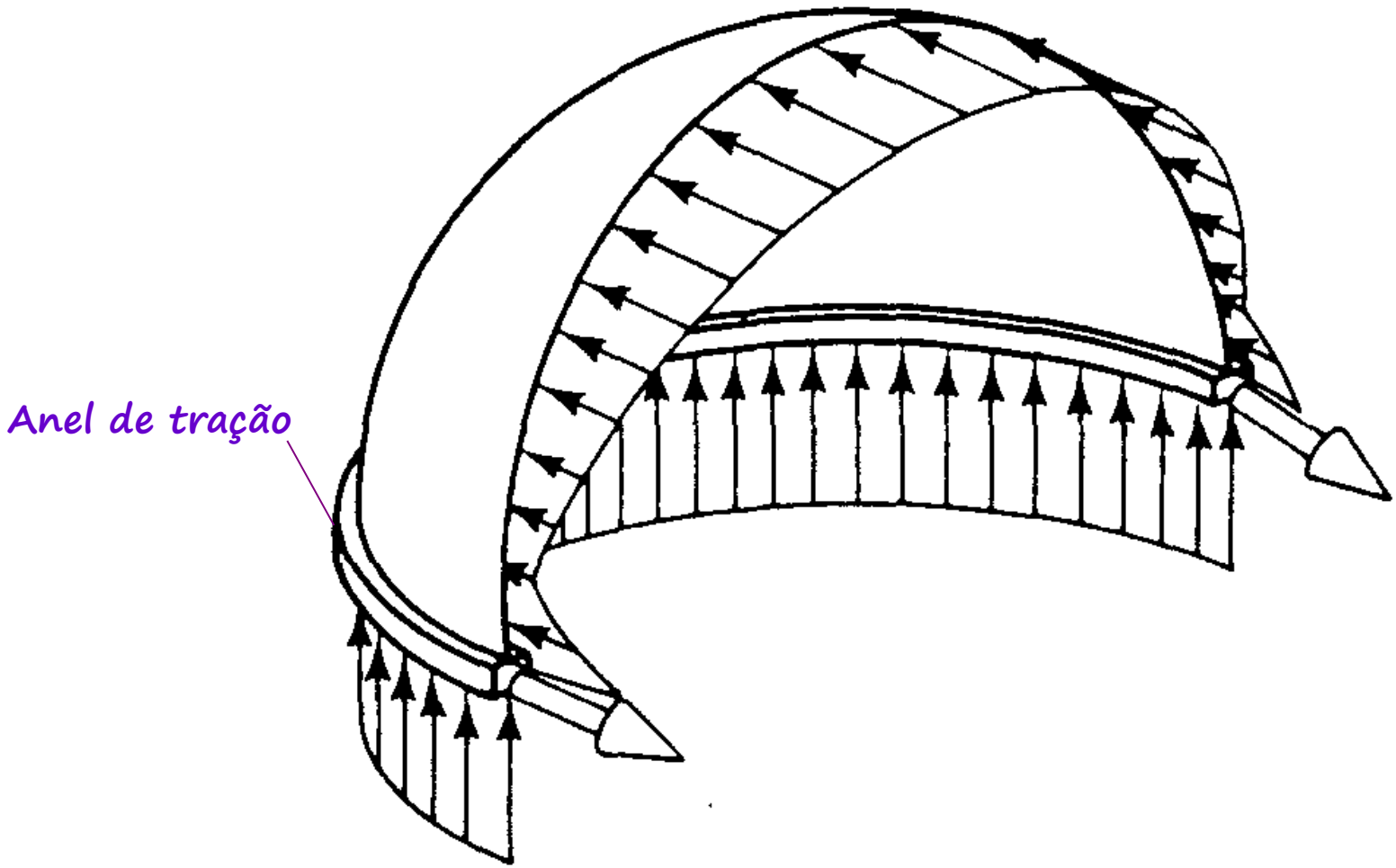


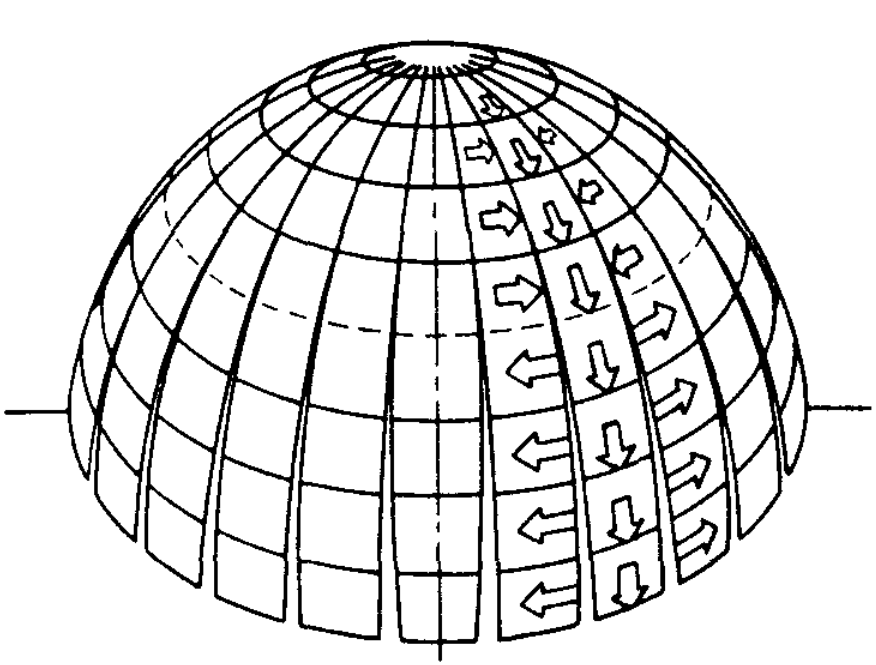

T = 549,455 lbs

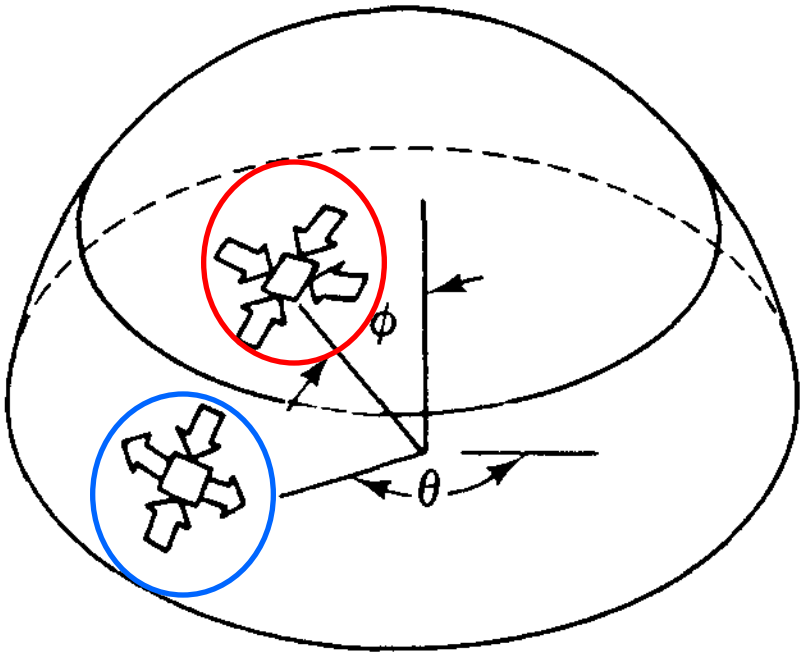


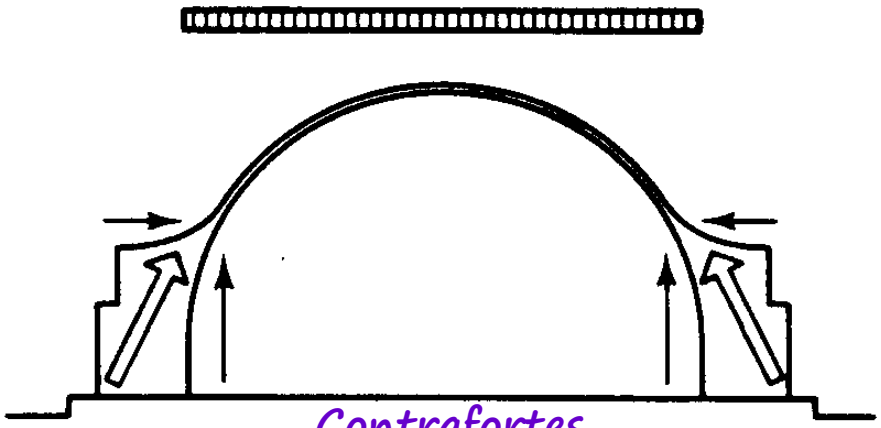




virtusroma
virtusroma.it

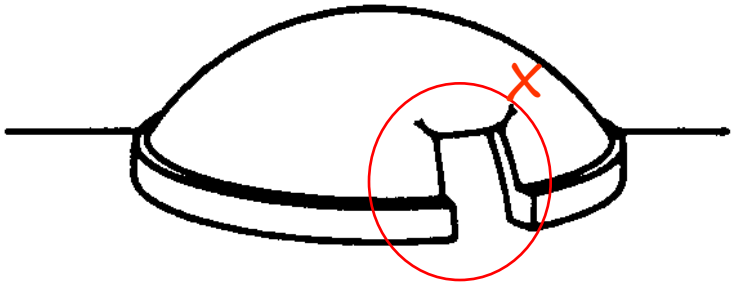

Anel de tração

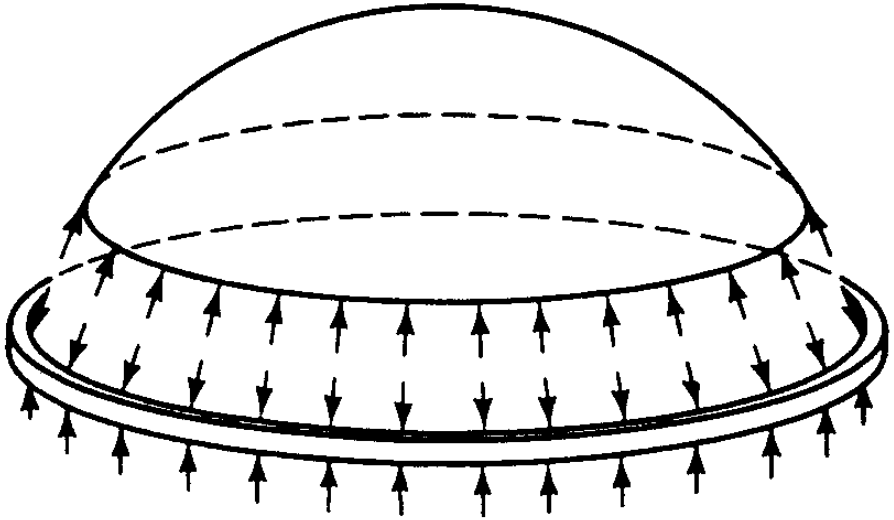



ϕ
θ

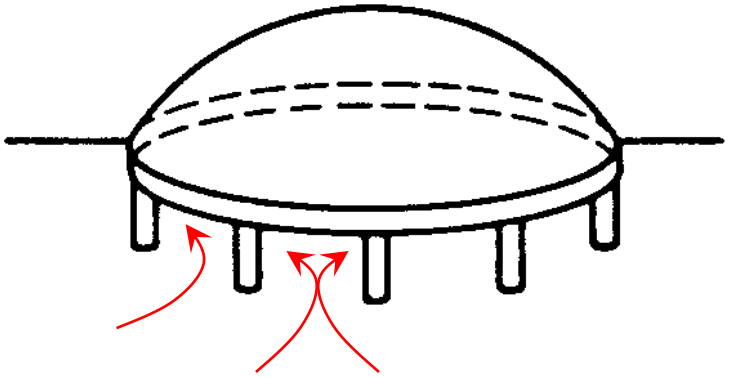


Contrafortes

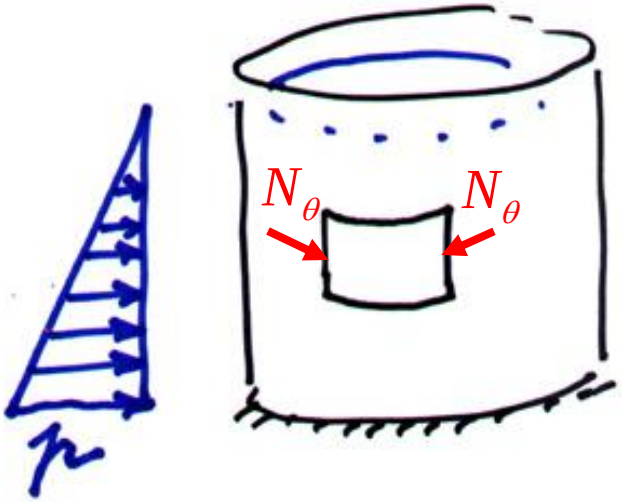




Anel de tração

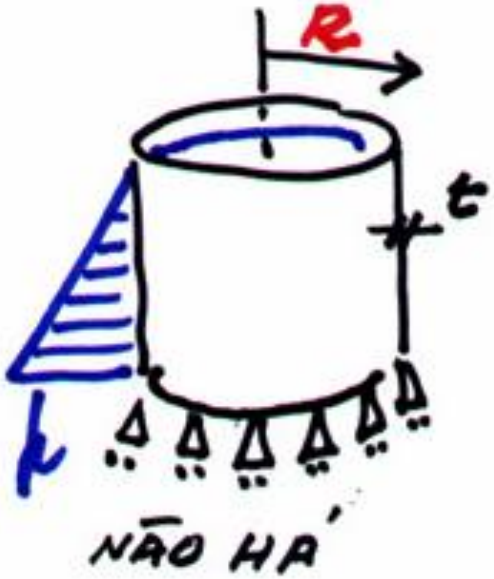


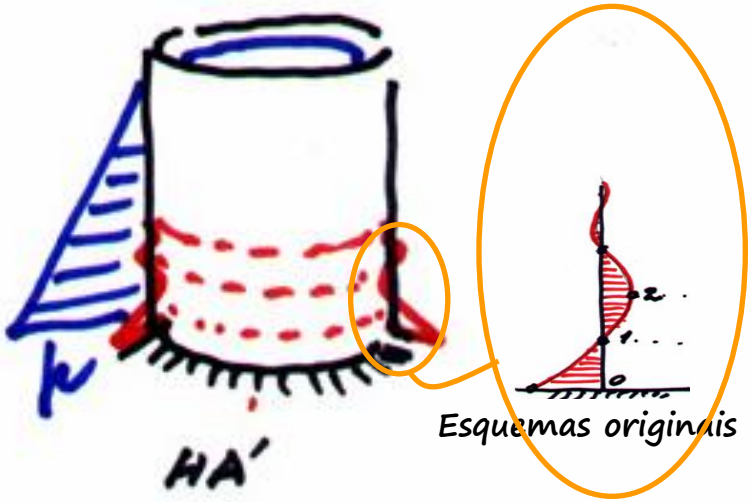
# Reservatórios



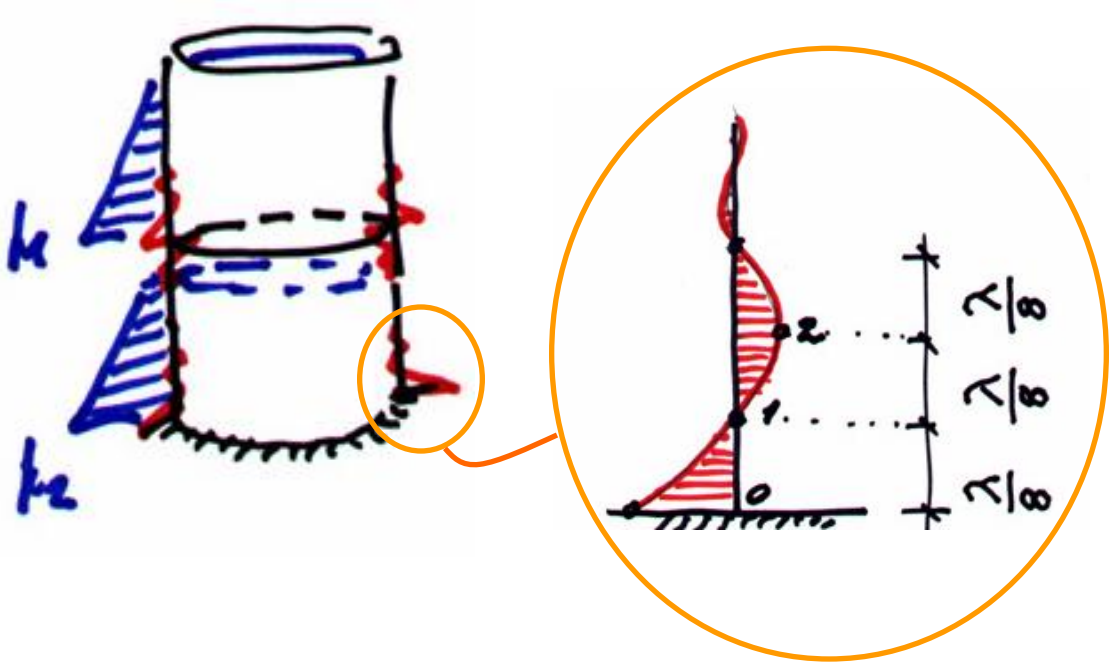

$$\frac{N_\theta}{R} = p_r$$

## 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:

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

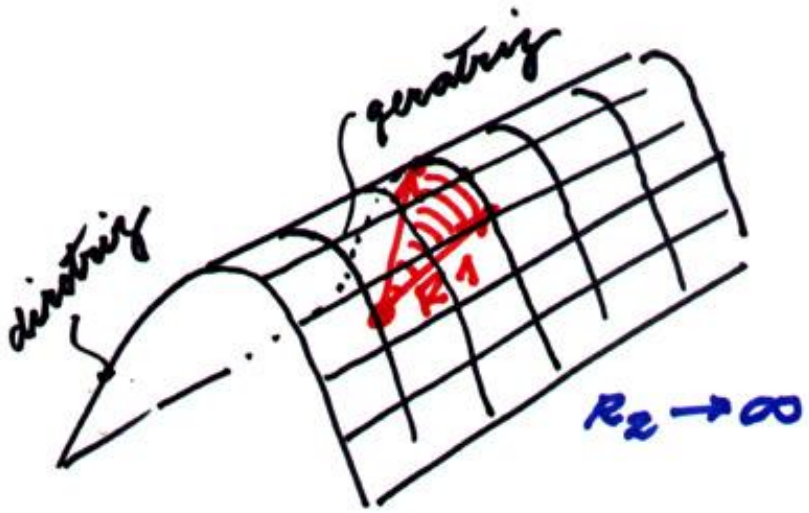
$$N_\theta = 600kN/m; \quad \lambda = 4.32m$$

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

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

Esquemas originais – Prof. Mário Franco

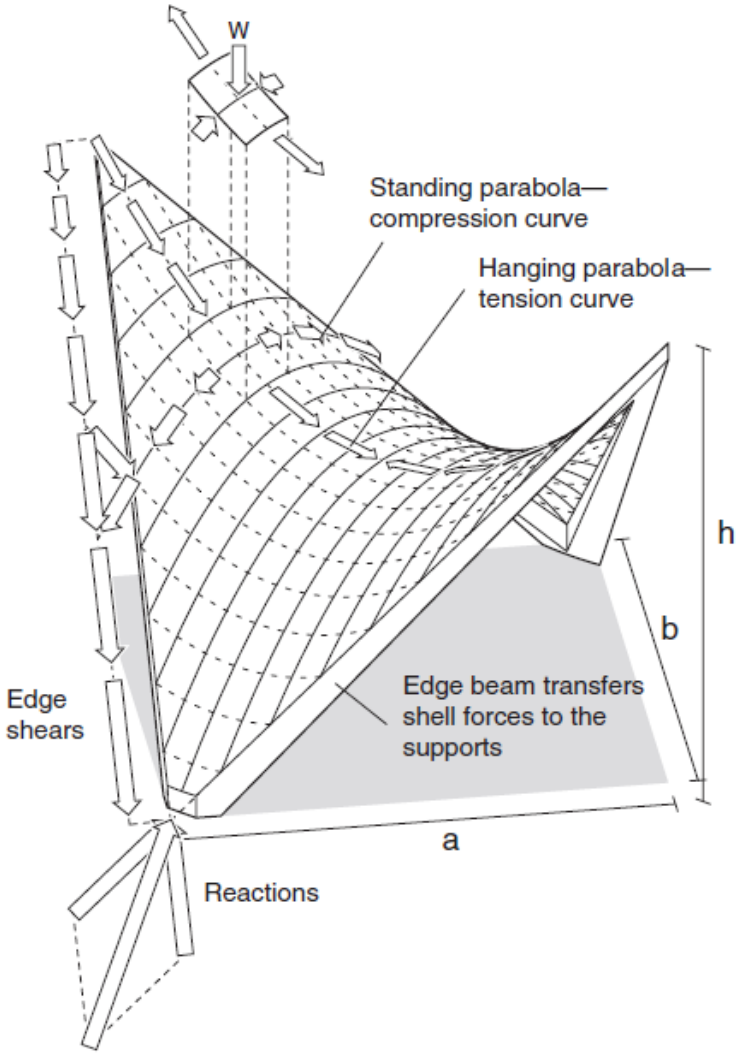
# CASCA CILÍNDRICA

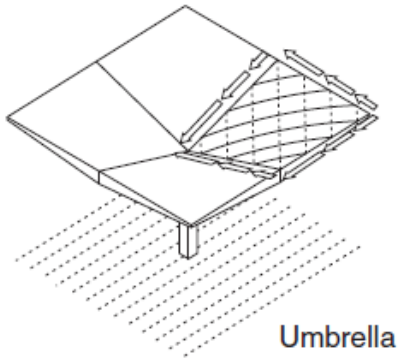




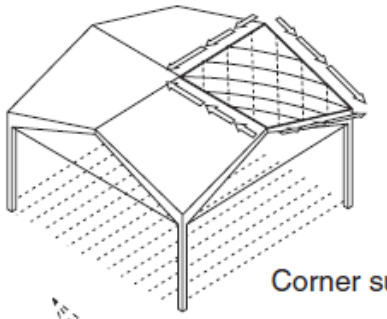
Esquemas originais – Prof. Mário Franco

# Parabolóide hiperbólico

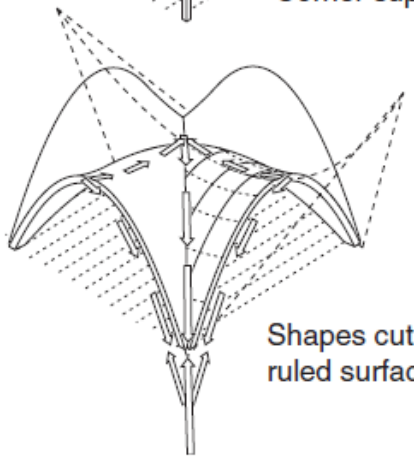


Umbrella shell



Corner supported



Shapes cut from
ruled surface

# Trullos



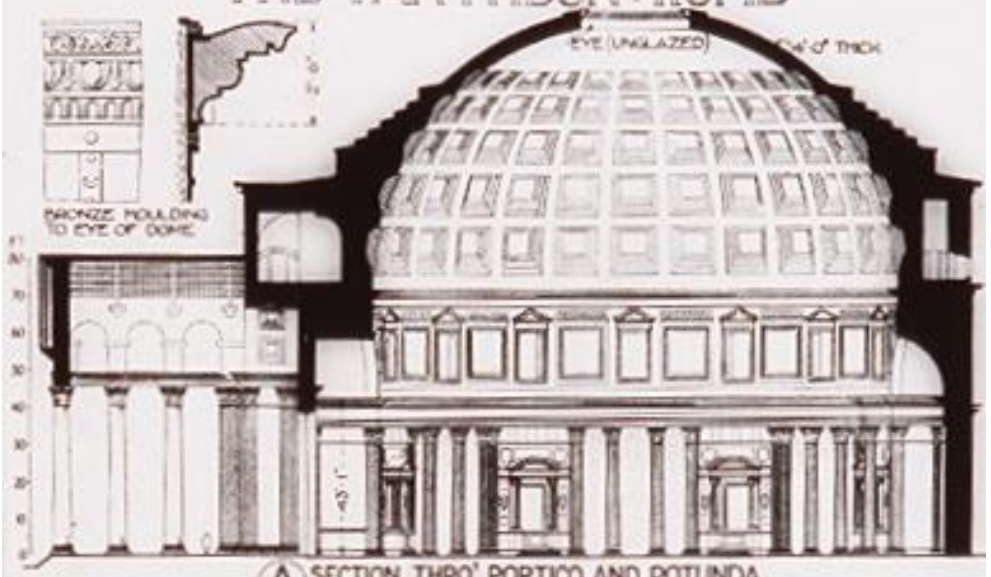






ROMAN ARCHITECTURE

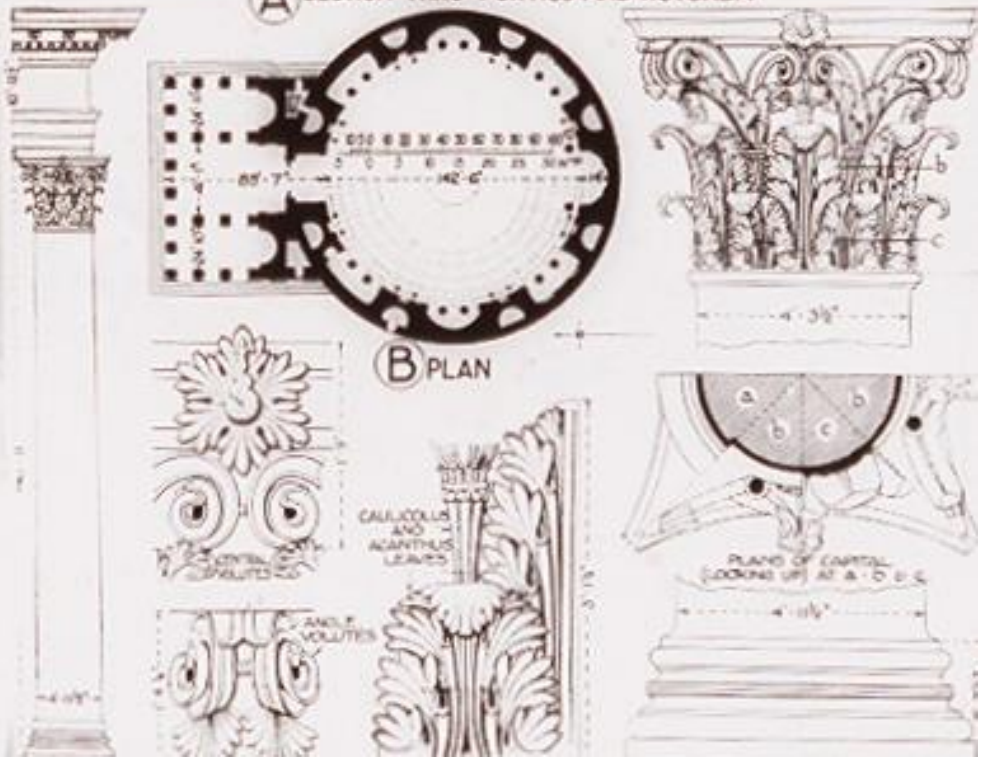
# THE PANTHEON : ROME




A SECTION THRO' PORTICO AND ROTUNDA

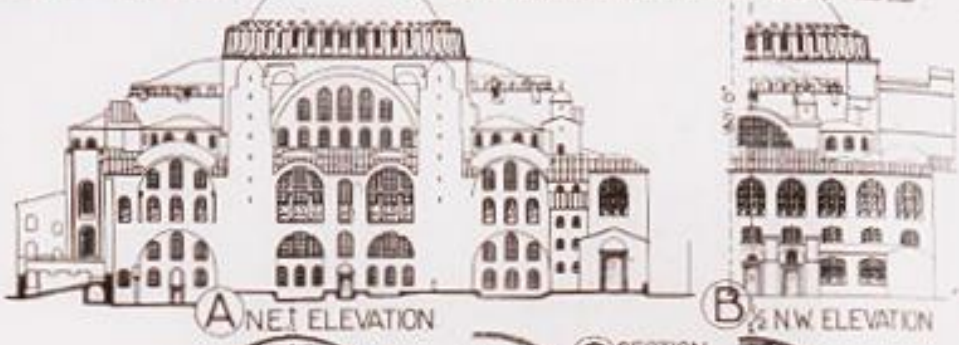


B PLAN



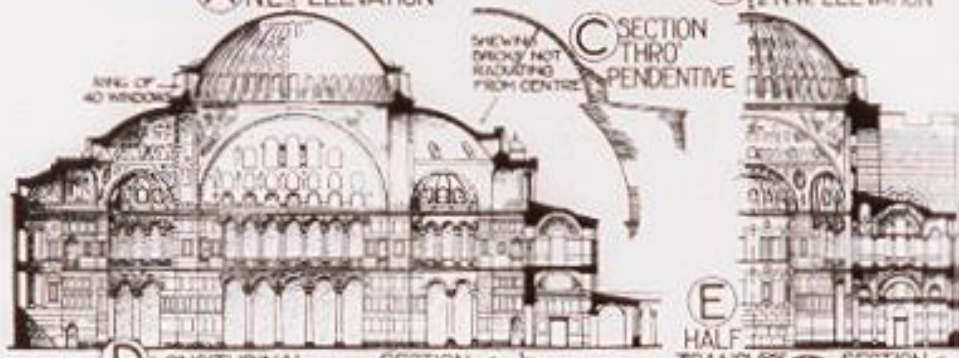

M·AGRIPPA·L·F·COS·TERTIVM·FECIT
Totocalcio

# S. SOPHIA CONSTANTINOPLE



A N.E. ELEVATION

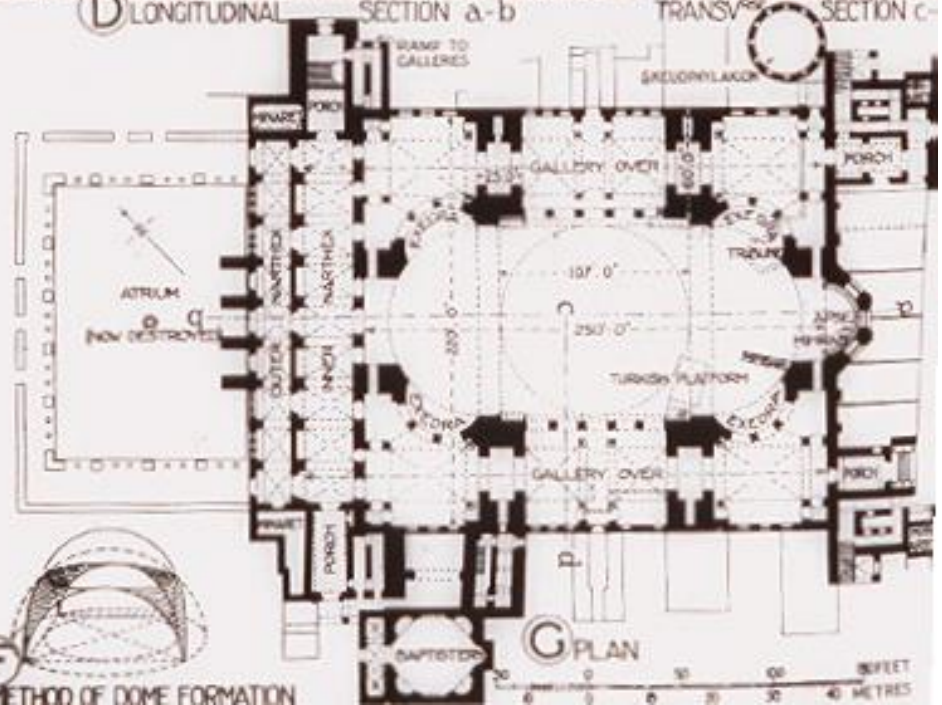
B ½ N.W. ELEVATION




C SECTION THRO' PENDENTIVE

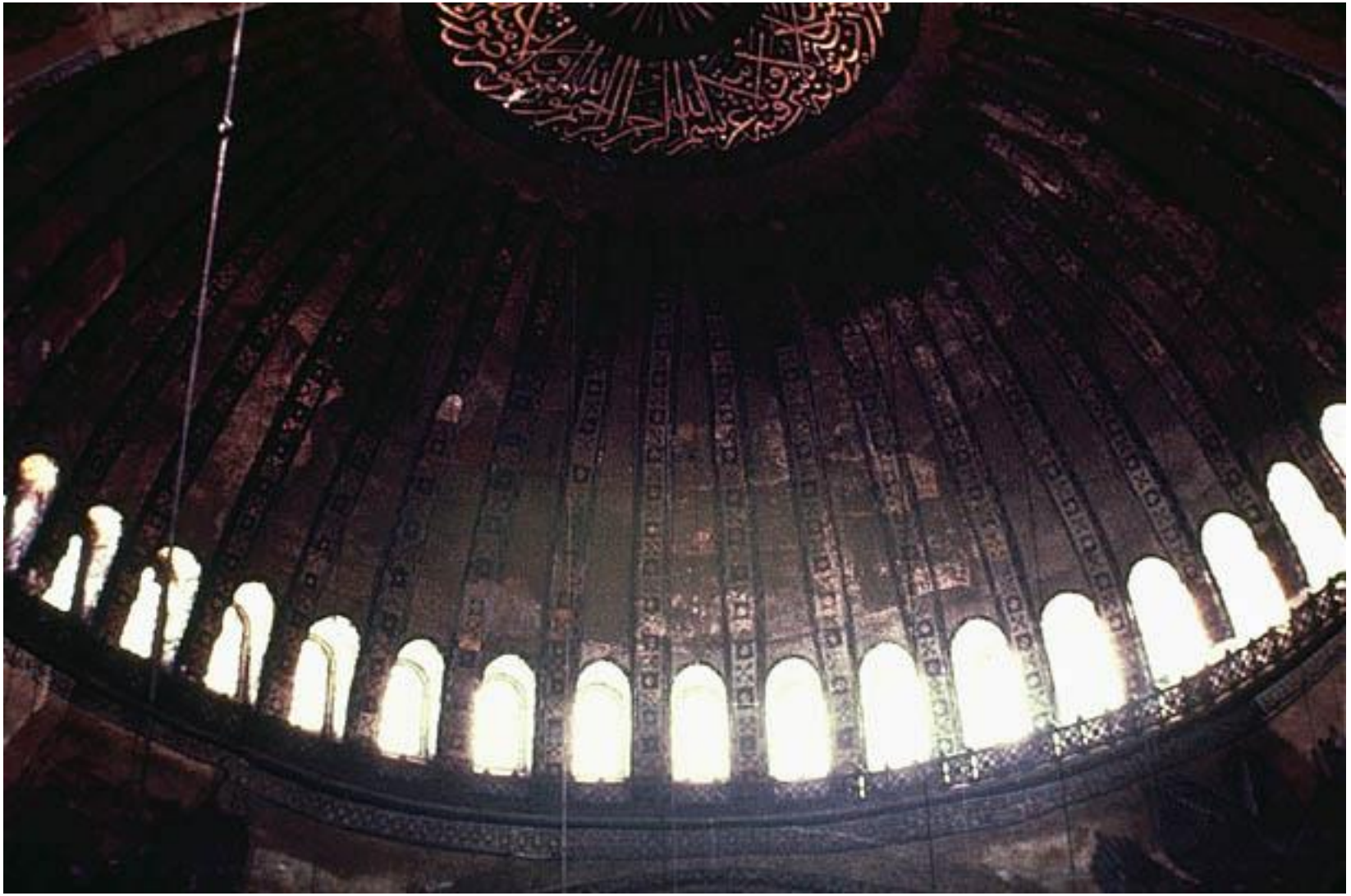
D LONGITUDINAL SECTION a-b

E HALF TRANSV[illegible] SECTION c-




F METHOD OF DOME FORMATION

G PLAN



# EVOLUTION OF GOTHIC VAULTING

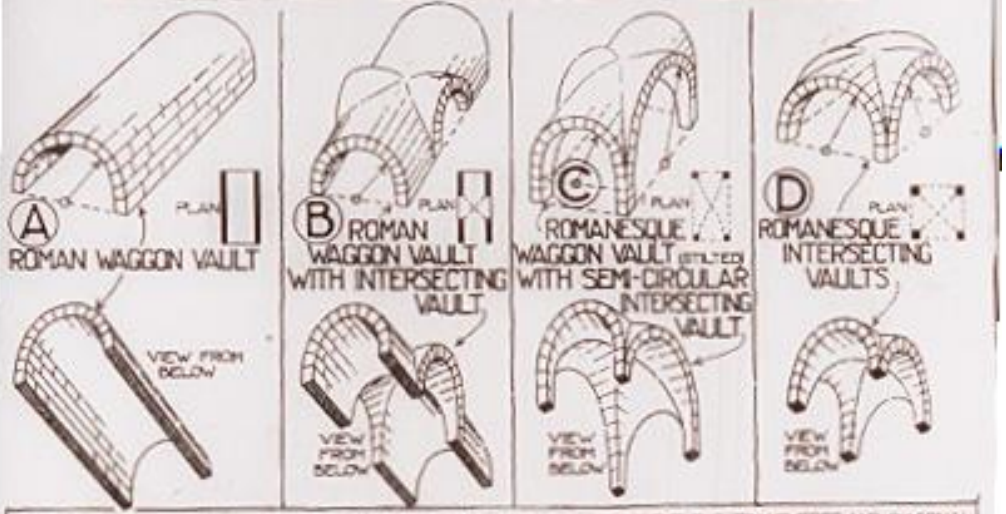
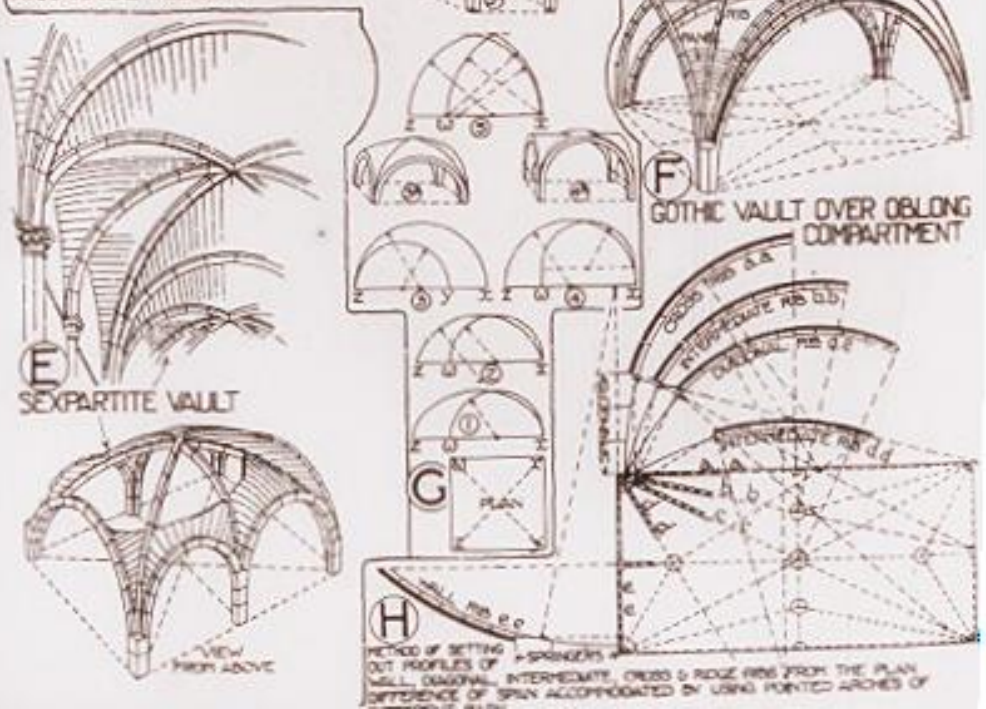


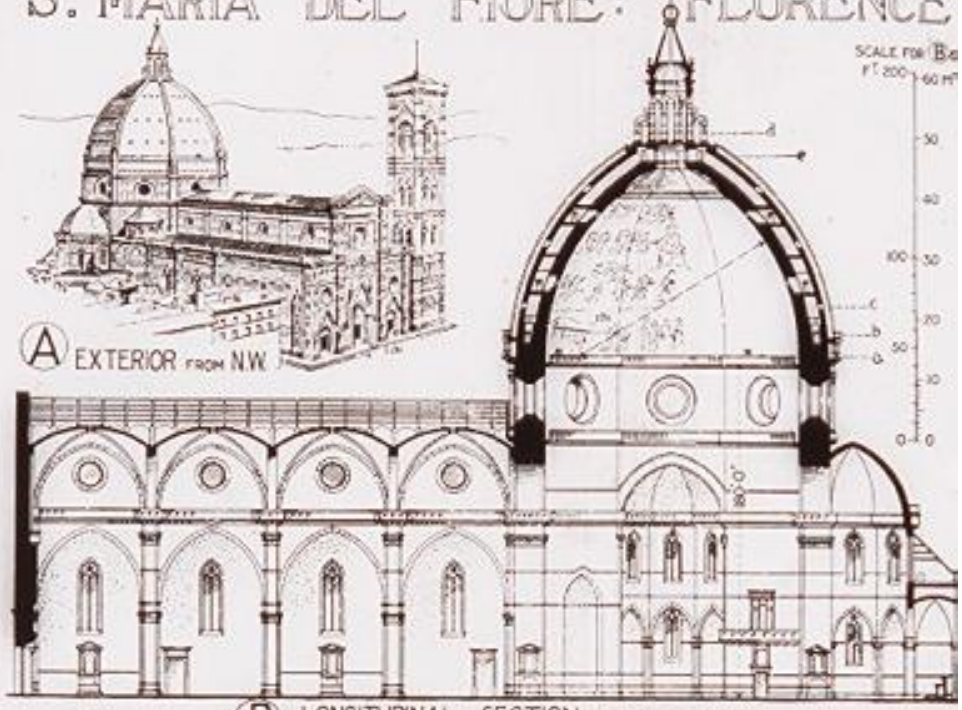

FIG 'G' IS THE PLAN OF A SQUARE VAULTING COMPARTMENT & FIGS 1-5 REPRESENT THE TRANSVERSE AND DIAGONAL RIBS, & ILLUSTRATE THE DIFFICULTIES OF REGULATING THE HEIGHT OF RIBS OF DIFFERENT SPAN OVER A SQUARE COMPARTMENT, AS THE PROBLEM IS TO KEEP THE CROWNS OF THE INTERSECTING VAULTS LEVEL.
① ROMAN CROSS VAULT WITH ELLIPTICAL DIAGONAL GROIN. ② ROMANESQUE RIBBED VAULT WITH SEGMENTAL DIAGONAL RIBS. ③ ROMANESQUE RIBBED VAULT WITH SEMI-CIRCULAR DIAGONAL RIB & TRANSVERSE RIBS RESULTING IN A DOMICAL VAULT 3A. ④ ROMANESQUE VAULT WITH SEMI-CIRCULAR DIAGONAL & TRANSVERSE RIBS, THE LATTER STILTED TO AVOID DOMICAL VAULT AS 4A. ⑤ GOTHIC RIBBED VAULT WITH POINTED ARCHES WHICH CAN BE MADE ANY HEIGHT FOR ANY SPAN THUS OVERCOMING ALL DIFFICULTIES AS 5A.



# S. MARIA DEL FIORE: †FLORENCE



A EXTERIOR FROM N.W.



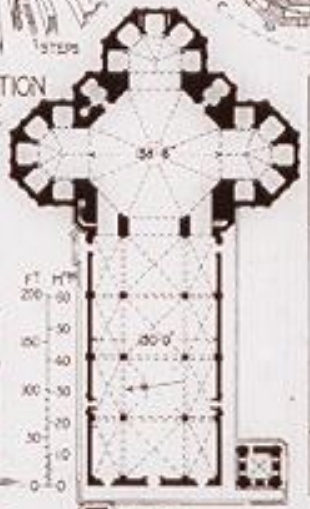
B LONGITUDINAL SECTION

LANTERN

C CONSTRUCTION OF DOME

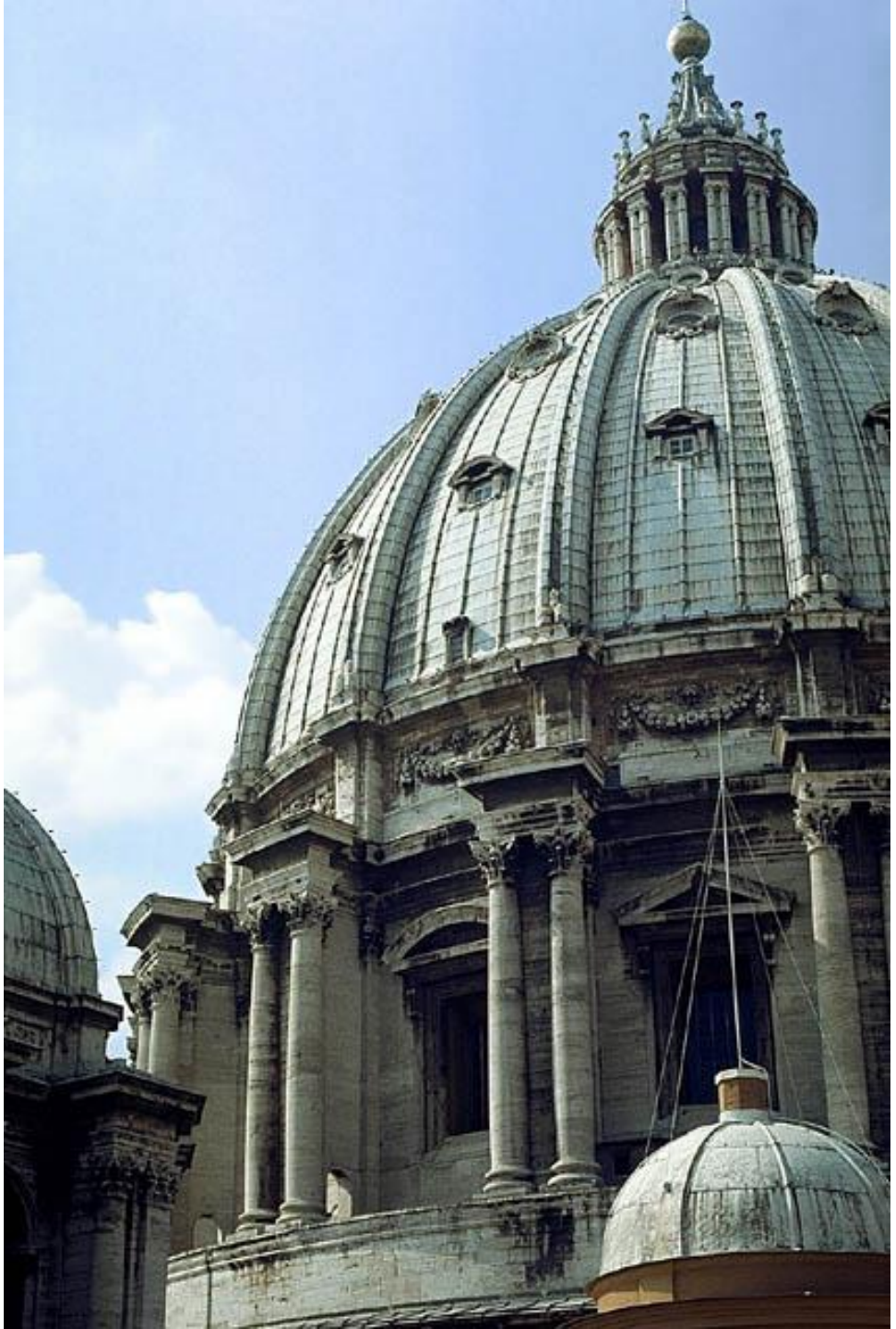
D SECTIONAL PLAN OF DOME

E UNCOMPLETED FACADE



F PLAN

G INTERIOR LOOKING E.




PETRVS ET SVPER HANC

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

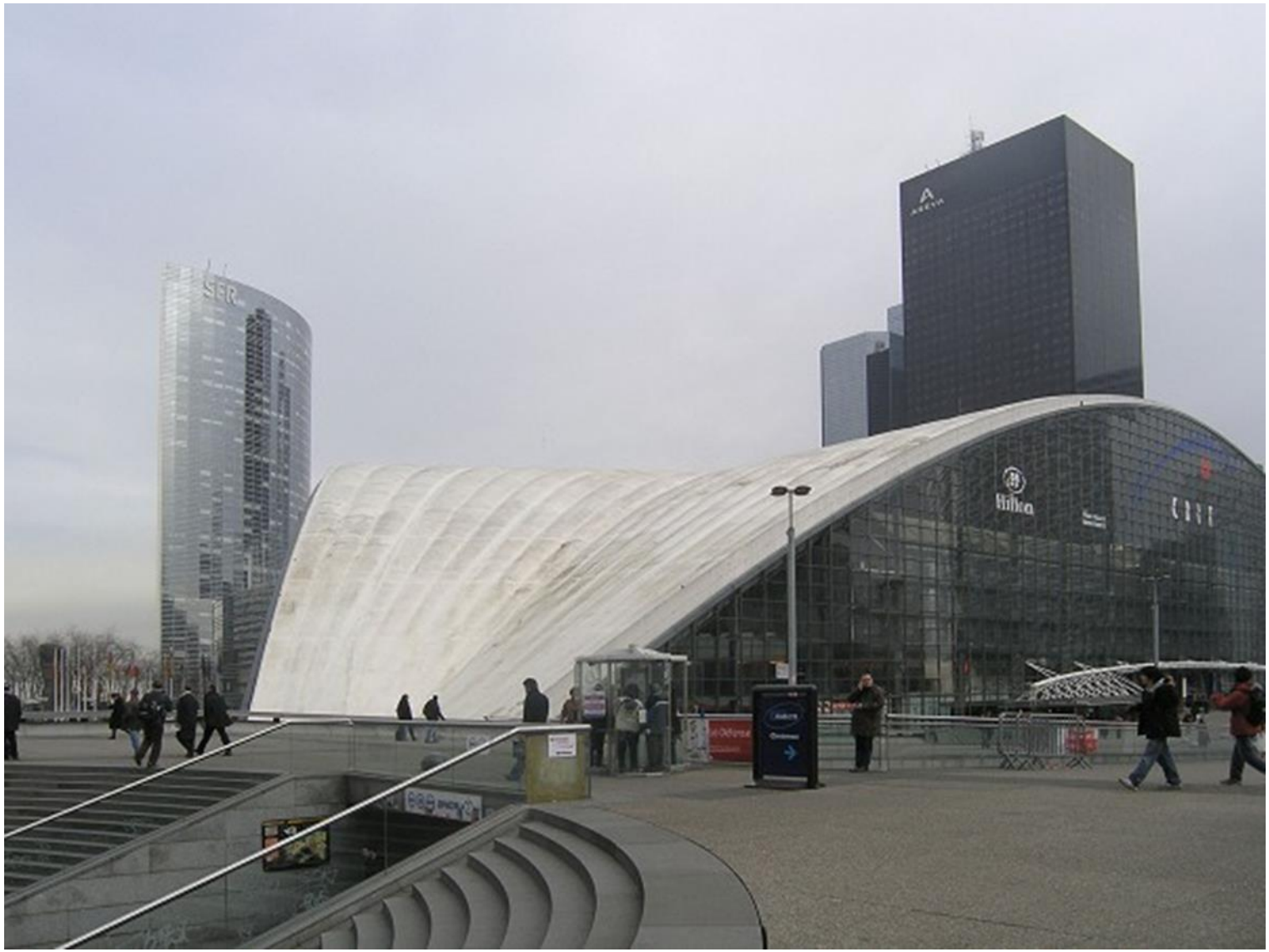
Xochimilco Restaurant Los Manantiales, Mexico, 1957/1958
Felix Candela (Eng), Fernando Alvarez Ordóñez; Joaquin Alvarez Ordóñez (Arqs)

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

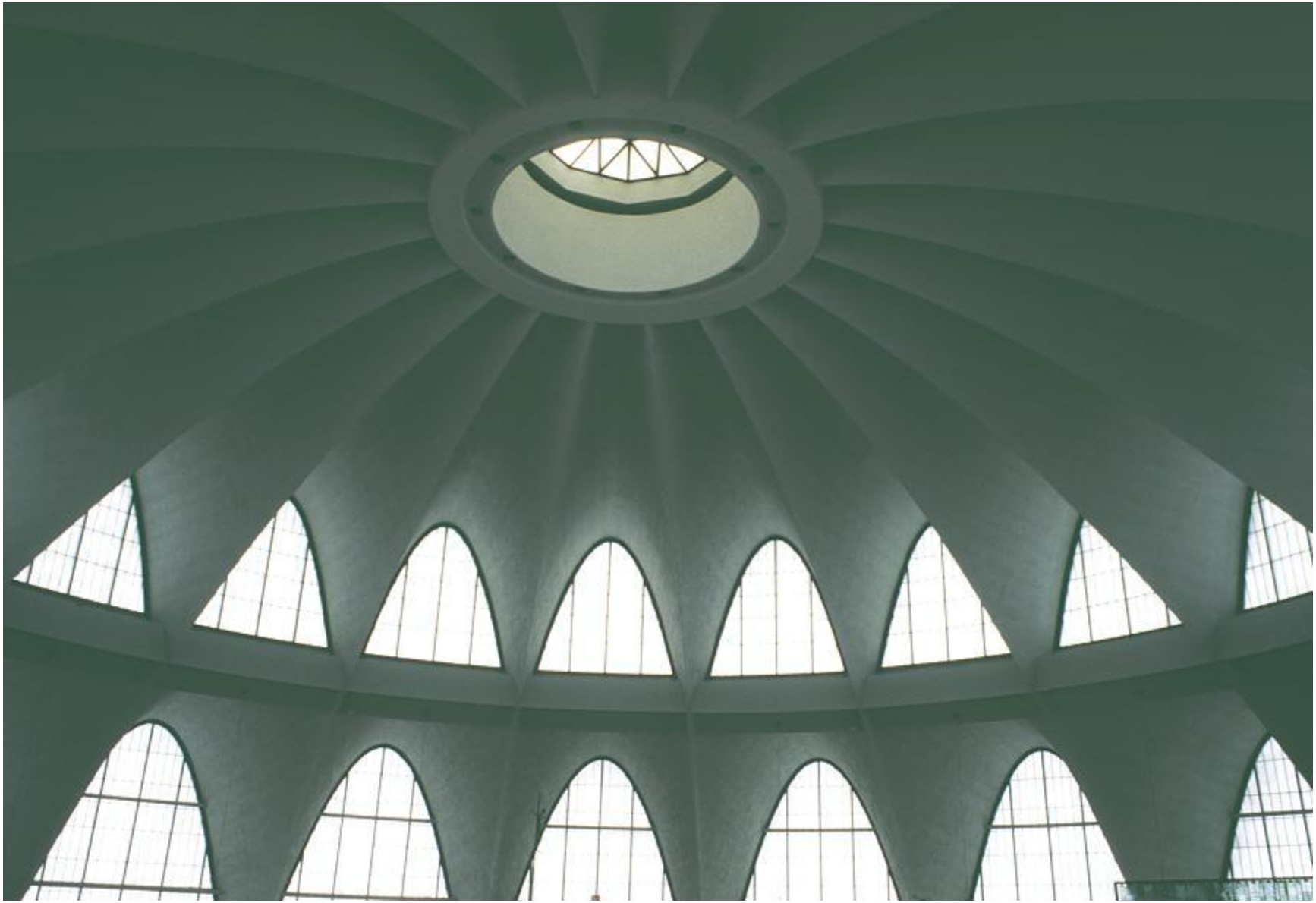
Architect: Eero Saarinen


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

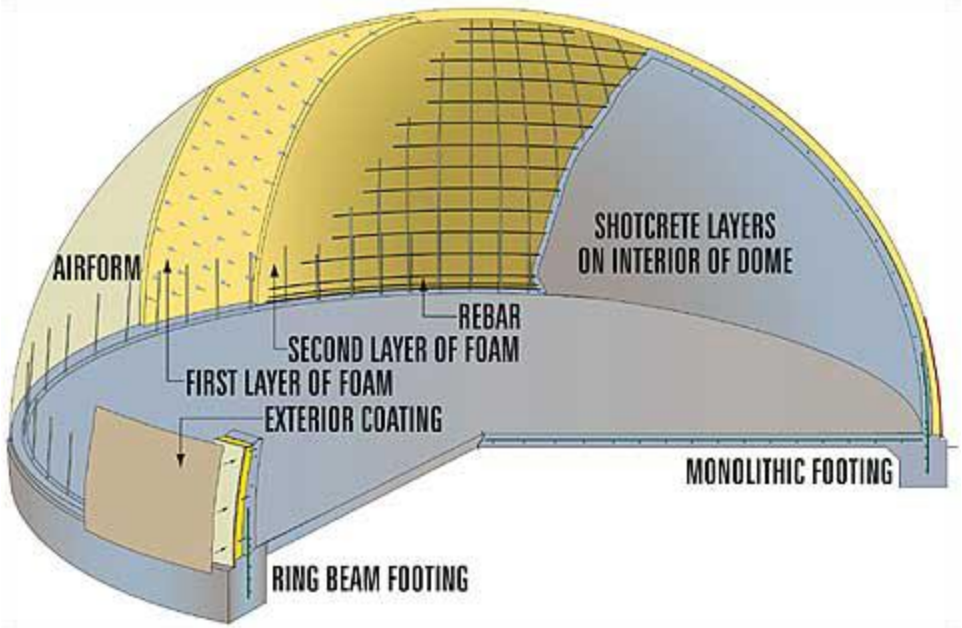

Heinz Isler – Bürgi Garden Center – Suíça, 1973

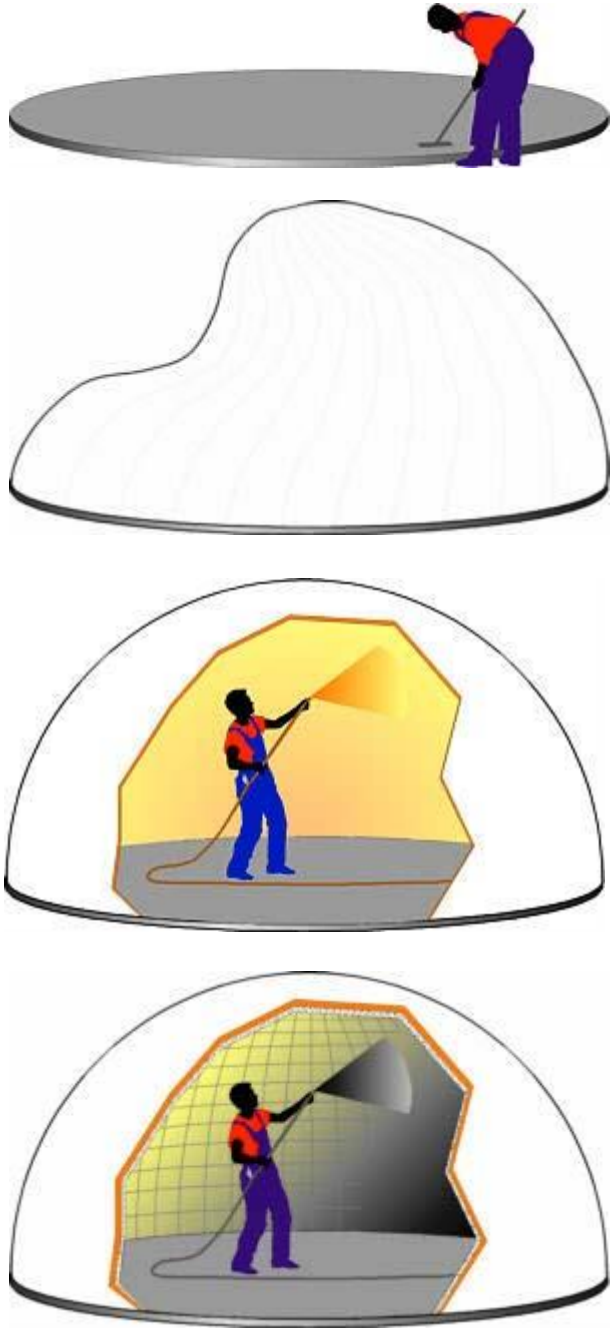
Heinz Isler – Bürgi Garden Center – Suíça, 1973

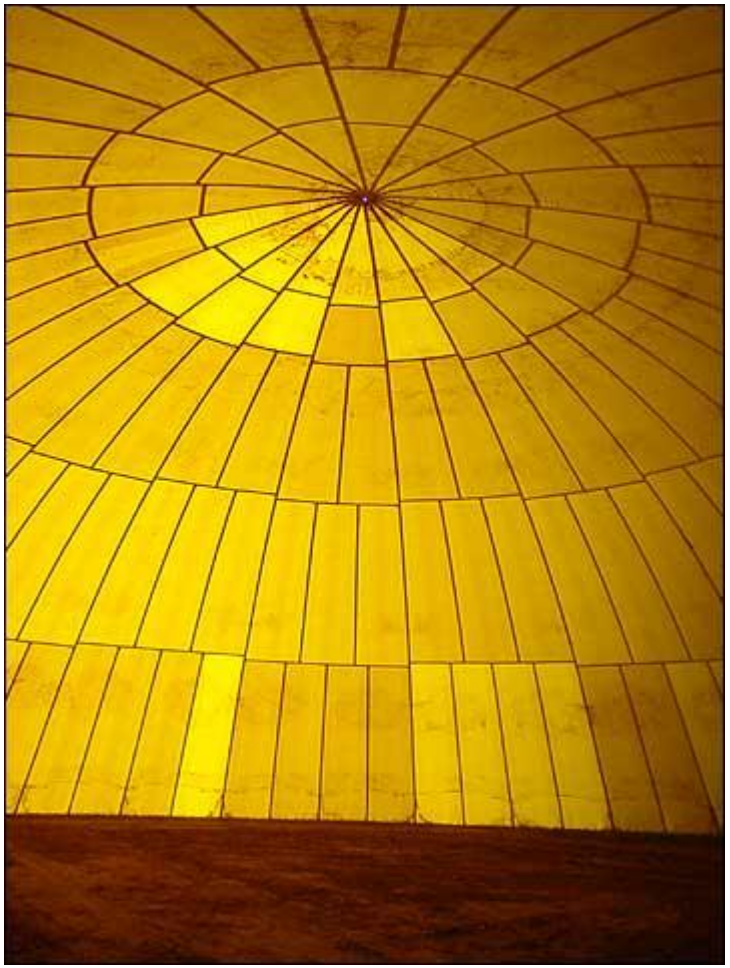
H. Isler, Brühl Sports Center , Suíça, 1982


Sistema Bini

The Kallangur Shopping Center, Queensland, Australia

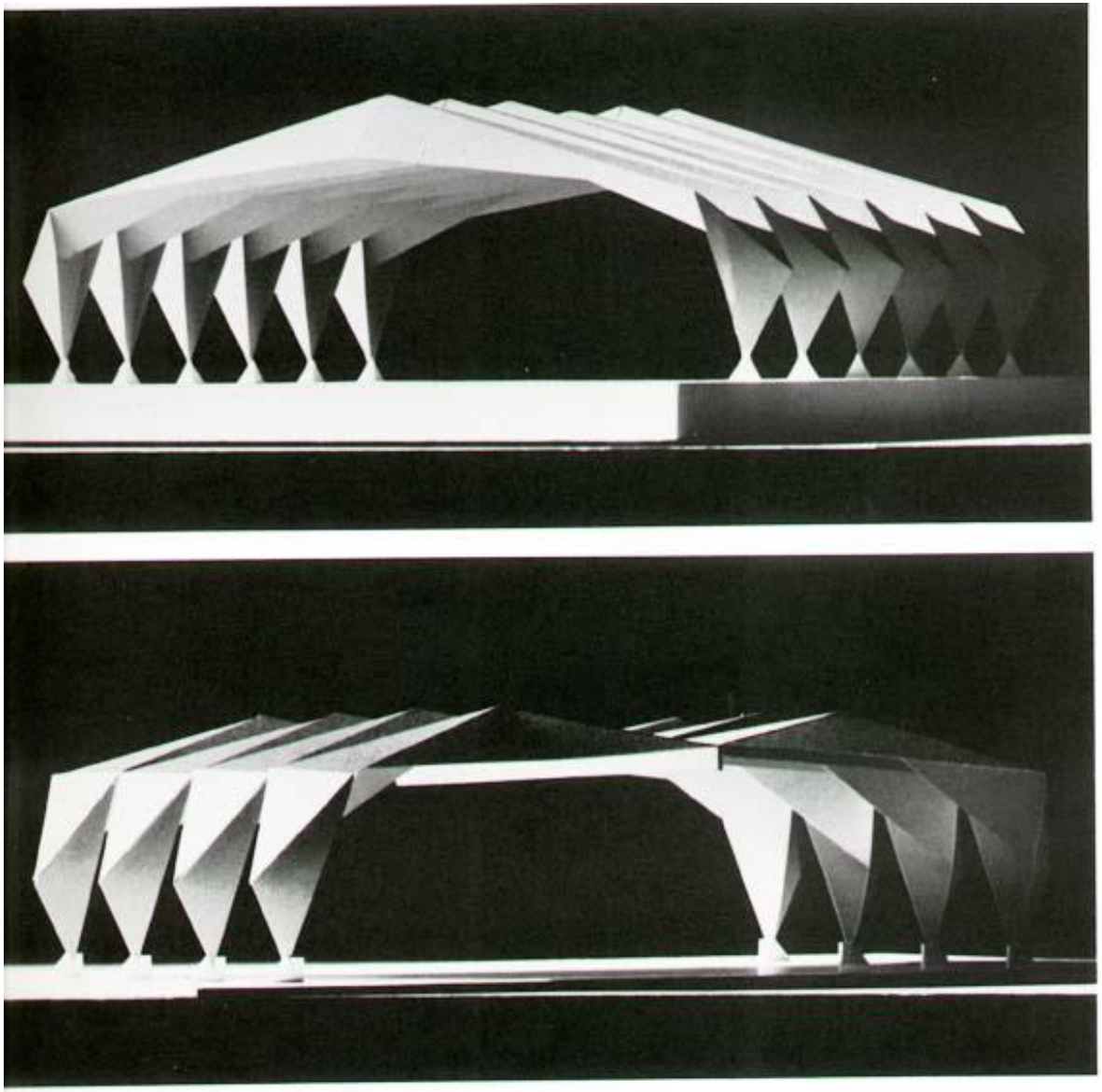

AIRFORM
SHOTCRETE LAYERS
ON INTERIOR OF DOME
REBAR
SECOND LAYER OF FOAM
FIRST LAYER OF FOAM
EXTERIOR COATING
MONOLITHIC FOOTING
RING BEAM FOOTING

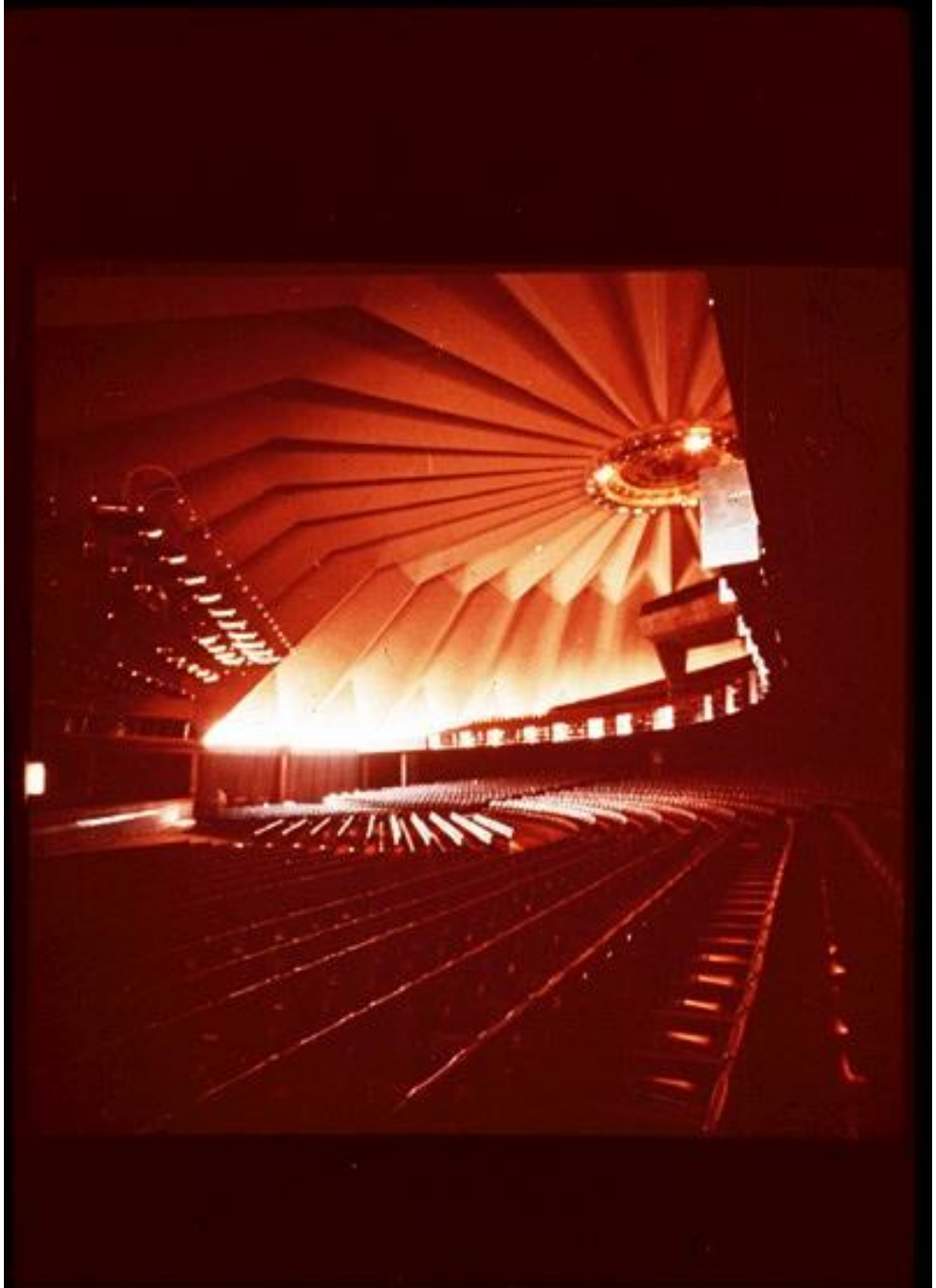


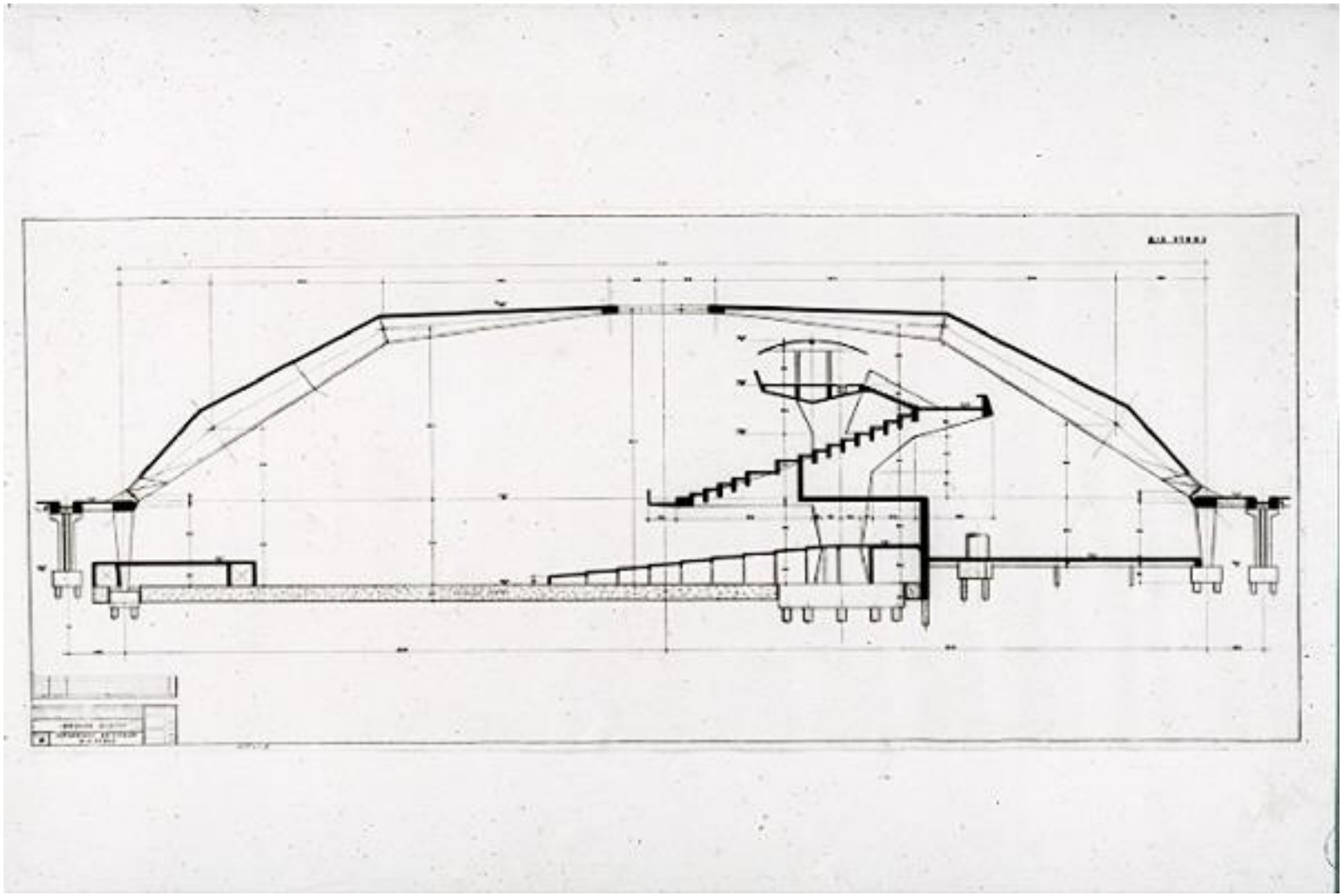


Palácio das Convenções - SP - 1967

Miguel Juliano e Silva, Jorge Wilheim

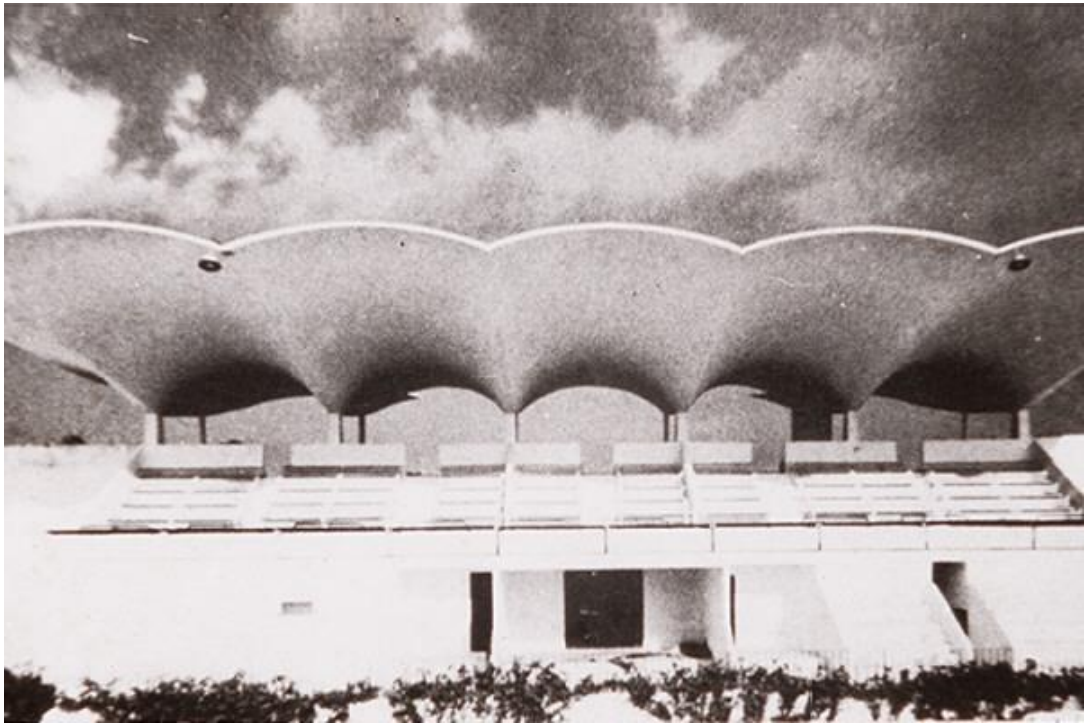


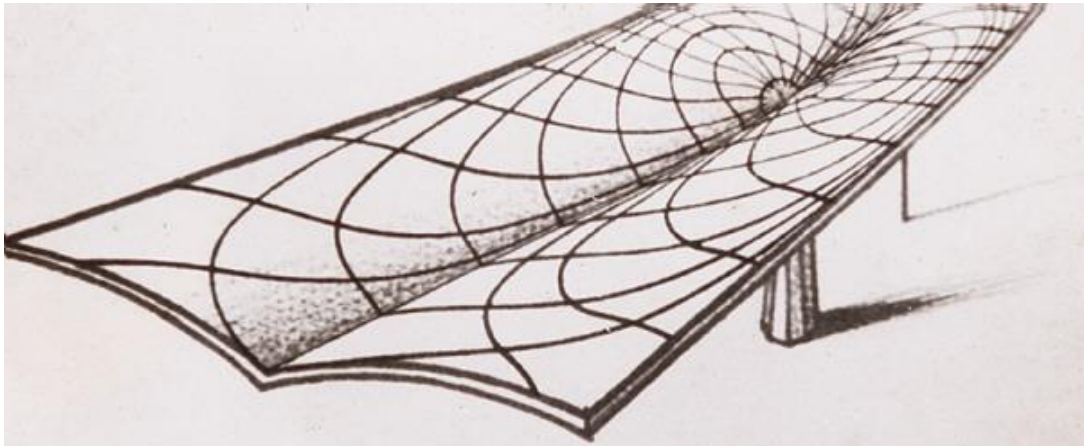




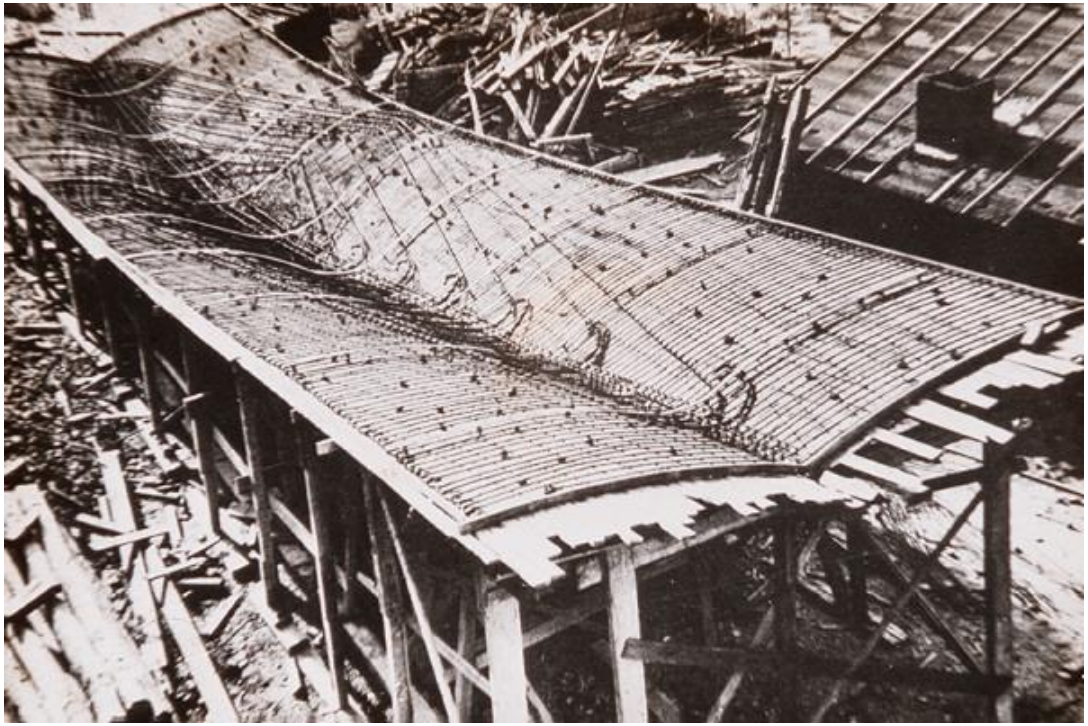
# Posto Catacumba - RJ - 1968

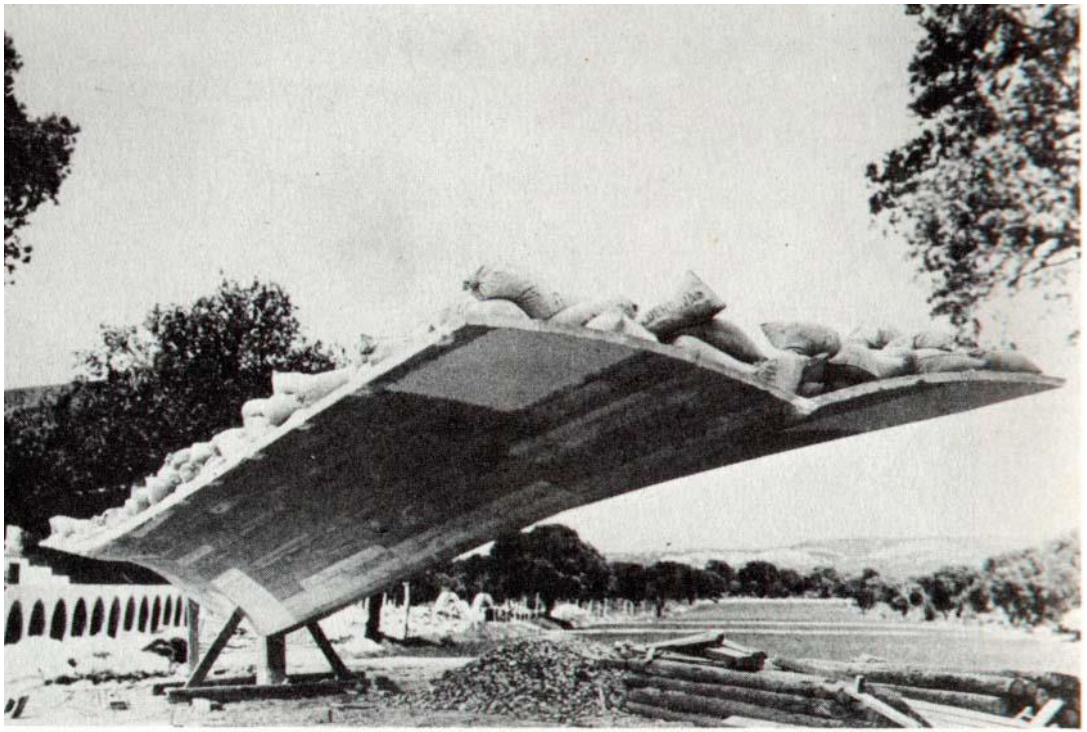
Dilson Gestal Pereira, Waldyr Antunes Figueiredo, Paulo Roberto M. Souza, Alfredo Lemos





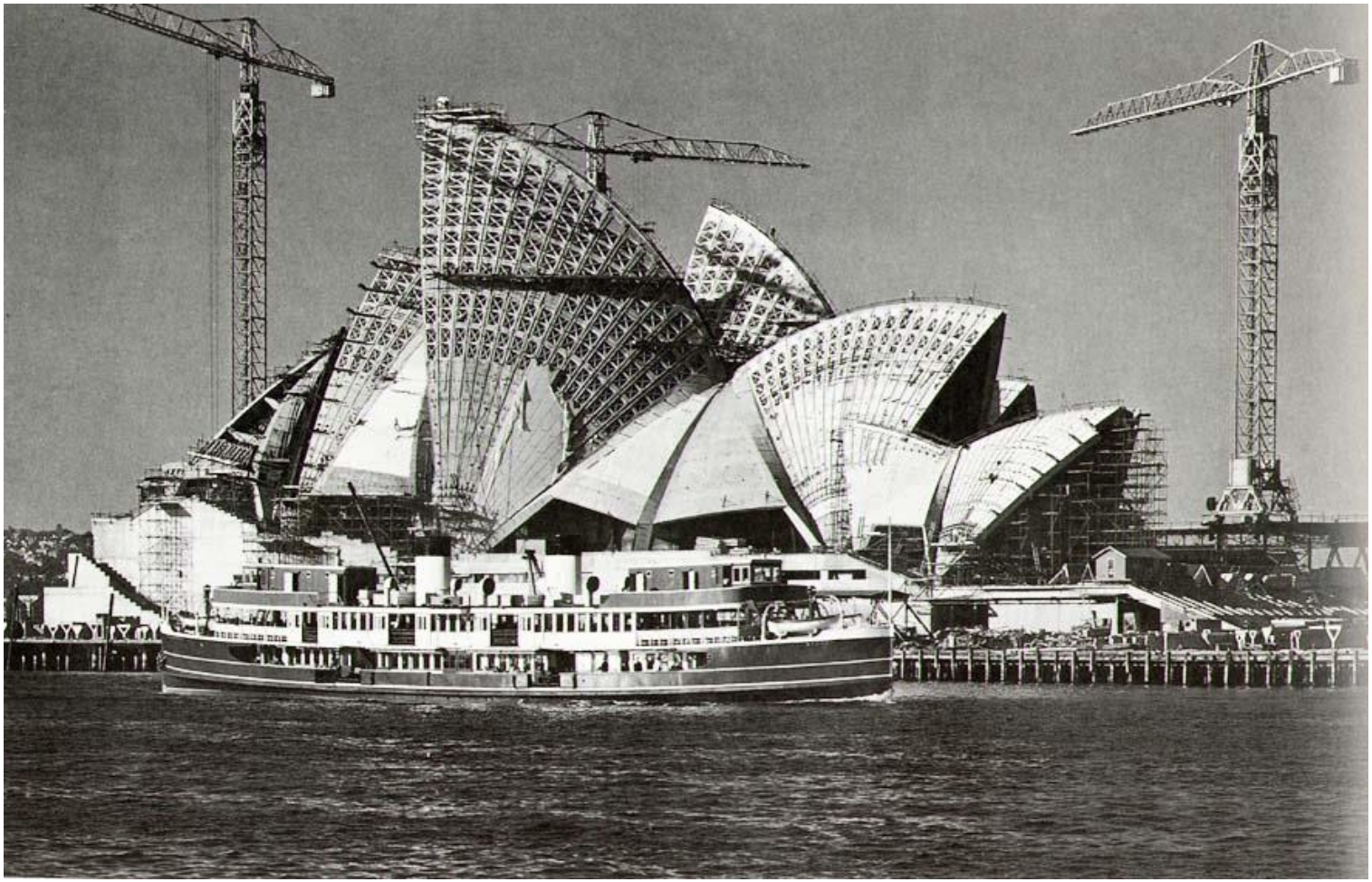
STRIBUTION OF STRESSES

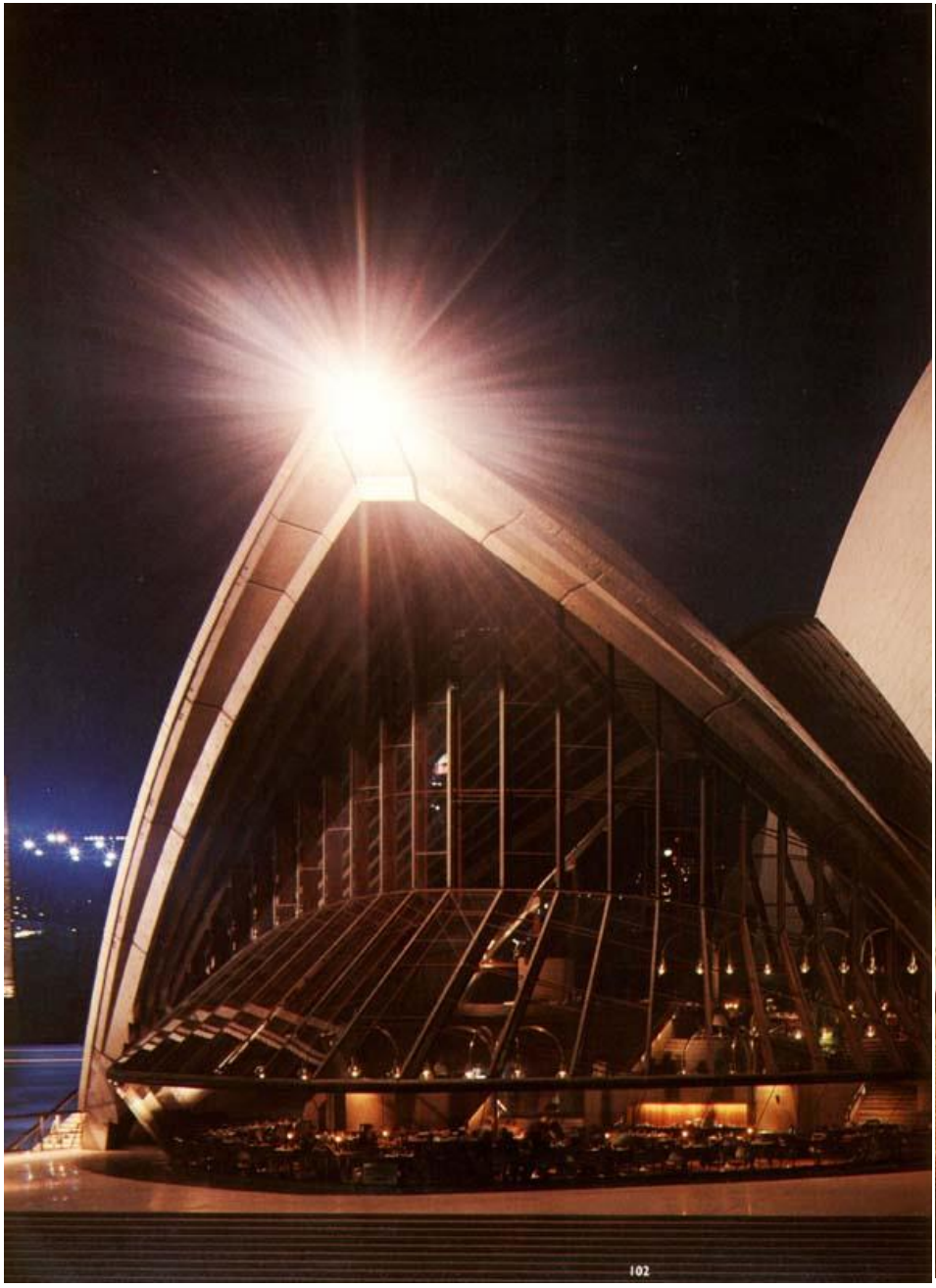




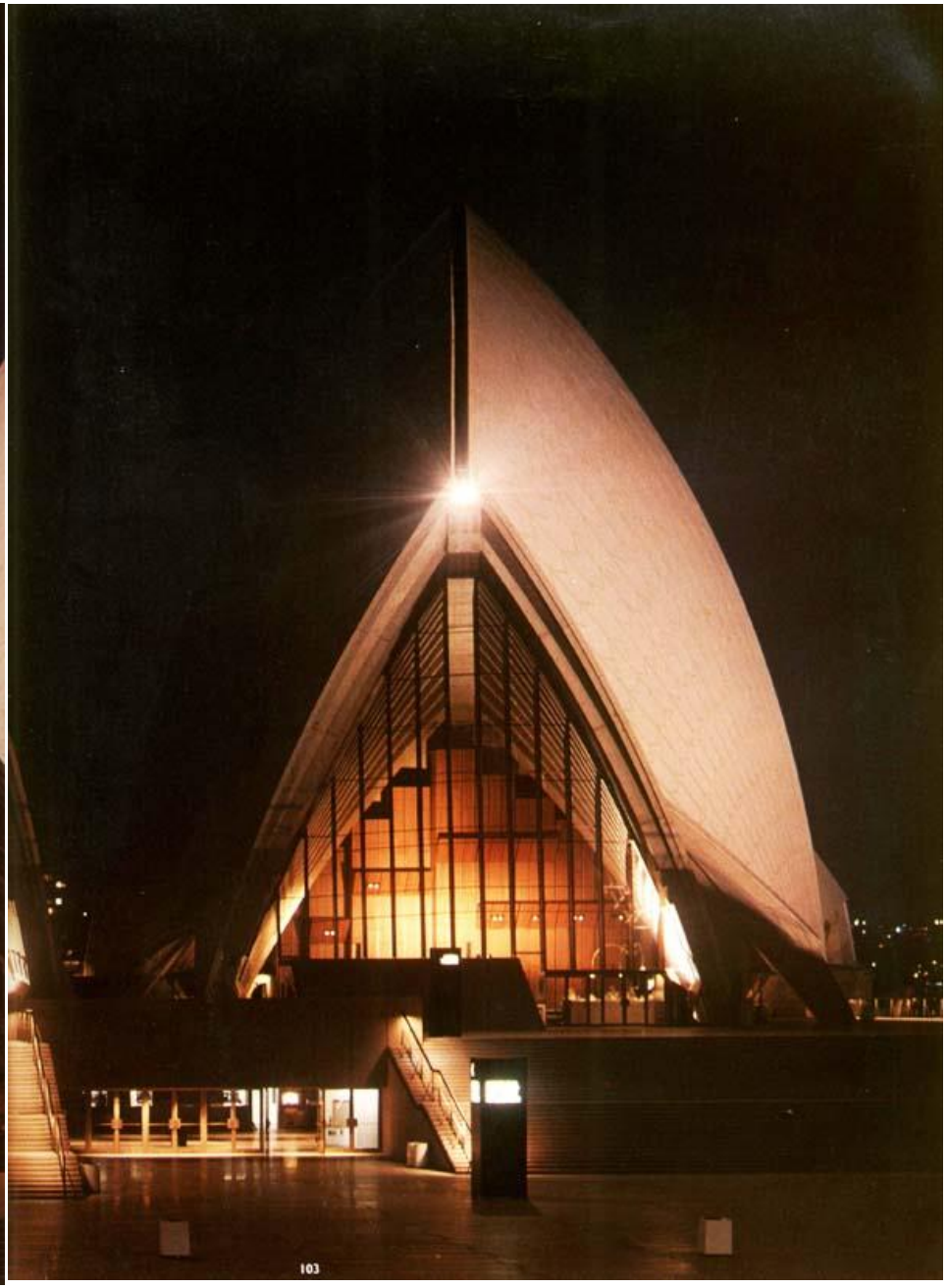
**Sydney Opera House (1958 – 1973)**

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



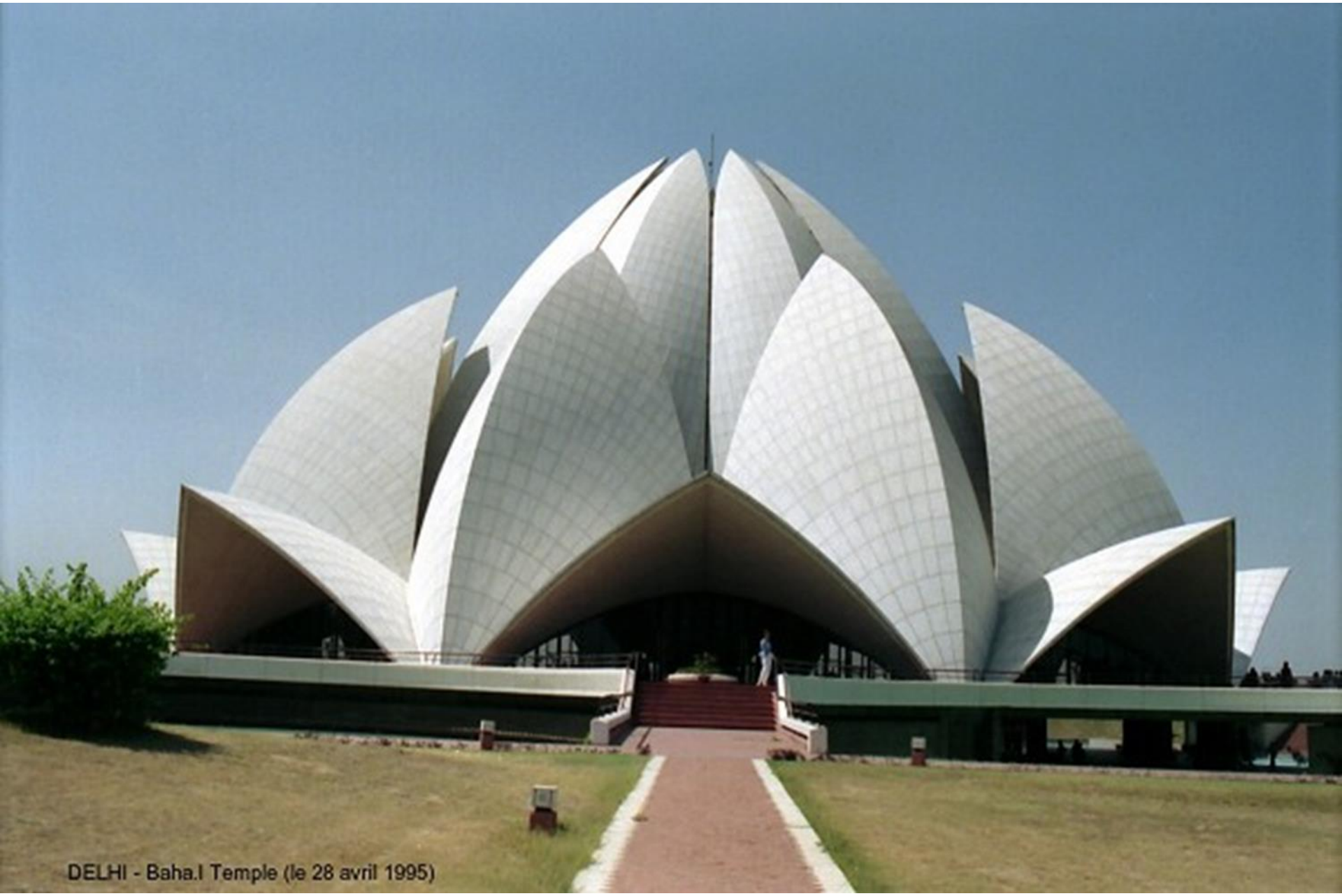


102

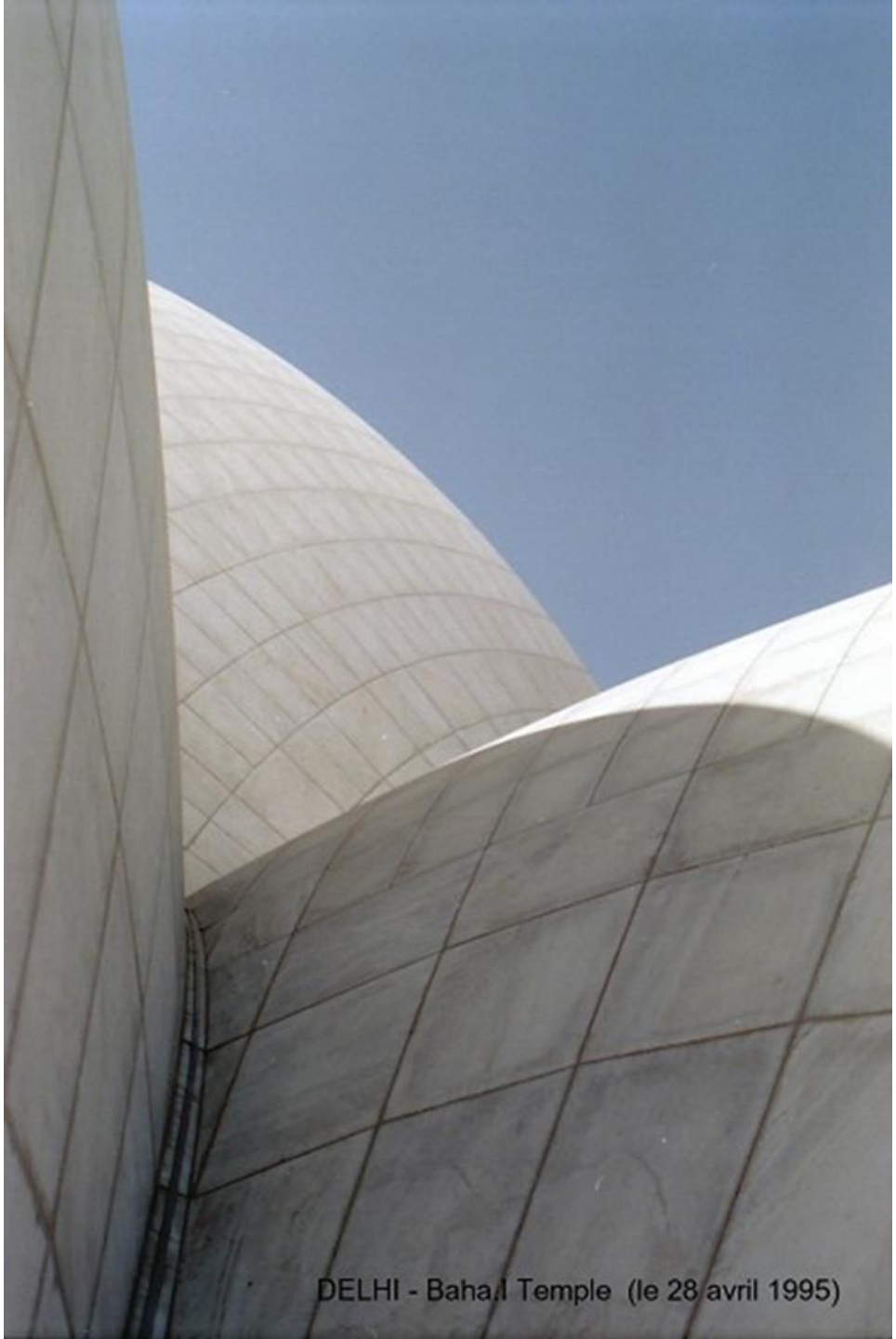


103


Fariborz Sahba (canadian architect)


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

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

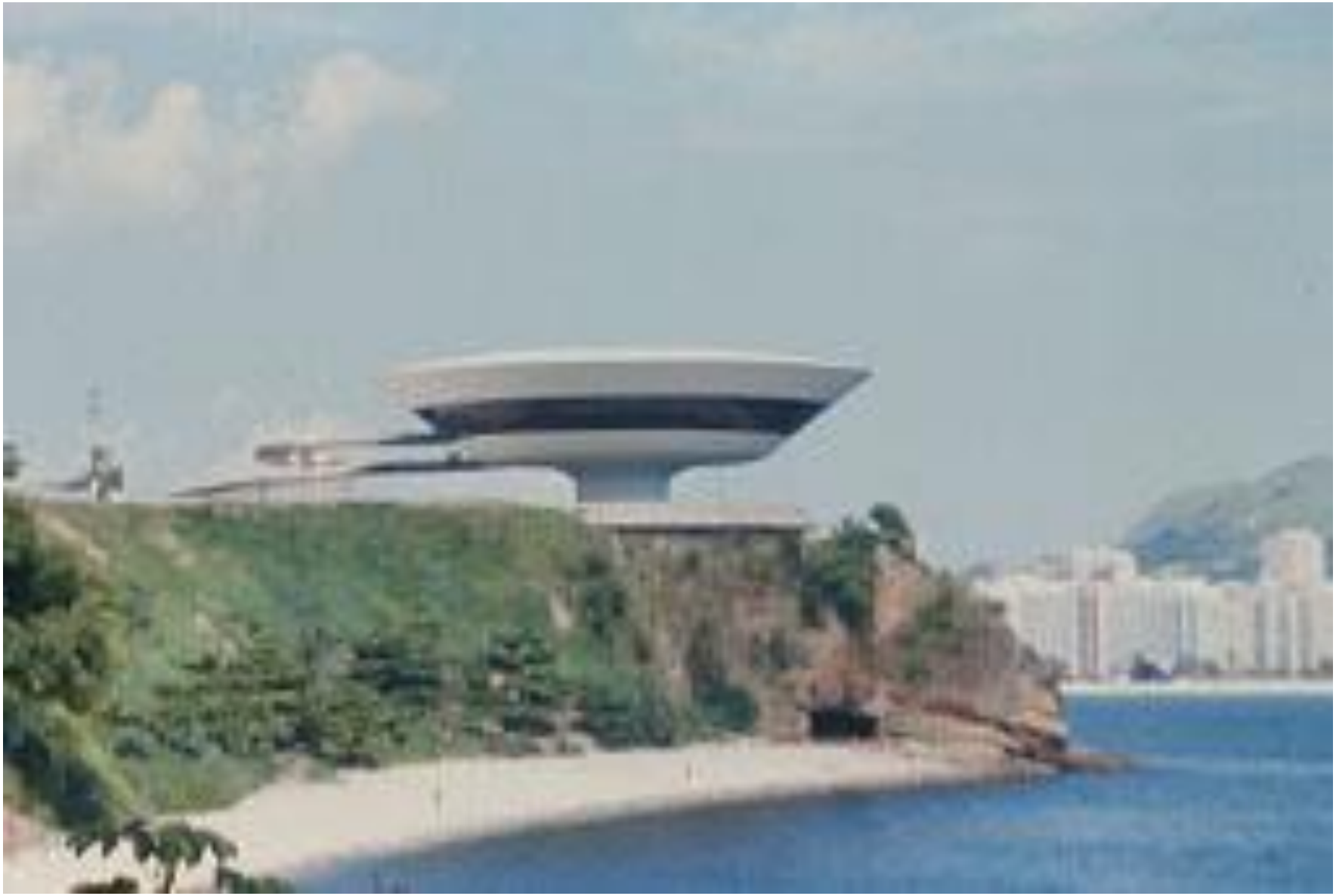

DELHI - Baha'I Temple (le 28 avril 1995)

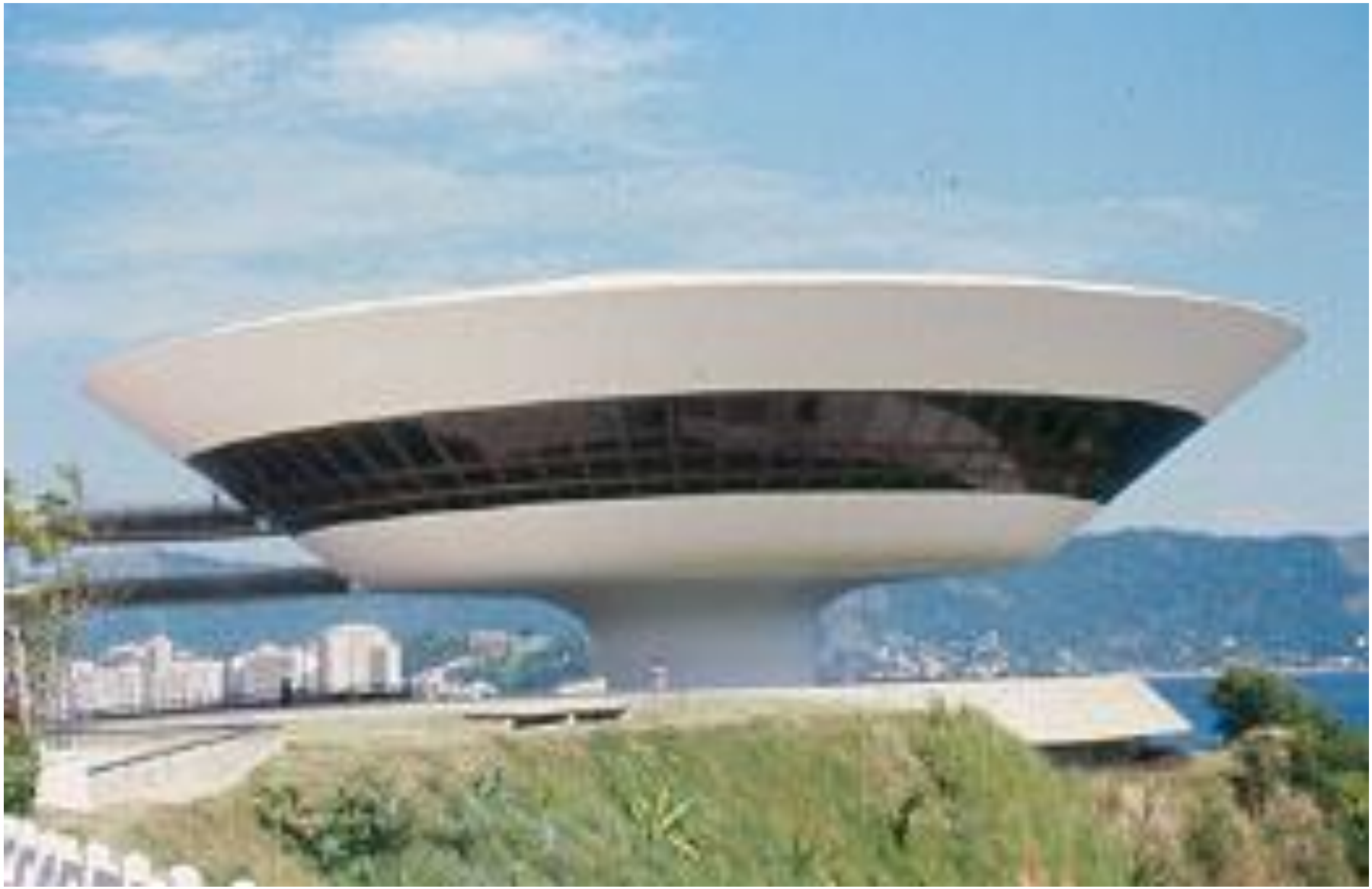
# Memorial da América Latina - SP - 1987

Oscar Niemeyer

# Museu de Arte Contemporânea - RJ - 1996

Oscar Niemeyer

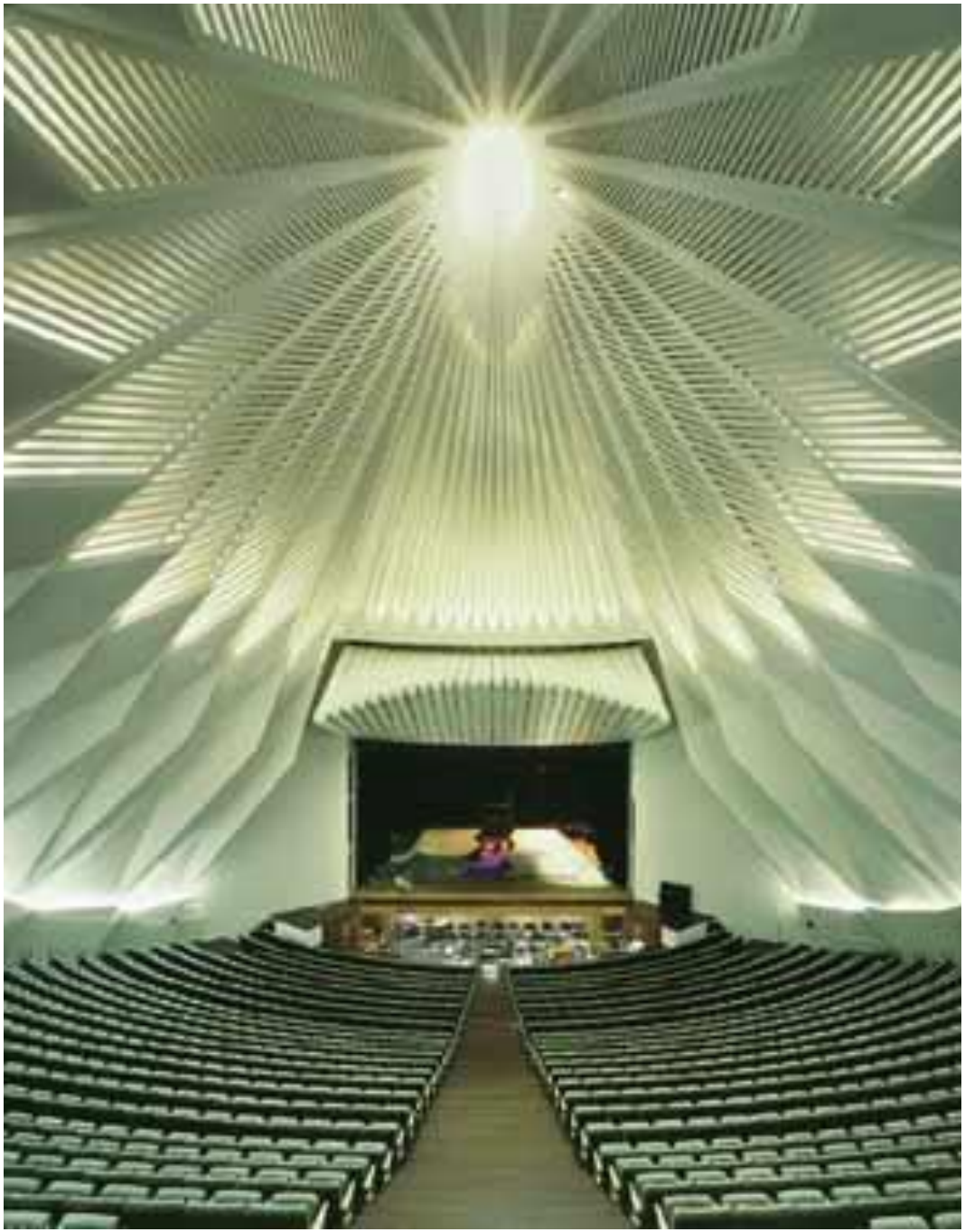




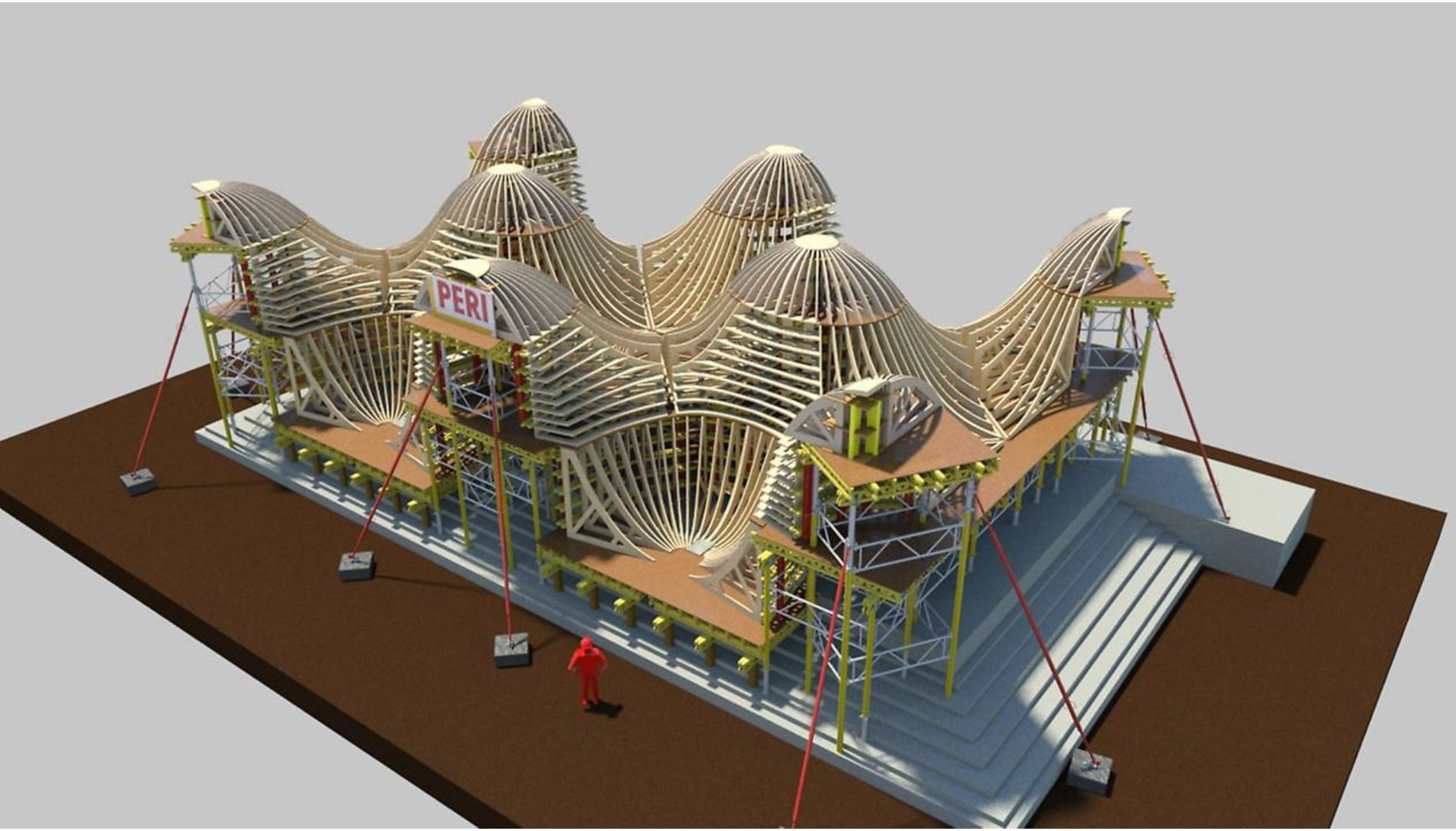

L'Oceanogràfic, Valencia , 2002
Félix Candela

**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.**



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


PERI