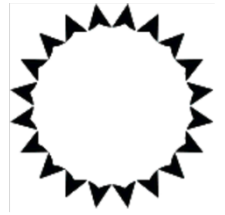




*EP-USP*

*PEF2603*  
*Estruturas na Arquitetura III -*  
*Sistemas Reticulados e Laminares*



*FAU-USP*

*Cascas*

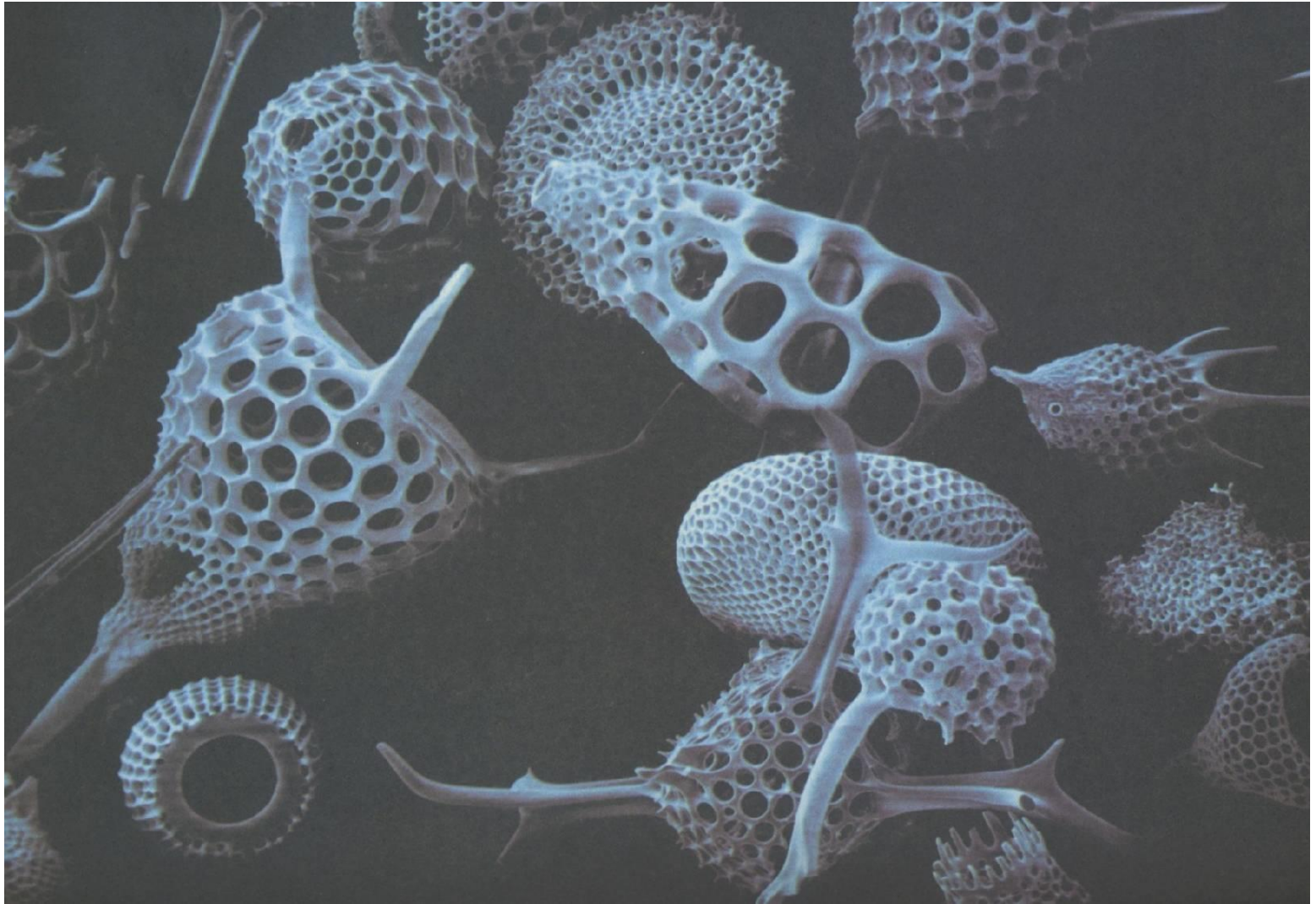
*Uma Visão Geral*

*(20/05/2019)*

*Professores*

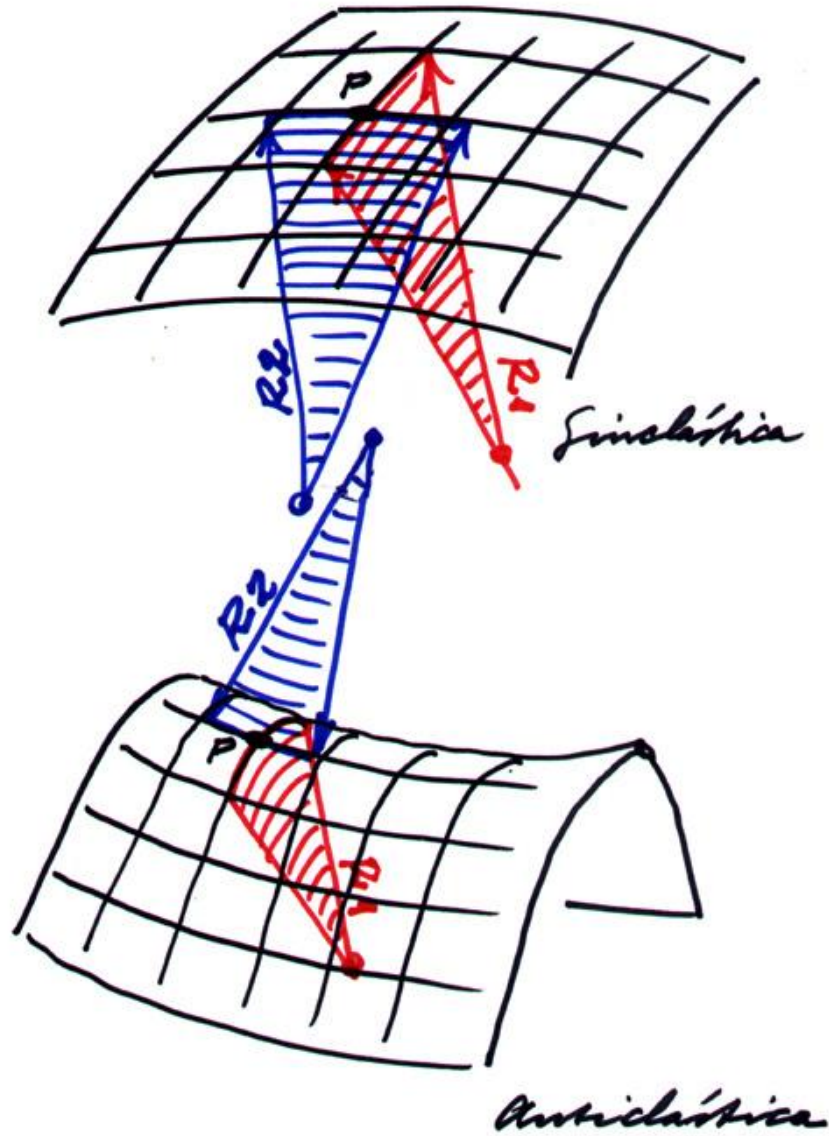
*Ruy Marcelo O. Pauletti , Leila Cristina Meneghetti, Luís Bitencourt Jr.*

*1º Semestre 2019*







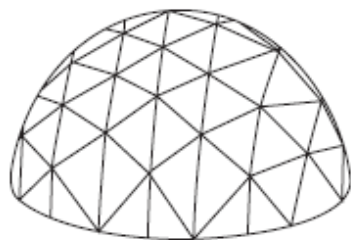


CURVATURAS

## Superfícies de Revolução



Esfera



Domo Geodésico



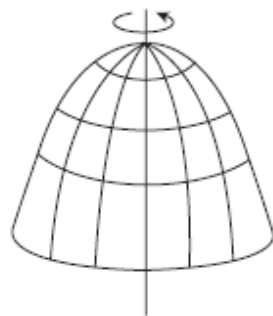
Domo de Schwedler



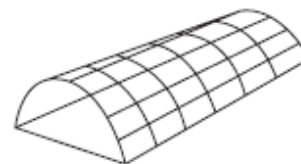
Domo Nervurado



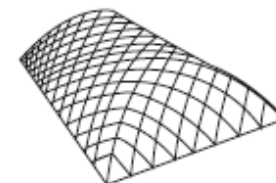
Elipsóide



Parabolóide



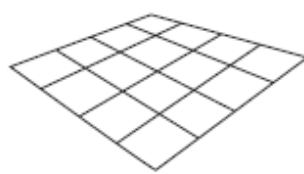
Cilindro Nervurado



Cilindro Lamelar



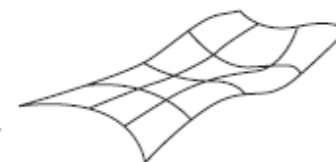
Casca funicular



Parabolóide  
Hiperbólico

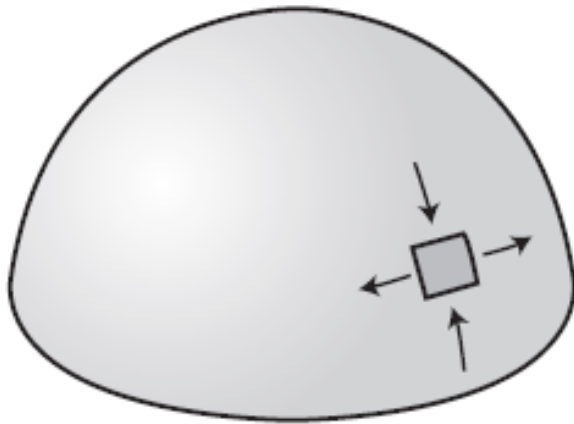


Parabolóide  
Hiperbólico

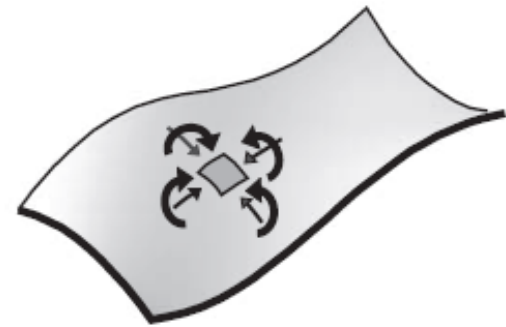


Superfície de forma  
livre

# Cascas x outras superfícies

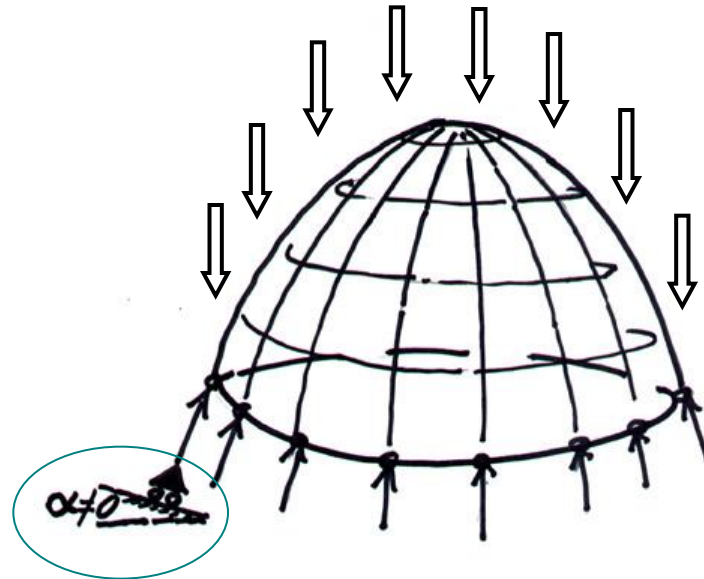


*Casca Funicular:  
comportamento de membrana  
somente esforços de tração e  
compressão*



*Formas complexas:  
presença de momento fletor  
aumento da espessura*

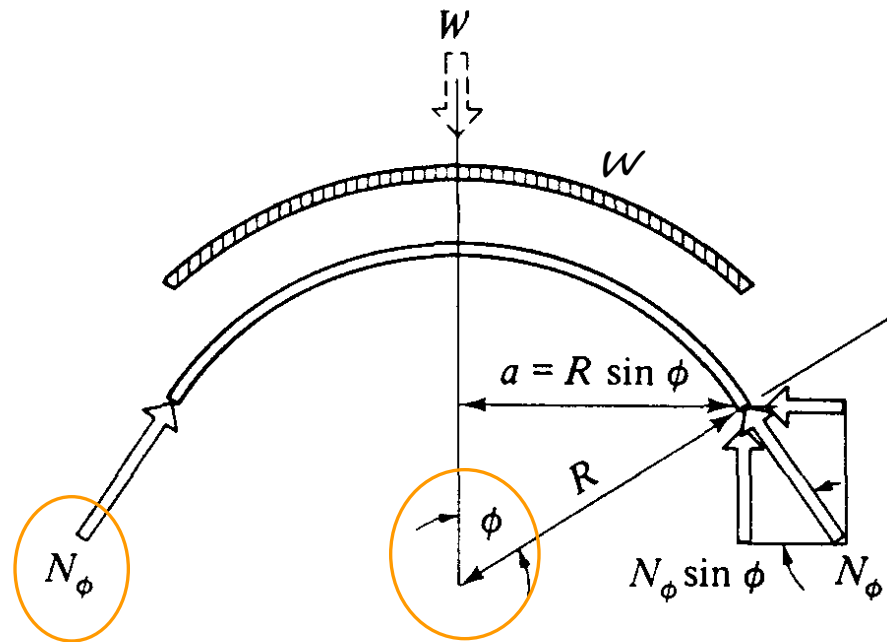
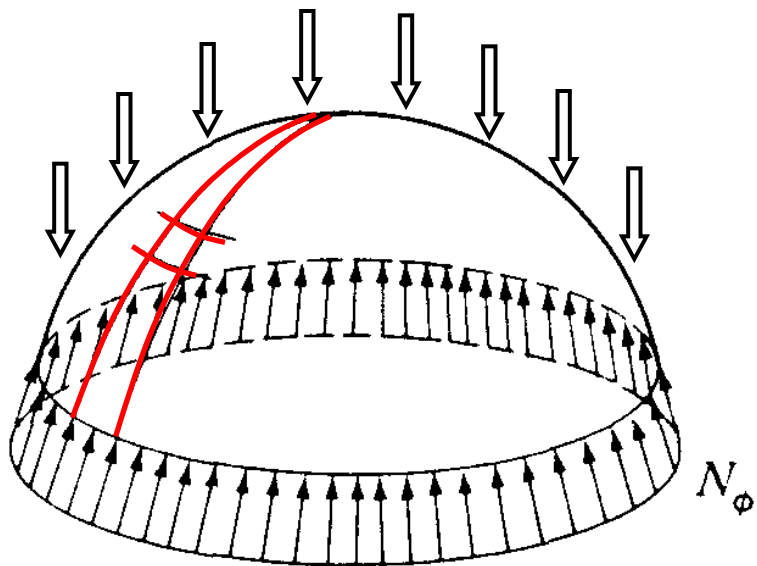
# Cascas



Casca Funicular  
ao carregamento

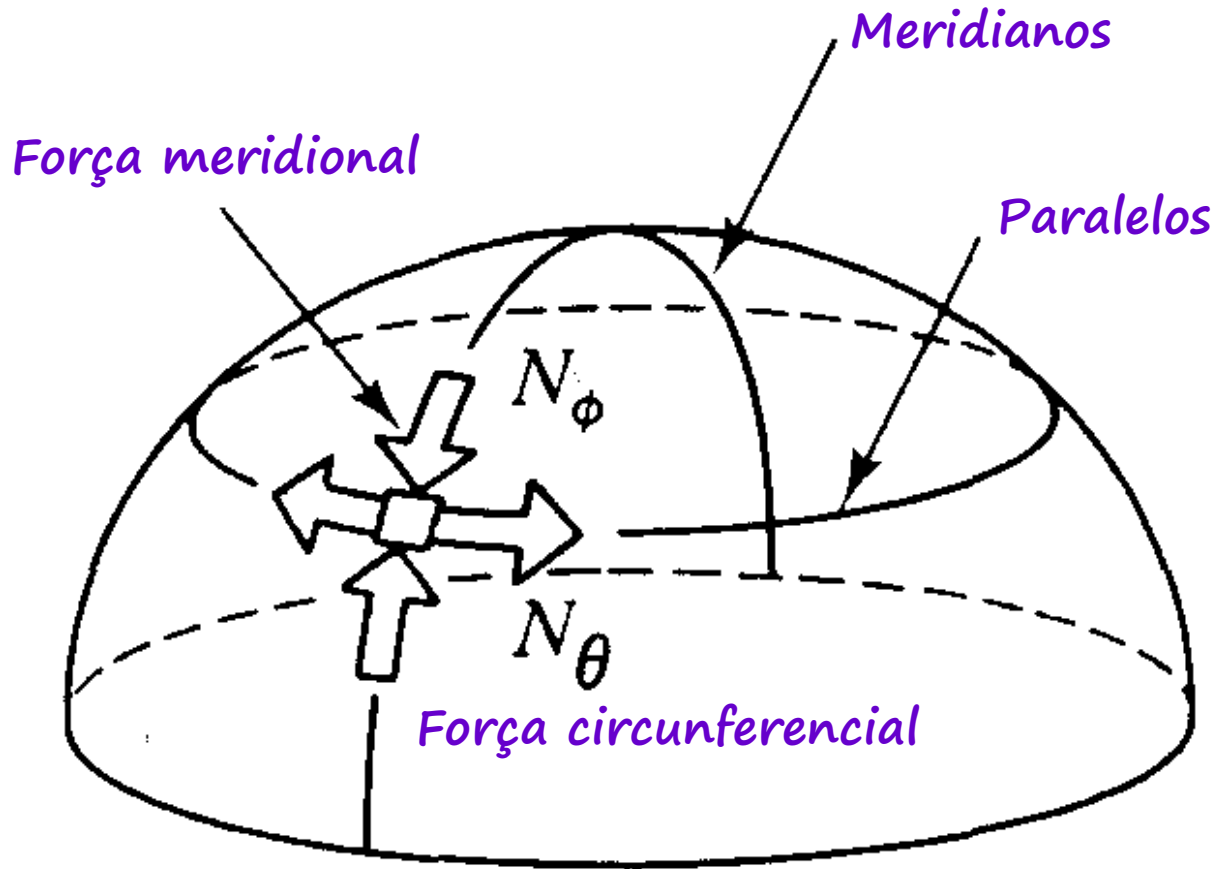


# Casca esférica sujeita a cargas verticais





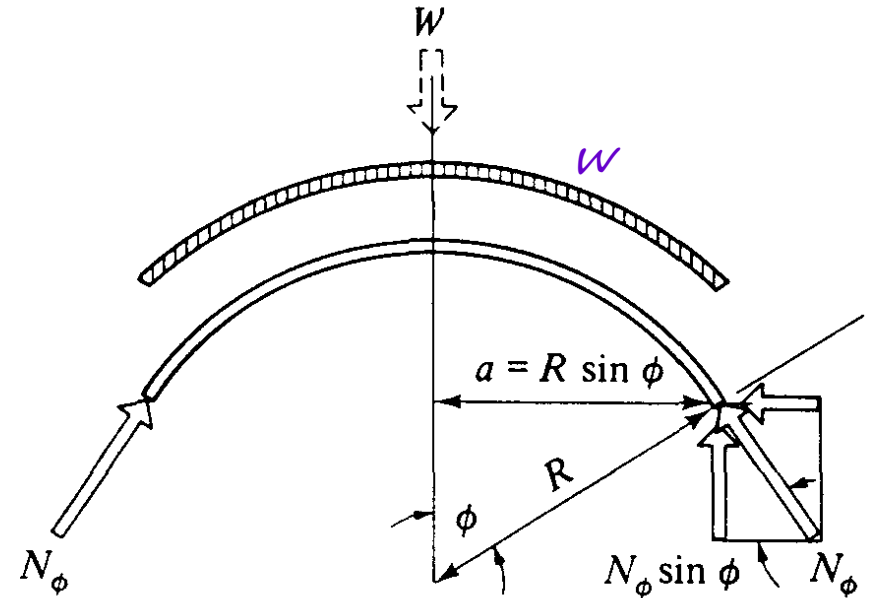
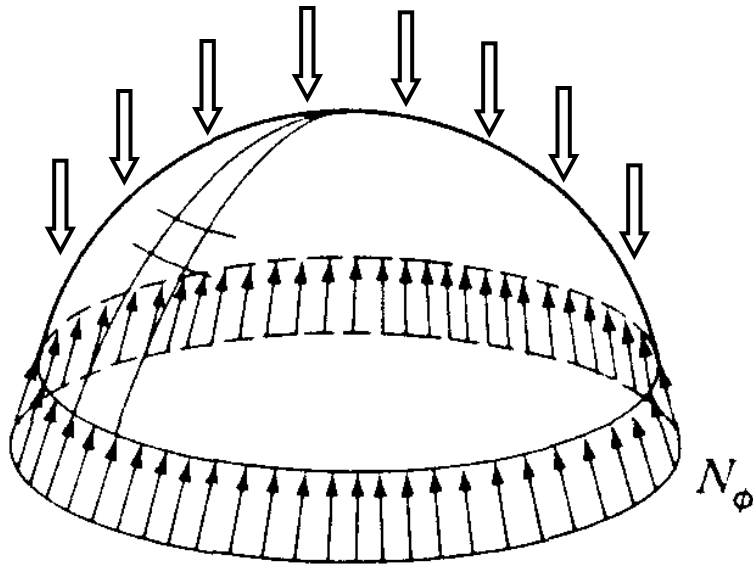
Casca parabólica:



Recordando a Equação de Laplace-Young:

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

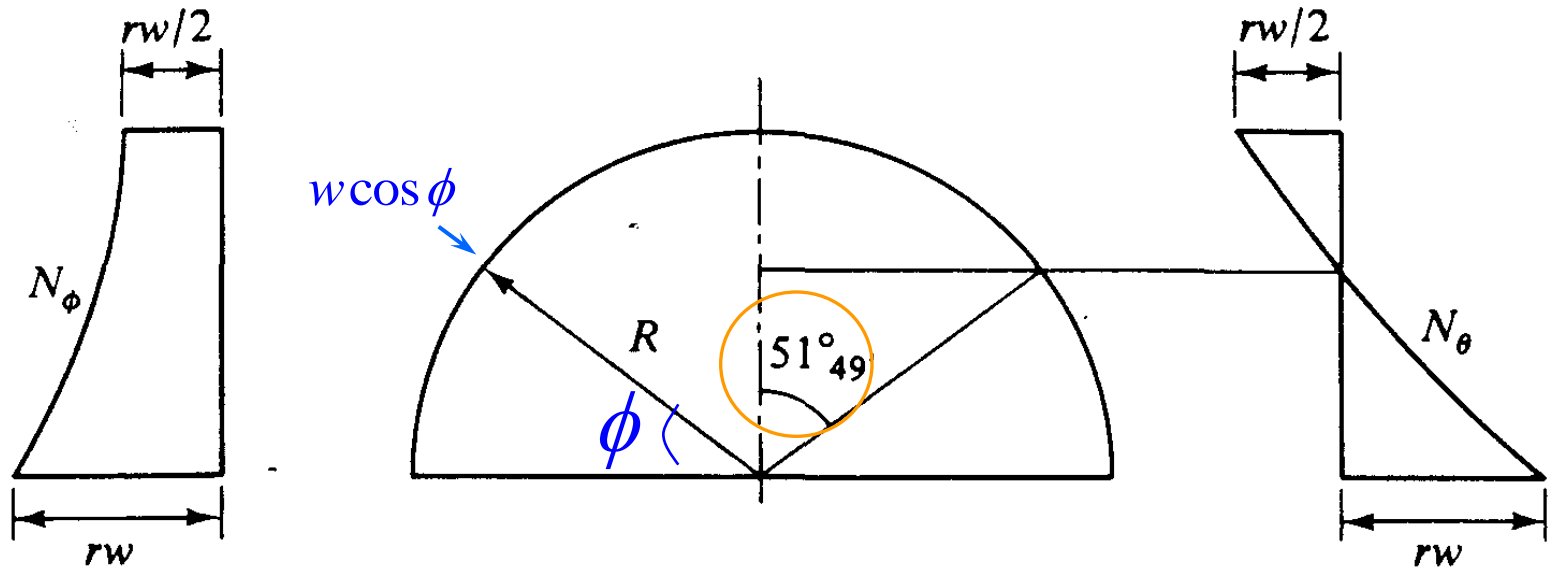
# Casca esférica sujeita a cargas verticais



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

Eq. Laplace:

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



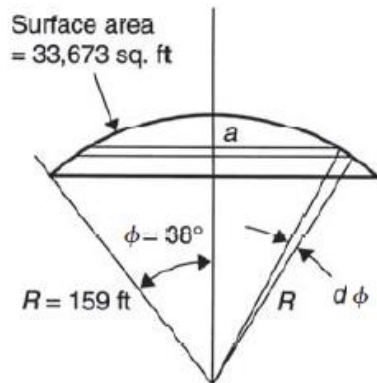
$$N_{\theta} = Rw \left( \cos \phi - \frac{1}{1 + \cos \phi} \right)$$



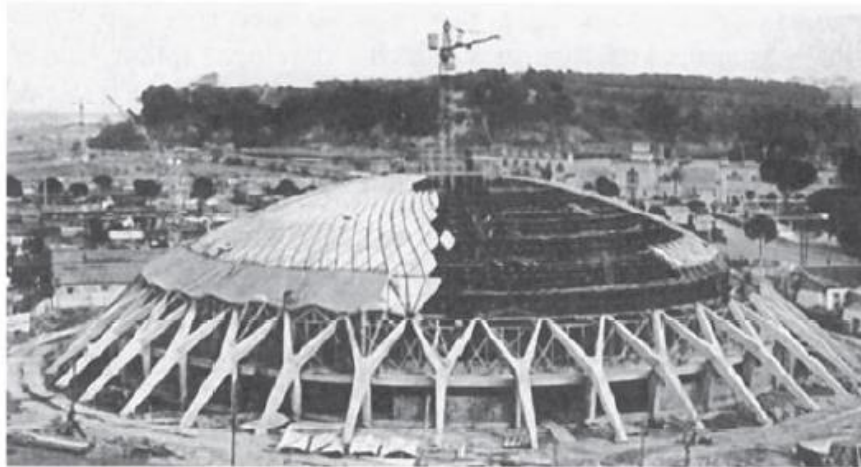
**Palazzetto dello Sport – 1956 – 1957**  
**Pier Luigi Nervi, Annibale Vitellozzi**  
**1960 Olympics**



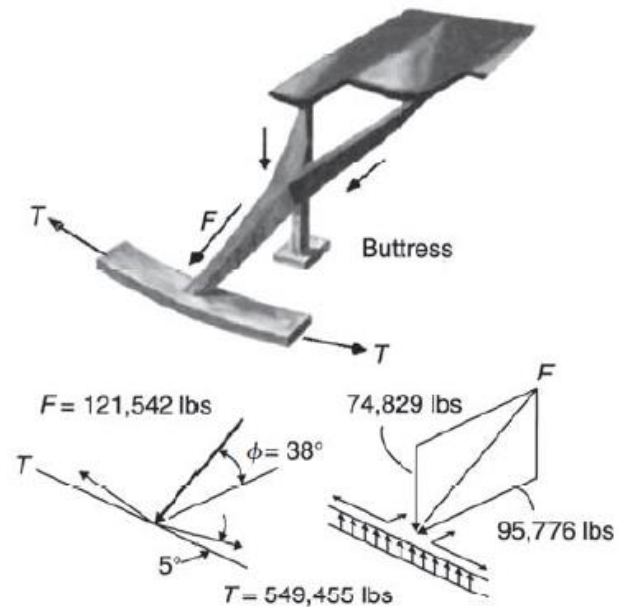
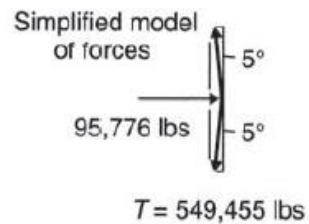
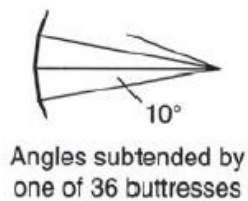
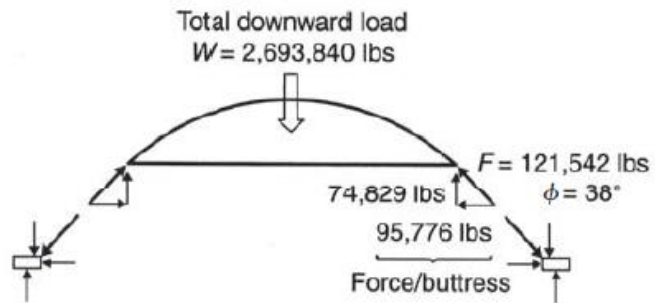




(a) Area calculations

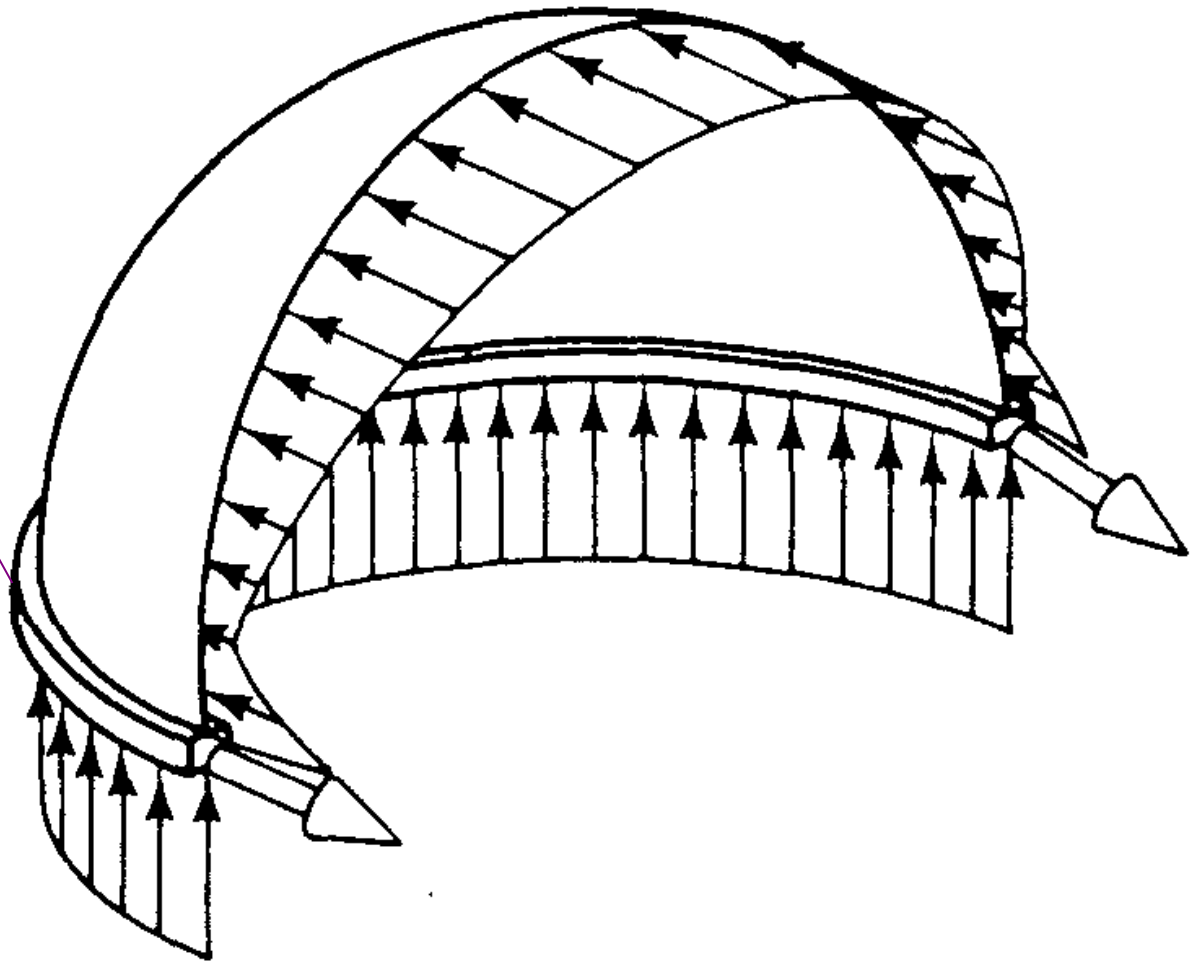


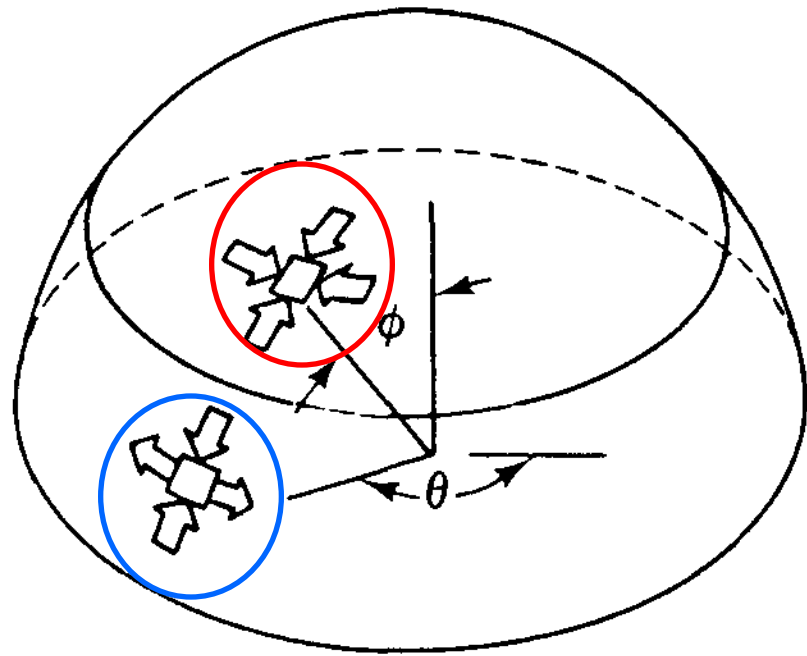
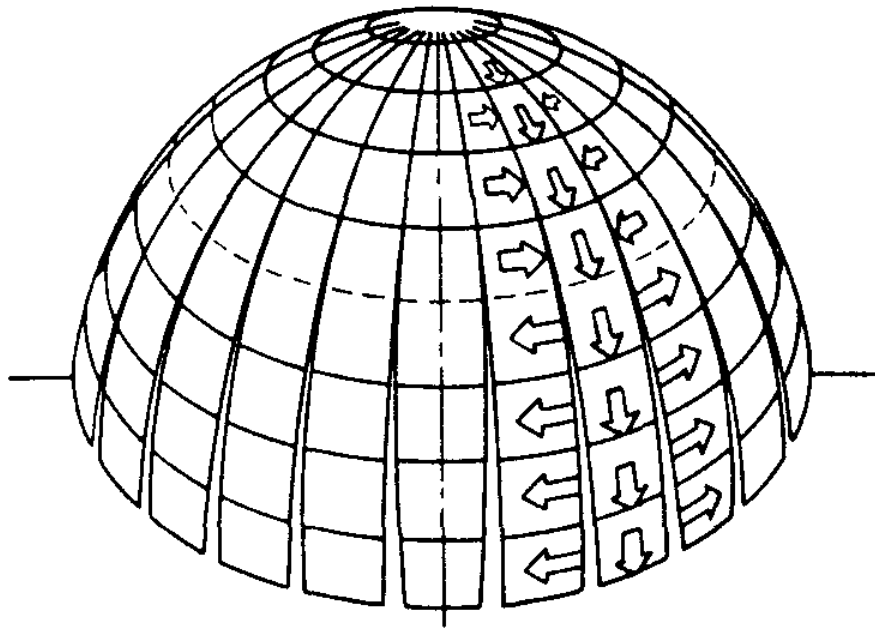
(b) Dome during construction

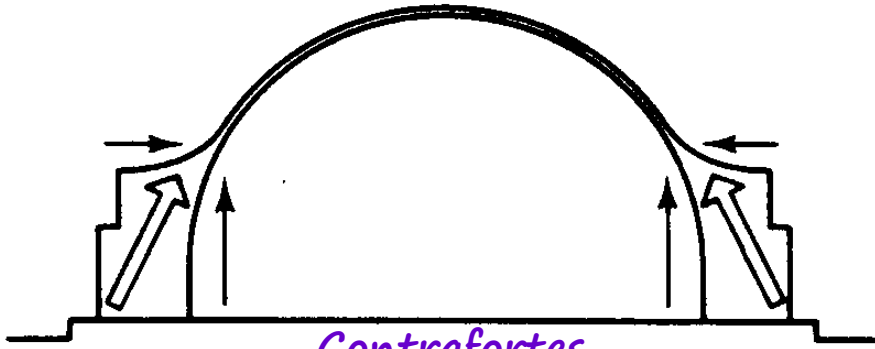




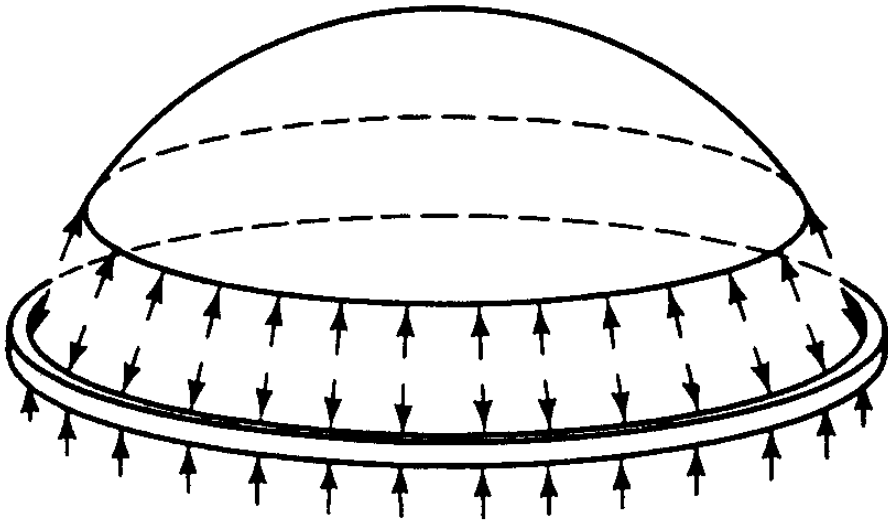
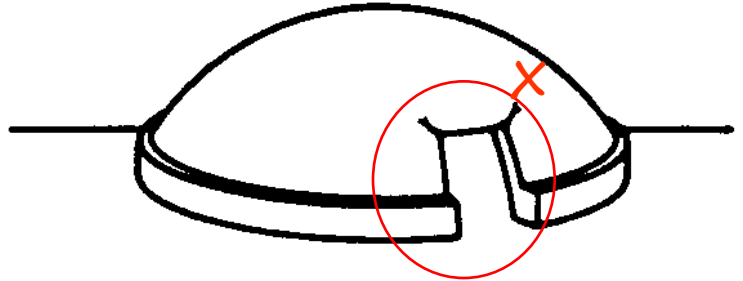
Anel de tração



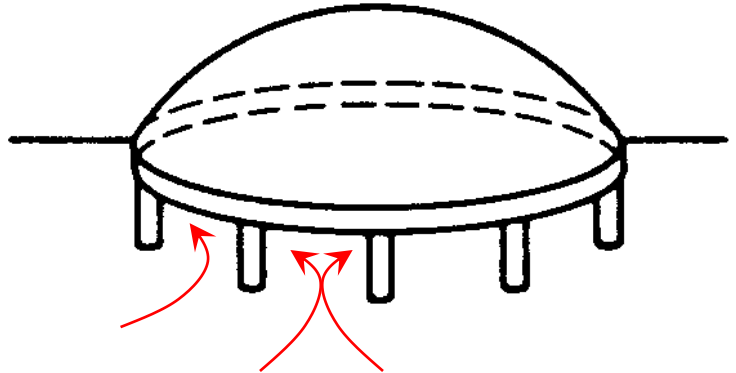




*Contrafortes*

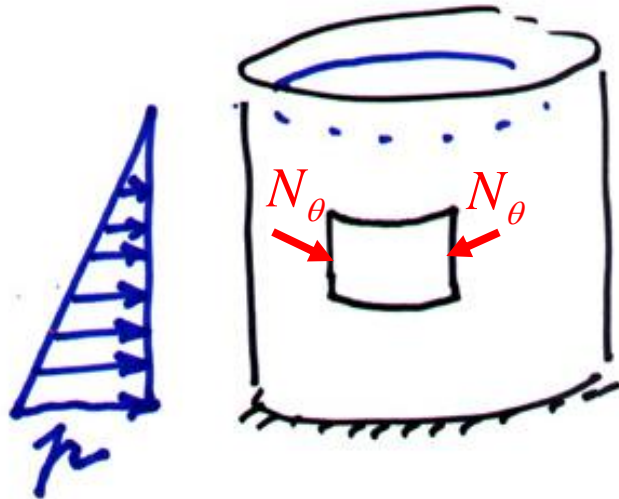


*Anel de tração*



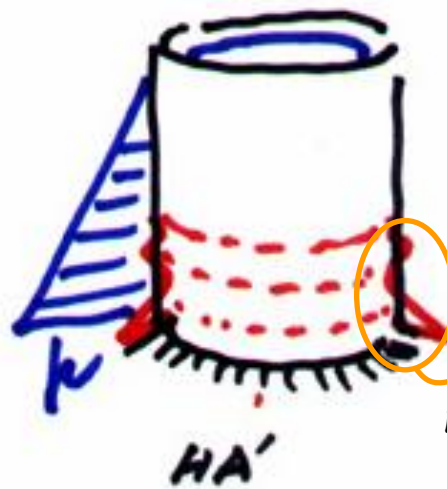
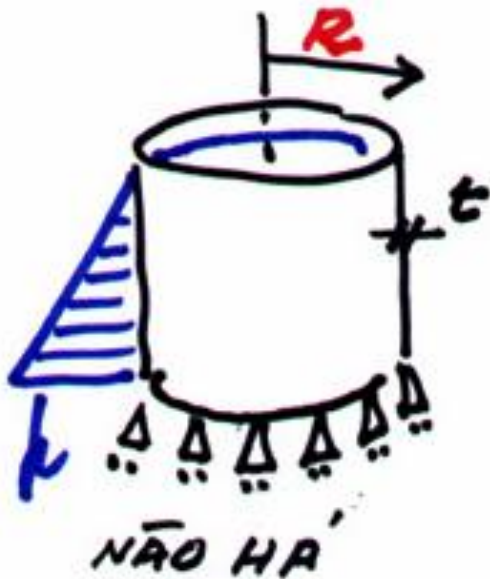


# Reservatórios

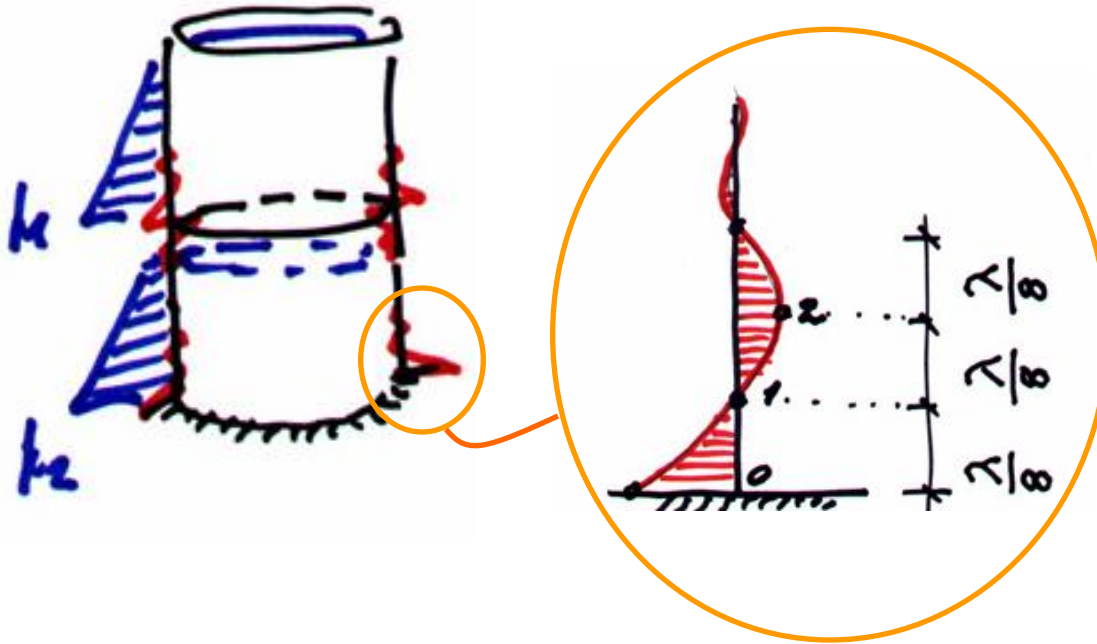


$$\frac{N_{\theta}}{R} = p_r$$

## PERTURBAÇÕES DE BURDA



Esquemas originais – Prof. Mário Franco



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

$$M_0 = 0.294 pRt$$

$$M_1 = 0$$

$$M_2 = -0.061 pRt$$

Exemplo:

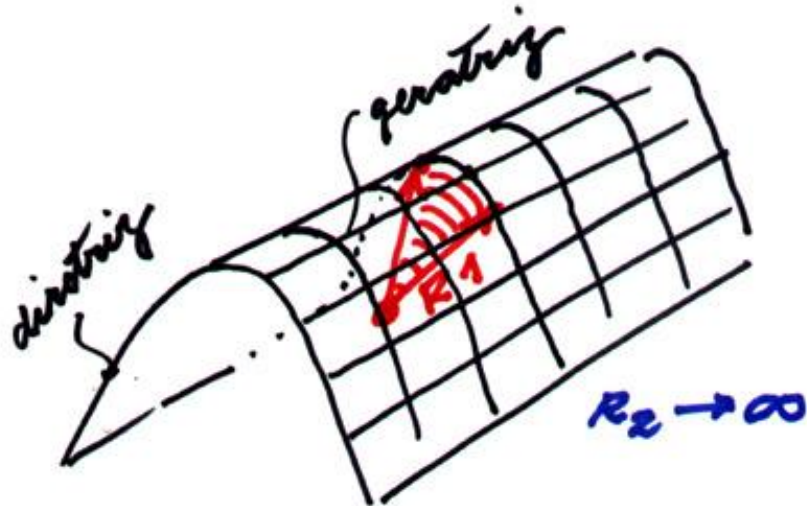
$$R = 4m, \quad t = 0.20m, \quad p = 150kN / m^2$$

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

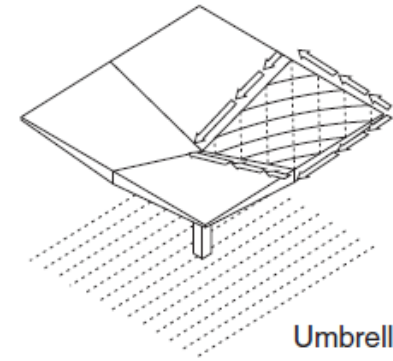
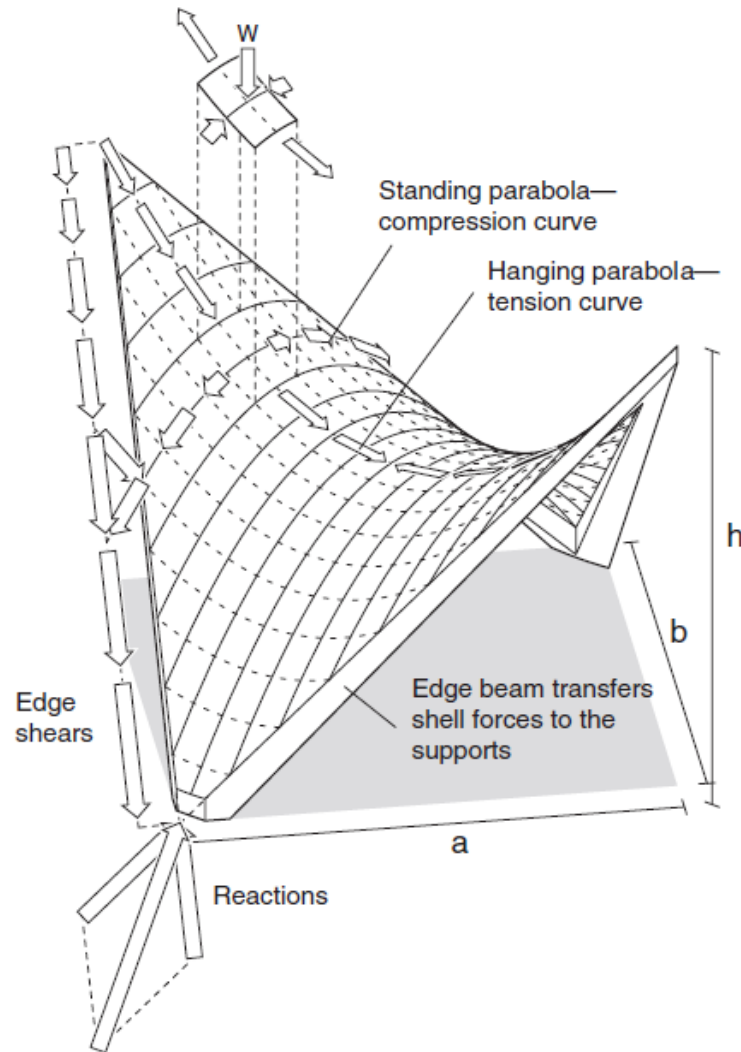
$$M_0 = 35,3kNm / m \quad (\phi 10 \text{ cada } 10cm)$$

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

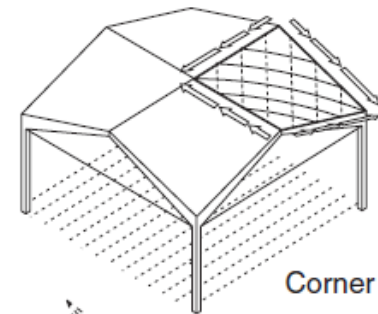
# CASCA CILÍNDRICA



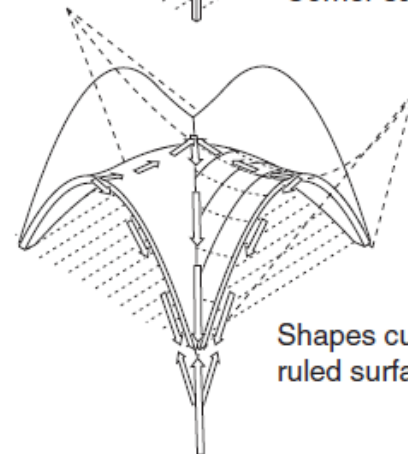
# Parabolóide hiperbólico



Umbrella shell



Corner supported



Shapes cut from ruled surface

# Trullos



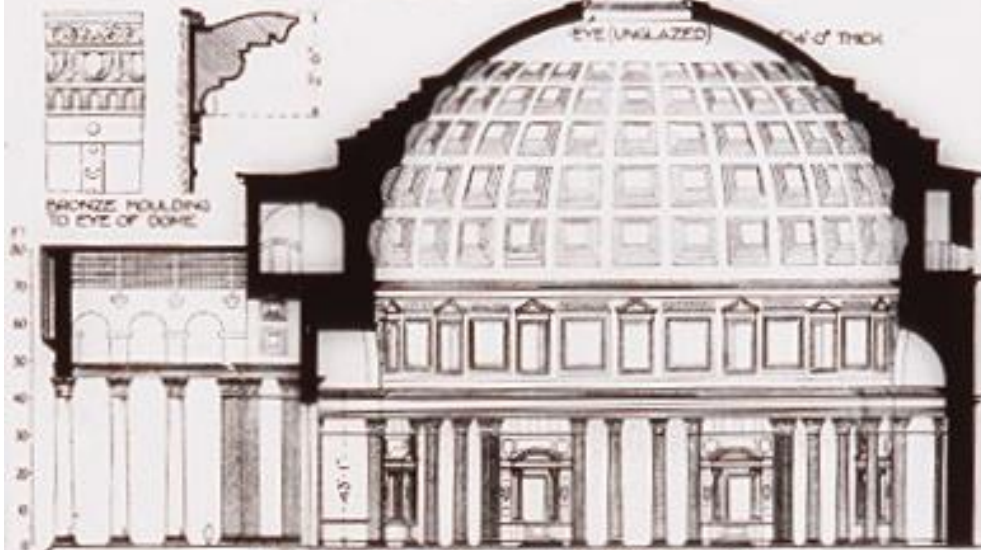




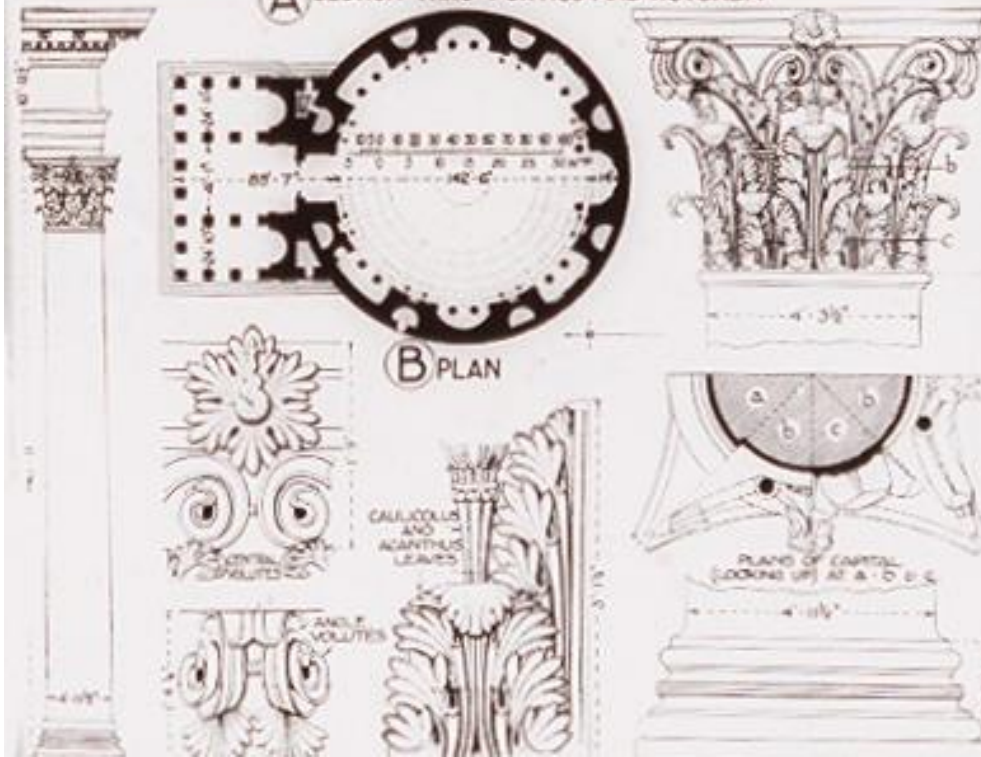




# THE PANTHEON: ROME



(A) SECTION THRO' PORTICO AND ROTUNDA



(B) PLAN

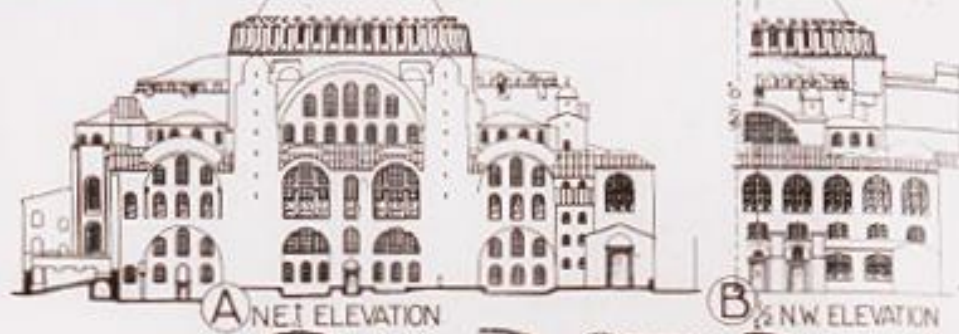






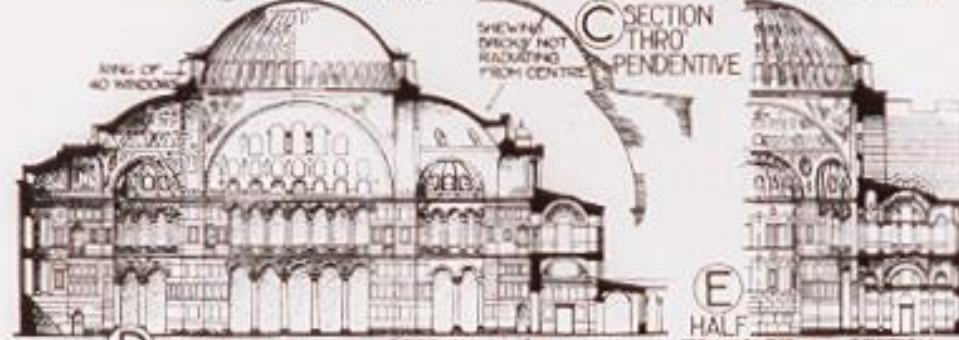


# S. SOPHIA CONSTANTINOPLE



(A) NET ELEVATION

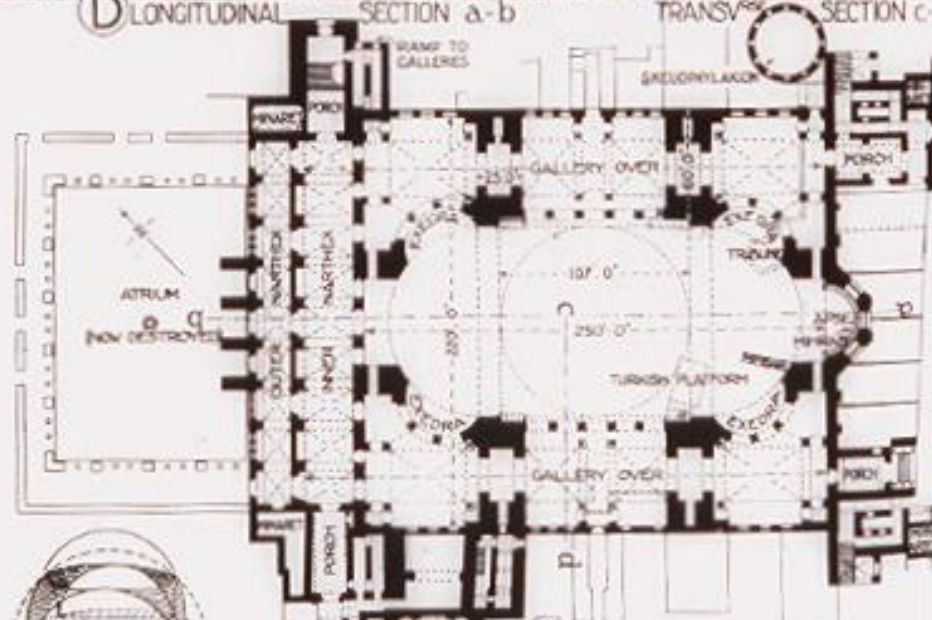
(B) S W N W ELEVATION



(D) LONGITUDINAL SECTION a-b

(C) SECTION THRO' PENDENTIVE

(E) HALF TRANSVERSE SECTION c-c



(G) PLAN



(F) METHOD OF DOME FORMATION











# EVOLUTION OF GOTHIC VAULTING

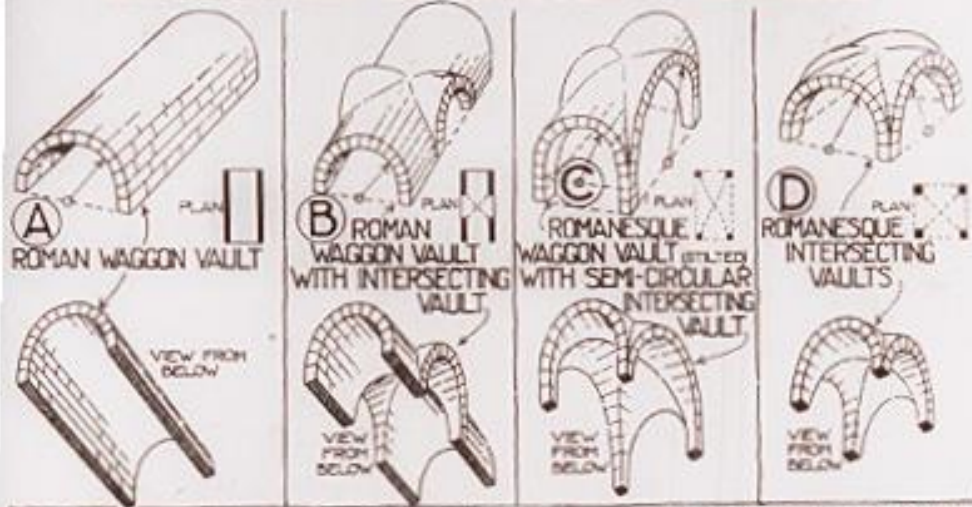
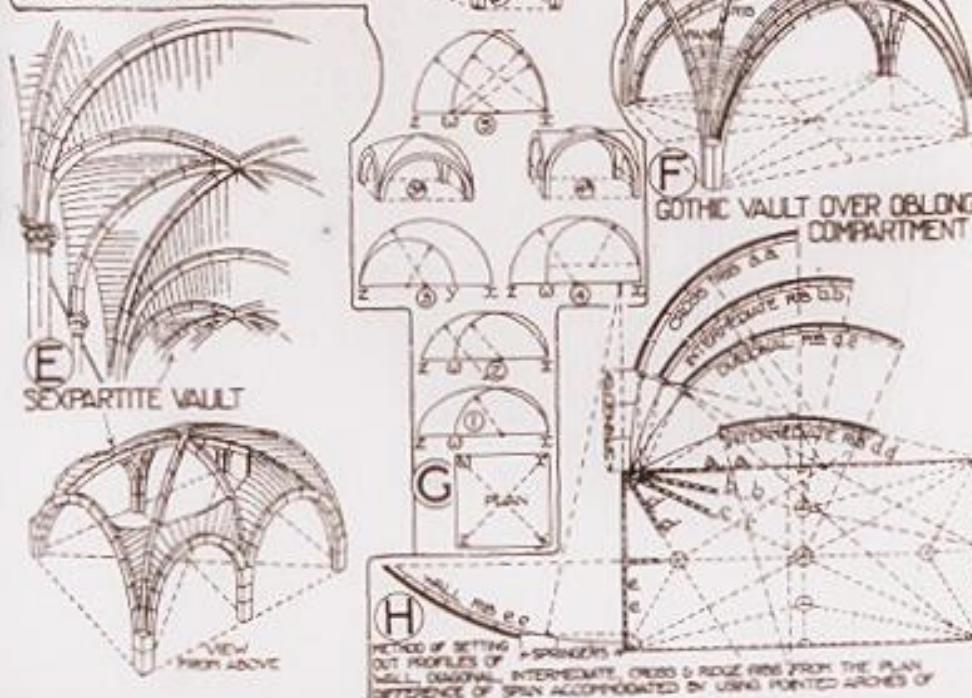


FIG. 10 IS THE PLAN OF A SQUARE VAULTING COMPARTMENT & FIGS 1-5 REPRESENT THE TRANSVERSE AND DIAGONAL RIBS & ILLUSTRATE THE DIFFICULTIES OF REGULATING THE HEIGHT OF RIBS OF DIFFERENT SPAN OVER A SQUARE COMPARTMENT, AS THE PROBLEM IS TO KEEP THE CROWNS OF THE INTERSECTING VAULTS LEVEL.

1 ROMAN CROSS VAULT WITH ELLIPTICAL DIAGONAL GROINS. 2 ROMANESQUE RIBBED VAULT WITH SEGMENTAL DIAGONAL RIBS. 3 ROMANESQUE RIBBED VAULT WITH SEMI-CIRCULAR DIAGONAL RIBS & TRANSVERSE RIBS RESULTING IN A CONICAL VAULT. 4 ROMANESQUE VAULT WITH SEMI-CIRCULAR DIAGONAL & TRANSVERSE RIBS THE LATTER STYLED TO AVOID CONICAL VAULT AS 4A.

5 ROMANESQUE RIBBED VAULT WITH SEGMENTAL DIAGONAL RIBS WHICH CAN BE MADE ANY HEIGHT FOR ANY SPAN THUS OVERCOMING ALL DIFFICULTIES AS 5A.





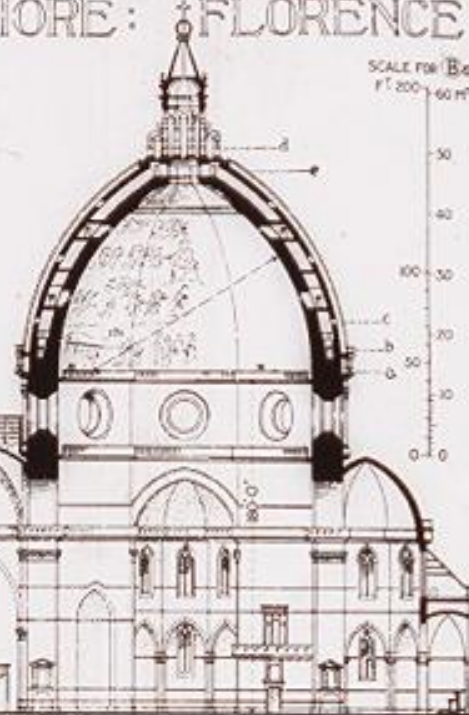




# S. MARIA DEL FIORE: FLORENCE



**A** EXTERIOR FROM NW



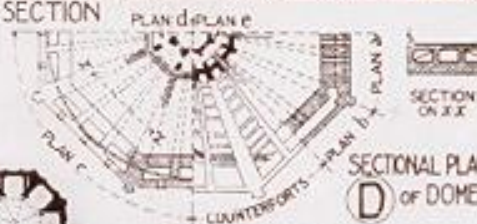
**B** LONGITUDINAL SECTION



LANTERN



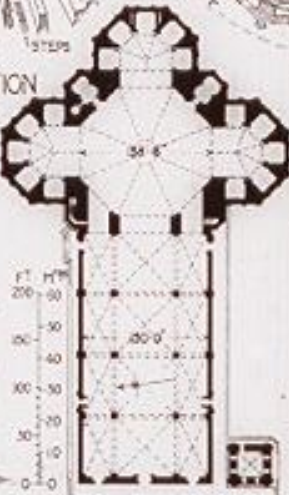
**C** CONSTRUCTION OF DOME



**D** SECTIONAL PLAN OF DOME



**E** UNCOMPLETED FACADE



**F** PLAN



**G** INTERIOR LOOKING E.













*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*



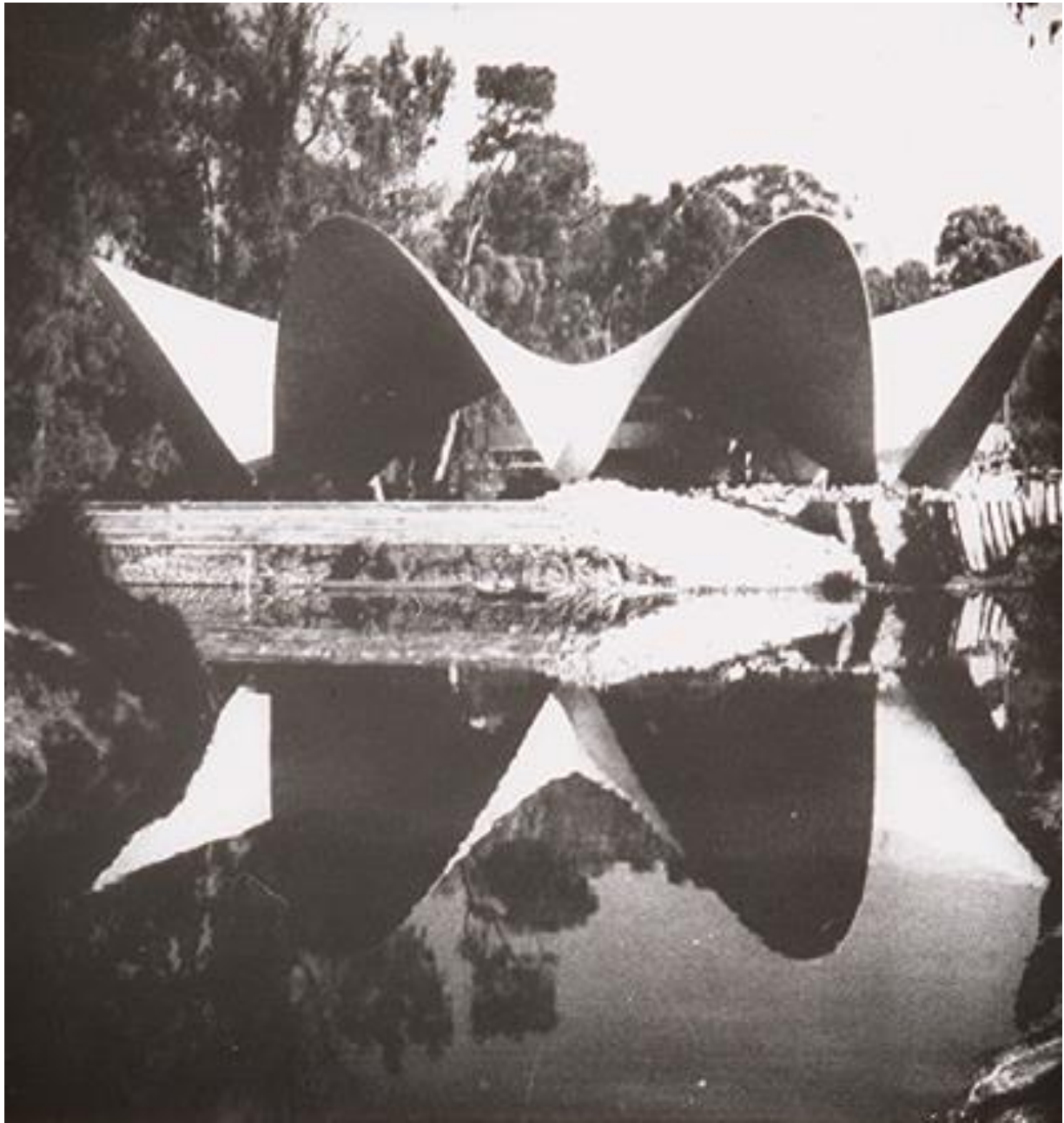


Planetário - SP - 1955

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)





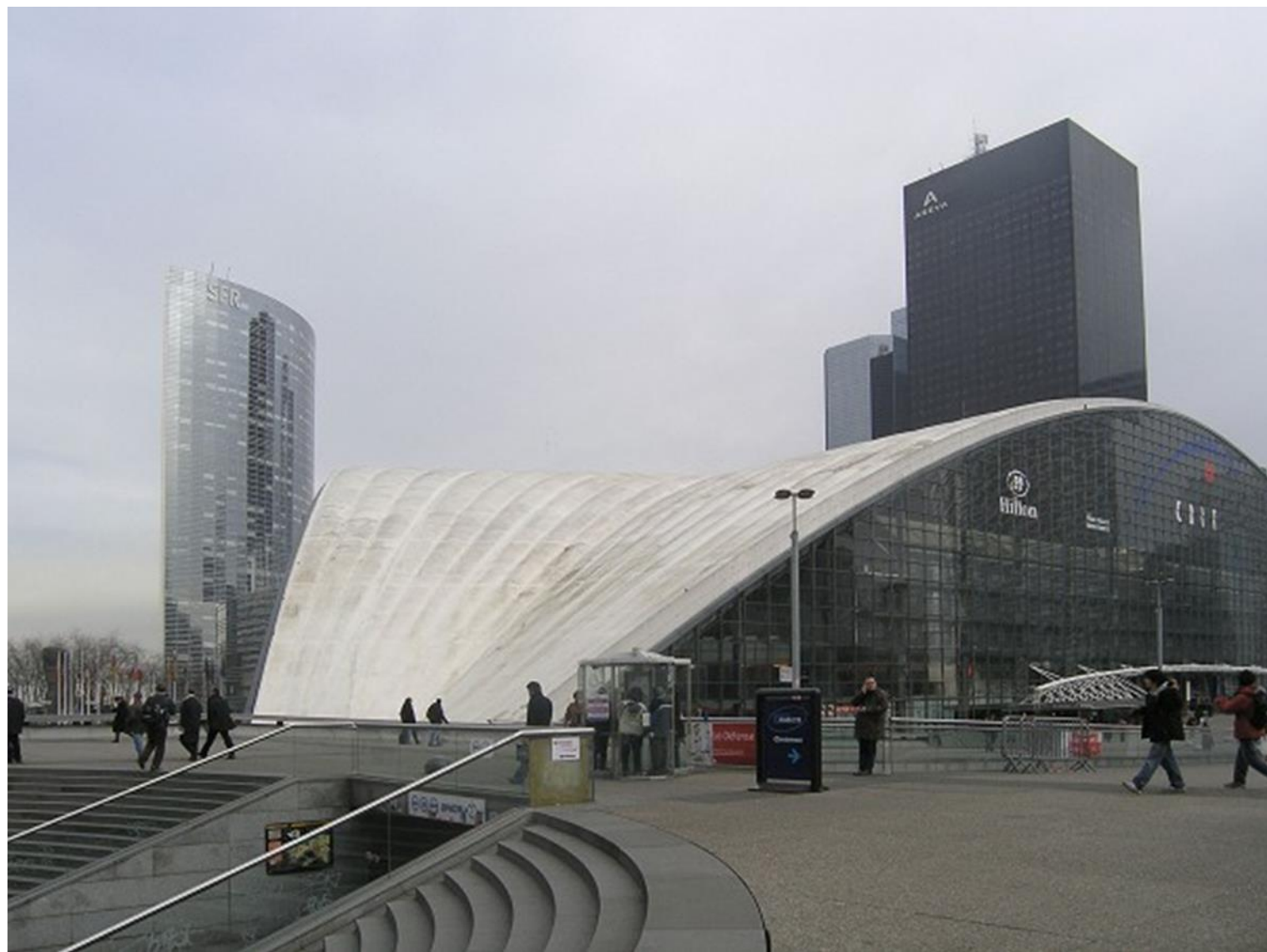


## CNIT

Centre des nouvelles industries et technologies,

Paris, 1956 - 1958

<b>Architect</b>	<a href="#">Robert Edouard Camelot</a>
	<a href="#">Jean de Mailly</a>
	<a href="#">Bernard Louis Zehrfuss</a>
<b>Engineer</b>	<a href="#">Nicolas Esquillan</a>
	<a href="#">Jean Prouvé</a>
<b>Consultant</b>	<a href="#">Pier Luigi Nervi</a>





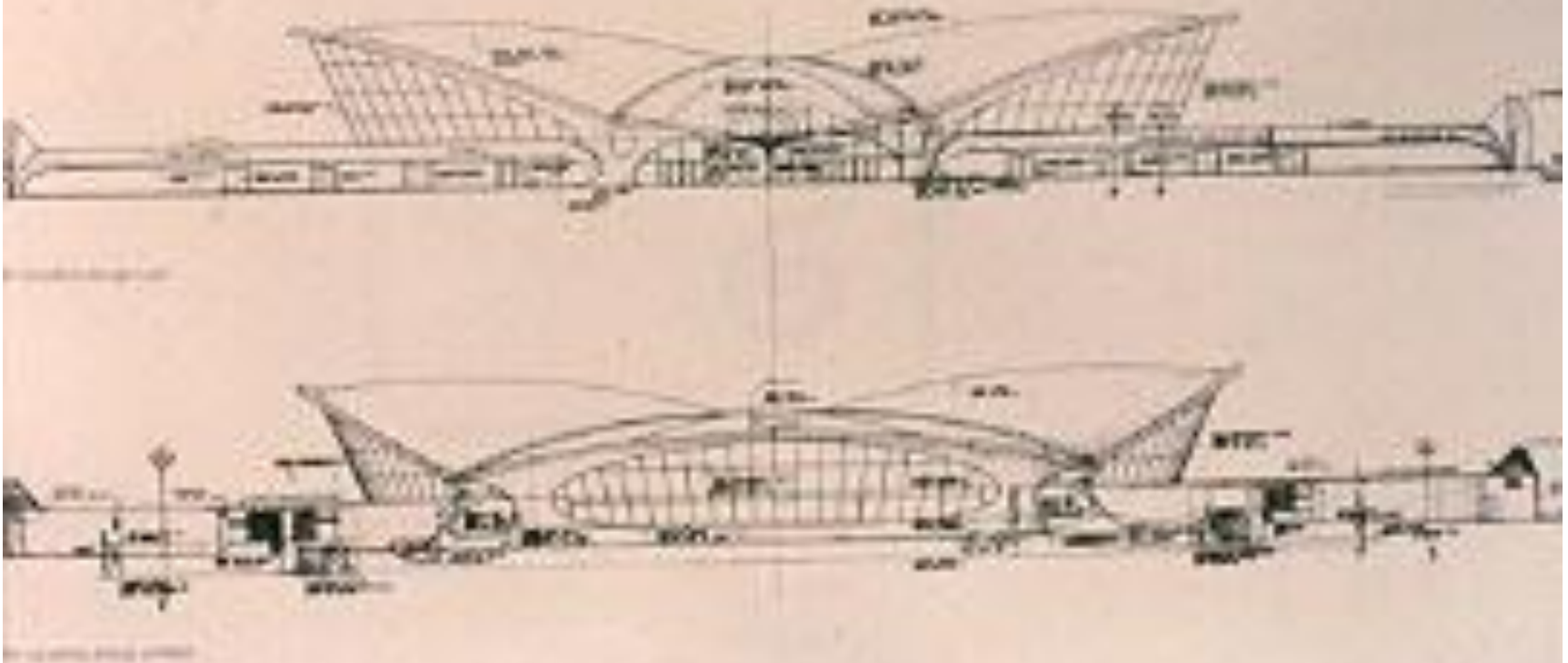




TWA Terminal at JFK International Airport , New York, 1956-1963

Design engineer: Boyd G. Anderson

Architect: Eero Saarinen

















DEPARTURES

FLIGHT	DESTINATION	STATUS
AA 100	NEW YORK	ON TIME
AA 200	LOS ANGELES	DELAYED
AA 300	CHICAGO	ON TIME
AA 400	DENVER	ON TIME
AA 500	PHOENIX	ON TIME
AA 600	PORTLAND	ON TIME
AA 700	SEATTLE	ON TIME
AA 800	TAMPA	ON TIME
AA 900	MIAMI	ON TIME
AA 1000	ATLANTA	ON TIME
AA 1100	MEMPHIS	ON TIME
AA 1200	INDIANAPOLIS	ON TIME
AA 1300	COLUMBUS	ON TIME
AA 1400	INDIANAPOLIS	ON TIME
AA 1500	COLUMBUS	ON TIME
AA 1600	INDIANAPOLIS	ON TIME
AA 1700	COLUMBUS	ON TIME
AA 1800	INDIANAPOLIS	ON TIME
AA 1900	COLUMBUS	ON TIME
AA 2000	INDIANAPOLIS	ON TIME

ARRIVALS

FLIGHT	ORIGIN	STATUS
AA 100	NEW YORK	ON TIME
AA 200	LOS ANGELES	DELAYED
AA 300	CHICAGO	ON TIME
AA 400	DENVER	ON TIME
AA 500	PHOENIX	ON TIME
AA 600	PORTLAND	ON TIME
AA 700	SEATTLE	ON TIME
AA 800	TAMPA	ON TIME
AA 900	MIAMI	ON TIME
AA 1000	ATLANTA	ON TIME
AA 1100	MEMPHIS	ON TIME
AA 1200	INDIANAPOLIS	ON TIME
AA 1300	COLUMBUS	ON TIME
AA 1400	INDIANAPOLIS	ON TIME
AA 1500	COLUMBUS	ON TIME
AA 1600	INDIANAPOLIS	ON TIME
AA 1700	COLUMBUS	ON TIME
AA 1800	INDIANAPOLIS	ON TIME
AA 1900	COLUMBUS	ON TIME
AA 2000	INDIANAPOLIS	ON TIME

Information Counter





ARRIVALS

FLIGHT	AIRLINE	STATUS
AA 123	AA	ON TIME
DL 456	DL	DELAYED
UA 789	UA	ON TIME
WN 101	WN	ON TIME
B6 202	B6	ON TIME
DL 303	DL	ON TIME
AA 404	AA	ON TIME
UA 505	UA	ON TIME
WN 606	WN	ON TIME
B6 707	B6	ON TIME
DL 808	DL	ON TIME
AA 909	AA	ON TIME
UA 1010	UA	ON TIME
WN 1111	WN	ON TIME
B6 1212	B6	ON TIME
DL 1313	DL	ON TIME
AA 1414	AA	ON TIME
UA 1515	UA	ON TIME
WN 1616	WN	ON TIME
B6 1717	B6	ON TIME
DL 1818	DL	ON TIME
AA 1919	AA	ON TIME
UA 2020	UA	ON TIME
WN 2121	WN	ON TIME
B6 2222	B6	ON TIME
DL 2323	DL	ON TIME
AA 2424	AA	ON TIME
UA 2525	UA	ON TIME
WN 2626	WN	ON TIME
B6 2727	B6	ON TIME
DL 2828	DL	ON TIME
AA 2929	AA	ON TIME
UA 3030	UA	ON TIME
WN 3131	WN	ON TIME
B6 3232	B6	ON TIME
DL 3333	DL	ON TIME
AA 3434	AA	ON TIME
UA 3535	UA	ON TIME
WN 3636	WN	ON TIME
B6 3737	B6	ON TIME
DL 3838	DL	ON TIME
AA 3939	AA	ON TIME
UA 4040	UA	ON TIME
WN 4141	WN	ON TIME
B6 4242	B6	ON TIME
DL 4343	DL	ON TIME
AA 4444	AA	ON TIME
UA 4545	UA	ON TIME
WN 4646	WN	ON TIME
B6 4747	B6	ON TIME
DL 4848	DL	ON TIME
AA 4949	AA	ON TIME
UA 5050	UA	ON TIME

DEPARTURES

FLIGHT	AIRLINE	STATUS	TO
AA 123	AA	ON TIME	NEW YORK
DL 456	DL	DELAYED	ATLANTA
UA 789	UA	ON TIME	CHICAGO
WN 101	WN	ON TIME	MINNEAPOLIS
B6 202	B6	ON TIME	MIAMI
DL 303	DL	ON TIME	LOS ANGELES
AA 404	AA	ON TIME	DENVER
UA 505	UA	ON TIME	PHOENIX
WN 606	WN	ON TIME	PORTLAND
B6 707	B6	ON TIME	HOUSTON
DL 808	DL	ON TIME	SEATTLE
AA 909	AA	ON TIME	SAN FRANCISCO
UA 1010	UA	ON TIME	SAN DIEGO
WN 1111	WN	ON TIME	SALT LAKE CITY
B6 1212	B6	ON TIME	INDIANAPOLIS
DL 1313	DL	ON TIME	KANSAS CITY
AA 1414	AA	ON TIME	MEMPHIS
UA 1515	UA	ON TIME	NEW ORLEANS
WN 1616	WN	ON TIME	OKLAHOMA CITY
B6 1717	B6	ON TIME	PHILADELPHIA
DL 1818	DL	ON TIME	RICHMOND
AA 1919	AA	ON TIME	TAMPA
UA 2020	UA	ON TIME	WASHINGTON
WN 2121	WN	ON TIME	WICHITA
B6 2222	B6	ON TIME	MIAMI
DL 2323	DL	ON TIME	LOS ANGELES
AA 2424	AA	ON TIME	DENVER
UA 2525	UA	ON TIME	PHOENIX
WN 2626	WN	ON TIME	PORTLAND
B6 2727	B6	ON TIME	HOUSTON
DL 2828	DL	ON TIME	SEATTLE
AA 2929	AA	ON TIME	SAN FRANCISCO
UA 3030	UA	ON TIME	SAN DIEGO
WN 3131	WN	ON TIME	SALT LAKE CITY
B6 3232	B6	ON TIME	INDIANAPOLIS
DL 3333	DL	ON TIME	KANSAS CITY
AA 3434	AA	ON TIME	MEMPHIS
UA 3535	UA	ON TIME	NEW ORLEANS
WN 3636	WN	ON TIME	OKLAHOMA CITY
B6 3737	B6	ON TIME	PHILADELPHIA
DL 3838	DL	ON TIME	RICHMOND
AA 3939	AA	ON TIME	TAMPA
UA 4040	UA	ON TIME	WASHINGTON
WN 4141	WN	ON TIME	WICHITA
B6 4242	B6	ON TIME	MIAMI
DL 4343	DL	ON TIME	LOS ANGELES
AA 4444	AA	ON TIME	DENVER
UA 4545	UA	ON TIME	PHOENIX
WN 4646	WN	ON TIME	PORTLAND
B6 4747	B6	ON TIME	HOUSTON
DL 4848	DL	ON TIME	SEATTLE
AA 4949	AA	ON TIME	SAN FRANCISCO
UA 5050	UA	ON TIME	SAN DIEGO

American Counter











← Gates 27-30      Gates 31-40 →





**St. Louis Abbey (or the Priory Chapel)**

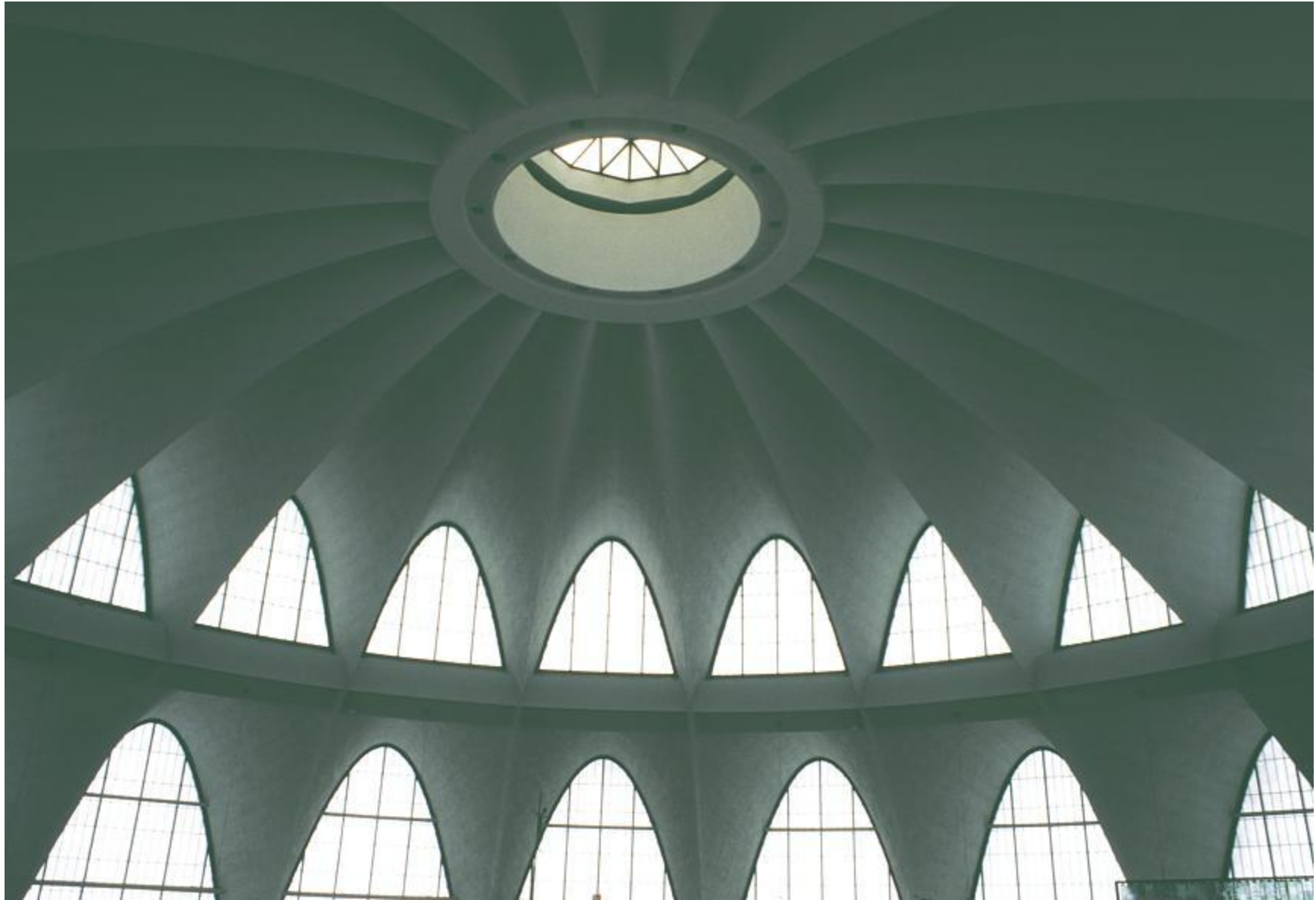
Gyo Obata of Hellmuth, Obata & Kassabaum (HOK) with Pier Luigi Nervi, consultant

1962













H. Isler, Wyss Garden Center, Suíça, 1961





Heinz Isler – Bürgi Garden Center – Suíça, 1973



Heinz Isler – Bürji Garden Center – Suíça, 1973



H. Isler, Brühl Sports Center , Suíça, 1982

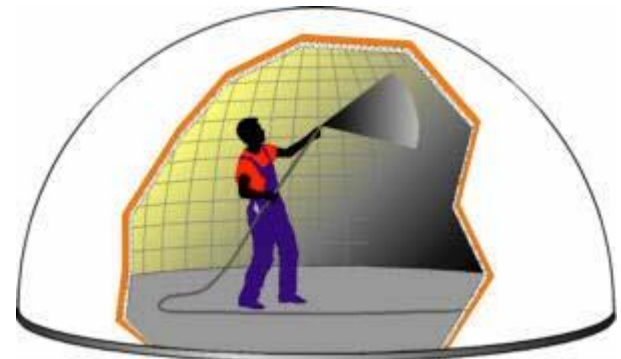
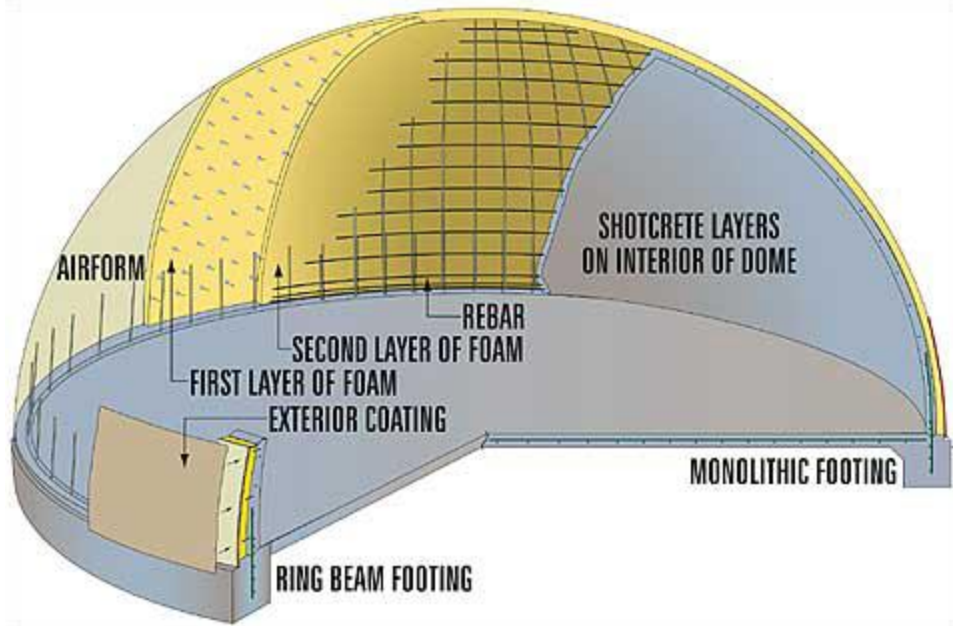




## Sistema Bini

The Kallangur Shopping Center, Queensland, Australia









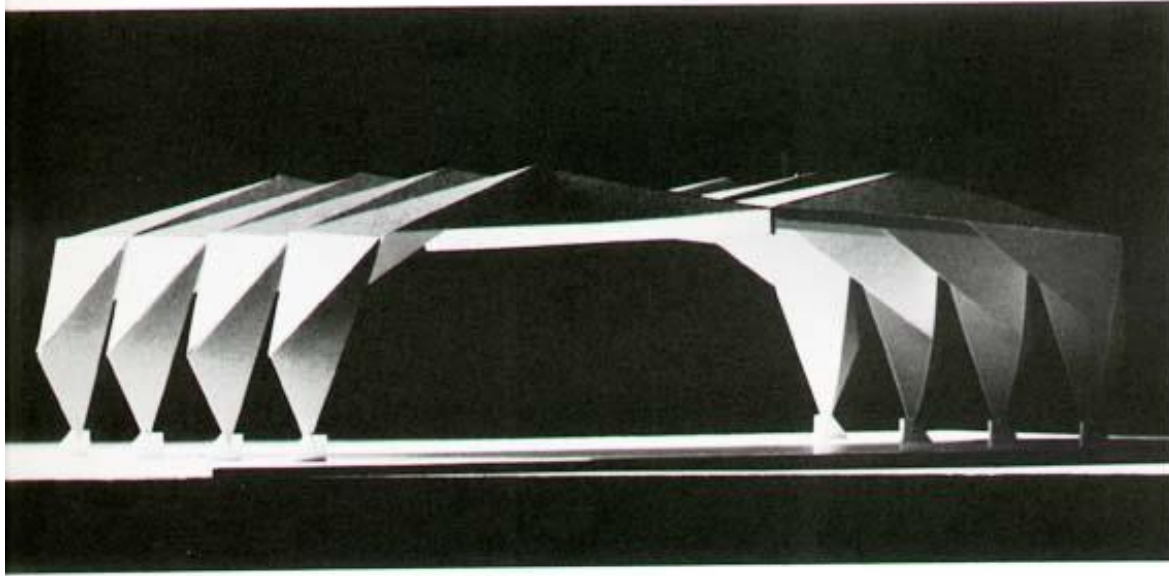
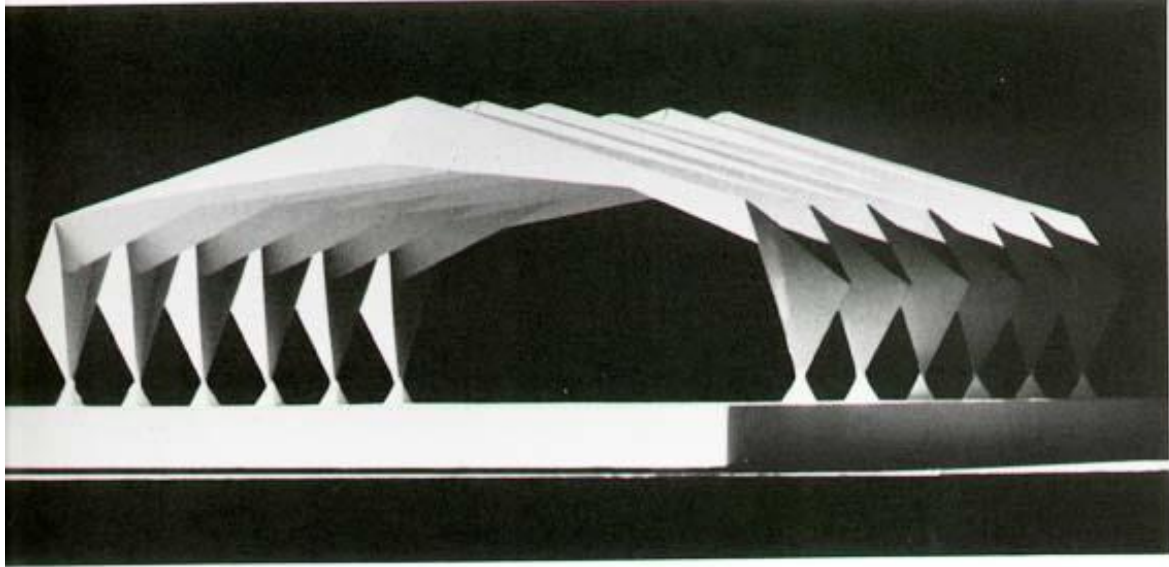






Palácio das Convenções - SP - 1967  
Miguel Juliano e Silva, Jorge Wilhelm

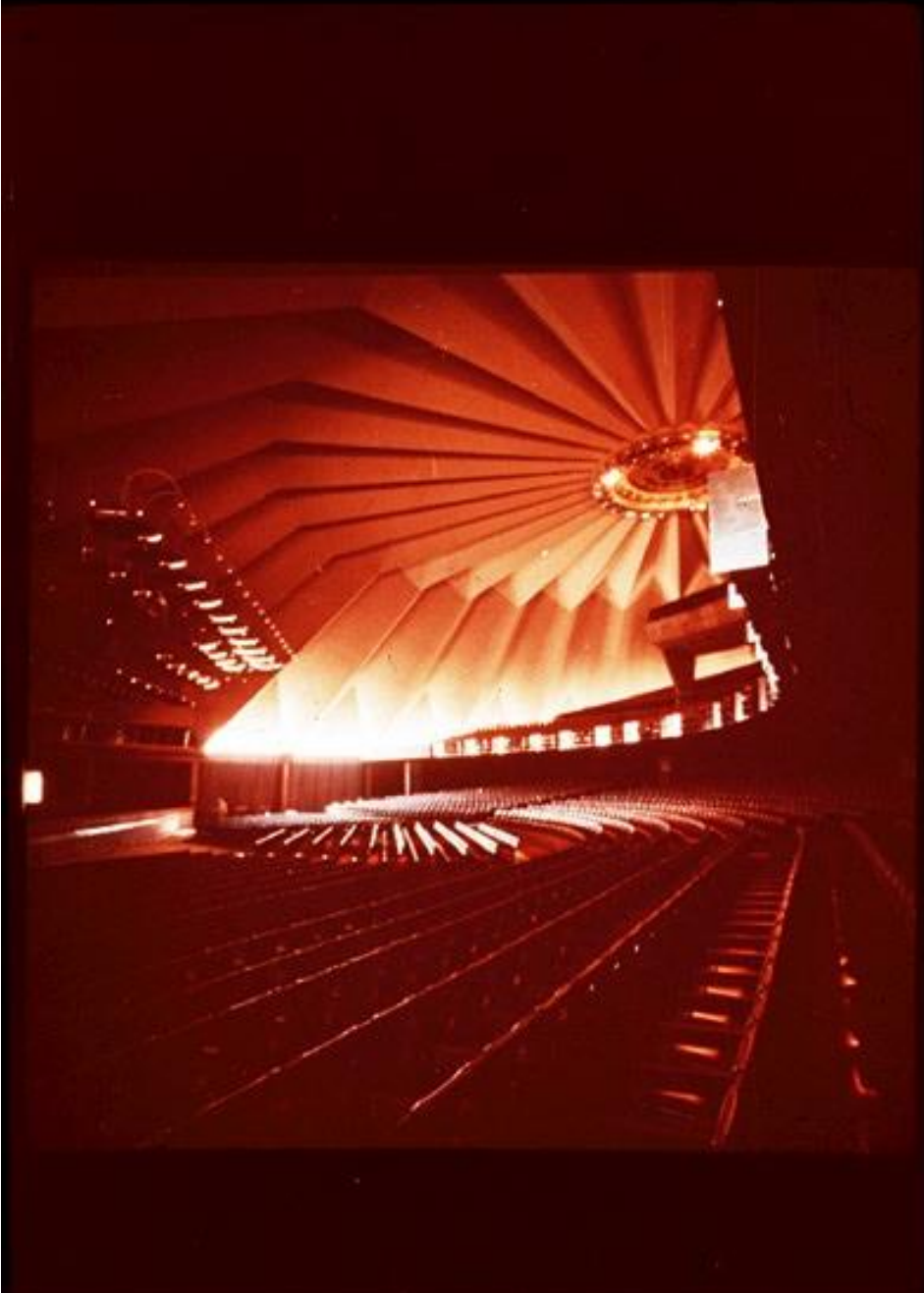


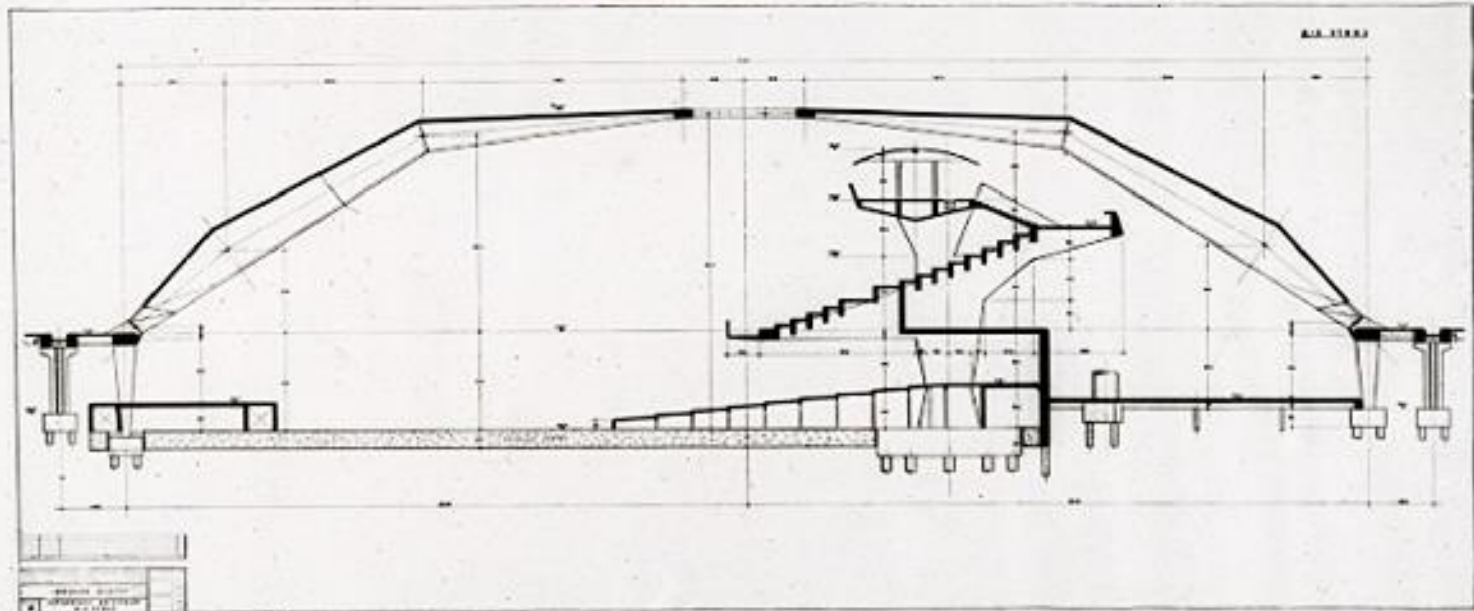












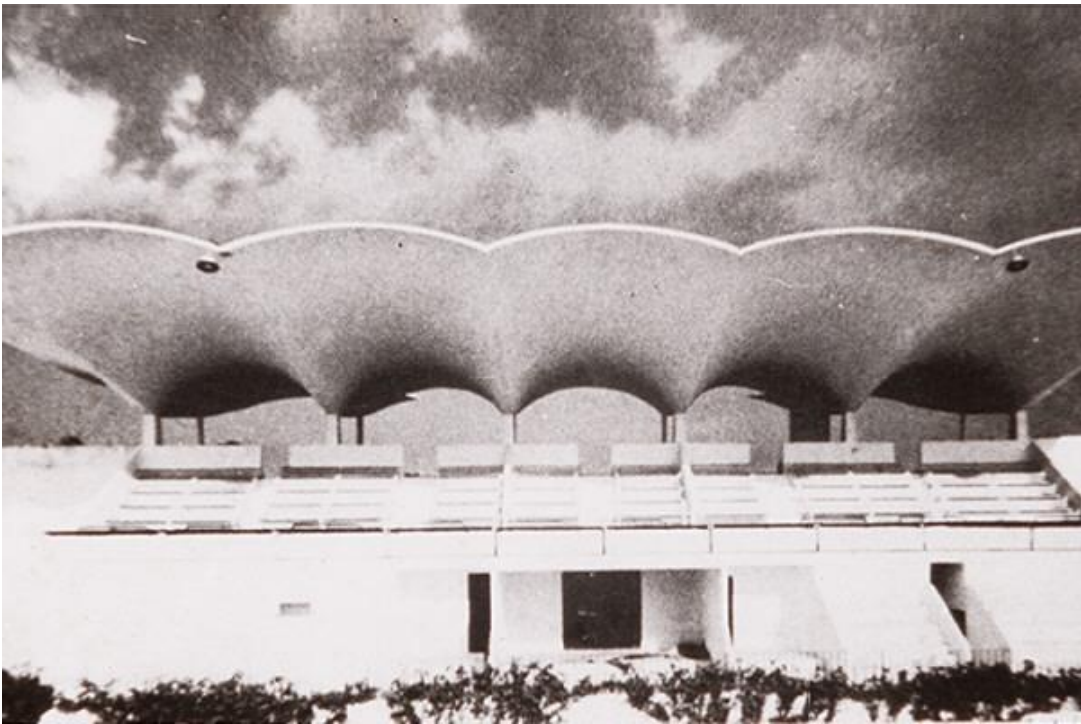
# Posto Catacumba - RJ - 1968

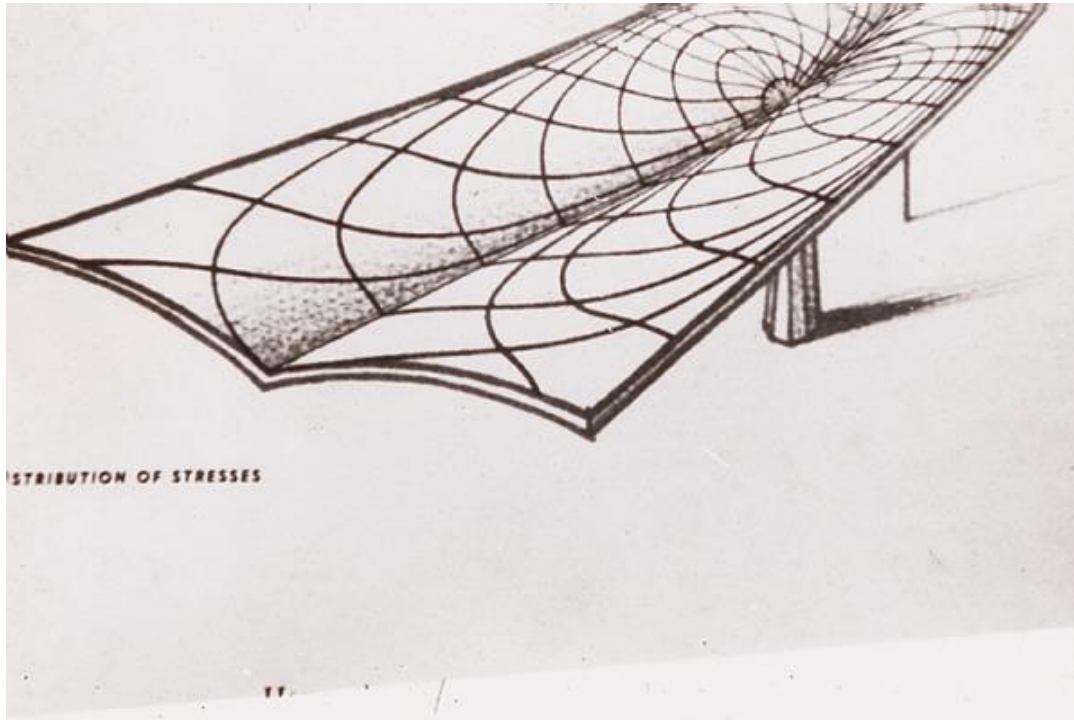
Dilson Gestal Pereira, Waldyr Antunes Figueiredo, Paulo Roberto M. Souza, Alfredo Lemos



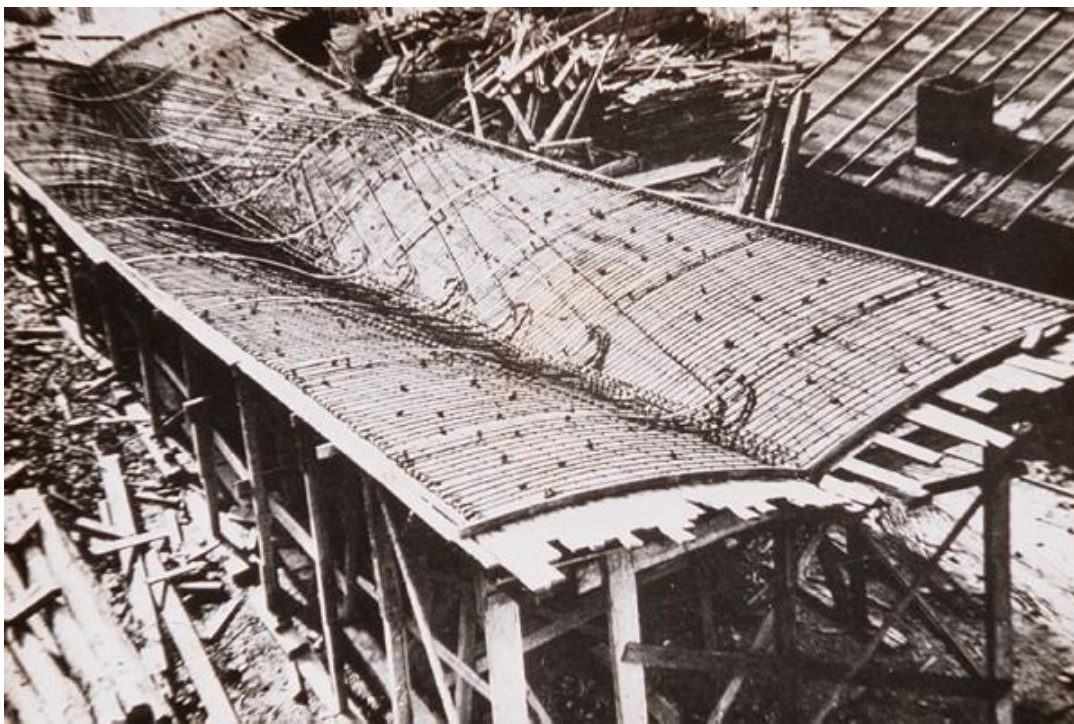


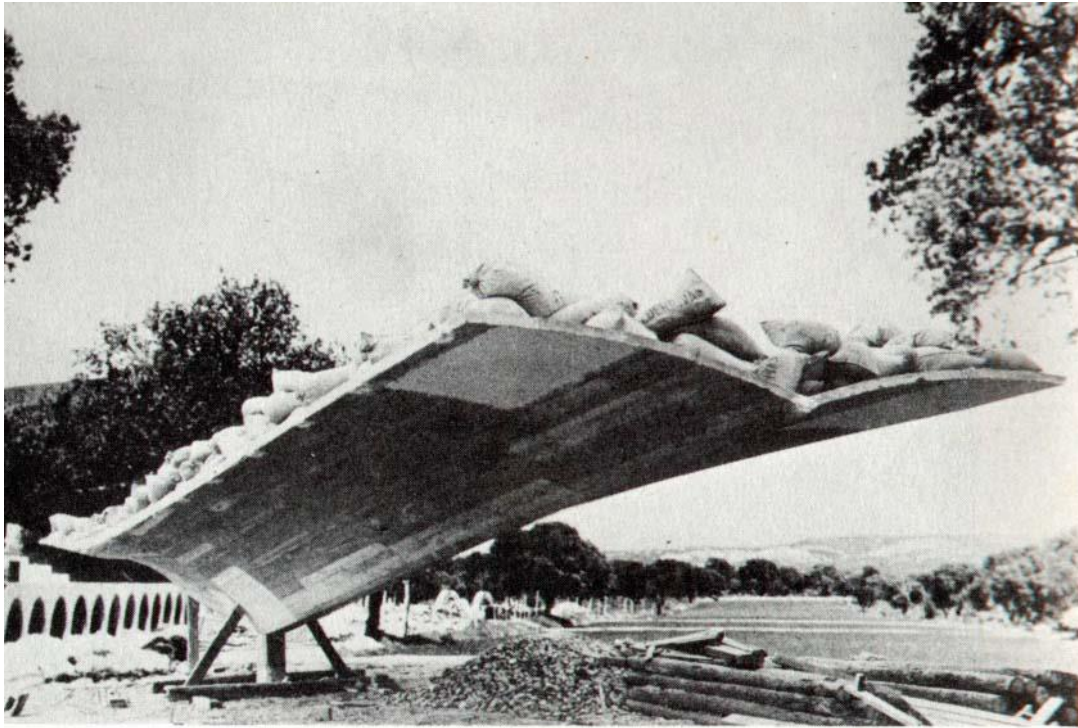










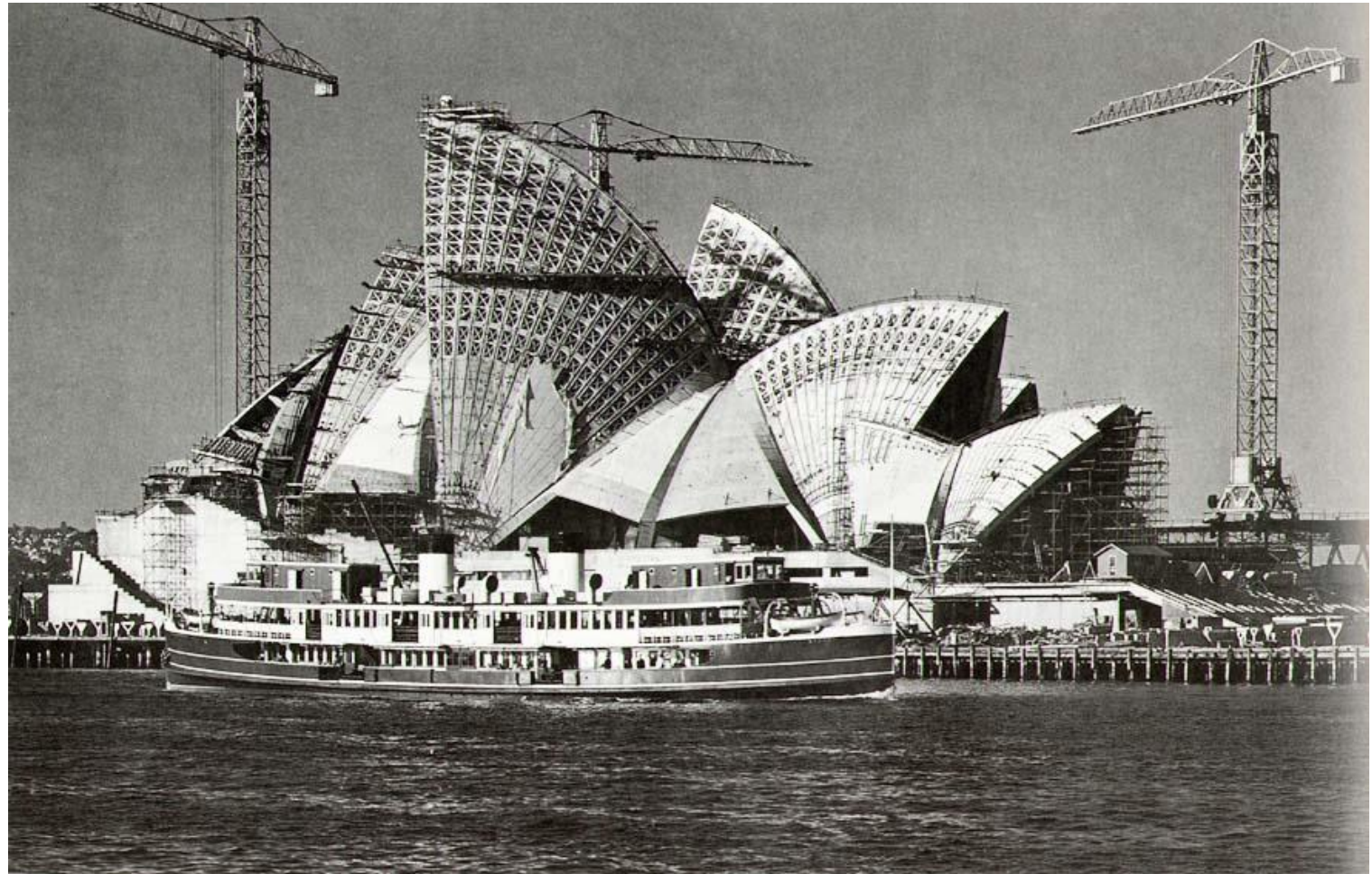




**Sydney Opera House (1958 – 1973)**

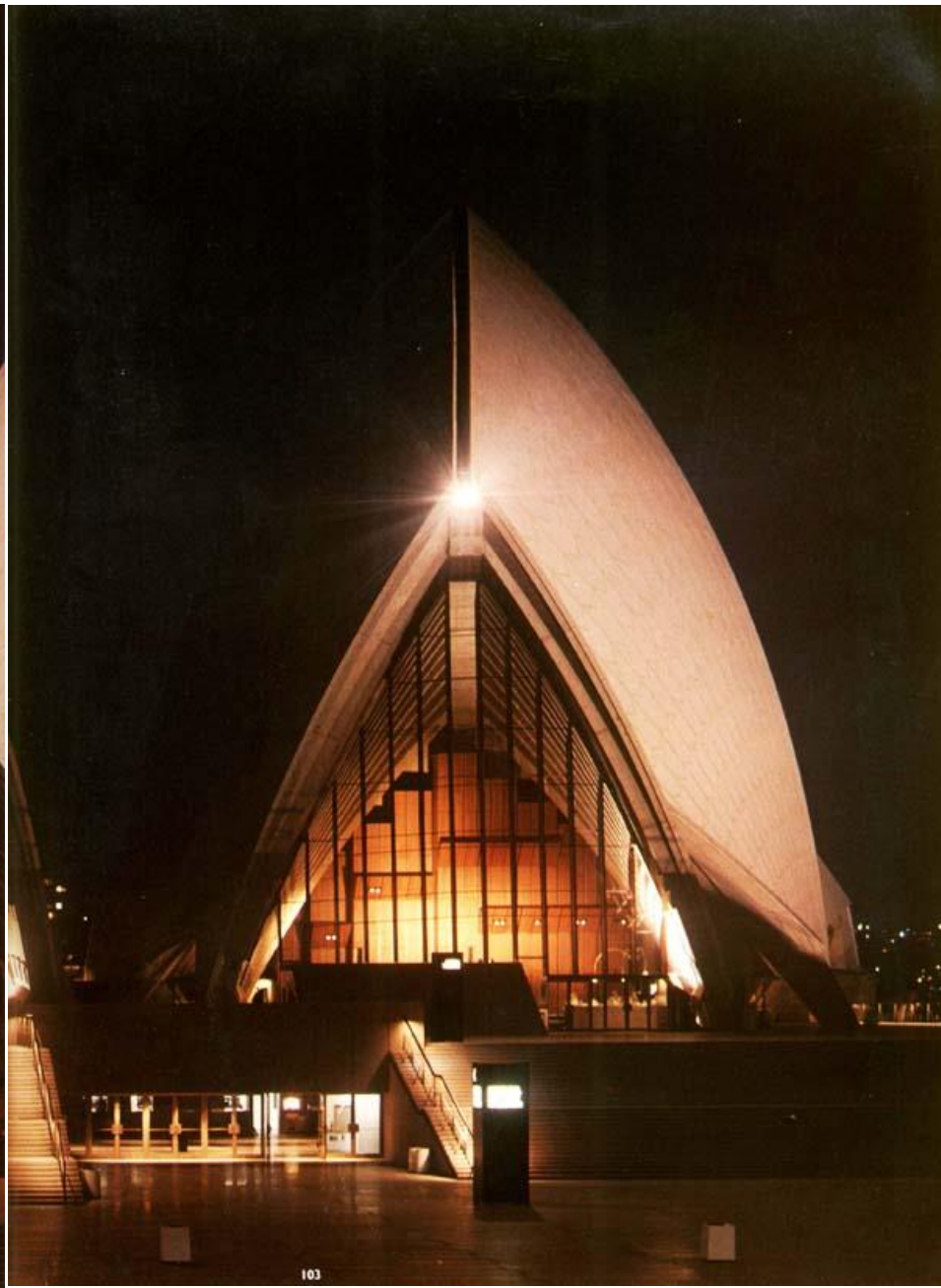
**Double thin shell ribbed ; Concept designer Jørn Utzon; Architect E. H. Farmer , Peter Hall, David Littlemore, Lionel Todd ; Engineer: Ove Nyquist Arup**









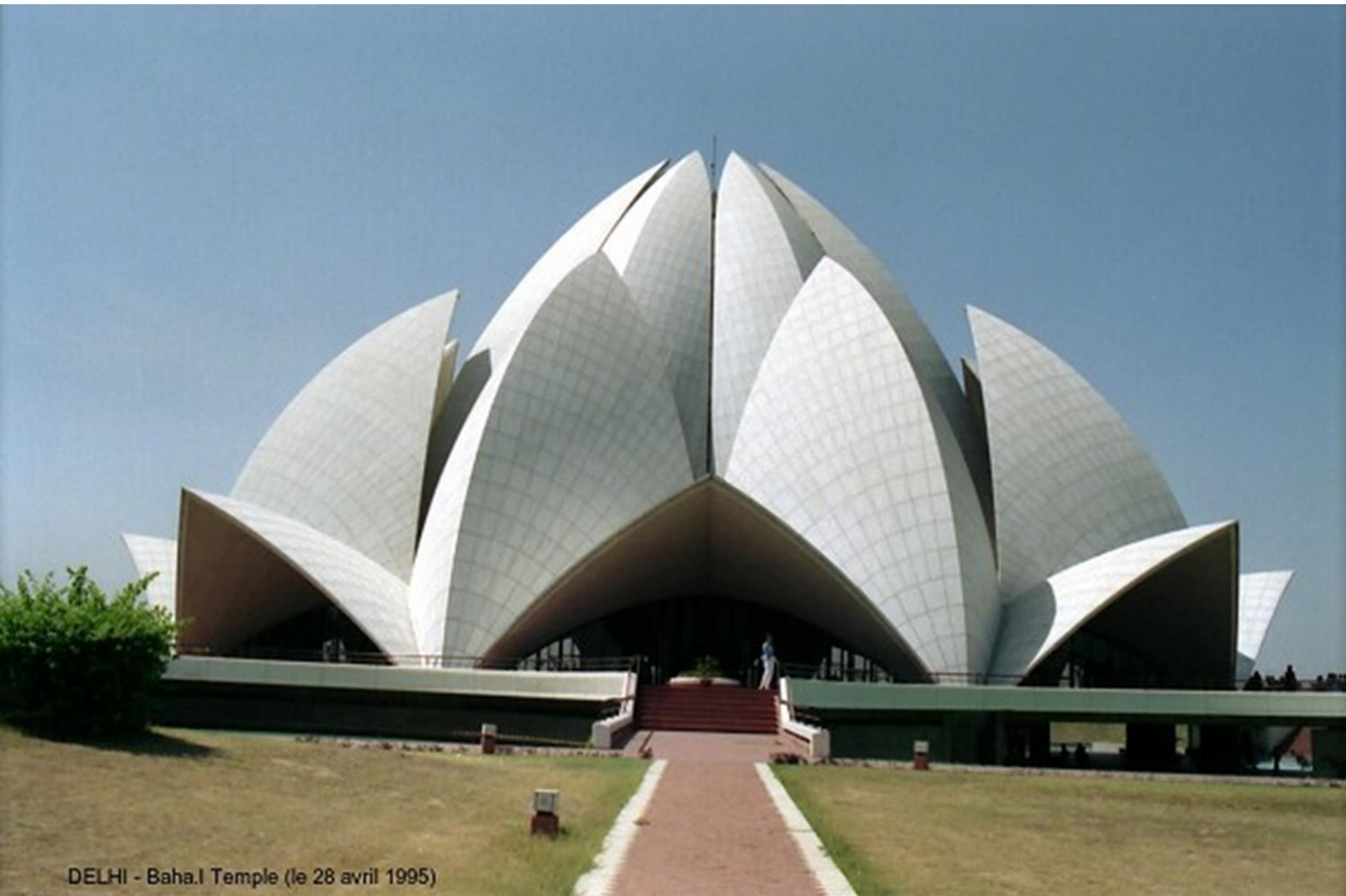






DELHI - Baha-I Temple (le 28 avril 1995)

Fariborz Sahba (canadian architect)



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





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





DELHI - Bahá'í Temple (le 28 avril 1995)

# Memorial da América Latina - SP - 1987

Oscar Niemeyer



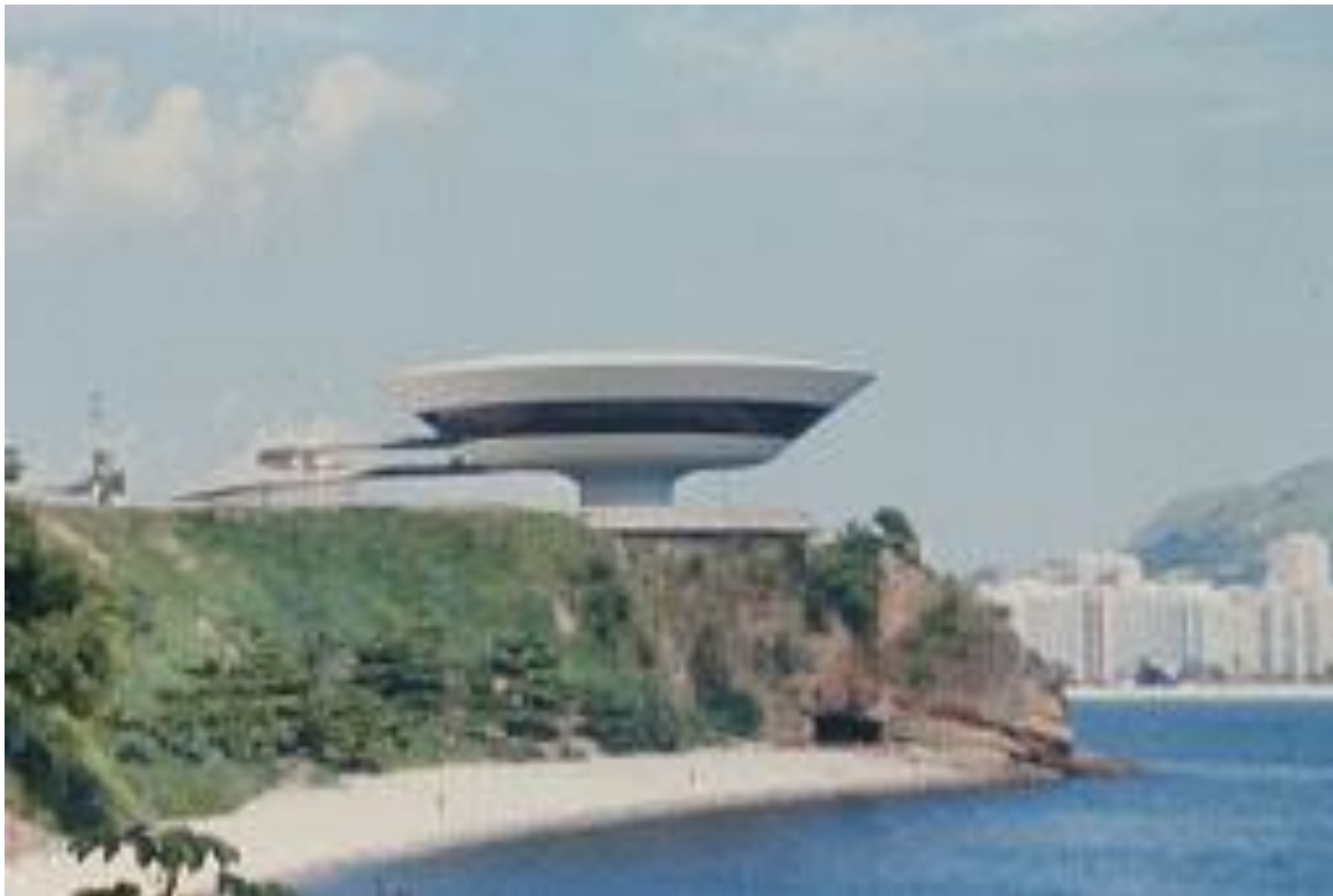


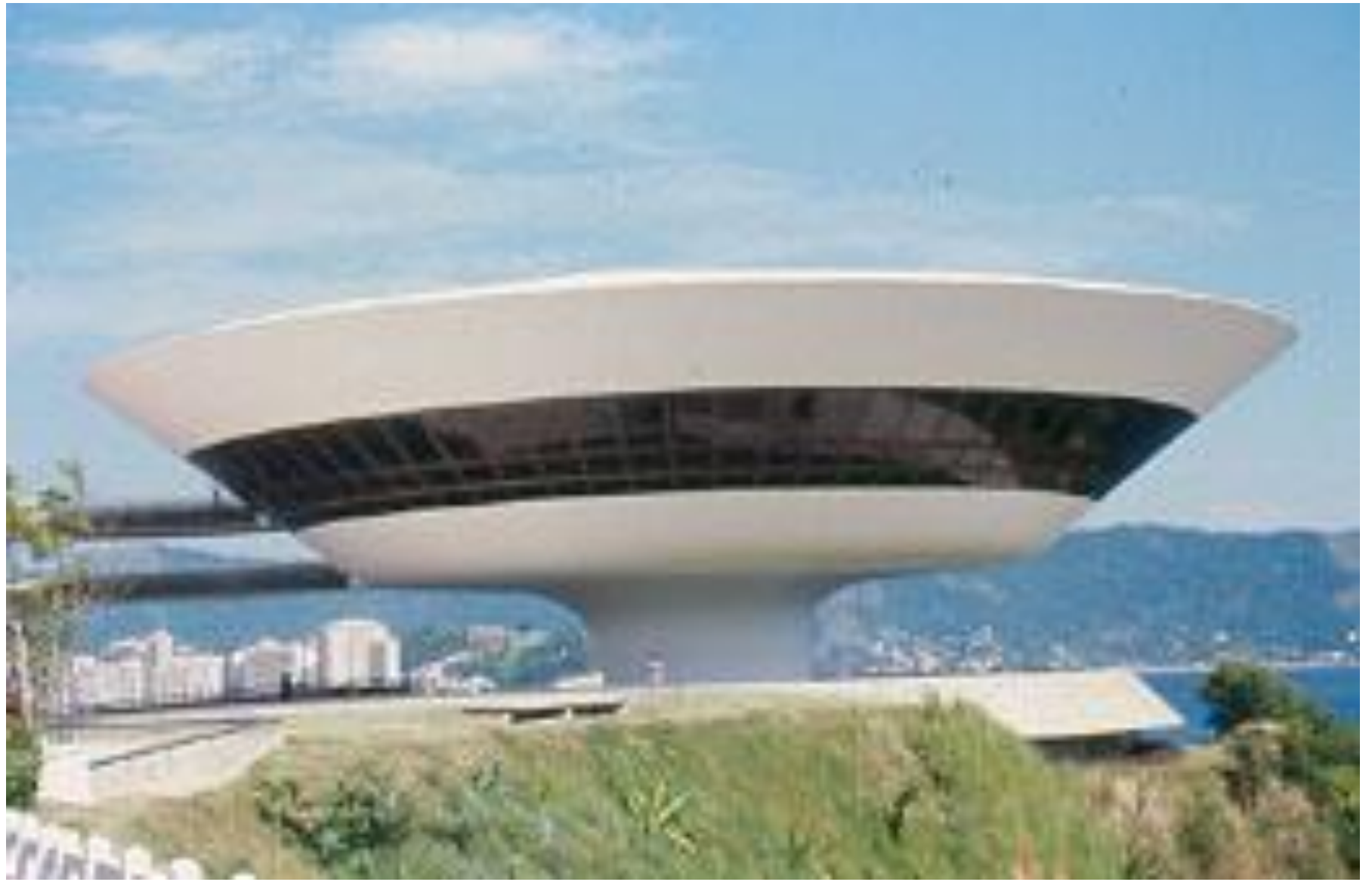




# Museu de Arte Contemporânea - RJ - 1996

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)*



















