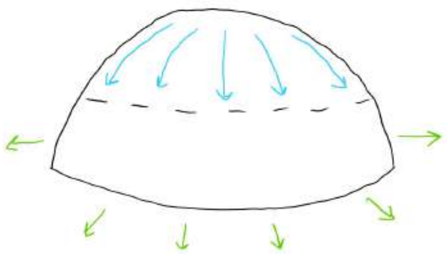
Structural Systems - Shell

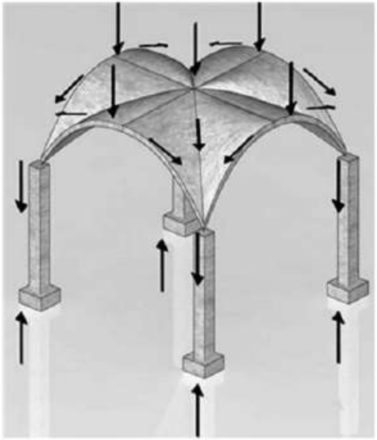
Ranjeet Das A/3317/2019
Nipun Mishra A/3305/2019
Vasudha Channe A/3361/2019

Introduction

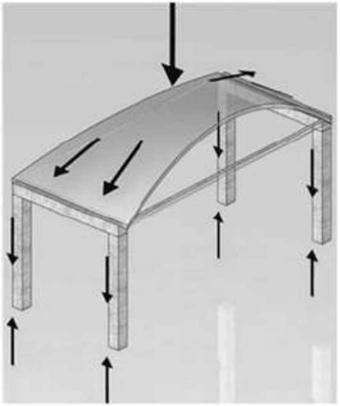


- A shell structure is made of curved sheets, in a natural curvature, that purely uses compressive forces in an inverted catenary or parabolic shapes.
- The thickness of the membrane like shells is tiny compared to the space they can span. But it is mainly membrane stresses that carry loads.
- There can be deep and shallow shells, where usually the top part develops compression due to gravity, and bottom develops tension due to being pushed outwards.
- Inspired by the natural shells of turtles, eggs and crustacea
- Have been developed over time through from stone masonry domes, to brick, concrete, steel and timber.

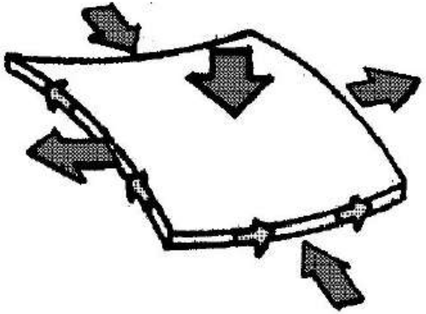
Load distribution



(h) Forces flow in cross vault



(f) Forces flow in conical shell

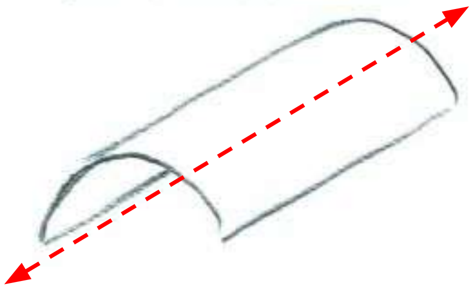


- The shape of a shell allows for loads to be evenly distributed so that every part is supports a small part of the total load

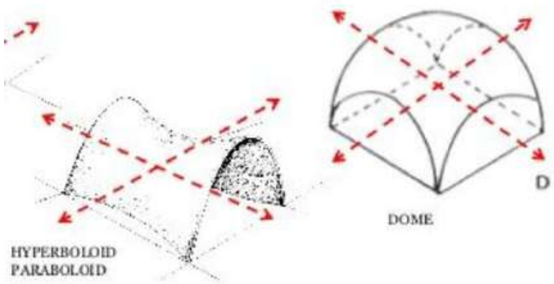
- When loads are applied perpendicularly to the surface, the surfaces surrounding it experience the force, and distribute throughout all the tiles or surfaces.

Types of shell structures

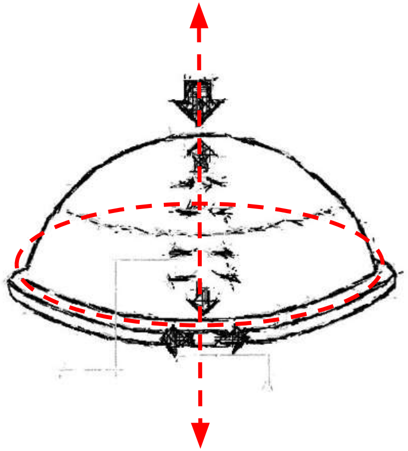
Single curvature/
singly curved shells



Double curvature /
double curved shells

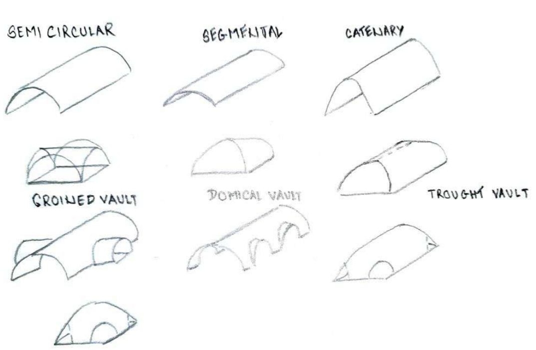


Rotational shells



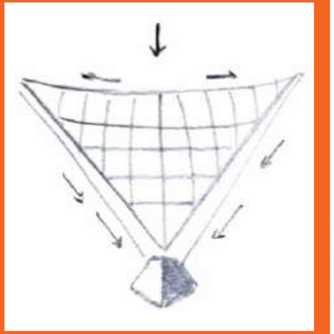
Single curvature shell

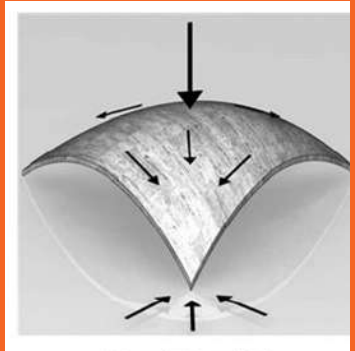
- Shells which are <u>curved on only one linear axis</u>; produce cylindrical or cone shapes called barrel vaults or conoid shells
- The structural behavior of the barrels shell is that it carries load <u>longitudinally as a beam</u> and <u>transversally as an arch</u>, and then <u>vertically through the supports</u>



Double curvature shell

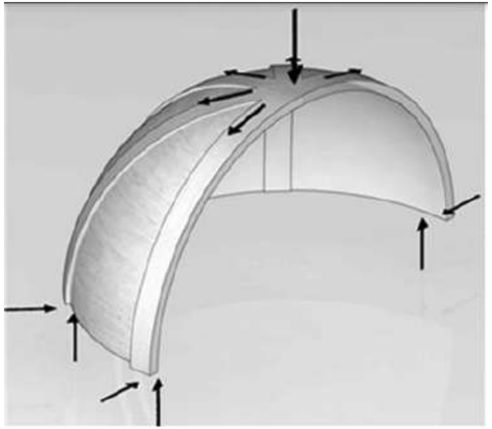
- Shells which are <u>curved on only two linear axis</u>; produced by rotating a parabola, ellipse or hyperbola about one axis, and are a part of a sphere, or a hyperboloid of revolution
- Due to the more tree paths for the load transfer, this is hypothesised to be <u>more effective</u>

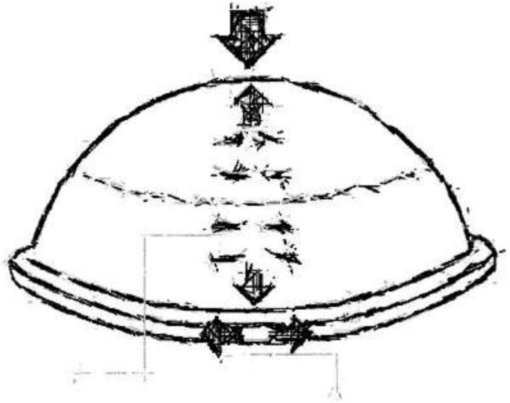


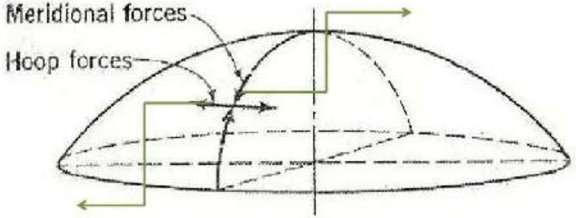


(g) Forces flow in curved shell

Rotational shell







- <u>Shells which are formed by rotating a plain curved shape about a vertical axis</u>; producing domes or different curvatures
- The structural behaviour of a dome is that the <u>load forces are evenly distributed</u> along the arch of the surface, till it reaches the support system

Advantages and Disadvantages

Advantages

1. The curved shape is a naturally strong structure and allows for covering over large spans of space without interior supports
2. Can be very thin shell, making it more light and economical
3. Can easily distribute loads across surface
4. Aesthetically appealing since it can cover large columns-free areas with an aesthetical and functional structure.

Disadvantages

1. Requires precise construction and supervision
2. Rise of roof may be unwanted
3. Outside forces can easily damage the exterior and/or weaken materials

Shell Construction Technologies


Barrel shell


Conoidal shell


Cantilevered shell

Shell design and construction technologies have been developing over time from stone masonry domes to brick, concrete, steel and then timber.

Construction technologies

1. Barrel shell

Barrel shells are one-way arched 'slabs' spanning between two parallel longitudinal supports. There are long barrels and short barrels. Long barrels behave like a beam, while for short barrel shells the top surfaces act like a series of adjacent arches.

2. Conoidal shell

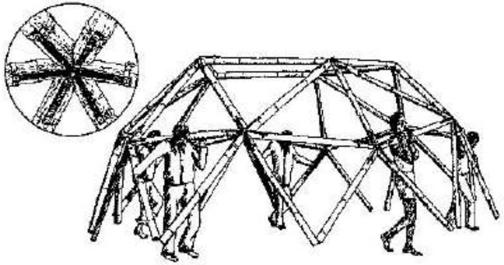
Conoidal refers to a geometric shell formed by rotating a parabola, ellipse or hyperbola about one axis. Conoids consist of two directrix and two straight line generatrices.

3. Cantilevered shell

These are shells that project outward from key points of support. Cantilevered thin shell structures create a sense of an illusion of floating. Just like a cantilevered beam, a cross-section of thin cantilevered shell displays zones with compression and tensile stresses which are transferred to supports by reinforcements and concrete masses.

Materials - Steel and Glass


- The steel was selected as a material for shell rods because of tensile stresses, which concrete cannot resist
- Cost effective, increases with increase in spam
- More convenient to place bars vertically on a sloping surface
- On large shells, patented steel scaffolding is often used and may be rented.



Materials - Bamboo

- Bamboo's strength-to-weight ratio is similar to timber, and its strength is generally similar to a strong softwood or hardwood timber.
- Plain bolted connections can show brittle behavior due to longitudinal splitting of bamboo culms. Providing confinement to bamboo culms at the connection zones increases resistance to this failure mode and brings significant improvement to strength and ductility.
- The use of bamboo as construction material must go through preservation process. It is because bamboo is vulnerable to termites and fungal attack. In construction, bamboo is generally preserved using borax boric acid solution through several techniques, such as immersion, gravitational or vertical soak diffusion, and injection using compressor machine

Materials - Masonry

- The principal components of masonry are the masonry elements and mortar embedment, include naturally available stones, dressed stones from quarries, made-up bricks of sun dried clay and burnt bricks in kilns.
- Mortar in masonry has developed from primitive mud, natural bitumen to a mixture of lime and sand and cement mortar.
- From a structural point of view masonry is a homogeneous material. The strength of the masonry is limited by its weakest joints. Its load-carrying capacity largely depends on the mortar strength. The allowed stresses in masonry are categorised into compressive axial, compressive flexural, tensile flexural and shear.

Materials - Concrete

- The use of concrete as a building material reduces both materials cost and the construction cost. As concrete is relatively inexpensive and easily cast into compound curves.
- Since concrete is porous material, concrete domes often have issues with sealing. If not treated, rainwater can seep through the roof and leak into the interior of the building.
- The seamless construction of concrete domes prevents air from escaping, and can lead to buildup of condensation on the inside of the shell.

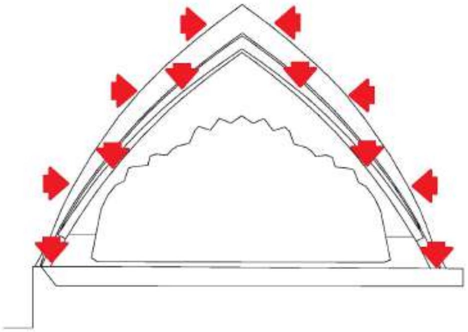
E1. Sydney Opera House

General Information;

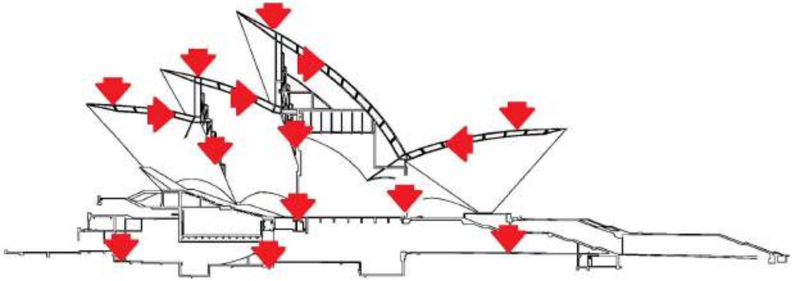
Building Types	- Opera House
Architect	- Jorn Utzon
Structural Engineer	- Ove Arup and Partners
Construction started	- March 2, 1959
Location	- sydney australia
Height	- 65m
Area	- 1.8ha

1. Each of the shell structures was a mirror arch taken from parts of a sphere, which Jørn Utzon the architect, had called the Spherical Solution. Not only were they stable in a structural sense, but also aesthetically coherent with the vision he had.
2. The shells of the Sydney Opera House are precast concrete panels supported by precast concrete ribs which are a series of parabolas
3. The shell structure distributes loads easily through its precast concrete ribs to the base of the entire structure

E1. Sydney Opera House



Horizontal Loading: External Loads are Transferred Down Along the Shell.



Vertical Loading: Follows the Interior Ribs Down to the Footings.

General Information

- Length - 611 ft
- Width - 380 ft
- Highest Point - 221ft
- 217 ft of steel cable
- 2194 precast concrete ribs (avg=15 tons)
- 67,000 square feet of glass
- 580 concrete piers (foundation)
- 479,160 square feet of usable and office space

Dead Load Calculations

Roof Ribs
2194 x 15 tons = 32,910 tons
Steel Cable (dia-3/4")
217mi x 5280ft x 1.25lb/ft = 716 tons
Laminated Glass
67000sf x 3.125lb/sf = 104 tons
Concrete Support Columns
582ft x 8ft x 143col x 82ft = 27,298 tons
Roof
30,015 tons
Air Conditioning
50 tons
Dead Load Total = 91,093 tons

Live Loads

611ft x 380ft x 80psf = 9,287 tons

Live and Dead Load Total

91,093 + 9,287 = 100,380 tons

Wind Loads

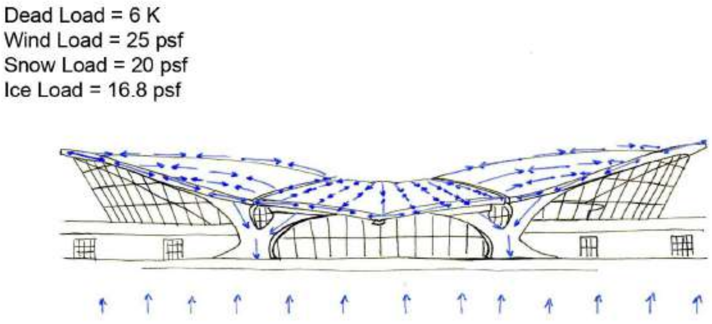
North Side
85,854sf x 77psf = 3305 tons
South Side
67,060sf x 77psf = 2581 tons
East Side
63,594sf x 77psf = 2448 tons
West Side
67065sf x 77psf = 2582 tons

E2. TWA Flight Centre

General Information;

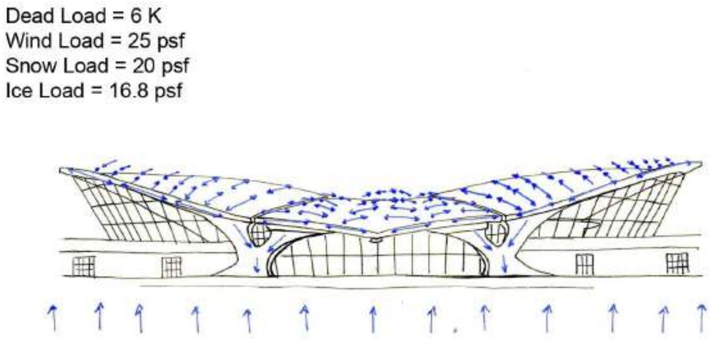
Building Types - Airport Terminal
Architect - Eero Saarinen
Construction started - June 1959
Location - New York City, New York
Height - 23m
Area - 7 ha

1. The roof is thin shell construction which uses a reinforced concrete shell roof supported at the corners
2. The roof consists of 4 shells; two upward-slanting shells at the edges, which resemble wings, and two smaller shells slanting downward toward the front and back of the structure
3. The rooftop shells converge at the center of the roof, where each of the four shells supports the others. Four "Y"-shaped piers support the roof, facing the front and back facades



TRANSFERRING MERIDIONAL FORCES

LOADING CONDITIONS

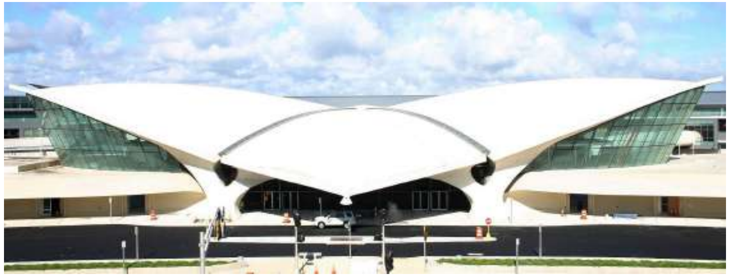


TRANSFERRING HOOP FORCES

LOADING CONDITIONS

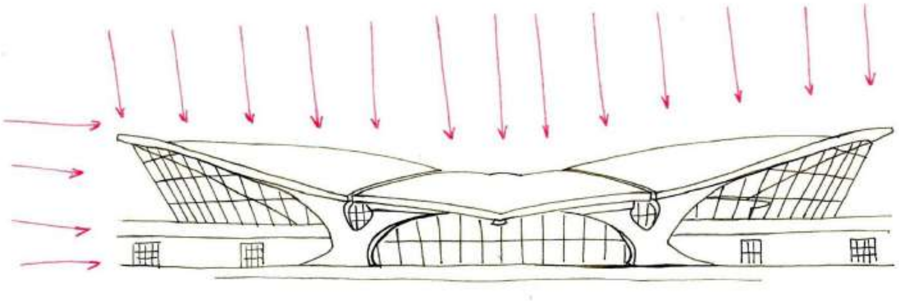
E2. TWA Flight Centre

Dead Load = 6 K
Wind Load = 25 psf
Snow Load = 20 psf
Ice Load = 16.8 psf



BUTTRESS (COLUMN) SUPPORTS

STRUCTURAL DESIGN



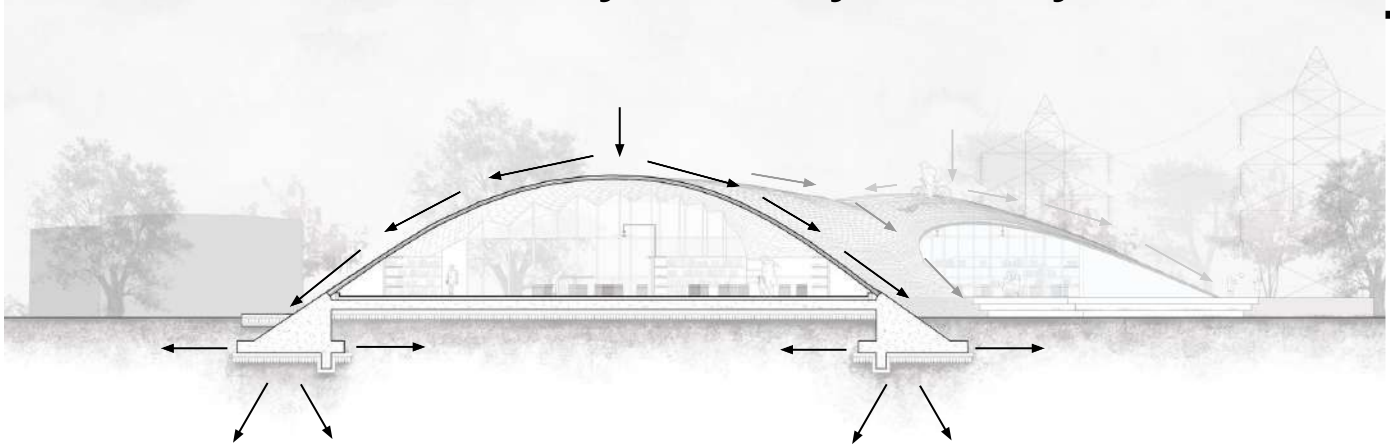
VERTICAL AND LATERAL LOADS

LOADING CONDITIONS

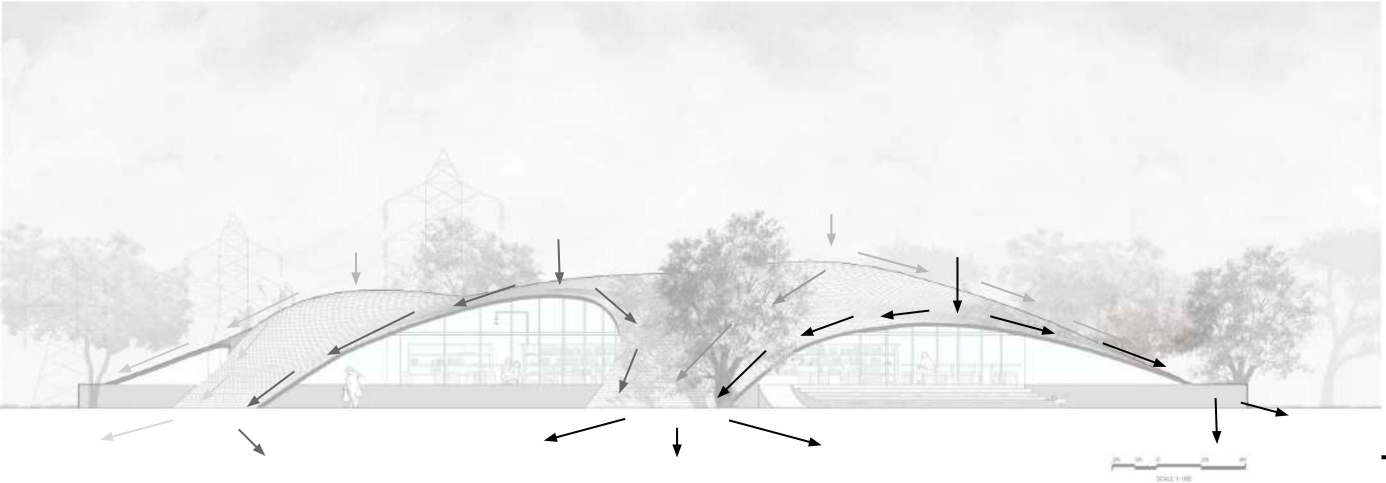
SHELL ROOF

STRUCTURAL DESIGN

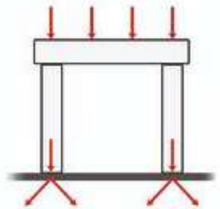
3. Maya Somaiya Library, Sharda School



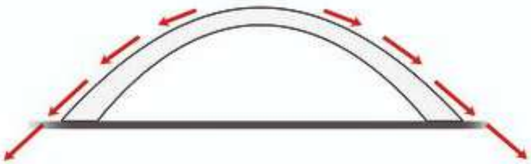
<u>General Information;</u>
Building Types - School Library
Architect -Sameep Padora & Associates
Structural Engineer - Sameer Sawant
Construction started: October 2018
Location - Kopargaon
Height - 6m
Area - 5750ft2



3. Maya Somaiya Library, Sharda School

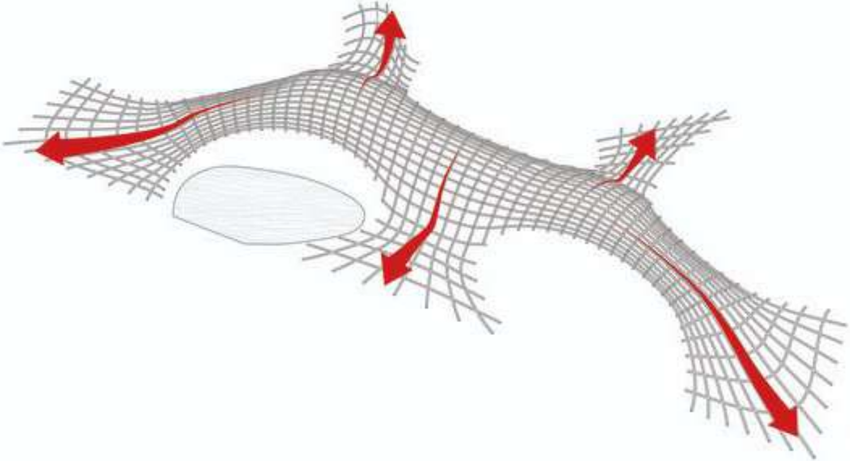


Conventional Trabeated Structure

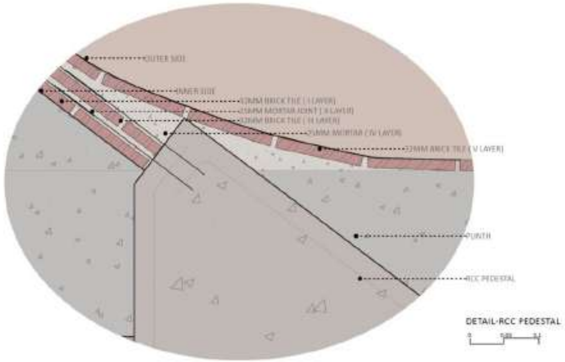


Forces acting on a Vault

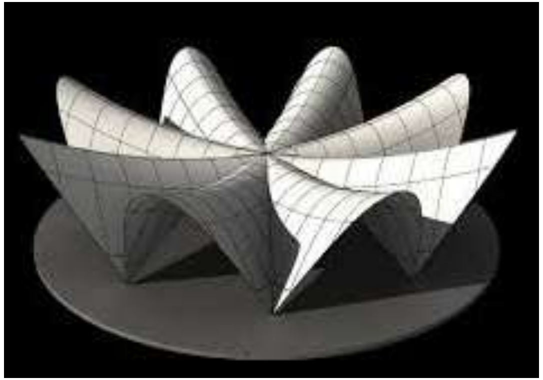
1. Has a span of the vaulted structure is 45x8 m, and it is 100 mm thick
2. The roof structure is 3 layers of 32mm thick brick, with underground concrete pedestals at contact points on the ground
3. The roof carries its self load, as well as live load of people who climb it
4. Was designed using Rhino Vault, which creates vaults only under the force of compression

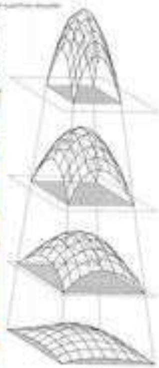


Sharda Library Force Diagram



4. L'Oceanogràfic





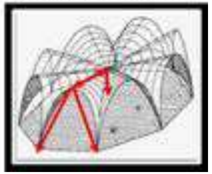
L'Oceanogràfic

Ubicación: Valencia, España

Arquitecto: Félix Candela

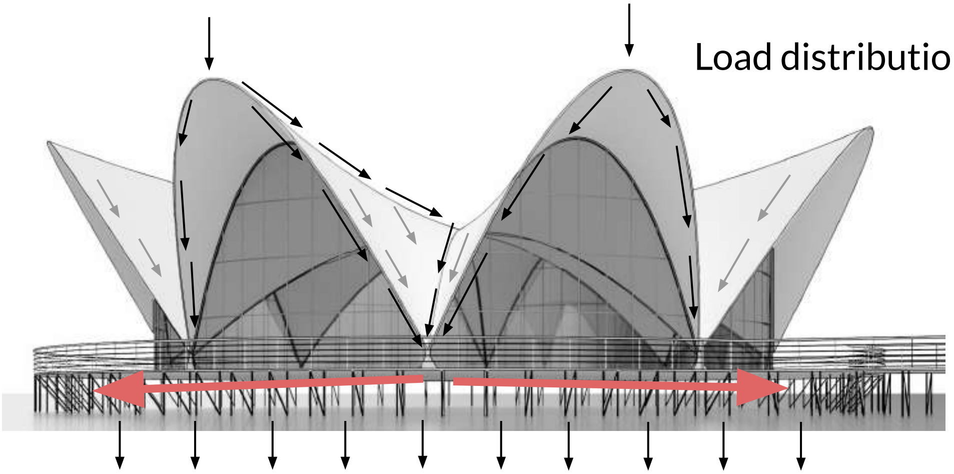
Sistema Estructural de Superficie Activa
Estructuras en estado de tensión superficial, tales como las placas, membranas y cáscaras.

Esta estructura esta compuesta de laminas de metal parabólicas. El espacio queda cerrado por las placas de vidrio debajo de la estructura. Este tipo de estructura permite crear un espacio amplio y flexible por dentro.



4. L'Oceanogràfic

General Information;
Building Types - Oceanarium
Architect - Felix Candela
Structural Engineer - Alberto Domingo and Carlos Lázaro
Construction started: October 1997
Location - Spain
Height - 26m
Land Area - 110000m2



1. This roof is made up of eight hyperbolic paraboloidal vaults arranged on a circular ground plan of about 140 feet in diameter. Apart from deeply recessed glass wall, the paper-thin (1 ⅝ inches) roof is the entire structure.
2. The buckling load might be improved by increasing the geometric curvatures and the shell thickness.
3. This geometry involves enough mechanical features to be a very efficient structure, even without stiffening elements such as edge beams. This implies that shell structures designed to behave as membranes are, by themselves, optimal structures.