Structural System in Architecture
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Lecture No -29
Application of Arch and Shell in Architecture

Concepts Covered

- Thrust Line: Application in the Gothic Cathedrals
- Application of Arch in Architecture
- Application of Shell in Architecture
- Design Exercise with Shell Structure

Learning Objectives

- To learn the application of Arch and Shell in Architecture
- Designing the Shell roof for a given space

Thrust Line: Application in the Gothic Cathedrals

If the thrust line is too inclined and goes beyond the width of the support, the system becomes unstable.

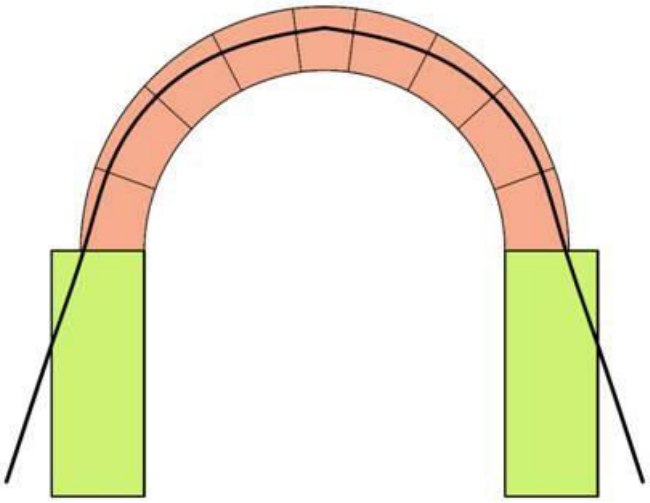


Figure 1 Inclined thrust line

For stability of the structural system, two alterations may be suggested:

1. Wider Pier absorbs the inclined Thrust line within it.

2. Additional gravity Load neatly supports and changes the line of action of Thrust Line (From Incline to vertical)

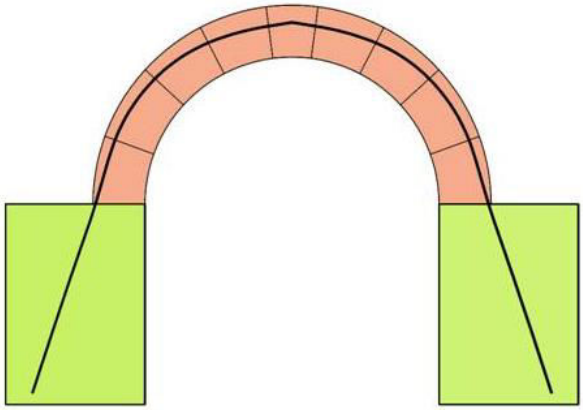


Figure 2 Wider pier

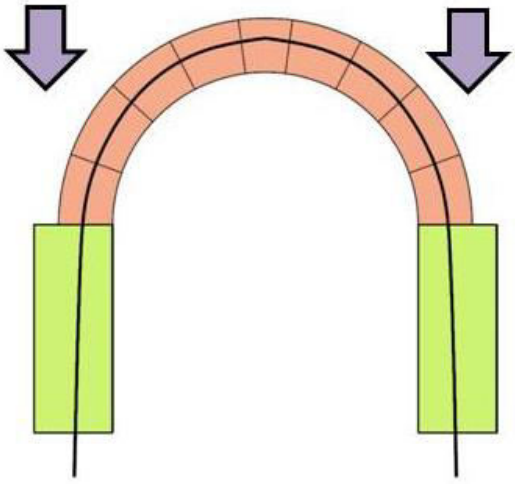


Figure 3 Additional gravity load

If you recall this theory was explained with the help of a short video wherein a few matchboxes were piled one above the other at first with the shorter side facing front and the with the longer side facing front as shown in the following figures. In both the cases the pile of matchboxes were pushed with the help of a mechanical pencil repeatedly.

Before **After**

Figure 4 Thrust action in case of shorter side facing front

The Figure 4 shows the before and after push screenshots of the pile when the shorted side was facing front. And as a matter of fact, the pile crumbled just after a couple of jolts.

Before **After**

Figure 5 Thrust action in case of wider side

Before **After**

Figure 6 Thrust action in case of wider side facing front and additional gravity load

In both of the above cases the pile had to be pushed repeatedly as it ceased to crumble even after repeated jolts.

Additionally, the following examples from the historical buildings also combat the thrust actions.

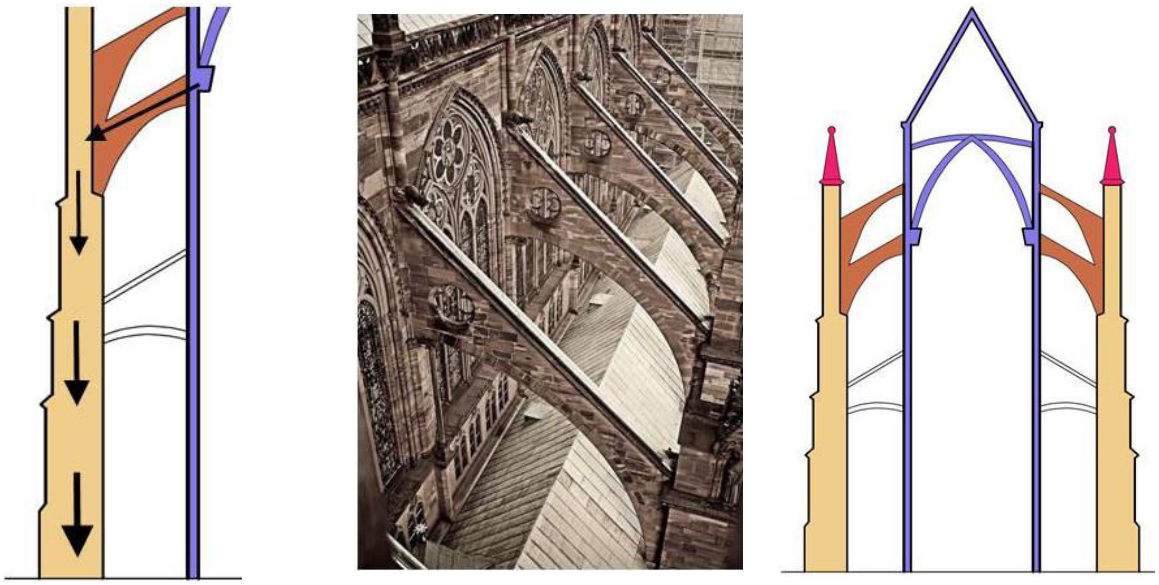


Figure 7 Flying buttresses

Figure 7 shows the flying buttresses. These are usually found in the buildings of ancient Gothic Architecture. The flying buttresses act as a member conducting the lateral thrust. Additionally, Figure 8 shows the pinnacle which adds the vertical weight and provides more vertical thrust.

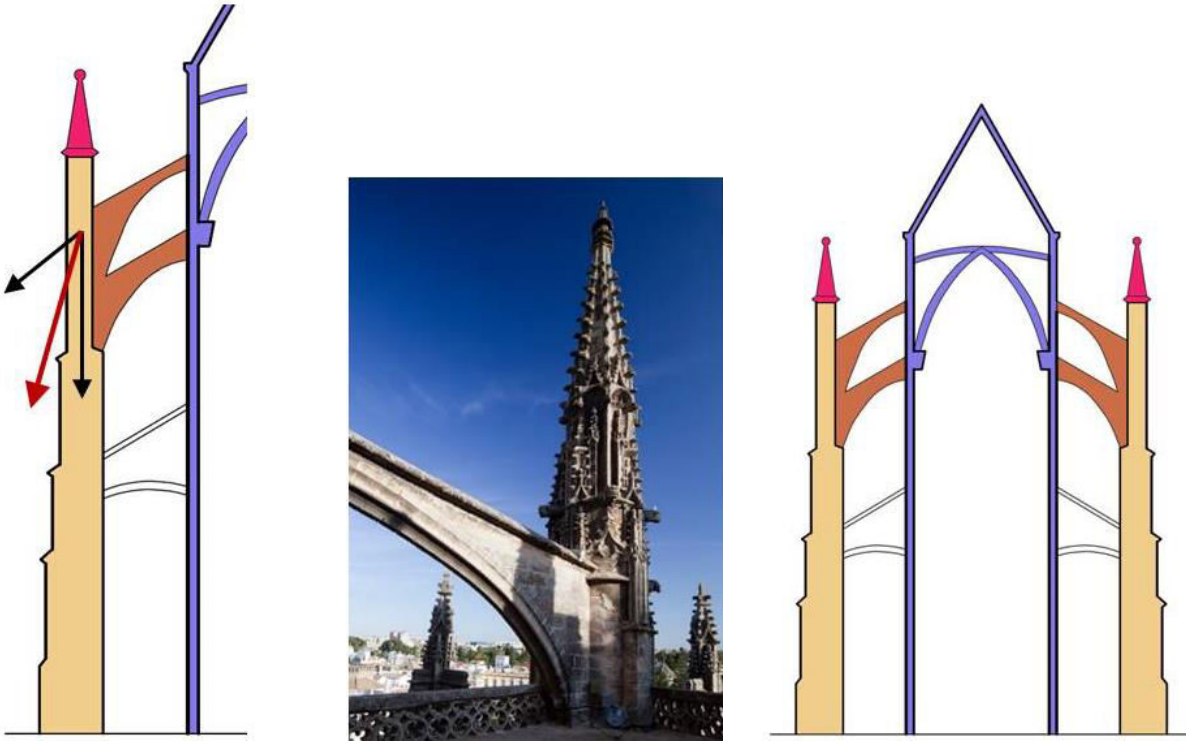


Figure 8 Pinnacles

Application of Arch in Architecture

Calgary Saddledome, Canada (1983)

Hyperbolic paraboloid shell roof and approximately elliptic in plan.

The central point of the roof is located 14 m below the highest point of the edge ring and 6 m above the lowest point of the edge ring.

Figure 9 Calgary Saddledome, Canada (1983)

Kunming Airport, China

Light weight roof profile supported by series of arches is the main structural attraction of this airport. The roof profile is inspired from the traditional Chinese Architecture, which is extremely light in weight and is a suspended kind of a ceiling which is further supported by the series of parabolic arches as evident from the figures below.

Figure 10 Kunming Airport, China

Padre Pio Pilgrim Church, San Giovanni Rotondo, Italy (2004)

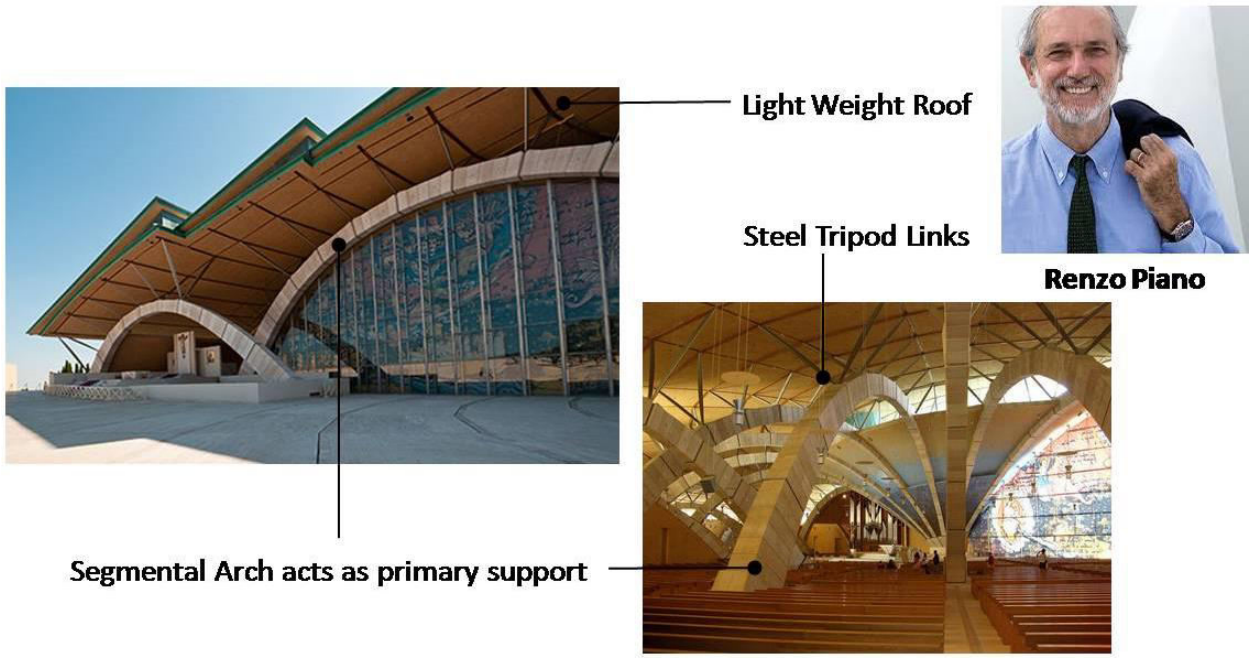


Figure 11 Padre Pio Pilgrim Church, San Giovanni Rotondo, Italy (2004)

Similarly, this masterpiece of the architect Renzo Piano also follows a similar principle wherein a lightweight roof was supported by a series of arches as the primary support which are again connected to the ceiling with the help of metal tripods which are also visible in the elevation.

Athens Olympic Sports Complex (2004)

Figure 12 Athens Olympic Sports Complex (2004)

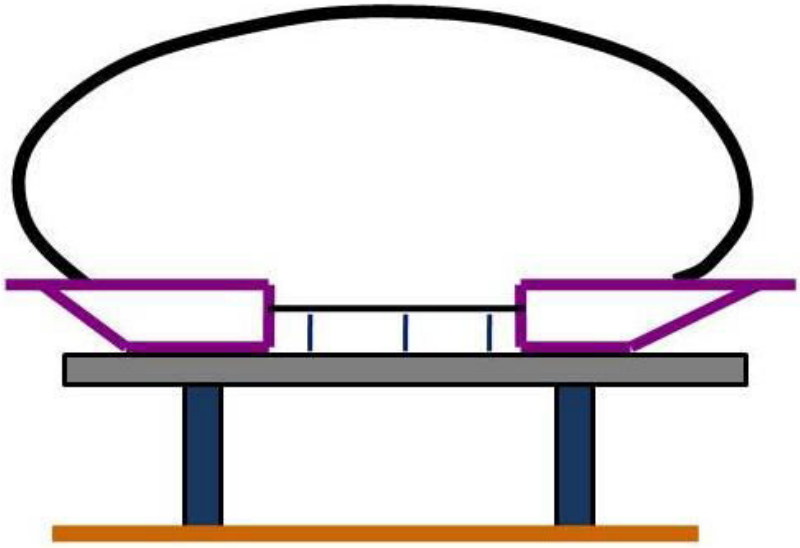
The roof was constructed over an already existing stadium by the architect Santiago Calatrava, in the form of two bent leaves enabling ample natural light within the building. Besides the most stark feature of the roof is that it is supported by two huge parabolic arches. Next, if you notice carefully in the figures you'll see that the arches are thicker towards the bottom and are anchored to the ground with the help of massive columns. Additionally, there are diagonal bracings joining

the base of the roof to that of the arches to take care of the thrust actions. And most importantly, the whole roof is suspended from these arches with the help of suspension cables.

Application of Shell in Architecture

Brin Station, Genoa, Italy: Use of Elliptical Arch

1. Elliptical Arch Ribs used as a long span supporting structure. Ribs are fabricated as Mild Steel Castellated Beams.



Each deep girder is supported by two Columns.

2. Ribs bent back and supported on a Pre-stressed Deck Floor.
3. Pre-stressed deck floor is finally supported by deep Cross Girder. The girder also supports the central railway track.

Figure 13 Brin Station, Genoa, Italy

Santa Justa Train Station, Seville, Spain: Use of Parabolic Arch

1. Parabolic arch profile is subjected to uniform load.
2. A funicular form minimizes the bending action.
3. Arches are supported by a deep side beam.
4. Beams are supported by circular mega columns.

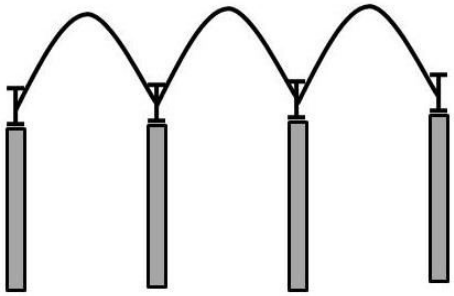


Figure 14 Santa Justa Train Station, Seville, Spain

L'umbracle, City of the Art & Sciences, Valencia, Spain : Use of Catenary Arch

The Umbracle is a 17,500 sq. m open to sky, landscaped and elevated exhibition zone designed by Santiago Calatrava.

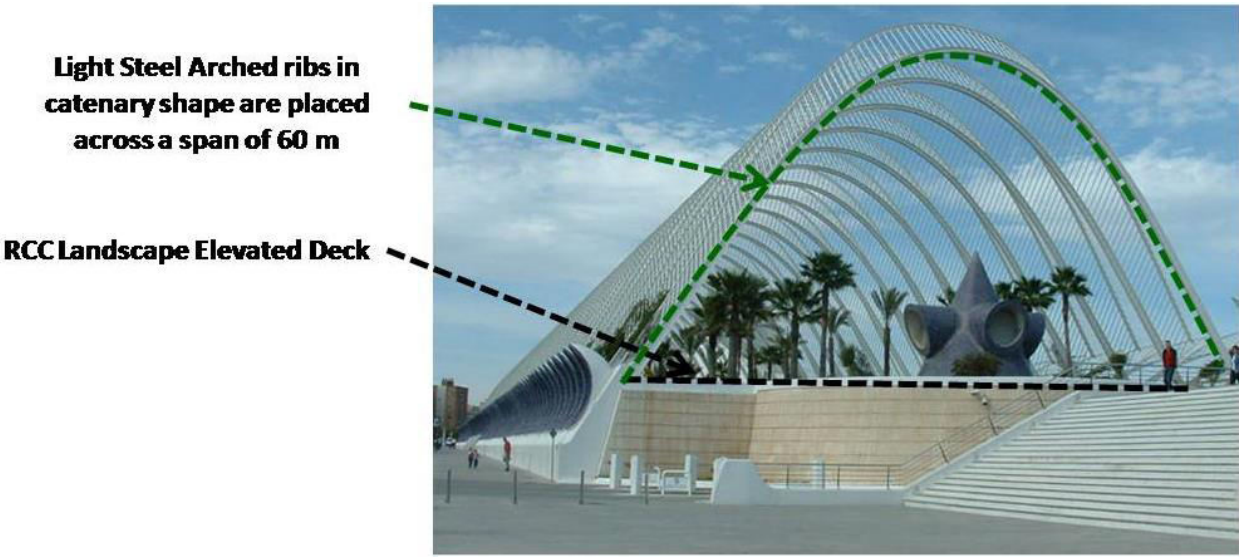


Figure 15 L'umbracle, City of the Art & Sciences, Valencia, Spain

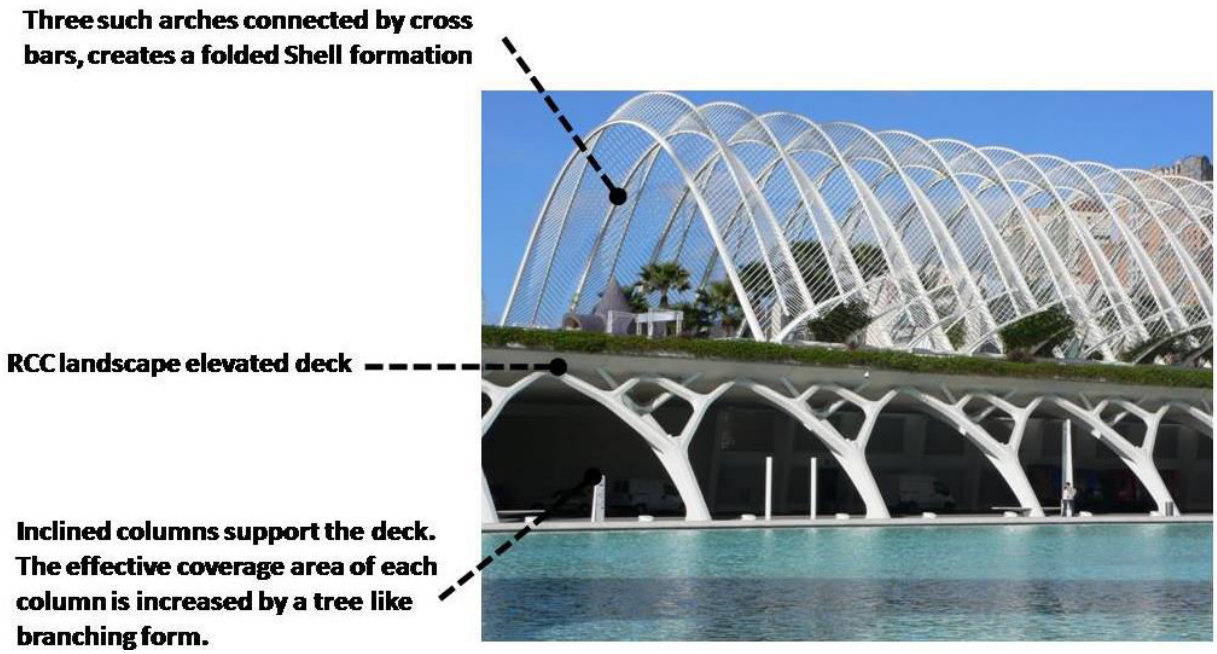


Figure 16 L'umbracle, City of the Art and Sciences, Valencia, Spain

Bilbao Airport, Spain (1990-2000)

The aerodynamics building form looks as if lifting upwards and trying to take off. The airport has a popular nickname of "The Dove".

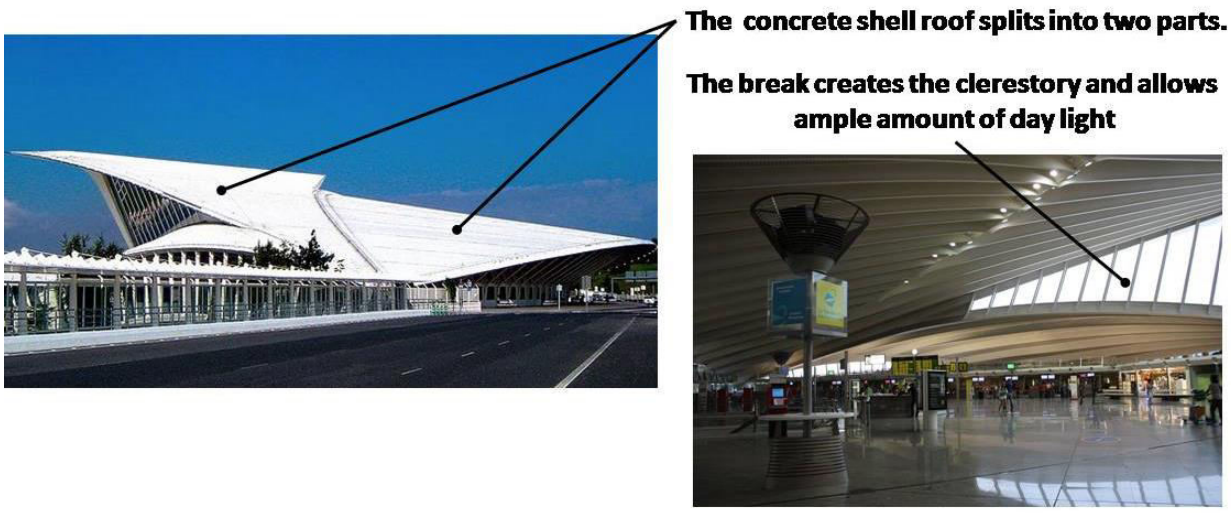


Figure 17 Bilbao Airport, Spain

Tenerief Auditorium

The building is composed with platforms at various level, rapped by the curved shells; a curved concrete cupola 60m high, crowned by a curving roof like a breaking wave.

Figure 18 Tenerief Auditorium

City of Arts and Sciences and Opera House in Valencia (2006)

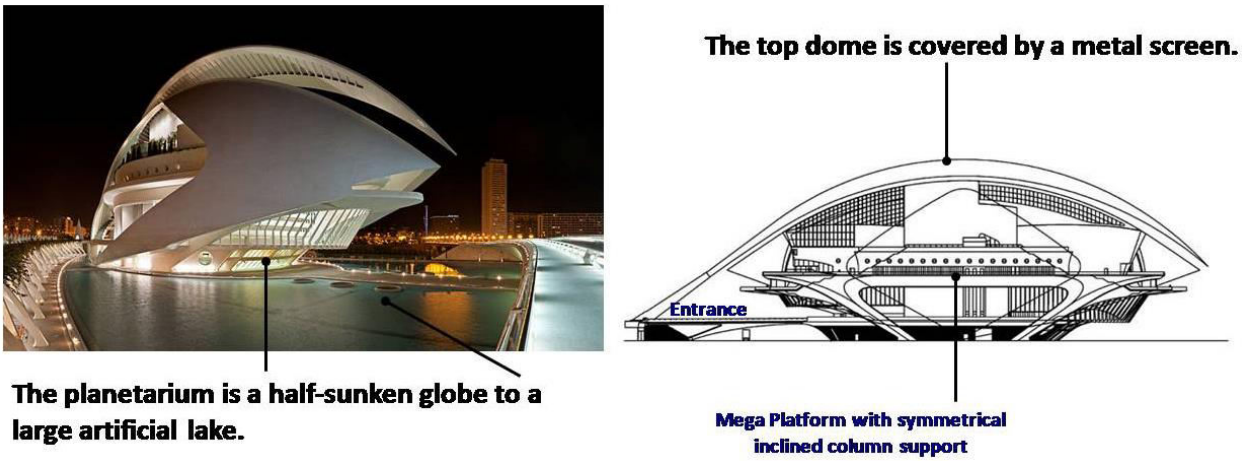
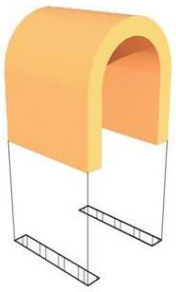


Figure 19 City of Arts and Sciences and Opera House in Valencia

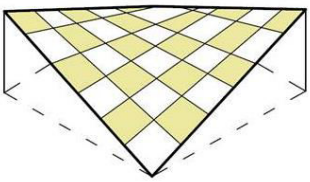
Design Exercise

1. Suppose you are provided with a given area as shown in the figure here, whose roof has to be designed. How would you do it?

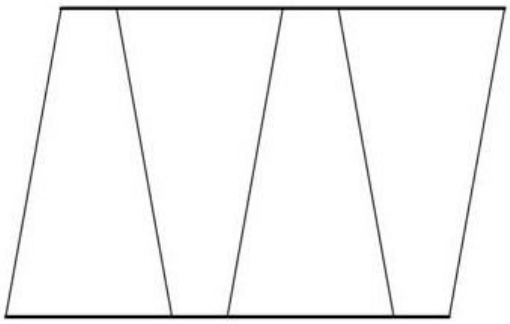
Solution:

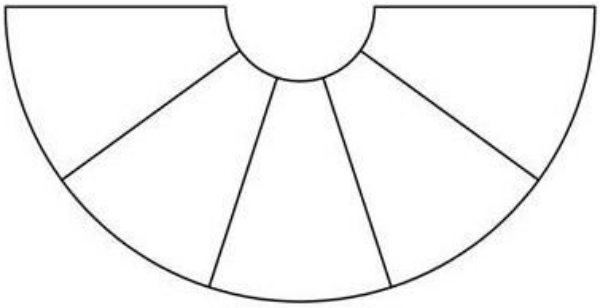


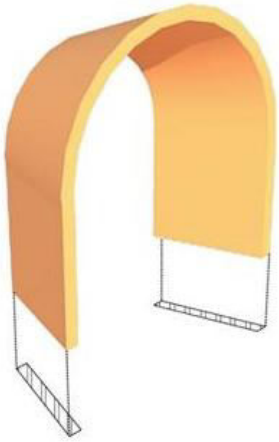
Firstly, you can either cover the span with barrel vaults. This might give the roof a very monotonous and boring look. To break that monotony you can also try varying the spans of each of the vaults and creating a symmetrical pattern eventually.

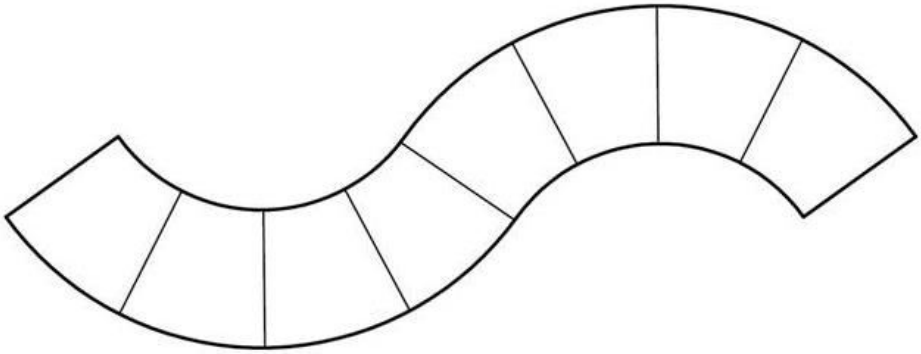


Secondly, the given area can be divided into various smaller modules. Every corner of each of the modules have to be supported over a column of varying height. Now each of these modules can be covered with ruled hyperboloid kind of surface as show in the figure here. This can either be a stell and glass structure above which you can have trailies to give it a very pleasant look or an RCC construction. The ariable height throughout the space will create an interesting profile.









Another interesting form can be achieved where instead of the barrel vault you go for the conoids. The possible arrangements with a conoid are shown in the previous figures. It is important to note here that even with the help of simple shapes you can create a very beautiful structure with interesting arrangements.

Sydney Opera House (1973)

The Sydney opera house is one such example as discussed in the aforementioned section. The pink and yellow coloured structures shown in the figure below are the arrangement of shells covering the auditoriums. The former face in one direction whereas the latter face in the opposite direction.

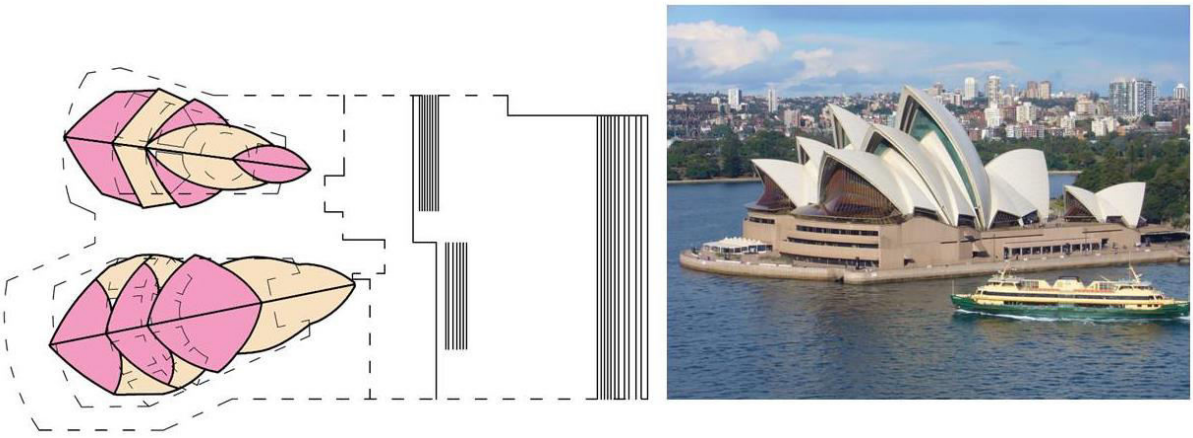


Figure 20 Sydney Opera House

Lotus Temple, New Delhi (1986)

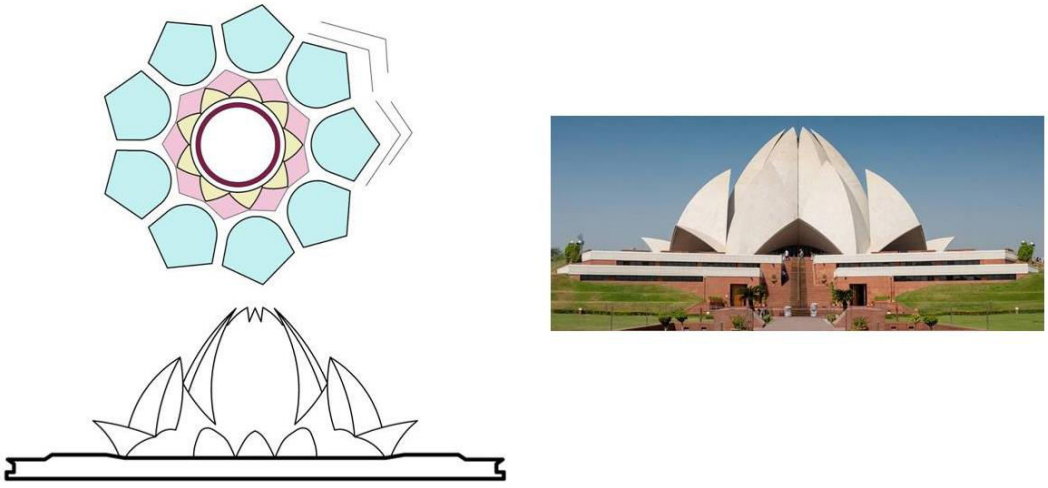


Figure 21 Lotus Temple, New Delhi

The lotus temple is a very beautiful example of a shell structure from our country.

References

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- **Structure Systems** By Heino Enge, Hatje Cantz Publisher
- **Structure and Architecture** By Meta Angus J. Macdonald, Elsevier Publication
- **The Structural Basis of Architecture by** Bjørn N. Sandaker, Arne P. Eggen, Mark R. Cruvellier, Routledge
- **Building Structure Illustrated** by Francis D.K. Ching, Willy

Conclusion

Finally, I'd like to conclude by stating:

Arch is a very elementary structural system, widely used in cathedrals and modern building. In contemporary architecture various types of shell structures are used by Architects in different buildings.

Homework

Q1. Develop profile, type and structural foot-print of a shell roof over the given hall complex layouts. Explain your solution through sketches of schematic Plan, Elevation and Section.