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# Comparative Study of Different Types of Shell Structure

Tanvi Lad [1]
Student, VIVA School of Architecture
Virar, India

Radhika Gaitonde [2]
Student, VIVA School of Architecture
Virar, India

Amisha Bhoir [3]
Student, VIVA School of Architecture
Virar, India

Vaishnavi Amberkar [4]
Student, VIVA School of Architecture
Virar, India

Mohsin Khan [5]
Prof., Assistant Prof., VIVA School of Architecture
Virar, India

Pratik Katalkar [6]
Prof., Assistant Prof., VIVA School of Architecture
Virar, India

**Abstract:- Shell structures are not just mere aesthetics, but also a modern version of innovative construction techniques. To understand the topic vividly this review paper focuses on comparative study of different types of shell structure. Through systematic comparison of case studies, this review paper also emphasizes on the applications and construction techniques that prevails in this type of long span structural system and highlights the scope for shell structures.**

***Keywords:-*** *Long Span; Grid Shell; Concrete Shell; Geodesic Dome Shell; Theory of Design; Double Curvature.*

## I. INTRODUCTION

A shell structure is a thin curved membrane or slab usually of reinforced concrete that functions both as structure and covering. The term “shell” is used to describe the structures which possess strength and rigidity due to its thin, natural, and curved form such as shell of egg, a nut, human skull, and shell of tortoise. Single curvature shells are curved on one linear axis and are a part of a cylinder or cone in the form of barrel vaults and conoid shells.

Double curvature shells are either part of a sphere, or a hyperboloid of revolution. The terms single curvature and double curvature do not provide a precise geometric distinction between the forms of shell because a barrel vault is single curvature but so is a dome. The terms single and double curvature are used to distinguish the comparative rigidity of the two forms and complexity of centering necessary to construct the shell form. Systems of rigid planes, able to resist tension, compression, or shear, in which the redirection of forces is affected by mobilization of sectional forces.

## II. LITERATURE REVIEW

The efficiency of dome structures and their building methods connected to masonry and wood (in earlier ages), steel and concrete (later eras) have been studied previously. Concrete dome buildings have received little attention, and this concept formed the basis of this research topic. Because of the scarcity of analytical research, it is reasonable to conclude that there is a strong demand for more study and development on this subject. It was required to first investigate how domes came to be in order to generate data to analyse. Dome (Lat.domus: 'house'), by Jacques Heymann and Francis Woodmans, (2012), gives a good overview of the history of domes. It describes the origins of the dome, its function, and the evolution of the structure throughout Europe, including the identification of key historic domes. Inflatable domes of Dante Bini were ground-breaking. Aurelio Muttoni's 'Concrete shells-towards efficient structures: construction of an elliptical concrete shell in Switzerland' is a proof of its evolution.

Fig 1. Myzeil façade Frankfurt

The efficient manufacture and optimization of shell structures is a major emphasis of this literature review. It delves into how the design and construction of these structures evolved in the field of architecture. It outlines form-finding techniques and other optimization strategies in particular. The section concludes with a recap of previous force-driven weave pattern optimization examples. By comparing the usage of weave patterns derived from principal stress vs other structural information, such as force flow vectors, the research in this review directly addresses this issue and offers knowledge in this field.

## III. METHODOLOGY

The selection for the topic begins with our introduction on Shells, as long span structures. It is interesting to understand based on the type of load acted on this system, the names have been derived. Under which one of the typologies of surface-active system, shell structure is what we are focusing. The methodology for research on shell structures deals the study of topic based on digital case studies via research papers, journals. Case studies contains the knowledge adopted with the relevance of its functionality, hierarchy, construction details, materials, delivered to the stream of its construction process of engineering of the structure defining its gravity nature & kinetic facades pattern as per the site conditions. The comparative analysis through the construction process evaluates the timeline taken for the span of its research for elaborating its ideas to implant in its essence as per the findings adopted in its methodology. Conclusions are being confined to those justified by the data of the research and limited to the scope of expansion in nearby future for which a sufficient basis has been provided by the data.

## IV. TYPES OF SHELL STRUCTURES

The classification of shell structure can be classified into three types namely, concrete shell, grid shell and geodesic dome shell.

### *A. Concrete Shell*

Engineered concrete shells that flow with the forces are incredibly efficient structures. Concrete is a building material with a high compressive strength and a low tensile strength. The applied loads cause mostly compressive normal forces in the shell when a shell design is in sync with the material properties, resulting in a very uniform and efficient stress distribution throughout the structure. A well-developed concrete shell, according to Mehlhorn (1996), has a favorable internal distribution of stresses (membrane state of stress) and very low bending moments.

➢ *Case Study: Sydney Opera House, Australia*

The Sydney Opera House, located in Sydney Harbour's harbour, is a performing arts centre that has been regarded as a masterpiece of modern architecture and a symbol of Australia since its opening in 1973. Jorn Utzon, a Danish architect, designed it after winning an international architectural competition in 1957.

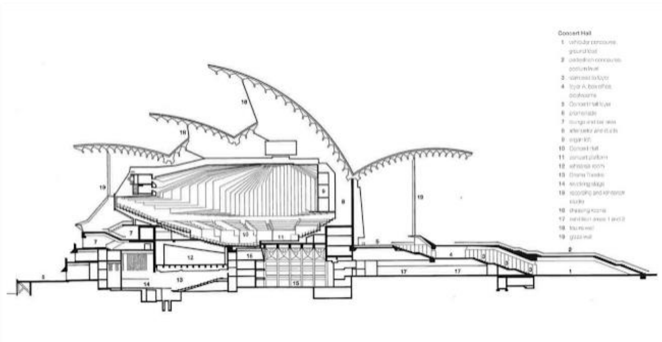

Fig 2:- Section Cut-Through Sydney Opera House

Fig 3:- Sydney Opera House, Australia

Although they are referred to as reinforced concrete shells, they are actually a system of concrete ribs that support a total of 2,194 precast concrete roof panels that are clad with over 1 million tiles. The tile surface is extremely detailed, with two types of tiles - one glossy white and the other matte cream. One of the earliest applications of computer analysis was with the design of the shells. Throughout the site, large sections were utilised from factories for these precast prefabricated components. The building's structure is of reinforced concrete, and its facades are polarized glass with steel frames. The shells are surrounded by white and cream mate tiles created in Sweden, which appear white from a distance. Pink granite from Tarana and plywood from New South Wales are the most common interior materials[1].

Fig 4. Ephemeral Cathedral, Paris

### *B. Grid Shell*

The term 'gridshell' refers to grids that behave like shells, which indicates that stresses occurring on the structure are mostly transmitted through compression and tension from a mechanical standpoint. These structures have the ability to cover long distances while using relatively less material. A gridshell is a grid that acts like a shell and a building method that takes advantage of the material's bending flexibility.

➢ *Case Study: Ephemeral Cathedral, Paris*

Long glass-Fibre tubes are joined together with scaffold swivel couplers to form the grid shell structure. The construction is made up of steel sleeves that connect one, two, or three composite tubes. The tubes' length was limited to 12 meters, to allow transportation. There are three layers of tubes placed on top of each other.

The structure is anchored to a concrete strip footing by a unique steel system, which ensures load transfer from the composite structure to the ground. The framework is fastened to the doors using a similar method. A poly (vinyl chloride) (PVC)-coated cloth, custom-made for the project, covers the framework. Because of the transparent component of the structure, the grid shell receives natural light. A double-lacing system is used to stretch the cloth on the periphery of a specialized beam. The lacing edge of the beam is composed of a bent composite rod fastened to the concrete slab at ground level.

*C. Geodesic Dome Shell*

Dome roofs and ceilings are hemispherical constructions that originated from the arch. The Romans were the first to use large-scale masonry hemispheres, which we still observe today. Because the dome imposes strains all around its perimeter, early structure such as the Roman Pantheon, utilized massive supporting walls. They produce wide open spaces with no restrictions; such that, they provide maximum area from a small surface area. Domes have the advantage of allowing us to design structures that are unrivalled for covering expanses with few internal supports. Triangular elements are generated when the geodesics intersect, and they have both local and triangular rigidity. The distribution of structural stress across the geodesic sphere is aided by triangular elements[8].

➢ *Case Study: Montreal, Canada*

For almost twenty years, Ar. Buckminster Fuller had been perfecting his designs. A diameter of seventy-six meters, the expansive sphere reaches an astounding 62 meters into the sky and thoroughly dominates the island on which it is located. The volume contained within it is so spacious that it comfortably fits a seven-story exhibition building featuring the various programmatic elements of the exhibit.

Fig 5. Montreal Bioshpere

## V. COMPARATIVE ANALYSIS

Concrete Shell Structure: Material used is concrete hence concrete shell structure. Shell structures are three-dimensional curved surfaces with one dimension that is much smaller than the other two. Shells do not alter much in shape when subjected to external loads. External loads are transferred from the surfaces of these structures to the supports via membrane stresses. Membrane stresses can be compression, tension, or a mix of the two.

Grid shell Structure: During the construction phase, the non-braced model is utilised to check the grid's behaviour. For obvious safety considerations and to ensure the accuracy of the final geometry, it had to be proved that the primary grid—the one without triangulation pipes—had no chance of buckling.

Indeed, the more probable the shape is to buckle, the more it can be triangulated in a buckled geometry that differs from the desired geometry. The triangulated grid model is used to ensure that the grid shell meets all structural requirements during its lifetime. The project demonstrates that composite grid shells can be used to generate free-form structures.

Geodesic Domes: In combination with other triangles, the triangle is a natural mathematical figure that delivers optimum efficiency with minimal structural effort. By building a succession of identical geometrical elements that are both self-supporting and light, Fuller created a dynamic framework in which individual components contribute to the overall structure.

## VI. FUTURE SCOPE

The most time-consuming parts of Isler's design approach were properly measuring the double-curved plaster cast made on the hanging membrane, building a physical surface model to evaluate the shell's structural performance, and checking for buckling instability. The development of a hanging model in the digital era is undoubtedly the most difficult element. Rapid and widespread three-dimensional scanning of double-curved surfaces is now possible. Architectural designers can now follow similar concepts thanks to particle spring simulation. However, there is a risk that designers will be persuaded to limit their form finding to computer modelling alone. Designers may quickly generate any shape using digital tools based on optimization criteria. Perhaps this gives you too much leeway. Basic aspects that can be disclosed by a physical model may be neglected in real time, such as the influence of scalability, construction feasibility, and so on.

## VII. CONCLUSION

According to Heinz Isler, who was a pioneer and master of reinforced concrete shell observed that computer aided design was a threat to 'natural design method'.

Modern designers are unlikely to follow Isler's method precisely but can adopt efficient shell forms through-

- The importance of shaping, that is finding a structurally and materially efficient shell form.
- The elements of shell construction that contribute to the overall architectural or artistic expression e.g., thinness of the shells.
- The functional relationship of the shell form to its architectural requirements and site context.

- The forming of complex curved surfaces through efficient construction.

With or without the aid of computers, designers can be encouraged to explore and test their designs using different modelling approaches, including physical models. To produce a beautiful thin reinforced concrete shell, one requires inspiration and much patience.

The comparative analysis of shell structure in this paper demonstrates that structural optimization and coverage of span as per the type of shell structure. This can lead to a more efficient design of the concrete shells and that such a tool is useful for designing thin shell concrete structures.

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