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THE IMPORTANCE OF GRID SHELL SURFACES IN ARCHITECTURE

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Abstract: This article examines the significance of toroidal surfaces in architecture, their geometric properties, and practical applications. The role of toroidal surfaces in providing structural strength, aesthetic appearance, aerodynamic performance, and energy efficiency is discussed. The geometric structure of the torus and the concept of Villarceau circles are also described. Using examples from historical and modern architecture, the advantages of employing toroidal surfaces in architectural design are demonstrated. The results indicate that toroidal surfaces serve as important structural and artistic elements in contemporary architecture.

Keywords: toroidal surfaces, Villarceau circles, torus, architecture, dome, arch, hyperbolic paraboloid, structural strength, parametric design, 3D modeling, energy efficiency.

Introduction. In modern architecture, aesthetics, strength, and functionality occupy an important place. From this point of view, curved and complex geometric surfaces are considered an integral part of architectural forms. They not only provide buildings with an attractive appearance, but also serve to ensure structural stability, air circulation, efficient distribution of light, and energy efficiency. Today, domes, arches, hyperbolic, and parabolic forms are widely used in world architecture. This article discusses the importance of grid shell surfaces in architecture, their geometric characteristics, advantages, and practical applications.

The Concept of Grid Shell Surfaces. A grid shell surface (toroidal surface) is a geometric surface formed by the rotation of a circle with radius r about an axis lying in its plane and located at a distance R from its center. Usually, a torus is considered under the following condition:

R > r

where **R** is the distance from the center of the torus to the axis of rotation, and **r** is the radius of the generating circle.

Grid shell surfaces occupy an important place in geometry and are considered one of the classical examples of complex spatial forms. A torus contains two main families of circles:

1. Parallel circles located around the center of the torus;
2. Rotating circles that generate the torus.

In addition, a torus contains two other special families of circles known as Villarceau circles. These circles are formed as a result of intersecting the torus with a special plane that is tangent to it at two points. An interesting feature is that such an intersection is not a complex curve but consists of two real circles.

Villarceau circles have the following characteristics:

– they intersect each other;
– they have a radius equal to that of the central circle of the torus;
– they form a chain-like interconnection with one another.

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This phenomenon was discovered in 1848 by the French astronomer Yvon Villarceau. Villarceau circles are of great importance in the study of topology, **Hopf fibration**, and **sliceform models**.

Figures 1, 2, and 3.

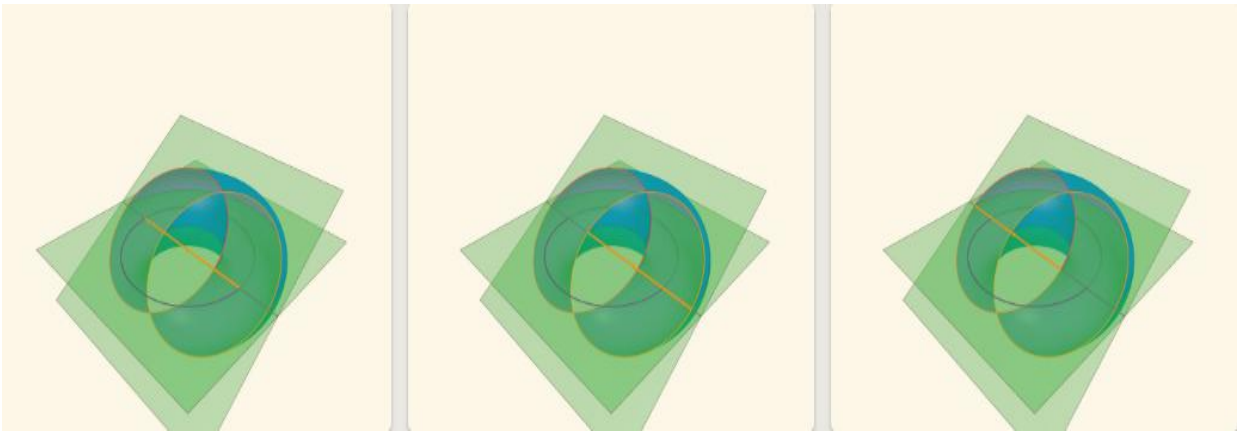


Figure 1

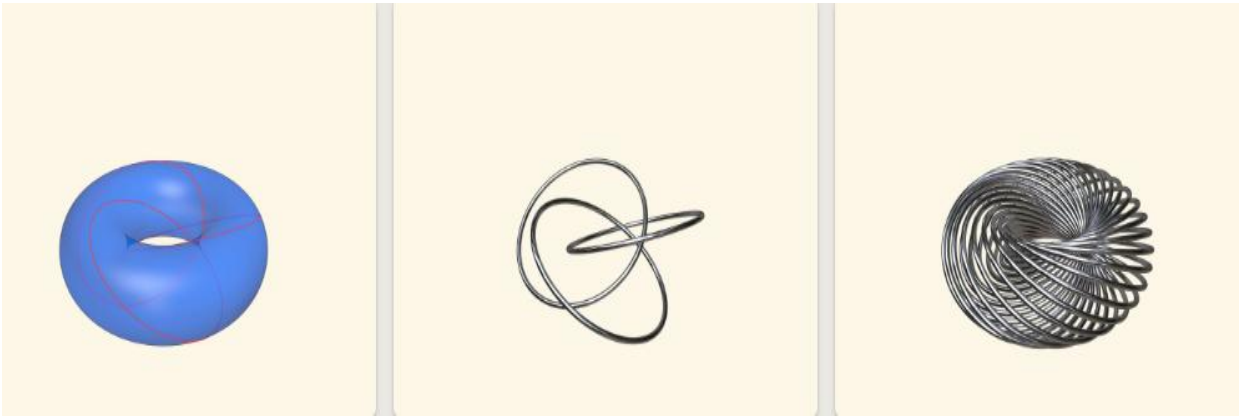


Figure 2

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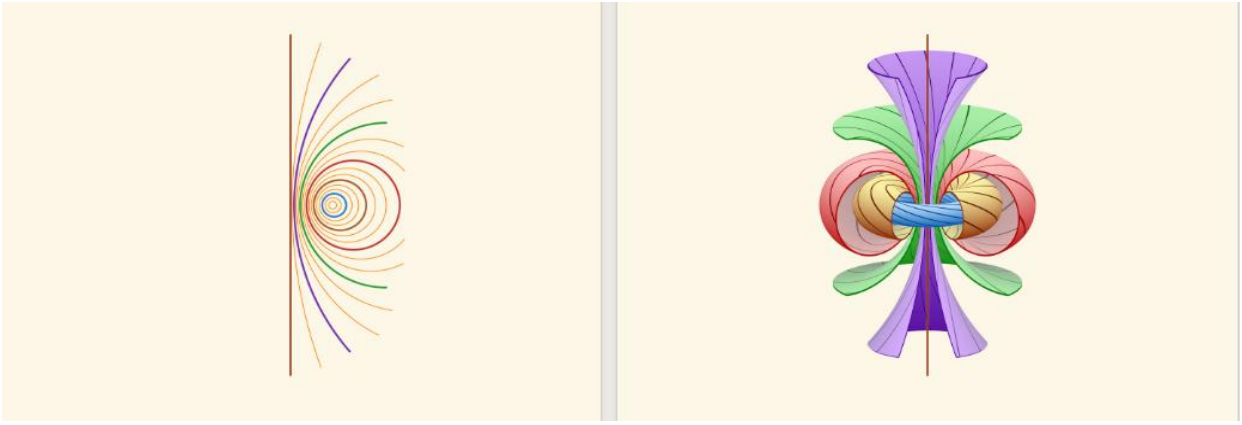


Figure 3

History of Grid Shell Surfaces in Architecture. Curved and toroidal surfaces have been used in architecture since ancient times. In particular, dome and arch structures have been widely applied in Eastern and European architecture. For example, complex dome structures can be found in the historic madrasahs, mosques, and mausoleums of Samarkand.

While ancient Roman architects developed arch and vault technologies, domes in Eastern architecture were elevated to a high level of artistic achievement. In the modern era, the development of construction materials such as concrete, steel, and glass has made it possible to create even more complex curved surfaces.

Advantages of Grid Shell Surfaces. Grid shell surfaces and other curved surfaces possess a number of important advantages:

Structural Strength. Curved forms distribute loads evenly across the surface. For this reason, domes and arches are capable of withstanding heavy loads. Such structures are widely used in bridges, stadiums, and large shopping centers.

Aesthetic Appeal. Curvilinear forms appear natural and pleasing to the human eye. Therefore, they enrich the architectural appearance of buildings and give them a distinctive character.

Aerodynamic Efficiency. Some grid shell and curved surfaces reduce wind pressure. This is particularly important for skyscrapers, stadiums, and large sports facilities.

Energy Efficiency. Curved forms make it possible to distribute light and heat efficiently. Glass domes help maximize the use of natural daylight and reduce energy consumption.

Types of Grid Shell Surfaces

Dome-Shaped Surfaces. These are among the oldest and most widely used forms in architecture. They are extensively applied in mosques, museums, and theater buildings.

Cylindrical Surfaces. These are used in tunnels, metro stations, and sports facilities. Such forms make it possible to cover large areas.

Hyperbolic Paraboloids. These are among the complex geometric forms widely used in modern architecture. They make it possible to create lightweight yet strong structures. Such surfaces are commonly found in the roofs of airports, stadiums, and exhibition centers.

Grid Shell Surfaces in Modern Architecture. The development of digital technologies and computer software has significantly facilitated the design of complex geometric surfaces. With the help of 3D modeling and parametric design tools, architects are now able to create complex forms with a high degree of accuracy.

Today, glass domes, free-form curved façades, wave-shaped roofs, and parametric design elements have become an integral part of modern architecture. This, in turn, gives cities an innovative and contemporary appearance.

O‘zbekistonda tor sirtlardan foydalanish. O‘zbekistonda egri va toroidal shakllar qadimdan me’morchilikda qo‘llanib kelinadi. Ayniqsa, Samarqand, Buxoro va Xivadagi tarixiy obidalarda gumbaz va arkalar muhim o‘rin egallaydi.

Registon ansambli, Go‘ri Amir maqbarasi va Bibixonim masjidi kabi me’moriy yodgorliklarda murakkab gumbaz konstruksiyalari yuksak mahorat bilan yaratilgan. Hozirgi kunda ham yangi masjidlar, madaniyat markazlari va zamonaviy jamoat binolarida egri sirtlardan keng foydalanilmoqda.

Challenges and Limitations. Despite the many advantages of grid shell surfaces, they also have certain complexities:

– complexity of the design process;
– high construction costs;
– requirement for precise engineering calculations;
– difficulty of maintenance and reconstruction work.

For this reason, the participation of highly qualified specialists is essential in the design and construction of such structures.

Conclusion

Grid shell surfaces are considered one of the important components of architecture not only from an aesthetic point of view but also from an engineering perspective. Their geometric properties provide structures with high strength, efficient load distribution, and rational use of materials. Although forms such as domes, arches, cylindrical surfaces, and hyperbolic paraboloids have been used in architecture since ancient times, today they are being designed in a more advanced form with the help of modern technologies.

The geometric structure of the torus and the Villarceau circles discussed in this article demonstrate how mathematically interesting and complex these surfaces are. An in-depth study of these geometric principles expands the possibilities for creating new structural solutions in the fields of architecture and construction. In particular, the development of parametric design, computer modeling, and digital fabrication technologies is significantly facilitating the accurate calculation and practical application of complex grid shell surfaces.

In addition, grid shell surfaces play an important role in increasing the energy efficiency of buildings, making effective use of natural lighting and ventilation systems, and ensuring environmental sustainability. This corresponds to the principles of sustainable development, which are among the main requirements of modern architecture.

In conclusion, grid shell surfaces not only enhance the artistic expressiveness of architectural forms but also effectively satisfy the technical and functional requirements of modern construction. In the future, with the further development of artificial intelligence, BIM technologies, and 3D modeling systems, the number of innovative projects based on grid shell surfaces is expected to increase, and their application in architectural and construction practice is likely to become more widespread. Therefore, an in-depth study of the geometric and practical characteristics of grid shell surfaces will remain one of the relevant directions of architectural and engineering sciences.

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