Proceedings of the 2023 International Conference on Mechatronics and Smart Systems
DOI: 10.54254/2755-2721/12/20230332

The application and value of curved roof in modern architecture

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Abstract: The roof is an essential component of a building and is sometimes referred to the "fifth facade" by modern architects. It serves as a load-bearing element as well as being a significant aspect of the building's overall appearance. Throughout history, architects have often used the roof as a way to express their own distinctive design ideas. The primary area of research covered in this essay is the application and value of curved roofs in modern architecture. The article will start with the development of curved roofs from modern surface architectural design concepts and architectural science and technology, then select actual building cases to analyze the structure of curved roofs, materials, and design concept, and from the building bionic design, the user's space feeling, and the urban environment, the three aspects to explore its unique value in architecture. It is hoped that this will serve as a reference for future architectural design.

Keywords: curved roof, modern architecture, design concept, value.

1. Introduction

Curved roofs have been used in architectural forms by various artisans since antiquity. According to their own needs for development and quality of life, people use various roof shapes in various buildings. For instance, traditional Chinese architecture has employed a variety of curved roof styles, while the traditional main church in Europe has a significant number of arched domes. The design theory system for curved roofs is getting richer, construction technology is getting more sophisticated, and architects are using curved roofs more frequently in their designs as a result of the advancements in the times, science, and technology. In terms of morphological shaping and structural generation, research is being done on curved roofs. The idea of modern architectural design has been introduced in numerous scholarly works. However, there aren't many resources available that discuss the special relevance of curved roofs in architecture and the potential benefits of combining the two, which is the main goal of this essay.

2. The development process of modern curved roofs

2.1. The development of the modern curved surface architectural design concept

The theoretical framework of modern architecture school is a significant contributor to the evolution of curved surface architecture. After the Second World War, the modern architectural school flourished

DOI: 10.54254/2755-2721/12/20230332

and gradually superseded the original western academic school to become the dominant school of architectural thought in society. It was founded between the two world wars. The modern architecture school discovered its own flaws after becoming the dominant school of thinking. Specifically, modern architecture should adapt to the material and emotional needs of the various members of society in their daily lives and activities. Since the 1950s, numerous design fads have developed to address this issue.It is mainly summarized into 8 categories: (1) the tendency to enrich and improve rationalism; (2) the rude tendency; (3) the tendency to pursue exquisite technology; (4) the tendency of elegance; (5) the tendency to focus on high industrial technology; (6) humanization and regional tendency; (7) the tendency to combine region and modernity; (8) the tendency of individuality and symbol. Geometrical figures, abstract symbols, and concrete symbols are three of them that make up personality and propensity. Numerous contemporary curving structures were created using a variety of themes, such as the American Pavilion at the 1958 Brussels World's Fair, Ronchamp Church in France and the Sydney Opera House in Australia and so on.

The ideological tendency of deconstruction that began to emerge in the late 1980s has an impact on another prospect for growth of contemporary curved surface architecture. Peter Eisenman, Bernard Tschumi, Frank Owen Gehry, Daniel Libeskind, Zaha Hadid, et al. are examples of notable individuals. Deconstructionist architects frequently use a variety of scattered structure and separation techniques, dismantling the axis, equilibrium, and symmetry in their works. They also produce multi-level diffusion and strange deconstruction spaces through the overlap, distortion, and fission of the entire structure into countless pieces. Deconstruction, from the standpoint of philosophical tendency, seeks out the unintentional potential of anti-logic and irrationality. Deconstruct architecture's fundamental philosophical tenet is to demonstrate the logic of insanity to the outside world by using rational components. London Aquatics Center in Britain, Guangzhou Grand Theatre in China, Guggenheim Museum in Spain, and other well-known constructions have been deconstructed.

2.2. Development of modern curved surface building science and technology

Without the advancement of architectural science and technology, it would be impossible to create the contour of a modern curved roof. After the Second World War, there was a significant growth in the variety of new building materials as well as the strength of steel and concrete. Buildings started to use a variety of alloy steel, specialty glass, and chemical compounds, which facilitated the usage of curved roofs. The curving roof creates a novel reinforced concrete thin shell in addition to the conventional concrete structure, as well as suspension structures, grid structures, film structures, tension structures, truss structures, inflatable structures, and so on. New building materials including nylon, new glass fiber, crystals, and different new composite materials, such as new aviation film materials polyfluoride, and nano carbon drill, have been employed in the construction of curved roofs since the turn of the twenty-first century[1]. The new large-span structure is built of thin, highly durable materials with a few millimeters of thickness, which not only allows for significant material savings and weight reduction, but also ensures the structure's safety and gives the building a more translucent, dexterous aspect.

Together with the contribution of building materials, computer-assisted parametric design is another significant factor. Prior to the adoption of computer-aided design, architects typically relied on hand-drawn drawings and manual models to create design schemes. Architects also had to travel to the construction site to oversee and change the work, which slowed down the process and left the scale inaccurate. Following the widespread adoption of computer-aided design in the twenty-first century, architects could readily create computer-generated drawings of curved buildings that are more precise and flexible than human ones. Among them, "NURBS modeling technology" has had the most impact on the curved roof design. Today, most curved building scheme models are studied by architects using software such as AutoCAD, Revit, Rhino, and others. According to the software, they may also create the most reasonable curved roof structure simultaneously. Architects can communicate with the contractor and other professionals involved in the construction process more effectively thanks to the now well-liked BIM software system (Building Information Model).

DOI: 10.54254/2755-2721/12/20230332

3. The use of curved roof in modern architecture

Various kinds of buildings are starting to adopt curved roofs as a result of the advancements in contemporary architectural design concept, architectural science, and technological innovation. This essay will use the four modern building[1] types listed below to illustrate the special benefits of curved roofs.

3.1. The Sydney Opera House

The Sydney Opera House is situated on Australia's Beniran Island. Design work on the opera house began in 1957 and was finished in 1973. The Sydney Opera House's design is reminiscent of a group of white statues, a sea reef covered in enormous shells, and a sailing boat about to set sail. This is so that Joern Utzon may admire the four facades' splendor from above. He therefore implemented the concept with a massive foundation and a shell-shaped dome. The structural issues with the roof were taken into consideration at the outset of the design by the architect. The thickness of the roof ranges from 100 to 500 mm. The shell- or sail-shaped roof constructed through a thin shell construction on the foundation, which is surrounded by the sea on three sides, represents the architect's unique understanding and emotion of the base. However, it still expresses the architect's design concept of unifying the form and structure and showing the particular personality and regional character of the building itself. The thin shell structure was later changed to an arch structure because of structural construction technology and engineering cost. The Sydney Opera House, which appears to be a thin-shell construction from the outside, actually belongs to the arch large-span structure system. The opera house has the following features: (1) a small round ridge and large arch ribs; (2) precast strengthened reinforced concrete; (3) 2,194 precast reinforced concrete sections serve as its roof; (4) 350 km of steel ropes were used to fix the concrete sections; (5) the Opera House weighs approximately 161,100 t; it is supported by 580 concrete piers deep at 25 meters below sea level; (6) Each concrete slice in the opera building weighs 15.5 tons, while the roof itself weighs 27,230 tons. The concrete's own weight lessens the roof arch's outward thrust, and the roof's 32 root, 2.5 m^2 square concrete column support works together to resist the roof arch's side push[2]. The Sydney Opera House's curved roof and arch structure give it a distinctive artistic shape and considerable fame.

Figure 1. Structure model diagram of the opera house.(Figure Source:[2]).

3.2. Ronchamp Church

Le Corbusier's famous design from the 1950s, Ronchamp Church, is a masterpiece. The church, which is situated in the Ronchamp mountains in eastern France, started construction in 1950 and was finished in 1953. The church is unique compared to conventional western churches because it is modest, without a bell tower or cross, and almost entirely curved in shape. The church's roof is inclined from east to west and folded up; it is made entirely of reinforced concrete. The roof has a thin shell structure comprised of two layers of reinforced concrete slabs. Two layers of sheet are folded at the edge with a maximum spacing of 2.26 meters between them, and the entire roof is then supported by two rows of concrete columns[3]. People may not immediately recognize it as a building when they first see it, but those who have attended religious events will recognize it as a church with a strong religious aura that can be incorporated with the events. Many unusual symbolic devices are used in the building,

[1] This article defines modern architecture as buildings completed in 1950 and later.

DOI: 10.54254/2755-2721/12/20230332

including the east end of the curly south wall, which symbolizes pointing to heaven, the house being heavy and closed, which suggests that it is a refuge from danger, the opening of the east corridor, which symbolizes welcoming the pilgrims; the inclined bending of the roofs and walls, the dim light in the room, the ceiling, and the fact that people have trouble judging size, direction, level, and vertical. The church's use of a curved roof reinforces the psychological importance of "God and selflessness" to Christian believers. The shape has proven successful despite controversy.

Figure 2. Ronchamp Church. (Figure Source:[4]).

3.3. Yoyogi National Gymnasium

The major stadium constructed for the 1964 Tokyo Olympic Games is called Yoyogi National Gymnasium, and it is situated in Tokyo, Japan's Shibuya area. It is a classic example of Japanese architect Kenzo Tange's style. The stadium has a swimming pool, a basketball court, and office and support spaces, with a total size of 34,200 m^2. The stadium's roof, which is primarily composed of ductile steel, resembles two shell-like parts. In order to achieve the enormous span of the interior space, the roof has a suspension cable structure. The bearing structure is mostly made of the flexible steel cable and its edge members[5]. The roof structure of the natatorium is comprised of two steel cables that run between the two towers to create a central component that resembles a suspension bridge. I-steel members that hang from the ring beam at the top of the spectator stands form the curved structure of the roof[6]. The hanging construction of a single tower column makes up the roof structure of the basketball arena. The single pull is thermoformed by 400 mm diameter steel pipe and connects with the ring beam at the top of the platform to support the suspension members of the roof. It spirals from the supporting tower's top to the concrete block that is anchored. This unique structure provides space for the interior of a reverse funnel and a skylight between the support tower and the suspended roof to improve the interior's ambience. The stadium's architects drew inspiration from old Japanese shrines and vertical cave shelters while creating it, and they also incorporated traditional Japanese emblems and their own unique interpretation of the Olympic spirit. The stadium achieves a high unity of material, function, structure, and proportion and is regarded as one of the most beautiful buildings in the world in the 20th century, thanks to Kenzo Tange's use of modern building materials and techniques, clever application of the curved roof to the building, and expression of traditional culture.

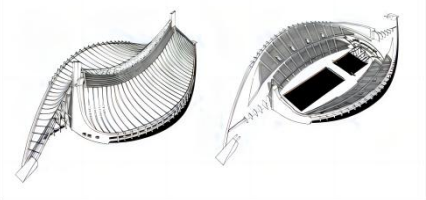

Figure 3. Structure model diagram of Yoyogi National Stadium(Figure Source:[5]).

3.4. Wangjing SOHO, China

Beijing's Wangjing SOHO is situated on a piece of land near the northeast corner of the intersection of Wangjing Street and Fu'an West Road. It is a combined office and commercial construction. It was started in 2010 and finished in 2014; the architectural design of the building was created by Zaha Hadid, one of her most well-known works in China. With a total area of 521,000 m^2, the building is made up of three towers. The towers are surrounded by several water features and distinctive fountains. Each tower is diverse in size and shape, lively and interesting, very centripetal, and has an auspicious

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significance. The overall shape of the building is a free curved form that resembles three peaks from the facade and three active carp from the plane. Due to its distinctive shape, the building can be viewed from any angle with a dynamic and attractive aesthetic feeling. The building's entire structure is made of a steel-frame reinforced concrete cylinder, and the roof's primary materials are aluminum plate and glass. The roof's main structural components are horizontal, vertical, and ring trusses[7]. The installation sequence of the steel structure is symmetrical from the middle to both sides during construction in order to ensure that the installed structure is always in a stable state, and the unloading process is also sequential unloading from the middle to the side[8]. Spatial streamline design is a technique used by Zaha Hadid in architectural design because it visibly simplifies everything. Each component of the design has a specific location and is grouped together to create a seamless whole. The architect also blended the traditional Chinese idea of feng shui, which holds that every mountain has every water, with the architectural language of movement, elegance, and coherence to the design. Wangjing SOHO can have such a distinctive surface shape, while it also cannot be left to Zaha Hadid's expert parametric design, construction of architects, structuralists, software engineers, and other relevant personnel using BIM and other software for repeated construction, calculation, and simulation, and ultimately do not change the building's shape to make the safest and most appropriate structure scheme.

Figure 4. Wangjing SOHO (Figure source:[9]).

4. The unique value of curved roofs in modern architecture

4.1. Promote the development of architectural bionic design

Architectural designs that mimic the form, color, structure, function, material, and use of natural resources found in nature are referred to as architectural biomimetic designs. Its goal is to increase resource efficiency, adaptability, and environmental affinity in order to foster harmony between people and the environment in which they live. The design of Yoyogi National Gymnasium adopts the bionic composition technique, and the roof shape imitates the shape of the shell and the external threads to shape the distinctive visual effect. The architectural shape of this building is entirely distinct from the structure and form of traditional Japanese architecture. The Sydney Opera House's roof shape is inspired by the contours of shells and sailing boats, and it blends with the site's geographical features to harmoniously combine the building with the natural environment. The distinctive design of Ronchamp Church creates a singular metaphor that causes people to have a wealth of associations, including closed hands, a floating duck, a nun's headgear, and others[4]. This result was achieved because the architect employed abstract bionic design to create the plan. The goal is to achieve harmony between the structure and the surrounding natural environment so that the architectural form and the natural form are more similar. The bionic design of architecture suggests that it has a duty to protect the environment. A building designed to resemble a living thing might express a person's affinity for the environment more than a typical high-rise building, serving as a constant reminder of their love and care for the environment. The curved roof, which mimics the characteristics of living things, develops into a distinctive architectural element. When applied to a building, it demonstrates the humanization of the building, helps to integrate the building with the surrounding natural environment, and encourages the sustainable development of the building environment.

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4.2. Improve the space experience for users.

The interior space of the building generated by the varied curving surface is both majestic and athletic. Compared to flat roofs and slope roofs, curved roof shapes have a greater sense of flow and rhythm, which can adapt to a range of irregular planes. According to findings from gestalt psychology study, people are more stimulated and attracted to complex, nonlinear, or disordered visuals, which may awaken their curiosity[10]. Space that is circular, curved, or bent can give people a sense of direction and encourage them to travel along its axis. Sometimes, when creating a curved roof, the architect will deftly employ the qualities of its spatial shape to deliberately cause the user to have a certain psychological effect, give them a certain spiritual sensation, or draw people's attention in a specific way.

The suspension cable structure, grid structure, membrane structure, and other new long-span structures are frequently employed in modern curved roofs. The following three qualities describe these structures: 1. It can adjust to the various spans of the construction space. 2. The various profiles and mild curvature changes can significantly increase space consumption. 3. Lightweight and thin thickness. The curved roof creates rich acoustic and optical effects in the building's internal space because of its structural features. For instance, the spatial shape of the music hall of the opera house with the curved roof enables the sound waves to have more reflected surface, producing a deeper echo effect. The goal is for every audience member to experience the finest performance effect possible. The majority of buildings will open skylights on the rooftops to boost the natural light in order to meet the lighting requirements of the inside area. When compared with flat roofs, skylights on curved roofs may more effectively bring in natural light from various angles to enhance the lighting. For instance, the natatorium suspension cable in Yoyogi National Gymnasium rises from the roof, and a structural gap between the roof and the cable is designed as a space for natural lighting and artificial lighting, forming a bright light belt in the room; some Windows of the exterior wall are combined with the window design, turning the direct natural light into scattered light[5]. This improves the visual experience for the audience and lessens the negative impacts of glare.

4.3. Adjust the increasingly high-density urban environment

Many modern cities have extremely high floor-to-area ratios, and in the crowded skyscrapers, people frequently experience depression. Therefore, architects now have to deal with the issue of how to build a relationship between architecture and the urban environment.

In 2009, SOHO China won the auction for the Wangjing B29 plot project land in Beijing's Chaoyang District. Northeast of Beijing is an area called Wangjing, which has a sizable population. With the growth of the city, Wangjing has emerged as an important site for IT companies. It is also the high-tech industrial development zone in Beijing that is closest to the city center and has the most convenient transportation options. Plot B29 is situated parallel to the airport expressway on the main axis of the Wangjing planning. Plot B29 is destined to become the core of Wangjing due to its unique geographic location and its connections to the nearby buildings[9]. Plot B29 is surrounded by the ring road and the 45-degree road rather than the straight jing road due to its location in the northeast corner. In the process of designing wangjing SOHO, Zaha Hadid made the decision to draw design inspiration from Beijing's urban environment. She then used Beijing's distinctive cultural context to give the building an urban context and artistic conception[11]. She also linked architectural design, environment, and the urban context, in order to create a great landmark building. Therefore, Wangjing SOHO has been given a curved design that complements its surrounding buildings and preserves the original site's shape. When people are inside the building, they don’t feel depressed. The building is also close and startling, and its curved roof gives rich space to the city skyline. Generally speaking, Wangjing SOHO is an excellent instance of how the architects used their comprehension of Chinese urban culture into their architectural design. Curved roofs and shapes are friendlier and more natural-looking than the typical flat roof and cube design, which can help control the high-density urban environment.

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5. Conclusion

Curved roofs are a distinctive type of modern architecture that are both the result of modern architecture's ongoing development process and its constant pursuit of innovation. Its special significance in modern architecture goes beyond the aesthetic value of architectural modeling and represents the focus on the achievement of modern architecture for sustainable development, technological innovation, urban development, and other factors. Modern architects should consider the urban environment while creating curved roofs in order to give users the best possible physical and psychological experience inside the building. While aiming for aesthetic beauty, architects should take advantage of the curved roof to increase the building's functionality and energy efficiency and to accomplish the coordinated growth of man, the building, and nature. Therefore, curved roofs will continue to be crucial and to generate new potential value.

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