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Preface

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An overview of structural designs and building materials in shell structure for the mosque and the future development

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An overview of structural designs and building materials in shell structure for the mosque and the future development

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Abstract. The developments of technology in realizing contemporary designs become a hot issue for the development of the mosque's appearance and shape. The development of the shell building in the mosque which is quite attractive to the public was the construction of the Cologne Central Mosque in Germany in 2017. For the point of view that shape of the building is a new era in the use of shell structures in the mosque. The shell structure commonly used as a dome of the mosque that is used as a symbol of the mosque buildings in general use and continues to this day which began from the era of the caliphate. This paper will present a review of the structural designs and building materials on the shell structure of the mosque which has been developing from time to time. And can be used as a possible new reference in the future developments of mosque architecture.

1. Introduction

The influence development form of the mosque with a dome was happened because of the effect of Christians building traditions (Greece and Roman). The famous dome formation in Roman times is the Pantheon which was founded in 27 BC that becomes a building with the use of a spectacular shell. With its well-known concrete shell affecting the development of the dome shape in general in the world, especially in the discussion of this article on the dome shape of the mosque. Islamic culture that progressive developed begins when compiling the Umayyah caliphs' policy of shifting its power centre from Medina to Damascus in 661 AD and power up to 750 AD. From the association had been done before he became a caliph with the Romans, the caliphate produced mosque architecture with a dome-shaped, so it became the early history of the development of the mosque until the next time [1]. During the Roman and Persian conquests, Muslim rulers began to build cities, palaces, fortresses from the Persian lifestyle. Islamic architecture that is known today has started by Umayyah rulers and spread by Muslim rulers to this day [2]. Umayyah (661-750) build the stone dome, the grand mosque of Kairouan and Damascus which are examples of Islamic Architecture in the Umayyad period [3]. Formation of the dome from time to time is a symbol for the building of the mosque which is an architectural form and it is used as a marker of the existence of mosques in various places in the world. But lately the design of the mosque with a dome which is a shell structure not just to the top only(decoration), but more flexible so that the area inside the shell is also used as a space that is the prayer room and other functions. This article provides an overview of the above along with materials used both in the mosque in the past and its development.

2. Method

The method used in this article is a review of various literature studies from various existing references. The data in this article is taken from secondary data.

3. Result and Discussion

3.1 Shell Structure

Shell structures must have thin, solid and curved. Shell behaves like a membrane that it receives the force of compressive, tensile, and shear on its surface. The thin of the shell makes a shell has little bending resistance. This shell distributing force spread all over the surface, unsuitable for centre force [4]. The ideas of this structure that it is inspired by nature are the most optimal and efficient structure. These structural examples in nature are turtle shells, eggshells, peanut shells, conch shells, etc. This shell with a curved surface can be categorized as a single curved, double curve or free from. The barrel vault is an example of a single curved that it is distributing force in one direction only. Whereas the double curved channel with a two-way system structure (it is distributing force in two directions), namely a synclastic and anticlastic. Like dome, a synclastic has an existence of the endpoints is in parallel places. Saddle-like shape and hyperbolic paraboloid are examples of anticlastic that the curvature has a different sign and different directions. Whereas free-form surfaces are even more complicated that it cannot be determined by curvature.

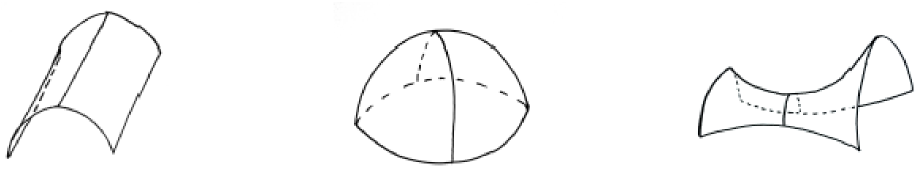

Figure1. Types of Shell [Single-curved, Double-curved (Synclastic and Anticlastic)].

3.2 Form-finding approaches

The efficiency of the shell if it is well designed, so it is a high level of the structure. There are several ways for form-finding approaches. They are analytical shapes described by mathematics, the evolution of two-dimensional structures, mechanical or funicular shapes, pneumatic shapes, free forms, and shapes obtained by numerical optimization [5]. Analytical Shells using mathematical functions so this some shell shapes can be explained completely. The evolution of two-dimensional is obtained by rotating, extruding of two-dimensional elements. An example is the structure of barrels and domes obtained with this approach. One mathematical function that has been widely used in designing shell structures includes cylinder, conoid, hyperbolic paraboloid, spherical, torus and hypar structures. Free forms can be formed using digital computer-aided design with the architect's imagination. But its weaknesses may still find practical difficulties during their construction even if free forms can be more aesthetic Pneumatic shapes that this form is obtained with the help of the use of or gas pneumatics, by pumping gas in a balloon such that it is placed on a dynamic structure that will change shape according to the bubbling that occurs due to pumping gas. The model was built to adjust the computer model and to get a more realistic shape is mechanical or funicular shapes. This model of mechanical shape can be made using chains that are hung and interconnected (Figure 2). The model of mechanical shape is built on a special frame and a hanging chain freely under its weight. The interconnection of various chains allows for the development of forms as needed. After the required shape is obtained, the displacement along the chain is measured at a location corresponding to the computer model node. Then the displacement measurements are carried out by moving the coordinates in Excel and then compared to the computer model [6].

3.3 Building Shell's Material

3.3.1. Concrete.

The shell with concrete became famous when the building of Pantheon was founded in Roman. The Romans were aware of the weight of the Pantheon dome shell, so the dome was made with lighter building materials at higher levels to reduce the weight of the dome itself. The concept of lightweight aggregates are used to produce lower density concretes, which are advantageous in reducing the self-weight of structures and also have better thermal insulation than normal-weight concrete. To make it lower density obtained with using aggregate materials that may have air voids. Pumice, naturally volcanic rock that occurs in nature, has been used since Roman times, but it is only available at few locations, and artificial lightweight aggregates are now widely available [7].

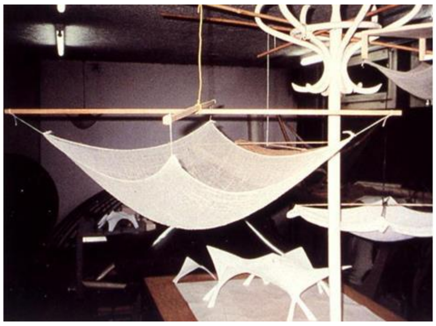

Figure 2. Hanging Cloth Model [8]

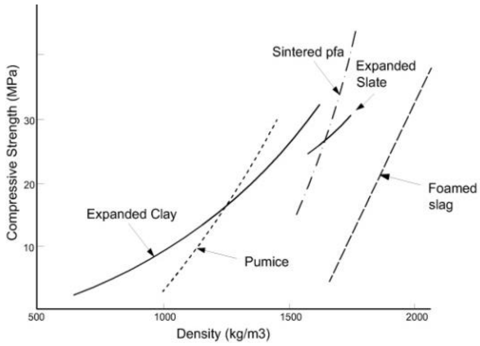

Figure 3. Typical strength density relationships for concrete containing selected lightweight aggregates [7]

The aggregate materials on the top make use of lighter volcanic pumice and tufa, different from the lower section using travertine and terracotta aggregates which they are havier. It is believed that varying mixes of concrete were laid in horizontal layers with formwork coffers deeply set to further reduce self-loading [9]. Three types of the artificial lightweight aggregates are sintered pulverized fuel ash, formed by heating the pelletized ash from pulverized coal used in power stations until partial fusion and hence binding occurs. The second type is expanded clay or shale, formed by heating suitable sources of clay or shale until the gas is given off and trapped in the semi-molten mass. The third type is foamed slag, foamed by directing jets of water, steam and compressed air on to the molten slag from blast furnaces. But the weakness of lightweight aggregates at the top, the concrete with lower strength as the result (figure 3).

3.3.2. Steel Rebar and Lightweight Steel Rebar.

Use of rebar, so then the technic usually with formwork so it can be poured or sprayed with mortar or concrete. When shells with steel ribbed, it can be covered with glass-fibre reinforced concrete installed as fabrication elements. The lightweight steel rebar can be made for the dome when the cover does not weight material. It can be covered by enamel or another lightweight steel covered material.

3.4 Structural Designs and Shell Materials of Recent Mosque

3.4.1. Al Sakhra Dome Mosque.

The Dome of the Rock was designed and built during the caliphate of Abd al-Malik, the 5th Umayyad caliph of Islam (685–705 AD), and its construction was completed in 692 AD under the supervision of Raja ibn Haywa and Yazid ibn Sallam who are thought to have been in financial and administrative control [10]. The building is octagonal with a wooden dome with a diameter of 20.44 m. A 9.5 m high octagonal-shaped like a drum has become the main building with a dome as a roof placed on it. The dome has a height that is approximately the same as its diameter.

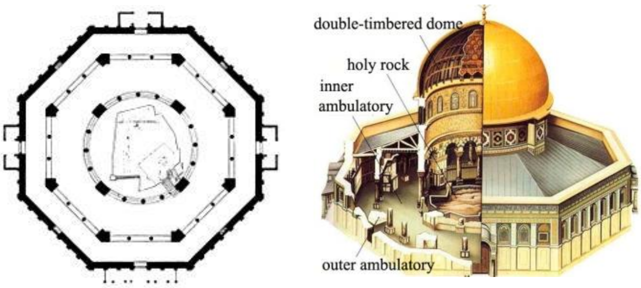

Figure4. The floor plan and the section of Al Sakhra Dome Mosque [11].

Using wood as material from its dome shell is a two-way structural system consisting of meredional and transverse ribbed that constructed as ribbed dome type. Structural design on the dome of the shell using a half-ball surface or synclastic with wooden ribbed domes, and covered up with coloured and gilded stucco. The first time this dome was originally roofed with lead covered in gold.

3.4.2. Hagia Sophia.
With the fall of Constantinople into the hands of the Ottoman Empire 1453 and the conquest of Hagia Sophia and turned into a mosque. Byzantine Hagia Sophia architecture became an inspiration for many Ottoman mosques at that time until now. The dome is carried on four spherical triangular pendentives, one of the first large-scale uses of them. The pendentives are the corners of the square base of the dome, which curve upwards into the dome to support it, restraining the lateral forces of the dome and allowing its weight to flow downwards. The dome has a diameter of 32 m with a dome thickness of about 60 cm. The main building material for the dome is brick and mortar. Mortar from sand and ceramic pieces that are equivalent to concrete at that time. The dome construction weighed 150 pounds per cubic foot, the average weight of stone construction at the time. The dome was designed by Anthemios of Tralles and Isidoros of Miletos, this dome had repaired the collapse due to the earthquake in 558 AD and then was rebuilt with a height of 54.6 m. The dome is supported by four large arches on the four sides of the supporting wall.

Figure 5. Hagia Sophia Mosque [12]

Figure 6. Hagia Sophia's dome [13]

With the except for the principal piers of stone, the entire building is of brick and mortar in a volumetric relationship of about 1 to 1.6. This ratio implies a form of concrete with brick aggregate, a plastic material of the type that made curving plans ad roof practicable in later Roman and Byzantine buildings. This material weighs roughly one hundred and fifty pounds per cubic foot, or about the same as average stone masonry construction. Because of plasticity and ease of laying up, brick and mortar can be used over greater distances than cut stone. As monumental domes go, that of Hagia Sophia is rather low. It less than a hemisphere, substending about 162°, and rises forty-seven feet from impost to crown. The ratio of rises to diameter is 44 to 1, much lower than in later, larger domes such as Saint Peter's (78 to 1) [13].

3.4.3. Sultan Ahmed Mosque/ Blue Mosque.

The large dome of the Sultan Ahmed mosque has a diameter of 25.5 and a height of 43 m at its centre. The dome is supported by four very large piers. This mosque is a Byzantine architecture and it is a source of ideas for other Ottoman mosques. At first, this mosque was a church during the time of the Byzantine emperor and was later transferred to a mosque with the addition of a small dome built during the sultan Ahmed I between 1609 and 1616.

Figure 7. Dome of the Sultan Ahmed Mosque, covered by handmade ceramic tiles [14]

Figure 8. Four pillars support the dome's blue mosque [15]

3.5 Cologne Mosque as Contemporary Mosque

- The span of the main shell 26 m
- The material: Exposed concrete (the concrete is lightweight concrete to minimize heat bridges.
- The building shell is a two-way system shell
- Complex supporting structures and building state
- Special features: fire protection, earthquake certification and construction states certification
- Modern style blend with Ottoman Architecture style completion on 9 June 2017, architect: Paul Bohm
- Two-way system shell supported by meredional and longitudinal rebar steel [16]

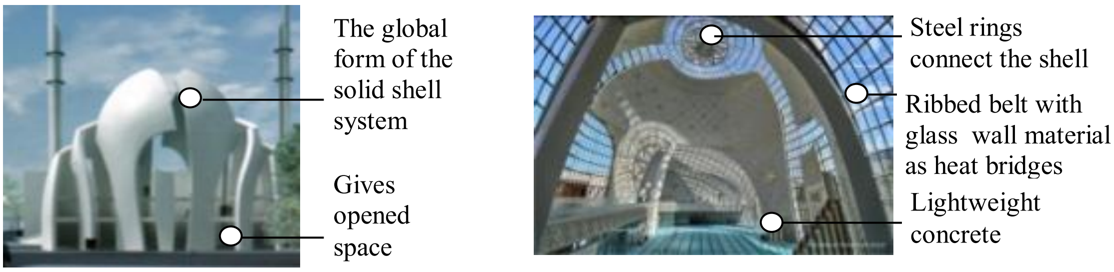

Figure 9. Cologne Mosque [17]

The Cologne mosque has a floor area of more than 20,000 m^2 which is the mosque with the centre of the largest Islamic community in Germany. Glass facade gives a broad impression and attracts attention. With its shell structure or dome made of curved reinforced concrete covering an area of 1000 m2, with a dome height of 34.50 m. The design of the Cologne mosque structure features a mosque that looks like it is not a two-way system because there are those some use the shell. Just near the top of the dome, a steel ring connects the shells to form a coherent structure. The unique shape of the cologne mosque requires reinforced concrete material by installing a good formwork installation using reinforced concrete in place. Modular formwork and supports are needed which are very heavy loads [18].

Figure 10. Several concrete shell segments gradually growing together and meet to form a cantilever [18]

Figure 11. The formwork and reinforced concrete material cast-in-situ [19]

3.6 The Next Development

The development of the mosque in this discourse, for example, was the mosque design competition at the Kosovan capital of Prishtina. An open international competition for designing the mosque was finally launched in 2012, with submissions having to be made by March 2013. The Porto Consortium from OODA gave submissions in the form of a dome that gave symbols to the symbol heaven as a protective envelope that is manifested in a double dome that is fibrous skin and interior tissue in it, added towering tall towers. The building, called 'butt plug building', was designed by Italian architects Paolo Venturella and Angelo Balducci, which features a dome covered with solar panels that look futuristic. It does not have a minaret but uses a double screen with an outside facade of louvres covered by photovoltaic films as solar panels and allows for natural ventilation. [20] The designs with the use of minaret still become one symbol of the new development of the mosque.

Figure 12. Mosque Shell's design from Zaha Hadid [20]

Figure 13. Mosque Shell's design from Porto Consortium of OODA [20]

Figure 14. 'Butt Plug Building' [20]

4. Conclusion

The design of a building will form an artificial environment. Then we need both functional and aesthetic design. This is needed to be able to add value to the environment, in addition to providing challenges for the new design of a mosque. The shell structure itself is very interesting to get important characters can provide added value to the environment, structural efficiency, and function as a design producer. At present, the technology (form-funding, formwork, and construction methods) are becoming increasingly easy. There is a new formation that opposes Islam itself. The most important thing is that the development without purely leaving the Islamic symbolism that has existed for thousands of years but can integrate it well.

References

[1] A. Fanani, *Arsitektur Masjid*. Bentang Pustaka Yogyakarta, 2009.
[2] M. Ul Huq and A. Haque, "'Does Islamic Architecture Reflect Islam (Faith)?,'" in *UIA 2017 Seoul World Architects Congress*, 2017.
[3] R. Talgam, *The Stylistic Origins of Umayyad Sculpture and Architectural Decoration.* Otto Harrassowitz Verlag, 2004.
[4] D. Ching, Francis D.K; Onouye, Barry S; Zuberbuhler, *Building Structures Illustrated, Patterns, Systems and Design*. Wiley, 2013.
[5] H. Haakonsen, "The Function of Form, Conceptual Design of Modern Shell Structures," NTNU-Trondheim Norwegian University of Science and Technology, 2013.

[6] Z. Asmaljee, “Form-Finding of Thin Shell Structures,” 2013.
[7] P. Domone and J. Illston, *Construction Materials*, Fourth Edi. New York: Spon Press, 2010.
[8] Y. Liem, *Graphic statics in funicular design: calculating force equilibrium through complementary energy*. TU Delft, 2011.
[9] B. Addis, *Building: 3000 Years of Design Engineering and Construction*. Phaildon Press, 2007.
[10] M. A. Islam and Z. F. AlHamad, “The Dome Of The Rock: Origin Of Its Octagonal Plan,” *Palest. Explor. Q.*, vol. 139, no. 2, 2007.
[11] D. S. Omer, “The Rock Inside the Aqsa Mosque – What’s it All About?,” *20 March*, 2019. [Online]. Available: https://www.aboutislam.net. [Accessed: 10-Sep-2019].
[12] B. Lampkin, “13 Sage Facts About the Hagia Sophia,” *19 February*, 2016. [Online]. Available: http://www.mentalfloss.com. [Accessed: 20-Sep-2019].
[13] W. MacDonald, “Design and Technology in Haga Sophia,” *Perspecta*, vol. 4, pp. 20–27, 1957.
[14] B. M. Kantar, “The Blue Interpretation of Art: The Blue Mosque,” *Turk Neurosurg*, vol. 24, no. 4, pp. 445–450, 2004.
[15] R. Saoud, “Muslim Architecture under Ottoman Pattronage,” 2004.
[16] “Cologne Central Mosque.” [Online]. Available: https://www.structurae.net.
[17] “No Title.” [Online]. Available: https://www.spiegel.de. [Accessed: 20-Sep-2019].
[18] Ernest and Sohn, “Mosque in Cologne: elaborate in situ concrete dome construction,” *Struct. Concr.*, vol. 12, no. 2, p. A5, 2011.
[19] C. S. Heiermann, “No Title,” 2011. [Online]. Available: www.flickr.com/ photo.
[20] S. Hitchins, “The Difficulty of Designing A Mosque for Prishtina,” 2019.