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METHOD TO DEVELOP THE DOUBLE-CURVED SURFACE OF THE ROOF

Abstract: *This work present two methods for determining the development of double-curved surface. The aims of this paper is to show a comparative study between methods for determination of the sheet metal requirements for complex roof cover shape. In first part of the paper are presented the basic sketch and information about the roof shape and some consecrated buildings, which have a complex roof shape. The second part of the paper shows two methods for determining the developed of the spherical roof. The graphical method is the first method used for developing of the spherical shape. In this method it used the poly-cylindrical method to develop the double-curved surface. The second method is accomplishing by using the dedicated CAD software method.*

Key words: *roof shape, descriptive geometry, developed surface, CAD.*

1. INTRODUCTION

Nowadays the rapid development of the building with complex surface prior require to use the graphical methods. From the oldest times the people has used approximate methods to make roofs with complex surface for different buildings. The style and shape of the roof varies depending on the geographic location, type of the building and the nation from that area, or country. In the ancient time the construction of the many buildings are accomplished according to golden ratio proportion. Using this method, the buildings have a beautiful aspect and a strong structure.

Since the 18th century the mathematician Gaspard Monge published the first treaty of Descriptive Geometry, creating a graphical representation approach of the spatial object in orthogonal projections, solving many problems in an easy and precise engineering manner.

2. ROOF SHAPES

Some of the arhitectural roof shapes, used especially in the case of the religious buildings, which are composed of arches of a circle, [7], [9] are presented below:

• *Semicircle*

The ends of the semicircle points that define the roof are collinear with the center point, the shape of the arch are presented in figure 1.

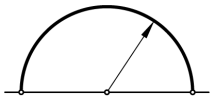


Fig. 1 Semicircle arch.

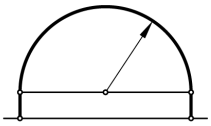


Fig. 2 Stilted semicircle.

Stilted semicircle arch, presented in figure 2, are ends extended below of the center point of the center arch. These are vertical lines from the center point of the arch. Semi-circular arch is especially characteristic of Romanesque architecture.

• *Segmental arch*

The extreme points of this construction are located above of the center point arch. The curve is an arch with an angle less than 180 degrees, as can be seen in figure 3.

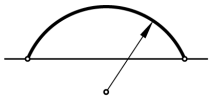


Fig. 3 Segmental arch.

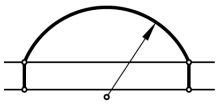


Fig. 4 Stilted segmental arch.

The stilted segmental arch center is located below of the ends. Both ends of the arc are extended by two vertical line segments. The shape of the stilted segmental arch is presented in figure 4.

• *Horseshoe Arch*

The ends of the horseshoe arch, presented in figure 5, are situated below of the arch center. This architectural style is called Moorish arch, and it's based on the Islamic concept. The construction of the mosques' roof uses the horseshoe arch. This arch has an angle greater than 180 degrees.

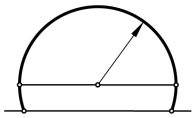


Fig. 5 Horseshoe.

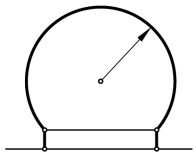


Fig. 6 Stilted Horseshoe.

The stilted horseshoe has the ends of arch extended with two vertical line segment, as can be seen in figure 6.

• *Pointed Arch*

This shape is specifically of the gothic style. Figure 7 presents the shape of the pointed equilateral construction.

The radius of the arch has the same size with the base of the constructions. The pointed lancet arch, presented in figure 8, has a radius size greater than the base length.

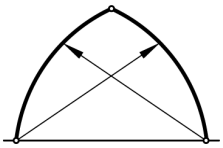


Fig.7 Pointed equilateral.

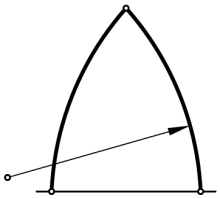


Fig. 8 Pointed lancet.

In figure 9 is presented the pointed obtuse shape. The center of the arch is situated on the horizontal line with the arch start point. Pointed segmental shape presented in figure 10 has the arch center situated below of the arch start point.

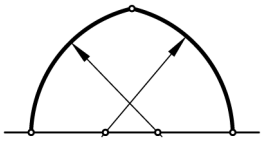


Fig. 9 Pointed obtuse.

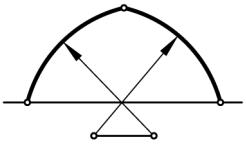


Fig. 10 Pointed segmental.

• *Three centered arch*

Construction of the three centered arch is composed of three arcs of circle, as shown in figure 11. The center of the extremity arch is placed on the horizontal line.

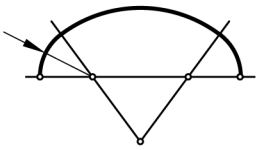


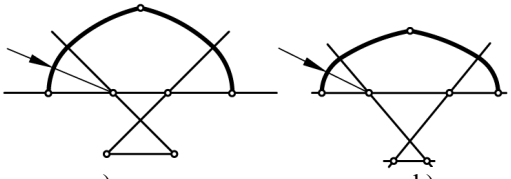
Fig. 11 Three centered arch.

Fig. 12 Quasi four-centred.

When the shape is composed from two circle arch, which are drawn to the tangent segments, like it is in figure 12, the shape is called quasi four-centred.

• *Four-Centered Arch*

This shapes are presented in figure 13 a, b. Four-centred arch are parts of four different circle. This arch style has been considered characteristic to England, but it was common in Flanders.



a) b)

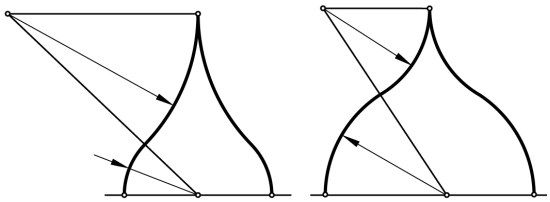
Fig.13 Four-Centered Arch.

The arch presented in figure 13, a), b) is called Tudor arch.

Architectural Tudor style was developed in medieval England, during the Tudor period (1485-1603).

• *Ogee Arch*

The ogee arch consisting of a concave arch and a convex arch, with vertical ends. This ogee arches were feature of the English gothic architecture and it are used mainly for decoration, because does not have a strong resistance to the action of the environmental loads. The shapes of the ogee arch are presented in figure 14.

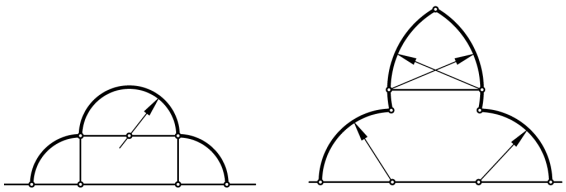


a) b)

Fig. 14 Ogee Arch.

• *Trefoil arch*

Trefoil shape is composed from three center arch, as can be seen in figure 15, a, b.



a) b)

Fig. 15 Trefoil arch.

• *Pointed arch trefoil*

The shape pointed arch trifoliate presented in figure 16. This shape is used mainly for decoration, characteristic of Gothic architecture, characterized by the ribbed vault. A shouldered arch, presented in figure 17, is a style of arch used especially over a doorway. Those shapes are called Corbels [1], [5]. This style is applied in castle constructions, inside and outside, or in the bridge constructions [3].

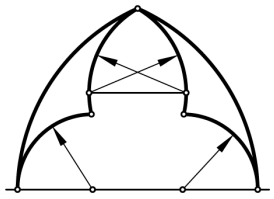


Fig. 16 Pointed arch trifoliate.

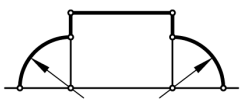


Fig. 17 Shouldered arch.

Among the many buildings that have spherical roof are mosques. The oldest mosque, Quba Mosque was built in the Islamic style in 622 in Medina, Saudi Arabia [8]. In figure 18 is presented a view of this mosque, it can be observed the semi-spherical elements from the roof, specific of the Islamic architectural style.

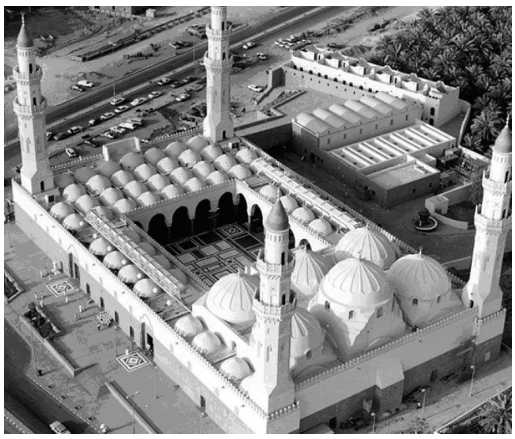


Fig. 18 Quba Mosque from Medina, Saudi Arabia [8].

Another dome construction is presented below in figure 19, were is presented the picture of Dome of the Rock from Jerusalem, Iterioer [6].

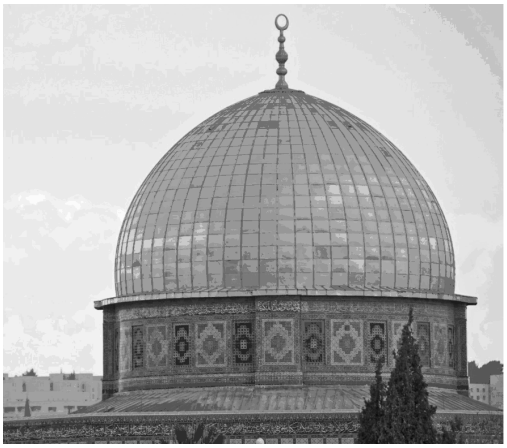


Fig. 19 Dome of the Rock from Ierusalem, Iterioer [4].

In the following paragraphs are presented two methods to develop the spherical and cylindrical surface. In the first method is applied the graphical descriptive methods and second method are solved using CAD modelling techniques.

3.1 Descriptive geometry method

It is known that the sphere is a double curved surface and is not developable, however it can be developed using the approximatively methods, divided the surface in small elements [2]. The most popular methods for developing the spherical surface are:

- poly-cylindrical method (Gore method) – this method is applied to approximate development of the spherical surface dividing surface into single-curved cylindrical surface. Precision of the results is influenced by the number in which is divided the spherical surface, if the surface is divided into several elements the accuracy of the results is higher.
- poly-conical method – this method it used to approximate the development of a spherical surface by substituting the double-curved surface into single-curved conical surface.

In figure 20 are presented the semi-sphere and cylindrical surface development using construction with the poly-cylindrical method. The height of the cylinder surface is 3 m and the radius of the semi-sphere are 2 m.

After solving the problem with descriptive geometry method result an approximate length of the unfolded cylinder equal to 12.24 m.

3. DEVELOPING METHOD

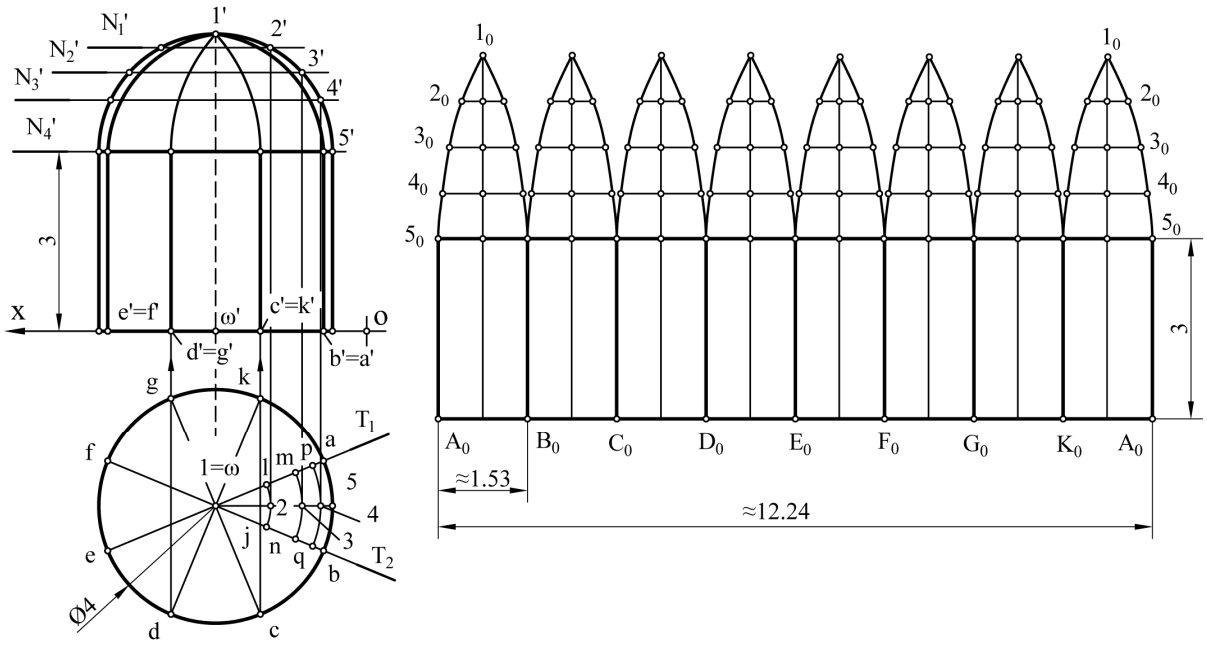


Fig. 20 Semi-sphere and cylindrical surface development using construction by the poly-cylindrical method.

3.2 CAD method

Developed of the semi-sphere and the cylindrical surface it solved using the CAD dedicated software. Three-dimensional model is modelled in SolidWorks, using the surface module. The surface is developed using Flatten surface command. In the first step is developed the cylinder surface, resulting a necessary length of the sheet metal of 12.56 meters, figure 21. The spherical surface is developed in figure 22.

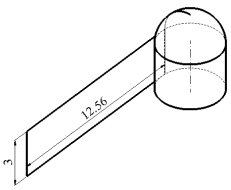


Fig. 21 Cylinder development.

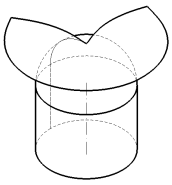
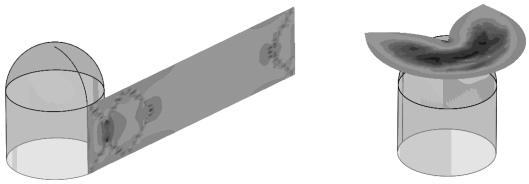


Fig. 22 Semi-sphere development.

Deformation plot of the cylinder surface and semi spherical surface are presented in figure 23 a), b), were can be observed the distribution of the deformation necessary to fold the model.



a) b)

Fig. 23 Deformation plot of the cylinder and semi spherical surface.

In table 1 are presented the area results of the studied surface. It can be seen that the results of the CAD method are more accurate than the ones offered by the descriptive geometry method.

Table 1

Comparative results

	Descriptive geometry	**CAD**
Area of the cylindrical surface	36.72	38.67
Area of the spherical surface	24.88	24.91

4. CONCLUSION

In this work are presented two methods to develop double-curved surface. Watching the results, it can be observed that the CAD method provides more accurate results. A great advantage for using CAD software are given by the accuracy of the problem results. A considerable disadvantage is represented by the necessity of specialized training and high cost of software. Every method used in the paper presents specific advantages. Descriptive geometry method is suitable for educational purpose, creating a better vision of the spatial and orthogonal representation of the body and surface.

REFERENCES

[1] Abushadi, E., *The evolution of Islamic arches till 1250,* 17pg, Department: American University in Cairo. Dept. of Arab and Islamic Civilizations, April 27, 2011, http://dar.aucegypt.edu/handle/10526/4291, Accesed: 2017-02-14.

[2] Bodea, S, Geometrie descriptivă, Publisher Risoprint, ISBN 973-656-353-7, Cluj Napoca, 2006.

[3] Bjurstrom, H., Capacity assement of a bridge with backfill- A case study of the Glomman Bridge, ISSN 1103-4297, Master of Science Thesis, Stockholm, Sweden, 2009.

[4] Camhi, N., *The Manipulation of Sacred Places: The Role of Jerusalem's Temple Mount in the Construction of Identity*, An essay submitted to the faculty of Wesleyan University in partial fulfillment of the requirements for the Degree of Bachelor of Arts with Departmental Honors in the Art History Program, Middletown, Ct, 2012, http://wesscholar.wesleyan.edu/cgi/viewcontent.cgi?article=1875&context=etd_hon_theses, Accesed: 2017-02-03.

[5] Harris, C., *Dictionary of architecture & construction,* Fourth Edition, DOI: 10.1036/0071452370, 2006, https://evrosoriou.files.wordpress.com/2011/05/dictionary-of-architecture-and-construction.pdf, Accesed: 2017-02-10.

[6] Kaptan, K., *Early Islamic Architecture and Structural Configurations,* International Journal of Architecture and Urban Development Vol. 3, No. 2, Spring 2013, http://ijaud.srbiau.ac.ir/article_591_5f29d7ae86d363f7bf593124a0e84686.pdf, Accesed: 2017-02-06.

[7] Rahimi, A., Zahra, A., Etezadi, S., *The methodology of Iranian curved arches (Sagh) based on their geometry,* Journal of Applied Environmental and Biological Sciences, TextRoad Publication, ISSN: 2090-4274, 2015.

[8] http://www.islamguru.com/2016/05/masjid-quba.html, Accesed: 2017-03-02.

[9] http://www.catholicliturgy.com/index.cfm/ Fuse Action/EncyclopediaArticle/Index/15/SubIndex/149/ EncyclopediaIndex/27, Accesed: 2017-01-02.

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