ISBN 978-981-14-1684-2
Proceedings of 2019 the 9th International Workshop on Computer Science and Engineering
(WCSE 2019 SUMMER)
Hong Kong, 15-17 June, 2019, pp.847-852
doi: 10.18178/wcse.2019.06.126

Analytical Surfaces and Bionic Forms in Contemporary Architectural Design

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Abstract. The paper considers numerous impressing architectural designs that are studied both from the point of view of architectural bionics and analytical geometry. It provides many examples that demonstrate the inseparable relationship of architecture, nature and science. Knowledge of analytical geometry and application of natural forms to the architecture allow architects to create buildings that are not only beautiful in appearance, but also possess such important qualities as strength, rigidity and stability.

Keywords: analytical geometry, analytical surfaces, analysis, architectural bionics, mathematical description of surfaces, shape, design, nature.

1. Introduction

In our century of innovative ideas and technical capabilities, more and more buildings and structures are being created that seem unrealistic from the point of view of the recent past. At present, architects and engineers use new architectural forms and surfaces in their projects that can be described using the appropriate analytical equations. This approach gives an opportunity to erect buildings with more harmonious appearance and to design their elements to be more reliable as engineering structures.

The purpose of this paper is to attract the attention of architects to different types of analytic surfaces that have similarities to natural forms, as well as to show the prospects and opportunities of the buildings forming on the basis of such surfaces. We consider the possibility of architectural designing on the basis of some analytic surfaces and also try to select the corresponding analytic surfaces for some interesting architectural projects, which have shapes similar to some natural objects. All necessary equations for most of the surfaces mentioned in the article can be found in [1].

2. Main part

Architectural shaping has always been associated with natural forms. In the past, people did not have enough knowledge in the field of architectural design and analysis of structures, and they mainly had to rely on their intuition and got a lot of ideas from the nature. But later it was proved that in many cases a suitable analytical geometric surface can be chosen for many natural forms, therefore quite all natural objects really have harmonious forms.

The basic principles of architecture were formulated by an ancient Roman architectural theorist Vitruvius two thousand years ago. These principles are “strength - utility- beauty”. And geometry is directly involved in providing of all of these factors in architectural objects. In ancient Greece an architecture was considered to be one of geometry‘s sections. Nowadays relationship between architecture and mathematics still exists. A

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modern architect should know not only specific architectural subjects, but he also should be aware of analytical geometry, mathematical analysis and other branches of mathematics, mathematical modeling techniques, fundamental principles of mechanics and some other sciences.

There are many strong and beautiful natural spatial systems: mollusk shells, skeletons of sea urchins, shells of insects, etc. For example, shells of bird eggs have been for a long a standard of strength. The ratio of the hen's egg diameter to the thickness of its shell is equal to 1:130. After the invention of reinforced concrete it has become possible to build spatial structures made of this material with a ratio of 1:1800.

Fig. 1 Theater-Museum of Salvador Dali in Figueres,

Fig. 2. Office center “Easter egg” in Kiev, Ukraine

Fig. 3. Office building in Mumbai, India

Nowadays shells are commonly used for different types of buildings. And the shape of the egg continues to be a source of inspiration for architects. This shell is one of the strongest and perfect natural forms, which are often used in architecture. The examples of this are: Theater-Museum of Salvador Dali in Figueres, Spain (Fig. 1), a retail and office center “Easter egg” in Kiev, Ukraine (Fig. 2), an office building in Mumbai, India (Fig. 3) and others. A geometrical analog for this natural form is a surface "Egg" which is a surface of revolution of the fourth-order (Fig. 4) [1].

Another shape which is very common in nature and in human activity is a spiral form. There is huge variety of spiral shapes of plants and animals. They are also widely used in architecture. The spiral shape allows making an extended to be more compact and helps to maximize the architectural space. A striking example of such compactness in nature is a shell of mollusk Pahidikus. Its diameter is 0.4 m, but if we could deploy it on the plane as a tape, then its length would be 10 m.

The shape of a spiral, used in architecture, can provide great savings of building area, which is very important for the modern cities. From the functional point of view spiral forms are often very useful and necessary, for example, in the construction of garages, certain types of industrial buildings, ramps, slopes, etc.

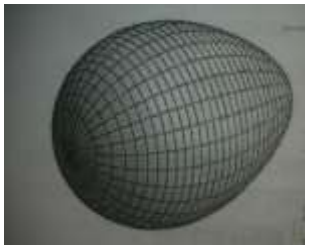

Fig. 4. A surface "Egg"

Fig. 5. A surfaces “Spiral auger”

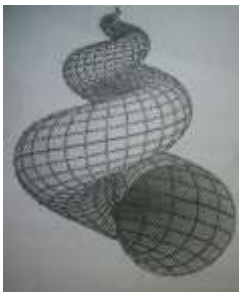

Fig. 6. A surface “Seashell”

There are a number of cyclic analytic surfaces whose shape is similar to the form different shells and mollusks. They are, for example, such surfaces: a spiral tube with a flat surface of the center line in the form of a logarithmic spiral, surface “Spiral auger”, surface “Cornucopia”, surface “Seashell”, spiral surface “Shell without a crown” and others [1]. The surfaces named “Spiral auger” (Fig. 5) and “Seashell” (Fig. 6) have been used in some architectural projects. The prototype of the house “Strombus” (Fig.7), which was designed by architect Javier Senosian and built in 2006, became a shell “Strombus Gigas” (Fig. 8). Another interesting example is the house “Nautilus” [5] in Mexico (Fig. 9). The nature prototype for this building was a clamshell “Nautilus” (Fig. 10). The entire construction of this house was made of Ferro-cement which was

reinforced with steel grids. The thickness of the Ferro-cement used for this structure was 5 cm. This material is very good for building of thin-walled structures.

Fig. 7. The house "Strombus"

Fig. 8. A shell "Strombus

Fig. 9. The house "Nautilus"

Fig.10. A clamshell "Nautilus"

The "Bubble House" (Fig. 11), located in Cannes, has been specially designed by architect Antti Lovag for famous French fashion designer Pierre Cardin. This architect often uses the ideas of organic architecture and natural forms for his projects. A geometric analogue for this form is the Schwarz' Surface (Fig. 12), which is one of the triply periodic minimal surfaces [3].

Commercial and Exhibition Center "POD" (Fig. 13) is located in the city of Kuala Lumpur (Malaysia). The building as a whole has a shape of a teardrop, it consists of separate compartments of the surface "Elliptical cylinder" (Fig. 14) [1].

Fig. 11. The "Bubble House"

Fig.12. A Schwarz' Surface

Fig. 13. Exhibition Center "POD"

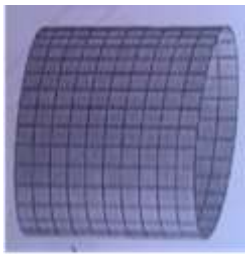

Fig. 14. Surface "Elliptical cylinder"

Flowers have very beautiful natural forms, and many architects often used similar shapes in their designs. For example, it is the building constructed by architect Felix Candela in the form of a water lily (Fig. 15). The shape of the building can be mathematically described by the umbrella surface (a paraboloid of revolution with radial waves (Fig. 16); it can be formed by flat parabolas whose vertices coincide with the central fixed point) [1].

Fig. 15. A building of architect Felix Candela

Fig. 16. An umbrella surface

Fig. 17. A "Temple of Light"

Fig. 18. A rotating surface

A Chilean “Temple of Light” (Fig. 17) has the form of a yellow lily. Its shape can be described by one of the rotating surface (Fig. 18) [1].

Fig. 19.
The project «Lilypad»

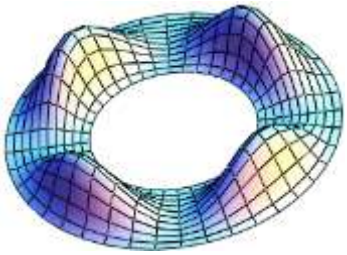

Fig. 20.
A surface of a velaroidal type

In Fig. 19 it is shown the project «Lilypad» of a French architect Vincent Callebaut. This is a project of ecological floating islands that should solve the problem of raising the level of water in the oceans. The project is to be realized by the end of the XXI century; the floating islands should take up to 50,000 refugees fleeing the floods. A geometric analogue of this object is shown in Fig. 20. This is a surface of a velaroidal type on the ring plane with two families of sinusoids [2].

A very beautiful example of another building in the shape of a flower is the famous “Lotus Temple”, which is located in New Delhi, India (Fig. 21).

Fig. 21.
“Lotus Temple”

Fig. 22.
“Villa Casa Folha”,Brazil

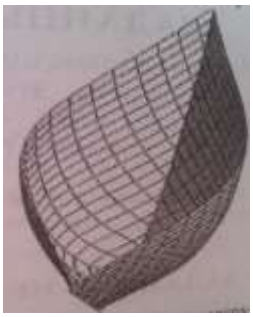

Fig. 23.
An Aerohydrodynamical surface

Another interesting example is “Villa Casa Folha” [6] in Brazil (Fig. 22). Such shapes can be formed by the means of different surfaces. For example, they can be formed with combination of several identical elements of aerohydrodynamical surface (Fig. 23). This surface of the 6th order has a continuous framework of plane curves [1].

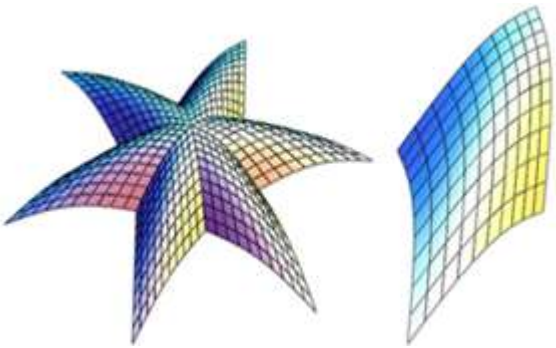

Fig. 24. Koons surfaces

Also very interesting shapes similar to a flower or to a starfish can be obtained using some repeated compartments of Koons surfaces (Fig. 24). Koons surfaces and possibilities of an architectural design on their basis have been considered by V.N. Ivanov in [2].

V.N. Ivanov from the Peoples' Friendship University of Russia have proposed some types of polyhedral box-curved surfaces [3] which can give a lot of interesting ideas for architects. Especially interesting are those surfaces that have some analogs among nature forms. Below we'll consider some of the architectural designs, whose shape can be described by any of the box-like surfaces.

A new architectural design, which was claimed to be the new wonder of the world, is planning to be built in Dubai. It will be a complex of four towers of different height (from 54 to 97 floors), which look similar to burning candle flames (Fig. 25). The project was designed by an architectural company "Thompson, Ventulett, Stainback & Associates". Its geometric analogue is one of the many-sided box-like curved surfaces [3] (Fig.26).

Fig. 25. A complex in Dubai

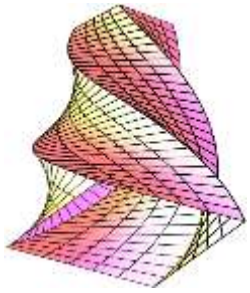

Fig. 26. A many-sided box-like curved surface

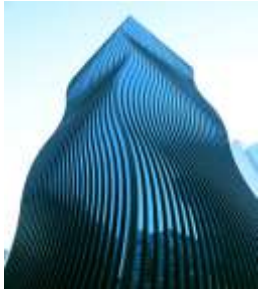

Fig. 27. A skyscraper "GT Tower East" in Seoul

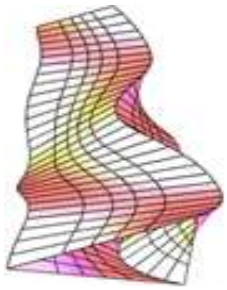

Fig. 28. A many-sided box-like curved surface

Dutch architectural company "Architecten Consort" completed construction of a skyscraper "GT Tower East" in Seoul (Fig. 27). This 130-meter "lump" has the shape of waves; it makes a strong impression because of all-glass facade that reflects the sky and the surrounding landscape. The geometric analogue is also one of the many-sided box-like curved surfaces showed in Fig. 28 [3].

An American company Transparent House presented a project entitled «Crescent Moon Tower» - a skyscraper in the form of a crescent (Fig. 29). The shape of this building can be described by an analytic surface called "Horn". This is a circular surface with forming circles of variable radius in the plane of the beam with a helical center line of constant pitch (Fig. 30) [1].

Fig. 29. Crescent Moon Tower

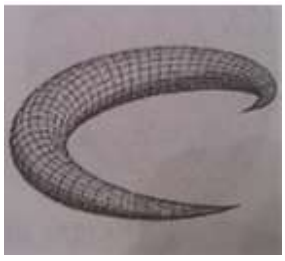

Fig. 30. A helical center line of constant pitch

This paper have been studied a lot of interesting designs which are similar to natural and geometrical forms. When an architect uses natural forms in his architectural designs, he has an opportunity to create aesthetically attractive buildings [5], [6], [7], [8], [9]. There is a fairly large amount of literature on architectural bionics, for example, books of Y.S. Lebedev [4] and others [10]. Also, there are a number of studies concerning analytic surfaces, including such a fundamental one as the "Encyclopedia of analytic surfaces" is [1]. In [11] generalized parametric computer modeling was used for variant forming of bionic architectural objects.

3. Summary

In this paper an attempt was made to find examples of a triple relationship between architecture, nature and science (represented by an analytic geometry). Knowledge of analytic geometry and application of natural forms in architecture allow to create buildings that are not only beautiful by appearance but also have such important qualities as strength, stiffness, stability.

4. Acknowledgements

This paper was financially supported by the Ministry of Education and Science of the Russian Federation on the program to improve the competitiveness of Peoples' Friendship University of Russia (RUDN University) among the world's leading research and education centers in the 2016-2020. The publication has been prepared with the support of the «RUDN University Program 5-100».

5. References

[1] S.N. Krivoshapko, V.N. Ivanov. *Encyclopedia of Analytical Surfaces*. Springer International Publishing, Germany, 2015

[2] S.N. Krivoshapko, S.L. Shambina. Investigation of surfaces of velaroidal type with two families of sinusoids on annular plan. *Structural Mechanics of Engineering Constructions and Buildings*. 2009, **4:** 9–12

[3] V.N. Ivanov Geometry and forming of the polyhedral box type surfaces on base cyclic surface. *Structural Mechanics of Engineering Constructions and Buildings.* 2012, **2**: 3-10

[4] Yu.S. Lebedev, V.I. Rabinovich, E.D. Polozhay and others. *Architectural bionics* (in Russian). Stpoyizdat, Russia, 1990

[5] Viktória Sugár, Péter Leczovics, András Horkai. Bionics in architecture. *YBL Journal of built environment*. 2017, **5** (**1):** 31-42

[6] S.L. Shambina, A.A. Kazarian. Application of bionic forms and approaches of analytical geometry to modern architectural design. (In Russian) *Structural Mechanics of Engineering Constructions and Buildings*. 2015, **1:** 3-11

[7] Information on http://adonay-forum.com/masterskaya_sudbyi_adonai__aura_i_energetika_doma/eko_arhitektura_i_dizayn/msg15022/? PHPSESSID=074e011db0150ef3677b3f446757ed76#msg15022

[8] Information on http://buildd.ru/archives/10899

[9] Information on http://www.makonstroy.ru

[10] Viktória Sugár, Péter Leczovics, András Horkai Bionics in architecture. *YBL Journal of Built Environment*, 2017, 5 (1): 31-42. DOI: 10.1515/jbe-2017-0003

[11] G.A. Virchenko, S.L. Shambina. Computer variant surface modeling of bionic architectural forms. *RUDN Journal of Engineering Researches.* 2016, 3: 79-83 DOI: http://dx.doi.org/10.22363/2312-8143-2018-19-4