

JAKUB ŚWIERZAWSKI

ORCID: 0000-0003-3878-0500

Higher Technical School in Katowice, Poland

SCIENCE-INSPIRED ARCHITECTURE

INSPIRACJE NAUKĄ W ARCHITEKTURZE

Abstract

The Creation of a building depends on both architect's imagination and their technical skills. Architecture has used technological progress from the earliest times as well as science which followed engineering and technology of construction. Years ago, forms observed in nature were followed and interpreted, and inspirations came from traditions and religion. With the development of science, a new source of inspiration appeared. Penetration of the world of science into creation of architecture, observed nowadays, is a continuation of search and the use of patterns which have always existed in architecture. Science shows beneficial effects on joining thoughts in disciplines different from one another, such as: culture, arts, technology. In the times of searching for suitable energy technologies in the process of designing and architectural constructing, inspiring solutions are more frequently searched for in the world of nature and science, which debunks the myth of the 'distance' of architecture from science.

Keywords: architectural design, modern architecture, science-inspired architecture

Streszczenie

Stworzenie budynku uzależnione jest od wyobraźni architekta, ale także od warsztatu technicznego, którym dysponuje. Z postępu technicznego architektura korzystała od najdawniejszych czasów, a w ślad za techniką i technologią budowania korzystała z nauki. Niegdyś naśladowano i interpretowano formy obserwowane w przyrodzie, inspiracje pochodziły z tradycji i wiary. Wraz z rozwojem nauki pojawiło się nowe źródło inspiracji. Widoczne współcześnie w kształtowaniu architektury przenikanie świata nauki jest w dużej mierze kontynuacją poszukiwań, a także wykorzystywaniem wzorców istniejących w architekturze od zawsze. Nauka ukazuje dobroczynne skutki łączenia myśli w dziedzinach od siebie odmiennych, jak kultura, sztuka, technika czy technologia. W dobie poszukiwań technologii energetycznie optymalnych także w zakresie projektowania i budowania architektonicznego coraz częściej poszukuje się inspirujących rozwiązań w świecie przyrody i nauki, obalając mit „odległości” architektury od nauki.

Słowa kluczowe: architektura współczesna, inspirację nauką w architekturze, projektowanie architektoniczne

1. INTRODUCTION

Implications which come from the use of the computer in architectural design moved the imagination of architects. Such implications are seen from the concept until the making of the building. They also made getting inspirations from the world of nature and science easier. The article brings the chosen examples of blending inspirations from science into architecture closer. Architectural objects, which in their form and architectural concept refer to the ideas taken from science were presented. However, no attempt of ordering the elements associated with the

inspiration with science in architecture was made, yet the author focused on the description of architectural ideas, which implementation extends already known possibilities of constructing.

Inspirations with the world of science, observed in contemporary creation of architecture are largely a continuation of the search and use of patterns already existing in architecture. At the beginning, the forms observed in nature were followed, later canonical proportions and shapes were formed through interpretation and copying. The difficulty in the common understanding of processes which exist in nature makes the use of natural patterns not easy, while environment and processes may be described in the following way:

- abstract, mathematical logic,
- empirical, discursive theories describing experiences and observations,
- philosophy of designing pro-ecological architecture.¹

With the development and widely introduced mathematics into other disciplines, biology among them, it became possible to describe the phenomena using the language and logic of mathematics.² The development of digital techniques of constructing has made the concepts based on mathematics, simulation or widely understood reference to natural processes more accessible.³

Charles Jencks, fascinated with architectural inspirations coming from the world of science recalls the projects of Frank Gehry, Nicholas Grimshaw and Peter Eisenman as examples of using the computer in generating forms in architecture based on mathematics and natural sciences.⁴ The important question for him was, how the next generation refers to the laws and creation of surrounding universe through arts and architecture. In history, the answer comes from tradition and religion, yet with the development of science a new source of inspiration appeared.⁵ In the present discourse, these inspirations may have their source in:

- euclidean geometry,
- fractals,
- topology,
- evolutionary algorithms,
- theory of chaos,
- Catastrophe theory.

For Charles Jencks, the reference to mathematics was the most important event in architecture at the end of the 20th century.⁶ The buildings which accompany this discussion have a complex, individualized geometry, and were worked out with the use of digital techniques of design. Different ways of approaching the designing of the buildings created curvilinearly together with different motivations are observed. They range between the desire to design differently with the use of digital techniques and inspiration with science.⁷

¹ J. Słyk, *Źródła architektury informacyjnej*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2012, p. 140.

² I. Stewart, *Matematyka życia. Jak równania pomagają odkrywać tajemnice natury*, Prószyński i S-ka, Warszawa 2014, pp. 20–26.

³ J. Burry, M. Burry, *The New Mathematics of Architecture*, Thames & Hudson, London 2012, pp. 8–13.

⁴ C. Jencks, *The architecture of the jumping universe. A polemic: how complexity science is changing architecture and culture*, Academy Editions, Chichester 1995, p. 14.

⁵ C. Jencks, *The Iconic Building*, Rizzoli, New York, 2008, p. 209.

⁶ C. Jencks, *The architecture of...*, *op. cit.*, pp. 47–60.

⁷ J. Burry, M. Burry, *op. cit.*

In the times of searching for energy suitable technologies of construction, very often inspiring solutions are looked for in the world of nature and science. Contemporary understood 'ecological' way of world perception rejects consumerism, but optimistically assumes the possibility of understanding the mechanisms of nature and coexisting with them.⁸ Such idea of world perception coexists with the slogans of energy- and resource-efficient economy in the 1970s.⁹ The concept of buildings adjusted to such factors as exposition to sun, wind power or closeness to water leads to grater effectiveness of the building thus to the increase of the comfort of the user. Optimization programmed in this way may be seen in some well-known buildings of contemporary architecture. Computer programs generate the form based on the guidelines made by an architect, sometimes creating different versions of solutions. Mathematical account of reality enables to create buildings in astonishing, often admirable forms. The buildings may be created suitably according to material and energy factors. References to nature and biology may be found in the statements of architects. Charles Jencks calls it the reference to 'effective designer' in *Iconic Building*.¹⁰ References to nature have different forms and are not always associated with usability of the building. More or less abstract inspirations may be found, as well as inspirations with processes observed by science, described by the use of mathematical language. The way of inspiration is not always possible to be explicitly defined. For example, Santiago Calatrava states that the structure of L'Hemisfèric in the City of Art and Science in Valencia resembles the human eye.¹¹ The shape of the Bridge of Peace in Tbilisi from AMDL studio refers to marine animals. The multifunctional Balna centre in Budapest has an association with a whale. The following buildings were presented in the article:

- Olympic Swimming Pool in Beijing inspired with Weaire-Phelan geometry,
- Australian Wildlife Health Centre inspired by minimal surface of Costa and cell automata,
- Dome of the Louvre in Abu Dhabi referring to fractals.

2. THE PERMEATION OF INSPIRATION FROM SCIENCE

The buildings which belong to the so-called *biomorphic forms* are characterized by their shape, which is associated with the form met in biology. In such convention, the search for form may refer to the association of an event, which is related to the location. Very often these are objects with complex, astonishing forms, usually created curvilinearly. Architects such as Zaha Hadid or Frank Gehry do not refer to inspirations which come from nature although the forms of the buildings bring such associations to mind, for example the residential skyscraper called *New York by Gehry* which curvilinear elevation surfaces were inspired by sculptures and works of Bernini.¹² The reference to terminology

⁸ J. Słyk, *op. cit.*, p. 142.

⁹ N. Juzwa (ed.), *Architektura i urbanistyka współczesnego przemysłu*, Wydział Architektury. Politechnika Śląska, Gliwice 2010, pp. 13–19.

¹⁰ C. Jencks, *Iconic...*, *op. cit.*, pp. 196, 206–211.

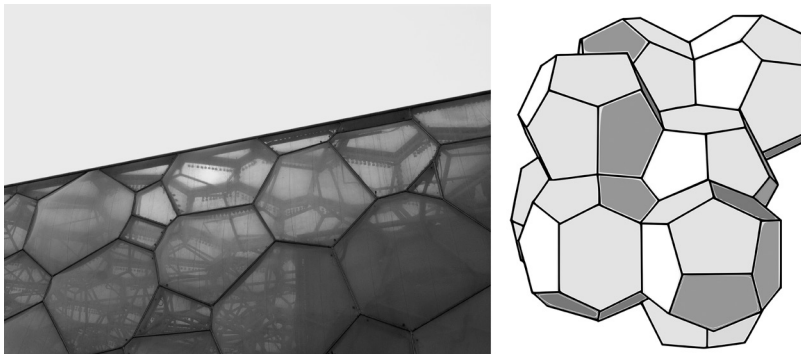
¹¹ Ciudad de las Artes y de las Ciencias [in:] Santiago Calatrava Architects & Engineers, www.calatrava.com/projects/ciudad-de-las-artes-y-de-las-ciencias-valencia.html?image=8&view_mode=overview (access: 19.06.2021).

¹² F. Dischinger, *Frank Gehry. A sit-down with artist of architecture* [in:] The Wall Street Journal,

associated with nature is often mentioned by the authors of buildings as a significant inspiration for the project even if reference of the form to nature is not a leading motive of the project.¹³

Mathematical conceptions and ideas may be used by architects to some extent ‘directly’ to distinguish the building. Relationship with *mathematical* conception helps to obtain the necessary form, which usually requires elaboration using a computer programme. One of the famous examples is the Olympic Swimming Pool in Beijing designed by PTW Architects, Arup and CSCEC in 2008.

The outside of the building brings associations with large water drops or a box filled with foam, while in reality it is Weaire-Phelan geometry mapping. Such geometry is a reply to the so-called Lord Kelvin problem on how to divide the space into cells with the same cubature and minimal surfaces. The geometry consists of 12 and 14 wall cells. The organic appearance of the building was obtained by reversing geometry and trimming it to the rectangular shape of the building.¹⁴ 12 wall cells consist of regular pentagons and 14 wall cells are built up of pentagonal and hexagonal walls (Ill. 1). The building construction was elaborated by the use of a dedicated programme, which on the basis of given scenarios analysed the loading of construction. On the basis of analyses, the programme matched the size of construction elements’ dimensions. The model created in this programme enabled checking different versions of construction, as well as the automatic generating of construction sketches. ‘Drops’ visible on the elevation are made from ETFE foil. Their geometry was influenced by their contour and internal pressure. Numerically controlled machines were used in their production.¹⁵



Ill. 1. A segment of the Beijing Olympic facade designed by PTW Architects, Arup and CSCEC, 2008 and a sketch of the Weaire-Phelan geometry. Own work based on: photo by Lian Chang, CC BY 2.0, <https://www.flickr.com/photos/diametrik/4973981390/> and Tomruen, public domain, <https://commons.wikimedia.org/w/index.php?curid=10471229> (access: 19.06.2021).

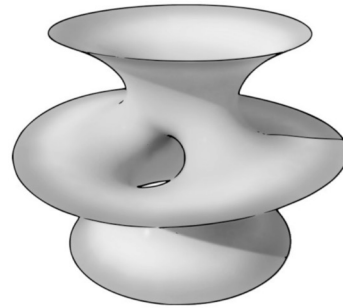
updated 2.04.2011, <https://www.wsj.com/articles/SB10001424052748704474804576222872016570928> (access: 19.06.2021).

¹³ C. Jencks, *Iconic Building...*, *op. cit.*, p. 208.

¹⁴ T. Wallisser, *Other Geometries in architecture: bubbles, knots and minimal surfaces* [in:] M. Emmer, A. Quarteroni (eds.), *Mathknow: Mathematics, Applied Science and Real Life*, Springer, New York 2009, pp. 95–97.

¹⁵ *Ibidem*.

Mathematical concepts to which architects refer serve as the characteristic element in the project, which may be connected with the usability of the building. The example of penetrating mathematical inspirations into architecture is the Australian Wildlife Health Centre (architect Minifie Nixon, 2006–2007). The assumption of the architects was to reverse traditional vet clinic ‘inside out’ and bring the procedures and operations closer to visitors, which usually are performed behind the closed doors. Functional programme of the building was elaborated in cooperation with hospital staff. The building serves as a hospital for the inhabitants of the ZOO and is also a place where wild, wounded animals are treated, rehabilitated, and prepared for being set free again. In the courtyard of the building and around it there are rooms with glass walls such as: operating theatre, laboratory, examination room and convalescence unit. Thanks to this, the visitors may observe the work of veterinarians in the laboratory or operating theatre. Above the courtyard there is a large curvilinear structure of a golden membrane. It has a continuous, funnel-like shape with three openings. These openings allow both illumination of the building and its ventilation. What is more, the size and colour of the structure according to architects refer to a dome which has a representative role.¹⁶



- III. 2. Australian Wildlife Health Centre, arch. Minifie Nixon, 2006–2007 and a sketch of Costa's minimal surface. Own work based on: Gabrielle Dimech, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=32508025> and By Anders Sandberg, CC BY-SA 3.0, <https://commons.wikimedia.org/w/index.php?curid=21538299> (access: 19.06.2021).

The geometry of the structure was designed in accordance with the conception of Costa minimal surface (III. 2), which was described by the Brazilian mathematician Celso Jose da Costa. The Costa surface is ‘a complete minimal surface which can be encased in defined topology’. It is an element which has the smallest surface for its limits, may be continued with no limits and does not cut itself. Until the discovery of the surface by Costa in 1984, the only known surfaces with such properties were: plane, helicoid (screw plane) and catenoid (solid of evolution made by the turnover of the catenary), all of which are well known in architecture. The Costa surface was discovered due to ‘experimental mathematics’, which uses computers to examine a number of cases before formal evidence is applied. Such surfaces cannot be recognised directly, they require calculation process, which iteratively finds the ultimate form from the set of limitations.¹⁷ Bricks on the elevation are placed in a way to imitate the

¹⁶ N. Stead, *Australian Wildlife Health Centre* [in:] ArchitectureAU, 1.03.2006, <https://architectureau.com/articles/australian-wildlife-health-centre/> (access: 20.03.2021).

¹⁷ J. Burry, M. Burry, *op. cit.* pp. 20–23.

so-called cell automation/machine. The layout of cells was defined by a computer algorithm, which generating the pattern took into consideration elements of architectural elevation such as doors and windows. Cell automation is a set of 'coloured' cells on the grid with a certain shape, which evolve by a certain number of steps in accordance with a set of rules based on conditions of neighbouring cells. Cell automata were tested in the early 1950s as a possible model of biological systems. Including mathematical conceptions into the project of the building may be understood as a reference to the fundamental processes which rule the nature. The creators of the building hope that due to such experiences and closeness to animals, the visitors will be more responsible for wildlife.¹⁸

Computer tools allow creation of curvilinear, continuous surfaces as well as relatively easy adjustment to conditions without losing the integrity of the concept. It encourages some architects to look for their own designing models and templates and an abstract approach to mathematical and/or geometrical matters inspires them. The dome of Louvre in Abu Dhabi created by Jean Nouvel in 2007–2017 is worth mentioning here. Above exhibition pavilions, which by their layout resemble an old urban structure of the town, there is a large, shallow dome with a span of 180 meters. The dome is decorated with complex, geometrical template and refers to traditional Arabic coverings protecting from the sun. The structure of the dome infiltrates sun rays into interior, creating a 'rain of light.'¹⁹ It is possible thanks to the construction made of truss, which from top and bottom is finished with 8 layers of perforated linings put one on top of each other. Each layer makes a geometrical pattern, which consists of repeated shapes resembling stars, yet the patterns on the layers are reversed and rescaled against each other. The dome protects against strong sun but it illuminates the interior in a planned way. In order to develop the pattern of translucency, different variants of projects were examined and complex analyses of exposition to sun were carried out. The dome consists of 400,000 various elements, weighs 7,500 tons and is supported in four places. Multilayered layout of similar geometrical patterns resembles fractals (Ill. 3). At first sight the structure seems to be chaotic, however after some observation its orderliness becomes visible.²⁰

Fractals are figures and self-similar curves in which the pattern appears in smaller and smaller elements of the whole. Enlargement of each part looks like the whole structure. Benoit Mandelbrot (1924–2010) elaborated the theory of fractals in 1975, which makes it possible to describe and examine irregular and chaotic geometrical structures. It considers fractal objects earlier described, such as the Koch curve and Sierpinski's carpet and triangle.²¹ Fractals are suitable for bringing closer shapes existing in nature, such as coastlines or snowflakes, which are difficult to describe with Euclidean geometry. Computer technology

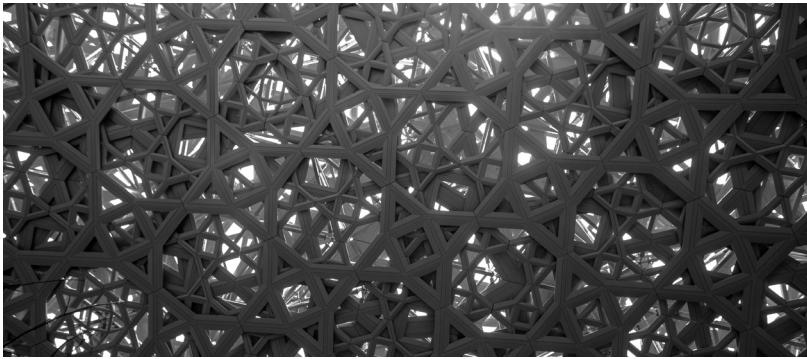
¹⁸ *Ibidem*; A.L. Harris, *Case Studie* [in:] A.L. Harrison (ed.) *Architectural Theories of the Environment: Posthuman Territory*, Routledge, New York, 2013, pp. 182–189.

¹⁹ Louvre Abu Dhabi [in:] Ateliers Jean Nouvel, <http://www.jeannouvel.com/en/projects/louvre-abou-dhabi-3/> (access: 22.03.2021).

²⁰ J. Burry, M. Burry, *op. cit.*, pp. 62–67; Louvre Abu Dhabi: Dome [in:] Buro Happold, <https://www.burohappold.com/projects/louvre-abu-dhabi-dome/> (access: 22.03.2021); A. Andraos, *Problemizing a Regional Context: Represntstion in Arab and Gulf Cities* [in:] H. Molotch, D. Ponzini (eds.), *The New Arab Urban: Gulf Cities of Wealth, Ambition, and Distress*, New York University Press, New York 2019, pp. 62–63.

²¹ A. Rooney, *Fascynująca matematyka*, Bellona, Warszawa 2013, pp. 203–205, 297.

made it possible to carry out more accurate studies on the theory of fractals and enables the use of the language of fractals in creation of geometry reflecting the natural way of evolution. The investigators of the history of architecture noticed the elements of philosophy related to fractals in the architecture of Indian temples as well as in Gothic and Art Nouveau Architecture. Smaller elements of the buildings refer to themselves. It should be mentioned that these projects were created thanks to architects' intuition and were created before the theory of fractals had been observed and described.²²



Ill. 3. The dome of Louvre in Abu Dhabi, Jean Nouvel, 2007–2017. View from inside of the building. Photo by Mzagerp, CC BY-ND 2.0, <https://www.flickr.com/photos/mzagerp/41641642055/in/photostream/> (access: 22.03.2021).

3. SUMMARY

Summing-up, scientific discoveries usually come from outside architecture, yet the creativity of architects allows for their use in the process of creation.²³ Over the centuries, the search for new solutions has made it possible to introduce new elements and new solutions into architecture in each period of time. The needs but also dreams related to the birth of formation of architecture, sometimes precede technical abilities. It forces architects to elaborate new implementing methods. At the same time scientific discoveries and inventions influence the creators who want to use them in their projects. The potential of novelty constitutes an added value or value that shows the architectural innovation of the building.

It is obvious that science and technology are used in architecture and apart from providing designing tools, they make up a source of inspiration. What is more, they affect the language of architecture, which takes the ideas from the world of science and produces its own abstracts. Scientific discoveries, new possibilities of digital tools, as well as the talent and intuition of a human being are closely related in the search for new architectural solution.

²² Y. Joye, *Fractal Architecture Could Be Good for You*, Nexus Network Journal, 2007, no. 9, pp. 311–320, DOI 10.1007/s00004-007-0045-y

²³ H. Straub, *Die Geschichte der Bauingenieurkunst. Ein überblick von der Antike bis in die Neuzeit*, Birkhäuser, Basel 1964, pp. 290–291.

References:

- [1] Andraos A., *Problemizing a Regional Context: Represntstion in Arab and Gulf Cities* [in:] Molotch H., Ponzini D. (eds.), *The New Arab Urban: Gulf Cities of Wealth, Ambition, and Distress*, New York University Press, New York 2019.
- [2] Burry J., Burry M., *The New Mathematics of Architecture*, Thames & Hudson, London 2012.
- [3] Ciudad de las Artes y de las Ciencias [in:] Santiago Calatrava Architects & Engineers, www.calatrava.com/projects/ciudad-de-las-artes-y-de-las-ciencias-valencia.html?image=8&view_mode=overview (access: 19.06.2021).
- [4] Dischinger F., *Frank Gehry. A sit-down with artist of architecture* [in:] The Wall Street Journal, updated 2.04.2011, <https://www.wsj.com/articles/SB10001424052748704474804576222872016570928> (access: 19.06.2021).
- [5] Harris A.L., *Case Studie* [in:] Harrison A.L. (ed.) *Architectural Theories of the Environment: Posthuman Territory*, Routledge, New York, 2013, pp. 182–189.
- [6] Jencks C., *The architecture of the jumping universe. A polemic: how complexity science is changing architecture and culture*, Academy Editions, Chichester 1995.
- [7] Jencks C., *The Iconic Building*, Rizzoli, New York 2008.
- [8] Joye Y., *Fractal Architecture Could Be Good for You*, Nexus Network Journal, 2007, no. 9, pp. 311–320, DOI 10.1007/s00004-007-0045-y
- [9] Juzwa N. (ed.), *Architektura i urbanistyka współczesnego przemysłu*, Wydział Architektury. Politechnika Śląska, Gliwice 2010.
- [10] Louvre Abu Dhabi [in:] Ateliers Jean Nouvel, <http://www.jeannouvel.com/en/projects/louvre-abou-dhabi-3/> (access: 22.03.2021).
- [11] Louvre Abu Dhabi: Dome [in:] Buro Happold, <https://www.burohappold.com/projects/louvre-abu-dhabi-dome/> (access: 22.03.2021).
- [12] Rooney A., *Fascynująca matematyka*, Bellona, Warszawa 2013.
- [13] Słyk J., *Źródła architektury informacyjnej*, Oficyna Wydawnicza Politechniki Warszawskiej, Warszawa 2012.
- [14] Stead N., *Australian Wildlife Health Centre* [in:] ArchitectureAU, 1.03.2006, <https://architectureau.com/articles/australian-wildlife-health-centre/> (access: 20.03.2021).
- [15] Stewart I., *Matematyka życia. Jak równania pomagają odkrywać tajemnice natury*, Prószyński i S-ka, Warszawa 2014.
- [16] Straub H., *Die Geschichte der Bauingenieurkunst. Ein überblick von der Antike bis in die Neuzeit*, Birkhäuser, Basel 1964.
- [17] Wallisser T., *Other Geometries in architecture: bubbles, knots and minimal surfaces* [in:] M. Emmer, A. Quarteroni (eds.), *Mathknow: Mathematics, Applied Science and Real Life*, Springer, New York 2009, pp. 95–97.

Author's Note

Jakub Świerzawski, PhD, Arch.

Graduated from the Silesian University of Technology, 2011, PhD degree obtained in 2017 at the Łódź University of Technology, dissertation: Curvilinearity in Architecture. History. Present Day. Ideas. Examples, thesis supervisor: Nina Juzwa, Jan Salm. Doctoral thesis awarded by the Minister of Investment and Development in 2019, since 2019, Dean at the Faculty of Architecture, Civil Construction and Applied Arts, WST Katowice, he cooperates with the National Institute of Architecture and Urban Planning.
jakub.swierzawski@wst.pl