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Fig. 1. Frank Lloyd Wright: Fallingwater House, Bear Run, Pennsylvania, 1939. A unique example of organic architecture is the Kaufmann Residence or Fallingwater House in Bear Run, Pennsylvania (1935-1939). The three-storey weekend house is set in a very unusual location: on a cliff above a waterfall. The cantilever structure sits on top of the waterfall, which is invisible but can be heard. The house is a prime example of a modern technology in natural surroundings.

Sl. 1. Frank Lloyd Wright: Kuća Fallingwater, Bear Run, Pensilvanija, 1939. Kuća Kaufmann ili Fallingwater, Bear Run, Pensilvanija (1935.-1939.), jedinstveni je primjer organske arhitekture. Trokatna vikendica smještena je na neobičnoj lokaciji – na stijeni iznad slapa. Konzolna konstrukcija postavljena je iznad vodopada koji se ne može vidjeti, no kojeg se šum može čuti. Ova je kuća vrhunski primjer moderne tehnologije u prirodnom okruženju.

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Interpretations of Organic Architecture

Interpretacije organske arhitekture

biomimicry
computational geometry
Gaudí, Antoni
organic architecture
Wright, Frank Lloyd

biomimikrija
računalna geometrija
Gaudí, Antoni
organska arhitektura
Wright, Frank Lloyd

The notion of organic architecture originally sprung from the ideas of Viollet-le-Duc and Ruskin, which influenced Wright and Gaudí. The second interpretation of organic architecture is based on mathematic and geometric laws that originate in nature. According to the third interpretation, organic architecture finds inspiration in nature and emulates the shapes of living organisms.

Pojam *organska arhitektura* potječe od Viollet-le-Duca i Ruskina, koji su izvršili utjecaj na Wrighta i Gaudija. Druga interpretacija organske arhitekture temelji se na matematičkim i geometrijskim zakonitostima koje postoje u prirodi. Prema trećoj interpretaciji, organska arhitektura nalazi inspiraciju u prirodi i oponaša oblike živih organizama koji reagiraju na vanjske utjecaje.

Introduction

Uvod

The second half of the 19th century saw a new revival of Gothic architecture as well as the classical rules of Greek architecture. The proponents of these new architectural principles, Viollet-le-Duc and John Ruskin, were inspired by natural shapes and processes while simultaneously advocating the continuation of the medieval handcrafted art tradition as opposed to introducing new industrial methods.[1]

Eugène Emmanuel Viollet-le-Duc (1814-1879) was a French Gothic revival architect and a restorer of French medieval buildings. Through his knowledge of Gothic architecture, he perceived architecture as a harmonious system of construction and composition, yet without the imitation of Gothic forms and details. He defended the scientific rational approach to nature, based on geometric and physical laws. Along with many 19th-century theoreticians, he was convinced that, unlike painting and sculpture, architecture must not simply imitate nature, but should emulate its laws. He sought inspiration in the study of organic shapes such as leaves and animal skeletons (i.e. bats' wings). Although the art of construction is a human creation, he claimed, the extent of human helplessness forces the artist to emulate nature's use of the same elements, the same logical methods, the same subordination to certain laws and the same transfers.[2] According to Viollet-le-Duc, the laws of nature stand in a complex mathematical, physical and functional interdependence, culminating in Unity *(Unité)*. Construction, the strongest foundation of the Law of Unity, can also be found in nature.[3] Using the gothic model he insisted that materials must be used honestly and that buildings' exterior should reflect rational construction.

Some believe that Viollet-le-Duc was influenced by John Ruskin (1819-1900), one of the 19th-century philosophers, who strongly influenced the architects of the period, particularly through his essay *The Seven Lamps of Architecture* (1849), emphasizing the significance of the handcrafted and honest display of material and construction.[4] He insisted that buildings should express the power of nature, and ornamentation should draw on nature and its creations. Beauty should stem from nature and be designed to fit mankind.

In the late 19th and early 20th century, Viollet-le-Duc and Ruskin strongly influenced entire generations of their readers both in Europe and in the USA.[5] Architecture turned in a new direction and we see the emergence of organic architecture, to be further refined into different interpretations. This article's purpose is to define each interpretation of organic architecture, to find the respective most influential representatives, as well as to present the key laws that influenced architectural design and planning.

Origins of Organic Architecture

Počeci organske arhitekture

Initially, Viollet-le-Duc's and Ruskin's publications gained popularity in the USA. Their influence ranged from architectural theory to providing specific design motifs to an eclectic American architecture.[6] Their works took root with the periods' leading American architects, also with Louis Sullivan and his young apprentice, Frank Lloyd Wright. In Europe,

1 Zevi, 1950: 86
2 Viollet-le-Duc, 1854-1868: 476
3 Viollet-le-Duc, 1854-1868: 340
4 Ruskin, 1981
5 Reiff, 1988: 34
6 Reiff, 1988: 32
7 Zevi, 1950: 66
8 Sullivan, 1901-02: 48
9 Sullivan, 1901-02: 47
10 Outward appearance resembles inner purpose.
11 Hoffmann, 1969: 177
12 "Be warned this word 'organic' is like the word 'nature'. If taken in a sense too biological, it would not be what it is: light in darkness; it would be a stumbling block." [Wright, 1958: 160]
13 Nute, 1997: 271-288
14 Satler, 1999: 16
15 Zevi, 1950: 68
16 Wright's architecture is characterised by an entirely new approach to building design, particularly the design

they especially inspired the Catalonian architect Antoni Gaudí of Barcelona.

• **The organic architecture of Frank Lloyd Wright** – The first definition of "organic architecture" was introduced by Louis Sullivan (1856-1924) in his work *Kindergarten Chats* (1901).[7] Sullivan defined the concept of "organic" in correlation with the concepts of "organism", "structure", "function", "growth", "development" and "form". All these words imply the initiating pressure of a living force and a resultant structure or mechanism whereby such force is made manifest and operative.[8] He claimed that "if the work is to be organic, the function of the parts must have the same quality as the function of the whole".[9] Therefore, the key concept of organic design is derived from Sullivan's "form follows function" axiom.[10]

Under the influence of Viollet-le-Duc's work *Dictionnaire raisonné de l'architecture française du XI^e au XVI^e siècle* (1856), Frank Lloyd Wright claimed that while every architect must study the history of architecture, he must not copy the forms of the past in design and constructing, but should only explore their generic principles.[11] Wright's understanding of the relation between architecture, architect and nature wholly agreed with Viollet-le-Duc's. Moreover, he found confirmation for his "organic"[12] ideals in Japanese art and traditional architecture[13], and by connecting the conventional Western version of space with the Eastern one he created his own architectural style.[14] Wright's understanding of Japanese architecture gave rise to his demand for unity, harmony and simplicity as well as for the demand to respect the nature of building materials and the uniqueness of anything individual. Wright failed to fully verbally define his organic architecture[15], yet its principles are expressed in his works[16]:

– The nature of the location – susceptibly respecting the landscape – The location's nature entails observing local tradition and creating a building with natural materials. The building is a frame of its environment or showcases unusual elements of the surrounding terrain. To him, it was important to bring the outside world into the house and let the inside of the house go outside.[17]

– Observing the investor's needs – The investor's needs can be interpreted very practically, i.e. with the required number of rooms for a family and where its members might prefer to gather. A house is a refuge, which he emphasizes with the central placement of the fireplace for the family to gather around. Also, Wright always studied how a building might enhance family activities and elevate the family's everyday life to the level of art.

– Observing the artistic identity of materials[18] – The natural pattern of the building material becomes an integral ornament of the building.

Wright's worship of nature[19] is expressed through his dominant horizontal lines rising from the starting point – the plains of the prairie landscape; through the organic connection between the building and its surroundings – the buildings seem to grow from the ground[20], connected with nature by terraces, covered garden walls, flower beds and decorative containers (urns). Wright beautifully connects architecture and nature, matters organic and geometric, natural stone and concrete, the interior with the exterior, and nature with space[21] (Fig. 1). For many, Wright is the true father of organic architecture and indeed, he inspired entire generations of younger architects.[22]

• **The organic architecture of Antoni Gaudí** (1852-1926) – Gaudí created a unique organic architecture profoundly different from Wright's. He adopted Ruskin's idea that "ornament is the origin of architecture" and under Viollet-le-Duc's influence recognised the Gothic as the only true acceptable style of architecture. The Gothic form was for Gaudí at the same time functional and aesthetic, and he discovered how to adapt the language of nature to the structural forms of architecture.

Gaudí was inspired by the organic shapes of nature. He found abundant examples of these, for instance in rushes, reeds and bones. Unlike Wright, Gaudí did not integrate a building's natural surroundings by connecting it with the interior; instead, he explored the static forces of nature and used its principles in the structure of the building. He established a sensitive relationship with nature and translated it into a highly original and often zoomorphic ornament that features prehistoric, extinct species of gigantic monsters,

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of houses. He reduced the number of rooms by combining their functions in a large living space with a central fireplace. He used large glazed areas to connect the external environment of the house with the interior. The natural environment of the prairie was the inspiration for the horizontal lines that characterised his architecture. His buildings are low in height, close to human scale and with a great feeling for the natural setting in which they are built. [Wright, 1969: 141-142]

17 Wright, 1954: 33

18 "All materials are beautiful, their beauty much or entirely depending upon how well they are used by the architect." [Wright, 1954: 53]

19 "I came to feel that in the nature of Nature – if from within outward – I would come upon nothing not sacred. Nature had become my Bible." [Wright, 1957: 21]

20 "I had an idea that every house in that low region should begin *on* the ground, not *in* it as they then began, with damp cellars." [Wright, 1954: 16]

21 Nute, 2000: 26, 37

22 Pearson, 2001: 39

Fig. 2. Antoni Gaudí: Park Güell, Barcelona, Spain, 1900-1914. Gaudí displays the greatest proximity to nature. He often imitated forms from nature in his work. The colonnades form caverns that seem to have evolved naturally.

Sl. 2. Antoni Gaudí: Park Güell, Barcelona, Španjolska, 1900.-1914. Gaudí iskazuje veliku povezanost s prirodom. U svojim radovima često oponaša oblike iz prirode. Redovi stupova tvore šupljine koje izgledaju kao da su prirodno nastale.

Fig. 3. Antoni Gaudí: Facade Casa Milà, Barcelona, Spain, 1910. The façade is divided according to the movement of the parabolic and hyperbolic arch and creates an impression of sea waves. It is a triumph of Gaudí's organic architecture.

Sl. 3. Antoni Gaudí: Casa Milà, pročelje, Barcelona, Španjolska, 1910. Pročelje je artikulirano prema oblicima paraboličkog i hiperboličkog luka, a podsjeća na morske valove. Ovo je vrhunac Gaudijeve organske arhitekture.

dragons and dinosaurs, as well as trees and plants.[23] He blended all of the above into a unique style of organic architecture. He hated monotony of colour, finding it unnatural: nature never showed itself monochromatically or in complete uniformity of colour.[24] He explored and developed these approaches throughout his life: each and every Gaudí's project is innovative and all are integrated through their author's love and respect for nature and geometry. Some of the undisputed triumphs of Gaudí's organic architecture are the Park Güell (1900-1914; Fig. 2), Casa Milà (1906-1912) and Casa Batlló (1904), not to mention the unique Sagrada Familia (whose construction began in 1886).

Gaudí left a permanent mark on 20th-century architecture: his influence can be found in the works of Pier Luigi Nervi, Otto Frei, Hundertwasser, Oscar Niemeyer, Felix Candela, Santiago Calatrava and many others.

Mathematics and Geometry as Tools for Organic Shapes

Matematika i geometrija kao alati za organske oblike

We are surrounded by an infinite diversity of shapes. Patterns and shapes in nature include mathematical rules and reflect regularity, unity and symmetry, which are experienced as harmony. What we find so attractive in nature is in fact mathematic regularity[25], serving also a basis for the assessment of its beauty. Mathematics is an instrument that has been used by builders throughout history.[26] To this day, it remains a bridge between design and construction.[27] Geometry, the branch of mathematics exploring spatial characteristics of bodies and relationships between them, has been an inspiration and a tool for architectural design since ancient times.

- **Correct geometric shapes** – The earliest civilizations found their inspiration for simple, basic geometric shapes in nature. They created harmonic proportions by connecting the circle, ellipsis, triangle and rectangle (i.e. the Golden Section)[28], which generated the logarithmic spirals[29], basic curves and growth. Spirals are represented in the volute of the Ionic column, the oldest architectural examples of a spiral building is the Tower of Babel.[30] By means of the Golden Section, the Greeks defined the distances between columns. Both the Taj Mahal and the Notre Dame observe the proportions of the Golden Section.[31] From basic geometric shapes, the Etruscans developed the arch and the vault, and the Romans continued this development by expanding it into the dome[32], a much stronger supporting construction as the hitherto known post and beam. Gothic architecture adopted Greek geometry and enhanced it by incorporating the Celtic emulation of natural shapes. In decoration, trees and plants shapes were used as the first true triumph of matters organic in architecture. Along with other geometric shapes, the circle became the basic design aid of a Gothic cathedral. The structures derived from underlying star diagrams, subdivided by polygons (especially pentagons and decagons), which related directly to the Golden Section. Renaissance elevated architecture into a new science. It demanded that every part of a building be integrated into a system of mathematical ratios.

Thus, the entire history of shapes in architecture is based on geometric shapes found in nature. Even in the late 19th and early 20th centuries, shapes used in the revival of Greek and Gothic architecture were based on mathematical laws and further scientific research. In 1917, D'Arcy Wentworth Thompson, in his study *On Growth and Form*, found that the biological shapes of plants and animals were not influenced only by evolution. The guiding principle of evolution is optimisation, which can also be described or proven with the laws of mathematics, physics and mechanics. Man then used these laws to create patterns of built structures. According to Thompson, form is a mathematical problem, whereas the problem of its growth is a physical problem.[33] Thompson's book became an instant classic for the understanding of natural geometry in the dynamism of growth and physical processes.

Also based on natural laws, the new findings of mathematicians in the 20th century proceeded to define new shapes and translate them into architectural design.[34] The mathematician Benoit Mandelbrot, the father of fractal geometry of the 1970s, found that the apparent dis-

23 Zerbst, 2005: 115

24 Zerbst, 2005: 202

25 Finsterwalder, 2011: 15

26 Birindelli, Cedrone, 2012: 105

27 Pottmann, 2009: 61

28 Juvanec, 2009: 196

29 Successions of golden triangles.

30 Birindelli, Cedrone, 2012: 106

31 This is a widely present post festum speculation and observation and not a generic approach of the explicit presence of Golden Section in architecture.

32 A support structure with greater bearing capacity than the old post and beam.

33 Thompson, 1945: 142

34 Birindelli, Cedrone, 2012: 105

35 Kuhlmann, 2008: 38

36 Exhibited in maquette form in 1958-59 at The Museum of Modern Art in New York.

37 Rising while staying around a vertical axis.

order of nature reveals, on closer inspection, repetitions of certain structures. Peter Eisenmann incorporated fractal geometry in design in the Wexner Center at Ohio State University (Columbus, Ohio, 1989). Charles Jencks incorporated catastrophe theory into architectural design, while Greg Lynn introduced complex curved and folded plans.[35]

Thanks to powerful algorithms, the mathematical objects now have an immediate way of being created or represented easily and quickly. The imagination of the shapes to which the architect can be inspired, through the mathematical framework, goes well from the simple triangles and circles to the complex curved forms, like the logarithmically curved spirals in Bruce Goff's Bavinger House (Norman, Oklahoma, USA, 1955) or the flattened spheroid in Friedrick Kiesler's Endless House.[36]

The geometrical surface denoted helicoids, which are two dimensional spirals.[37] An example of this is Eero Saarinen's staircase in the General Motors Technical Centre (Warren, Michigan, 1956). While in Frank Lloyd Wright's Guggenheim Museum (New York, 1959, Fig. 4), the helicoid is the building itself and not only an element of it, hence revolutionizing both the role and the direction of the geometrical surface.[38]

Convenient geometrical objects to use in architecture are so-called ruled surfaces[39], which are present in Le Corbusier's Phillips Pavilion (Brussels, 1958), Felix Candela's Oceanographic (Valencia, Spain, 2003), Toyo Ito's Relaxation Park (Torrevieja, Spain, 2006) and elsewhere.[40]

Antoni Gaudí, in designing the Sagrada Familia, used many ruled surfaces. In his Gothic and organic vision of architecture, he used geometrical structure present in nature. Many pillars of the Sagrada Familia are hyperbolic hyperboloids[41] that are in fact inspired by tree trunks. Gaudí designed balanced constructions (standing erect like a tree with no need for inner reinforcement or external support) using roped, hyperbolic and parabolic arches and vaults, as well as slanting and spiral piers, and testing the complicated constructional forces with weighted models[42] (their results are currently verified using computers).

- **Free space lines** – Ruskin said that "It will evidently follow, upon our application of this test of natural resemblance, that we shall at once conclude that all perfectly beautiful forms must be composed of curves, since there is hardly any common natural form in which it is possible to discover a straight line."[43] For Ruskin, exceptional beauty was inseparably connected with natural shapes such as the outlines of mountains, the inclination of glaciers and the curves of organic forms of shells, fish or willow leaves.[44] Nature is not determined only by strict mathematical laws of Euclidian geometry. For this reason the architecture of organic forms does not always abide to strict geometric laws.

In his essay *Inspiration* (1886), Louis Sullivan described the fusion of geometric and organic shapes as natural principles of design, also found in a transcendental, religious dimension. In practice, he joined geometric and organic forms by designing refined plant motifs with simple squares, cut by diagonals and orthogonal axes. He recognized "feminine" principles in floral, organic shapes originating in primary geometric "masculine" shapes.[45] Le Corbusier, famous for works consisting of boxy, functional, and sterile volumes, designed Chapel Notre Dame du Haut (Ronchamp, France, 1950-1955) as an irregular sculptural form where the walls, the roof, and the floor slope, all in free curvilinear forms.[46]

In his book *Wege zur Form* (1952), Hugo Häring (1882-1958) claims that form is inherent in every location and every element of a building, while the architect's task is to discover and develop it. According to Häring, function stems from nature and life, whereas architectural expression originates from human reason. Functional shapes have remained the same everywhere in the world throughout history, whereas expressive shapes are limited by blood and knowledge and depend on time and place.[47] The organic and functional in architecture is also reflected in his house of Gut Garkau in Lübeck (Germany, 1924-1926).[48] He spoke of buildings in terms of organic display. Although this did not automatically lead to the curve instead of the orthogonal form, it led away from the power and predominance of the straight line and the right angle.[49] Häring's ideas greatly influ-

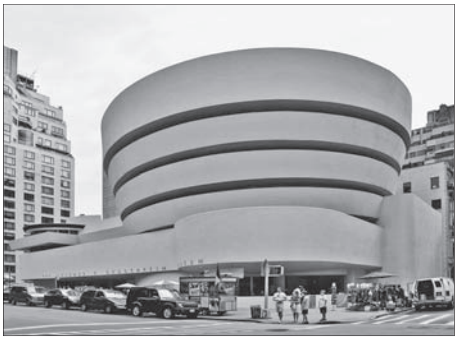

Fig. 4. Frank Lloyd Wright: Solomon R. Guggenheim Museum, New York City, New York, 1959. The Guggenheim Museum, a unique spatial architecture and a monument to modernism, is cast in a concrete tower composed of concentric circles and rises as far as a dodecagon dome on the roof. The exhibition space is created on the walls along a spiral ramp in the inner rotund and not in the closed interiors like in other museums.

Sl. 4. Frank Lloyd Wright: Muzej Solomon R. Guggenheim, New York City, New York, 1959. Muzej Guggenheim jedinstveni je primjer arhitekture i spomenik moderne. Njegov betonski toranj sastoji se od koncentričnih krugova s dvanaesterokutnom kupolom na vrhu. Izložbeni prostor čine zidovi spiralne rampe u unutrašnjosti kružne građevine, a ne zatvoreni interijeri kao u drugim muzejima.

Fig. 5. Friedensreich Hundertwasser: Waldspirale, Darmstadt, Germany, 2000. The spiral form represents shelter. Windows of various sizes and heights are arranged in the wall in a geometrically irregular and seemingly disorganised way, because they serve the residents inside and not the observers outside.

Sl. 5. Friedensreich Hundertwasser: Waldspirale, Darmstadt, Njemačka, 2000. Spiralni oblik predstavlja sklonište. Prozori različitih veličina i visina smješteni su na zidu u nepravilnom i naizgled neorganiziranom geometrijskom uzorku, budući da služe stanarima iznutra, a ne promatraćima izvana.

38 Birindelli, Cedrone, 2012: 109

39 A ruled surface is a surface such that through each of its points passes a straight line contained in the surface.

40 Birindelli, Cedrone, 2012: 110-111

41 One of the ruled surfaces.

42 His results have now been verified by computer modelling.

43 Ruskin, 1981: 104

44 Fuller, 1988: 61

45 Sullivan, 1979: 188

46 "The essence of composition is a radical deviation from orthogonality, fading as a silent yet certainly not minimalistically intoned manifesto ... it is inspired by unique organic forms. Here, the interplay between the concave and the convex ripens to complete plasticity associated with historical reminiscences: the inspiration is unleashed so by catacombs as by Borromini." [Košir, Krećić, Zupančić, 2007: 39-40]

47 Häring, 2001: 321-322

48 Blundell, 1999: 56

49 Pearson, 2001: 44

Fig. 6. Gustave Eiffel: Eiffel Tower, Paris, France, 1889. Construction was inspired by the human femur bone, which is very good at handling off-centre stresses.

Sl. 6. Gustave Eiffel: Eiffelov toranj, Pariz, Francuska, 1889. Građevina je inspirirana ljudskom bedrenom kosti kao efikasnim osloncem.

Fig. 7. Norman Foster: Gherkin Tower, London, 2003. The hexagonal skin of the building was inspired by the Venus' flower basket sponge, which has a lattice-like exoskeleton.

Sl. 7. Norman Foster: Toranj Gherkin, London, 2003. Šesterokutna ovojnica zgrade inspirirana je oblikom spužve s rešetkastom vanjskom ljušturom.

enced Alvar Aalto[50] (Helsinki University of Technology, 1949-1966) and Hans Scharoun (Berliner Philharmonie, 1960-1963).

It was Friedensreich Hundertwasser (1928-2000) who brought expressing with free space lines originating in nature to new heights in organic architecture. He looked up to Gaudí's organic architecture, yet his lines were not based on strict geometry. Hundertwasser, with his painter's soul and his love and acute sense of nature, introduced natural spiral shapes to architecture. For Hundertwasser, a building had to meet the need for protection and shelter: it had to be a safe cave. Unlike Wright, who designed an orthogonally shaped shelter, Hundertwasser's shelter is composed of spiral shapes that can lead outwards or inwards. Although his houses rather resemble a mole's burrow, their chimneys and particularly windows serve as a connection with the outside world. Hundertwasser claims that the design of a house must incorporate its natural surroundings and express two basic principles[51]: the horizontal belongs to nature ("Duty to Tree"), whereas the vertical belongs to man ("Right to Window"; Fig. 5).

Biomimicry – Architecture Inspired by Nature

Biomimikrija – arhitektura inspirirana prirodom

Architecture finds inspiration in nature. Ruskin wrote that "forms which are not taken from natural objects must be ugly".[52] Analogies between man-made artefacts and living organisms have been a persistent theme in Western thought since antiquity.[53] The Egyptians, Greeks and Romans incorporated natural motifs, such as tree leaves, into their columns. The Sagrada Familia is a good example of using functional forms from nature in the solving of constructional problems: Gaudí used columns that modelled the branching canopies to solve static problems in supporting the vault. The Eiffel Tower was inspired by the human femur bone, which is expert at handling off-center stresses (Fig. 6) and the ceiling of the Crystal Palace by the ribbing of the Amazon water lily.[54]

In the early 20th century, two books enhanced the search for models from nature to be used in architectural design, the first being the *Kunstformen der Natur* collection (1899-1904) by Ernst Haeckel (1834-1919), a celebrated German biologist, zoologist and natural scientist. The artwork consists of 100 prints of various organisms, many of which were first described by Haeckel himself. The subjects were selected to embody organization, from the scale patterns of boxfishes to the spirals of ammonites to the perfect symmetries of jellies and microorganisms, while images composing each plate are arranged for maximum visual impact. Among the notable prints are numerous radiolarians, which Haeckel helped to popularize. *Kunstformen der Natur* was influential in early 20th-century art, architecture, and design, bridging the gap between science and art.

The second is the already discussed influential work *On Growth and Form* (1917) by the renowned biologist and mathematician D'Arcy Wentworth Thompson (1869-1948). The book pioneered the scientific explanation of morphogenesis, the process by which patterns are formed in plants and animals.[55] It highlights the laws governing the size of organisms and their growth, statics and dynamism in the functioning of cells and tissues, including the phenomena of membranes under tension, symmetries and cell divisions, along with the engineering and geodesics of skeletons in simple organisms.[56] Thompson's description of radiolarians is one of the most comprehensive.[57] He discovered that organisms developed their own structural forms in response to forces in interrelation to movement that strengthens the organism when necessary, reinforcing structures in critical places by means either of reinforcement or the reduction of redundant material.[58] He de-

50 "The impulse to cover the Paris pavilion with timber may have come from H. Härings 's Garkau farm (1924) but the expression of the timber became a mark of Finland." [Pleština, 1995: 416]

51 Hundertwasser, 2007: 68

52 Ruskin, 1981: 101

53 Rousseau, 1972

54 Benyus, 2008: 30

55 Thompson, 1945

56 Bonnemaison, Beesley, 2007: 7

57 Bonnemaison, 2007: 71

58 Tzonis, Lefaivre, 1995: 127

59 Thompson, 1945: 10

60 Fuller, 2008: 373

61 Gorman, 2005: 198

62 "Bubble domes, too small for man-occupancy, are made by nature at possibly the highest mass production velocity anywhere manifest to man." [Fuller, 1969: 146]

63 The Geodesic Dome is the only structure that becomes more solid with size. It covers the largest possible volume in relation to the surface area embraced by the volume.

64 Fuller, 1969: 132, 189

65 Skejić, Androić, Bačić, 2012: 203

66 Previously the Swiss Re Tower.

67 Benyus, 2008: 30

68 "Paralelly with the building, the machine came into being. But while the development of the architecture is based on form variations, the development of the machinery is founded on an intelligent domination over the laws of nature by means of using energy, functional constructions, kinetical properties, interrelated communicativity and the communication with the man." [Mutnjaković, 1995: 114]

69 Everything in the nature-mimicking house machine is subordinated to function – where the function is the huscribed how a limited set of constructional principles and proportional geometries shaped the form of organic structures in the natural world.[59]

Inspired by the plates of Ernst Haeckel and D'Arcy Thompson, Buckminster Fuller (1885-1983) believed that he was investigating "nature's laws of evolution defy all static patterns".[60] He perceived radiolarians as sources of infinite design strategies which, through his knowledge of geometry, he translated into architectural constructions and even patented.[61] Fuller is perhaps best known as the inventor of the Geodesic Dome, the lightest, strongest, most cost-effective structure ever devised.[62] The Geodesic Dome is a spherical or semi-spherical shell-like structure composed of a grid of triangles, with local triangular tension on the spherical surface, which conduct forces throughout the structure.[63] The American Pavilion at Expo 1967 in Montreal, Canada (Fuller and Sadao), constructed on three-quarters of a circle, measures 250 feet in diameter, while the Geodesic Dome above Lower Manhattan (New York, 1968) would measure two miles in diameter.[64] The Geodesic Dome gave rise to a new type of construction: the shell. Fuller patented many spatial geometric shapes that provided inspiration to later generations of architects.[65] The space frame inspired Norman Foster in his projects of London's Stansted Airport (1991) and the Reichstag Building (Berlin, 1999). Meanwhile, Otto Frei used a geodesic tent in the roof construction of the Olympic Stadium in Munich (1972).

Biomimicry remains a component part of the 21st century architectural design. The Gherkin Tower in London[66] (Norman Foster, 2003) has a hexagonal skin inspired by the Venus' flower basket sponge (Fig. 7), which hosts a lattice-like exoskeleton that appears glassy and glowing in its underwater environment. The fibrous lattice helps to disperse stress on the organism in various directions and its round shape reduce the forces of strong water currents. Meanwhile, the Eden project in Cornwall in the United Kingdom (Grimshaw Architects, 2001) is a series of artificial biomes with domes and was inspired by radiolarians.[67]

Special attention is warranted by projects executed by the Croatian architect Andrija Mutnjaković for his visionary research of possible integration of natural laws into architecture[68] (Homobil[69]; House-Flower[70] (Fig. 8) – from emulating natural forms (Ornitottero[71]) and connecting dwellings to their environment[72] (Kynetichome[73]) to questions on gravity (Cocoonplan[74]; Fig. 9, 10) and suggestions on concepts of living in a terciar town in the postindustrial era, when the planet will encounter overcrowding problems (Urmobil[75]). His works reflect an organic approach in an anticipation of the future high-tech, techno-futuristic architecture. His bio-urban solutions and ideas are also of considerable interest.[76]

Digital Architecture of Organic Forms

Digitalna arhitektura organskih formi

Beginning in the 1990s, digitalization of the planning process marks both a remarkable progress as well as a trying challenge in ar-

man being. A special mechanism adapts horizontal and vertical components and staircases to current human needs. Project, International competition Mt. Olympus, Hollywood, 1964. [Mutnjaković, 1995: 75-108]

70 The building has a clear inspiration in the bionic sketch of flowery Gothic. Project, International competition Una porta per Venezia, 1990. [Mutnjaković, 1995: 151]

71 The building's bionic form stems from Da Vinci's study of bird wings Ornitotter. Project, International competition La casa piu'bella del mondo, Reggio Emilia, 1988. [Mutnjaković, 1995: 119]

72 "The building on the level of the mankind that enters its second industrial revolution should have spaces adequate at least to the imagination of the nature, it should possess kinetical constructive systems, it should dispose of dynamic volumes, it should have an impregnation of internal and external areas, it should communicate with the human being organoleptically and sensorially, it should join the man's space with the nature [Mutnjaković, 1995: 116]

73 "... be opened towards the macrocosmos of the sun and the stars, the night and day, and connects the inside living space with nature." Project, National competition Saint Peter's Church, Split, 1970 [Mutnjaković, 1995: 157-190]

74 The Hover Home is human reality. The most effective forms of living space were created by nature, among them the silken cocoon membrane – firm, soft, spherical, ventilated, and flexible. Living space within a helium filled balloon is afloat, and, with the help of an engine, can fly. The Hover Home is a possible alternative to the urban cataclysm. Project, International exposition of international architecture, Wroclav, 1981 [Mutnjaković, 1995: 51-74]

75 Project, International competition Portant sur un projet d'une unite d'habitation fabriquee à l'echelle industrielle, Luxembourg, 1976 [Mutnjaković, 1995: 207-224]

76 The terciary home will provide opportunities to remove the limits of industrial pollution, establish a direct contact between nature and dwelling and integrate the urban organism with all manifestations of nature. [Mutnjaković, 1988: 15]

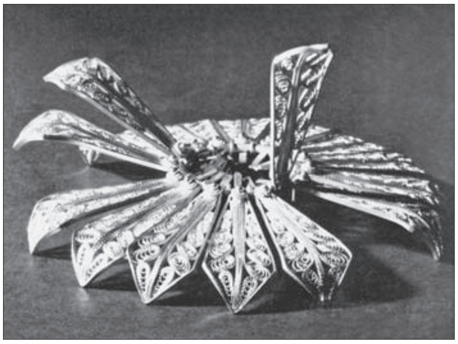

Fig. 8. Andrija Mutnjaković: House-Flower: project for international competition Una porta per Venezia, Venezia, 1990; the model: a variant of open position of the house

Sl. 8. Andrija Mutnjaković: Kuća-cvijet: projekt za međunarodni natječaj *Una porta per Venezia*, u Veneciji, 1990.; model: varijanta otvorene pozicije kuće

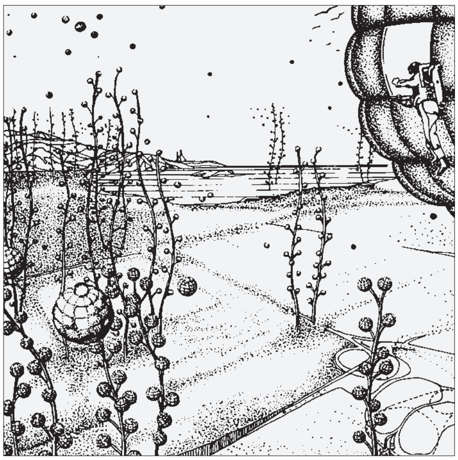

Fig. 9. Andrija Mutnjaković: Cocoon plan, the project exhibited at the international exposition of international architecture, Wroclaw, 1981, a perspective view of hovering home

Sl. 9. Andrija Mutnjaković: Kokonplan, projekt izložen na međunarodnoj izložbi internacionalne arhitekture u Wroclawu, 1981., perspektivni prikaz lebdeće kuće

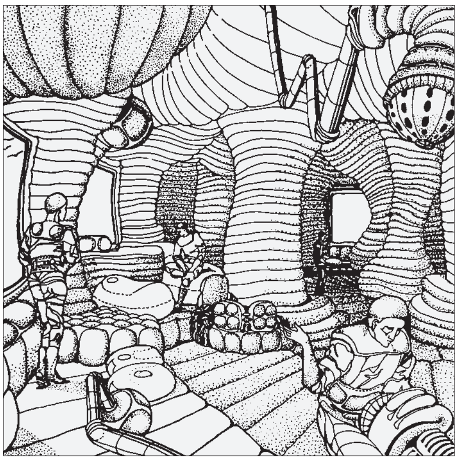

Fig. 10. Andrija Mutnjaković: Cocoon plan, the project exhibited at the international exposition of international architecture, Wroclaw, 1981, a sketch of the balloon interior

Sl. 10. Andrija Mutnjaković: Kokonplan, projekt izložen na međunarodnoj izložbi internacionalne arhitekture u Wroclawu, 1981., skica interijera

Fig. 11. Frank Gehry: Guggenheim Museum, Bilbao, Spain, 1997. The museum, although heavily dependent on digital curved surface modelling software, was developed from such gestural and sensual investigations in sketch and model form. Once the sculpted form was finalized, an exact digital model described the building in mathematically defined curves and surfaces.

Sl. 11. Frank Gehry: Muzej Guggenheim, Bilbao, Španjolska, 1997. Iako je ova građevina u značajnoj mjeri nastala na temelju računalnog programa za modeliranje zakrivljenih površina, ona je utemeljena na istraživanju pokreta u skici i formi. Nakon što je oblikovana forma finalizirana, precizan digitalni model opisao je građevinu u matematički definiranim krivuljama i površinama.

Fig. 12. Wojciech Kakowski, Marcin Mostafa and Natalia Paszkowska: Polish Pavilion, Expo 2010, China; macroscale lace pattern on the façade

Sl. 12. Wojciech Kakowski, Marcin Mostafa i Natalia Paszkowska: Poljski paviljon, Expo 2010., Kina; uzorak čipke u makromjerilu na pročelju

chitectural design. Organic shapes, previously conceivable and implementable only by the greatest minds (such as Gaudí, Wright and Fuller) are, due to computers and parametric tools, readily accessible. New tools contain all concepts developed in the past: from the ideas of Ruskin, Viollet-le-Duc, Wright and Gaudí to the 20th-century mathematicians and Greg Lynn, William Mitchell, Peter Eisenmann, Frank Gehry and the pioneers of digitalization in architecture[77], thus offering new opportunities for design in synergy with nature, mathematics, geometry and intuition.

Although digitalization facilitates the mastering of organic lines and spaces, this is really not organic but parametric design. In other words, the approach to design has changed. In parametric design, objects are no longer designed but calculated, allowing the design of complex shapes with surfaces of variable curvature that would be difficult to represent using traditional drawing methods, and laying "the foundation for a non-standard mode of production". It is now possible to produce series-manufactured, mathematically coherent but differentiated objects, along with elaborate, precise and relatively cheap one-off components.[78]

In the 1980s and 1990s, the software industry invested in computer-aided design systems that encoded knowledge about the calculation and displays of free-form curved shapes specified by a few parameters. As a result, these became widely and inexpensively available.[79] Buildings were once materialized drawings, but now, increasingly, they are materialized digital information.[80] Development processes and systems based on digital engineering, complex geometry and biological principles[81] are incorporated in the design of contemporary architecture. These processes and systems allow for innovations in contemporary design. The innovative approach is supported by computer-enabling mathematical modelling and processing. With the use of contemporary computer technologies and modern design, the image of the façade changes and heralds the birth of completely new forms. In contemporary architectural planning, computer support is required at all stages from planning to the preparation of the production process: CAD[82] and CAM[83] engineering and CNC[84] technology are used throughout.

- **Computational geometry** – To create virtual and physical shapes, digital architecture employs computer modelling, programming, simulation and imaging. Digital architecture is made possible by complex computations offering a wide range of complex forms assisted with high-performance computer algorithms. Thus, new geometries emerge that were hitherto impossible using the conventional, drawing-board approach. Gaudí tested his constructions of organic forms by means of models.[85] Although Hundertwasser's buildings seem completely random, a result of instant inspiration, the architect built accurate models that even featured greenery on terraces and painted decoration.[86] Mutnjaković's Homobil, Kyneticdome, House-Flower (Fig. 8), Ornitottero exist only as models. But the development of computer methods gave rise to radical changes in the architectural process of design. Models are no longer necessary. CAD software[87] can be upgraded with the DMU[88] digital tool, which facilitates accurate visualization and serves instead of a prototype. The DMU tool was initially employed in the design of cars and planes; Frank Gehry was the first to employ it in architecture for the Guggenheim Museum in Bilbao (1997[89]; Fig. 11).

In the late 1980s, in-depth research into computer modelling enhanced and allowed for a shift in design from planning and modelling to more mathematical approaches using parametric tools. The result was NURBS.[90] This tool can thoroughly process any shape or form, from simple two-dimensional lines, a circle, an arch or a curve, to more complex three-dimensional organic surfaces or bodies. Today, a growing number of architects are designing with NURBS. It was, for example, employed in the design of the Graz Art Museum (Austria, Peter Cook and Colin Fournier, 2003; Fig. 13) and the Aquatics Centre project in London (Zaha Hadid, 2012).

To develop forms with new computer techniques, generating software is used, such as the L-system, a "botanical" algorithmic system that is otherwise used for the simulation of plant growth in laboratory tests and simulations.[91] Algorithmic design procedure was the only way of creating the roof above the Great Court of the British Museum in London (Norman Foster & Partners, 2000), the Serpentine Gallery Pavilion in London (Toyo Ito, 2002) and the 2008 Olympic Games facilities in Beijing, China (the Beijing National Aquat-

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77 Picon, 2010: 8
78 Zellner, 1999
79 Mitchell, 2005: 43
80 Mitchell, 2005: 41
81 Parametric architectural design, the creative process of which is comparable to the biological process of morphogenesis.
82 Computer-aided design
83 Computer-aided manufacturing
84 Computer numerical control
85 Zerbst, 2005: 34
86 Hundertwasser, 2007: 69
87 AutoCad, ArchiCad, etc.

ics Center Water Cube, PTW Architects; the National Stadium Bird's Nest, Herzog & de Meuron).[92] Using radically revolutionary geometry gave rise to a completely new approach in architecture design – the architectural circles of Greg Lynn, Bernhard Franken and others call it morphogenesis. Initially used in the biological sciences, the expression refered to the emergence of forms and patterns in an organism through growth and differentiation processes[93] and represented a digitalization of what D'Arcy Thompson explored a full century before.

• **New Ornamentation** – Using CNC technology in design gives architects control of real-size processes through very precise technical operations and material applications, which has led to the revival of ornaments and patterns on façades. Contemporary software can generate extremely small differences in thousands of patterns, creating a selection of patterns in a very short period of time. Façades facilitate spatial, visual and conceptual effects.[94] Ornaments on the façades of Jeddah International Airport in Saudi Arabia (OMA, 2005), the IMKZ Library in Cottbus, Germany (Herzog & de Meuron, OMA) and the Polish Pavilion at Expo 2010 in Shanghai, China (Wojciech Kakowski, Marcin Mostafa and Natalia Paszkowska, 2010) (Fig. 12) are but a few of the many examples of new forms of ornamentation that are increasingly frequent in contemporary architecture.[95]

The use of computer methods in design marks the beginning of a new chapter of constructional ornamentation.[96] The Sendai Mediatheque in Sendai, Japan (Toyo Ito, 2001), the Prada Aoyama Epicenter in Tokyo (Herzog & de Meuron, 2003), the Gherkin Tower in London (Norman Foster, 2004), the Simmons Hall Student Housing at MIT in Cambridge, UK (Steven Hall, 2002) and the Seattle Central Library in Washington, USA (OMA/LMN, 2004; Fig. 14) are some examples of constructional ornamentation that clearly show that ornament on a contemporary façade is no longer merely a result of design, but also a starting point of construction.

Conclusion

Zaključak

Organic architecture as developed in the 20th century encompasses three concepts:

– The original concept of organic architecture meant the incorporation of nature in the design of a building. Wright perceived it as a blending of a building with its surroundings, while Gaudí searched for natural laws that could be incorporated in a building's construction and design (early 20th century).

– The second interpretation presents organic architecture as a style of architecture based on natural forms that are, as a rule, not straight. They are defined by mathematical and geometric laws that also originate from nature. Architectural forms stem from accurate geometry or are designed completely freely or intuitively (mid and end 20th century).

– The third interpretation of organic architecture is based on biomimicry, the search for models in living organisms and the translation of these patterns into the design, functional or technological aspects of a building (21st century).

However, the borderlines between these individual concepts are not always clear. Indeed, they are rarely mutually exclusive and in real life, usually overlap or complement each other. Over the last decade, a new approach to organic architecture has arisen due to architecture digitalization or computation. This offers exciting and efficient tools for the planning of complex shapes and forms that can originate both in geometry and in biomimicry. Several projects of new organic architecture based on these new achievements have already been implemented, but there are new technologies and tools on the way which will assist in designing buildings much as nature would (for example the computer tool simulating plant growth which was employed in the Digitally Growing Tower in New York; Dennis Dollens, 2005).[97] Thus, computation opened new opportunities for expressing the original ideas of organic architecture. Or, according to Peters and Peters[98] in their *Inside Smartgeometry*, "Computation is not 'just' a tool – there can be no doubt that it is fundamentally changing architecture". And this includes (indeed primarily), organic architecture. The organic architecture of the 21st century is facing new challenges. Presently, it mostly focuses on non-orthogonal forms due to the design potential of digital tools. But the principles of sustainable architecture demand that buildings are connected with their surroundings as much as is possible, meaning that contemporary architecture is returning to the original, Wright's interpretation of organic architecture.

[Translated by Amidas d.o.o., lector Nataša Jančar]

Fig. 13. Peter Cook and Colin Fournier: Graz Art Museum, Austria, 2003. Constructed from about 1,300 individually shaped, translucent Plexiglas panels covering the biomorphic building.

Sl. 13. Peter Cook i Colin Fournier: Muzej moderne umjetnosti u Grazu, Austrija, 2003. Oko 1300 individualno oblikovanih poluprozirnih panela od pleksiglasa pokrivaju biomorfnu građevinu.

Fig. 14. OMA/LMN: Seattle Central Library, Washington, 2004. The differential structural performance of the envelope has been made visible to produce a differentiated patterning of the façade.

Sl. 14. OMA/LMN: Središnja knjižnica u Seattleu, Washington, 2004. Konstruktivna izvedba ovojnice vidljiva je kako bi tvorila diferencirani uzorak na pročelju.

88 Digital MockUp
89 Szalapay, 2005: 207
90 Non-Uniform Rational Basis Splines, a mathematical model that facilitates a graphic representation of complex mathematical formulas or the making of 3D models.
91 Issa, 2014
92 Szalapay, 2005: 60-77
93 Leach, 2008: 96
94 Pell, 2010: 12
95 Levit, 2008: 70-85
96 Ruby, Ruby, Ursprung, 2004: 85
97 Weston, 2003: 214
98 Peters, Peters, 2013: 11

Bibliography

Literatura

1. Benyus, J. (2008), *A Good Place to Settle: Biomimicry, Biophilia, and the Return of Nature's Inspiration to Architecture*, in: *Biophilic Design: The Theory, Science and Practice of Bringing Buildings to Life* [eds. Kellert, S.R.; Heerwagen, J.; Mador, M.], Willey, New York
2. Birindelli, I.; Cedrone, R. (2012), *Modern Geometry versus Modern Architecture*, in: *Imagine Math. Between Culture and Mathematics* [ed. Emmer, M.], Springer-Verlag Italia: 105-115, Milan, Dordrecht, Heidelberg, London, New York
3. Blundell, J. P. (1999), *Hugo Haring: The Organic Versus the Geometric,* Edition Axel Menges, Stuttgart, London
4. Bonnemaison, S. (2008), *The Skin of the 'Sky Bubble' at Expo '67*, in: *On Growth and Form: Organic Architecture and Beyond* [eds. Beesley, Ph.; Bonnemaison, S.], Tuns Press and Riverside Architectural Press: 66-73, Halifax
5. Bonnemaison, S.; Beesley, PH. (2008), *Why Revisit D'Arcy Wentworth Thompson's On Growth and Form*, in: *On Growth and Form: Organic Architecture and Beyond* [eds. Beesley, Ph.; Bonnemaison, S.], Tuns Press and Riverside Architectural Press: 7-13, Halifax
6. Finsterwalder, R. [ed.] (2011), *Form follows nature: A History of Nature as Model for Design in Engineering, Architecture and Art,* Springer, Wien, New York
7. Fuller, P. (1988), *Theoria: Art, and the Absence of Grace,* Chatto&Windus, London
8. Fuller, R. B. (1969), *Ideas and Integrities,* Collier Books, New York
9. Fuller, R. B. (2008), *Utopia or Oblivion: The Prospects for Humanity*, Lars Müller Publishers, Baden
10. Gorman, M. J. (2005), *Buckminster Fuller: Designing for Mobility,* Skira, Milano
11. Häring, H. (2001), *Wege zur Form*, in: *Hugo Häring* [ed. Schirren, M.], 321-322, Ostfildern-Ruit
12. Hoffmann, D. (1969), *Frank Lloyd Wright and Viollet-le-Duc*, "Journal of the Society of Architectural Historians", 3: 173-183, USA
13. Hundertwasser, F. (2007), *Hundertwasser Architecture: For a More Human Architecture in Harmony With Nature,* Taschen, Hong Kong, Köln, London, Los Angeles, Madrid, Paris, Tokio
14. Juvanec, B. (2009), *Basics of Proportional Systems in Architecture,* "Prostor", 1 (37): 192-199, Zagreb
15. Košir, F.; Krečič, P.; Zupančič, B. (2007), *Le Corbusier,* Fakulteta za arhitekturo: Arhitekturni muzej, Ljubljana
16. Kuhlmann, D. (2008), *Old and New Organicism in Architecture: The Metamorphoses of an Aesthetic Idea,* in: *On Growth and Form : Organic Architecture and Beyond* [eds. Beesley, P.; Bonnemaison, S.], Tuns Press and Riverside Architectural Press, Halifax
17. Leach, N. (2008.), *Digitalna morfogeneza*, "Oris", 51: 96-107, Zagreb
18. Levit, R. (2008), *Contemporary Ornament, The Return of the Symbolic Repressed*, "Harvard Design Magazine", 28: 70-85, USA
19. Mitchell, W. J. (2005), *Constructing Complexity*, in: *Computer Aided Architectural Design Futures 2005,* Proceedings of the 11th International CAAD Futures Conference, Vienna University of Technology, Vienna, Austria, June 20-22 [eds. Martens, B.; Brown, A.], Springer: 41-50, Dordrecht
20. Mutnjaković, A. (1988.), *Tercijarni grad*, Izdavački centar Radničkog sveučilišta "Božidar Maslarić", Osijek
21. Mutnjaković, A. (1995.), *Kinetička arhitektura / Kinetic Architecture*, Architectonica Croatica, Zagreb
22. Nute, K. (1997), *Frank Lloyd Wright and Composition: The architectural picture, plan, and decorative design as 'organic' line-ideas*, "Journal of Architectural and Planning Research", 4: 271-288, USA
23. Nute, K. (2000), *Frank Lloyd Wright and Japan*, Routledge, New York, London
24. Pearson, D. (2001), *New organic architecture: the breaking wave*, University of California Press, Berkeley, Los Angeles
25. Pell, B. (2010), *The Articulate Surface,* Birkhäuser, Basel
26. Peters, B.; Peters, T. (2013), *Inside Smartgeometry: Expanding the Architectural Possibilities of Computational Design*, Wiley, Chichester
27. Picon, A. (2010), *Digital Culture in Architecture,* Birkhäuser, Basel
28. Pleština, L. (1995), *Three points on Finnish Architecture*, "Prostor", 3 (10): 407-422, Zagreb
29. Pottmann, H. (2009), *Geometry and New and Future Spatial Patterns*, "Architectural Design", 79 (6): 60-65, USA
30. Reiff, D. D. (1988.), *Viollet-le-Duc and American 19th Century Architecture*. "Journal of Architectural Education", 1: 32-48, USA
31. Rousseau, G. S. [ed.] (1972), *Organic Forms: The life of an Idea,* Routledge and Kegan Paul, London
32. Ruby, I.; Ruby, A.; Ursprung, P. (2004), *Images, A Picture Book of Architecture,* Prestel Verlag, Munich, Berlin, London, New York
33. Ruskin, J. (1981), *The Seven Lamps of Architecture*, Farrar, Straus and Goroux, New York
34. Satler, G. (1999), *The Architecture of Frank Lloyd Wright: A Global View*, "Journal of Architectural Education", 53: 15-24, USA
35. Skejić, D.; Androić, B.; Baćić, D. (2012), *Tensegrity Structures: Innovative Light Structural Systems*, "Prostor", 1 (43): 198-209, Zagreb
36. Sullivan, L. (1901-02), *Kindergarten Chats*, Cleveland
37. Sullivan, L. H. (1979), *Kindergarten Chats and other Writings,* Dover Publications, New York
38. Szalapaj, P. (2005), *Contemporary Architecture and the Digital Design Process,* Architectural Press, Oxford
39. Thompson, D. W. (1945), *On Growth and Form,* At the University Press, Cambridge, The Macmillan Company, New York
40. Tzonis, A.; Lefaivre, L. (1995), *Movement, Structure and the Work of Santiago Calatrava,* Birkhäuser, Basel
41. Viollet-Le-DUC (1854-1868), *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle,* Vol. 8, Paris
42. Viollet-Le-Duc (1854-1868), *Dictionnaire raisonné de l'architecture française du XIe au XVIe siècle,* Vol. 9, Paris
43. Weston, R. (2003), *Materials, Form and Architecture*, Laurence King Publishing, London
44. Wright, F. L. (1954), *The Natural House*, Horizon Press, New York
45. Wright, F. L. (1957), *A Testament*, Horizon Press, New York
46. Wright, F. L. (1958), *The Living City,* Horizon Press, New York
47. Wright, F. L. (1969), *The Future of Architecture*, Mladinska knjiga, Ljubljana
48. Zellner, P. (1999), *Hybrid Space: New Forms in Digital Architecture*, Rizzoli International Publications, New York
49. Zerbst, R. (2005), *Gaudi: The complete buildings,* Taschen, Köln
50. Zevi, B. (1950), *Towards an organic architecture*, Faber&Faber Limited, London

Sources

Izvori

Internet Source

Internetski izvor

1. Issa, R. (2014), *Generative Alghoritms: Lindenmayer-System (L-System)*, http://www.grasshopper3d.com/profiles/blogs/generative-algorithms (accessed 9.8.2014).

Illustration Sources

Izvori ilustracija

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Fig. 10.	Mutnjaković, 1995: 73
Fig. 12.	Photo: Simon Petrovčič

Summary

Sažetak

Interpretacije organske arhitekture

Koncept organske arhitekture objedinjuje brojne interpretacije utemeljene u prirodi. Ovaj rad prikazuje glavne protagoniste razvoja organske arhitekture, kao i neke jedinstvene zamisli koje su iz nje potekle i utjecale na arhitekturu 20. i 21. stoljeća. Tijekom druge polovice 19. stoljeća došlo je do ponovnog procvata gotičke arhitekture i klasičnih principa grčke arhitekture. Viollet-le-Duc i J. Ruskin, inspirirani prirodnim oblicima i procesima, postali su predvodnici novih koncepata u arhitekturi. Njihove ideje odjeknule su zapadnim svijetom, izvršile utjecaj na brojne arhitekte i pridonijele formiranju triju interpretacija organske arhitekture.

Prva interpretacija organske arhitekture, nastala na temelju tvrdnje L. Sullivana 'forma slijedi funkciju', pretpostavlja integraciju prirode u projekt građevine, a to je poslije F.L. Wright unaprijedio svojim zahtjevima za jedinstvom, harmonijom i jednostavnošću, poštivanjem prirode i građevinskih materijala, kao i jedinstvenošću svakoga individualnog elementa. Zbog svojega koncepta integracije organske materije i geometrije, prirodnog kamena i betona, unutrašnjeg i vanjskog prostora, prirode i prostora, Wright se općenito smatra utemeljiteljem organske arhitekture koji je značajno utjecao na brojne generacije mlađih arhitekata.

Proučavajući principe statike u prirodi kako bi ih poslije primijenio u svojim graditeljskim projektima, A. Gaudí je utemeljio svoj jedinstveni stil organske arhitekture. Njegov utjecaj vidljiv je u radovima P.L. Nervija, O. Freia, Hundertwassera, O. Niemeyera, F. Candela, S. Calatrave itd.

Druga interpretacija organske arhitekture definira ju kao arhitektonski stil, bez iznimke utemeljen na neravnim, odnosno zakrivljenim prirodnim oblicima. U prirodi su uzorci i oblici koji se doimaju skladno zapravo utemeljeni na matematičkim pravilima koja reguliraju pravilnost, jedinstvo i simetriju. Razlog privlačnosti prirode je njezina matematička pravilnost koja ujedno služi kao osnova za procjenu njezine ljepote. Klasično djelo D'Arcy W. Thompsona omogućava razumijevanje geometrije prirode koja se zrcali u matematičkim uzorcima njezinih struktura. U svojoj knjizi *On Growth and Form (O rastu i obliku)* dokazao je da evolucija nije jedini čimbenik koji je odgovoran za razvoj bioloških vrsta biljaka i životinja, ukazujući istovremeno na važnost djelovanja zakonitosti matematike, fizike i mehanike u ovim procesima.

Polazeći od zakonitosti u prirodi, daljnja matematička istraživanja tijekom 20. stoljeća omogućila su definiranje novih formi i tako je nastala fraktalna geometrija (P. Eisenmann) i teorija katastrofe Charlesa Jencksa. Moćni algoritmi danas omogućavaju brzo i jednostavno stvaranje i prikaz matematički utemeljenih formi. Ovaj novi matematički okvir zamislivih oblika kao izvora arhitektonske inspiracije danas se kreće u rasponu od jednostavnih trokuta i krivulja sve do složenijih zakrivljenih formi, kao što su helikoidi (F.L. Wright, E. Saarinen), pravilne površine (Le Corbusier, F. Candela, T. Ito), hiperbolični hiperboloidi (A. Gaudí) itd.

Priroda, međutim, nije određena samo strogim matematičkim zakonitostima Euklidove geometrije. U prirodi postoje i drugi oblici, kao što su obrisi planinskih lanaca, ledenjačkih padina ili krivulje organskih oblika života. H. Häring je ustvrdio da svaka lokacija i svaki strukturalni element ima vlastiti oblik koji čeka da ga neki arhitekt otkrije i dalje razradi. Slobodne prostorne linije koje izrastaju iz prirode, između ostaloga, izvršile su utjecaj na arhitekturu Hundertwassera.

Treća interpretacija organske arhitekture temelji se na biomimikriji – potrazi za modelima živih organizama kako bi se njihovi uzorci replicirali u formi, funkciji ili tehnologiji projektiranja građevine. Od svojih početaka, a osobito tijekom 20. stoljeća u radovima E. Haeckela *Kunstformen der Natur*, kao i u već spomenutom djelu *On Growth and Form*, arhitektura se uvijek okretala prirodi kao svome izvoru inspiracije. Oba su autora proučavala oblike živih bića i rado ih povezivala sa zakonitostima fizike, koji su opet omogućavali bolje razumijevanje njihovih formi.

U radiolarijima (jednostaničnim organizmima) opisanima u navedenim knjigama B. Fuller je pronašao savršene forme za strategije projektiranja, koje je preveo u nekoliko graditeljskih projekata i u geodezijskoj kupoli – najlaganijoj, najjačoj i najefektnijoj konstrukciji ikad projektiranoj. Oblike Fullerovih formi prostorne geometrije oponašali su O. Frei, N. Foster, Grimshaw Architects itd.

Danas su organske forme, koje su prije nekoliko desetljeća samo geniji mogli razraditi od ideje do primjene, dostupne putem računalnih i parametrijskih alata. Digitalizacija arhitekture ne pruža samo mogućnost korištenja sinergije s prirodom, matematikom, geometrijom, intuicijom itd. u projektiranju već i u implementaciji.

Moguće je stoga serijski proizvesti matematički koherentne, no različite objekte zajedno s razrađenim, preciznim i relativno jeftinim jednokratnim komponentama. Razvojni procesi i sustavi utemeljeni na digitalnom inženjerstvu, kao i na kompleksnoj geometriji i biološkim principima, povezani su u suvremenom arhitektonskom projektiranju. Korištenjem modernih računalnih tehnologija i projektiranja slika pročelja se mijenja i nagoviješta sasvim nove oblike. Kako bi stvorila virtualne i fizičke oblike, digitalna arhitektura danas koristi računalno modeliranje, programiranje, simulaciju i sliku.

Tako se rađaju nove geometrije kakve dosad nije bilo moguće kreirati konvencionalnim crtačkim pristupom. CAD računalni program može se nadograditi DMU digitalnim alatom (F. Gehry). Parametrijski alati NURBS olakšavaju grafički prikaz složenih matematičkih formula ili kreiranje 3D modela (P. Cook i C. Fournier). Tijekom projektiranja CNC tehnologija daje arhitektima mogućnost kontrole procesa pomoću vrlo preciznih tehničkih operacija i primjena materijala, što je dovelo do ponovnog procvata primjene ornamenata i uzoraka na pročeljima. Međutim, granice između triju opisanih interpretacija organske arhitekture nisu uvijek sasvim jasne. Zapravo, one su rijetko uzajamno isključive i u praksi se često preklapaju ili nadopunjavaju.

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Biographies

Biografije

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