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RATIONALISM OR INTUITION IN THE AGE OF ALGORITHMIC METHODS OF SEARCHING FOR STRUCTURAL FORMS

RACJONALIZM CZY INTUICJA W DOBIE ALGORYTMICZNYCH METOD POSZUKIWANIA FORM STRUKTURALNYCH

Abstract

In designing, it is important to systematize the needs – many of them can be defined and described, but there are also those that are difficult to clearly define. Given the possible diverse views of the same object, it should be objectively recognized that the search for spatial forms, that would suit the user in his physical and metaphysical needs, is a creative process. In striving for the perfect form, architects rely on intuition by referring to known canons of beauty and mathematical rules, and technology and art interrelate interdependently. Modern digital design tools provide new possibilities which enable the use of bionic patterns and help us improve our knowledge about the constructions designed by Nature. Therefore, the question should be asked whether the process of algorithmization of space modelling is cold rationalism or some intuitive way towards architecture.

Keywords: shape optimization, structural forms, bionics, algorithms, generative modelling

Streszczenie

W projektowaniu istotnym działaniem jest systematyzowanie potrzeb – wiele z nich można zdefiniować i opisać, jednak są też takie, które trudno określić jako oczywiste. Biorąc pod uwagę zróżnicowane spojrzenie na ten sam obiekt, należy obiektywnie uznać, iż twórczym procesem są poszukiwania takiej formy przestrzennej, która odpowiadałaby użytkownikowi w jego fizycznej i metafizycznej potrzebie. W dążeniu do formy doskonałej architektki bazują na intuicji, odwołując się do znanych kanonów piękna czy reguł matematycznych, a technika i sztuka współzależnie przenikają się. Wprowadzane współcześnie do projektowania narzędzia cyfrowe dostarczają nowych możliwości, umożliwiając wykorzystywanie wzorców bionicznych oraz zgłębianie wiedzy o budowie Natury. Dlatego też należałoby postawić pytanie czy algorytmizacja procesu modelowania przestrzeni to chłodny racjonalizm, czy jeszcze pewna intuicyjna droga do architektury.

Słowa kluczowe: optymalizacja kształtu, formy strukturalne, bionika, algorytmy, generatywne modelowanie

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1. Introduction

If the point in space is an energy event, then Architecture is the sum of those events, and the forces acting on them are vectors with different sizes and directions of application – in addition, variable in time. The author of this concept, which initiated the digital modelling of space in architecture, is Buckminster Fuller – a constructor and an architect in one person, a philosopher, a pioneer of hi-tech architecture. The attempt to understand and record the creative process of building construction is a strong need of those for whom architecture is an art and passion. Technical aspects are easier to understand – they realize what is elusive, non-obvious – a moment of inspiration, a flash of ideas. What if this moment of enlightenment arises due to an accidental collision of several energy points – like the value of the dice thrown in a „dice game” – creating a new system of dependent elements? If it were possible to analyse all the possible variants, it could turn out that, as in a dice game – success does not depend on luck, but rather on calculation skills. Algorithmization of digital tools used by architects today provides new opportunities for architectural design. Even such a creative and charismatic process as conceptual design is often subjected to verification by self-monitoring machines or is entirely created as a result of their work. These actions are undertaken in search of new quality, which manifests itself on the one hand in the attempt to capture and name the *genius loci* of spatial solutions, and on the other, inspired by the technology of Nature, it strives to rationalize technical solutions.

2. Cooperation of art and technology in the construction of architecture

Engineering plays an important role in the design of the materialized forms of building art – it is a tool for the realization of artistic concepts, but also a source of inspiration for architects. At the same time, it is the reality which reveals the quality of architecture and its tectonic solutions – their rationality, innovativeness or randomness. Mies van der Rohe stated that “function is art” – and by following this direction, it becomes obvious that good architecture should be born from the unity of art and technology. Being aware of the possibilities of today’s building technologies, it is worth returning to the relationship between technology and art, to search for logic and beauty in it. An example of such unity can be found in “structural forms”¹. Along with technological progress, increasingly amazing buildings are being created, including constructions that it was previously impossible to build. The digitization of the design environment requires architects not only to constantly improve their skills, but also to understand the processes related to the optimization of engineering solutions, in particular those that are respon-

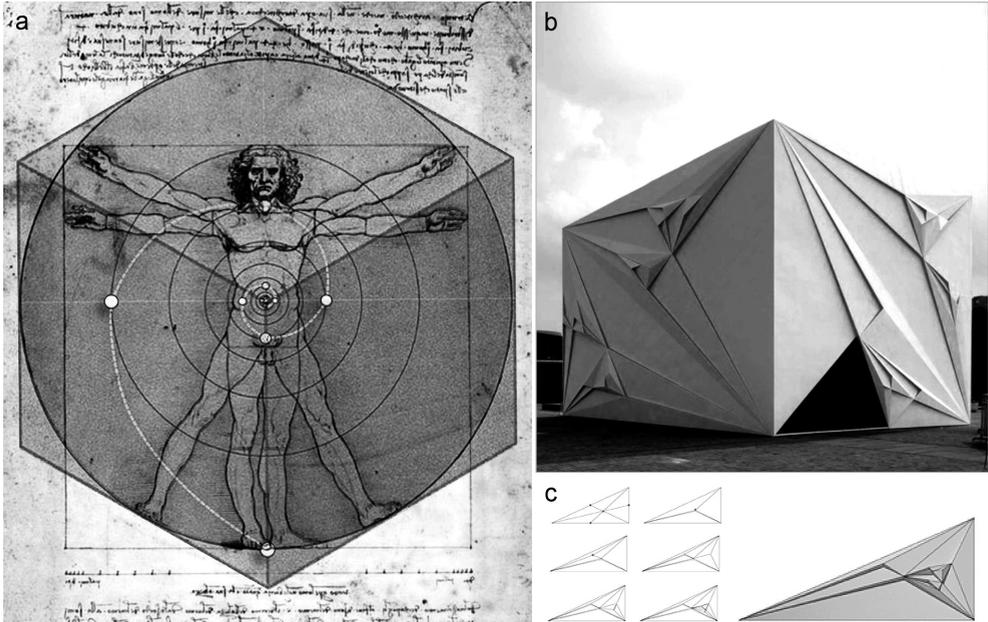
¹ C. Siegel, *Structure and Form in Modern Architecture* (original title: *Strukturformen der modernen Architektur*, translation based on the translation by Eugeniusz Pliszek, for *Formy strukturalne w nowoczesnej architekturze*, p. 8, “Arkady”, 1974: “We, on the other hand, want the term “structural form” to be understood not as an accidental or occasional shape, but as a typical and enduring image of the shape. We want to conceive it as a specific, construction-based form of expression, which thanks to its inclusion in the architectural order and in accordance with the laws of nature, has the power of expression in the general sense.”

sible for the optimal shaping of structural forms. The development of construction techniques leads to a situation in which the construction fills the freely shaped architectural forms. “Separating” these two disciplines from each other may have its justification in the search for beauty, but it runs the risk of losing any restrictions which may lead to ineffective engineering solutions.

2.1. Beauty and construction logic

Beauty is perceived intuitively – it results from the preservation of proportions, harmony, moderation and usability, but is nevertheless perceived and evaluated with the help of the senses. Although subjectivity predominates in the perception of beauty there are many canons that condition its parameters. These canons are mainly based on the perception of the human eye and on metaphysical experiences that are strongly related to the theory of aesthetics, truth and good. Therefore, is intuition accidental and unpredictable? – or perhaps by following the thought of Protagoras of Abdera that “*man is the measure of all things*” one should look at the analogies between the proportions of the human body in comparison with the proportions used in the masterpieces of world architecture. Harmony, rhythm and beauty of a building are after all a feeling expressed by complex numerical, dimensional and proportional means related to the scale of a man, his individual parts and their relation to the whole architectural work. The history of architecture describes many rules based on the proportions of the human body, among which are the most famous antique canons of *Polykleitos* and *Lysippos*,² or the theoretical study “The ten books on architecture” (“*De architectura libri decem*”), in which Vitruvius set the canon assuming the theoretical division of the human body into modules that can be inscribed into a circle and a square. It is on the basis of these assumptions of Vitruvius from the first century BC that Leonardo da Vinci made the famous fifteenth-century sketch depicting the human body with spread arms and legs, inscribed in a circle – in which the centre of the circle and at the same time the central point of the human body is the navel (Ill. 1a). The search for the canons of beauty leads to the beginnings of life, to the scientific answers to the question of how the universe, life and many other phenomena in nature were created, which we cannot explain. Despite the lack of definitive answers, the search direction seems to be included in the Pythagorean thought that “*number is the essence of things*”, which can be confirmed by the use of the *golden ratio* in buildings’ designs. Similarly, the *Modulor* by Le Corbusier, which became a turning point in the history of architecture and set the standards for mass-produced industrial designs, resulted from a study of the human body in motion (during everyday activities) and determining the minimum surface that a person needs to live. Interestingly, the three dimensions created by the intervals of the human body (the three squares

² E. Gawell – doctoral dissertation on the *Synergy of spatial form and statics in optimal design of grid structures*, Warsaw University of Technology, Faculty of Architecture, 2015, p. 10–11: „Polykleitos (an ancient sculptor, lived and created in Athens and Olympia in the 5th century BC) adopted the average width of a finger as the basic unit of repetition; multiplied by four, equal to the width of the hand. According to the un preserved treatise *The Kanon*, in which Polykleitos concluded his theory of the proportions of the human body, the human height consisted of 8 modules, of which the head constituted 1/8 of the whole body. (...) According to the Lysippos’s canon, the head was 1/9 of the entire human figure, head with the body occupied 4 modules, while the other five modules determined the length of the legs”.



III. 1. **a** – author’s collage: Leonardo da Vinci’s XV-th century sketch made on the basis of Vitruvius’ conjectures and the geometry of the golden ratio; Pavilion ‘Embedded Project’ pavilion designed by HHD_FUN in collaboration with Xu wenkai, an artist. Shanghai, 2008; **b** – perspective view; **c** – diagrams showing the fractal divisions of the right triangles located on the facade of the pavilion

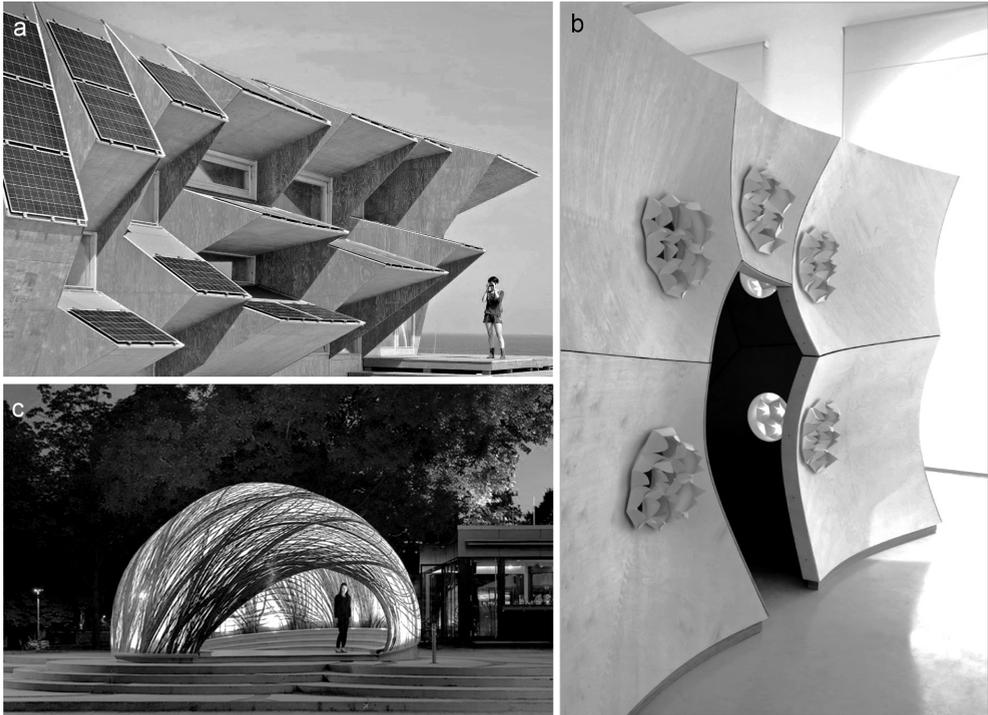
overlapping each other with the dimensions of 1131 x 1131 mm, in which a man’s silhouette is inscribed) form a series of golden ratios: foot, solar plexus, head, and the fingers of an outstretched hand. The above-mentioned analyses conducted on the beauty of the human proportions confirm the existence of numerical dependencies and canons describing the subjective sense of aesthetics. Numbers play a key role in understanding harmony, beauty and perfection of form. In architecture, which, like no other field of art, is based on mathematics, we can observe the dependencies of many technical disciplines, numerical actions and proportions that translate into the timeless beauty of the building. In addition, the shaping of structural forms based on the canons of beauty made the pursuit of harmony and moderation simultaneously organize the spatial layouts thanks to a logical, mathematical structure. The result of the mathematical activities carried out over the architectural work, which the architect intends to be beautiful, should be based on logical solutions, at the same time giving a sense of harmony and moderation – a sculpture whose shape is strictly conditioned by mathematical and geometric principles, devoid of superfluous elements. An example of such a homogeneity of beauty and structural logic are, among others gothic cathedrals in which the characteristic structure of cross-ribbed vaults and buttresses enabling the replacement of brick walls with glazing. Architectural styles and emerging tendencies significantly affect the quality of the interaction of architecture and supporting structures. For example, postmodern ideologies, which emphasized the importance of building ideas and the readability of functions have contributed to breaking up the form – understood as a coherent architectural and constructive

element. Similarly, neomodernism, which continued to deny the modernist thought which treated the building as a whole. An introduction of a controlled chaos theory to architectural theory began to appear in the visions of Peter Eisenman. The turning point came with deconstructivism, which broke away from the modernist principles such as “form serves function”, “purity of form” and “fidelity of materials” which contributed to the emergence of a new quality of tectonic solutions, among others: the ideas of fragmentation in masses and curvilinearity. Deconstructivist concepts caused a shift towards the logical shaping of structural forms – the linking between the ideas of “looking back”³ with the developing digital modelling technologies have spurred architects’ search for spatial solutions in non-Euclidean geometries. Such actions have positively affected the coordination of the work between the architect and the engineer, as the unconventional shapes of the designed buildings often require unconventional structural solutions, yet still consistent with the aesthetics designed by the architect.

2.2. Technology of nature in the search for synergistic solutions

Nature contains a lot of beautiful and at the same time logical solutions – and the harmony of these two elements strives for perfection, it delights and also constitutes an unsurpassed ideal for the “world created with a human hand”. In the search for intuitive solutions, analogies to the natural world are obvious – nature is primarily based on instincts, but due to the adaptive processes of living organisms, which are subconscious behaviors that cannot be controlled, they are a natural element of evolution. Additionally, the intuitive activities of nature are accompanied by a high level of rationality – probably because of the synergy of these two behaviours (intuition and rationality) bionic models constitute the *spiritus movens* for the contemporary ideas of sustainable development in construction. Bionics are not a new concept in architecture – the fascination with building structures created by nature has been observed in human works for centuries, often also as an intuitive activity. However, modern digital tools allow us to get closer to Nature’s technology, not only through the innovative architectural forms, but above all by recreating the biological processes of structure creation through generative modelling (Ill. 1b, c). Architectural design has therefore become a complex process of searching for optimal spatial solutions – rational not only in the attention required for designing technical solutions, but also in the terms of functionality, impressions or social sphere (integration of users, relations with the environment, etc.).

³ Peter Eisenman, being heavily influenced by Deleuze’s theories, has developed a new way of looking at objects defined as “looking back”, which questioned the so-called rational thinking, when the viewer perceives not what he sees but what he knows. Eisenman believed that the classic concept of vision, which was widespread in the Renaissance (a descriptive perspective created in the 15th century) ceased to adhere to the present, as it allowed the viewer to see the subject from only one point of view. The conditions for the new method of seeing, according to Eisenman, are based on depriving, for example, a window, door, column and other such elements, their former context and old semantics. Eisenman presented the practical application of his concept in the unrealized project of the Max-Reinhardt-Haus building. The form of the building paraphrased the Möbius strip – a figure with one surface, as an example of uninterrupted continuity between the interior and exterior.



III. 2. a – Endesa Pavilion by IAAC (Institute for advanced architecture of Catalonia), Dock Marina in Barcelona, 2011 – perspective view; b – HygroSkin pavilion, designed by Achim Menges Architect, Oliver David Krieg and Steffen Reichert, Orléans-la-Source, France, 2013 – perspective view; c – Research Pavilion, designed by ICD/ITKE – University of Stuttgart, 2015 – perspective view

3. Generative modelling – intuitive rationalism

In the pursuit of synergistic architectural and structural solutions, the inspiration with bionics is one of the most interesting concepts of searching for innovative solutions in architecture, where the beauty and logic of the spatial form are often results of sophisticated and high-quality design. Forms shaped in morphogenetic processes have the features of natural systems such as ease of adaptation to the environment and high functional, material and energy “efficiency”. Therefore, computer programs for 3D modelling based on algorithms that make it possible to generate bionic structures, are very popular not only among architects, but also among engineers responsible for the technical side of design.

The search for forms using generative modelling tools is characterized by order resulting from the fact that the algorithms require entering of the input data and recording steps. Therefore, in shaping of the forms that can be implemented and can be used in architecture, it is necessary to give logic to the processes of generative modelling. For this purpose, fractal geometry is often used, the characteristics of which are determined by self-similarity (each fractal part at any low level of development has a structure

resembling the whole), fractal dimension (describing the degree of roughness of the fractal) and iterative design (repeating the same procedure an infinite number of times). Fractal theory is a mathematical language by means of which we can simplify and write down the fractal structures observed in nature, such as those of clouds, plants or tectonic systems of our planet, as well as phenomena created by nature. Thanks to the development of computer technology, the research in the field of fractal theory is not only becoming more accurate, but it also enables us to map out the intuitive and rational structural solutions of the natural world.

An example of an object that was created as a result of the algorithmic process of reproducing biological behaviours is the Endesa Pavilion developed by the IAAC (Institute for Advanced Architecture of Catalonia). The pavilion was completed in 2011 as part of the BCN Smart City International Congress in Dock Marina in Barcelona, as a prototype of a “self-sufficient” building that operates thanks to solar energy obtained from photovoltaic panels (Ill. 2a). Reinterpreting the modernist slogan ‘*form follows function*’ (L. H. Sullivan), the authors of the project proposed a new slogan ‘*form follows energy*’ – as insolation was the main parameter in the algorithmic search for the form. The elevation has been divided into segments that “follow” the sun. Individual panel segments have their slopes assigned in such a way as to make the most efficient use of solar energy, while at the same time protecting the interior of the pavilion from overheating. As a result, the form opens and is more sculpted towards the south and is less active towards the north. The form of the pavilion as a unity of architecture, construction and installation solutions – is a structure shaped under the influence and with the help of parameters of dependencies set by the designers (resulting from a set of spatial and technical goals, relations with the environment, technological possibilities, etc.). Despite the fact that the geometry of the object is complex and looks chaotic, it is the result of the work of algorithms that, due to the specific nature of the iterative process, order the tasks, leaving no room for randomness and arbitrary interpretation⁴.

Another look at the use of bionic patterns in architecture is the search for mobile solutions that mimic the behavior of living organisms. An example of such design is the HygroSkin pavilion, in which the architects – Achim Menges Architect, Oliver David Krieg and Steffen Reichert, used the anisotropic properties of a material that hygroscopically reacts to changes in humidity (Ill. 2b). The designers were inspired by spruce cones, which deform depending on the variable humidity of the air, using only the hygroscopic properties of the cells (without the need to consume additional energy). The mapping of a material with similar properties was a great challenge for engineers and required the development of an individual project for a material and construction system that would not require sensory equipment, motor functions or an additional energy source. By using the simple and logical principle observed in the natural world, the architects created a self-regulating outer shell. The project used the anisotropic characteristic of wood – individual elements of the pavilion were built from composite veneer; in the central part of each cell there are “scales” made from maple wood veneer, which is sensitive to moisture. Each element of the shell has a different shape, created by an individually designed and analyzed morphology. In the pavilion, the degree of openness and

⁴ W. Rokicki, E. Gawell, *Algorithmic modelling in the development of modern architectural forms*, as part of post-conference materials ‘XXII Symposium on Computer Geometry’ – SCG’ 2013.

porosity of the coating is constantly adjusted, modulating the flow of light and translucency, and all changes occur within the material itself.

An important aspect of the use of bionic models in architecture is also material and construction optimization. In nature there are many examples of building materials with such excellent physical parameters that a real possibility of mapping their structure and strength properties would cause a breakthrough in construction. This is why specialist knowledge from the fields of biology, biomimetics, biochemistry and nanotechnology are increasingly used in the development of new material technologies. Modern trends in material optimization, such as functional surfaces, rely on introducing modifications to the material structure to improve strength – modifications include shell activation, chemical changes, changes in morphological structure or other regulations. However, pending the improvement of material and construction technologies, it is possible to observe the development of new implementation technologies that are modelled on basis of living organisms. Formative technologies can be an example of that – the latest and the most innovative from the current implementation technologies – using self-steering robots and machines. For example, the improvement of 3D printing technology (including printing with resin, glass fibre reinforced concrete, etc.) provides new implementation possibilities, and geometries that until now were impossible to implement are becoming a reality. One of the more interesting examples of the use of formative technologies are pavilions designed in research units in Stuttgart such as the Institute for Computational Design (ICD) and the Institute of Building Structures and Structural Design (ITKE). In 2015, a pavilion based on patterns taken from bionic systems was built, where the inspiration was the water-spider's behavioural system, in which, in order to survive, the spider forms a cocoon around itself that protects it from the aquatic environment. The robot placed in an air-filled ETFE membrane distributed threads of carbon fibre on the surface of the membrane – after the material cured, a self-supporting structure was obtained (Ill. 2c).

In the era of generative modelling tools, the process of form finding takes the form of rationalization of solutions, although it is intuitive due to the bionic nature of assumptions – it is a subconscious process (the results of iterations are often unpredictable) that cannot be controlled, and we can only allow or reject solutions proposed by the machine. Such a tool undoubtedly serves creativity, at the same time significantly affecting the way of thinking about the designed object, the consequences of the decisions made, or the subsequent stages of the design process. For example, contemporary architectural concepts are increasingly often a precisely analyzed and optimized solution, selected from many variants – when not long ago the concept was treated as a preliminary sketch, not particularly obliging in engineering terms. The architect's work environment is also undergoing transformations – on the one hand, the role of the architect changes, as his main task becomes introduction of a series of input data and connection, and controlling the process of generating the form, on the other, the share of disciplines involved in the creation of architecture is constantly increasing.

4. Conclusion

The intuitive path to architecture leads through the interdependent actions of all the disciplines involved in building construction – regardless of their design tools. The essence of this path is the experience and the ability to make rational decisions. One of the timeless elements in shaping beautiful and logical solutions is the use of mathematical-geometric principles and

the inspiration taken from the designs of Nature is a development of this concept. The ability to apply the principles of golden ratio or repeating the shapes observed in nature determines the beautiful proportions of the designed buildings, but it also indicates rational engineering solutions. Revealing the complexity based on a specific rules and similarities is an interesting creative activity based on rational intuition – for which the source is Nature and its complexity far exceeds the beauty seen only in proportions.

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