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THE STRUCTURALISM OF CONTEMPORARY ARCHITECTURAL DETAILS IN GENERATIVE MODELLING METHODS

STRUKTURALIZM WSPÓŁCZESNYCH DETALI ARCHITEKTONICZNYCH W GENERATYWNYCH METODACH MODELOWANIA

A b s t r a c t

Detail is the "lens" of architecture – it shows the level of advancement of construction and material technologies, but it is also a testament to the author's skills – his knowledge, sensitivity and commitment. The combination of technology and art has always been important in the design of details. Modernism rejected ornaments, regarding the "machine for living in" as an architectural ideal. In the trends that appear in architecture, architectural detail obtains a new meaning, partially due to the structuralism of the created forms. In the search for aesthetics and beauty, architectural detail is more and more often shaped through the prism of rational engineering solutions. Generative modelling methods are becoming particularly helpful in interdisciplinary design, as they enable imitation and adaptation of the patterns found in nature.

Keywords: structural detail, bionics, algorithms, generative modelling

S t r e s z c z e n i e

„Źrenicą" architektury jest detal – ukazujący istotę poziomu zaawansowania technologii budowlano-materiałowych, ale także świadczący o umiejętnościach autora – jego wiedzy, wrażliwości i zaangażowaniu. Od zawsze ważnym działaniem w kształtowaniu detali było łączenie techniki i sztuki. W idei modernizmu odrzucono ornamentykę, stawiając za wzór m.in. „budowlę-maszynę". W nurtach, które pojawiają się w architekturze, detal architektoniczny uzyskuje nowe znaczenie m.in. przez strukturalizm tworzonych form. W poszukiwaniu estetyki i piękna detal architektoniczny coraz częściej jest kształtowany przez pryzmat racjonalizacji rozwiązań inżynierskich. W projektowaniu interdyscyplinarnym generatywne metody modelowania stają się szczególnie przydatne, umożliwiając też naśladowanie i adaptowanie wzorców spotykanych w przyrodzie.

Słowa kluczowe: detal strukturalny, bionika, algorytmy, generatywne modelowanie

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1. Introduction

The architectural detail is a visible element of the building, located in the foreground – reflecting the artistic idea, as well as the material technique used by the architect. Depending on the architectural style, the proportions between art and technology in the details changed – from one extreme, where the real structure of the building was covered by Baroque ornament, to the other, connected with the modernist idea of a "machine for living in" that rejected ornament and emphasized the structure. Contemporary directions of research aided by digital modelling tools clearly aim towards the rationalization of engineering solutions. Nevertheless, they are also aimed at creating individual spatial solutions and seeking new quality in architecture. Inspiration by Nature's technology is an important element of such research and it manifests itself in the attempts to reconstruct bionic models with the help of algorithmic modelling of not only the structure of living organisms, but also the processes of their biological development. Bionic modelling leads through the optimization of the shape to the spatial forms that are rational and original in form – then the architectural detail is visibly structural and the construction, as the dominant element, becomes both the functional skeleton as well as the ornament.

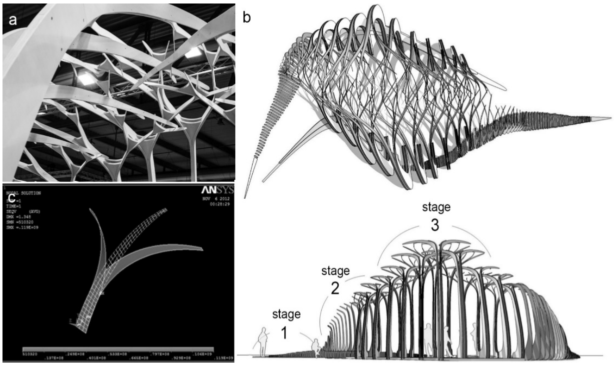
2. Generative modelling in intuitive design of rational architecture

In search of structuralism of the contemporary detail one should pay attention to two key aspects that determine the form – shape and material. Perceiving architecture through the beauty of its solids and the truth of the material is an intuitive action evoking analogies to sculpture and associating the architect's work with that of a sculptor who brings out the meaning from a "dead" piece of material.

However, architecture is also created by a number of other elements, which often remain in a conflict that require comzpromises[1] – one of them being function, which rationalizes the process of creative exploration. Regardless of the changes taking place in designing building forms or in improving construction and material technologies, these two basic elements "work together" in the search for architecture, by reflecting harmony, moderation and beauty. "Form follows material" is one of the principles of contemporary construction, which is an attempt to define new relationships, among which function seems to be treated as secondary. However, this is only a seeming impression – function is still important to the quality of architecture, but in the era of algorithmization its parameters are defined by computers. The tasks leading to the development of material and building technologies become more complex and their overarching goal is to push the limits of the possibilities of making any form a reality. In recent years shapes and materials have undergone many engineering optimizations stemming from the developing bionic trends, which try to reproduce the space-time models derived from the natural world. The use of morphic language leads to analogies with organic structures, which result in logical and at the same time aesthetic structural solutions. The intuitive rationalism of biological processes resulting from the need for constant adaptation to the changing conditions

[1] Modernist architects assumed that functionality defined the beauty of the building and the main principle of the modernist idea (authored by L. Sullivan) *form follows function* emphasized the priorities in search for spatial solutions.

becomes part of the design process thanks to the algorithmization of computer programs supporting the processes of architectural design. One of the bionic models used in architecture are fractals, whose source analogies are abundant in nature[2]. Going beyond the framework of Euclidean geometry, the fractals describe images with a structure resulting from the recursion of self-similar elements[3]. Thanks to the iterative structure that can be translated into an algorithm, fractals are now one of the most interesting ways to shape structural forms. Examples of generative modelling tools include L-systems which map out structure of plant growth on the basis of a principle similar to the creation of a Pythagoras tree[4]. An interesting example of



Ill. 1. *Fractal Forest: Monalisa Pavilion*, 2012 – designed by Ian Md Rian in collaboration with the students of the Polytechnic University of Turin; ***a*** – the pavilion during the presentation at the MadeExpo exhibition in Milan, 2012; ***b*** – digital structural model showing the individual stages of the biological development of poplars; ***c*** – structural detail subjected to strength analysis in the ANSYS program

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2 E. Gawell – doctoral dissertation on the *Synergy of spatial form and statics in optimal design of grid structures*, Faculty of Architecture, Warsaw University of Technology, 2015, thesis supervisor: prof. WUT Ph.D. Eng. (prof. PW dr hab. inż.) Wiesław Rokicki.:
The fractal equivalents observed in nature, such as e.g. clouds, plants or the tectonic systems of our planet, confirm the assumption that the fractal theory is a natural way of development and changes that take place in the universe. It is also a mathematical language by means of which we can describe, for example, a natural phenomenon, even if it seems chaotic and accidental. Thanks to the advances in computer technology it is possible to conduct ever more accurate research in the field of fractal theory, and the use of fractal language allows us to create geometry which is the natural way of development. The use of the geometry of chaotic structures in architecture and demonstration of their complexity based on specific order and similarity might be an interesting endeavour.

3 P. Heinz-Otto, J. Hartmut, S. Dietmar, *Granice chaosu, cześć 1: Fraktale* (original title: *Fractals for the Classroom,* part 1: *Introduction to Fractals and Chaos*; translation based on the translation by: K. Pietruska-Pałuba, K. Winkowska-Nowak), p. 152, Wydawnictwo Naukowe PWN, Warsaw 2002.

4 The structure of the Pythagoras tree (based on the Pythagorean theorem) is constructed by the following sequence: step 1 – draw a square; step 2 – draw an isosceles triangle whose hypotenuse is one of the sides of the square; step 3 – join two squares to the free sides of the triangle. Understanding the basic principle of the Pythagoras tree creation allows for any modifications, for example by changing the length of the arms of the attached triangle. Just by changing the orientation of the triangles, one can get completely different fractal images despite the fact that the structure is made of the same elements and the same recursive procedure.

using a fractal image generated with the Lindenmayer system (L-system) in search of a structural detail is the Fractal Forest: Monalisa Pavilion. The project was created by Ian Md Rian during workshops conducted with the students at the Polytechnic in Turin, the completed Pavilion was presented in 2012 at the MadeExpo exhibition in Milan. The pavilion refers to the stages of growth of poplars, and the individual stages of their development are visible in the structural elements arranged in the appropriate sequence. The idea of representing the biological development process in space can be divided into three stages: the period in which the plant is closed in the grain, the time of growth and maturation of the plant, which has a clearly outlined tree structure and the state in which the tree becomes a building material[5]. The period of early poplar growth was expressed in the installation that precedes the entrance to the pavilion, where the benches are. The second stage, when the young and mature trees merge into the family which forms the forest, is represented in the main zone of the pavilion – the tree-like supports with diverse geometries lean towards the interior and lean against each other creating the roof of the pavilion. Mature poplars "grow" enough so that seats are formed at their bases and their extensive crowns create a shelter from the sun. The third, final stage, in the tree's "life" cycle was expressed in the construction and material technology of the pavilion. The individual structural elements were made of poplar plywood, and because the selection of the appropriate technology was not obvious, the pavilion's form was gradually built – first a small scale model was made and was subjected to smaller loads, then the final form was created. Initially it was composed of one layer of plywood, which was successively reinforced with additional layers of material (Ill. 1). In search for the shape, in order to specify the dimensions of the structural elements, generative modelling tools (Rhinoceros, Grasshopper, Python) were used as well as the ANSYS calculation program, which was used to perform static and strength analyses. A characteristic feature of the use of generative tools in the modern process of architectural design is that the tools are now used at all stages of design – starting from a multi-variant concept, through specialized analyses, where the goal is to rationalize technical solutions, to finishing with executive processes. The imitation of intuitive and rational behaviors observed in the natural world increasingly translates into the entire process of creating architecture. In addition to the basic task of designing the form, analogies in the creative process include determining the systems of dependencies, modifying solutions (multi-criteria optimization) and the development of material technologies in pursuit of better technical parameters.

3. Morphology of contemporary details

The structural architectural detail shapes the form, just like an impressionist painting viewed from a distance, which presents the whole work constituting the history of a place, its people and their relationships; when viewed from up close, reveals the painting technique, texture of the canvas, the shape and variety of the brush strokes, among others, displaying the author's temperament. Although contemporary detail is built on non-Euclidean geometries, it is subject to the same rules related to aesthetic reception as historical detail. The logic and

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[5] "Architecture, Fractal & Nature-www.iasefmdrian.com", Fractal Forest (Monalisa) Pavilion: MadeExpo 2012, Milan, 17.03.2013, [accessed: May 29, 2018], <https://iasefmdrian.wordpress.com/tag/poplar/>

beauty of the construction has its source in elements that "cooperate" by becoming one – a carrier of physical and artistic strength. The contemporary structural detail, shaped using generative design tools, is closely related to the structural form – it is a clear continuation of the idea of structural logic. An example of this is the 3D Printed Bridge project, which is to be built in Amsterdam. The design by Joris Laaram is based on the innovative MX3D performance technology of 3D printing with metals and resin. The bridge structure consists of two arboreal supports (modelled with the help of a fractal structure generator) shaped in such a way that the forces from the openwork deck are transferred to the tree-like structures that visibly thicken towards the landing (Ill. 2a). The self-similarity and recurrence, characteristic of a fractal image, determine the structure of the bridge to such an extent that the detail becomes homogeneous, reproducing the geometry of arboreal supports constructed at a smaller scale. The biomorphism of buildings constructed nowadays makes understanding of the structure of modern details – both in form and material – an important element of architecture.

Ill. 2. *3D Printed Bridge*, Amsterdam 2017, – design: MX3D / Joris Laaram; ***a*** – visualization showing the process of printing of the structure; *Cultural Center Jean-Marie Tjibaou*, an ethnographic and cultural institution in Numea, New Caledonia, 1998 – designed by Renzo Piano; ***b*** – a perspective view showing how the design is inscribed into the local landscape; ***c*** – structural detail of the connection between different topologies

3.1. Detail designed from connections

Connecting independent parts is the basic task of an architectural detail. This need results from many factors, such as expression of the artistic idea, expressing beauty though proportions, variety of textures, references to the local tradition and materials, etc. Another aspect is the functionality of the detail, which "reveals itself" only in close proximity. For example, the characteristic form of the Jean-Marie Tjibaou cultural center in Numea (New Caledonia) by Renzo Piano perfectly fits into the landscape referring to the local materials and building traditions. However, from a closer distance, the detail reveals a new quality – individual building elements are clearly contemporary due to proportions, material, function, etc., and additional horizontal blinds were added in accordance with the idea of sustainable development, they protect against the sunlight while maintaining transparency of the barrier (Ill. 2b, c). Another important justification for combining various materials is the possibility of solving technical problems related to obtaining better structural properties of building elements (eg. joining wood with steel allows for larger spans). In fact, structuralism of details expressed by means of connections, due to the clear division of individual elements, makes it possible to rationalize structural solutions due to the distribution of forces – by, for example, shaping stretched elements as tendons and compressed elements as rigid rods. This simultaneously leads to logical perception and shaping of the whole form, which is expressed by, among others, the tensegrity idea[6]. Contemporary bionic trends in architecture continue and develop the technical and artistic principles of designing connections, with the difference being that the morphic character of the pattern enforces homogeneity of the structural solutions. An example of such thinking can be observed in the Modular Timber Structure by Bastien Thorel. The design comprises structural arches joined together in a parallel system – individual flat elements (4 types of modules – according to ill. 3b) overlap and stiffen each other. A number of analyses were carried out for the project, including load simulations in ANSYS, which showed that concentrated stress distribution occurs at the place where flat elements are connected. Due to the lack of the required rigidity, the number of connectors was doubled and the morphology of the joints was modified[7]. In the search for the new quality of detail solutions shaped by the structuralism of connections, development of material technologies is necessary, in particular optimization based on introducing modifications in the material structure (functional surfaces). Modifications also take place on the basis of biological processes (biomimicry) and include shell activation, chemical changes, morphological structure changes or other regulations which lead to product improvement, without negatively affecting the material's characteristics. The development of structural connections is mainly supported by computer programs which help in optimizing structures by numerical calculation methods.

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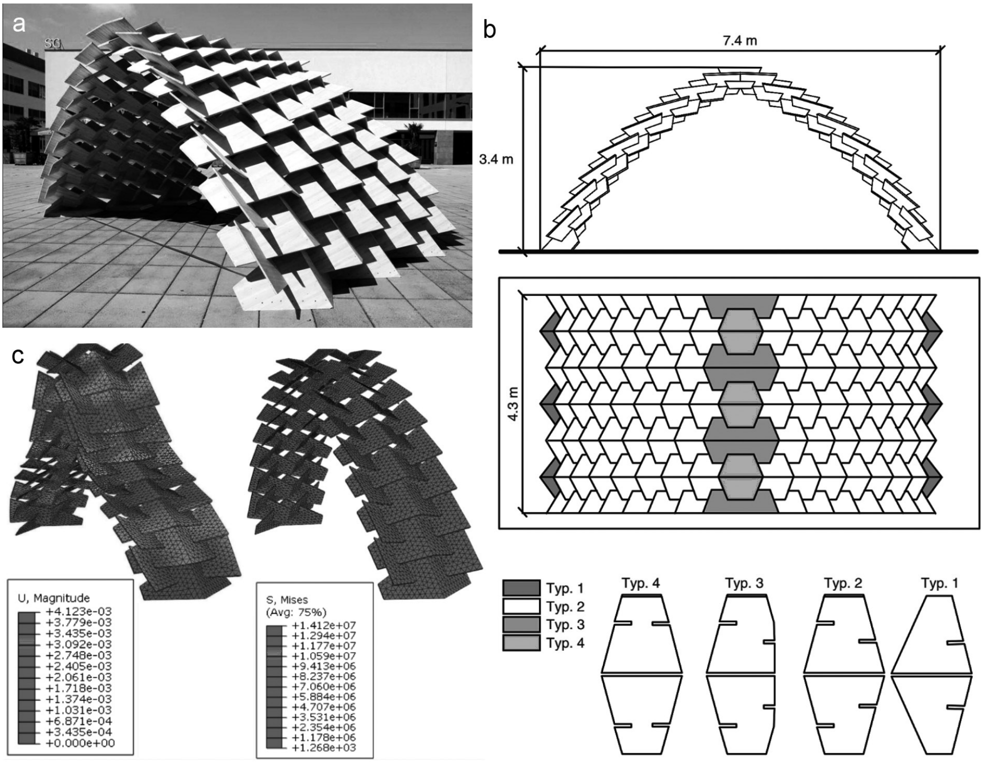
6 The idea described in the twentieth century by B. Fuller and K. Snelson, which consists of maximizing tensile elements and minimizing the number of compressed elements, which due to e.g. buckling adversely affect the materials such as steel. Tensegrity structures are an example of a rational and intuitive design resulting from the mapping of cell stabilization of organic structures.

7 S. S. Nabaei, Y. Weinnand, *Geometrical Description and Structural Analysis of a Modular Timber Structure*, International Journal of Space Structures, vol. 26, No 4, 2011, Multi-Science Publishing Co. LTD, United Kingdom, p. 321–330.



Ill. 3. *Modular Timber Structure* – designed by Bastien Thorel, Germany, 2008–2009; ***a*** – perspective view; ***b*** – conceptual sketch showing the detail design concept; ***c*** – static and strength analysis; from the left: deformation diagram showing the deformation of a single structural arc under its own weight and a stress diagram

3.2. Detail design from the form

In the creation of details whose structuralism results from the form, one should turn towards homogeneous material and technological solutions. Examples can be found as early as in the primitive buildings shaped intuitively by primitive people. A. Gaudí's architecture consists of monoforms built on the logic of the natural world. Additionally, the form dominates over the material and it is difficult to indicate connections, because the curvilinear planes determine the surface without bends or sharp edges. Importantly, the morphology of the Art Nouveau buildings of A. Gaudí stems from the structural logic modelled after the technology of Nature, constituting a synergistic solution of architecture and construction. This idea is continued by bionic explorations of reinforced concrete structures, among which the works of engineers such as Robert Maillart, Eero Saarinen, Eduardo Torroja, Pier Luigi Nervi and Felix Candela deserve special attention. Another example is the artistic and structural legacy of Otto Frei, whose projects should be considered a breakthrough in the context of innovation resulting from the use of minimal areas, as well as modern technological and material solutions. The unrealized project for the renovation of the Main Railway Station in Stuttgart from 1997 (together with the architects: Ingenhoven, Overdiek, Kahlen and Partners) is a prime example of unconventional design of details of the vertical supports, where the parabolic columns let the light in from one side, deciding on the quality of the project. The creative search for structural solutions which remain homogenous in materials can be found is also the domain of Santiago Calatrava, who, as early as in the 1990s, drew attention to the tectonic solutions in the movement of human body. This can be observed in his designs such as the Oriente Railway Station in Lisbon. The City of Arts and Sciences (original name: Ciudad de las Artes y las Ciencias) designed by S. Calatrava in Valencia circa 2002 described as the district of the "future" is an interesting example of bionics, where the beauty of organic shapes harmonizes with the construction logic. An important element in designing details from the form are the new tendencies based on simplified mapping of bionic structures as well as biological development processes. This, in turn, requires individual treatment of the construction and material technologies, among which the fabrication of building components and the robotisation of the manufacturing processes are playing increasingly important roles. An example of digital fabrication of building elements is the research pavilion made at the University of Stuttgart by the Institute for Computational Design (ICD) and the Institute of Building Structures and Structural Design (ITKE). The pavilion was created as part of a one-and-a-half-year research project in which the students as well as lecturers had participated, forming

Ill. 4. *Research Pavilion* – design by ICD/ITKE, Stuttgart; ***a*** – perspective view; ***b*** – the process of building the structural detail; *Mars Pavilion*, designed by Form Found Design; ***c*** – perspective view; ***d*** – a robot during the construction of the object

a multidisciplinary team consisting of architects, constructors, biologists and palaeontologists. The project used research on the structure of a beetle's carapace, which is characterized by its high structural efficiency. By creating simplified rules describing the carapace, the designers pointed out the rules for the structural morphology of the detail. The pavilion was built of fabricated, non-modular elements, manufactured according to the same principle consisting of two six-axis industrial robots weaving glass fibres on steel frames. The initial fibres tensed linearly, with the addition of subsequent layers. Thanks to the precise ordering of thread distribution the fibres could interact with each other, creating a characteristic saddle surface (double curved). In order to improve the strength of the structure, after the static and strength simulation, each of the fabricated elements was locally reinforced with carbon fibres (Ill. 4 b). The unusual shaping of the detail of the research pavilion would not be possible without the development of proprietary implementation technology, which made it possible to obtain a rational solution when it comes to material consumption – the roofing with an area of approx. 50 m^2 weighs 593 kg. An additional advantage of such a fabricated solution is the lack of production waste, which usually occurs in traditional prefabrication. By designing the detail from homogenous materials, one of the most interesting executive processes is the use of self-steering machines. An important element of this approach is the robotisation of the entire creative process, from modelling of the design assumptions to implementation. An example of an organic grid structure being created entirely as a result of the work of robots is the Mars Pavilion, (Ill. 4c, d). The computer program controlled the work of the robot by manipulating its arms, to which fabric sleeves were attached which created an adjustable formwork – in this manner it was possible to add concrete reinforced with steel fibre at any desired angle in order to increase the strength. The use of formative building technology enabled the construction of a complex structure in which there are no repetitive elements in a very short period of time.

4. Conclusion

The structuralism of contemporary details is the development of architectural thought, the aim of which is to indicate aesthetics, beauty and logic through the truth of form and material. The direction of this search is currently determined by the technology of Nature, whose philosophy is naturally characterized by intuitive rationalism. Algorithmization of tools used in the process of creating architecture leads to interesting changes, which translate to an increasingly visible breakthroughs in construction. The use of robotics in the design process and to achieve stronger construction-material technologies may raise concerns about the role and work of architects. Therefore, an important element of the ongoing transformations in the work environment of designers is the parallel and intuitive development of the ability to rationalize technical solutions.

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