Architectural Ephemerids in Terms of Generative and Parametric Design

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Abstract—Nowadays architectural taste and the knowledge in fields such as architectural theory and practical abilities are not sufficient for being a good designer. Architects keep discovering multidisciplinary skills helpful in creating advanced designs. The use of digital generative design systems in designing becomes more prevalent - for the first time being an architect means not only that one has to design the form and function of the building, an architect must understand the way the buildings live, from the conceptual phase till demolition.

One of the most powerful directions in contemporary architecture is generative and parametric design. Thanks to the possibilities granted by computer-aided design, architects can strive for surprisingly simple, free shaped structures which have not been possible up until this point. Since the XXI century mathematical algorithms have become more architecturally friendly and can be used to design more biomimetic forms. The aim of this paper is to present the newest trends in finding inspirations for the designing of contemporary buildings. Looking at living organisms in search for inspiration is probably most common.

In this text we have analyzed pavilions with one shared quality – their small size. Thanks to their size pavilions give the opportunity to focus on particular design problems in terms of specific mathematical solutions, while still being buildable architectural objects.

While analyzing Expo pavilions for their innovative construction systems, materials, or technology context, it can be clearly seen that those buildings are no longer just buildings covering the exhibition but are intriguing, mesmerizing and interesting to the public. Pavilions are becoming the showpiece which invite the public to take part in events such as expo. Because of that, every detail designed by architects is essential and makes those ephemerals rare and unique.

Index Terms—generative design, parametric design, temporary architecture, architectural vision, conceptual architecture, bionic architecture, biomimetic architecture

I. INTRODUCTION

In 21st century architecture, we can observe a noticeable breakthrough resulting from the transition from the traditional design methods to digital tools. The dynamically progressing digitalization "penetrates" the design processes related to the creation of architecture, which can be seen in the recent developments of the BIM programs. BIM enables the design of an object at all the stages of design – from ideation through construction, its use, and even renovation, demolition and recirculation). Computational methods of digital modelling provide new possibilities in the creative search for "eco-efficient" architectural forms. At the same time, they lead to changes in the design process - a fixed sequence is reversed: instead of flat drawings of plans, sections and elevations defining the final shape of the object, we create three-dimensional objects which are at the same time a record of information about the whole building system. Thanks to the availability of advanced, generative techniques as well as engineering achievements, designers are able to imitate patterns found in nature. In their ephemeral and unique nature, pavilion objects become the object of an architectural game that subordinates computational algorithms in reference to rational creative thought. Architecture is also becoming more organic, "gaining" a certain naturalness that characterises the world of nature. The architect can make better use of tools available today to shape architecture in the environmental aspect. The role of the architect and the manner in which he or she designs are clearly changing: "For the first time in history architects do not design but rather 'generate' geometric objects by using a specific set of imperatives encoded in parametric equations' sequences. Parametric tools "make" complex, multi-variant assumptions 'transformed' into rational, simple decisions" [1]. Generative methods of modeling load-bearing structures, especially in the design of small scale objects, greatly accelerate their creation. This is particularly visible in such objects as pavilions, sheds, or observation towers, where unconventional structural solutions are increasingly used. Examples of generative
design research projects include the works created by students at the Faculty of Architecture of the Warsaw University of Technology as part of the Structural Design course (5th sem.), where generative modelling methods are used to create optimal structural forms (with the help of Rhinoceros, Grasshopper, Karamba). Relatively small in scale but original objects, such as footbridges, pedestrian-bicycle footbridges (up to 40m in length), pavilions, small architecture (platforms, bus stations), and observation towers (up to 40 m in height) are attractive design tasks in simplified analysis of the shape and structural solutions.

II. DESIGN PROCESSES BEFORE COMPUTER- AIDED DESIGN

Structural architecture design is visible in the work of well-known designers from previous centuries, architects and constructors such as Maciej Nowicki, Stephane de Chateaux, Felix Candella, Pier Luigi Nervi, Frei Otto or Buckminster Fuller. They are known for their optimisation research, the basis of which, regardless of the type of material, was the use of its properties in order to minimize costs, time of construction, facilitation of performance, etc. In most cases, objects designed by them, whether they were gridshells or shell structures, had advanced geometries and shapes. Prototype objects were mostly the result of research based on experimental methods of determining the forces and of the “flow” stress distribution. This resulted in objects with surprisingly little use of material interacting with the system of forces. P.L. Nervi describes the beauty of buildings designed according to the laws of physics as follows: “...I am deeply convinced- and this conviction is strengthened by a critical appraisal of the most significant architectural works of the past as well as of the present- that the outward appearance of a good building cannot and must not be anything but the visible expression of an efficient structural or constructional reality. In other words, form must be the necessary result and not the initial basis structure” [2]. An example of such design is the German pavilion in Montreal by Frei Otto in 1967 which was initially built using a physical model, where the distribution of forces was studied, and the appropriate materials and distribution of supports were adopted.

When designing architectural objects with the help of generative tools, many questions arise already at the conceptual stage, where not only the optimization of structures is often designed along with the fabrication process. The task of computer-aided design is to find the relation between unique forms and forces acting on them, and then the technology of their execution which is visible mainly in the structures of continuous and gridshell type coverings. The design process consists of the “emergence of a form” which in turn generates the initial form of the object. Generation of structural forms at the conceptual stage is connected with the use of specific structural systems and materials in mind, those which best cooperate in terms of force distribution. The morphology of structures includes geometrical analysis and analysis of relations between the form and forces acting on it, as well as the construction technology, computer design, or prototyping. In the 21st century, the most developed digital methods allowed for design, analysis, and multi-directional optimisation of structures based on many parameters. With the help of digital tools, designers are able to calculate the optimal spatial structures for the given loads. After analysing the dynamics of application of bionic patterns in architecture, it seems that the creation of such materials is a matter of near future. Thanks to the use of mathematical algorithms operating on the basis of the set requirements of proportionality, minimum or maximum dimensions, etc., the software creates an individual solution for the indicated boundary conditions. This is particularly interesting from the prefabrication point of view which nowadays is more often characterized by the idea of postfordism, where the pursuit of unification does not exclude the creative search for individual solutions. "The use of the computational capacity of computers has made it possible to test many concepts concerning the laws of nature. Knowledge of the rules has become the basis for formal experiments. These, in turn, form the basis for the designer” [3].

III. THE IMPACT OF BIONIC-BASED DESIGN ON ARCHITECTURE OF SMALL PAVILIONS

In their search for inspiration, contemporary architects increasingly use the possibilities offered by parametric and generative design, using mathematical rules describing the structures occurring in nature. Architects using computer software for the generation of multi-variant solutions through advanced mathematical records can analyse creations found in the natural world [4]. Architecture becomes not only the materialization of the design process but also the effect of an in-depth analysis and systems rationalisation. Algorithmics leads to geometries that were far too complicated, often impossible to construct, until recently. The programs that most often help architects with such projects are Grasshopper, Generative Components, City Engine, CATIA - which was originally used in projects for the aerospace industry, Midas Gen, Revit, or Vectorworks. The objects generated by the algorithms “adapt” to the given boundary conditions, regardless of whether they describe the forces acting on the object, environmental conditions, functional requirements, etc., or whether they are used to describe the forces acting on the object [5]. In addition, the obtained solutions are effective which results from the definition of the algorithm. Parametric design is a process that usually results in a single iteration of geometric information, and hierarchy occurs between its individual elements [6].

While searching for bionic solutions, architects implement natural forms into architecture (e.g. Voronoi divisions or fractals) materials as systems (behaviour of soap bubble) or ecosystems (inspired by termite mounds ventilation or distribution of forces in arboreal systems). Biomimetic architecture according to P. Bharati is a modern philosophy in architectural design which consists of using systems borrowed from nature and implementing
them in building design technology [7]. In recent years, research based on tracking the behaviour of various organisms has been carried out at many universities. An example of bionically inspired design at the operating system level is Silk Pavilion developed at MIT in 2013.

Silk Pavilion "owes" its unusual structure to the combination of parametric design and biomimetic construction. The designers of the pavilion observed the system of how the silkworms spin their cocoons and decided to build an installation which was based on a similar process. A robot arm braided the silk fibre-base on a steel dome-like structure formed by 26 panels, suspended from the ceiling. The threads formed a 1,000-metre-long thread, on which 6,500 silkworms could move. The creators of this pavilion emphasised that they were most fascinated by the combination of two separate worlds: computer technology and biology. "We've managed to motion-track the silkworm's movement as it was building its cocoon," said Oxman. "Our aim was to translate the motion-capture data into a 3D printer connected to a robotic arm in order to study the biological structure in larger scales" [1]. The designers' intention was to create a structure similar to a 3D printed one, but without the limitations of 3D printing - in the possibility of making a larger installation, without additional supports. Thanks to this solution, a complete installation in terms of structure and materials was achieved.

An example, in which the system of behaviour of living organisms were also referred to is the series of pavilions of the Institute for Computational Design and Construction in Stuttgart. The effect of the annual projects was created by students- structures were constructed with the use of printing robots. One of them is the pavilion made in the academic year 2013/14. The inspiration for this pavilion was the first protective pair of wings (Latin Elytrae) - chitin reinforced with the protein structure of the beetle (Latin Hoplia Argentea). After morphogenic analysis of the armour and scanning of its cross-section, it was decided to reproduce its micro-division and distribution of the material in its structure in the designed pavilion. It was created with the use of carbon fibre printed on polygonal panels according to a given algorithm using a KUKA robot. The entire pavilion was assembled traditionally.

Figure 1. Silk Pavilion a) view b) silkworms on a precast silkweb continuing casting the "cocoon structure"

Figure 2. ICD ITKE Research Pavilion 2013/14 a) view, b) construction phase, c) KUKA robot in panel printing process, d) section of Hoplia Argentea’s Elytrae scale x800

IV. STRUCTURAL ARCHITECTURE

The ability to create new architectural forms with the help of digitalised design depends on the perceptive and cognitive abilities of architects. The generative and parametric design process is a dynamic process of discovery of new possibilities and qualitative cognition. The designer's role in the use of generative tools is to interpret countless results by creating parametric models or genetic algorithms analysed in static calculations to create topologically variable surfaces, isomorphic skeletons, emergents and self-similarity processes.

The Vulcano Pavilion, designed by Yu Lei and Xu Fend, reaching a span of 8m in the period of its creation, was the largest object made entirely using 3D printing. Similarly to the Silk Pavilion, Vulcano Pavilion was
inspired by the behaviour of silkworms. The structure of the pavilion’s covering is based on three outer supports and an inner pillar, and the coating system consists of two types of elements - transparent triangular panels in the middle part and full polygonal panels located in the outer part of the pavilion. The shape of the pavilion was obtained using generative tools.

![Vulcano Pavilion](image1)

**Figure 3.** Vulcano Pavilion a) detail of the panels, b) view of pavilion

In the research analyses on open pavilions made by the authors of the article, obtaining effective structural divisions of grids is a task that should be solved when analysing paradigms from two disciplines: architecture and construction as an interdisciplinary issue. For example, such activities are natural in the developmental processes of living organisms. The aim of the research was to determine the structurally optimal geometry of the curvature of the pavilion and the effective density of the roofing grid. Given set distances and location of supports, solutions of structurally effective shapes of the roofing were sought. Local compaction and expansion of the grid is an attempt to optimize the structure - too many elements cause the deadweight to increase stresses in individual elements and cause greater deformations. In the course of the research, tests of selected geometric curves were carried out based on a triangular pattern of divisions. Preliminary analysis and shaping of structures was carried out with the use of the Grasshopper/Rhinoceros program, and material optimisation was then performed in Robot Structural Analysis software.

![Robot Structural Analysis](image2)

**Figure 4.** Robot Structural Analysis calculations on one of the designed at TU Warsaw a) deformations b) stress c) extensiveness

V. EXPO PAVILIONS ARCHITECTURAL DESIGNING

The 21st century in architecture is a time for searching futuristic visions in architecture. This is particularly visible in the architecture of exhibition pavilions, which are a testing playground for architects in search of innovative solutions. In the changing architectural environment, technological and material changes require tests to be carried out on objects whose design and construction time will not take too long. What seemed unfeasible in the 20th century architecture, becomes natural and possible to build in the 21st century.

“The contemporary period is a time of various searches, with the lack of clearly established and generally binding rules, but also an attempt to create new values”[8].

The analysed examples of small pavilion objects made in research centres refer to the projects of exhibition pavilions, e.g. for World Exhibitions. The parametric trend visible in EXPO has been maintained since the turn
of the 21st century. Due to the standard requirements for pavilion buildings, technological novelties are introduced more slowly than in experimental pavilions due to technological and material limitations. An example where it was not possible to build a pavilion according to the project was the pavilion designed by Shigeru Ban for the EXPO exhibition in Hanover in 2000. In spite of quite accurate structural calculations which showed that a "paper" structure is able to carry loads, it was not a structural material according to German law. Therefore, it was necessary to add a wooden structure, which became the supporting frame for the pavilion. The construction of such a weak material as cardboard was possible thanks to the use of compression and stretching elements only. The structure was covered with weather-resistant impregnated paper.

Figure 5. Shigeru Ban Pavilion EXPO Hanover 2000, detail of paper-cable structure supported by wooden trusses.

A characteristic pavilion from the exhibition in Hanover in 2000, which shows the strong integration between architectural and structural designing, is the 16,000m² open roofing by Herzog+partner BDA in cooperation with engineers: IEZ Natterer GmbH. With reference to the theme of the exhibition "Man, Nature, Technology", the designers took into account the postulates related to the idea of sustainable development. One of them was the use of wood as a construction material. The form of the roofing consisted of 10 interconnected modules (resembling a giant umbrella) each with a size of 40x40 m. Each module (weighing 36 tons) consisted of a central support with characteristic grid and a two-way curved roof whose geometry "rises" upwards on the supports (the height difference between the lowest and highest point of the curvature was 6m). An additional element inscribing in the subject matter of the exhibition was the covering of the roof slopes with a waterproof membrane from which rainwater was drained to the centre of the pylons. The two curved roof slopes transferred the loads to the 19-metre-high brackets located at the edge.

Figure 6. German Pavilion EXPO 2000, Hannover a) view, b) detail of joints

Successive world exhibitions showcase the possibilities of projects of unprecedented form, and their inspiration being, among others, the observation of animate or inanimate nature. An interesting example of such thinking was the Vanke Pavilion designed in 2015 by Daniel Libeskind at Ingresso Expo in Milan. On three floors (partly 2-storey foyer) there was over 1000m² of usable area. The curvilinear form of the pavilion, 12 metres high, has been covered on the outside with glazed tiles, which, together with the change in the quality of daylight or viewing angle, change colour from red to glossy gold and bright white. The façade finish of the Vanke Pavilion was the key and highlighted the biomorphism of the project. The façade tiles were designed especially for the pavilion by Daniel Libeskind and an Italian tile manufacturer (Casalgrande Panada). The unique design of the tiles is based on fractal divisions (aperiodic tilings). The architect not only created an unusual visual effect on the façade through a distinctive pattern resembling dragon skin, but also presented a material with self-cleaning and air-purifying properties. An additional innovation was the use of individual tile fixing on sub structure system, which ran around the building. Such action allowed to adjust the angle of inclination of the tiles (60.0 x 60.0 x 1.2 cm) to the architectural design. The result is a wavy geometric pattern that seamlessly connects the interior with the exterior.
Analyzing the directions of development of contemporary pavilions, one can see a dominant tendency in the pursuit of design consistent with sustainable development, which is particularly visible in the subject matter of world exhibitions. Architects’ access to increasingly improving programs which facilitate design allows to avoid a number of mistakes already at the conceptual phase. Thanks to the creation of computer models of buildings, it is also possible to analyse thermal and acoustic comfort, as well as visibility or sunlight—important in the creation of modern buildings. Computer-aided design no longer focuses solely on the creation of a synergetic form and structure of a building, but also on the later functioning of buildings during their use.

Contemporary architecture cannot be limited to knowledge related only to the fields directly related to architecture. The profession of an architect requires observing new achievements in many different fields such as construction, biology, computer science, mathematics, materials science, chemistry or acoustics.

Comprehensive, in-depth interdisciplinary knowledge enables better use of modern tools and methods in design.

Worldwide exhibitions provide unique opportunities to follow creative achievements in solving many problems of contemporary architecture. Unique examples show innovative, unconventional ideas of creative architects.

The resulting non-standard pavilions are also an opportunity to analyze the design ideas of leading architects—their pavilions are exhibits of technological and intellectual capabilities, in which surprisingly simple technical or material solutions have been applied to achieve complex visual and functional qualities.

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