

## CREATIVE INSPIRATIONS AND TECHNICAL THOUGHT IN THE ARCHITECTURAL DESIGN OF CONTEMPORARY OPEN PAVILIONS

### INSPIRACJE TWÓRCZE I MYŚL TECHNICZNA W TWORZENIU ARCHITEKTURY WSPÓŁCZESNYCH OTWARTYCH PAWILONÓW

#### Abstract

The paper presents selected examples of contemporary pavilion facilities that were inspired by biomimicry and were created as a result of parametric algorithms. As small scale objects, with a simple function, pavilions constitute a testing ground for interdisciplinary architectural design. Such objects emphasize the synergy of intuition and technological rationality. Thanks to the availability of advanced generative techniques and contemporary achievements of engineering, designers are able to reproduce the patterns found in nature. Due to their ephemeral<sup>1</sup> and unique nature, pavilion objects become a proving ground for architectural ideas which subordinate computational algorithms to rational creative thought. Architecture becomes organic, closer to the natural world and the architect uses contemporary computational tools to shape and mould the design for the environmental context.

*Keywords: generative algorithms, topology, morphology, pavilion objects, pavilions, fabrication*

#### Streszczenie

W referacie przedstawiono wybrane przykłady współczesnych obiektów pawilonowych, które były inspirowane biomimikrą i powstawały w wyniku poszukiwań parametrycznych. Niewielkie skalą, o nieskomplikowanej funkcji małe obiekty pawilonowe stanowią poligon doświadczalny do interdyscyplinarnego projektowania architektury. Takie obiekty uwydatniają synergię intuicji i racjonalności techniki. Dzięki dostępności zaawansowanych technik generatywnych oraz osiągnięć inżynierskich projektanci są w stanie odwzorowywać formy spotykane w przyrodzie. W swojej efemerycznej<sup>2</sup> i niepowtarzalnej naturze obiekty pawilonowe stają się przedmiotem gry architektonicznej podporządkowującej algorytmy obliczeniowe racjonalnej myśli twórczej. Architektura staje się organiczna, zyskując naturalność, jaką cechuje świat przyrody, a architekt wykorzystuje narzędzia do współczesnego kształtowania architektury w środowisku.

*Słowa kluczowe: algorytmy generatywne, topologia, morfologia, obiekty pawilonowe, pawilony, fabrykacja*

<sup>1</sup> ephemeral (from Greek *ephēmeros*)<sup>[1]</sup> – in the general sense – a being, a thing or a phenomenon lasting for a very short time; something transitory.

<sup>2</sup> efemeryda (z gr. *ephēmeros*)<sup>[1]</sup> – w znaczeniu ogólnym istota, rzecz lub zjawisko przemijające szybko i bez śladu.

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## 1. Introduction

In their unique nature, pavilion objects are a vast field for architectural exploration, where the creators can subordinate computational algorithms to rational creative thought. Architectural design is much more elusive than and cannot be regarded as just material engineering or structural optimization – *the creation of architecture begins with observation, from the ability to see, which itself is a creative act as it entails having to recognize the perceivable spiritual and intellectual reality which it inherently emanates*<sup>3</sup>.

In the 21st century, we observe an increase in the use of computer aided design tools. Not only to carry out static calculations, but also to design forms that have been impossible to achieve thus far. Computer aided design is both irreplaceable in the process of data processing in creating the architectural forms and invaluable when optimizing structures or materials. Since ancient times, architecture has been subordinated to the rules of logic and geometry, and the ancient canons determined what was beautiful. Contemporary analytical design does not depend on any specific order. It is more of an aesthetic-visual process in which the use of computer aided design is often the only way to achieve the intended architectural goal. The use of generative modelling tools has introduced many significant changes to the way in which we design today.

The exhibition pavilions analysed in this article were created in accordance with the principle of the unity of form, function and structure. Due to the specific goals and requirements accompanying the creation of such objects, they often present unconventional solutions, they impress with their simplicity, but also with the use of the latest technologies. The widened appeal of pavilions and their creation for world exhibitions has contributed to the development of prefabrication technologies, solutions for constructing larger spans as well as the creation of new spatial structures. The design works and research on small scale open pavilion structures are responsible for the development of fabrication methods at the design conceptualization stage.

## 2. Intuitive design – patterns from nature

*Man's creative intuition has always referred to the surrounding environment. In art, and even more in technology, Nature was a reference point, a source of inspiration and the final judge of the results*<sup>4</sup>. Inspiration from bionic patterns is the current trend which dominates in the design of temporary structures, which are mainly pavilion objects. The search for patterns and imitation of nature has accompanied man since ancient times. The ancient Greeks noticed patterns in nature that served them in determining the harmony and proportions of their orders. Leonardo Da Vinci and later the Wright brothers, who modelled based on his works and invented flying machines, were inspired by the way birds fly. Designers of modern office buildings are looking for inspiration in the natural ventilation systems of termite mounds. Modern technologies which support design

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<sup>3</sup> Translation based on: R. Loeglera, *Tworzenie architektury- od wolnej myśli do skonsolidowanej formy*, Architecturae at Arbitus, Oficyna wydawnicza politechniki Białostockiej 2/2016, Białystok 2016.

<sup>4</sup> R. Tarczewski, *Topologia form strukturalnych*, Oficyna Wydawnicza Politechniki Wrocławskiej, Wrocław 2011, p. 13.

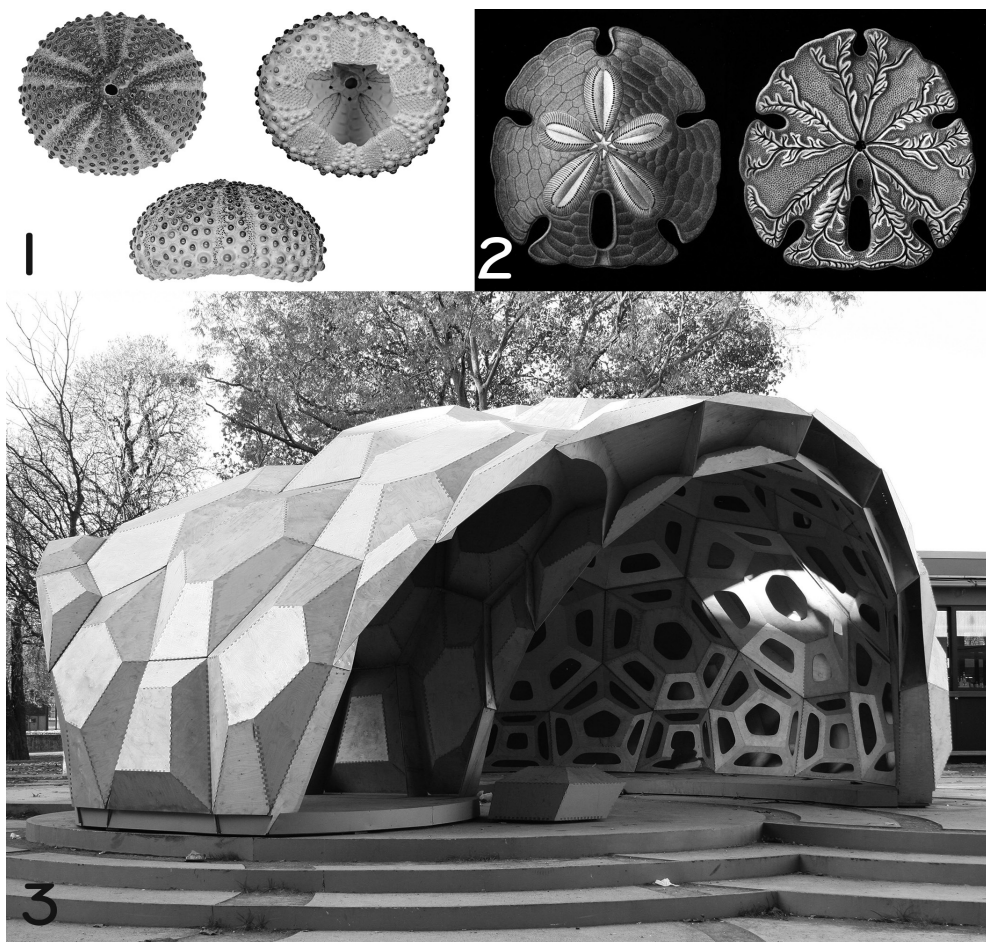
processes enable imitation of nature in architecture at various levels, allowing the designers to achieve bionic shapes and model living organisms' ways of functioning. In a relatively short time the designers are able to design and optimize even very complex biomimetic structures.

Biomimetics are now creatively used by designers not only because they allow for the design of structures which were previously impossible, but also to join the sustainable development trend of imitating nature as physical form-creating systems. In general, this is an issue of multidisciplinary design striving to obey the laws of nature and not only the aesthetic expression. Janine Benyus, considered as the forerunner of biomimetics, thinks that nature is *A model, measure and a mentor*<sup>5</sup>.

An example of the application of bionic patterns in the process of designing pavilion structures is the project by the Institute for Computational Design (ICD) in conjunction with the Institute of Building Structures and Structural Design (ITKE) in Stuttgart. The project used the shape morphology of sea urchins which was then translated into a topology algorithm with the help of computational programs. The computational technologies allowed for the analysis of various bionic structures and helped in identifying the most effective structural system based on the Sand Dollar sea urchin (Sea Cookie) [*own names of the sea urchin*]. The heterogeneous skeletal shell of the sea urchin served as an inspiration in simplifying fabrication and construction of a model. It resulted in the development of a modular system, where the diversified panels follow the geometry of the pavilion. In areas where the curvature of the structure is small, the panels reach a height of over 2.0 m, while the edge cells measure only about 0.5 m in height. Due to the fact that the pavilion is a multidirectional structure, the cells are oriented in accordance with the resulting stresses. Each node joins three cells in order to simplify the transfer of forces. The ability to effectively extend bionic principles and performance and applying them to different geometries through computational processes is quite innovative, as evidenced by the fact that this complex morphology of the pavilion can be built from very thin sheets of plywood (6.5 mm).

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<sup>5</sup> J. Benyus, *Biomimicry: Innovation Inspired by Nature*, HarperCollins Publishers, New York 1997.



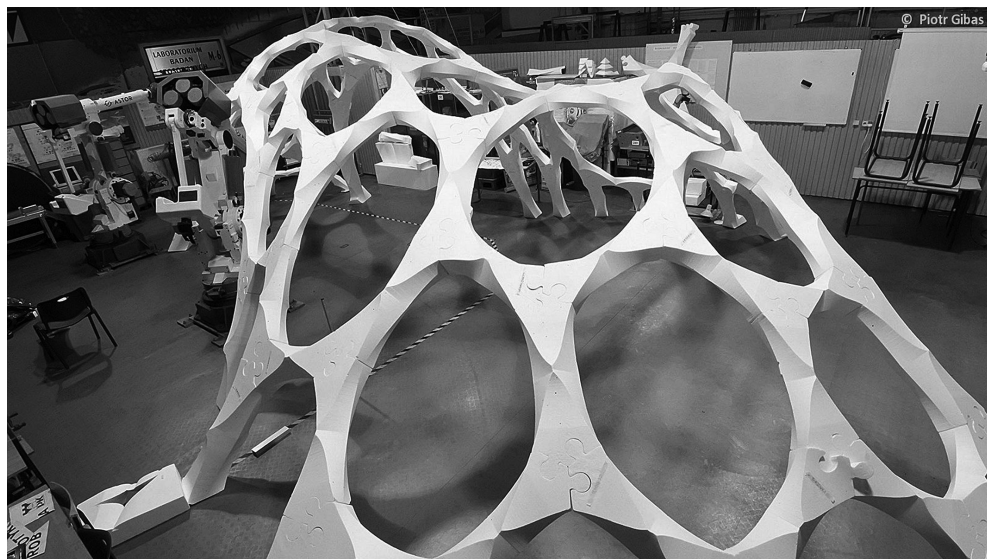
- III. 1. Sea urchin *colobocentrotus atratus*; source: [https://en.wikipedia.org/wiki/Colobocentrotus\\_atratus](https://en.wikipedia.org/wiki/Colobocentrotus_atratus) (access: 2018-06-10)
- III. 2. Sea urchin Dollar Sand; source: [https://lookfordiagnosis.com/mesh\\_info.php?term=Rollinia&lang=3](https://lookfordiagnosis.com/mesh_info.php?term=Rollinia&lang=3) (access: 2018-06-10)
- III. 3. ICD / ITKE Pavilion 2011; source: [https://commons.wikimedia.org/wiki/File:ICD\\_Research\\_Pavilion\\_2011\\_Stuttgart\\_01.jpg](https://commons.wikimedia.org/wiki/File:ICD_Research_Pavilion_2011_Stuttgart_01.jpg) (access: 2018-06-10)

### 3. Generative and parametric algorithms in biomimetic design

The basic patterns taken from Nature which are used in the architectural world are the golden ratio, emergence, morphogenesis, mathematical formulas created by Mandelbrot in 1975, or systems of self-similarity (these are, among others, the Sierpinski triangle, Koch snowflake, Peano curve).

Through the use of generative algorithms, programs such as Grasshopper, Paracloud GEM and Generative Components have become so prevalent in the last century that they

can be used to implement patterns taken from nature. They allow the designers to make real models without the need to make technical drawings (difficult to draw as in the case of projects created in non-Euclidean geometries). An example of this type of research is the experimental parametric pavilion by the Imago Scientific Society at the Department of Descriptive Geometry, Technical Drawing and Engineering Graphics at the faculties of Architecture and the Mechanical Engineering of the University of Krakow. According to the file2factory paradigm, all data necessary to create the object was transferred directly between the digital fabrication tools and the manufacturing process. The spatial form and the robot's way of working have been designed in the Grasshopper / Rhinoceros program. The whole structure measures 12x7x3m and it was made of 132 foamed polystyrene elements cut digitally.



III. 4. The pavilion while under construction; source: <http://arch.pk.edu.pl/blog/2018/04/17/eksperymentalny-pawillon-parametryczny/> (access:2018-06-10)

The use of biomimetics on a larger scale is possible thanks to the use of digital design support tools and the creation of modern programs enabling morphological and topological changes. Leading to a more streamlined optimization processes, topological changes of structural systems deforms the structure which affects the process of improving local systems, while at the same time streamlining structural calculations by the finite element analysis method.

#### 4. Construction optimization methods for architecture

FEA (Finite Element Analysis) is currently one of the basic methods of computer-aided engineering calculations. This method results in a geometrically discrete model,



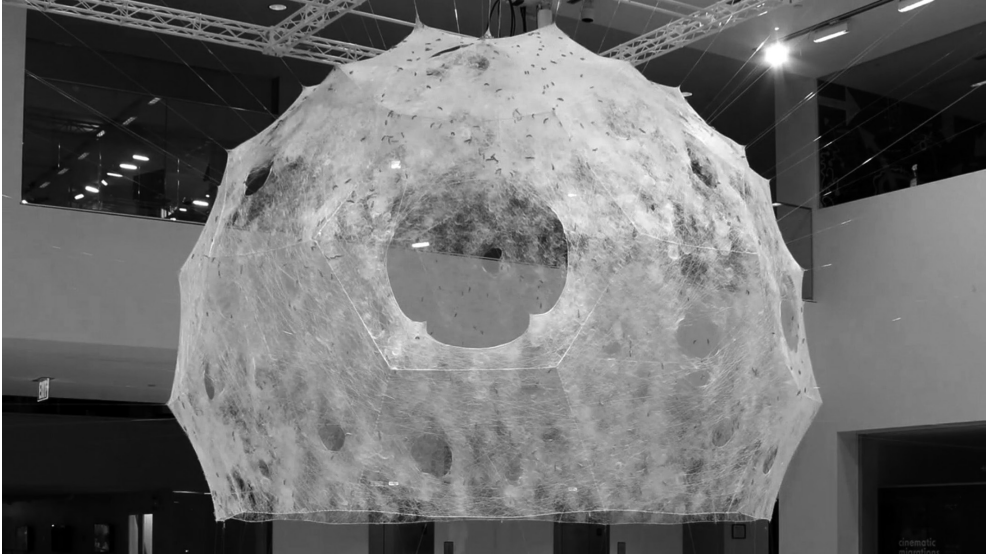
which is divided into as simple as possible components connecting at nodes. This method transforms systems with an infinite number of degrees of freedom into statically determinate elements, which are simple to analyze, and is extremely useful in calculating topological changes in structures as one of the main tools in calculating the construction of architectural objects.

## **5. Digital fabrication**

Modern shaping of structural forms often requires the use of modern materials or even the creation of custom materials with specific parameters. An example of a change in thinking about form may be the industrial revolution that fell on the years when the Crystal Palace pavilion in London was constructed. Giant water lilies were Paxton's inspiration for the design. The whole building was made of steel and glass. The building's body was designed in such a way as to combine traditional architecture with modern building technologies. The skeleton structure was erected in an unprecedented time of five months. Analogically, modern technical and technological thought have a significant impact on the development of architectural design. Architects are now able to optimize material use by introducing the technical properties of materials into mathematical algorithms which are used in the conceptual phase. It helps not only by optimizing the construction, but also helps by improving the efficiency of fabrication. Architects such as F. L. Wright saw the need to adjust the conceptual phase to the materials used: "Every new material means a new form, a new use if used according to its nature".

Examples of pavilions that use modern materials or unconventional ways of using old ones may be Silk Pavilion made of silk threads, the Pulp Pavilion made of ground waste paper, or the ICD / ITKE pavilion from 2013–2015, where the whole pavilion was made by a robot printing with carbon fibre on a prepared membrane imitating the way in which spiders build their shelters.

The Silk Pavilion owes its unusual structure to "combining" parametric design and biomimetic structure at an architectural scale. The pavilion's designers who were inspired by the way silkworms create their cocoons decided to develop an installation based on steel frames with 26 panels. Then, the panels were connected and suspended to the ceiling, forming a dome, where the silk fibre was woven using a robotic arm – imitating the way silkworms move. These threads formed a foundation with a total length of 1000 m, which could provide habitat to 6500 silkworms. The intention of the designers was to create a structure without additional supports, based on 3d printing and adaptation to larger objects. Thanks to this solution, a coherent installation in terms of structure and material was achieved.



Ill. 5. Silk Pavilion; source: <https://magpieaesthetic.com/silk-pavillion-cnc-deposited-silk-silkworm/> (access: 2018-06-10)

## 6. Production optimization

Digital fabrication systems, such as CNC machines, enable us to prepare components in a short time, irrespective of whether they are repeatable or individually formed.

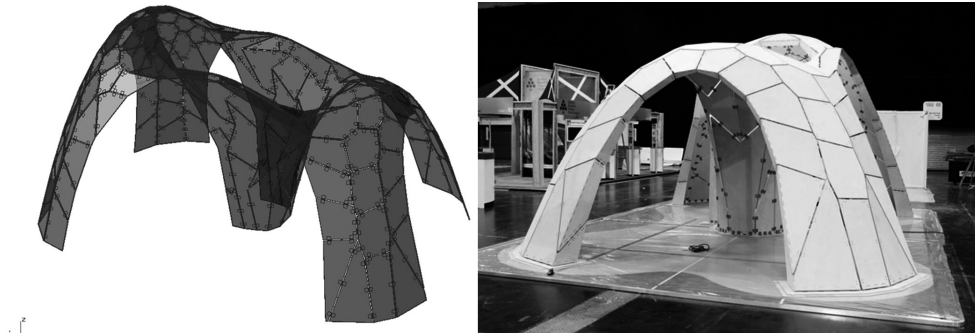
Nowadays, architecture is in a transitional stage between the introduction of design optimization tools, which facilitate the design of individual objects, and the Fordist stage<sup>6</sup>, where the recipient is a mass consumer and production is focused on the standardization and unification of products. The postfordist era rejects repetitiveness while at the same time providing flexibility to the means of use of individual elements, making it easier to create “custom-made” products adjusted for their specific context. Fabrication with CNC machines is an example of this process of creating repetitive and individual elements and does not differ in the time required or affect material use. The examples of those both types of manufacturing are shown in pavilions such as the TRADA pavilion designed by Ramboll Computational Design (individual shape adjustment of particular elements) and the Dragon Skin Pavilion designed initially by the students of Tampere University of Technology in Hong Kong (fabrication of repeating elements).

An interesting example of the use of bionic patterns in pavilion design with the help of FEA method can be found by analyzing the Trada pavilion. It resulted from exploration of the possibilities of double-curved surfaces, similar to those researched by A. Gaudi or F. Otto. The numerical analysis and the use of algorithms for freeform modelling were aimed at simplifying calculations as well as to prepare for fabrication. In the design phase, instead of the

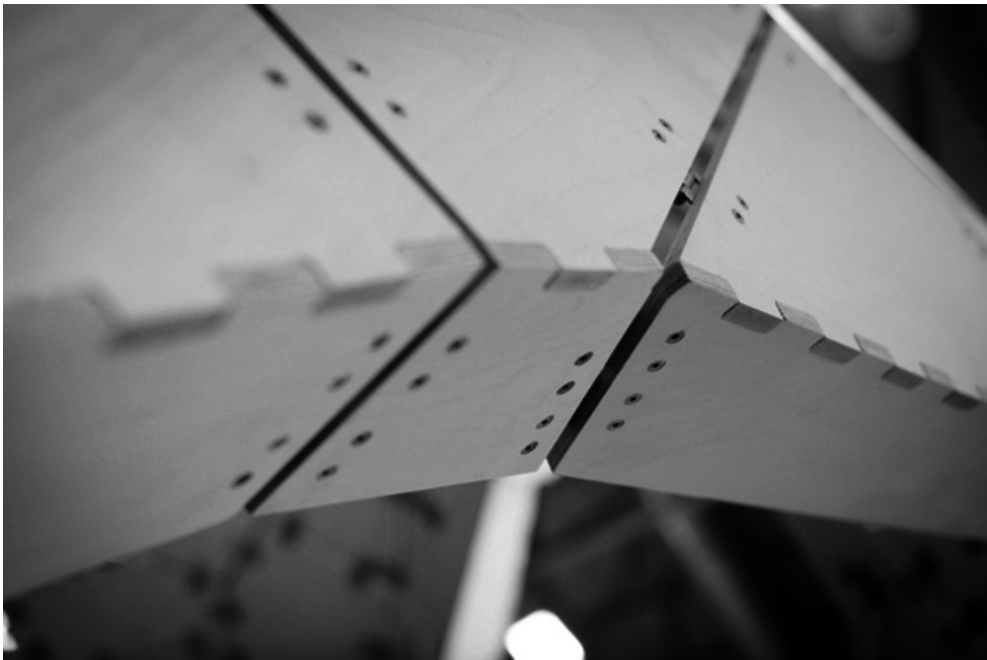
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<sup>6</sup> A model of work organization introduced by H. Ford, which consisted of multi-series mass production.

traditional division into triangles, the surface was organised in such a way that the main panels were always hexagonal, while the panels at the edges were 3 to 6 sided polygons. This reduced the number of connections between the panels, which shortened the assembly process while maintaining the stiffness of the structure. A CNC machine was used to create the 15 mm thick plywood panels (as well as the holes necessary for mounting the hinges) The digital file, passed to the machine's router, was developed in the Grasshopper plug-in for Rhinoceros, which allowed for the design and effective arrangement of panel divisions and their connections.



III. 6. The model of the Trada pavilion generated using the Grasshopper plug-in; source: <https://www.scoop.it/t/algorithm/p/2806847144/2012/09/27/trada-pavilion-grasshopper> (access: 2018-06-10)



III.7. & 8. Trada Pavilion, detail view; source: <http://www.evolo.us/parametric-timber-pavilion/#more-21451> (access: 2018-06-10)



An example of a pavilion built with identical repetitive elements is the pavilion designed by a student group from the Tampere University of Technology in Finland in 2011 and later recreated in Hong Kong at the Architecture Biennale. The project used a combination of new material and an algorithm that generates the whole object. The 15mm thermoplastic plywood, cut out into square panels on a CNC machine, was transmitted to a robot. Special incisions in the panels allowed for the pavilion to be constructed without the use of additional mounting. The panels were heated to about 150°C and bent with a press. In this manner, the single-curved panels could be used to assemble the pavilion in 8 days after the concept was finished.



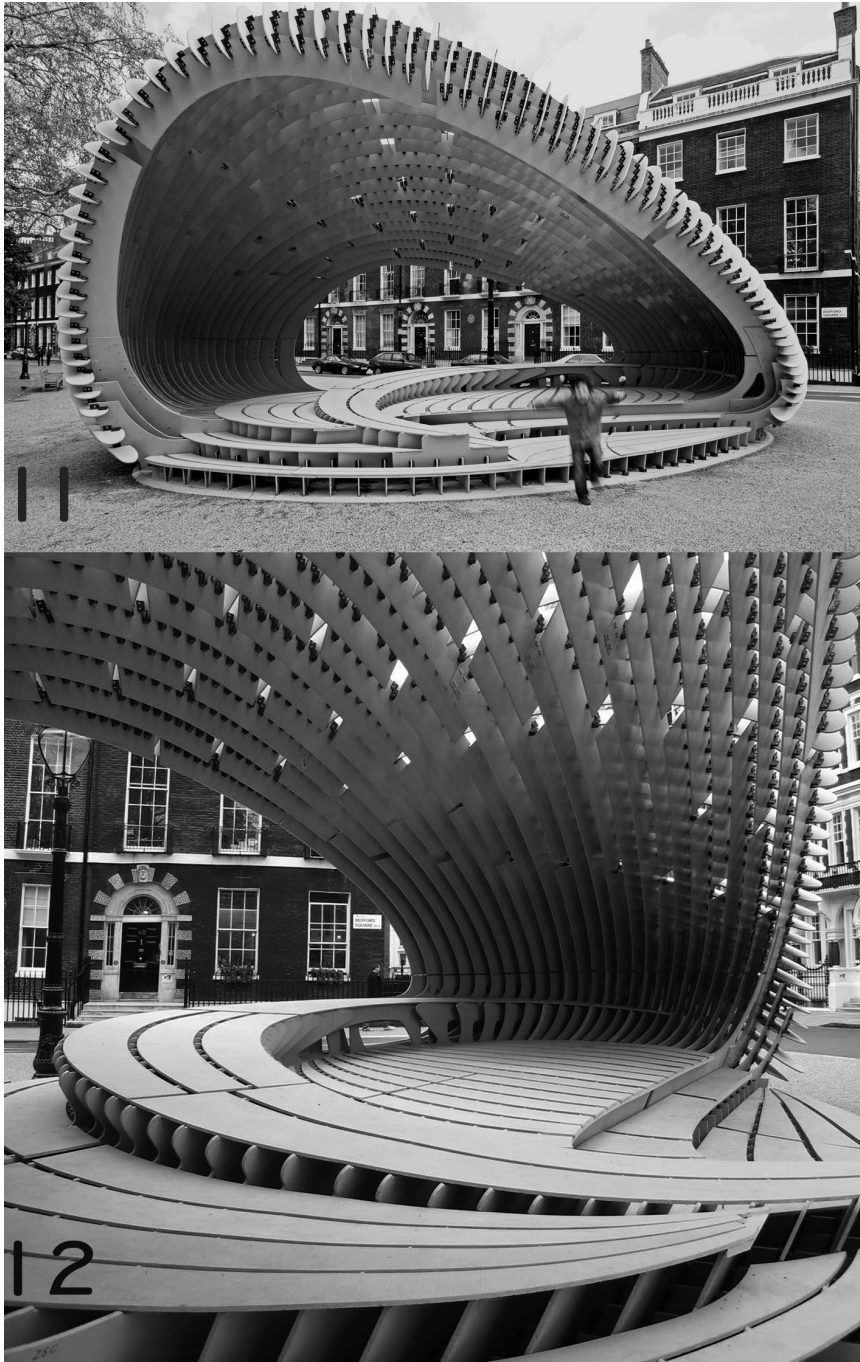
III. 9.–10. Dragon Skin Pavilion; source: <https://wordlesstech.com/dragon-skin-pavilion/> (access: 2018-06-10)

An example of a pavilion that combines all the aspects described above is the Space Pavilion. The pavilion was selected through a competition to celebrate the tenth anniversary of the Design Research Laboratory at the Architecture Association School in London in 2008. Speed and ease of assembly, low cost of fabrication and simplicity and aesthetics of the design were the evaluation criteria. The material was used efficiently if we assume that the extending roof would become a place to rest. Designed by Alan Dempsey and Alvin Huang, the object was created as a result of the discretization of a seashell inspired building shell. At the widest point, the pavilion extends over a length of 10 m. In order to increase the tensile strength of the prefabricated concrete elements a series of thorough material tests in terms of strength properties were necessary, due to the use of the innovative Fiber-C reinforced concrete. The Austrian company Rieder was involved in the fabrication of the concrete panels. The pavilion was made of 850 individually designed 13 mm thick concrete panels cut on CNC machines. A total of 2,000 steel joints with a thickness of up to 15mm were made, additionally all joints were modelled individually, depending on the angle they intersect the structure. To facilitate the fabrication of such a large number of joints, computational methods have been used.

The digital fabrication was also intended to simplify the assembly of the pavilion. Finished concrete elements were adjusted in such a way that it would be possible to assemble the whole pavilion in a relatively short time, without additional specialized equipment.

## **7. Conclusions**

The development of research on the implementation of biomimetic patterns, computational algorithms and their application (by means of computational design) in search for forms, optimization of construction and material have led to the emergence of modern and innovative architectural solutions. A deeper understanding of the patterns taken from nature at various life levels of living organisms has enabled technologists and researchers to propose innovative architectural forms with aesthetics similar to those found in nature. Bionic patterns are inspiring and thanks to the interdisciplinary joint activities in design and fabrication they become not only an aesthetic element but they also improve the functioning systems of the designed objects.



III. 11.– 12. Space Pavilion; source: [http://www.akt-uk.com/projects/\[c\]space drl ten pavilion](http://www.akt-uk.com/projects/[c]space%20drl%20ten%20pavilion) (access: 2018-06-10)

As Peter Zellner noted, “Architecture is recasting itself, becoming in part an experimental investigation of topological geometries, partly a computational orchestration of robotic material production and partly a generative, kinematic sculpting of space”<sup>7</sup>.

The ability to digitally design innovative architectural forms is still dependent on the perceptual and cognitive capabilities of the architects. The generative and parametric design processes are dynamic processes allowing us to discover new possibilities and gain qualitative understanding. The role of the designer in the use of generative tools is the interpretation of countless results by creating parametric models or genetic algorithms analyzed in static calculations when creating topologically variable surfaces, isomorphic skeletons, emergents or processes of self-similarity. One could repeat after L. M. van der Rohe *where technology achieves true perfection, architecture is created*.

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<sup>7</sup> P. Zellner, *Hybrid Space, new forms in Digital Architecture*, Rizzoli, Nashua, 1999.