Implementing Biomorphic Design

Design Methods in Undergraduate Architectural Education

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In continuation to Generative Design Methods, this paper investigates the implementation of Biomorphic Design, supported by computational techniques in undergraduate, architectural studio education. After reviewing the main definitions of biomorphism, organicism and biomimicry synoptically, we will assess the application of a modified biomorphic method on a final year, undergraduate design studio, in order to evaluate its potential and its suitability within the framework of a research led design studio, leading to an RIBA accredited Part I degree. Our research findings based on analysis of design outputs, student performance as well as moderators and external examiners reports initiate a constructive debate about accomplishments and failures of a design methodology which still remains alien to many undergraduate curricula.

Keywords: CAAD Education, Strategies, Shape Form and Geometry, Generative Design, Design Concepts

INTRODUCTION

The term Biomorphism ultimately derives from Goethe and was firstly introduced by the British poet and writer Geoffrey Grigson in 1935, in relation to the work of the sculptor Henry Moore (Kosinski 2001). It is composed out of the Greek words βίος (life, living) and μορφή (form). Strongly related to Surrealism, it was used to describe the creative synthesis between cubism and abstract art. It has been often associated with fluid, organic shapes in art, architecture and design. Particularly in architecture, the term has been related to nature inspired forms, naturally occurring patterns and shapes.

The notion of organicism promotes harmony between architecture and nature to the point where form and natural context merge into one. Key components have included Imre Makovecz (Kuhlmann 1998) and Frank Lloyd Wright, who, as Aldersey-Williams (2003) points out, took the approach to new heights. Even though organicism and biomorphism are related (and are often used - incorrectly - synonymously), there are significant differences between them. Organic architecture, as Wright himself defined it, does not necessarily resemble natural forms, but rather relates to materiality and integration into a natural context.

Finally, the term 'bionics' - combining 'biology' and 'technics', or 'electronics' - was invented by US Air Force colonel Jack E. Steele and presented at a 1960 'Bionics Symposium', entitled 'Living Prototypes - The Key to New Technology' (Nachtigall 2005). Aiming to inform engineering and technology with knowledge
and aspects of performance as they have evolved in nature, bionic design can be seen as an aspect of biomorphism. However, bionic, or biomimetic, architecture implies not only the form-related aspects of mimicry, but the inherent qualities of construction as well (Gruber 2011). Gruber also points out that Frei Otto's research studies on membrane surfaces, and Buckminster Fuller's tessellation techniques for dome geometry, were most probably the first attempts to integrate bionics into architectural design. It is in the last ten years - by incorporating emerging technologies and tools, such as parametric, algorithmic and generative design methods - that architects and engineers claim to have moved beyond a mimicry of geometry and order, and into enhancing environmental, structural and material performance by learning from the mechanisms and properties found in nature. New terms such as zoomorphism, geomorphism and anthropomorphism have arisen in order to specify the particular source of inspiration or mimicry in each case (in these instances, animals, geology and humans, respectively).

Even though these terms appeared only in the 20th century, nature has always been a paradigm for artists and architects. Looking back in the origins of western architecture, such as the design of ancient Greek temples, nature always plays an important role, not only in terms of shape and appearance but also in defining proportions and structure. Various other attempts to incorporate nature into design and architecture have been taking place from ancient times until our days, in almost all architectural movements. Starting with traditional architecture around the world, continuing with Arabic ornaments or architects and designers during Art Deco and art Nouveau, Antonio Gaudi in the beginning of the 20th century, until Oscar Niemeyer, Frei Otto in the 50's and 60's continuing with Sandiago Calatrava and Sir Norman Foster in our days.

Through the rise of digital design and fabrication techniques, bio inspired design is becoming more and more important in today's architectural practice and academic framework, calling for innovative educational concepts in both undergraduate and postgraduate curricula.

AIMS AND OBJECTIVES:
Main aim of this research paper is to evaluate the suitability and implementation of biomorphic design methodologies into undergraduate design studio. Furthermore, we will investigate a variety of contemporary biomorphic design methods by monitoring design case studies, using different approaches and techniques, practiced in the academic framework of Studio 04, one of the five graduate year's design studio units in our University. The studio encourages the use of digital design and fabrication tools, as well as physical modelling and drafting techniques.

Figure 1
Diagram of design method applied in the design experimentations presented.
Our main research questions can be described as follows:

- How can biomorphic design methodology be integrated in an undergrad design studio module?
- Which are its strengths and weaknesses?
- Does the applied design methodology achieve its objectives in producing innovative design solutions and increase students’ design skills and future employability?
- Does the integration of biomorphic design methodology in undergraduate level seem appropriate?

RESEARCH METHOD AND FINDINGS

Our design method was based on three main phases, Analysis - Morphogenesis - Metamorphosis (Agkathidis 2015), aiming the production of complete architectural proposals, in a research led educational framework. Analysis was focusing on precedent studies originated in nature, where design properties, design intentions and parameters were identified. During Morphogenesis abstract generative models (Figure 1) were developed by incorporating the parameters of the previous phase. Finally, during Metamorphosis, the previous prototypes were translated into building proposals, including all necessary deliverables, such as floor plans, sections, details, physical models and visualisations.

The method described here, was applied on a 12 week, design studio unit with a cohort of 63 students, tutored by six tutors, part of a total of 240 students in the entire year cohort. Students had to work collaboratively during the first four weeks (analysis and morphogenesis) and develop their individual projects in the remaining time of eight weeks. The final project submissions were first marked by the entire group of studio tutors, second marked and moderated by a team, not involved in tutorials and examined by external examiners. The entire process was monitored during two semesters. Analysis of design outputs, marking statistics, moderator and external examiners reports, which will be presented in the final paper, are offering an analytic evaluation overview of biomorphic design methodologies integration in undergraduate education. In addition, we will present a categorisation of the various design experimentations using nature as a source of formal inspiration, spatial / typological innovation, organizational method or as a tool for performative integration into structure and geometry.

We will present four characteristic design experimentations, which were produced by applying the method described previously and proceed to discussions and conclusions based on the analysis of the collected data.

DESIGN EXPERIMENTATION 01: HILL AND VALLEY

Our first design experimentation initially analysed hill and valley formations resulting from the movement of water (Figure 2). They emerge through the movement of tidal currents on the soft, formable sandy soil of the sea.
During the phase of morphogenesis, a Grasshopper algorithm was developed in order to generate surface deformation prototypes in hills and valleys by simulating the flow of water along vectorised pathways. The algorithm required the introduction of ‘attractor paths’ in order to develop various landscape-like iterations. As a second step, a number of these iterations were materialized as physical models using contour crafting, CNC milling and 3D printing technologies, which then offered up a range of different tectonic solutions (Figure 3).

Finally, hill and valley typologies resulting from the water-flow simulation process served as the spatial prototype for a spa facility, composed of hills, caves and valleys, and able to accommodate pools, saunas, steam rooms and relaxation zones (Figure 4). The building’s double-curved roof helps its integration with the building site, a green, hilly landscape. Toyo Ito’s reinforced concrete roof-scape for the Kakamigahara Crematorium (Turnbull 2012) served as a structural precedent for this project.

**DESIGN EXPERIMENTATION 02: BIRD’S NEST**

This project analysed reciprocal structures in nature, such as they appear in birds’ nests. Structures like these are formed from at least two elements, each of which is supported by another. All elements meet with each other along the span and not at the vertices.

During the morphogenesis phase the team experimented with different surfaces composed of various types of units, starting with physical models and continuing with Grasshopper algorithms and digital modelling. In particular, it examined the relationship between unit, shape morphology and structural performance, such as plane surfaces, and single and dou-
Following these investigations, reciprocal timber shell structures were developed in order to accommodate an event/pavilion space. Investigations into cladding solutions included textile membranes (Figure 6) and ETFE foils.

**DESIGN EXPERIMENTATION 03: SNAKE SKIN**

This project analysed reptile skin and scales (Figure 7). Taking place within the educational framework of the Raffles Design Institute in Shanghai, with the assistance of third-year students, this study involved translating snakeskin patterns into a scale-like, foldable surface, composed of units that were stuck together. The final surface was found to be flexible enough to form a large variety of shapes. Handmade models were constructed from standardized strip modules, but the final design was based on a folded unit created using a parametric Grasshopper algorithm. Thus, the prototype evolved into a non-standard solution, made from irregular modules.

Finally, the prototypes were transformed into a shading/space-dividing wall, with the 1:1 prototype built from recycled cardboard panels. Each module was laser-cut and then assembled layer by layer. The final output proved to be an extremely stiff and stable structure, which also allowed for spectacular lighting effects (Figure 8).

**DESIGN EXPERIMENTATION 04: BRANCHED BLOCKS**

This project analysed branching and growth algorithms in trees. During morphogenesis, branching algorithms appearing in nature were applied to different geometrical units, such as lines and cubic volumes, by using a Grasshopper script (Figure 9). A set of iterative models (digital and physical) was produced, exploring structure, organization, massing and typology.

The final project proposal translates the typological prototypes produced during the form-finding (Figure 10) exploration into a volumetric accumula-
tion of cubic spaces, aiming to accommodate a thermal baths and spa facility. The same branching algorithm was used as the primary organizational tool. The proposed building achieves an innovative spatial/organizational floor plan, and the massing is integrated into the landscape (Figure 11).

DISCUSSION AND CONCLUSIONS
The way that nature has influenced design in the above design experimentations falls into several categories, which in turn give rise to a number of conclusions. Some projects, such as the 'Branched Blocks', use nature mainly as a source of formal inspiration. Although this approach is often criticized by some, it has always been a legitimate approach to form-finding, especially in relation to mathematical rules and equations, and it leads to a chain of innovative solutions related to tectonics, typology, materiality and fabrication.

Other projects are concerned with using nature as a source of spatial/typological innovation. The 'Hill and Valley' project, for instance, proposes a new building type inspired by the topology of sand formation. The entire spa complex evolves as a continuous surface, hosting each of its functions either by enclosure or through surface deformation into hills and valleys. Yet other examples, like the 'Branched Blocks' project, operate on an organizational/compositional level. In this project a generative, branching algorithm was applied in order to organize the layout and massing of a building, again leading to unexpected spatial and typological innovation.

Finally, some projects focus on the relationship between geometry and structural performance and/or material innovation (e.g. 'Snakeskin', 'Birds Nest'). Both of these projects use algorithms as a means of achieving structural and formal coherence, while focusing on smart material fabrication solutions by using either timber or paperboard- a reminder of the pre-computational attempts of Otto and Candela.

Although biomorphic projects are often criticised for ignoring contextual integration, case studies like the 'Hill and Valley' project demonstrate a high degree of integration into the natural context. The same can be said for the 'Branched Cubes' thermal bath proposal, which manages to achieve contextual integration with its design and materiality and could therefore claim proximity to Wright's definition of organismism as a unification of design and nature. Another important observation is that biomorphic design solutions can operate on many different levels, ranging from the size of an object or a building component, through to a whole building, or even projects on an almost urban scale.

The positive effects of including biomorphic design in architectural education are obvious. The undergraduate design schemes shown here demonstrate a high degree of structural and typological innovation, combined with well-functioning floor plans and sections. The appropriate level of knowl-
edge has been acquired, as verified by external examiners, enhanced by the acquisition of new skills (e.g. digital design and fabrication). Such case studies prove that undergraduate architectural education can move beyond the boundaries of classical curricula and offer innovative design methodology that is in tune with both the zeitgeist and with the evolving demands of the job market. In addition, simple, even playful, large-scale exercises like the Snakeskin installation wall prove that there is both metaphorical and literal space for 1:1 scale constructions in undergraduate education. Traditional structures and hierarchies in education, though, do present several barriers to be overcome; this approach requires site simplification, and teaching content must be adapted to the appropriate level, addressing antiquated and unnecessary health and safety requirements, and providing instruction in computational skills, an area that is often ignored.

The projects featured in this paper clearly demonstrate the enormous potential of biomorphism and bionics for developing innovative solutions and design-based research. They met all accreditation requirements set by RIBA and ARB and did not receive negative comments or remarks by the external examiners, thus proved to be appropriate for an undergraduate design studio module.

Meanwhile, the strict boundaries between terms such as biomimicry, biomorphism, zoomorphism, geomorphism, anthropomorphism, organicism and bionics are becoming ever blurrier. Emerging computational tools and design techniques, such as generative, algorithmic and parametric design, in combination with digital technologies like CNC fabrication and 3D printing, are embracing nature as a source of inspiration, and will allow constructive new synergies between biology and architecture in the years to come.
ACKNOWLEDGMENTS

My acknowledgments go to the design team of ‘Hill and Valley’, Sen Lin, Haochen Jia, Jun Zhou and Jin-hui Zhu, the design team of ‘Bird’s Nest’, Maria Kaik, George McLoughlin, Oluwaseyi Oladimeji, David Oldham, Yipei Tan, the design team of ‘Sankeskin’, Timur Bissenbayev, Yuzhan Cheng, Qiuchen Yu, Minxuan Zhu and Ben Prasetya Tanuatmaja and the design team of ‘Branched Blocks’, Xiao Gu, Yuedi Liu, Yangt- ing Yang, Jingley FU and Wenxuan Zhang.

In addition, my grateful acknowledgements go to the Studio 04 tutors, Richard Dod, Daniel Wiltshire, Ürün Killic, Fei Chen and Simos Vamvakidis, for their enthusiasm and hard work, and to the workshop team of Stuart Carroll, Michael Baldwin, Stephen Bretland and Aleksandar Kokai at the Liverpool School of Architecture.

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