A Course on Biomimetic Design Strategies

Sevil Yazıcı¹
¹Ozyegin University
¹www.sevilyazici.com
¹sevil.yazici@ozyegin.edu.tr

Although redesigning curricula by integrating the CAD tools into architectural education has been an ongoing interest, a new understanding towards solving design problems holistically should be investigated in architectural education. Because natural systems offer design strategies to increase performance and effectiveness with an extensive formal repertoire; incorporating multi-faceted biomimetic principles into the design process is necessary. It is critical to increase skills of students towards algorithmic thinking, as well as to deal with performance issues and sustainability. This paper aims to discuss an undergraduate elective course titled "Sustainable Design and Environment through Biomimicry" which was taught by the author in architectural degree program of Ozyegin University Faculty of Architecture and Design in Fall 2014-2015. Following the exploration of individual research topics, findings were implemented into design problems. The challenges encountered in the teaching process and future lines of the work are discussed in the paper.

Keywords: Biomimetic principles, Computational design, Architectural education

INTRODUCTION

Ecological and systemic awareness was first presented by Aristotle (384-322 BC) as a metaphysical vision of the systemic and ecological order of nature in his biological systematic. Systems are established through the interaction of its components. If the system disintegrates, the components loose its synergetic properties (Skyttner, 2005). Likewise, the entire alive and inanimate matter found in nature is connected to each other within a system unity. Biomimicry aims to investigate complex, however highly efficient matter found in nature, as an interdisciplinary research field.

Two major approaches were defined considering the relationship between nature and architecture: One of them is based on the inspiration of architectural form through natural forms, imitation of its properties such as patterns. The other one is based on learning from natural forms by trying to understand behavioral and generative properties (Selçuk and Sorguç, 2009). Design strategies are changed from top-down to bottom-up. An integrative approach in design is necessary to unite various disciplines (Kolarevic, 2008). Computational design techniques enable establishment of systems, even with complex properties in a holistic manner. Biomimetic principles were used in the past years in design projects by focusing on structural and archi-
tectural demands within integrated computational design systems, in terms of form finding and fabrication strategies (Menges, 2008; Bueno, 2009; Oxman, 2010). The work based on biological principles offers design strategies for higher performance and effectiveness (Schwinn et al, 2012).

There has been an ongoing interest of educators in redesigning curricula, by the means of integrating computational design tools into the architectural education (Kvan et al, 2004). Assessment of design process and production in the context of sustainability, in order to ensure the diversity and productivity of biological systems became a critical aspect in today’s architectural design production. This requires innovative solutions from energy efficient systems, to reduction of material amount used in a building. Issues related to the effectiveness and performance assessment, including structural or environmental performances are generally considered as separate courses and not integrated into the design studio in undergraduate level in general. It is a necessity to increase awareness in this problem, as well as to challenge new design methods in architectural education. Therefore, multi-faceted biomimetic principles should be considered in the design process and incorporated to the architectural design education, along with computational design tools.

This paper aims to discuss an undergraduate elective course titled “Sustainable Design and Environment through Biomimicry” in the axis of biomimetic design strategies and computational design. The course was conducted in Architecture Program of Ozyegin University Faculty of Architecture and Design in Istanbul at Fall 2014-2015. The intent of this course was to solve design problems as integrated systems.

**TEACHING METHOD**

The course consisted of 19 students, ranging from 1st to 3rd year of undergraduate architectural education and the skills and knowledge of the students varied. In terms of technical skills, although some participants obtained skills related to the advanced 3d digital and parametric modeling, some of them had no experience with CAD tools in the past. They were given four different modules as a part of the course:

1. Introduction to the systems thinking and computational design
2. Discussing sustainable design strategies
3. Specifying individual research problems
4. Application of research findings into a design problem

In the first module of the course, concepts such as holism, goal seeking, inputs and outputs, transformation of inputs to the outputs, hierarchy and differentiation were investigated as a part of systems thinking (Yazici, 2011). Following the discussion of theoretical background of the course related to the systems thinking and computational design, sustainable design strategies in general architectural profession were discussed in the second module. Commonly used terms, such as green, ecological, environmentally friendly etc., assessed with rating systems like LEED and Breeam that are goods and services, laws, guidelines and policies that affect the ecosystems and environment minimal or less, were discussed. The first two modules took place in the first 6 weeks of a 15 weeks semester.

By establishing a general understanding related to the current condition of the building industry, students investigated individual research topics, in terms of biomimetic principles, a matter or phenomenon found in nature. The task was to implement their findings into a design problem as a part of a building system, such as a façade, mechanism, building material or as an organizational logic. The intent of the research project was to bring solutions to increase energy efficiency by accommodating different performance requirements, from energy to structural performances, as well as by reducing the amount of material used. Parametric modeling enables to create differentiated systems. By introducing and adjusting parameters, transitions, from one phase to another one can be achieved by producing a family of results, which creates a large sample
pool available for comparison (Vermisso, 2011). Topics which students investigated varied from lindenmayer systems and voronoi, to phototrophy, gecko feet, topology optimization and more. Students with different technical skills used different media to present their ideas, by specifying parameters, rules and relationships of the system.

The outputs can be investigated in three different categories; including generation of morphological and organizational relationships, translation of properties and processes in nature adapted to the design process.

**Generation of morphological and organizational relationships**

Although natural systems seem to obtain only some basic rules, the output may be highly articulated and complex, such as in fractals, swarm, chaos etc. Extracting some rules from nature and re-building mathematical models of systems have been an interest by architects/designers in the past decade. It is identified that the first group of students observed natural systems, in terms of its morphological/organizational properties. Lotus leaf and bird bone structure were analyzed as organizational models.

Lotus leaves are large, however their cross sectional thickness is small and obtain a long and detailed vascular network, in which the weight is distributed evenly. Lindenmayer systems (L-systems) were investigated to get a deeper understanding of the system. L-systems can be defined parametrically:

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G = (V, w, P);
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in which

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where \( V \), \( w \) and \( P \) represent the variables, a string of symbols from \( V \) defining the initial state of the system and a set of production rules or productions respectively. Because L-systems are defined as formal grammar systems, which are used to define the behavior of
plant cells and model growth processes generating fractals, the model was used by a student in the class as a form generation method in the design process. The results were varied from a structural system, into a façade element and a partition wall pattern. A parametric model was generated to test different options (Fig. 01).

Bird bone structures were investigated by another student in terms of its formal organization. Based on the research undertaken, it was found out that birds have been affected under many skeletal evolution and presented adaption by time. To optimize the energy of a flying bird, the bone structure needs to be light and should obtain voids to minimize its weight. The participant’s intent was to design a structure with less weight by introducing voids and increase structural efficiency. Therefore, voronoi model, based on portioning plane into regions based on distance to points in a specific subset of the plane, was used in the parametric design medium. Parametric model could be adjusted by defining the volume of the voids within the structure and reduce the weight of it (Fig. 02)

**Translation of Properties**

Observations in nature can be interpreted, abstracted in some level and translated into building components or mechanisms, such as kinetic systems. In regards to the biomimetic approaches used in architectural design process, there is a shift from the static aesthetics of organic form into a performance based bio-materiality, driven by responsiveness. This can be investigated through the evolution of botanical specimens (Perez, 2006).

As a part of the course, one of the students focused on the phototropism activity observed in
plants. Phototropism is irreversible response to the external stimuli and plants are directed towards the sun. Auxin hormone (IAA molecules), which controls elongation in plants, changes its position based on the direction of the sun. Normally, it is found on the top or in the middle part of the plant. If the plant doesn't get sun light from different parts, then the IAA molecules are positioned in the place that there is no sun, and the plant growth direction is affected by that.

The working principle of phototropism movement of plants were translated into a responsive façade mechanism, consisted of solar panels. A kinetic mechanism was necessary in response to the sensors, which should calculate the sunlight angle and intensity of the light. Receiving the sun light vertical or almost vertical in relation to the solar panels should increase the amount of energy collected. Based on the angle of the sun, the facade would able to respond to the sun light and collect the sun energy efficiently. Therefore, sun monitoring systems were necessary to maximize the energy performance. Components and several iterations regarding the facade openings were designed. A parametric model was developed, in which individual façade panels could be controlled and were able to rotate, by generating a global pattern on the façade (Fig. 3).

Another student investigated Gecko, a lizard species which lives in humid tropical regions. Gecko has a very flexible movement capability compared to a lizard. The reason is that gecko's toes obtain hair-like extensions called setae, micro-hairs over 2 million in number and their size is 1/5000 of a millimeter. A strong adhesion occurs between the surface that gecko moves and the micro-hairs. It demonstrates a mechanism driven by van der Waals force, a weak force which is the sum of the attractive or repulsive forces between molecules or between parts of the same molecule. When gecko moves, it pushes its foot to the surface and pulls it back slightly, so that the micro-hairs interact with the surface at maximum. If gecko's toes would be covered by an adhesive material, gecko would need more energy to break the connection with the surface. In terms of abstracting and translating this property, into another form of use in a building system, the participant developed a building material, which was modulated by a certain degree of differentiation and could be called as new brick. The interlocking mechanism of the elements enabled to avoid the use of mortar, which is inevitable for masonry structures. Therefore, the amount of material would be reduced towards a more sustainable construction of a building (Fig. 4).
Processes in nature adapted to the design process

Optimization is a process observed in nature. For instance, bionic materials like bone and wood are optimally designed in respect to their loading. By investigating structural optimization methods (Kato, 2010), topology optimization was investigated further by another participant of the course. The main concepts of an optimization problem were investigated, including design variables, which can be altered in the optimization process; objective functions, which represent the goal of the optimization; and constraints, which represent design criteria to be satisfied.

Topology optimization method solves a problem of distributing a given amount of material in a design domain subject to load and support conditions, by maximizing the stiffness of the structure. It calculates stresses affecting the geometry based on specific boundary conditions and loads, and organize efficient structural arrangements. Maximum stiffness with minimum material is achieved in various organisms for different function. For instance, adding and removing material from the geometry based on tension; was investigated by ESO/Evolutionary Structural Optimization and BESO/Bi-directional Structural Optimization (Xie et al., 2005; 2011). Similarly, EiForm was developed for truss systems that uses topology optimization (Shea et al. 2005).

One participant investigated bone structure, shaped according to the pressure and tension forces of the muscles through the evolution process and naturally optimized; and applied the principles of topology optimization in a design project, a table design, with the intent of generating a structurally efficient geometry by removing materials which were structurally not necessary. In the process, CAD and parametric modeling tools, as well as optimization tool Millipede (Topostruct Script), a structural analysis and optimization component were used. The boundary conditions, including loads and support regions of the table were defined. During the process, series of iterations have been developed. Although these geometries presented enough information about the topology, iterations did not have clean geometries because of the low precision of the computation. Therefore, they were re-modeled for achieving a smoother geometry (Fig. 5).

CONCLUSIONS

Evaluating architectural design process by means of sustainability becomes inevitable in today’s production. In undergraduate architectural education, issues related to the effectiveness and performance assessment, including structural or environmental performance, are generally considered as separate courses and not integrated into the design studio in general. Students should obtain a higher awareness towards the environment in which they live and related performance issues. Natural systems can be identified through highly defined, rational and rule-based models, which can be translated into computational design models. Although the idea of redesigning the curricula with an understanding to integrate computational tools into architectural edu-
cation as an integral part is not novel, there is a necessity to develop a more comprehensive approach to adapt multi-faceted problems in the design process, by developing algorithmic thinking. The elective course titled "Sustainable Design and Environment through Biomimicry" taught by the author was conducted in Fall 2014-2015 at Ozyegin University for undergraduate students, in order to deal design problems as holistic systems, as well as to enable awareness towards performance issues and sustainable design. As the scope of this course, natural systems were examined and findings of a selected matter or phenomenon were implemented in a design solution. Based on the outputs, it is identified that students learn from natural systems in three different ways including generation of morphological and organizational relationships, translation of properties and processes in nature adapted to the design process.

The major difficulty encountered in the process was that since biomimicry is an interdisciplinary field, students had challenges to interpret the information which was not directly related to the architecture / design profession. For the future lines of the work, the intent is to teach this method not only to the architecture students, but to the multidisciplinary groups of students from different departments, such as mechanical and structural engineering, biology and computer science, so that the participants might focus in the research phase and collaborate effectively.
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