Comparing Biomimicry and Living Materials Approaches in Computational Design

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Abstract
Although biomimicry and living materials approaches are two important methodologies for integrating nature with computational design, they have not been explored, scrutinized and exploited, yet. In a view to alleviate this problem, this paper focuses on the study of comparing these approaches in the context of two case studies in 3D printing. The analysed projects were completed by important scholars in the field and represent best practices. Especially the reason for choosing these studies is that they express the difference of the methods used in sharp lines and they provide the opportunity to be compared with all the details thanks to the expertise of the institutes in which they are made by.

Keywords: Biomimicry, living materials, computational design, nature, additive manufacturing.

Introduction
Computational design can be defined as the application of algorithmic thinking and systems view in design processes. Since the early beginnings in 1970s, computational approaches have been very influential in the theory and practice of architecture and become a main driver of innovation in the field. As a complex, selfregulating and sustainable system, nature has always been a source of conceptualization and inspiration for computational design. The relation between biology and computational design can be traced back to Charles Darwin's theory of evolution (Darwin, 1964) which later led to explanations of variation (phenotype) among population with the same genetic material (genotype) due to environmental conditions (Mayr, 2001). The morphological works of D'arcy Wentworth Thompson is another inspiration for computational design. Thompson developed the "theory of transformations" which showed how the differences between the forms of related species could be represented geometrically. Both investigations have been influential in computational form-finding studies and facilitated the development of a new field called digital morphogenesis which stands for generative processes in which complex shape development, or morphogenesis, is enabled by computation (Menges & Ahlquist, 2011).

A review of studies at the intersection of biology and computational design reveals that their main approach has been based on analyzing, understanding and adapting nature's processes and designs i.e. biomimicry. In 1990s, Janine Benyus popularized the term "biomimicry" (from bios, meaning life, and mimesis, meaning to imitate) in her book "Biomimicry: Innovation Inspired by Nature" by defining nature as the best solution to solve human problems (Benyus, 1997). In 2006, Benyus co-founded the Biomimicry Institute and developed a design process model for bio-inspired design. Biomimicry is a growing area of research in architecture and still has a wide range of unrealized potentials.

On the other hand, the last years of 2010s witnessed the development of a totally new approach to the utilization of nature in design as "living materials". "Living materials" refer to materials composed of living cells that form or assemble the material itself. Such systems have the self-regulating, adaptive, and sustainable features of living organisms in addition to the engineered physicochemical or mechanical properties which enable production and maintenance at multiple scales (Nguyen et al., 2018). Living materials research attracted interest of important research organizations including the MIT Media Lab (MIT Media Lab.), the Wyss Institute at Harvard (Wyss Institute) and the Defense Advanced Research Projects Agency (DARPA) of the U.S. (DARPA, 2016).

This paper mainly focuses on the two terms: biomimicry and living materials in the field of architectural design research. The particular research questions of the study are the following:

1. What are the main arguments of biomimicry and living materials approaches?
2. What are the process steps of applying these approaches in the case studies?
3. What are the advantages and disadvantages of the two approaches experienced in the case studies?
4. What can be the implications of these case studies for further work in biology-oriented computational design?

By the lead of these questions, two different approaches in design are examined and compared. The topic of bio-computational design methods are discussed in this paper by comparing two different case studies on two different approaches. The similarities and the differences, the areas of usage and the advantages and disadvantages of these approaches constitute the contents of the paper.

Bio-Computational Design and Its Use in the Field of Architecture

Biomimicry in Architecture

Earth has an amazing system and order in between the plants, animals and even microorganisms for more than 3.8 billion years since the first bacteria. From the bottom of ocean to the sky, all living creatures established some standards and solutions in order to be able to execute their lives. For example; they managed to turn themselves into different forms to create a living space or found the ways to control body temperature according to the conditions of their habitat. Furthermore, living creatures are managing these without damaging the world by fossil fuels or pollutions in a high rate (Benyus, 1997). In time, humankind started to exploring the nature and figuring out the solutions of it. This enabled them to take steps to adapt what they learned from nature to their own lives and as a result, biomimicry, a concept based on learning from nature, emerged. Some early approaches of biomimicry also can be found in the works of people like Leonardo da Vinci and Filippo Brunelleschi who have important places in the history of world. They both combined art, science and the beautiful work pattern of nature. For example, in the sketches of Da Vinci, it is possible to see the studies which he made on birds, human skeleton and the motion of water, etc. while designing some inventions like the flying machines. To give an example of Brunelleschi's studies, the strength of eggshell was examined and used to design a thin and light dome structure which can resist forces. The mechanical strength of the eggshell comes from the parabolic shape which has a great load-bearing capacity. This is due to the tangential distribution of forces according to the parabolic curves. From the very beginning of history to the present, many scientists and artists have worked on nature as a basis to their studies, art and inventions in a biomimicry approach.

Biomimicry, as a definition of word, means imitating the nature by analyzing an organism or a system. This concept started at the beginning of 1960s by the result of studies on flora and fauna ecosystems. However, the term became popular in the late 1990s by the researcher and the author Janine Benyus. Benyus' book "Biomimicry: Innovation Inspired by Nature" is a main source for the researches on the biomimicry. In this book, Benyus defends that the most of the solutions, that we are trying to find in life, have been already solved by the nature. Benyus believes that the standards of life must be defined by the features of the natural world. Humankind must be inspired by the nature and should improve it according to needs of own. In addition, she also defends that this approach of biomimicry should be based on learning from nature, not by extracting or consuming (Benyus, 1997). Nature provides models like leaves, spider webs, cells, coral reefs and forests. As an example, leaves used as inspiration to the design of solar cells and computers signal systems are majorly based on the cells' feature of transmitting messages (Benyus, 1997). If we need to explain the concept by the words of Benyus which is "doing it nature's way", biomimicry can help us, people, to change the world. In the conditions of using the advantages of biomimicry, it is possible to expect results that will gain energy, time, cost, etc. on the areas of growing food, designing materials and generating energy.

Living Materials in Architecture

Living materials are biological building materials that includes the participation of microorganisms by the collective of biology, chemistry, architecture and engineering fields. Microorganisms, algaes and bacterias may work as a factory for developing building materials by multiplying, healing and absorbing. They mainly have abilities of self-replication, self-regulation, self-healing, self-sustainability and environmental responsiveness (MIT Media Lab.). Living material approach mainly focuses on two main issues; absorption of chemicals and toxins out of the water and air and growing the diagrammatic capacity of organisms by multiplying themselves. Most of these organisms mainly do photosynthesis and use carbon dioxide, sunlight and water. As a result of this, they have a key role on carbon absorbing and cleaning the atmosphere, so, by that, decrease the effects of climate change. Some of them has also ability to remove metals and toxical components out of the aquatic and urban habitats. They mainly focus on the potential of toxicity indication and biosensoring. As the second focus point, these microorganisms have ability to multiply themselves and by filling into the cracks, repair the fractures as a result. This ability of multiplying themselves also used in the area of tissue engineering and printing. That can be achieved by embedding several cell types into hydrogels and patterning differently according to the functional usage of them (Lode et al., 2015).

Microalgaes and bacterias have a great potential on the biotechnology field. The ability of exploiting solar energy and turning carbon into valuable metabolites such as biofuels, food and oxygen provides advantage in terms of use in many areas (Lode et al., 2015). In the field of architecture, living materials are used for assembling the material, extending the expiration and modulating or increasing the functional performance of the materials. For example, they are used as a biofiltration system to remove nutritions, heavy metals and industrial pollutants, which increases as a return of urbanization, from water and air. By the help of these organisms, environment is purified from pollution and this causes an increase in quality of life.

The Process Steps of Applying These Approaches in the Case Studies

One of the projects was conducted by Achim Menges and his colleagues (Felbrich et al., 2018) and it proposed an alternative to the usage of rapid additive manufacturing and fused filament fabrication. These popular methods are quick in both prototyping and production on small scale projects, however, for large scale projects, they are not meeting the needs and therefore it causes some limitations. For this project, shell building process of snails was examined and as a result, it was understood that this could overcome these limitations. Snails produce the periostracum which is a soft and pliable protein based organic film on the shell (e.g. Figure 1). The film works as a form-giving surface and wraps the calcium carbonate layer of the shell after it hardens. This behaviour of the snail shell structure was a biomimicry based inspiration to the researchers and continuous extrusion of free form of periostracum.

In this project, thermoplastic material was used as equivalent to the periostracum. It is a plastic polymer which is pliable and moldable by heating and gets shape by cooling. The extrusion technique was used for giving shape to the thermoplastic. For extrusion, the material was melted and pushed through a die which helped to create very complex cross sections. Thermoplastic mold was extruded by an industrial robot, reinforced by concrete and created as a double layered curved surface.

Figure 1. Snail Shell

Figure 2. Target Surface / First Strip / First Layer

Figure 3. Test Piece, 1.2 mm high/24 cm wide doubly curved composite shell

The other project was undertaken by Marcos Cruz and his colleagues by the collaboration of two different disciplines: architecture and biochemical engineering (Malik et al., 2019). This project took the “living materials” approach and a bio-printing technique was developed by using the microalgae. The microalgae was printed and immobilized into the alginate based hydrogels. Hydrogels are polymeric networks which are filled with water. They maintain chemical and physical crosslinks while they draw a large amount of water into their systems. Viscoelastic behaviour of hydrogels helps them to avoid deformation of the structure. In the project, hydrogels were formulated with methylcellulose and carrageenan, and contained water between 80% - 92.5% concentrations. The variability of water percentage changed the viscoelastic abilities of the hydrogels and this helped them to be more suitable for the pneumatic extrusion system which was combined with an industrial robotic arm as an effector.

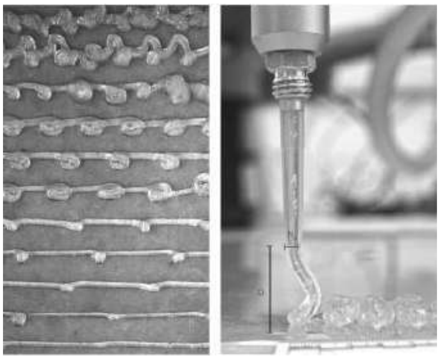

Figure 4. Distance / Nozzle Diameter

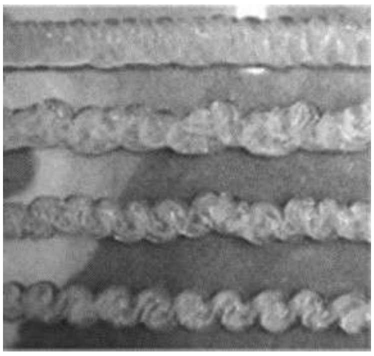

Figure 5. Flow Rate

The hydrogels got into a gelation test and the printing time delayed between the layers to achieve a satisfactory printing resolution. By that, homogenously bind of layers was aimed. In the project, 1000x500mm fibrous hydrogel panel (e.g. Figure 6) was produced to test the system and for 21 days, panel had been regularly hydrated and the cellular growth had been observed. The pattern of the design was edited to get the maximum efficiency from the design and aimed to achieve a multilayered extruded hydrogel with varying resolutions and increasing on both surface area and algae connection with its surroundings. The branched shaped design of the geometry helped the bioremediation by the flow of water over the algae-laden hydrogels' surface. That design like branches was also generated to consist of layers, which have different compositions, on one axis to connect biocompatible layers. According to the branches, the panel shape was divided into three horizontal layers and every layer had its own density and pattern which was fabricated with different hydrogel viscosities and distances between nozzle and platform. The bottom layer was the densest and had 7 layers of 5mm nozzle-platform distances. It also had the highest viscosity of hydrogels. However, besides those, the main difference of this layer was that it has no algae cells. The other layers contained immobilized algae cells of 3 and 6 layers of 5mm distances. The higher water capacity in between the three layers was in the top layer. This layer permitted optimum cellular growth and augmented photosynthetic activities. Immobilization of all three layers had been provided by $CaCl_2$ in the printing, process.

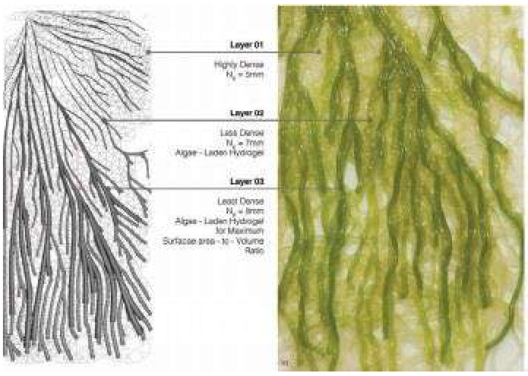

Figure 6. Robotic fabricated algae-laden hydrogel panel (1000 x 500 mm)

This latter work has gained attention as a pivotal project that can form a basis into the fields of algal bioremediation and bioenergy by the interaction between material selection, design and hydrogel production.

Discussion and Conclusion

Both biomimicry and living materials approaches on bio-computational design are still developing and used by the designers and researchers. They both have lots of subtopics under the main titles to examine and produce data to the projects that can be done after. The main advantage of the living materials approach is that the materials used in design are microorganisms and they can easily proliferate over time and get results quickly, as opposed to loss in terms of materials. On the other hand, in the mold based project, it is impossible to use the material after. For that, it may be possible to take another step towards the sustainability of the project by considering the possibilities of reusable materials in mold-based manufacturing.

In the research of "Green bioprinting", it is suggested that biofabrication will become a dominant technology in the 21th century due to the wide range of potential applications and being out of the traditions (Krujatz et al., 2015). According to that, as architects, we can discuss that in which concepts we can take advantage of the living materials, in how big project it may be possible to include the use of these organisms and how and according to what the usage areas of mold-based manufacturing and manufacturing which living organisms are integrated vary.

These two research case studies are important since they shed light on developments in integrating biology and computational design for architecture. In both studies, the evaluation of the approaches and the results of prototypes and printing revealed some beneficial features in terms of creating large scale built environment projects. This paper analysed these two studies and presented a discussion on biomimicry and living materials approaches within the framework of the research questions posed in the introduction. We conclude that architectural community needs more systematic inquiries into the methodologies used in innovative applications. The authors hope that the detailed analyses presented in this paper would facilitate further studies in this track.

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