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MODELS AND PROTOTYPES OF BIOMIMETIC DEVICES TO ARCHITECTURAL PURPOSES

Silvia Lenyra Meirelles Campos Titotto,***

* Department of Aerospace Engineering – Center of Engineering, Modelling and Applied Social Sciences – Universidade Federal do ABC – Santo Andre, Brazil.
** Department of Architecture – Institute of Exact Sciences and Technology – Universidade Paulista – Sao Paulo, Brazil.

Abstract

This paper presents some results of an ongoing interdisciplinary research about models and prototypes of biomimetic devices via installations and the focus of this paper is to outline this research role in architectural purposes as it perpasses the cultural and heritage contexts by being a way of understanding and living in the world as well as taking place in the world as devices or environments that pass on to future generations to use, learn from and be inspired by. Both the theoretical and the experimental work done so far point out that installations built with association of laser cutting and rapid prototyping techniques might be on the best feasible ways for developing and testing new technologies involved in biomimetic devices to architectural purposes that put both tectonics and nature as their central theme.

Keywords

Conceptual design, models, prototypes, functional morphology, biomimetic devices, installations

1. *Introduction: the research group*

This paper outlines part of an ongoing interdisciplinary research developed at the Department of Aerospace Engineering of the Federal University of ABC in postdoctoral level and at the Department of Architecture of Universidade Paulista by a research group named "Biomimetic structures (whose principal investigator is this paper's author) that is interested in practical-experimental implications as well as theoretical approaches, via analysis and synthesis of biomechanics of living beings and application of its principles in sustainable bioinspired design, seeking technological innovation to the built environment that aims to be passed on to future generations to use, learn from and be inspired by. The current research projects tangent the fields of art and technology as they seek to elucidate structural principles through three-dimensional production of models and prototypes via installations, discussing principles of dynamic structures, such as stability issues, types of structures, behavior under load, material properties and its influence to the structural behavior, and the interaction of installations with both the natural and built environment in their surroundings. In short, the group aims to inject new concepts and ideas in the field of bioinspired structures with dynamic behavior in order to suggest design optimizations to known structures or amplify the range of applications by proposing innovative solutions based on concepts of biomimetics, as in nature, form and function are inseparable.

1.1 *Contextualization of biomimetics for architectural purposes*

Architects have commonly used biology as a library of shapes, as it could be clearly seen for instance in Art Nouveau and Jungendstil artworks. It means that some concepts might have been apocryphal in their derivation or been the product of overenthusiasm (Coineau & Kresling, 1987), while others have been successful as structural rationale, such as the designs by Frei Otto, an architect with engineering background, that makes direct and useful reference to nature and so produces efficient lightweight tensile structures taking direct inspiration from membranes, bones and spider webs.

Doing the appropriate translation of nature mechanical functions into architectural purposes may not be easy. Nowadays many researchers from the natural sciences actually argue that quite often the technical abstraction is possible only because a biologist has pointed out an interesting or unusual phenomenon and has uncovered the general principles behind its functioning.

Despite of the fact that a number of architects, engineers and scientists have been currently developing methods for searching biological literature for functional analogies to implement, no general approach has been developed for biomimetics yet (Vincent, 2006).

A simple and direct replica of the biological prototype is rarely successful but it is rather possible with the current state-of-art although some form or procedure of interpretation or translation from biology to technology is required. In the point of view of this paper's author, models and prototypes via installations are possibly the best avenues available for this kind of experimentation so far.

1.2 Installations made by architects

Over the last few decades a rich and increasingly diverse practice has emerged in the cultural world that invites the touch, the occupancy and the experimentation of the work wherever it is placed in the natural or in the built environment.

As Bonnemaison and Eisenbach (2009) points out, these temporary artworks that have become known as installations were firstly influenced by early site-specific sculptures, happenings and conceptual art. In the 1950s artists such as Allan Kaprow described their room-size multimedia works as environments but when this type of work became a major movement in the 1990s there was a shift in terminology to the word installation (Kwon, 2004).

Installations are site-specific three-dimensional works that offer a lot to the experimental field of architecture, in spite of their differences to its conventional design. Therefore, it means that even if their demise is planned from the outset; their ephemerality encourage freedom to experiment, their functions turn away from utility in favor of criticism and reflection and they foreground the content.

For architects, installations are a way to explore architectural ideas without the limitations imposed by clients as well as they present an opportunity to explore ideas that can later be incorporated into built work (Bonnemaison & Eisenbach, 2009). As the critic and architect Mark Robbins puts succinctly, "*in some way, an installation is a distillation of the experiences of architecture*"[1].

This seems to be what also outcomes from some of the creative kinetic physical models via the use of sensors that were designed, built and experimented by this paper's author (Fig. 1).

Accordingly to what was stated by the historian Julie Reiss (1999), *"there is always reciprocal relationship of some kind between the viewer and the work, the work and the space, and the space and the viewer*"[2], in a way that corroborates to the idea that the most important aspect of installations is the viewers' presence as in integral part of the installation. Installations are, along with paper projects and competitions, possible paths to comment on and critique the status quo, and to imagine new forms, methods, and ideas in architecture.

So one might ask: why a research of that kind collaborated at a department of aerospace engineering? Because when it is totally free from the pressure of the real world functions to which the conventional architecture has to curve itself, the space concepts are experimented well beyond what is feasible now and today. As a result, cutting edge research is brought out not only considering mainly the methods and procedures of space design itself but also it allows broader contexts where architecture devices maybe be tested for expressive futuristic innovations.

1.3 Contextualization of biomimetics for architectural purposes

According to Harkness (2001), the field of study that would be later labeled as biomimetics was first approached in 1957 by Otto Schmitt who was a polymath, whose doctoral research was an attempt to produce a physical device that explicitly mimicked the electrical action of a nerve (Schmitt, 1969) but the word "Biomimetics" had its first public appearance in Webster's Dictionary in 1974, with the definition that it is "*The study of the formation, structure, or function of biologically produced substances and materials (as enzymes or silk) and biological mechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones.*"

[1] Mark Robbins, in interview with Sarah Bonnemaison and Ronit Eisenbach on May 5th, 2007.

[2] Julie H. Reiss. From Margin to Center: The Spaces of Installation Art (Cambridge, MA: MIT Press, 1999: xiii).

Overall biomimetics is a subject area that is fairly well interconnected and it may be considered as a single discipline but within this connectivity, biomimetics does involve distinct subfields. So, nowadays, multi-collateral uses have been piling over that initial concept.

1.4 Context definition for the concept of bioinspired models and prototypes

There are recent indirect evidences that new interesting for technological innovations for architectural purposes can be opened through the study of the structural and functional morphology as well as aerodynamics of organic membranes supported by branched structures – such as the insect wings and plant leaves, which are both subject to large displacements and deformations.

Such organic structures have structural synthesis, lightness, toughness, flexibility, adaptability and portability, which are highly desirable characteristics for architectural applications that present limitations of space and mass, in addition to being subject to severe weather conditions.

Concepts such as these, coming from biomimetics, can be applied to aerospace structures (Brasil *et al.*, 2014), as well as architectural applications specially those that are subjected to other kinds of random dynamic excitations and hostile environments such as autonomous underwater vehicles, which can be seen in this work as potential avant-garde architectural applications (Titotto, 2013; 2014a; 2014b).

2. Design principles for the bioinspired living machines

The term architects use to describe their interest in construction details is tectonics. The word architect itself is derived from this term, which suggests that tectonics is at the very core of the profession (Bonnemaison and Eisenbach, 2009). Tectonics has maintained a central place in the discipline as architects innovate with new materials and assemblies. This type of exploration is usually investigated with a full-scale "mock-up, which has a long tradition in architectural offices and can be tested for strength and performance or evaluated for appearance and architectural installations that take tectonics as their subject build on this tradition (Bonnemaison and Eisenbach, 2009). Although every architectural installation necessarily involves tectonics, the models and prototypes under development by the mentioned research group push the boundaries of materials and assemblies. The following sections will further state main design principles that the author finds relevant for the design and fabrication of bioinspired devices understood as new living machines in coexistence with natural species around them.

2.1 Context definition for the concept of bioinspired structures

There is a current scientific-technological trend that understands the future environment as the product of the co-existence of natural organisms and living machines based on the biomimicry design concepts.

It is well known that design and engineering are rendered much easier with use of biomimetics theory, because every time a new technical system is designed, it may be possible to start fresh, trying and testing various biological systems as potential prototypes and striving to make some adapted engineered version of the biomimetic device which is being created (Vincent, 2006).

The nature and organization of biology and engineering are very different: organisms develop through a process of evolution and natural selection; biology is largely descriptive and creates classifications, whereas engineering is a result of decision-making; it is prescriptive and generates rules and regularities (Vincent, 2006). Types of classification can be hierarchical (e.g. phylogenetic), parametric (e.g. cladistic, or like the Periodic Table) or combinatorial (Vincent, 2006). However, the driver for change in biology and engineering may well be the same: the resolution of technical conflict (Vincent, 2006).

Furthermore, one of the basic features of living systems is the appearance of autonomy or independence of action, with a degree of unexpectedness directly related to the complexity of the living system. This gives living systems great adaptability and versatility, but at the expense of the predictability of the system's behavior by an external observer. In general, unpredictability in technical systems is not accepted; indeed, it is very much avoided (Vincent, 2006). But it is needed to be considered even in the current technology, since nearly every technical system is actually a combination of a technical system in the narrow sense, and a living (usually human) system which is the operator of this technical system (Vincent, 2006). This immediately suggests a broader and more general definition of the term technical system—a biological system, part of the functions of which is delegated to a device that is mostly artificial and/or non-living (Vincent, 2006).

The results are not always welcome, mainly when another route of biomimetics is taken, because the more closely an artificial system is modeled on a living prototype, which is typically complex and hierarchical, the more frequently there are emergent effects, which are unpredictable, therefore mostly unexpected and often harmful (Vincent, 2006). This might ultimately lead to biomimetic devices that might not work in the way that humans take advantage of its functions and services neither collaborate to the implementation of a society that does not argue over nature and manlike creations.

2.2 Architecture and its possible responsible attitude towards nature

The installations developed within this work group focus on the mechanical properties of nature in architecture and in doing so, they remind that architecture can help shape a more responsible attitude towards nature. In different ways, these models and prototypes argue for an ecology that recasts the relationship between the built and natural world as one of symbiosis and interdependency. Faced with an engineering problem, the human tendency is to achieve a solution by changing the amount or type of the material or changing the energy requirement and that in general means to increase it. However, in biology the most important variables for the solution of problems at these scales are information and space.

This comparison between the few materials of biology and the many materials of technology has become popular as an interdisciplinary field. It appears that biological systems have developed relatively few synthetic processes at low size at which the contribution of energy is significant; but the main variety of function is achieved by manipulations of shape and combinations of materials at larger sizes achieved by high levels of hierarchy, where energy is not an issue (Vincent, 2006).

This is a very subtle biomimetic lesson. Instead of developing new materials each time for new functionality, already existing materials should be adapted and combined (Vincent, 2006).

2.3 Biomimetic materials for the living machines

Nature has been a constant source of inspiration to architects from crystalline geometries in the Renaissance to the curved forms of Art Nouveau in the end of the nineteenth century. While one can still trace the search for form into the organic world today there is a much stronger and deeper awareness and a desire to show the beauty of interdependency between artifice and nature (Bonnemaison and Eisenbach, 2009). So it is genuine that researches focused on biomaterials take the stage.

Indeed many biological tissues and devices boast remarkable engineering properties. The toughness of spider silk, the strength and lightweight of bamboos or the adhesion abilities of the gecko’s feet are a few of the many examples of high performance natural materials (Barthelat, 2007).

In recent years, more and more of these materials have been systematically studied with the objective of duplicating their properties in artificial man-made materials (Barthelat, 2007).

The total replication of these natural materials for engineering purposes would not make much sense for several reasons (Barthelat, 2007).

First, not every single microstructural feature observed in these materials serves a structural purpose (Barthelat, 2007). It is therefore critical to identify the exact microstructural features and mechanisms that control the overall performance of the material (Barthelat, 2007). This is even more relevant in the context of technical limitations in fabrication—natural features which would be very hard to duplicate in artificial material may not actually be needed from a mechanistic point of view (Barthelat, 2007).

Second, the rules for material selection are different in engineering and nature. There are severe restrictions on material selection in nature (limited availability, biocompatibility, etc.) that do not necessarily apply in engineering (Barthelat, 2007).

Engineers have more freedom in the choice of materials. Again, a good understanding of the mechanics of the natural materials is critical there, because in order to swap materials in the design of composites one must understand and predict the overall effect on the performance (Barthelat, 2007).

Fig. 1: Titotto, Silvia (2012). Tarantula experiment: using laser cutting, 3D priting and Arduino programming.

2.4 Principles for biomimicry design

Understanding the structure–function relationships (Tab. 1) is key in developing products that are, for instance, adaptive, thermoresistant, superhydrophobic, or self-healing, examples of which are plentiful in nature (Eadie & Ghosh, 2011).

From the engineering point of view, a material that self-heals and adapts its microstructure to load would revolutionize the way engineers design mechanical components. The traditional failure and reliability criteria and the design approach would have to be revised.

How to design a mechanical component when the material it is made up of adapts to stresses and self-repair? These 'next-generation' materials will only be made possible by close collaborations between structural and mechanical engineers, materials scientists, chemists and biologists (Barthelat, 2007).

The obvious need for sustainability requires not just mimicking natural design but also the process (Eadie & Ghosh, 2011).

Tab. 1: The sum up of the principles

Minimization of heat and energy dissipation
Minimization of wear
Reduction or complete elimination of environmental hazards via toxic artificial lubrication
Sustainable chemistry and green engineering principles
Biomimetic approaches to shapes and materials
Surface texturing
Environmental implications of coatings
Design for degradation;
Real-time monitoring
Sustainable energy applications

There is a huge potential to obtain new or unusual combinations of material functions/properties by structuring a given material and other assemblies can readily provide an ideal test-bed for this concept (Eadie & Ghosh, 2011).

2.5 Biomimetic processes and fabrication

Alongside Thibault's formal expression and Lund's performance art, another strain of work inspired by land art looks at the environment as an ecosystems, and artists such as Hans Haacke, Alan Sonfist and Joseph Beuys take on the environmental issues by contesting the idea that artists can only depict nature, while, in the same vein, the work of Philip Beesley uses a redemptive strategy to demonstrate how humans' relationship to nature is not only based on perception but also on empathy (Bonnemaison and Eisenbach, 2009).

Biomimicry, in its strictest interpretation, is the process of emulating nature's ways of finding a solution including 'designing' and 'making' with the least environmental impact (Eadie & Ghosh, 2011) but it is much more than that, specially when culturally speaking.

In fact, biological systems should be seen more as concept generators in terms of transfer of principles and mechanisms rather than something to copy, literally (Eadie & Ghosh, 2011). Modern technologies have made it possible to design and manufacture products/ systems that are based on nature (Eadie & Ghosh, 2011).

Modeling also plays a significant part, and in this area, the emerging multiscale models are the most promising due to their ability to capture and integrate mechanisms over several length-scales (Barthelat, 2007). The duplication of key features in artificial materials remains a challenge (Barthelat, 2007).

While innovative fabrication approaches have recently been proposed, no techniques can currently generate small-scale features and integrate them into larger structure with a sufficient degree of control (Barthelat, 2007).

Compared with traditional fabrication techniques self-assembly uses very little energy and, therefore, offers a sustainable approach to fabricating materials (Barthelat, 2007).

However, the process or the technology to do so has not always been purely eco-friendly (Eadie & Ghosh, 2011). It is primarily because nature's implementation of a concept into a system is far different than that developed by humans (Eadie & Ghosh, 2011). In nature, growth is the primary means of 'manufacture' rather than fabrication. If biomimicry is to be used as a new principle in designing housing, sustainability must be part of it (Eadie & Ghosh, 2011). Biomimetics can help rethink the human approach to materials development and processing and help reduce ecological footprint (Tab. 2).

The large array of materials available often lead to blending or mixing to develop a new product or improve an existing one (Eadie & Ghosh, 2011). This makes it immensely difficult, at times, to eventually recycle the product. Use of limited variety of materials in nature makes it easier to recycle (Eadie & Ghosh, 2011). With only two polymers (proteins and polysaccharides) in use, it is much easier for nature to separate and recycle (Eadie & Ghosh, 2011). Natural systems are inherently energy-efficient and adaptable (Eadie & Ghosh, 2011). In order to be sustainable, biomimicry products must emulate this feature as well.

Tab. 2: The whole implementation of the concept above includes expertise on five subfields

Structural bioengineering (the geometry and structural properties of biological materials);
Biomaterials science (the assembly and fabrication of biological materials);
Biomimetic actuators (artificial muscle and its underlying technologies in material science);
Ethology-based robotics (constructing robot hardware based on animals)
Robotics (controlled and autonomous operations based on biology via pattern recognition, neural networks, etc)

3. *Biomimicry for architectural design*

Biomimicry is the design principle behind the mobile, sensitive and reactive elements of the new era of architecture that aims to overwhelm all senses.

As building are increasingly equipped with sensors, actuators and other technologies that make up the "smart homes" – where they automatically respond to changes in ambient temperature Eco–sustainable research & development via conceiving, designing, planning, making and testing some creative kinetic physical models via the use of sensors and flexible materials for deployable structures has been done by the author. It is about technological innovation via biomimetic structures based on case studies of mechanisms present in cephalopods (Pignatelli *et al.*, 2011; Ligon & McGraw, 2013), porifers and ctenophores.

The models and prototypes design aims to be symbiotic: a mutually beneficial relationship in which different organisms would be make good use out of this association. The benthos would benefit from technological innovation initiatives that aim to recover the damage caused by destructive technologies while pre-existing natural biological ecosystems would coexist with living machines in order to promote development initiatives of low ecological footprint.

Their kinetics might occur via dielectric elastomers actuators and their bodies might have lightweight structures based on membranes supported by branching structures.

Tab. 3: Four trends to be promoted for the successful achievement of the bioinspired housing, according to the author

Development of branching structures to be used in smart furniture
Study of jellyfish locomotion for development of experimental autonomous underwater vehicle
Dynamic color and texture change on walls via study of chromatophores of cephalopod skin (octopus, squid and cuttlefish) and possible development of a "smart wall"
Active control of the flow of air in buildings via study of encrusting porifers and planktonic comb jellies

4. *Final considerations*

Biomimetics operates across the border between living and non-living systems. The benefits to be gained from biomimetics are not yet totally obvious, other than to deepen the human race's box of technical tricks ((Tab. 3). However if biological functions and processes are less reliant on energy, as many studies suggest, then the implications of its mimicry could be very significant to the living machines in the co-existence of natural and built environments.

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