Deployable structures: natural organisms and living machines

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Abstract

This paper aims to discuss ways to build dwellings or devices that are able to adapt to the different challenges posed by the dynamics of nature, ensuring safety and comfort of residents and requiring minimal intervention in the environment around them. The success of this endeavor depends on new concepts and paradigms of construction related to biomimcry. It is intended to develop and to apply knowledge of the bioinspired deployable structures whose integration with the environment would be such that to react to stimuli. Ideally the house will not be passive compared to what some may, like living beings, perform functions in sync with the environment in order to restore the balance constantly disturbed. Weather will be the input of this new concept for housing; the rain to cease on alert for possible flooding and water harvesting will rule the sun's energy will not be wasted since solar panels capable of maximizing the light gathering with coordinated movements will be installed on your roof, the wind will induce the movement of walls and windows in order to maintain thermal comfort under any weather conditions and even materials able to withstand and fight fires will be employed to ensure the safety of its occupants. The potential of implementation of those improvements is also discussed, for instance, how much robotics is necessary to actually conceive an intelligent dwelling and also why the proposed design concepts are not limited to an specific environment once the concept of biomimetics to living machines can be applied over any situation that needs or is under the mentioned behavior, from aquatic mediums to the space vacuum.

Keywords: conceptual design, deployable structures, functional morphology, structural morphology, form finding, membrane structures, smart behavior, sustainability.

Resumo

O presente trabalho busca discutir maneiras de construir habitações ou abrigos que sejam capazes de se adaptarem aos diferentes desafios impostos pela dinâmica da natureza, garantindo a segurança e o conforto dos moradores e impondo a mínima intervenção no ambiente à sua volta. O êxito nesta empreitada depende de novos conceitos e paradigmas de construção relacionados à biomimética. Pretende-se desenvolver e aplicar conhecimentos relativos à estruturas deployable bioinspiradas cuja integração com o ambiente seja tal que a permita reagir a estímulos. Idealmente a casa não estaria passiva ante ao que a cerca, podendo, assim como os seres vivos, desempenhar funções em sincronia com o ambiente, de modo a reestabelecer o equilíbrio constantemente perturbado. Intempéries seriam o input deste novo conceito em moradia; a chuva a deixaria em alerta para possíveis enchentes, sendo a captação de água uma regra, a energia do sol não seria desperdiçada já que painéis solares capazes de maximizar a captação da luz com movimentos coordenados estariam instalados sobre sua cobertura membranal, o vento induziria o movimento de paredes e aberturas de modo que se mantivesse o conforto térmico sob qualquer condição climática e até materiais capazes de suportar e combater incêndios seriam empregados para garantir a segurança de seus ocupantes. O potencial de implementação dessas melhorias também é discutido, por exemplo, o quanto a robótica é necessária para realmente torná-la uma habitação inteligente e também porque os conceitos de design propostos não se limitam a um ambiente específico, uma vez que o conceito de biomimética para máquinas vivas pode ser aplicado sobre qualquer situação que tenha ou esteja sob o comportamento mencionado, tanto em meios aquáticos quanto no vácuo espacial.

Palavras-chave: design conceitual, estruturas deployable, morfologia funcional, morfologia estrutural, busca da forma, estruturas de cabo e membrana, comportamento inteligente.

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1. Introduction

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 [4], while others have been succesful 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 spiderwebs.

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 [1]. A simple and direct replica of the biological prototype is rarely successful, even if it is possible with current technology because some form or procedure of interpretation or translation from biology to technology is required. Nowadays many researchers from the natural sciences 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, although many architects and engineers use biology as an inspiration.

According to Harkness, [2] 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 [3] 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 biologicalmechanisms and processes (as protein synthesis or photosynthesis) especially for the purpose of synthesizing similar products by artificial mechanisms which mimic natural ones.*"

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, multicolateral uses have been piling over that initial concept.

1.1 Context definition for the concept of bioinspired deployable structures

There are recent indirect evidences that new interesting for technological innovations for deployable devices, i.e., those that can be retractable, portable, collapsible, pantographic, expandable or tensegrities, 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 of deployable class, for instance, tethered satellites, space antennas and solar panels [34], as well as others architectural applications, specially those that are subjected to other kinds of random dynamic excitations and hostile environments auch as autonomous underwater vehicles.

2. Design principles for the new bioinspired deployable living machine housing

The following sections will further state main design principles that the authors find relevant for the design and fabrication of bioinspired deployable housing understood as new living machines in coexistance with natural species around them.

2.1. Natural organisms *versus* living machines

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 [1].

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The results are nor always welcome, mainly when another route of biomimetics is taken, because the more closely an artificial system is modelled on a living prototype, which is tipically complex and hierarchical, the more frequently there are emergent effects, which are unpredictable, therefore mostly unexpected and often harmful [1].

This may ultimately lead to biomimetic devices that may not work in the way that humans may take advantage of its functions and services neither collaborate to the implementation of a society that does not argues over nature and manlike creations.

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 [1]. Types of classification can be hierarchical (e.g. phylogenetic), parametric (e.g. cladistic, or like the Periodic Table) or combinatorial [1]. However, the driver for change in biology and engineering may well be the same: the resolution of technical conflict [1].

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 behaviour by an external observer. In general, unpredictability in technical systems is not accepted; indeed, it is very much avoided [1]. 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 [1].

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 [1].

2.2 Biomimetic materials for the living machines

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, that in general means to increase it. But 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 [1].

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 [1].

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 highperformance natural materials [11].

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 [11].

The total replication of these natural materials for engineering purposes would not make much sense for several reasons [11].

First, not every single microstructural feature observed in these materials serves a structural purpose [11]. It is therefore critical to identify the exact microstructural features and mechanisms which control the overall performance of the material [11]. 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 [11].

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 [11].

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 [11].

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2.3 Principles for biomimicry design

Understanding the structure–function relationships is key in developing textile products that are, for instance, adaptive, thermoresistant, superhydrophobic, or self-healing, examples of which are plentiful in nature [8].

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 [11].

The obvious need for sustainability requires not just mimicking natural design but also the process [8].

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 [8].

The sum up of the principles are such as follows:

- 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; and
- Sustainable energy applications.

2.4 Biomimetic processes and fabrication

Modelling 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 [11]. The duplication of key features in artificial materials remains a challenge [11].

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 [11].

Compared with traditional fabrication techniques self-assembly uses very little energy and, therefore, offers a sustainable approach to fabricating materials [11].

2.5 Sustainability aspects

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 [8].

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 [8]. Modern technologies have made it possible to design and manufacture products/ systems that are based on nature [8]. However, the process or the technology to do so has not always been purely eco-friendly [8]. It is primarily because nature's implementation of a concept into a system is far different than that developed by humans [8]. 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 [8]. Biomimetics can help rethink the human approach to materials development and processing and help reduce ecological footprint.

The large array of materials available often lead to blending or mixing to develop a new product or improve an existing one [8]. 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 [8]. With only two polymers (proteins and

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polysaccharides) in use, it is much easier for nature to separate and recycle [8]. Natural systems are inherently energy-efficient and adaptable [8]. To be sustainable, biomimicry products must emulate this feature as well.

3. Housing Project

Technological innovation via biomimetic structures based on case studies of mechanisms present in cephalopods, porifers and ctenophores. I have been independently carrying out 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.

The housing 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. 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) and robotics (controlled and autonomous operations based on biology via pattern recognition, neural networks, etc).

For the successful achievement of the bioinspired housing, four trends must be promoted, according to the authors:

• 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" [17], [18];

• active control of the flow of air in buildings via study of encrusting porifers and planktonic comb jellies; and

• development of branching structures to be used in smart furniture.

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. 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 natural and built environment co-existence.

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