1

A Cultural Perspective on Biomimetics

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1. Introduction

Gecko's feet, lotus leaves, blue butterfly wings, spider's silk, fireflies, mother-of-pearl…. All these wonders of nature, which traditionally filled the pages of natural history magazines have attracted the attention of materials scientists over the past decades. They have often been presented as models to design and engineer optimal structures. And this renewed interest in natural systems has undoubtedly brought about innovating strategies in chemistry, materials science and nanotechnology.

But what exactly does mimicking nature mean? Can we really transfer nature's "technology" to human projects? Does talking about "nature's technology" even make sense?

The view of technology copying nature is as fascinating as it is deceiving. We all know that in aeronautics, repeated attempts to mimic birds' flight have led to spectacular failures. Hence the basic principles of modern technology are anything but inspired by nature: The mechanical machines, metallic alloys, combustion engines, jet engines, direct synthesis of ammonia, etc… have no equivalent in nature. They proceed from the fundamental laws of physics, thermodynamics, and aerodynamics rather than from imitating nature. At the other end of the spectrum, we all know a few examples of successful inventions, such as the Velcro, which was inspired from cockleburs clinging to socks or dog's fur after a hike in the hills. Yet failures to imitate nature by far outnumber the rare successful biomimetic inventions. (Vogel, 1998) Does this mean that biomimicry strategies are generally doomed to fail?

This chapter will consider the current biomimetic trends from a broad historical perspective. Its aims are to pin-point what prompted the renewed interest in biological structures and processes in the field of high-tech materials, and to clarify what kind of relations exist between nature and artefacts in emerging technologies. Finally, it will make the case for a paradoxical use of mimicry strategies.

2. Challenging nature

First of all, it is important to keep in mind that chemistry is the subject of a number of strong and deeply rooted stereotypes in our culture. The image spread by Goethe's Faust and Shelley's Frankenstein of the alchemist mixing mysterious liquors in a dark laboratory, trying to rival Nature , has prompted the association of chemistry with the mythical figure Hubris, or even Man's original sin of pride. Chemistry thus ends up irresistibly connoting the idea of boundary transgression.

This stereotype is reminiscent of the philosophical disputes raised by medieval alchemists' attempts to make gold. They were blamed for counterfeit, because according to the prevailing scholastic culture, there was literally an essential difference between natural gold and alchemist's gold. The latter could only be an imitation of the real thing. Artificial gold may have looked like its natural counterpart, but it had to be deprived of the 'substantial form' inherent to natural gold. (Emerton,1994) This argument was based on Aristotle's view of technology (*technê*) as imitation of nature (*physis*). The view that artefacts were necessarily deprived of inner movement or 'substantial form' was propagated in medieval times by the scholastic tradition, and constituted an obstacle to technological advances . Alchemical and mechanical arts were blamed for being 'against nature'. (Newmann, 1989)

The resilience of the cultural stereotype seeing chemistry as being against nature, is the symptom of the values attached to the cultural boundary between nature and artefact, as well as between inanimate and animate matter. Throughout history, the culture of chemistry has been associated with the promotion of artificial over natural. Significantly, early attempts to produce in the laboratory natural products normally made inside living organisms - such as urea -, were used for metaphysical purposes to fight against vitalism rather than for technological purposes. The claim that Wölher's synthesis of urea in 1828 destroyed the metaphysical belief in the vital force is a legend forged by nineteenth-century chemists wanting to demonstrate that life was merely a set of physico-chemical phenomena. (Brooke, 1968, Ramberg, 2000) The urea mythology is still alive today in chemists' communities.

Indeed, such metaphysical challenge was an integral part of Marcellin Berthelot's defence of chemical synthesis. He planned to synthesize all the compounds made by living organisms, using only elements and the range of molecular forces. (Berthelot, 1860) Starting with the four basic elements—carbon, hydrogen, oxygen, and nitrogen—and proceeding systematically from the most simple to the most complex compounds, he boasted that chemists would synthesize the most complex compounds and dissipate the mystery of life.

Such attitude made it easy for physiologists such as Claude Bernard, to retort to arrogant chemists that synthesizing a product from its elementary principles did not mean getting the properties of living beings. (Bernard, 1865) Bernard also emphasized that the synthetic agents used by chemists in their laboratories were very different from those created by organisms. (Bernard 1866) In brief, chemists could imitate nature's structures but they could not emulate its processes and properties.

Should we consider the revival of biomimetism at the turn of the twenty-first century a new challenge to Bernard's defence against ambitious chemists? Are we now in a position to emulate natural processes and properties, and consequently to blur the boundaries between natural and artificial?

3. Looking for technological solutions in nature

The recent biomimetic trend in materials design seems to proceed from quite different and more pragmatic motivations. In the context of the fierce competition in space and military technologies that marked the Cold War period, conventional materials such as wood, metal, paper, ceramic, and polymers were deemed no longer relevant to making missiles and rockets. Hence chemists and materials scientists were encouraged to design high-performance materials with unprecedented combinations of properties for example materials as light as plastic, with the toughness of steel and the stiffness or heat-resistance of

ceramics. This goal was achieved through the development of a new approach, known as "materials by design". (Bensaude-Vincent, 1997) For instance, starting from the functions of a particular airplane's wing, the best structure combining the set of properties required to perform those functions could be designed. The corresponding list of requirements thus translated into a list of performances, then a list of properties and finally into a structure. Thus function became the priority in the design process, while material became the outcome.

The design of materials-by-design relies heavily on the technology of composites. In contrast to conventional materials with standard specifications and universal applications, composites created for aerospace and military applications were developed with the functional demands, and the services expected from the manufactured products in mind. Such high-tech composite materials, designed for a specific task, in a specific environment, are so unique that their status becomes more like that of biological structures than standard commodities.

Therefore modest creatures such as insects, molluscs, butterflies, spiders or even protists became the subject of intense interest for materials chemists who had to design high-performance composite structures for space or military programs. Paradoxically, such materials-by-design came to replace materials extracted from the natural world, even as chemists and materials scientists came to realize that high-performance, multi-functional materials already existed in nature. As Stephen Mann -a natural scientist who entered the field of materials science- wrote: "We can be encouraged by the knowledge that a set of solutions have been worked out in the biological domain". (Mann et al., 1989, p. 35)

Amazing combinations of properties and adaptive structures can be found in the merest of creatures. Sea-urchin or abalone shells, for example, are wonderful bio-mineral structures made out of a common raw material, calcium carbonate: They present complex morphologies and assume a variety of functions. Spider webs are made of a an extremely thin and robust fiber, which offers unrivaled strength-to-weight ratio. Marine biologists were invited to apply the structure and performance concepts and methods of materials science to studying mollusc shells. Biomineralization thus emerged as a new research field which could "teach many lessons" to materials scientists. (Lowenstam H.A. and Weiner S., 1989; Mann, Werbb,Williams, 1989).

Plant biologists also started applying a materials perspective to their traditional objects of investigation. Not only are any plants currently being re-evaluated as potential sources of environmentally safe raw materials (biodegradable polymers or biofuels), but wood, the oldest and most common construction material, is now being described as 'a composite material with long, orientated fibers immersed in a light ligneous matrix, presenting a complex structure with different levels of organization at different scales'.

The complex hierarchy of structures in biomaterials is what biomimetic chemists most envy nature. Each different size scale, from the angström to the nanometer and micron, presents with different structural features. The remarkable properties of bio-materials, such as bone or tendon are the result of such complex arrangement at different levels, where each level controls the next one. (National Advisory Board, 1994) In other words, here is a level of complexity far beyond any of the complex composite structures that materials scientists have been able to design.

Another feature of biomaterials that scientists try to achieve in their own man-made materials is their adaptability to the environment. Designing responsive, self-healing structures was one the major objectives of materials research in the 1990s. To this end,

programs on smart or intelligent materials were launched. On a basic level, intelligent materials are structures whose properties can vary according to changes in their environment or in the operating conditions. For example, materials whose chemical composition varies according to their surroundings are used in medicine to make prostheses. Some materials, whose structure varies according to the degree of damage caused by corrosion or radiations, are able to repair themselves. At the heart of the problem is the creation of in-built intelligence. It requires to have at least some embedded sensors (for strain, temperature, or light) and actuators, so that the structure becomes responsive to external stimuli.

Yet, materials chemists have been impressed by more than the elegance and the performances of biomaterials. Over the past decades, their attention has turned not only to composite and multifunctional structures but to nature's building processes themselves. Self-assembly, (i.e. the spontaneous arrangement of small building blocks in ordered patterns) is ubiquitous in living systems. In nature, the mortar and the bricks of biominerals are made simultaneously and self-assemble through the use of templates while the process is tightly controlled at each level. Self-assembly is the ultimate dream for materials designers. Such processes are crucial for designing at the nanoscale, where human hands and conventional tools are helpless. In addition self-assembly is extremely advantageous from a technological point of view, because it is a spontaneous and reversible process with little or no waste and a wide domain of applications. (Whitesides & Boncheva, 2002, Zhang 2003 , *MRS Bulletin*, 31 January 2006) Thus self-assembly appears as the holy grail of twenty-first century materials science:

> "Our world is populated with machines, non living entities assembled by human beings from components that humankind has made…. In the 21st century, scientists will introduce a manufacturing strategy based on machines and materials that virtually make themselves; what is called self-assembly is easiest to define by what it is not."(Whitesides, 1995)

How can we make machines and materials build themselves without active human intervention? To reach this fascinating goal, two contrasting strategies are being developed: The former which can be labelled 'soft chemistry' brings about deep changes in chemical culture; the latter which can be labelled 'hybrid technology' tends towards the substitution of biotechnology for chemical technology.

4. Two alternative strategies

On the chemical side, many processes are being explored with the aim to make variants of nature's highly directional self-assembly. The challenge for chemists is to achieve the self-assembly of their components and control the resulting morphogenesis, without relying on instructions from the genetic code. To meet this challenge, chemists have mobilized all the resources available from physics and chemistry: Chemical transformations in spatially restricted reaction fields, external solicitations such as gravitational, electric or magnetic fields, mechanical stress, gradients and flux of reagents during synthesis. They take advantage of all sorts of interactions between atoms and molecules. Instead of using covalent bonds traditionally used in organic chemistry, they rely on weak interactions such as hydrogen bonds, Van der Waals and electrostatic interactions. Chemists also use templates surfactants mesophases to build such as mesoporous silica, or conduct synthesis in compartments. They

make self-assembled monolayers using microfluidics and surfactants, which in turn enables the move from atomic and molecular level structures to macroscopic properties.

To imitate nature's processes of self-assembly, chemists have developed a new "chemical culture" for which Jacques Livage coined the phrase "chimie douce" (soft chemistry) in 1977. Whereas conventional synthetic chemistry usually takes place in extreme conditions which are costly in terms of energy, uses large quantities of organic solvents and produces undesirable waste products, biomimetic chemistry relies on chemical reactions taking place at room temperature in rather 'messy', aqueous environments. Such approach using quasi-physiological conditions, generating only the renewable, and biodegradable by-products associated with nature's synthetic processes, is used to make new materials at the low cost. The development of soft chemistry has led to the use of increasingly complex raw reagents, including macromolecules, aggregates and colloids. The 'Supramolecular chemistry', promoted by Jean-Marie Lehn in 1978, makes extensive use of hydrogen bonds in an attempt to reproduce the receptor-substrate interaction specificity, itself a hallmark of biology. Thanks to these forms of molecular recognition and assembly mechanisms, building blocks can self-assemble to form supra-molecular structures, and even generate macroscopic materials.

As self-assembly relies on spontaneous reactions between building blocks, it presupposes that the instructions for assembly are either an integral part of the material components themselves, or that they are the product of their interactions. Although inanimate matter is deprived of a genetic program, it is not viewed as a passive receptacle upon which information is imprinted from the outside. Molecules have an inherent activity, an intrinsic *dunamis* allowing the construction of a variety of geometrical shapes (helix, spiral, etc). This dynamic is not an obscure and mysterious vital force; nor is it an algorithm or a set of instructions embedded in a machine. It is instead a blind process of creation using combinations and selection without an external designer. Although chemists often use the paradoxical phrase 'we self-assemble molecules', the process takes place without human involvement. The subject "we" just initiates the process of self-assembly by securing the necessary agencies and appropriate conditions.

By contrast, in hybrid biotechnology strategies, natural structures and processes are truly 'engineered', or at least 're-engineered'. Such strategies are often seen to be more promising than biomimetic attempts. It can seem more reasonable to make use of the exquisite structures and devices selected by biological evolutionary processes in order to achieve our own goals, rather than to try and imitate them. In particular, it is rather tempting to use biological devices of molecular recognition to move along the path prescribed by the so-called Moore's law, to build smaller and smaller electronic circuits that assemble without human manipulation. In 2003 Erez Braun, a biophysicist from Technion at Haïfa announced that he used the complementarity of DNA strands to make nanotransistors. Now the use of DNA strands is routine practice in the laboratory, and is awaiting applications on an industrial scale.

5. Technomimetism

Synthetic biology develops a radical program to rewrite the genetic code formerly deciphered by molecular biology and genomics over the past decades. It aims to synthesise artificial organisms beyond what nature has created. In addition to the synthesis of new functional sequences, synthetic biology includes the design of gene circuits analogous to

electrical components and circuits, with oscillators, switches, etc…. Another goal is to make up a minimal genome – deprived of all superfluous functions but able to support a self-replicating organism. Such minimal genomes could be used as 'chassis' on which desired functions could be grafted in the same way synthetic chemists used to graft functions on a benzene ring.

Hybridizing and synthetic biology strategies rest on the view that living systems are collections of devices that can be abstracted from their environment decoupled from other functions and put at work in artificial machines. They are treated like parts in a clock. The designer of artificial machines borrows the specific material or devices "invented" by biological evolution regardless of their specific environment. The fact is that traditional technologies have been doing just that for centuries. They extracted resources such as wood, bone, or skin and processed them to make a variety of artefacts. Similarly, nanotechnology and synthetic biology extract a number of small units, which are as close as possible to the building blocks of living systems (DNA, bacteria,..), in order to build artefacts from the bottom-up. Bio-molecular systems are broken down into elementary units, redefined as functionalities, and abstracted from their own environment. Furthermore, these elementary units can be processed and modified through genetic engineering to perform specific tasks in an artificial environment.

Synthetic biology is explicitly aimed at creating bio-systems operating along the principles of engineering. Instead of making artefacts mimicking nature, synthetic biologists synthesize living organisms modelled after machines. Synthetic biology can therefore be seen as a technomimetism, an alternative strategy to biomimetism, which is consequently dismissed as a poor amateurish strategy:

> "If biological engineering were aviation, it would be at the birdman stage: some observation and some understanding, but largely naive mimicry. For the field to really take flight, it needs the machinery of synthetic biology. […] At the turn of the last century, the Wright brothers achieved manned flight not by mimicking natural systems, but by applying the principles of engineering and aerodynamics. Similarly, synthetic biology allows us to dispense with biological mimicry and design life forms uniquely tailored to our needs. In doing so, it will offer not only fundamental insights into questions of life and vitality but also the type of exquisite precision and efficiency in creating complex traits that genetic engineers could previously only dream of. » (anonymous editorial, 2009)

Unlike biomimetism, technomimetism is a kind of engineering which consists in implementing the rationality of machines in natural systems. Biosystems have to be redesigned along the principles of engineering because they are too complex or have not been optimized by evolution for human purposes. Synthetic biologists like Drew Endy are proud to apply the engineering approach to biosystems. His main purpose is to "make routine the engineering of synthetic biological systems that behave as expected". (Endy, 2005) The emphasis is on constructing reliable artefacts that get rid of all the messiness and unpredictability of natural systems. Standardization of the bioparts is the first requirement for the design of technomimetic biosystems. The Registry of Standard Bioparts created in Berkeley is meant as a catalogue of the standard parts bioengineers can compile into a physical structure once they have targeted their system's specifications.

A number of synthetic biologists go beyond the ambition of redesigning life according to the basic principles of engineering. Their purpose is to make life as it could be, rather than as it

is. In order to create living organisms as different as possible from all existing life forms, they aim to synthesize unnatural DNA. Steven Benner for instance insists that the four-base DNA code might not be the only way to reproduce and pass on genetic information. Consequently he has made up an alien DNA, which contains two artificial nucleotides in addition to A-G-C-T, and which is already licensed and marketed by a company called EraGen-Bioscience. Benner's ambition is to expand the genetic information system to twelve bases. Owing to the difficulty of confining genetically modified organisms to laboratories, his "alien genetics" is promoted as a way to circumvent the risks of contaminating the environment, and possibly as a way to support life on other planets, to create new parallel forms of life.

6. A reciprocal mimesis

Is it a mere coincidence that a strong movement of technomimetism runs parallel to an equally strong movement of biomimetism? In a famous study of machines and organisms, French philosopher Georges Canguilhem noticed that organisms have often been described in technological terms, even though there is no reason why *a priori,* this analogy between organisms and machines should not work the other way round. (Canguilhem, 1947) In fact a quick glimpse at history suggests that the analogy works both ways.

While Aristotle, in his *Physics*, claimed that technology imitates nature in his biological works, he described nature according to the model of technology. Human arts provided a lot of images that helped clarify how nature worked in living beings. They served as models to understand that all natural beings were end-directed. "As *technê*, so *phusis*" was a conviction that informed Greek medicine. (Von Staden, 2007).

By contrast, when modern science emerged in the seventeenth century, nature was conceived according to the model of machines, and described as a passive, rigid, precise clock mechanism. Descartes' theory of animal machines spread a mechanical understanding of life, with the mind being the exception. Later, eighteenth-century materialist philosophers repudiated Descartes' separation between mind and body, and claimed that all human functions were mechanical processes. It is against this philosophical background that Jacques de Vaucanson or Pierre Jaquet-Droz created their famous automata. (Riskin, 2007) These ancestors of modern robots were used to test the mechanical views of mind and body as much as for entertainment.

In the course of the twentieth-century, our representation of nature and life has been reconfigured again and again. First the mass production of polymers by synthetic chemists brought about what is called the "plastic age". It encouraged the view that nature was rigid and limited, in contrast to the plasticity and indefinite potentials of artefacts. (Bensaude-Vincent, 2007). Since the mid-twentieth century, our understanding of the brain and of living cells have been deeply transformed by cybernetics and information technology. Significantly, it was in the 1960s, when cybernetics raised great enthusiasm, that biomimetism became its own field of research. It was then named "bionics", a term coined in 1958, and defined by Jack Steele of the US Air Force as "the science of systems whose function is based on living systems, or which have the characteristics of living systems, or which resemble these". (quoted in Vogel, 1998, p. 250) Bionics was thus centred on systems, while biomimetics was more concerned with mechanics. According to Waren Mc Culloch in 1962, biomimetics encompassed all areas in which organisms may copy each other. It included technological inventions as much as, for example, the mimetic behaviours displayed by some insects.

In the 1960s, computer technology provided the conceptual framework for molecular biology. From the metaphor of the program, which prevailed through "the century of the gene" to the more recent metaphor of "genetic circuitry" used in synthetic biology, information technology has continuously inspired our understanding of life at the molecular level. (Fox Keller, 1995, 2002) And molecular biology, in turn, inspired nanotechnology, at least if we assume that Richard Feynman's famous 1959 lecture at the meeting of the American Institute of Physics actually foretold the future. His celebrated vision that "there is plenty of room at the bottom" was explicitly inspired by the then recent discovery of DNA's structure and function by Francis Crick and James Watson. The storage of huge amounts of information in DNA macromolecules persuaded him that it may be possible to store the entire Library of Congress on the pin of a needle.

Nanotechnology illustrates well the self-reinforcing interaction between technological paradigms and views of nature. According to the definition given in the US National NanoInitiative, nanotechnology is: "Working at the atomic, molecular and supra-molecular levels, in the length scale of approximately 1 – 100 nm range, in order to understand, create and use materials, devices and systems with fundamentally new properties and functions because of their small structure." (Roco, Bainbridge, Alivastos, 2000, p.3)

Having access to the nanoscale blurs a number of boundaries, which had been already challenged by chemistry and materials science. On the one hand, nanoscientists argue that at the nanoscale, the boundary between inanimate and living matter no longer makes sense. DNA for example, is seen as a chemical macromolecule made up of four pairs of bases which does not enjoy any privileged status such as witholding "the secret of life". On the other hand, the boundary between science and technology is also blurred, the ultimate constituents of inorganic and organic systems are viewed through engineering lenses. The building blocks of matter and life are considered as devices or machines. Atoms, molecules, micelles, DNA, proteins and neurons, all natural entities are viewed as functional units capable of performing interesting tasks. They are characterized by what they perform rather than by what they are made of. Living systems are viewed as molecular manufactures and the analogy is often used as proof that a particular project can be achieved – in other words, if nature can do it, so can we.

Simultaneously, biologists describe the molecular components of cells as tools or machines operating at the macromolecular level: Ribosomes are assembly lines for proteins, myosin fibers are motors, polymerases are copy machines, membrane proteases are electric fences, and so on. Even though biologists generally agree with the idea that living systems are the results of blind and random evolution rather than of design, they still describe them as devices designed for specific tasks. In the past, descriptions of organisms and cells as little factories were occasionally used for teaching or popularizing purposes. But following the introduction of the genetic code in the early times of molecular biology, these metaphors became more than expository tools. They started providing heuristic models, and guidelines for research and design.

Eric Drexler, one of the champions of nanotechnology, took the metaphor of the cell machinery for granted and promoted his "molecular manufacture" as a biomimetic manufacture. The main feature he retained from biology was that bio structures are built from bottom-up, molecule-by-molecule rather than carved from bulk material. He could then contrast two styles of technology: the conventional style, which prevailed from prehistoric flint-choppers to micro-electronic chips works from the top down, and generates waste, pollution and many nuisances. Molecular manufacturing, which shapes artefacts

atom-by-atom, would open a new era of clean, efficient, energy saving manufacturing. Thanks to universal assemblers modelled after ribosomes, we should be able, in his view, to pick and place atoms and dispense with dirty and messy chemical manufactures.
Thus, between nature and technology exists a two-way traffic of concepts, images and models. As French philosopher Maurice Merleau Ponty pointed out in 1956: "We cannot think about nature, without realizing that our idea of nature is permeated by artefacts". (Merleau Ponty, 1956, p. 120). Nature and artefacts are mutually defined by an ambivalent relationship of connivance and rivalry.

7. How to deal with mimicry?

If nature and technology are continuously reconfigured in a process of mutual mimesis, we may feel like we are trapped in a circle. All circles however are not necessarily "vicious". Indeed, analogies and attempts to mimic can prove extremely fruitful. Ironically though, their heuristic power does not so much rest on analogies as it does on differences. I will argue that mimicry is more interesting as a differentiation strategy than as attempts to copy or emulate a model.
In particular, Drexler's assumption that 'bio is nano' prompted many criticisms, and emphasised the differences between our vision of machines and the "biological machinery". In an essay entitled *Soft Machines,* Richard Jones's argued that the 'machines' found inside living cells work on principles which are quite different from those of conventional machines. (Jones, 2004) Firstly, living systems unlike organic chemistry do not use rigid molecules: Proteins, for example, can readily change their shape and conformation. Secondly, instead of channelling the traffic of materials by means of tubes and pipes, living systems take advantage of Brownian motion, which moves molecules and continuously bombards them with nano-objects. In addition, at the molecular level where bio-machinery operates, inertia is no longer a crucial parameter, while surface forces, particularly viscosity, determine whether or not nano-objects will stick together.
From a chemical perspective, the differences between the strategies used in the evolution of life and laboratory procedures are also striking. Funnily enough, nature was never taught laboratory procedures and laboratory procedures require conditions that are far from common in nature such as high temperature, pressure, or vacuum. Chemists have been taught how to work with pure and homogenous substances, which have stable compositions. They can control reactions carried out at the bench, by limiting the number of parameters involved. In contrast, natural substances are chemically impure and riddled with faults; most of them are mixtures or composites. In addition, nature never uses metals as structural material. Nature operates along lines, which look unorthodox to the eye of ordinary chemists, at ambient temperature, and in the presence of a whole range of perturbations.
The constraints in nature differ from the constraints met by chemists and materials engineers in the laboratory. Through trial and error, nature spent billions of years designing and perfecting high-performance structures capable of sustaining life. Life itself, according to the Darwinian evolution, generated a great variety of species and selected the beneficial variants. Engineers work in quite different conditions to evolution, which require projects, planning, anticipation and selective pressures coming from time, money, safety, and security. Despite its strong power of attraction, the view that nature is the perfect standard for design is misleading. In fact, so great is the gap between human design and nature's

processes of fabrication, that any project of 'technology transfer' from nature to factory would be totally inadequate.

Nature cannot provide a model for human technologies, because the same performance criteria cannot be applied. Let us for a moment try to evaluate nature's performances along our criterion of optimization: What does optimization even mean for biosystems? Is it more efficient devices? Our notion of efficiency rests on the principle of *maximum de minimo*: For instance getting the highest resistance from the lowest quantity of matter, or getting a maximum amount of benefits at minimum costs. (Quintinilla & Lawler, 2000) Obviously, this kind of economical rationality does not even register in natural systems. Should we therefore adopt a more qualitative definition of efficiency, such as being a match between means and end? No sooner would we do this than we would stumble upon a new obstacle to determine what the ends of nature may be. As long as we assume that biological evolution is not a teleological process, it would be arbitrary to decide whether its ends are reproduction, or survival, or adaptation for example; or whether these ends should concern individuals or populations etc..

8. Conclusion

Simply copying nature is out of the question. Strictly speaking, nature does not teach anything. It does not deliver either lessons or recipes, which could be applied to technological projects. Nature is basically inexorable, indifferent to our projects and concerns. Living organisms may be seen as holding the answers to questions arising from biological evolution, but they cannot meet our needs resulting from military and economic competition, or societal concerns (for instance health, energy saving or pollution…).

Taking inspiration from nature is a more relevant attitude, and often results in a better understanding of the differences between nature and technology. Bio-inspired designers having to elucidate the principles at work in biomaterials, have to sort out the main variables and constraints operating in the natural world and are gradually able to confront them with the variables and constraints of technological design. In reality, we take inspiration from our understanding of nature, which in itself is inspired from the dominant technological paradigms of our time. The main merit of bio-inspiration is to emphasize the differences between nature and technology and to restore the polarity, which technomimetic strategies have tended to blur.

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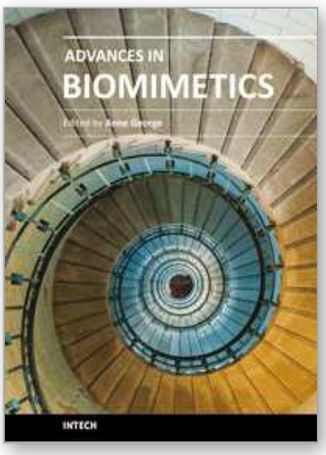

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The interaction between cells, tissues and biomaterial surfaces are the highlights of the book "Advances in Biomimetics". In this regard the effect of nanostructures and nanotopographies and their effect on the development of a new generation of biomaterials including advanced multifunctional scaffolds for tissue engineering are discussed. The 2 volumes contain articles that cover a wide spectrum of subject matter such as different aspects of the development of scaffolds and coatings with enhanced performance and bioactivity, including investigations of material surface-cell interactions.

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