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ZOOMORPHISM AND BIO-ARCHITECTURE: BETWEEN THE FORMAL ANALOGY AND THE APPLICATION OF NATURE’S PRINCIPLES

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Summary. The environment, ecology and sustainability are important concerns in much modern technological innovation. Since these concerns are of particular relevance to the field of construction, proposals are being made concerning materials, elements and systems, as well as design and conception.

Zoomorphism and bio-architecture, disciplines that look to the design of living things for their inspiration, are two of the directions that have been taken. Nature's models are viable precisely because they are the result of over 500 million years of evolution governed by the principles of economy, efficacy, adaptation and sustainability. However, the use of such models can also produce unwanted outcomes when, rather than applying nature’s principles, the designer uses a formal analogy. For this reason, we have investigated some examples of both options and present some key indicators to help distinguish between the two.

1 INTRODUCTION

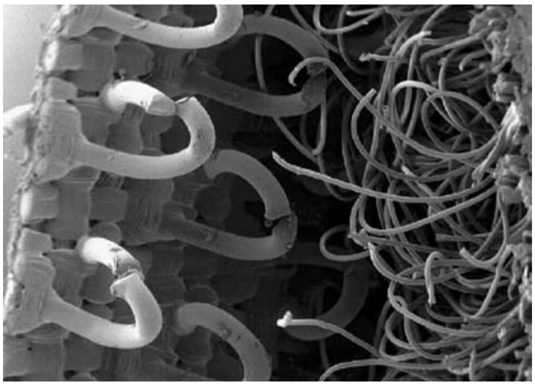
The evolution of our culture during the twentieth century, and in particular of technology, has made it essential to take into account sustainability and the environmental implications of our actions (A. Cuchí, 2005). In order to reduce the impact of our society on the environment, to address the scarcity of available resources and to prevent the exhaustion of the capacity of natural systems to absorb pollution, it has become clear that we must apply the strategy of the four Rs: reduce, reuse, recycle and rehabilitate (B. Edwards, 2005).

One of the ways this strategy is being implemented is through biomimetics. Biomimetics is the study of living organisms that have been evolving for over 500 million years in harmony with their natural environment and without compromising the general continuity of the system as a whole.

2 THE APPLICATION OF NATURE'S PRINCIPLES

Nature’s models are not usually directly applicable to industry because they are the result of a very slow evolutionary process driven primarily by the need to optimize survival and reproduction. To achieve this twofold objective, living beings are based on such principles as energy saving, recycling, optimization of form, economy in the use of locally accessible materials, adaptation to the environment, and sustainability. Although our objectives are not quite the same, all of these principles can also be applied to construction, helping us to save materials and energy, to achieve more efficient and sustainable solutions, and to reduce costs and improve function and durability. Some examples are discussed and the results obtained are presented.

3 BIOMIMETICS IN INDUSTRY

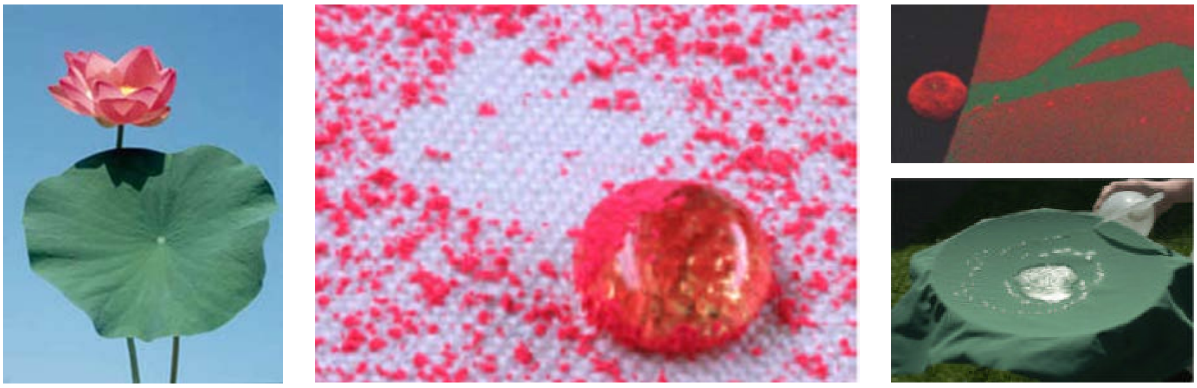


On observing how thistles adhered to the coat of his dog, George de Mestral invented a fastening system based on the use of many small flexible hooks. His invention was patented in 1955 under the name “velcro”, made by combining parts of the French words “velours” (velvet) and “crochet” (hook) (Swiss info.ch, 2007).

Based on observation of the manoeuvrability of fish swimming through coral reefs, Mercedes Benz optimised the wind resistance of its vehicles (Daimler Chrysler, 2005).

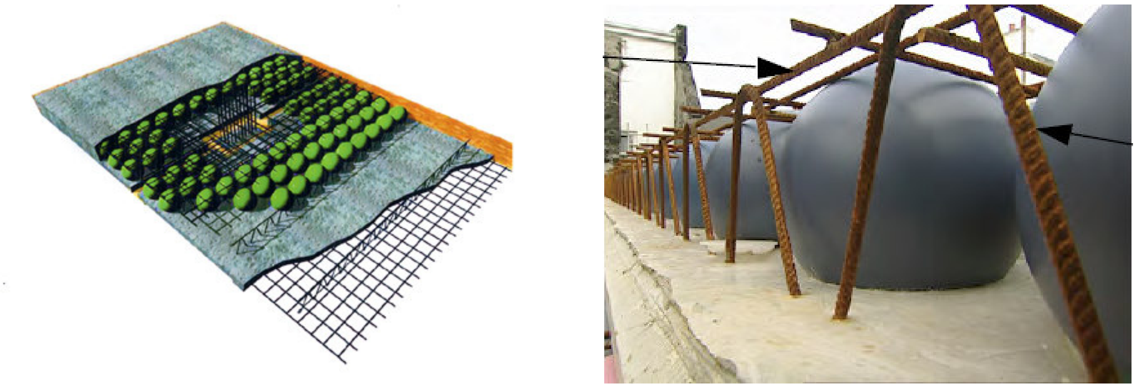
4 BIOMIMETICS AS APPLIED TO PRODUCTS AND ELEMENTS

Researchers have investigated the self-cleaning mechanism of the water-repellent lotus leaf. When it rains, the droplets do not wet the leaf but rather quickly run off it, carrying away any surface dirt. The results of this research have been applied to the design of textiles and

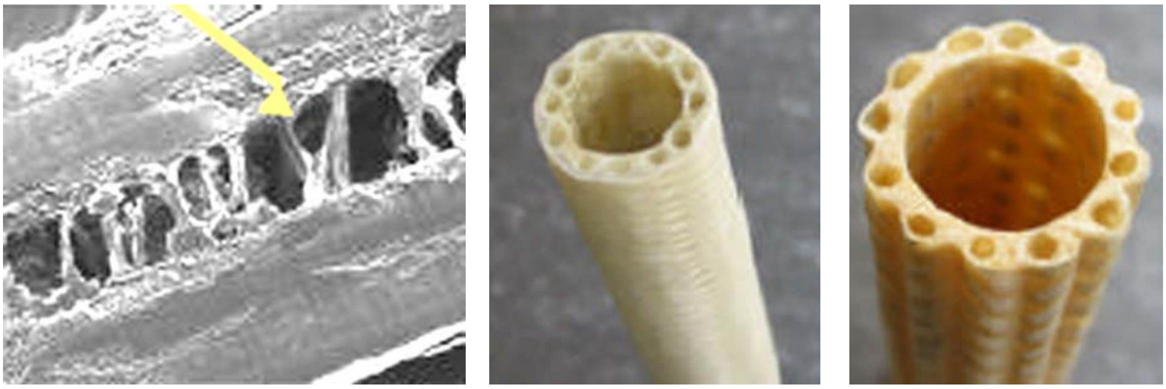


self-cleaning paint (Institute of Textile Technology and Process Engineering, Denken-dorf).

Wasps nests and bee hives can support 45 times their own weight thanks to the hexagonal shape of their cell structure. This design has been used to lighten panels and structural elements (Museo de Ciencias Naturales, 2004).



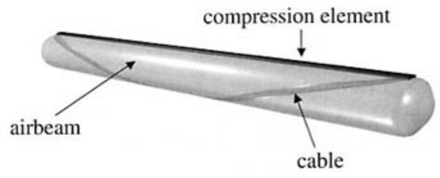
Reducing the amount of material used where less is needed is another principle used to lighten structures. Examples include the vaults used in flooring slabs and the more recent Bubble Deck technology, which uses plastic balls to lighten biaxial reinforced concrete slabs (Bubble Deck, 2006).



Pultruded fibre struts have a structure similar to that of the stems of certain plants (institute of textile technology and process engineering, Denkendorf).

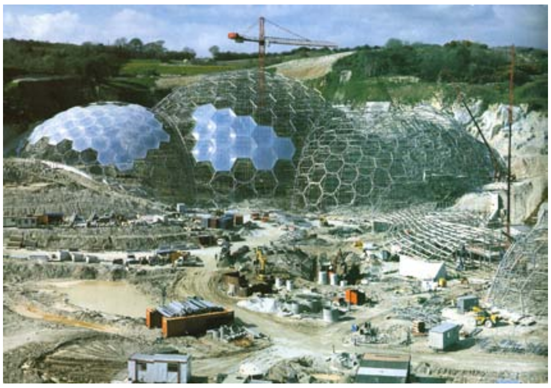
5 BIOMIMETICS AS APPLIED TO SYSTEMS

The use of branching tree structures radically reduces the span required, making the whole structure lighter. (Almuñécar Aquarium, 2007 and Stuttgart Airport, 1990).

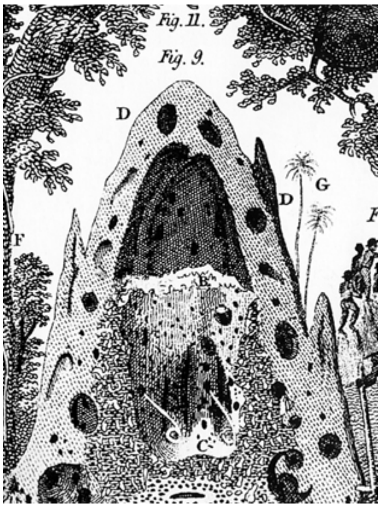


The basic set up of a Tensairity girder.

Tensairity pneumatic beams were inspired by the combination of compressive and tensile forces that surround the fluid in plant stems (Tensairity, 2003).



The structure of the biome domes in the Eden Project in Cornwall is optimized by using hexagonal frames to enclose the maximum surface area within the minimum contiguous boundaries. (M. Jackson, 2000).



The passive cooling system used in termite mounds has been used in troglodyte houses in Uchisar and more recently in an office complex in Harare (Zimbabwe), where it replaces mechanical air conditioning (D.G. McNeil, 1997).

Folding structures can adapt to climatic conditions. The parasols on the Mosque in Medina (1992) and the Venezuela Pavilion at the Hanover World's Fair in 2000.

6 THE LIMITATIONS OF BIOMIMETICS

When transposing solutions from nature, we must take into account the considerable differences between organisms and objects. These are shown in the box below.

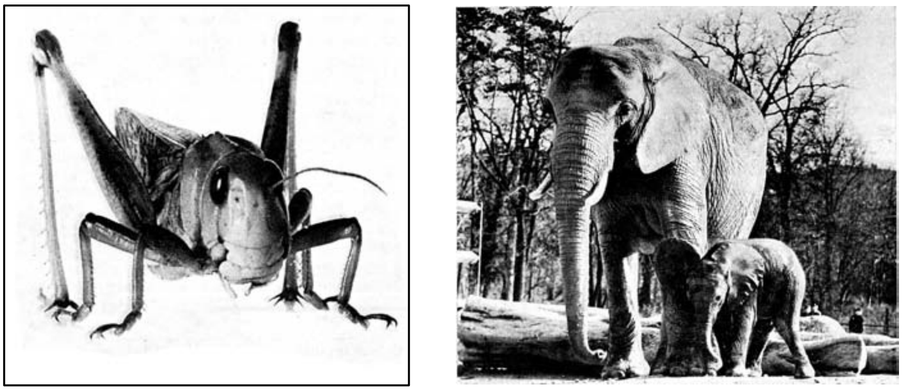
LIVING ORGANISMS	OBJECTS
Geometry	
Have no 90º angles. Have curved and rounded surfaces.	Have many acute and 90º angles. Have many flat planes with straight edges.
Structure and Composition	
Are damp and flexible structures. Contain no metals. Contain many composite materials. Contain abundant microscopic elements. Produce heterogeneous materials, such as wood.	Are dry, rigid structures. Contain metals. Include relatively few composite materials. Use homogeneous materials, such as steel.
Mechanisms	
Have folding articulations (the orientation of a cat's ear is altered through changes in its curvatures). The motor elements (muscles) rely on contraction. No wheels and shafts are used. Gravitational energy (when walking) and elastic energy (when jumping) are stored. A muscle is the sum of a set of identical small parts, and the individual functioning of each part is independent of the others.	The orientation of a hinge is changed by rotation on an axis. Engines rely on expansion. Wheels and axles are used. Energy is stored in various forms: gravitational (pendulum and counterweight), elastic (spring or bow) electrical (battery), and inertial (flywheel). The motor is a machine that cannot operate if any part is missing or malfunctioning.

LIVING ORGANISMS	OBJECTS
Structural Behaviour	
The tension-deformation curves are concave. They interact with the demands made on them and adapt. They resist unfavourable forces and take advantage of favourable ones.	The tension-deformation curves are convex or straight. They passively resist and give in to forces that make demands on them. (Sand dunes are formed by action of the wind.)
Evolution	
They started much earlier and have evolved more slowly. They evolve to enhance their reproductive mechanism and survival. They are created in the moment of reproduction. They constantly renew themselves. After a year, all of the cells have been renewed.	They evolve much more quickly. They evolve by invention, discovery, development and planning. Designed objects work correctly from the very beginning. They do not renew themselves. Unless maintained, they erode or degrade. (The molecules in the pyramids today are the same ones that have been there since the structures were first built).

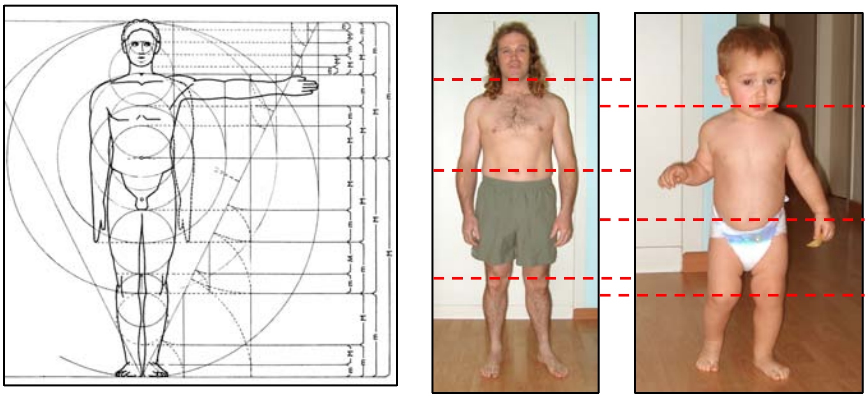
7 THE RISKS OF FORMAL ANALOGY IN ARCHITECTURE. CHANGE OF SCALE : THE COLLATERAL EFFECTS OF THE ZOOM

There is a risk in architecture of limiting biomimetics to a formal analogy. Every natural form is the result of a series of interacting factors, including, for example, environment, structural behaviour, function and economy. Imitations that fail to take into account the factors that gave rise to the model, that is, the context in which it evolved and the requirements it satisfies, can easily lead to very different outcomes than those obtained by the original. The results of such designs may be structures that are costly to build and maintain—buildings that devour energy and resources and are inefficient, poorly adapted, unsustainable and unrecoverable.

The change of scale is one of the must common areas of error. Changes in the scale of a model modify the behaviour and characteristics that depend on geometry because they alter the proportion between length, surface area and volume. As the size is reduced, the relationship with the exterior increases. In small animals, gravity is less important than aerodynamic resistance. The relation between the weight of an object and its cross section increases as size increases, so that large animals are proportionally weaker.

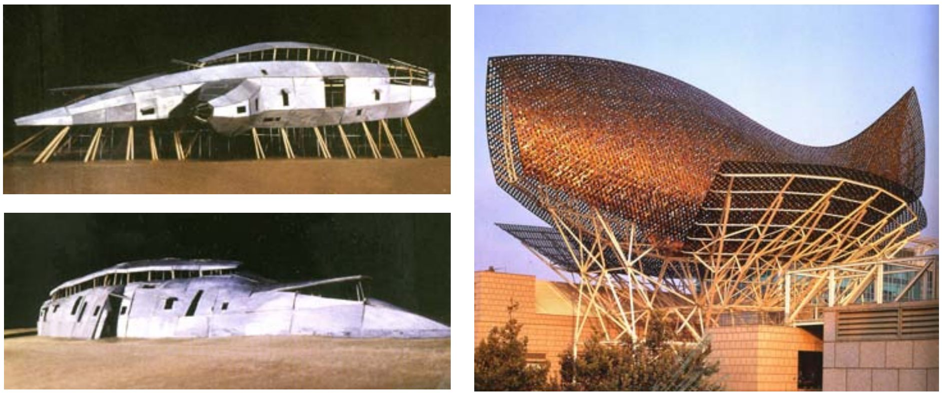


Note that nature never changes the scale of a structure. When the size changes, so does the form, the proportions or the material (H.Hossdorf, 1972).

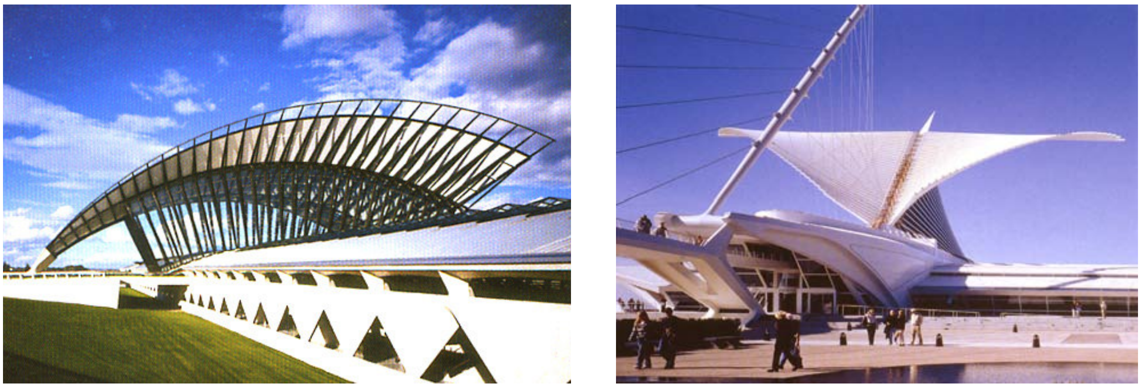


As organisms grow, the proportion between their parts change to preserve functionality.

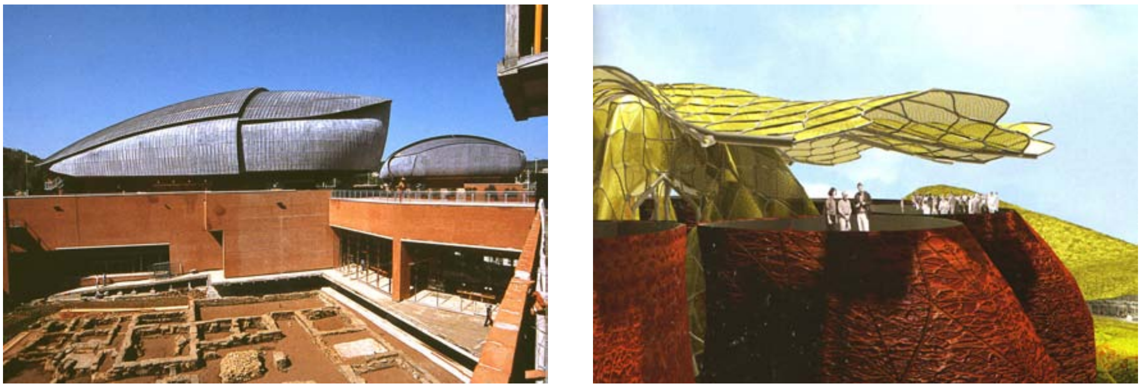
8 FORMAL ANALOGIES



Carp and slug by M. Sorkin, 1991 and the fish by F. Gehry in the Olympic Port of Barcelona, 1992.

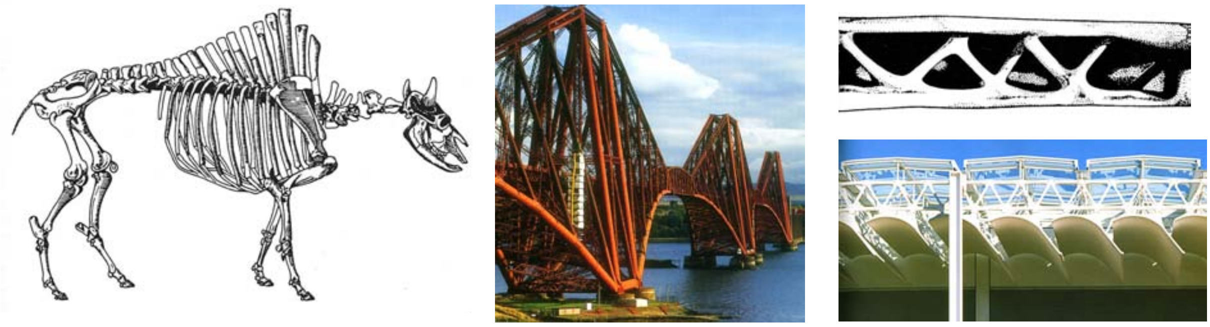


Lyon-Satolas railway station, 1994 and the Milwaukee Art Museum addition in 2001 by S. Calatrava.



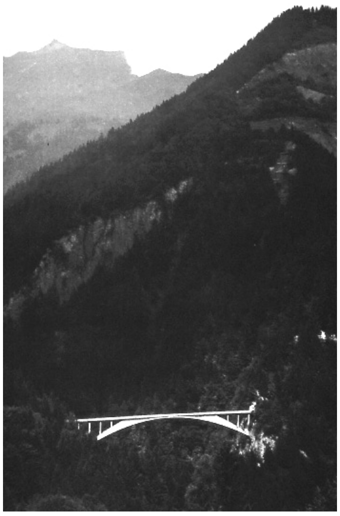
The armadillos in the “Parco della Musica” by R. Piano, Rome 2002 and the zoomorphic structures in the Arca del Mundo Park in Costa Rica, 2002.

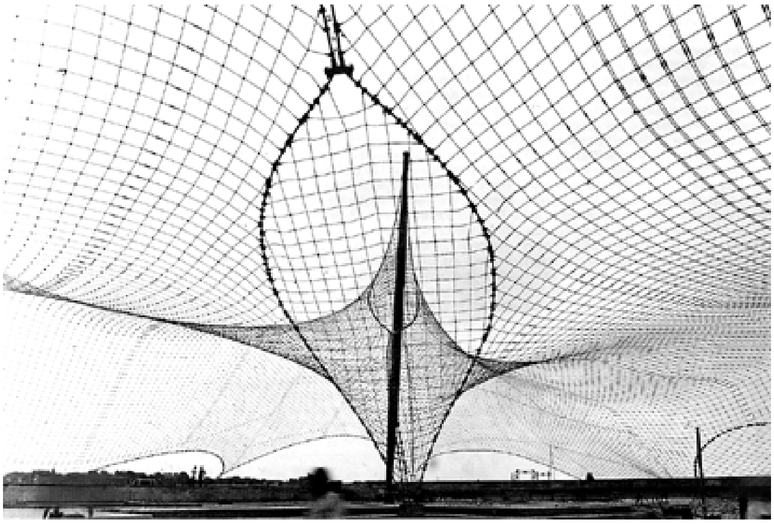
9 APPLICATIONS OF PRINCIPLES OF NATURE



Structures: the bison’s skeleton and the Forth Bridge, T. Bouch, 1878. The Warren truss from the vulture’s wing and the Menil Museum in Houston by R. Piano, 1987.

Protection: the skin as a regulating mechanism. Sendai Mediatheque , Toyo Ito, 2001.Ventilated facade of the United Kingdom Pavilion in the Seville Expo, N. Grimshaw, 1992. Leicester Space Centre, N .Grimshaw, 2002.





Form adapted to the characteristics of the materials: Salginatobel Bridge, Grisons, R. Maillart, 1930. German Pavilion in the World Exhibition in Montreal, F. Otto, 1967.

10 CONCLUSIONS

- The principles of the construction of living beings can provide inspiration and suggestions because for millions of years nature has distilled economy, efficacy, adaptation and sustainability.
- Taking into account the changes in context and requirements, nature’s principles can be applied to construction in order to:

  • reduce the weight, amount and cost of materials needed and lightening the constructive elements

- save energy in manufacture and use
- improve thermal behaviour
- recycle materials and reduce the amount of waste generated by the construction and use of the building
- simplify construction, use and maintenance by using simpler solutions (for example, passive solutions).
- reduce maintenance (for example, by increasing the durability of protective elements).
- reduce accidents, responsibilities and litigation arising, for example, from the risks of falls, slips, impact, trapping or the manipulation of heavy elements.

- mere observation and imitation of the form can give rise to outcomes different from those obtained by the original model because the aim is not to copy, but to learn.

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