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Bio-mimic to Realize!
Biomimicry for innovation in architecture

Lidia Badarnah

Abstract
The growing interest in biomimicry suggests that engineers are becoming more aware that nature has much to offer in order to improve the way our systems function. Biomimicry already achieved and realized some of the advanced and efficient technologies in materials and products. However, it is still largely unrealized in the architectural design. Two case studies are presented and show two possible applications of biomimicry to realize innovations in shading and ventilating for building envelopes.

Biomimicry
Biomimicry is a multidisciplinary field, where many active groups including philosophers, computer scientists, physicists and chemists work in cooperation with biologists and engineers. Biomimicry refers to the design based on principles, processes and methods extracted and abstracted from nature. This approach results in designs that are similar to the functional concept of an organism or an ecosystem. The biomimicry field is rapidly growing as both an academic and an applied discipline, and this is noticeable in the dedicated journals and the growing research through the years. This growing interest in biomimicry suggests that engineers are becoming more aware that nature has much to offer in order to improve the way our systems function.

Realize biomimicry in architecture

As mentioned above, biomimicry is noticed in products and materials rather than buildings. Aldersey-Williams’s presents projects that are translated from the animal world in different ways, but most do little more than mimic a form. Nonetheless, biologically inspired technologies are being developed for different areas of building construction such as insulation, windows, electric lighting, controls and mechanical systems. During 3.85 billion years, living organisms have been perfectly optimizing their waives without consuming fossil fuel, polluting the planet or risking their future. What better lessons could there be?

Biomimicry in architecture could achieve higher levels of sustainability and potentially regenerative architecture. A building, in McDonough’s vision, could be designed in a similar way to the functioning of an ecosystem. Pedersen investigates the possibilities to mitigate the impact of climate change on the built environment via biomimicry. She demonstrates different ideas to be applied in the design for short, medium and long term response to climate change. The integration of understanding the living world into architecture could lead to an important step towards a more sustainable and resilient built environment able to adapt to climate change. Relations between biomimetics and improved psychological and physical well-being were also investigated by Pedersen and Keller; they argue that lower environmental quality reveals less environmental interest and in turn a lower quality of life.

Moreover, addressing the negative environmental impacts by incorporating biomimicy into design could lead to a more functional, liveable, loved and beautiful habitat for ourselves.

We tend to design one function at a time, resulting in separate solutions for different tasks. The final product would be the assembly of the different parts together, but in this case the whole will be only be the sum of its parts. Biomimicry in architecture could achieve and create buildings that function as systems and organisms or as their integration.

Realize with nature’s leading models/champions
The leading models of nature are the organisms that have developed optimized strategies and challenged their harsh or extreme environmental conditions. Termite mounds are one of

Speedo Fastskin. Swimsuits inspired by sharkskin. This new development emulates the dermal denticles of sharkskin that reduces friction drag and they support the muscles to some extent.

DaimlerChrysler Bionic car. Design based on the shape of the boxfish (fig. 1), due to its large volume and surprisingly aerodynamic shape, and on studies of stress-relieving shapes in tree growth.

Velo. Invented by George de Mestral in 1941. Burdock seeds were stuck to his clothes and his dog’s fur, and after observing these seeds he realized its hook and loop system. His intention was to replace the zipper with the Velcro.

Lotus. Lotus leaf effect (fig. 2). A self-cleaning paint inspired by the lotus leaf surface. The texture of the surface at the nano-scale makes it easy to repel dirt. The same surface properties are being developed in metals.
1. Box fish
© Andy Isaacs

2. Lotus effect: due to surface properties, water and dirt are repelled without leaving any tracks.

3. Termite mound

4. CH2 Building in Melbourne, Australia

5. Thorny Devil – native Australian lizard

6. The breathing skin when inhaling (above) and exhaling (below)

7. The process of air exchange that occurs in the breathing skin, basic component
   and lung-like chamber combination

8. The basic component deforms from phase a to phase b and vice versa. The arrangement of the components creates an envelope that has the ability to perform dynamic continuous changes

9. Expansion and contraction of the lung-like chamber
   a. The lung-like chamber consists of two surfaces attached to each other at their edges creating a specific volume in the basic component
   b. c. Piezoelectric wires are attached to the sucking surface of the lung-like chamber to control the sucking and expelling
   d. The air flow is controlled to flow through the lung in one direction.
   It works the same way as our veins and the shafts of the sea sponge.
the extraordinary natural systems that keep steady temperatures of 30°C inside, while the temperatures outside range from 2°C (at night) to 40°C (during the day), and by this performance it is considered one of nature's leading champions.

The Eastgate Building (1991) in Harare (Zimbabwe) is an extraordinary example for using less energy (10% of the energy of a conventional building) by imitating the strategies of local natural systems, the termite mounds (fig. 3). The building is using the same principle of regulating temperatures as the termite mound, where the termites continuously open and close heating and cooling vents all over the mound throughout the day. The architect, Mick Pearce, used exactly the same principle for the design, resulting in a building that has no air-conditioning and virtually no heating.

Another of Pearce’s buildings is the CH2 building in Melbourne (fig. 4). This is another example of mimicking termite mounds for higher efficiencies in building performances.

Mimicking natural processes were documented by the biologist Janine Benyus in her book *Biomimicry: Innovation Inspired by Nature*. Pearce tried to implement this approach into his designs.

Photovoltaic cells are a classic example of biomimicry used for buildings; they were a result of understanding the function of plant leaves for solar energy absorption, while producing no pollution. These cells, with current new technologies, could be integrated in windows and generate electricity while allowing daylight to penetrate the building.

The bumpy surface of the Namib desert beetle encourages catching water droplets from the surrounding fog. This principle from the organism was the inspiration for catching and trapping moisture in the fog in the Hydrological Center for The University of Namibia.

Finding nature's leading champions for specific performances is enjoying great interest among some scientists. They are hoping to make a device inspired from the thorny devil (fig. 5) that mimics the mechanism to develop water-capture technologies for dry regions.

Realize biomimetic case studies for building envelope innovation

Nature presents an infinite source for research and has always inspired technology and led to effective algorithms, methods, materials, processes, structures, tools, mechanisms and systems. Living organisms have unique integration geometries and techniques that allow them to adapt to different environments. They can sense and react to local changes causing a global behaviour.

Investigating and analysing natural systems can result in models for dynamic and adaptive materials. And we are able to analogously apply solutions abstracted from nature to a desired system. Size and proportion are important in such systems and should be considered prior to abstracting principles.

The building envelope could be considered our third skin or the extended buffer between our body and the exterior environment. If we go back in time and look at the beginning of our evolution then we see that the first shelters for humans were clothes and natural caves, and later on shelters built from raw materials. Growing communities developed cities where houses protected each other, thus creating a single unit with an external wall. A sudden reduction to a single barrier evolved with the development of individual buildings and has resulted in increasing the demands on the envelope for each building. The increasing demands on and requirements of the envelope resulted in a multi-layered construction. The way of construction where services are attached to the envelope providing separate and isolated solutions, where the whole is just the sum of its parts, has resulted in complex systems that are difficult to control, need constant maintenance and have a limited lifetime.

Our approach is not to imitate nature but to observe its principles and methods and transform and develop these principles to realize sophisticated technological solutions for building envelopes.

Realize 1: The 'breathing' skin

In this section, we present some breathing organisms and circulation systems (air exchange) which can be found in many living creatures for different tasks. The main methods and principles are abstracted and transformed to develop the presented envelope (fig. 6). This case study is based on the work done by Badarnah.

Nature models and principle extraction

The Asconoid sponge, respiratory systems, veins and the skeleton and surface of a sea sponge were investigated for this case.

We found that gas exchange is performed through a series of actions and related mainly to parts movements in the air pressure to create a flow against the exchange tissues. The surface area of the exchange is greatly expanded by dividing the system into many small parts, chambers or sub-branches. The gas exchange is a continuous process, and it depends on the pressure variations. Integration patterns are based on simple basic geometry to create more complex functionality of the system.

Principle abstraction and transformation

Based on the principles and methods, a breathing skin for buildings was designed. In our work we referred to the following methods:

- generating gradient pressure by parts movements;
- increasing and decreasing the volume to result in sucking and expelling;
- dividing the system based on hierarchy;
- controlling the air-exchange by designing the surface pattern (sea sponge);
- controlling the direction of flow through integrated valves.

These methods provide the base-line for our development. By this transformation we consider the envelope of the building as a ventilating system that improves the functionality of the building skin.

Transformation results

We developed a skin that reacts to changing conditions and influences the air pressure on the surface to perform a process of inhaling and exhaling (fig. 7). The system is created by a specific arrangement of a basic component (fig. 8), where orientation and the geometry of the components allow deformations in order to perform the inhaling and exhaling process. The airflow is controlled to flow in one direction through the lungs of the components (fig. 9).
10  Horizontal growth, Fibonacci series for compact horizontal packing

11  The angle of incidence determines energy density
a. Leaves normal to sun radiation for maximum energy gain
b. The effect of different inclinations on the projection
c. Top, front and projection view

12  Lower layers of leaves bend for maximum light perception
a. Lower leaves get bigger with smaller inclination if γ < β. Alternation of 90 degrees is adopted in this plant in order to catch more sun light
b. The effect of the inclination, preventing self-shading

13  Venus Flytrap. At right, a cross section showing different extensibilities for the inner and outer surfaces
By developing the present breathing skin we are dealing with a system that is an integral part of the building envelope and which functions as a protective layer too.

Realize 2: The 'shading' system
From summarizing the techniques used in plants for reacting to sun radiation, three main categories were recognized for maximum and minimum light exposure. Leaf distribution, orientation and dynamics play a significant role in influencing the efficiency of solar radiation. Morphological and physiological factors influence light interception in plants\(^{20}\), where it affects photosynthesis and rate of plant productivity\(^{21}\). This case study is based on the work done by Badamiah\(^{16,19}\).

Main principles used in plants

Distribution

The combination of arrangement and density of leaves affects leaf distribution in plants for photosynthesis efficiency\(^{22}\). In the extreme, we find two ways of photosynthesis efficiency: the leaves are distributed either in a single layer with high density or multi-layer distribution with loose density\(^{23}\). The leaf density of plants influences the plant's projected area, which affects sunlight interception capability\(^{24}\). Form and proportion are additional factors affecting photosynthesis efficiency\(^{25}\). Some plants have special arrangements that could be described mathematically, e.g. Fibonacci series (fig. 10), which are adopted for compact and dense packing of members.

Orientation

In plants, sun tracking is achieved in two ways. In the first, leaves move perpendicularly to the direct sun rays. Such leaves are called diachroitic leaves. In the second way, leaves move parallel to the direct sun rays. This type of leaf is known as paraheliomorphic\(^{26}\). Heat load, leaf temperature and transpiration rate are reduced with paraheliomorphic movements\(^{27}\). Diachroitic movements (fig. 11) allow a high solar irradiation and result in maximum rates of photosynthesis throughout the day\(^{28}\). Regulation of leaf inclination (fig. 12) is one of the mechanisms to avoid shading by neighbours\(^{29}\).

Dynamics

Plasticity in response to sunlight is one of the dominant aspects of plant architecture\(^{30}\). This plasticity is recognized when leaflets shift from a vertical position to a horizontal position. In this process plants increase their internodes and petiole length, and leaves increase their area while reducing mass per unit area. Dynamics in plants are generated via their nastic structure\(^{31}\); it has different functions, such as rapid bending, which is recognized in the Venus Flytrap. Its closure is achieved through the property differences at the exterior and interior surfaces of the wing (fig. 13). Another function is orienting horizontally or vertically; this property is adapted basically to track sun radiation. The centralization of vascular bundles in the leaf stalk allows the leaf to bend.

Principles abstraction and transformation

Leaves in plants have unique properties in order to track sun radiation. For maximum exposure, leaves tend to have a clear organization and distribution with an adaptive inclination and relatively high plasticity in the plant's body. At minimum exposure, plants are less dynamic and reactive with having high exposure, e.g. at noon. Besides, they tend to have low leaf inclinations, preventing conditions such as are normal for rays.

Hence, Geometry is a major aspect for determining the distribution, inclination and dynamics. For the design process we referred to the following methods:

- Mono-layer at dense distribution for maximum light capture
- Plasticity, in order to adapt to different inclinations
- Different inclinations of leaves in relation to sun rays;
- the generated projected area could be maximized
- Leaves normal (perpendicular) to sun rays
- Special surface properties, for flexibility
- Increasing leaf area combined with reducing mass per unit,
- for better photosynthesis process
- Petioles extension, in order to prevent self-shading
- Stem elongation for maximum light capture

Transformation results

Using principles and methods from plants and their transformation, a shading system (figs 14, 15) was designed with the ability to track the range of sun radiation throughout a day (fig. 16). It is able to adjust for different inclinations and distances from the envelope (figs 17, 18). Current shading technologies deal, basically, with extensions either vertically or horizontally. They tend to have the same angle of inclination when flipped (fig. 19). Computer simulations showed the improvements achieved with considering azimuth and altitude angles of the shading elements. Allowing the sheets to fold could add another level of flexibility for the shading system (fig. 20).

Conclusions

Biomimicry is rapidly growing in both directions; as an academic and as an applied discipline, it can be observed in the dedicated journals and the growing research through the years\(^{32}\). This growing interest in biomimicry suggests that engineers are becoming more aware that nature has much to offer in order to improve the way our systems function. However, the potential of this field of research in the creation of novel innovations is still largely unrealized as a method in architectural designs. Cooperation between scientists from different fields, especially biologists, is required to realize designs that function as an organism.

The case studies opened new perspectives for new possible technical solutions for building envelopes, and pointed to the possible improvement inspired by nature.

Incorporating the concept of ‘how organisms function’ in our designs allows us to realize a new class of innovations and lays a fundamental foundation for a new architecture: bio-inspired, climatically oriented and environmentally conscious.
14 The shading system
   a. Front view, shading sheets and profiles in the back
   b. Side view, shading sheets connected to the tubular member via the elastic membrane
   c. Perspective view

15 Shading components' movement over the grid
   a. Shading components positioned to cover the radiation
   b. Shading components moved to the edges of the grid providing free visual contact and packing under each other

16 Sun's position. Altitude and azimuth angles determine the position of the sun. The altitude angle (θ) is the angle of the sun above the horizon and the azimuth (φ) is the angle of the sun’s projection on the ground plane relative to south. The hatched surface presents the sun radiation path throughout a specific day

17 The shading sheets inclination and their support elongation
   a-c. Showing different inclinations of the sheet connected to the support member by an elastic membrane
   d. The support tubular member elongation

18 The same projection area for two different surfaces of shading sheets normal to sun rays
   a. The shading sheet flat and normal to sun rays
   b. The shading sheet is divided into smaller pieces and positioned in different depths of ray direction

19 All shade blades have the same angle of inclination (θ) when flipped. Light grey indicates the old position and dark grey the new position

20 High altitude angles at noon. The shading sheets fold in order to provide more protection at the upper part