MOVECO

# CIRCULAR ECONOMY INNOVATION TOOLS

## Schools of thought - Biomimicry

Qualification Programme Handbook Module 3

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# 2. INTRODUCTION

## 2.1. INTRODUCTION

This document can either be used as background material for trainers and participants in a **workshop** or also by individual readers (**self-study** or within a self-formed study-group). For both cases, there are notes provided that guide through the material.

?

Indicative questions encourage you to reflect what you have just read.

In addition, throughout the text, you will find some indicative questions framed and marked by "?" that encourage to reflect what you have just read.

Cross-references to the case studies and further MOVECO materials help to deepen your knowledge about circular economy.

Moreover, there are cross- references to the case studies or other MOVECO material (such as the fact sheets) marked by "💡".

Practical exercises are pointed out for trainer-led workshops or self-study by individual readers or a self-formed study group

Further, the pencil sign points out practical exercises that can be done as part of a trainer-led workshop or in self-study by individual readers or a self-formed study group.

For the **practical** work, there are several **case studies** that invite discussion or reflection – paired with empty templates for worksheets that encourage looking at a self-chosen practical product example. In the end, there is a short quiz to test the knowledge gained in this section of the toolbox. You will find any specific terminology explained in the **glossary**. If you use this section as part of a workshop, there is an **evaluation form** at the very end that can be used to collect feedback at the end of the workshop.

# 3. CONTENT

## 3.1. SCHOOLS OF THOUGHTS – BIOMIMICRY GENERAL OVERVIEW

Biomimicry comes from bios, meaning "life," and mimesis, meaning "to imitate". Biomimicry is the design science that takes inspiration from nature to solve design problems in a sustainable manner. Nature is both the model, the measure and the mentor in biomimicry. The term biomimicry was coined by polymath Otto Schmitt in 1957, and first appeared as a generic term including both cybernetics and bionics. It became more popular since 2002, with the launch of the book written by Janine Benyus, named "Biomimicry: Innovation Inspired by Nature". According to Janine Benyus[1], there are nine basic laws of the "circle of life" that should be considered in any biomimicry-driven design, as follows:

- Nature runs on sunlight
- Nature uses only the energy it needs
- Nature fits form to function
- Nature recycles everything
- Nature rewards cooperation
- Nature banks on diversity
- Nature demands local expertise
- Nature curbs excesses from within
- Nature taps the power of limits

The life's principles are aligned with circular economy. Life counts on sunlight, water, fire, ground and gravity, on dynamic equilibrium, limits and boundaries, as well as cyclic processes. Thus, the design lens of biomimicry are:

- Evolve in order to survive: replicate strategies that work, integrate the unexpected, reshuffle information
- Adapt to changes: incorporate diversity, keep integrity through self-renewal, embody resilience through various means (e.g. decentralisation, variation, redundancy)
- Attune and be responsive to local conditions: leverage cyclic processes, use readily available energy and materials, use feedback loops, cultivate cooperative relationships
- Use life-friendly chemistry: use only primary benign constituents, do chemistry in water, use small subsets of elements
- Be resource efficient in terms of materials and energy: use low-energy processes, use multi-functional design, recycle or reuse all materials, fit form to function
- Integrate development with growth: self-organize, build from bottom to up, and combine nested and modular components.

There are many applications in our economy inspired by nature's "innovations"; innovations that have evolved in nature along many iterations ad refinements along 3.8 million years. We have now "property rights"-free sources of inspirations from nature in order to generate innovative solutions

[1] Benyus J: Biomimicry: Innovation Inspired by Nature, Morrow 1997

leading to zero waste ecosystems. Sources of inspiration can come from natural processes, natural systems or natural elements. Exceptional results of biomimicry are seen in industrial ecosystems, in fastening solutions, colouring without pigments, thermoregulation, preservation and storage, waterproofing and self-cleaning, super adhesives, energy generation, colour changing, structural stability, strength and flexibility, waterproof adhesive, etc. Nowadays industrial application domains inspired by nature include nanotechnology, senzoric, molecular engineering, materials, informatics, tissues and cellular engineering, biofuels and bio-products, mechanical design, avionics, robotics, furniture, buildings, and many other domains. Some examples will be included in this material. Biomimicry is a design science with huge potential for developing a sustainable economy.

Beyond changes in the ways we think about designing, producing, transporting, and distributing products, biomimicry also provides new streams of opportunity to deal with complex environmental and economic problems. There are two different approaches to biomimicry. One is the "reductive" approach that sees biomimicry as a transfer of nature's solutions into the domain of design and engineering. The second one is the "holistic" approach that perceives biomimicry as a measure to achieve ecologically sustainable products. Biomimicry does not imply a direct transfer of a solution from nature to a product, but rather a creative process of adapting observations from nature into sustainable products.

### 3.1.1 BIOMIMICRY BIOLOGY DESIGN SPIRAL

From an engineering perspective, we have to see biomimicry as a design tool that emulates strategies used by living things. Thus, biomimicry would be seen as a bridge between environment and economy in engineering design. The biology design spiral was proposed by Carl Hastrich to guide designers during their work on the path that is also used by nature in its iterative design process. Today, agile product management is very popular, especially in software industry, where things are complex and poor defined in their early stages. Biology design spiral is illustrated in Figure 1.

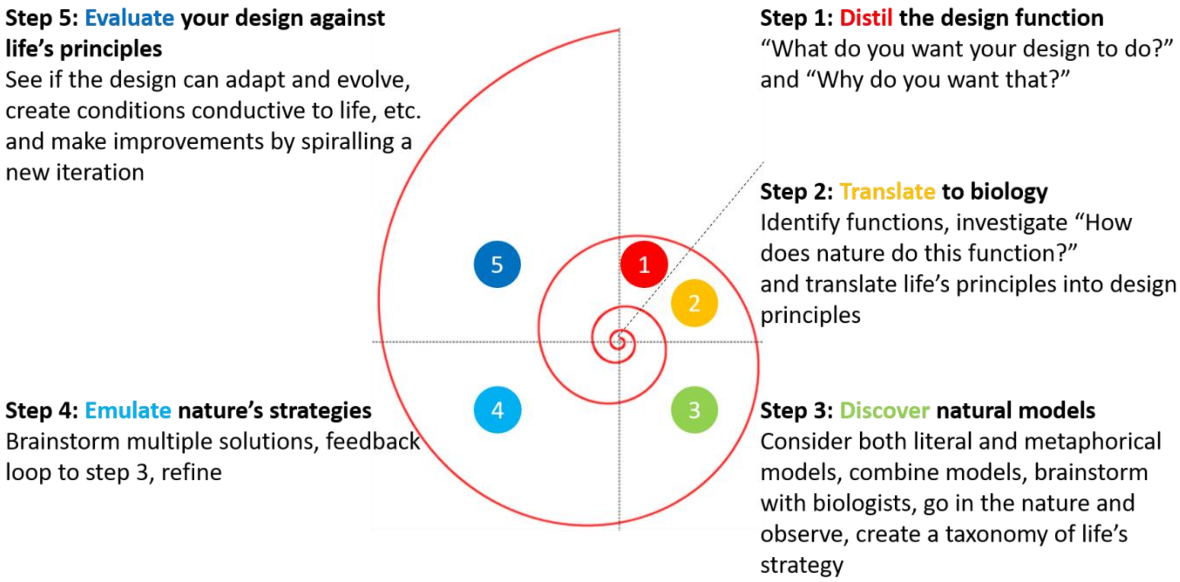
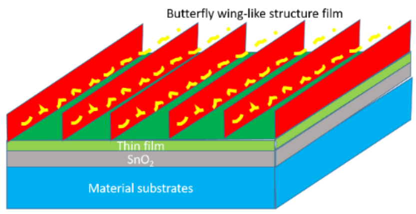



**Figure 1.** Biology design spiral

An example of biology design spiral application is further given in Table 1.

**Table 1.** Colour generation by biomimicry

| | |
|---|---|
| Distil | Create colour without chemical pollution |
| Translate | Colour reflection, spectrum absorption |
| Discover | See how butterfly is coloured |
| Emulate |  |
| Evaluate | Life-friendly chemistry; Use energy in an efficient way; bottom-up approach; minimal use of materials; low energy process; can recycle materials with no pollution from pigments |
| Biomimetic attributes | Structurally coloured fibres and fabrics |
| Inspiration | Butterfly wing scales refract and scatter light<br><br>Figure 2 |
| Practical application | Dye free fabrics |

| | |
|---|---|
| Design problem | Industrial toxins and energy consumption resulting from the fabric dyeing and manufacturing, colour fading and skin sensitivity to dyes |
| Biomimetic solution | The protein layers on butterfly wing scales to create colour by refracting light is used as source of inspiration. The interaction between the layers and light refraction create the presence of pigments. The illusion of colour is fade resistant. |

### 3.1.2 BIOMIMICRY DESIGN PROCESS

There are two major design processes in relation with biomimicry. The first category is when we have an engineering problem and then we look to a solution in nature. An example was the noise problem of the bullet train every time it came out of a tunnel, due to the change in air pressure. Engineers investigated different types of water-birds that dive from air to water and observed that kingfisher makes very little splashing. Thus, they redesigned the front of the train using the beak of the kingfisher as a model (see Figure 3). The result was a quieter, faster and more energy efficient train.

Figure 3 Biologically inspired design: the front of the bullet train as the beak of a kingfisher

The second category of biomimicry design is when we start from biology with a biological solution and move towards an application by analogy. A good example is the discovery of the self-cleaning mechanism of the lotus, based on small epidermis protrusions that cause the droplet to collect pollutants while it rolls of the lotus's leaf. From this discovery, several industrial applications were developed, such as self-cleaning paint, glass and fabric. Figure 4 shows a self-cleaning glass. Coating is activated by UV light. Coating breaks down the organic dirt; and by doing so it also reduces the adherence of inorganic dirt. Then, rain washes away the dirt.

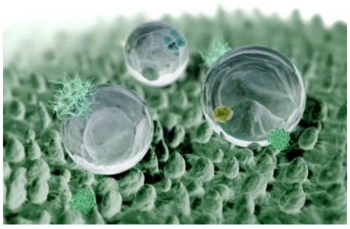


**Figure 4.** Biologically inspired design: self-cleaning glass as self-cleaning lotus's leaf

The first approach in biomimicry design is called "biomimetic design process from a problem to biology"[2]. The second approach is called "biomimetic design from biology to an application"[3].

### 3.1.3 BIOMIMIETRIC DESIGN PROCESS FROM A PROBLEM TO BIOLOGY

The biomimetic design process that moves from problem to a biomimetic solution is shown in Figure 5. There are six major steps in this methodology, including feedback loops, if the solution is not satisfactory.

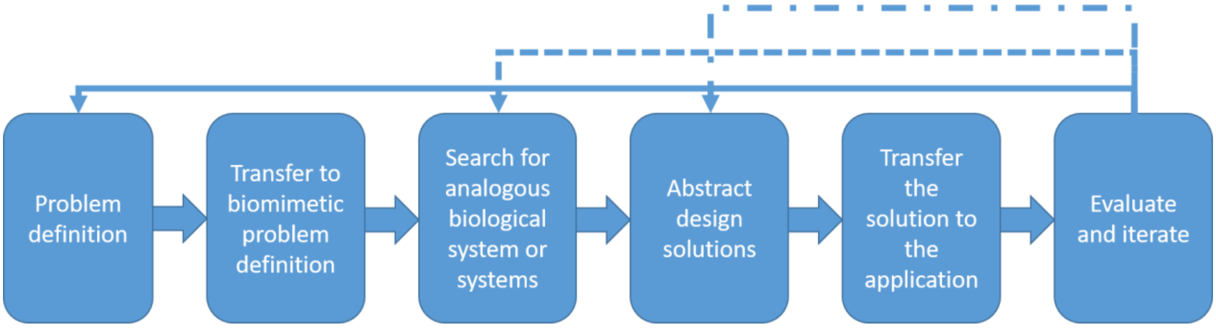



**Figure 5.** Biomimetic design process from problem to biology[4]

Problems are derived from customer requirements or from some observed opportunity and transformed by designers to technical specifications. In order to search for relevant solutions in nature, technical specifications have to be deployed into biomimetic oriented specifications that support the biological search. This process is called "bridging problem to biology". In order to perform this step, the guiding question is: "How do biological solutions accomplish function X?? The flow is shown in Figure 6.

[2] Springer International Publishing Switzerland 2016 Y.H. Cohen and Y. Reich, Biomimetic Design Method for Innovation and Sustainability, DOI 10.1007/978-3-319-33997-9_2
[3] idem
[4] Idem, processed scheme

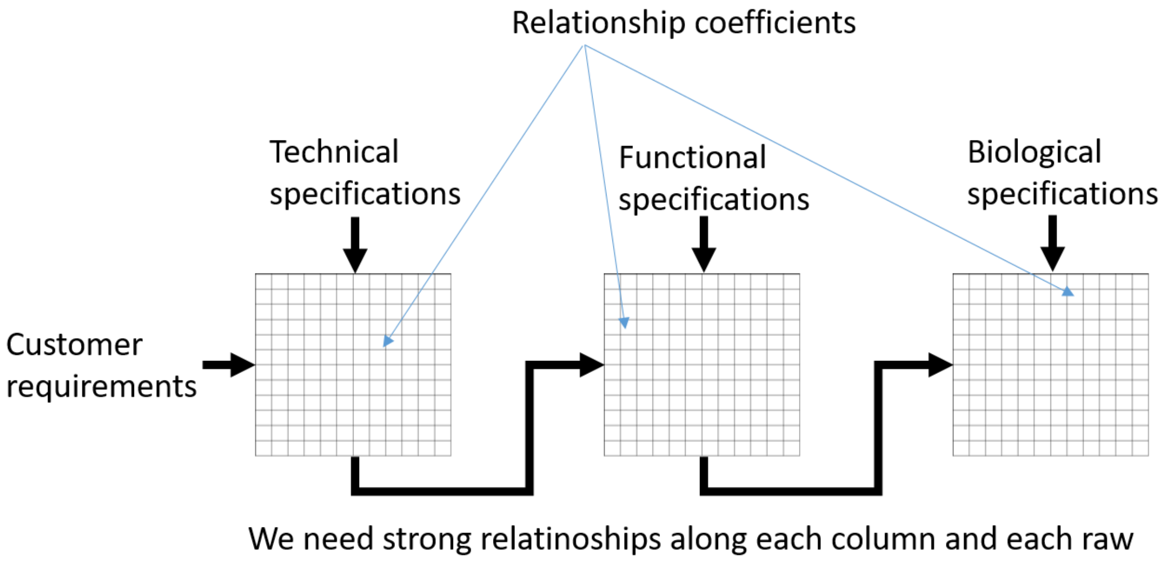



**Figure 6.** Deployment of customer requirements into biological specifications

Abstraction in the context of biomimetic design is the process where biological knowledge is translated into some working principles, strategies or representative models that explain the biological solution. This requires to simplify the biological complexity into some transferable design mechanisms or principles. The biological system is presented in the context of analogical reasoning. This creates the language that allows a designer to go back and forth, detaching from one domain and moving to the other to transfer the required knowledge. The abstraction stage is the core of the biomimetic design process. Thus, the model of a biological system is transferred into a model of a technical system. This means, we need to elaborate also the model of the biological system. It is a process that involves interdisciplinary teams. Abstraction requires knowledge about the biological solution. In case the available knowledge in the literature is not sufficient to understand the biological mechanism, further investigations are needed. The biological model has to explain how the problem is solved in biology and it is important to include references to functions, structures, behaviours, design principles or strategies in case they are related to the solution. Abstracted principles regarding biological solutions tend to indicate more biomimetic concepts, comparing to information about forms and behaviours of biological systems.

Exercise 1: think about your company. Can you Imagine a biomimetric design for one of your product? If yes imagine how can you solve such a design problem.

Can you elaborate a model of a biological system that is transferred into a model of a technical system?

Do you think there are ufficient in company resources to do so?

Check point 3.1.5 for examples

## 3.1.4 BIOMIMIETRIC DESIGN PROCESS FROM BIOLOGY TO AN APPLICATION

Biomimetic design process that considers discoveries from biology to innovations in industry is illustrated in Figure 7.

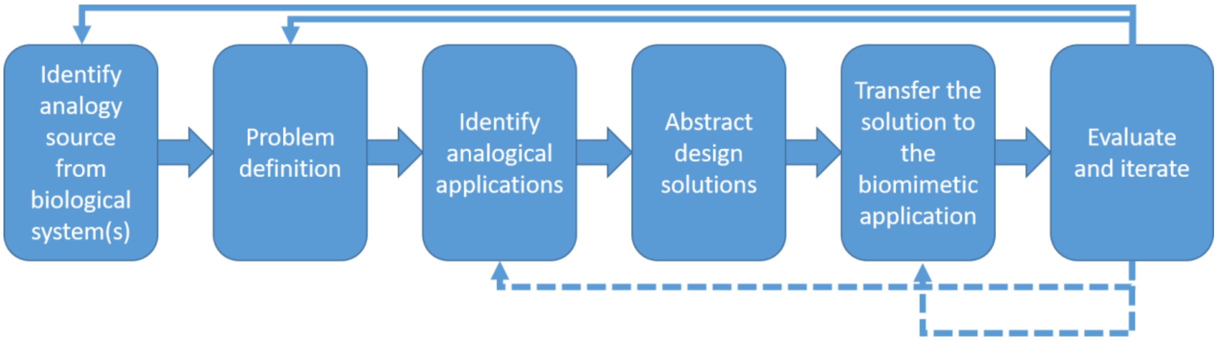



**Figure 7.** Biomimetic design process from biology to an application

Many biomimetic innovations occur in a moment of wondering how a biological mechanism works. The lotus effect was discovered when somebody observed a clean lotus leaf in a dirty environment. The way of how penguins stay ice-free though they live in very cold temperatures led to a biomimetic research to prevent ice formation on airplane wings. The wondering moment is called "Bio-WOW moment".

?

Can you imagine the steps from above implemented in your company?

Can you imagine the benefits both for company and environment?

## 3.1.5 EXAMPLES OF BIOMIMICRY IN PRODUCT DESIGN

There are a lot of examples in product design that are led by solutions already met in nature. Some of them have been further selected and shared in this material.

In order to improve dynamic behaviour of cars, Mercedes studied various shapes of fishes. Thus, the car manufacturer proposed some concepts such as the one in Figure 8. The balanced shape reduces air friction at minimum. It would be very possible that the shape illustrated in Figure 8 to be obtained by optimal design, using various evolutionary algorithms and simulation models. However, biological inspiration led in this case to much lower development costs and very short time to reach the optimal solution.

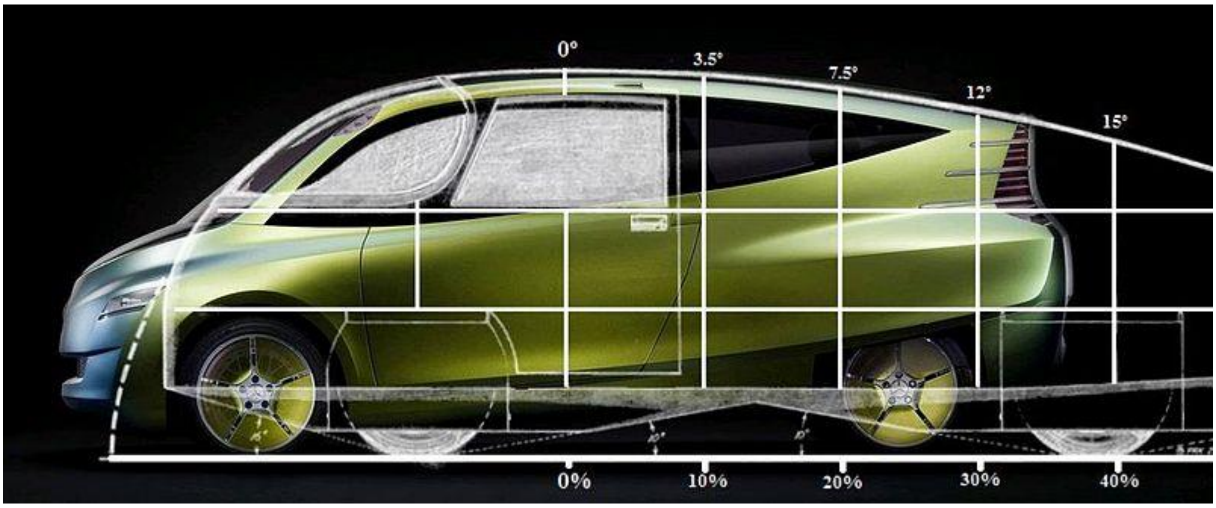



**Figure 8.** Bionic car concept from Mercedes-Benz

Another interesting example is the renewable packaging from Figure 9 (Mushroom® packaging). It is produced from waste of agricultural crops and roots (mycelium) of mushrooms. In this case, engineers observed the properties of mushroom's roots to imitate fabrics.

**Figure 9.** Biodegrabale packaging from mushroom' roots and waste of crops

Figure 10 illustrates a mobile legged robot inspired from the anatomy of dogs. In this case the challenge is not the discovery process, but rather the analysis of dog anatomy for motion: skeleton, dynamic balance, muscle structure and coordination. Transfer of biological model into the technical model is another challenge, because animal anatomy is very complex, including many muscles and a sophisticated system of coordination of motion and balance keeping during various types of movements. Dynamic behaviour requires deep studies in order to formulate a simplified technical model.

**Figure 10.** Bionic dog from Boston Dynamics

JDSU, a company that manufactures testing and measurement equipments, was inspired by the structural colouration of peacock train feather, which is not based on pigments, as in the case of example from Table 1. They designed special structure materials at nanoscale level to indicate various colours as required by specifications. An example is shown in Figure 11. In Figure 12 there are introduced two examples of biomimicry in designing optimal shapes of the blades in the **case of horizontal and vertical wind turbines. In both cases** wales are sources of inspiration. The concept is extended to cooling fans, airplane wings and propellers.

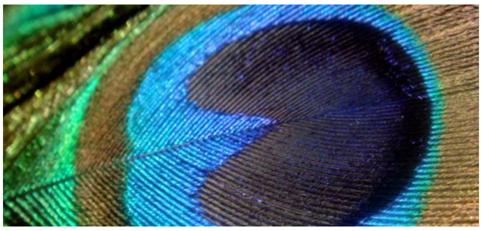


**Figure 11.** Bioinspired colouring from peacock feather

**Figure 12.** Biomimicry in designing optimal blades for H and V wind turbines

**Figure 13.** The flying mechanism of a dragon-fly in avionics

Figure 13 illustrates how the wings arrangement of a dragon-fly was a source of inspiration to design high-lifting capacity in case of helicopters. Other bioinspired solutions in avionics are shown in Figure 14.

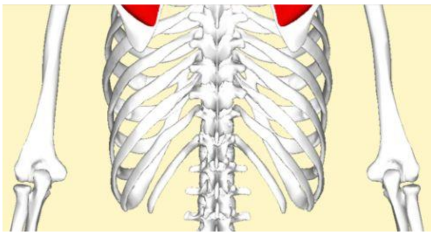
**Figure 14.** Military airplanes inspired from birds of prey

Pharmaceutical companies have shown promising results in treating various parasites in humans such as pinworm, hookworm and giardia with a plant named "Vernonia genus". Scientists who were watching chimpanzees discovered how they behaved when ill and how the chimpanzees seek out the plant "Veronia genus". Even we know that one out of four medicines are derived from a plant, there is still a fraction of the plant world known to humanity. By learning from other species and use the knowledge those species have gathered through their history of millions of years to make our search for new medical plants easier. Another example is the study of trees and human skeleton to improve the strength of technical structures at lower weights and minimal consumption of materials (see Figure 15).

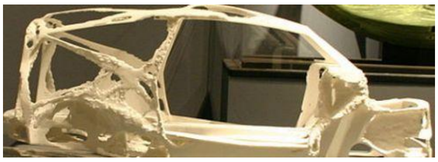
Picture 1

Picture 2

Picture 3



Picture 4



Picture 5

**Figure 15.** Strengthening structures with minimal material use

When looking at trees' structure their branches grow such as to maximize strength and minimize stress. This is performed by adding material and arrange the fibres in optimal places. The "Golden proportion" is often met in such arrangements, too; which is also a value for aesthetics (i.e. 1.618). Bones take this step further by removing material where it's not needed. This is due to the fact that bones have to carry moving loads but trees don't. EvoLogics is a company that developed a high-performance underwater modem for data transmission, being inspired by the way dolphins communicate and process sounds with accuracy. The problem is that the sound waves are affected when traveling through water because of the destructive interference with one another due to reverberation. By imitating dolphins, the new technology uses several frequencies in each transmission. This opens a new door and quality in the safety equipment that is used to let people know if a tsunami is on its way to land. Sensors can be dropped at 6000 meters in the sea and can communicate with satellites. Figure 16 illustrates the construction of this sensor. There are many other cases where biomimicry can be considered to save lives in case of natural calamities. Some examples are further given.

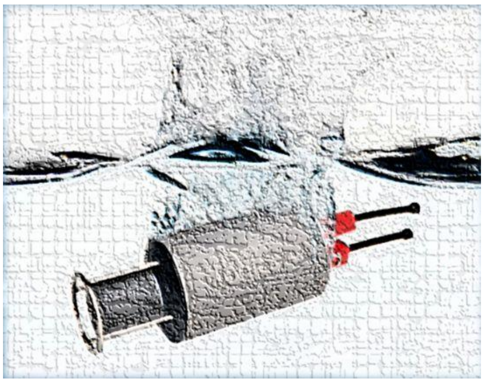


**Figure 16.** Sensor for underwater signal transmission inspired from dolphins

An interesting example is how ants design their nest to drain water in multiple directions, thus avoiding floods. This is shown in Figure 17 This solution can be considered in landscaping and planning to drain water.

**Figure 17.** Water radiation to avoid floods in landscaping

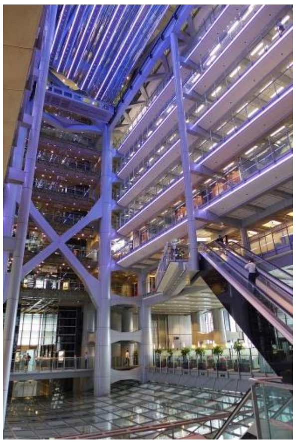


**Figure 18.** Biomimicry in improving building resistance to earthquakes

Another example is shown in Figure 18. It deals with study of human tendons such as to design more robust building structures in case of earthquakes. Thermoregulation by opening/closing vents and manipulating air currents inside the mound of termites is another example used in architecture. They open vents near the bottom to let in cool air, while hot air rises and exits vents at the top. The "Eastgate Centre", a shopping and apartment centre in Zimbabwe is inspired from termites' nest design. There are chimneys on the roof and open vents at ground level. Air enters in the building and is either cooled or heated depending on internal temperature. At night, the building cools. As the day begins and people move around, the building heats up. Hot air exits out chimneys and is replaced by cooler incoming air. By designing the building in this efficient manner the builders were able to save costs because no air conditioning system had to be installed. The lower energy bill continues to save the owners money and as a result, the tenants are charged less rent. This is highlighted in Figure 19.

**Figure 19.** Natural cooling using termite-inspired technology

**Figure 20.** Self-cleaning paint based on lotus hydrophobic properties

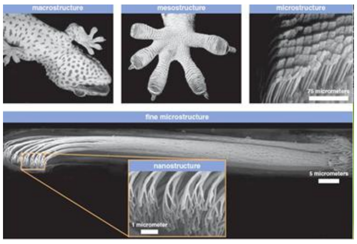
Sto Corp. has duplicated that "lotus effect" in Lotusan, a self-cleaning silicone exterior paint (see Figure 20). The coating, after it is applied, mimics the microstructure of the surface of a lotus leaf. Tiny peaks and valleys on the surface minimize the contact area for water and dirt. As a result, the coating is highly resistant to dirt, mold and mildew, and it offers excellent resistance to weather, chalk and UV rays. Lotusan is a flat finish paint available in 38 standard colours plus custom colour tints. The coating can be used for new construction and recoat projects over concrete, stucco, EIFS, and fibre cement board substrates.


Figure 21. Material able to trap and direct tiny amounts of liquid

The Stenocara beetle is a bug with exceptional abilities for water collection. The bug lives in desert and has a unique design of its shell. Its back is covered in small, smooth bumps that serve as collection points for condensed water or fog. The entire shell is covered in a slick, Teflon-like wax and is channelled so that condensed water from morning fog is funnelled into the beetle's mouth. Researchers from MIT were able to design a special material that is able to collect and channel very tiny amount of water (Figure 21). This material can be used to collect water in very dry areas. About 22 countries around the world use nets to collect water from the air, so such a boost in efficiency could have a big impact. Such materials are called super-hydrophilic, opposed to those inspired from the lotus leaf.


Figure 22. Wetsuit inspired from beaver's layer of blubber

Beavers have a thick layer of blubber that keeps them warm while they're diving and swimming. But they have another trick up their sleeves for staying toasty. Their fur is so dense that it traps warm pockets of air in between the layers, keeping these aquatic mammals not only warm, but dry. Engineers at the Massachusetts Institute of Technology created a rubbery, fur-like pelts that could be used to manufacture wetsuits for surfing, where people move frequently between air and water (Figure 22).




Picture 1

Picture 2

Picture 3

**Figure 23.** Fastening solutions inspired from nature

Figure 23 illustrates some famous solutions for fastening. The left side part of the picture shows solutions inspired from a small reptile called gecko. The right side illustrates Velcro straps. Velcro was invented by the Swiss engineer George de Mestral in 1941 after he removed burrs from his dog and decided to take a closer look at how they worked.

**Figure 24.** Pine cone as source of inspiration for engineering design

Cones produced by such trees as pines, spruce, hemlock, and fir respond naturally to different degrees of humidity by opening and closing, without consuming any electrical energy in doing so. Designing window blinds based on their mechanical properties that could open and close in response to moisture—but use no energy in the process—could conserve a lot of energy (Figure 24). A textile called Inotek has the ability to absorb sweat, in effect pulling it away from the body-leaving the body clean and dry. Using the structure of pine cones as a model, the textile mimics the cones' response to moisture, which opens and closes with higher levels. As sweat migrates toward the fabric, the fibres in Inotek begin to close like a pine cone, keeping moisture out. To keep the fabric breathing, tiny air pockets open along the surface of the textile as moisture sets in.

**Figure 25.** Chameleon inspires paint that can change its colour with temperature

Chameleons have the well-known ability to change colour. They do this by chromatophore expansion (pigment containing cells). This process was used as source of inspiration for paint that can change colour and have thermoregulatory properties (Figure 25). For example, it would be a light colour in the summertime and turn darker to absorb heat during the winter.

**Figure 26.** Structurally stable wheel inspired from bee gofer

The hexagon is the ideal support shape in nature. Circles do not work because there are gaps between adjacent circles. Triangles and squares do not work because they stack in even rows. Hexagons have staggered stacking and thus dissipate forces effectively. Resilient Technologies is a company that designed tires that mimic bees' gofer. These tires cannot pop.

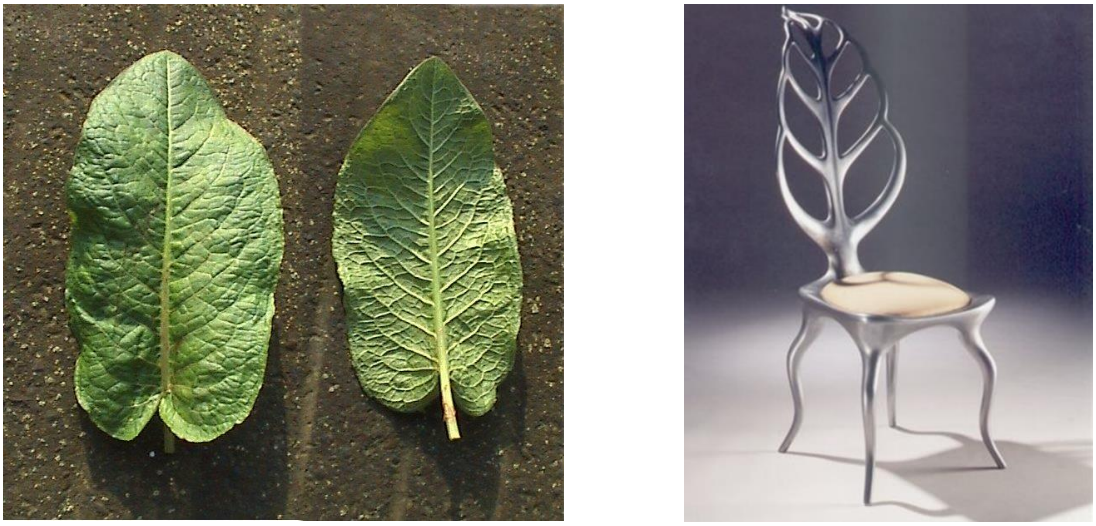


**Figure 27.** Bioinspired form that fits

The last example from this material shows how nature can inspire designers to build furniture (Figure 27). It is both an aesthetic issue and a functional issue, where form fits function.

## 3.2 EXERCISE 1

Select a product that is manufactured by your company or, as an alternative, any product you like. Analyse it from the perspective of biomimetic design. Propose improvements for each of the following steps in biomimetic design process from biology to an application.

| | Task | Description | Connection | Improvement |
|---|---|---|---|---|
| 1 | Identify analogy source from biological sistem (s) | | | |
| 2 | Problem definition | | | |
| 3 | Identify analogical applications | | | |
| 4 | Abstract design solutions | | | |
| 5 | Transfer the solution to the biomimetic application | | | |
| 6 | Evaluate and iterate | | | |

# 4 QUESTIONS & ANSWERS

## 4.1 QUIZ – QUESTIONS BIOMIMICRY

This quiz can be used at the end of the workshop to check whether the key content has been understood and to sum up the most relevant take-home-messages.

1. **Biomimicry generates solutions that lead to:**
   ☐ Zero waste ecosystem
   ☐ Less waste
   ☐ Reuse of materials
2. **The sources of inspiration for biomimicry come from:**
   ☐ Natural processes
   ☐ Natural elements
   ☐ Both
3. **From designers point of view, biomimicry is seen as:**
   ☐ A design tool that emulates strategies used by living things
   ☐ A classical design tool
   ☐ A new strategy
4. **How many design processes are in relation with biomimicry?**
   ☐ 1
   ☐ 2
   ☐ 3
5. **The biomimetric design process has:**
   ☐ 4 steps
   ☐ 10 steps
   ☐ 6 steps.

## 4.2 QUIZ – SOLUTIONS BIOMIMICRY

This quiz can be used at the end of the workshop to check whether the key content has been understood and to sum up the most relevant take-home-messages.

1. **Biomimicry generates solutions that lead to:**

■ Zero waste ecosystem

☐ Less waste

☐ Reuse of materials

2. **The sources of inspiration for biomimicry come from:**

☐ Natural processes

☐ Natural elements

■ Both

3. **From designers point of view, biomimicry is seen as:**

■ A design tool that emulates strategies used by living things

☐ A classical design tool

☐ A new strategy

4. **How many design processes are in relation with biomimicry?**

☐ 1

■ 2

☐ 3

5. **The biomimetric design process has:**

☐ 4 steps

☐ 10 steps

■ 6 steps.

# 5 GLOSSARY

- **Bio-based material:** ""Bio-"is Greek for life. Bio-based material refers to a products main constituent consisting of a substance, or substances, originally derived from living organisms. These substances may be natural or synthesized organic compounds that exist in nature. This definition could include natural materials such as leather and wood, but typically refers to modern materials. Many of the modern innovations use bio-based materials to create products that biodegrade. Some examples are: cornstarch, derived from a grain and now being used in the creation of packaging pellets; bio-plastics created with soybean oil, now being used in the creation of many modern products like tractors, water bottles, and take away cutlery." [5] **Biodegradable material**: "A material which microorganisms can break down into natural elements (i.e. water, biomass, etc.)."[6]
- **Biological metabolism** - The natural processes of ecosystems are a biological metabolism, making safe and healthy use of materials in cycles of abundance[7]
- **Biological Nutrient** - A material used by living organisms or cells to carry on life processes such as growth, cell division, synthesis of carbohydrates and other complex functions. Biological Nutrients are materials that can biodegrade safely and return to the soil to feed environmental processes[8]
- **Cascading**: see MOVECO fact sheet "Circular Economy: Terms & Definitions"
- **Compostable material**: "Materials that can be disposed with biological materials and decay into nutrient-rich material."[9] **Circular economy** - regenerative economy in which resource input and waste, emission, and energy leakage are minimized by slowing, closing, and narrowing energy and material loops
- **Cradle-to-Cradle®:** see MOVECO fact sheet "Supporting Tools for a Circular Economy"
- **Cradle to Grave** – "A Cradle to Grave system is a linear model for materials that begins with resource extraction, moves to product manufacturing, and, ends with a "grave" – when the product is disposed of in a landfill or incinerator"[10]
- **Decision** – "shall be binding in its entirety. A decision which specifies those to whom it is addressed shall be binding only on them"[11]
- **Directive** – "shall be binding, as to the result to be achieved, upon each Member State to which it is addressed, but shall leave to the national authorities the choice of form and methods"[12]

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[5] https://sustainabilitydictionary.com/2006/02/17/bio-based-material/ (26.03.2018) // "A material that is partially, or entirely made of biomass." https://www.ceguide.org/Glossary (26.03.2018)
[6] https://www.ceguide.org/Glossary (26.03.2018)
[7] Cradle to Cradle terminology – MBDC-http://www.c2cproducts.com/detail.aspx?linkid=1&sublink=26
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[11] European Network of Environmental law Organizations 2012 Implementation of the Waste Framework Directive in the EU Member States
[12] European Network of Environmental law Organisations 2012 Implementation of the Waste Framework Directive in the EU Member States

- **Down-cycle** - to recycle (something) in such a way that the resulting product is of a lower value than the original item : to create an object of lesser value from (a discarded object of higher value)[13] see: MOVECO fact sheet "Circular Economy: Terms & Definitions"
- **Eco-Effectiveness** – "The central strategy in the cradle-to-cradle development method and seeks to create industrial systems that emulate healthy natural systems. The central principle of eco-effectiveness is that "waste equals food." The concept was developed in response to some of the perceived limitations of eco-efficiency which critics claim only slow down the rate of environmental depletion and don't reverse the production of unused or non-recycled waste".[14]
- **Eco efficiency** – "Management philosophy that aims at minimizing ecological damage while maximizing efficiency of the firm's production processes, such as through the lesser use of energy, material, and water, more recycling, and elimination of hazardous emissions or by-products."[15]
- **Ecological sustainability** – "a bio-centric school of sustainability thinking that, based on ecology and living systems principles, focuses on the capacity of ecosystems to maintain their essential functions and processes, and retain their biodiversity in full measure over the long-term contrasts with technological sustainability based on technical and engineering approaches to sustainability"[16]
- **Ecosystem** - the interactive system of living things and their non-living habitat[17]
- **Ecosystem redesign** - a coherent framework for redesigning our landscapes, buildings, cities, and systems of energy, water, food, manufacturing and waste through the effective adaptation to and integration with nature's processes[18]
- **Energy efficiency**: "Energy efficiency improvements refer to a reduction in the energy used for a given service (heating, lighting, etc.) or level of activity. The reduction in the energy consumption is usually associated with technological changes, but not always since it can also result from better organization and management or behavioral changes ("non-technical factors")."[19]
- **Energetic use**: incineration of waste material that includes the use of the generated heat and energy for other processes
- **(Final) disposal**: see MOVECO fact sheet "Circular Economy: Terms & Definitions"

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[13] Merriam Webster dictionary
[14] https://sustainabilitydictionary.com/2005/12/03/eco-effectiveness/visited 26/02/2018
[15] http://www.businessdictionary.com/definition/eco-efficiency.html -visited 01.03.2018
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[19] https://hub.globalccsinstitute.com/publications/energy-efficiency-recipe-success/definition-and-scope-energy-efficiency (26.03.2018)

- **Incineration**: Waste destruction in a furnace by controlled burning at high temperatures. Incineration removes water from hazardous sludge, reduces its mass and/or volume, and converts it to a non-burnable ash that can be safely disposed of on land, in some waters, or in underground pits. However, it is a highly contentious method because incomplete incineration can produce carbon monoxide gas, gaseous dioxins, and/or other harmful substances.[20]
- **Innovation** - production or adoption, assimilation, and exploitation of a value-added novelty in economic and social areas[21]
- **Landfilling**: "The disposal and burying of solid waste. The degradation of the waste results in the creation of local air and water pollution."[22]
- **Lean production** - approach to management that focuses on cutting out waste, whilst ensuring quality[23]
- **Life-cycle** - series of stages in form and functional activity through which a system passes between successive recurrences of a specified primary stage[24]
- **Life-cycle analysis**: see MOVECO fact sheet "Supporting Tools for a Circular Economy"
- **Life-time** - the duration of the existence of a given particular system[25]
- **Locational patterns** - the patterns that depict the distinctive character and potential of a place and provide a dynamic mapping for designing human structures and systems that align with the living systems of a place[26]
- **Negative externality** - occurs when production and/or consumption imposes external costs on third parties outside of the market for which no appropriate compensation is paid[27]
- **Optimization** - finding an alternative with the most cost effective or highest achievable performance under the given constraints, by maximizing desired factors and minimizing undesired ones[28]
- **Permaculture** - a system of agricultural and social design principles centered around simulating or directly utilizing the patterns and features observed in natural ecosystems[29]
- **Place** - the unique, multi-layered network of ecosystems within a geographic region that results from the complex interactions through time of the natural ecology (climate, mineral and other deposits, soil, vegetation, water and wildlife, etc.) and culture (distinctive customs,

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[20] http://www.businessdictionary.com/definition/incineration.html (27.06.2018)
[21] with adaptations from http://www.ericshaver.com/the-many-definitions-of-innovation/ (27.06.2018)
[22] https://www.ceguide.org/Glossary (26.03.2018)
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[25] With adaptations from https://en.wikipedia.org/wiki/Lifetime (26.06.2018)
[26] https://www.researchgate.net/publication/273379786_Regenerative_Development_and_Design (25.06.2018)
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[28] http://www.businessdictionary.com/definition/optimization.html (26.06.2018)
[29] https://en.wikipedia.org/wiki/Permaculture (27.06.2018)

expressions of values, economic activities, forms of association, ideas for education, traditions, etc.)[30]

- **Recommendations and opinions** - shall have no binding force [31]
- **Recycling:** see MOVECO fact sheet "Circular Economy: Terms & Definitions"
- **Refurbishment:** "The refurbishment of something is the act or process of cleaning it, decorating it, and providing it with new equipment or facilities."[32]
- **Regenerative design** - a system of technologies and strategies, based on an understanding of the inner working of ecosystems that generates designs to regenerate rather than deplete underlying life support systems and resources within socio-ecological wholes[33]
- **Regenerative development** - a system of technologies and strategies for generating the patterned whole system understanding of a place, and developing the strategic systemic thinking capacities, and the stakeholder engagement/commitment required to ensure regenerative design processes to achieve maximum systemic leverage and support, that is self-organizing and self-evolving[34]
- **Regulation** - shall have general application. It shall be binding in its entirety and directly applicable in all Member States. – Source - Article 288 TFEU, [35]
- **Remanufacturing:** "The process of cleaning and repairing used products and parts to be used again for replacements."[36]
- **Restorative design** - sometimes called restorative environmental design; a design system that combines returning polluted, degraded or damaged sites back to a state of acceptable health through human intervention[37]
- **Resource efficiency**: "A percentage of the total resources consumed that make up the final product or service."[38] re-use: see MOVECO fact sheet "Circular Economy: Terms & Definitions"
- **Secondary resource/ secondary raw materials:** "Waste materials that are recovered, recycled and reprocessed for use as raw materials."[39]
- **Servitization** - refers to industries using their products to sell "outcome as a service" rather than a one-off sale[40]

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[30] https://www.researchgate.net/publication/273379786_Regenerative_Development_and_Design (25.06.2018)
[31] http://eur-lex.europa.eu/summary/chapter/environment.html?root_default=SUM_1_CODED%3D20,SUM_2_CODED%3D2003&locale=en
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[38] https://sustainabilitydictionary.com/2005/12/03/remanufacturing/ (26.03.2018)
[39] https://sustainabilitydictionary.com/2005/12/03/remanufacturing/ (26.03.2018)
[40] https://www.k3syspro.com/servitization/ (24.06.2018)

- **Source to sink** - simple linear flows from resource sources (farms, mines, forests, watershed, oilfields, etc.) to sinks (air, water, land) that deplete global sources and overload/pollute global sinks[41]
- **Stewardship** - ethic of companies, organizations and individuals that embodies the responsible planning and management of resources[42]
- **Sourcing:** "the act of getting something, especially products or materials, from a particular place"[43]
- **System thinking** - holistic approach of analysis and planning that focuses on the way the parts of a system interrelate each other and how systems work over time and within the context of larger systems[44]
- **Technical metabolism** - "Modelled on natural systems, the technical metabolism is MBDC's term for the processes of human industry that maintain and perpetually reuse valuable synthetic and mineral materials in closed loops"[45]
- **Technical nutrient** – "A material that remains in a closed-loop system of manufacture, reuse, and recovery called the technical metabolism, maintaining its value through infinite product life cycles "[46]
- **Upcycle** – "to recycle (something) in such a way that the resulting product is of a higher value than the original item: to create an object of greater value from (a discarded object of lesser value)"[47]
- **Upcycling**: see MOVECO fact sheet "Circular Economy: Terms & Definitions"
- **Waste**: see MOVECO fact sheet "Circular Economy: Terms & Definitions"

More: https://www.ceguide.org/Glossary

[41] https://www.researchgate.net/publication/273379786_Regenerative_Development_and_Design (25.06.2018)
[42] https://en.wikipedia.org/wiki/Stewardship (24.06.2018)
[43] https://dictionary.cambridge.org/dictionary/english/sourcing (26.03.2018)
[44] https://searchcio.techtarget.com/definition/systems-thinking (27.06.2018)
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**Online resources**

Biomimicry institute https://biomimicry.org/

Janine Benyus - Biomimicry 3.8 https://biomimicry.net/

**Online video sources**

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# 7 IMPRINT

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