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# Biomimicry – a useful tool for the industrial designer?

Shedding light on nature as a source of inspiration in industrial design

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## ABSTRACT

Designers and engineers are constantly searching for inspiration to solve their problems. One source of inspiration that has been used to some degree for centuries is nature. This practice is often referred to as "biomimicry"; innovation inspired by nature. This paper reviews existing literature and explores biomimicry information relevant for industrial design, as it is rather dispersed or intertwined with information from other areas. Perceived benefits and pitfalls are critically discussed, and the paper stipulates that to get the most out of biomimicry, it should be regarded as a way to enlarge the designer's solution-space. When used reductively - with the goal to find a solution, not to necessarily create an ecologically sound product – biomimicry can be seen as a supplement to the designer's existing toolkit. However, it should not be used bombastically and without consideration as if only nature holds the most suitable solution a design challenge. The paper includes the presentation of a newly developed tool for designers in the form of a card deck, displaying categorized sources of inspiration towards design solutions. This provides industrial designers with an easy starting point to work with this subject.

**Keywords:** ***Biomimicry, industrial /product design, inspiration, analogies, designer's toolkit***

## 1. Introduction

Designers and engineers are constantly searching for inspiration to solve their problems. One source of inspiration that has been used to some degree for centuries is nature, which has helped solve many problems of humanity through biological forms, mechanisms, systems, and analogies. In the industrial design-world this trend has previously not been too evident, but lately there have been serious attempts to tap nature for design-inspiration. This practice is referred to as "biomimicry"; innovation inspired by nature [1]. The goal of this article is to explore the use of biomimicry specifically for industrial design. The article also seeks to provide a starting point for industrial designers and students to work with this subject, as a literature base to help industrial designers get to know and approach biomimicry seems to be lacking. The current relevant information is rather dispersed, or intertwined with information from other areas. A reason why looking at biomimicry from an industrial design point of view is of interest, is because many of the disciplines from which industrial design incorporates knowledge, for example architecture, materials science, and mechanical- and structural engineering, have used biomimicry to come up with valuable solutions.

## 2. Definitions

"Biomimicry" literally means the imitation of life, the word coming from a combination of the Greek roots *bios* (life) and *mimikos* (imitation). However "biomimicry" is not a clearly defined term, and has many more or less synonymous notions, amongst these biomimetics, bionics, biognosis and bionical creativity engineering There are also disciplines bordering on biomimicry that use similar names, for example biomechanics and biophysics. In defining biomimicry, this paper follows Kennedy's definition [1]

> *Biomimicry (…) refers to studying nature's most successful developments and then imitating these designs and processes to solve human problems. It can be thought of as "innovation inspired by nature".*

Biomimicry does not usually mean the direct transfer of an observation in nature to the development of a product, but rather the creative implementation of biological concepts into products. The reason why biomimicry seldom involves direct copying of nature is explained by professor Robert J Full of the Department of Integrative Biology at The University of California, Berkeley [2]

> *Evolution isn't a perfecting principle; it works on the principle of "just good enough". If you really want to design something for a task, you have to look at the diversity of organisms out there and then get inspired by principles.*

A lot of the literature regarding biomimicry uses the terms "design" and "designer" as umbrella-terms to cover all kinds of creative activities and the individuals who perform them. However, for the purpose of this paper these terms are narrowed down and used more deliberately. Here, the term "designer" will be used to describe an individual working within the arena of industrial design, defined as

> *…the professional service of creating and developing concepts and specifications that optimize the function, value and appearance of products and systems…*

Following this definition, the "categories" of biomimicry considered in relation to design in this paper can be loosely grouped into four groups. The groups refer to those areas of industrial design where the use of biomimicry seems most feasible; 1) Materials (material science), 2) Mechanics/dynamics (general engineering and locomotion), 3) Structure (structural engineering and architecture), and 4) Form (architecture and art).

## 3. On Biomimicry

The term biomimicry first appeared in 1962 as a generic term including both cybernetics and bionics. In those days the term biomimicry referred to all kinds of imitation of one form of life by another, while the term bionics was defined as '…*an attempt to understand sufficiently well the tricks that nature actually uses to solve her problems'* [3]. Thus the term bionics was actually used earlier to cover more or less the same area as the term biomimicry does today. Biomimicry has lately become the preferred name, especially through Benyus' standard book [4]. Even though Benyus fronts biomimicry from an ecologically motivated point of view, today's increasing interest for biomimicry is only to some extend motivated by this. One of the major reasons why biomimicry is catching on may simply be that for the first time in history, we are currently at a point where we have the brainpower and tools to analyze nature, and to learn from its 3.8 billion years of research and development. Also, we have developed networks that allow professionals from different areas to work together as is necessary in order for biomimicry to be successful. To support this Julian Vincent, professor of biomimetics at the University of Bath, suggests that the potential for biomimicry is large [16]:

*...at present there is only a 10 percent overlap between biology and technology in terms of the mechanisms used.*

### 3.1 Approaches to biomimicry

As well as differences in how biomimicry is defined, differences exist in opinion concerning how biomimicry should be applied. These centre around two views often named the "reductive view" (or shallow biomimicry) and the "holistic view" (or deep biomimicry). In short, the reductive view sees biomimicry as a transfer of "biological technologies" into the engineering/design domain, whilst the holistic view sees biomimicry as a measure to achieve ecologically sustainable products, meaning products that do not harm the environment in their production, use or decay. The explanation of reductive biomimicry can be elaborated by recognizing that this approach focuses solely on the imitation of "a few features or functions of particular organisms or biological processes" [5]. This is the "traditional" kind of biomimicry, and does not have any explicit goal of obtaining sustainability through the mimicry of nature.

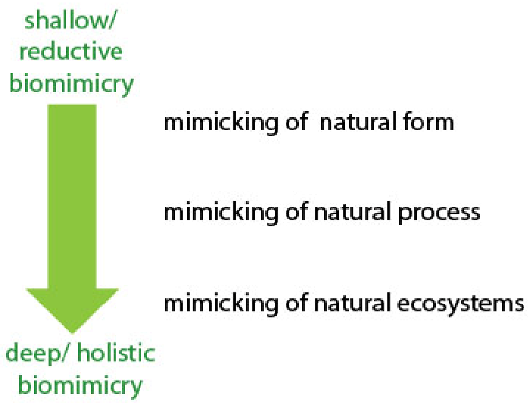


**Figure 1. Levels of biomimicry**

When discussing biomimicry application in design, Benyus divides biomimicry into three levels, from shallow to deep biomimicry. Reductive or shallow biomimicry composes the first level, and involves the *mimicking of natural form* (Figure 1). An example is mimicking the hooks and barbules in an owl's feather to create a fabric that opens anywhere along its surface. In line with the explanation of reductive biomimicry, this will help solve a specific problem, but there is no guarantee that is will yield an environmentally sustainable solution. This is pointed out by Bras et al. [5], stating that because biomimicry is an effort to imitate life, and life has proven to be sustainable, it is easy to believe that a biomimetic product will automatically be less ecologically damaging (less unsustainable) than non-biomimietic products. However, test results show that reductive biomimetic products cannot be regarded as more sustainable than the norm [5].

The second level involves *mimicking of a natural process*. This is a step towards deeper or holistic biomimicry, as production processes found in nature do not harm nature. For example, the owl feather self-assembles at body temperature without toxins or high pressures, by way of nature's chemistry.

At the third level, *mimicking of natural ecosystems* is classified as deep or holistic biomimicry. This view involves considering the whole way in which nature manages to produce without damaging the environment, through considering everything as part of a whole system. According to Belletire [6], for the designer wishing to act according to this principle this will mean becoming

*…versed in life-cycle planning that considers each step in the product design process, starting with the extraction of raw materials and ending with renewal or reuse of the manufactured product.*

The holistic view of biomimicry is thus an "eco-design" orientated approach. Followers of the holistic view acknowledge that a reductive approach to biomimicry "adds to the knowledge in specific domains while providing valuable new technologies" and emphasize that the reductive focus successfully achieves what it is after, namely being a "…tool for solving particular problems…in certain stages of the design process" [6]. However, the holistic viewers proceed by saying that

*…this reductive mindset holds important ramifications for biomimicry's application to sustainable engineering"* [6]

implying that, in their opinion, biomimicry reaches its full potential only when it is used in a holistic context. In this article however, biomimicry will be considered in its traditional way, i.e. reductive form, as the research question posed in the title seeks to clarify the usefulness of biomimicry for the sake of industrial design solutions, not of the environment.

### 3.2 Different applications of the reductive view

<u>Application 1</u>

This application is based on mimicking nature by trying, for example, to recreate properties of natural materials in a laboratory (not the material itself). Due to the technological requirements needed in this type of projects, this application is a fairly recent one, and always requires engineering efforts. An example is the development of artificial nacre (mother-of-pearl, Figure 2). This ceramic, found on the underside of the Red Abalone shell (Haliotis Rufescens) is twice as tough as high-tech ceramics, composed of alternating layers of calcium carbonate (in a special crystal form called aragonite) and Lustrin-A protein. The combination of hard and elastic layers gives nacre remarkable toughness and strength, allowing the material to slide under compressive force (Figure 3). The ability to nano-manufacture artificial nacre may provide lightweight, rigid composites for aircraft parts, artificial bone and other applications [7].

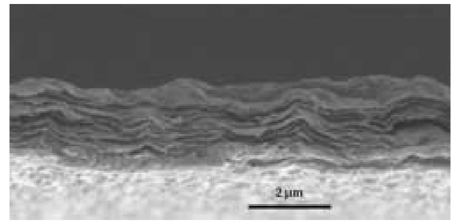


**Figure 2. Microscopy image of nacre [8]**

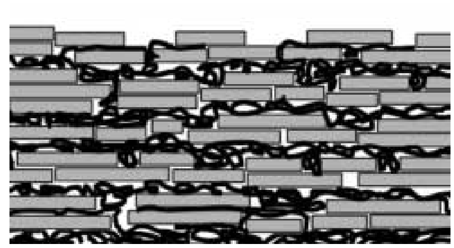

**Figure 3. Illustration of artificial nacre structure [8]**

<u>Application 2</u>

This application involves developing materials, products and systems through using analogies and metaphors from nature, and seeking [8] inspiration through systematic studies of nature. In this application, projects can be of a principally engineering or art- like nature. An example is the development of a self-sealing valve for a bicycle water bottle by the American design-firm IDEO. Normally, a cyclist has to draw out the nozzle with his teeth, squirt water into his mouth and then close the nozzle with his teeth again to prevent spillage and the entry of dirt into the bottle. The self-sealing valve mimics the tricuspid heart valve and only lets out water when it is squeezed, so that the cycler can open, drink and close in one motion [9].

<u>Application 3</u>

This application consists of using form/shape language from nature to create aesthetically pleasing products. It is used in design projects with a strong art-component. Examples include Antonio Gaudí´s buildings with rich, organic forms and decorations. Another aspect is the creation of understandable/approachable products using analogies to known things. An example where nature can be this "known thing", is how car headlights shaped as "aggressive eyes" can give the impression of a sporty and aggressive car, whilst "friendly eyes" can create the impression of a conservative and safe car (Figure 4).


**Figure 4. Cars with "friendly" and "aggressive" eyes.**

These three applications can be seen in relation to the 4 categories mentioned in chapter 2, showing the groups in which they will most likely be used (Figure 5). The figure also indicates whether a project in a certain category is likely to be more or less engineering or art oriented. Note that with Application 1 and 2 the designer or engineer uses biomimicry in a way that might not always be apparent to the user. In Application 3 the user is more likely to be able to recognize that biomimicry has played a part in the development of the project.

| | | |
|---|---|---|
| Materials<br>material science | Approach 1 | engineering |
| Mechanics/Dynamics<br>general engineering, locomotion | Approach 2 | |
| Structure<br>structural engineering, architecture | Approach 2 | |
| Form<br>architecture and art | Approach 3 | art |

**Figure 5. Applications in relation to design aspect categories.**

## 4. Biomimicry in industrial design

This section presents a number of case studies to show existing cases of biomimicry that can be regarded as industrial design. None of the examples are regarded as purely engineering or art, emphasizing that industrial design often lies in the middle of the two. The cases are chosen to give an idea of the scope of projects that can be achieved with biomimicry. Figure 6 shows how the cases relate individually to the applications as summarized in Figure 5. In the figure, A1, A2 and A3 represent applications 1 – 3.

| Case study | A1 | A2 | A3 |
|---|---|---|---|
| 4.1 Entropy carpet tiles | | ● | ● |
| 4.2 Boxfish car | | ● | ● |
| 4.3 Gecko tape | ● | ● | |

**Figure 6. Visual summary of case studies in relation to applications**

### 4.1 Case: Entropy carpet tiles

Normally, carpets are woven in rolls on broadlooms. There is a pattern on the broadloom, so one must ensure that the pieces are laid down perfectly to match the pattern when the carpet is cut into tiles. The ends of the roll therefore become waste, because they do not fit into the pattern. Interface, the world’s largest commercial carpet manufacturer, designed its Entropy carpet tiles to challenge this notion. Inspired by the fact that when a leaf is picked off the forest floor the forest floor is still beautiful, Interface designed a random, non-directional built-in pattern similar to that of a forest floor. Made from recyclable nylon and using a single dye lot that has 48 different color ways, the Entropy carpet tiles can be moved anywhere, face any direction; if a carpet tile wears out in a high traffic area or gets stained, it can be readily replaced. Randomness hides any evidence that older tiles are among newer ones, and the lifecycle for the whole carpet installation is extended. Following the success with Entropy, Interface has introduced a whole new product category of sustainable biomimicry inspired carpets named i2, and have subsequently launched over 100 additional i2 products.

### 4.2 Case: Boxfish car

To create a biomimetic concept car, designers and engineers at Mercedes-Benz looked for a specific example in nature. They searched not only for inspiration for an aerodynamic, safe, comfortable and environmentally compatible car in terms of details, but also for a formal and structural whole. The example they arrived at was a tropical swimmer; the boxfish

**Figure 7. Boxfish (Ostracion cubicus) [9]**

**Figure 8. The Mercedes-Benz car concept [10].**

(Ostracion cubicus, Figure 7) which has several characteristics that could be useful in a vehicle. Despite its boxy, cube-shaped body, the fish is outstandingly streamlined and therefore represents an aerodynamic ideal with a very low wind drag coefficient, a very important factor in car development. Through designing the car-body in accordance with the principles of the boxfish, 20 percent lower fuel consumption was achieved (Figure 8). The species' outer skin is composed of a vast number of hexagonal bone plates that overlap to form a rigid armor. This bony comb-like structure gives the fish a remarkable rigidity, protecting it against injuries, and it is also the key to its perfect mobility. This principle was transferred to the car, and up to 40 percent more rigidity was achieved in the external door paneling compared to conventional designs. Calculations showed that if the entire body-shell was made according to this principle, total weight could be reduced by around one third without diminishing strength and crash safety.

### 4.3 Case: Gecko tape

Several institutions worldwide have been involved in projects to mimic the mechanism employed by for example the gecko lizard to walk on surfaces, including glass. Research shows that gecko feet are covered with fine hairs (setae) or bristles which increase the contact area with the surface. Each of the bristles adheres to the surface using positive and negative molecular charges that create Van der Waals forces. These are the smallest existing attractive forces, but when combined by the billions they form the strongest adhesives known to man. Based on these discoveries scientists have developed a new adhesive, "gecko tape", containing billions of tiny plastic fibers, less than a micrometer in diameter, which are similar to the natural hairs covering the soles of geckos' feet. One square centimeter of gecko tape could support a weight of one kilogram. In addition, the feet of a gecko are self-cleansing, and the adhesion does not diminish in liquids or vacuum. Another interesting characteristic is that gecko tape can be reapplied and reused as it is easy to remove from the surface it is stuck to simply by levering the hair upward at a 30-degree angle [11]. Other animals that use the same principle as the gecko include beetles, spiders and flies. Figure 9 shows the principle of contact division in biological contact systems: heavier body weight requires finer surface structures (setae) in order to stick better to surfaces [12].

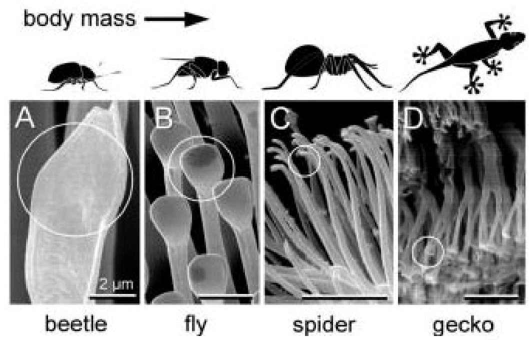


**Figure 9. Principle of contact division in biological contact**

### 5. Existing tools to incorporate biomimicry into the designer's toolkit

In order to help convert biomimicry from theory to practice like the cases in chapter 4 show, various methodologies have been developed. This is because even for designers that are aware of biomimicry and the opportunities it offers, the necessary biological material is often hidden in technical, scientific papers written for biologists, and rarely organized so that it is accessible to design and engineering functions. In 5.1 and 5.2 some attempt to overcome this are briefly discussed. Section 5.3 discusses these tools critically.

### 5.1 Biologists at the Design Table

Biologists at the Design Table (BaDT) is an effort started by The Biomimicry Guild to help introduce biologists to the design process [13]. The BaDTs are biologists who have training in a biomimicry design methodology developed by Benyus and biomimicry.net, and who excel in searching through biological research. They can find the natural strategies that meet specific design challenges, and assess which of those designs or system strategies are most promising. The biologists are experts at translating nature's strategies into strategies that meet design problems. They can also deliver feasibility analyses and plans of action for implementation of selected bio-inspired strategy. The service also exists as a service called "Dial-a-Biologist" which is an on-call biology service. Here, experts answer technical questions and partake in brainstorming to detect ways that nature's ideas can help improve a product or process. The service also provides lectures, workshops and networking between researchers/ scientists and design companies.

### 5.2 Databases

Several attempts have been made to develop databases to present designers and engineers with an easy and clear way to search for and access the biological information they need. Three attempts worth mentioning are:

- **The Biomimicry Database** is currently under construction by the Biomimicry institute and "…intended as a tool to cross-pollinate biological knowledge across discipline boundaries" [14]. It will be a place where designers, architects, and engineers can use advanced tools to search biological information, find experts, and collaborate to find ideas that potentially solve their challenges. The Biomimicry Database will include six different types of information to search/enter; challenges, strategies, organisms, people, citations and products.
- **The Chakrabarti system** is a method for generating novel solutions for product design problems developed by Chakrabarti and presented by Kolle [15]. The method seeks to provide analogical ideas for design, which can be biologically or artificially inspired. It is based on two parallel databases - one describing natural systems capable of certain motions (e.g. insects-flying, fish-swimming, grasshopper-jumping) and another containing artificial mechanical systems capable of various behaviours (gear-transmission, vacuum cleaners-suction, hole puncher-punching holes) –to facilitate interactive, analogical generation of alternative ideas relevant to solving a design problem. In order to do this, a common language for describing the motion behaviors in the two databases was developed. Testing of the system has shown that the subjects are able to produce a significant number of additional solutions using the software, but the results do not show how many of these solutions originate from the biological database.
- **TRIZ** is a well-known tool for creative innovations, based on a database of solutions from different domains, a list of 40 inventive principles distilled from an extensive analysis of successful patents, a procedure for abstracting problem definitions to a general state where they can be compared to any similar principal solution, and a contradiction matrix used to map relationships between the principal problems and the inventive principles [12]. Currently, not much biological data is included in TRIZ. However, a programme of work to integrate knowledge from the biological and biomimetic sciences into the TRIZ framework is currently being carried out at the University of Bath [16].

### 5.3 Critique of tools

The tools discussed above have been created to aid designers to access the large amount of biological data available from researchers. The designer's goal is often to find solutions to specific problems, and the tools are suited to this. These tools are good attempts to help designers use biomimicry in an efficient, logical and solution-orientated way, however some drawbacks exist. All are to some extent still in the development or initiating stages (concerning biomimicry), and as such it is difficult to predict there usability. In addition, The Biologists at the Design Table initiative, although a very hands-on way for designers to connect with biologists, is likely to be too expensive for freelance designers or small design studios. Also, an initial active choice to apply biomimicry in the project seems to be required to actually go to the step to use these tools, and this would be based on the expectation that the best solution to the problem is actually to be found in nature.

The databases mentioned, even if mostly still under development, could prove useful. They can be used more “sporadically” by designers searching generally for a solution, not requiring that biomimicry has been chosen as the “only way to go”. However, software access and possible subscription fees could pose problems, and another possible disadvantage is that the database systems involve learning a formal language to be able to search properly, requiring time, effort and maybe money from the designer or company. Therefore, it could be useful to have a tool that could help indicate to designers early in the design-process and without demanding a great deal of resources if biomimicry might be of interest in their particular project.

**6. Development of a new tool – The Biomimicry Card Deck**

Based on the considerations from 5.3, a Master level project at The Department of Product Design at NTNU resulted in the development of a biomimicry-inspired deck of cards, to help industrial designers enlarge their solution space for problem solving through biomimicry. The inspiration behind using the card-deck format was that the tool should be easily, quickly and cheaply accessible. Several themes for decks were explored with specific design challenges in mind; Figure 10 shows an example from the “packaging design” deck, which was developed into a prototype. Each card in the deck treats a specific example of how nature has solved the challenge of packaging. The picture-side of a card helps the designer get visually inspired by how nature has solved the problem, and the information-side presents information about the organism in question and why it might be interesting. Sources of further information are provided on each card. Using two or more packs of “Biomimicry Cards” together in a game of “Forced relations” is another way to use the cards; by combining cards from different packs in non-apparent ways, new combinations of possible product aspects and features can be discovered.


**Figure 10. Front and back side of a sample biomimicry card**

**7. Criticism of biomimicry**

In the case studies in chapter 4, the usefulness of biomimicry in industrial design has been highlighted, and to some extent ‘proven’. Even though biomimicry is viewed by some as the answer to many of man-kinds creativity and also ecological problems, several concerns exist. Many of these criticize the holistic view (which has not been the main theme of this paper) and the problems and contradictions this involves. However, some criticism towards biomimicry on the whole exists, thus including the reductive view.

Kaplinsky [17] points out that in biomimicry there can be an idolization of nature that in its extremity “…seeks to cut humanity and human achievement down to size”. His concern is that biomimicry and its focus on nature stands in contradiction to the human-centered outlook of industrial design, and that biomimicry fails to take notice of the complex network of human society which all designs work within. An answer to Kaplinsky's concerns could be that design is always *for a user*, and when biomimicry is seen as a possible way to enrich the solution space for design problems defined *based on the user*, there should be no colliding interests in using biomimicry in design.

Kaplinsky further points out that many biomimicry followers think of nature's design as optimized, even though only humans can optimize as, evolution can only proceed by small steps and never start from scratch. Nature's incremental optimization can produce some distinctly suboptimal results; no designer would make the nerve connection between the brain and larynx of a giraffe by looping it all the way down the neck and back up to the throat, like it is actually done in nature. Evolution however, was constrained by the anatomy of the giraffe ancestor, in which the nerve looped around a blood vessel at the base of the neck. Unlike nature however, human imagination can make leaps and work on radically new designs. As Kaplinsky puts it: "human innovation is at its most brilliant precisely when it moves beyond incrementalism".

A last word of critique towards biomimicry is that many past projects using biomimicry have been concept projects, like the Boxfish car (the case in 4.2); a success in testing and as a concept, but never launched. An explanation for this may be in the fact that, although biomimicry as a design approach is currently gaining momentum, it has formerly been the fascination of individuals, not (yet) necessarily of firms and corporations with the power and funds to commercialize products.

## 8. Discussion

Although the cases discussed in this paper are few in number, it seems that industrial designers embarking on projects with a mechanical/ dynamical and/or structural component are likely to find biomimicry to be an interesting arena to search for possible solutions. This seems logical, as natures engineering by necessity is "intelligent" as far as building (for example strong, lightweight constructions) and movement (for example the most logical pattern of movement is often the most energy efficient) goes. In general, projects involving some kind of "mechanism" in its function seem to be likely to benefit from biomimicry. In relation to Figure 6, these are projects situated in between art and engineering, not at the extremes of the spectrum.

For projects on the engineering side of the spectrum, designers are sometimes the first ones to recognize the need for a material with a specific set of qualities, and can thereby initiate research that could be of interest to pursue further for material scientists. Biomimicry is likely present many interesting solutions in the field of material science, even though the ones to use biomimicry to its fullest extent in this way might well be scientists, not designers.

On the art side of the spectrum, there are several examples of product styling inspired by nature (such as the Boxfish car and the Entropy carpet-tile), and nature does indeed have a richness of forms and shapes that can be of great inspiration in aesthetical, art-like designs, while delivering functional advances as well (*e.g.* reduced air-drag). Nature can inspire in developing aesthetically appealing products, as shapes derived from nature seem approachable and comforting. In general, one can say that projects involving a large amount of styling can benefit from biomimicry in the way that by browsing the array of forms that nature holds, designers are likely to find a large amount of inspiration for styling.

## 9. Conclusion

This paper has attempted to provide an overview of biomimicry for industrial design, and to provide a starting point for industrial designers to work with the subject. Through the exploration and case-studies in the paper, examples have shown that biomimicry can be very useful to the industrial designer. The main challenge seems to be how to access the information needed to use biomimicry in an effective and successful way. In response to these findings, an alternative, introductory tool has been introduced.

The important aspect to remember is that design is about arriving at the most satisfactory solution regardless of origin. This may sometimes imply using biomimicry, and sometimes not. To get the most out of biomimicry, it should be regarded as a way to enlarge the designer's solution-space; as an extra arena in which to search for solutions. When used reductively - that is saying with the goal to find a solution, not to necessarily create an ecologically sound product – biomimicry can be seen as a supplement to the designer's existing toolkit. However, it should not be used bombastically and without consideration as to if it is actually nature which holds the most suitable solution for the problem in hand. Other aspects to remember when considering using biomimicry, is that design-projects tend to have time- and fund constraints, and a demand to get products into production and commercialized. This implies that the designer in every project must contemplate whether biomimicry is the right way to go about finding the solution to her specific problem.

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