10th Conference on Engineering Education for Sustainable Development (EESD2020)

Nature knows better?

Nature as exemplar and/or inspiration?

Laura (L.L.) Stevens[2], Karel (K.F.) Mulder[1, 2], Helen (H.N.) Kopnina[2], Marc (M.J.) De Vries[1]

[1]Delft University of Technology, Delft, the Netherlands

[2]The Hague University of Applied Sciences, The Hague, the Netherlands

laura.l.stevens@gmail.com

Abstract

The arising of the industrial society and the growth of human population have been main causes of resource depletion, climate change and the decline of ecosystems. Industrial systems and technologies have brought economic and public health progress, leading to an unprecedented population in relatively good conditions. But often, the new technologies that enabled this development turned out not to be the miracle solutions that they had been claimed to be: plastics contained toxics and caused world-wide litter, industrially processed food turned out to be a threat to public health, information and communication technologies provided a wealth of information but also threatened democratic society, and military technologies to secure freedom threatened humanity's very existence.

In reaction, there was a tendency to return to natural products and production processes. 'Industry' and 'Modern Technology' became suspect. Slogans emerged that emphasized the value of nature: 'Nature knows better' emphasizing healthier products without synthetic chemicals and "Nature does not produce any waste" criticizing the whole industrial society. Many of these slogans are in fact not verifiable empirical statements, and some of them are erroneous. Hence, 'natural' and 'nature derived' products and production processes are not a priori to be preferred above man-made products as the sustainable solution. Why are man-made products and processes not considered to be natural like the ones made by other animals? The first question that this paper addresses is how to assess 'natural'-, 'nature derived'- and 'classic' solutions to design challenges. In the first part of the paper, it is shown by various short case studies that design solutions from nature have survived long periods of selection pressure, which implies that they are in balance with their natural environment.

The vast number of specific niches that ecosystems provide has created an abundance of natural design solutions. Hence, in the second part, the question will be addressed if the study of 'natural principles' can help industrial designers to think outside the box.

Understanding biological analogies remains difficult for design students. Preliminary empirical research showed students using these, intentionally or unintentionally, copied aspects which are often misinterpreted into their design, i.e. blindly copying form while leaving out process or system. Biomimicry education offers new and compelling insights to measure and evaluate products, aiming to improve the sustainability score. This study reviews basic steps on how biomimicry could improve design education.

Keywords: Biomimicry, Natural Principles, Technology Assessment, Technological Hazards, BioBrainstorm, Distant Analogies, Design Thinking, Design Education

1. Introduction

1.1. Technology and its impacts

The emergence of the industrial- and the post-industrial information society has often been criticized for all its (often undesired and unforeseen) (side-) effects. Historically, the first worries about the impacts of human activities led to the conservationists' movement which aimed at protecting endangered species and created the first natural parks such as Yellowstone Park in 1872. Preservationists went one step further; they claimed that not only species were endangered, but nature itself [1].

In more recent history, especially the criticism of Rachel Carson created a watershed; Carson showed that human activities not only threatened species, ecosystems, and even nature, but also the human society itself. Carson showed that technology not necessarily created 'progress' for society, but could in fact have more hazardous impacts for society than positive contributions. Especially chemicals were the focus of her criticism [2].

In reaction to Carson's criticism, there was a tendency for more natural materials: wool, cotton and linen terminated the advance of synthetic textiles[3, 4, p. 226]. The use of agro-chemical was quantitatively and qualitatively reduced. Natural solutions were considered better. The argument was often based on quality: synthetic materials were often highly flammable, lost their colours rapidly, and were sometimes irritating the skin. Agro-chemicals were criticized for leaving harmful residues at agricultural products and for the harms they caused for the land and the workers. Natural solutions were introduced in agriculture as an improved form of crop protection, and in textiles as better quality.

By aiming at original and innovative solutions, product designs might easily have flaws that do not show: e.g. a material of a design might not be toxic, but its colour, texture, shape, smell, or X might influence species in a devastating way. For example, anti-fouling agents (preventing growth of organisms on ship hulls) that were designed to be least toxic for the environment, turned out to stop invertebrates from replicating, thereby threatening a complete ecosystem. Moreover they were accumulating in the food chain [5]. Half a century after CFCs were designed to make refrigerators safer in regard to fires and toxic emissions, they turned out to create a world-wide disaster by breaking down the ozone layer[6]. The history of DDT[2], Thalidomide[7], breast implants and many other products provide additional examples of the introduction of disastrous products. These problems not only occurred in the chemical sector: Despite reassuring messages from scientists, nuclear reactors turned out to be no virtually infallible designs [8, 9]. Various failed designs have been extensively described in the media [10, 11].

Technological failures (i.e. failures of a technology to produce desired impacts while not producing unexpected, undesired impacts) have occurred regularly. A technology might still be commercially successful while being a societal failure. This applies for example to technologies such as addictive drugs and unsafe or polluting products. However, at the societal level failed products could imply a tremendous loss. It took for instance 30 years to replace CFCs worldwide. The costs were initially estimated at 3 billion US$[12]. Moreover, the ozone hole, caused by CFCs caused additional cases of skin cancer and harmed ecosystems especially in the Southern hemisphere.

Often mankind put too much trust in its man-made solutions, and neglected (or not even cared about) the undesired impacts that its products and processes had. This point was recognized in the 1960's: it was the start of Technology Assessment (TA) as a method to assess all of the impacts (whether beneficial or detrimental) of new technologies. The ambition of TA was a scientific one: to assess new technologies factual and objective. However, soon after the first TA studies had been carried out, it became apparent that such a claim for completeness cannot be justified, as new unexpected impacts of products and processes might always be identified. Moreover, stakeholders will evaluate the impacts of new technologies by different standards [13]. Hence, it is impossible to provide a scientific assessment of the merits of a new product or processes.

1.2 Design and uncertain impacts

The impacts of new technologies and their assessment cannot be established with certainty. However, the impacts of new technologies can be disastrous[7, 9, 11]. Extensive testing procedures have been developed to test the risk of various products and processes. However, despite these tests, new products might be introduced that cause undesired, or even disastrous impacts. This holds especially for long term and indirect impacts.

Technological principles that are present in living organisms, or in artefacts that these organisms use, have been tested for extremely long periods. If these principles would have had major (indirect) negative impacts on these organisms themselves, this would have shown. For instance: Too successful predators will eventually have killed all their prey, which will make them starve, and animals adapting to a very specific climate might be prevented to migrate in times of local food scarcity. Mankind can learn from nature how organisms develop a 'fit' with their environment, not just a 'fit' with the direct properties of their environment, but especially also a fit with the dynamic properties of that environment, and the (indirect) changes that an organism caused itself in that environment. Hence, nature selects species by being in balance with their environment, not just a static balance but a dynamic balance that secures survival during changing conditions. Such dynamics can even be mathematically described. by the Lotka-Volterra equations [14].

Therefore, in designing systems, products and processes, designers should prefer to follow the example of natural equivalents of the function that they need: these equivalents have adapted and survived a long-term selection pressure.

1.3 limits to biomimicry?

However, are there equivalents in nature for whatever function designers might need? Well probably not. For example,

1. nature has no equivalent to the high tenacity, moldability and high melting point of metals.
2. Nature has no treatment for bone fractures. Mammals with serious fractures generally die.
3. Nature has no highly efficient solution for overland transport of goods: 'wheeled' transport is more efficient than 'legged' transport.

-1. A first argument might be that nature does not need them, but such an argument would be tough to prove as needs do not express themselves. Nature produces strength e.g. glass sponges make intricate latticed glass structures at ambient temperatures[15] and Golden Orb Weaver Spiders make silk threads many times stronger than man-made metals [16]. But the answer might also be in the extreme conditions to produce metals: many common metals can only be formed at such high temperatures that no species can survive them.

-2. Individual fractures, like diseases might strengthen a species, as they act as an evolutionary sieve. This might contribute to the long-term success of a species; at the expense of many of its individuals. Hence evolutionary success might be at odds with medical treatment of individuals. This touches a deep root of human civilisation, i.e. caring for the underprivileged.

-3. Wheeled transport is an efficient way of land transport, but wheels are not of much use in a rough landscape, or in a landscape with steep hills. A more or less horizontal and hard surface is required. Therefore, wheeled solutions require not only a carriage with wheels, but also a 'road', which implies that it requires 'social organisation' in order to create and maintain both roads and carriages. Moreover, a wheel always contains two separate parts, a disk and an axle, which cannot grow from the same life form. However, nature more or less approached wheels and roads: some insects developed 'rolling' for transport, and ants create roads. So, perhaps nature might reach similar solutions to wheeled transport in future evolution.

Would mankind have been happier without any metals, surgery and wheels? It is not our aim to answer such a question but to show that nature might inspire designers to better understand the function of their design, and to generate more alternatives leading to designs that better fulfil needs.

2. Learning from Nature

For as long as humans have existed, we have looked to nature for inspiration to solve our challenges. This idea of emulating from nature was revived by Janine Benyus in 1997. Her book, Biomimicry, Innovation Inspired by Nature describes how we can look to nature, not to extract from nature, but to learn from its design principles and overarching patterns, all of which have survived years of (re-)production and testing [17]. Since 1997, the field of biomimicry has expanded to inform, educate, and share its knowledge through websites and education [18]. A design can mimic an organism using form, process or systems. The basic level, or use of form is characterized by having the physical structure like the organism it was inspired by. The use of process is characterized by mimicking behaviour of an organism and mimicking an ecosystem in design (the highest level) mimics multiple functions and relationships [19]. It is here that we can learn how to 'fit' ourselves and how to solve design challenges within the same operating conditions.

2.1. Biomimicry Emulation

The laws of science apply in living organisms as well as in man-made artefacts. Hence, we might learn by what principles organisms develop symbiotic relationships with their environment: they should protect themselves from this environment, but also take everything they need from that environment. In doing so, their own properties/behaviour should not have a detrimental indirect impact. In fact, this is exactly what we want for sustainable designs.

Learning might also take place at another level: organisms are in part systems that have metabolic- movement-, information processing-, sensory- and control systems. The efficiency of these systems, and their symbiosis is an important determinant for the abilities of an organism. Man-made systems are often ordered like natural systems.

When mimicking nature in design solutions, we think that three issues at stake here are relevant to discuss in this paper:

1. Emulating from life (organisms and their interactions) itself;
2. Emulating from artefacts that the organisms make;
3. Emulating the creative process of new transformational learning.

2.2. Emulating Life

Biomimicry practitioners, those who practice biomimicry, first look at the scope of a challenge and ask, 'what does the design need to do?' In doing so, they are describing the need by its function. Subsequently, they take this function and look to another context, that of nature, and investigate how nature would solve this need. The process of looking at one context (e.g. biology) and applying characteristics of this to the second context (e.g. design) is called Analogical Thinking [20]. Each solution would then be a form, process or system analogy or a combination of these with form being the lowest level and systems being the highest. One might visualize analogies in examples such as Sharklet anti-fouling surface texture that mimics the micro-pattern form of shark skin [21] or such as the behaviour of how blue mussels create a glue that can function under wet conditions and is mimicked in life-friendly and non-toxic plywood [22] or to indicate a systems analogy, the multitude of connections and relationships of mycelium and the internet. One insight is that being able to remember the ABC's of biomimicry, overarching patterns in life called Life's Principles, may aid in this higher level of transfer.

Life's Principles (figure 1) are regarded as the design lessons from nature, as aspirational goals and as sustainable benchmarks [19]. A well-adapted biological strategy must meet the functional needs of the organism in the context in which it lives in order to contribute to its survival. These 26 interconnected patterns from the same natural world flow into our design space because they are shared by the species that survive Earth today and thus, when integrated into a design, will also most likely facilitate and aid in the survival of the design. Practitioners use the principles to check and measure if the design has the same fit to pass the sustainability test and to check for missing limits and opportunities [23]. An example of a Life's Principle in a design might be that of using modular and nested components or using readily available material and energy (such as using nearby materials or utilizing sunlight and wind to power the designs' energy needs – or even the design process itself).

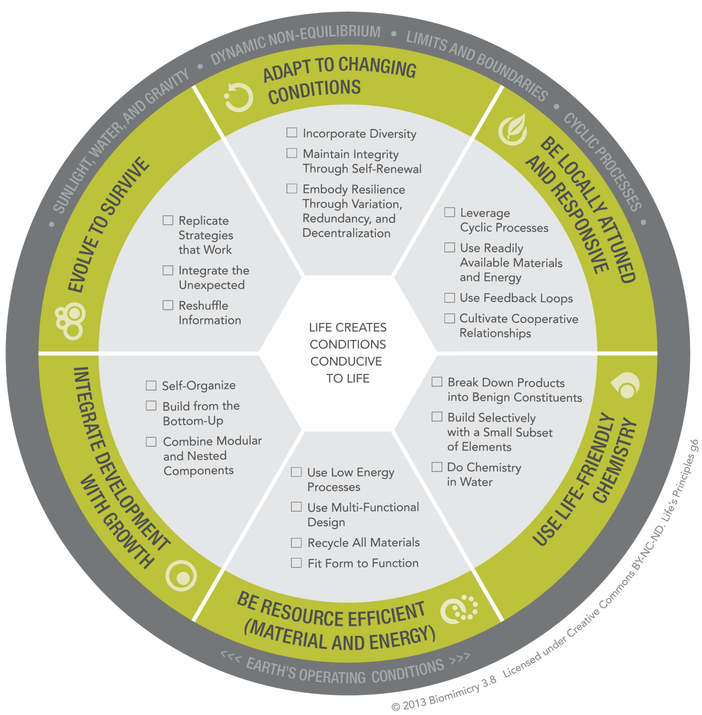

Figure 1: Biomimicry 3.8 Design Lens Life's Principles (permission granted to reprint in research)

2.3. Artefacts Design by Nature

Many organisms use tools or nearby materials to produce artefacts. Often these artefacts are shelter and to protect the organism from abiotic or other biotic factors. A hummingbird nest for example, is made from twigs and leaves, and from spider web silk that the hummingbird has gathered (eaten) and used as a flexible adhesive. The nest is thus flexible and can stretch while the chicks grow to accommodate their rapid growth [24]. Termites build huge mounds with a constant temperature on the inside of around 30.5^0C even when the exterior temperature is lower than 1.6^0C or exceeds 40^0C. Both are shelters of different sizes, and are interesting lessons for architects to emulate this building form, process and system. The Eastgate Building in Zimbabwe is one such example. By mimicking the termite mounds, the architect Mick Pierce could maintain the stable internal climate and save millions of dollars on costs for air conditioning and maintenance [25] by mimicking the interior airflow channels of the termite mounds.

2.4. Emulating Nature in Education

Biomimicry education brings nature into the classroom, creating a flow structure like nature does while raising awareness for sustainability concerns and giving students tools to do something about it [26]. The Challenge to Biology Design process pictured in figure 2 visualizes the full design circle which continues to repeat the phases through iterated cycles much like nature would do.

Ethos, or the ethical choices we make during design, as well as the reconnection to nature, are just as important as the emulation of natural strategies and mechanisms into design. Are our choices based on what nature would do and have we asked the question, 'what wouldn't nature do?'

The Big 5 of Education as stated by Naturalis Biodiversity Center in Leiden, the Netherlands, state that education should:

- Be awe inspiring
- Include real challenges
- Include relevant challenges
- Require scientific research and
- Cultivate inquisitiveness

Student survey responses have proven that all five requirements are included in biomimicry courses and challenges [26]. The scientific facts learned by the students opened their eyes to the multitude of breath-taking possibilities that were available when one simply looked to nature for solutions during the discovering phase. The challenges used in these design courses are real global issues geared towards solving some of the United Nations Sustainable Development Goals (SDG's). The challenges themselves thus also increased their knowledge of global climate and environmental issues. The most difficult part of Biomimicry Design Thinking (figure 2) is abstracting and translating what is happening in the biology into engineering principles the designer can integrate into the design. Once the design function need is known, relevant organisms who solve this function already are scientifically examined through research articles explaining how the function is carried out. Life's Principles guide the designer throughout the design process, creating ideas based on the visualization and description of those found strategies and mechanisms. Finally, these ideas are put to the test in a Life's Principle evaluation.

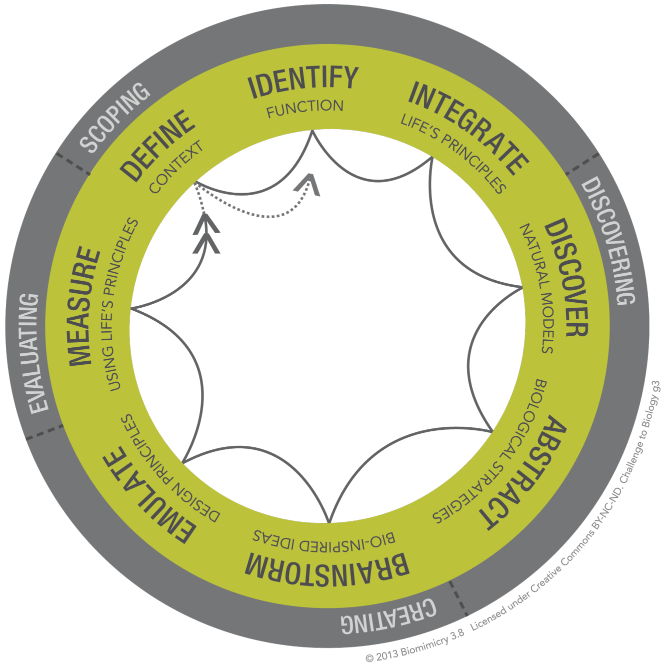

Figure 2: Biomimicry 3.8 Design Lens Challenge to Biology (permission granted to reprint in research)

3. Conclusion

Biomimicry education is motivating and inspires designers to look at the world around them to learn how nature has been solving the same issues for ages. If the question if everything can be designed by biomimicry is answered negatively, the question being asked for a design solution might not be the correct one. For example, humans have been successful in separating related entities: wheels and road surface, hard- and software, power generation and power consumption. Such divides do not occur in nature. The question we must ask in this case is, 'How would Nature move or distribute?' and consequently look to what the tested options are. By adjusting our design viewpoint to how nature would distribute locally or use readily available materials and energy for example, we can start to design for a future where humans have discovered how to survive as shareholder.

When the correct question is asked, every human challenge can be investigated through the field of biomimicry. Not only are the organisms in nature models for our designs when practicing biomimicry, but also the artefacts made by the organisms as well as the education leading us through the design phases. All are responsible for helping students to design better products regarding the environment in which the product must operate.

By not only testing our designs to the principles regarding the overarching patterns of life, but also by putting biomimicry education methodology to the same test, this sustainable education is placed into the same situations as life itself must follow to survive.

In conclusion, while biomimicry is an upcoming field and hundreds of practitioners graduate each year, education in the methodology needs visibility. It has been proven to cultivate curiosity in students, to inspire creativity and to offer yet unknown options at the design table. We have discovered that asking the correct question when deciding on a design approach is essential to move beyond what already exists and to investigate scientifically new ways of looking at a design challenge. When this open view is used, students thrive and want to learn and discover more, creating the educational atmosphere teachers thrive on[26].

References

1. Miller, C., *Gifford Pinchot and the making of modern environmentalism*. 2013: Island Press.
2. Carson, R., *Silent spring*. 1962, London: Hamish Hamilton.
3. Mulder, K.F., *Replacing nature, the arising of polymer science and synthetic fiber technology. The interaction between technology and science.* , in *Studies in Technology and Science*, B. Gremmen, Editor. 1991, LU Wageningen.: Wageningen. p. 239-262.
4. Ndiaye, P.A., *Nylon and Bombs: DuPont and the March of Modern America*. 2007: JHU Press.
5. Antizar-Ladislao, B., *Environmental levels, toxicity and human exposure to tributyltin (TBT)-contaminated marine environment. A review.* Environment International, 2008. **34**(2): p. 292-308.
6. Mulder, K.F., *Innovation by disaster: the ozone catastrophe as experiment of forced innovation.* International journal of environment and sustainable development, 2005. **4**(1): p. 88-103.
7. Botting, J., *The history of thalidomide.* Drug news & perspectives, 2002. **15**(9): p. 604-611.
8. Gamson, W.A. and A. Modigliani, *Media Discourse and Public Opinion on Nuclear Power: A Constructionist Approach.* American Journal of Sociology, 1989. **95**(1): p. 1-37.
9. Perrow, C., *Normal accidents: Living with high risk technologies-Updated edition*. 2011: Princeton university press.
10. Baudet, E.H.P., *Een vertrouwde wereld: 100 jaar innovatie in Nederland*. 1986: B. Bakker.
11. Veldhoen, L. and J. van den Ende, *Technische mislukkingen: de Planta-affaire, instortende bruggen, vliegdekschepen van ijs*. 1995: Donker.
12. Browne, M., *Grappling With the Cost Of Saving Earth's Ozone*, in *New York Times*. 1990: New York.
13. Van Eijndhoven, J.C., *Technology assessment: Product or process?* Technological Forecasting and Social Change, 1997. **54**(2): p. 269-286.
14. Lotka, A.J., *Elements of physical biology.* Science Progress in the Twentieth Century (1919-1933), 1926. **21**(82): p. 341-343.
15. Kulchin, Y.N., et al., *Optical fibres based on natural biological minerals—sea sponge spicules.* Quantum Electronics, 2008. **38**(1): p. 51.
16. Lewis, R., *Unraveling the weave of spider silk.* Bioscience, 1996. **46**(9): p. 636-638.
17. Benyus, J.M., *Biomimicry: Innovation inspired by nature*. 1997, Morrow New York.
18. University, A.S. *Master of Science (MS) in Biomimicry – Online*. 2020; Available from: http://biomimicry.asu.edu/education/asu-online-masters-degree/.
19. Baumeister, D., et al., *Biomimicry resource handbook.* A seed, 2012.
20. Casakin, H. and G. Goldschmidt, *Expertise and the use of visual analogy: implications for design education.* Design studies, 1999. **20**(2): p. 153-175.
21. Sharklet technologies, i. *Cision PR Newswire.* 2019 25 January, 2020]; Available from: https://www.prnewswire.com/news-releases/sharklet-a-biomimetic-antibacterial-and-antifouling-technology-launched-at-the-old-man-and-the-sea-a-sneak-peek-into-the-future-300969768.html.
22. AskNature. *Terrapin bright green*. 2016 25 January, 2020]; Available from: https://asknature.org/resource/purebond-technology-wood-glue-without-formaldehyde/.
23. University, A.S., *Course lecture Essentials of Biomimicry.* . 2016, Arizona State University.
24. sedona., T.h.s. *Hummingbird Predators.* . 2020 3 February, 2020,]; Available from: https://www.hummingbirdsociety.org/predators/.
25. Inhabitat. *BIOMIMETIC ARCHITECTURE: Green Building in Zimbabwe Modeled After Termite Mounds.* . 2012 3 February, 2020]; Available from: https://inhabitat.com/building-modelled-on-termites-eastgate-centre-in-zimbabwe/.
26. Stevens, L., et al. *Biomimicry Design Education Essentials*. in *Proceedings of the Design Society: International Conference on Engineering Design*. 2019. Cambridge University Press.