Rethinking the Role of Design within the Technological Advancements in Biomimetics and SynBio

Toufic Haidamous* a

*American University of Science and Technology
*Corresponding author e-mail: thaidamous@aust.edu.lb

Abstract: Digital technological advancements in Synthetic Biology has allowed breakthroughs that surpassed the realm of laboratory confinements to reach public democratization of biotechnology. Many designers are creating speculative objects that are used in possible, often provocative scenarios in order to open discussions and raise awareness. Both Biomimetics and SynBio find common ground in design and biology. In both cases, the designer is, hence, creating new bridges between biology and design. In SynBio, new imaginary products are made tangible to stimulate debate and communicate to the users, thus, a shifting role from the designer as a problem-solver (in Biomimetics) to the designer as a philosophical sense maker (in SynBio). This paper summarizes the findings of a research done within the context of a doctoral research study at IUAV, Istituto Univesitario accademico di Venezia. Comparison of both applications and implications will highlight convergences and divergences in the role of design for the current and next technology in Biomimetics and SynBio.

Keywords: biomimetics, SynBio, speculative design, design ethics

1. Introduction

Why is the particular interest to invoke biology, among all sciences to rethink and question the role of design? While there is no attempt to make the process of designing scientific, this research would lean towards subjecting the products of design and methodologies to scientific study. As Steadman states:

“Perhaps most significantly it is biology out of all sciences, which first confronted the central problem of teleology; of design in nature; and it is very natural that of all sciences it should for this reason attract the special interest of designers.”

(Steadman, 2008, p.8)

Glimpsing on the theory of biological analogy in recent references would definitely help in understanding a fragmented history where the recurring theme of analogy with biology is most
prominent. Peter Collin’s article on ‘Biological Analogy’, published in the architectural review in 1959, highlights and develops three main aspects of the theme—the relationship of organisms to their environment, Cuvier’s principle of the correlation of organs, and the relationship of form to function (Collins, 1959). Alan Colquoun comments on the biological fallacy implied in the ‘biotechnical determinism’ in which form is only the result of a process derived from operational needs and techniques, hence, form as a result of function and technology. Colquoun relates the nineteenth century cultural evolution and the modern movement to ‘biotechnical determinism’ (Colquoun, 1969). Chapter 11 entitled ‘Biotechnics,’ Plants and Animals as Inventors, in Steadman’s The Evolution of Designs contributes to a historical discussion and tracing of the terms ‘biotechnique’ and ‘biotecnic’ (Steadman, 2008). This understanding of biotehnics as considering nature as a model that holds a variety of answers and solutions is confronted by a new engineering approach to bioscience—the emerging field of synthetic biology, “the intentional design (or redesign) of biology” (Ginsberg, et al, 2014, p.X).

“Synthetic biology is a young field with growing global momentum, enticing engineers, biologists, chemists, physicists, and computer scientists to the laboratory bench to manipulate the stuff of life. These self-styled pioneers of biological engineering aspire to redesign existing organisms using engineering principles like standardization; some even seek to construct completely new biological entities.” (Ginsberg, et al, 2014, p.X)

2. Research Methodology

In the case of biomimetics, a deductive reasoning will be adopted to obtain conclusions about the role of design in a top-down approach. The multiple premises that were investigated in biomimetics are the epistemological origins, biomimetic design methodologies, comparison of realized biomimetic applications and an interview with the Italian designer Carla Langella, founder of Hybrid Design Lab, who has worked in and taught for many years biomimetic design. The general role of design in this part is assumed to have a more practical and innovative aspect relating to the needs of the market, hence the role of the designer as a problem-solver and taking advantage of natural biological processes to find solutions to the problems.

In Synbio, the role of design was analyzed by using inductive reasoning taking into consideration and studying through observations many products and artefacts to come up eventually with generalizations about the role of design in synthetic biology, hence, a bottom-up approach will be endorsed in this part of the research. It was found in the literature review for the aforementioned part that speculative design is crucial when a multidisciplinary approach with science in general and synthetic biology in particular is being investigated (Dunne and Raby, 2013). Also, an interview with the speculative designer Alexandra Daisy Ginsberg was conducted to gain more insights about her work and the role that design plays in the field of synthetic biology.

Because this research addresses the role of design influenced by the implications of technological advancements of biology, it was found that Biomimetics and Synbio may seem to have different dimensions; however, after examining the results obtained, this research will state divergences as well as convergences in the role of design.

3. Biomimetics

The use of Biologically-Inspired Design (BID) is clearly not new. Scholars, designers and inventors as early as Leonardo Da Vinci have been seeking inspiration from nature for design innovation (Romei,
There is now a common belief that humans will become more sustainable using BID as a catalyst for innovation in a range of industries (Benyus, 1997, Bar Cohen, 2006, and Holden, 2006). An increasingly used term ‘sustainability-oriented innovation’ (SOI) focuses on a broader view of corporate relationships to nature and society and has become a key conversation in corporate strategy (Klewitz, et al, 2014, Nidumolu, 2009). BID has been criticized to have an ‘technocentric’ approach which is effective as a human-focused tool for innovation, but lacks an ‘ecocentric’ approach that would define nature as having intrinsic value and connects humans to natural systems (Marshall, et al, 2009).

3.1 Epistemological Origins

For the purpose of understanding ‘biomimetics’, we also look at other terms that hold in their fields biologically informed disciplines. A theoretical understanding of each of bionics, biomimetics, biomimicry, and bio-inspiration is fundamental to explore the common ground of interdisciplinary collaboration arising between scientists and designers. In the 1950’s, Otto Schmitt coined the term biomimetics, a derivative of Greek words Bios (life) and mimesis (imitate) (Bar-Cohen, 2006). In 1938, Schmitt’s publication, Cathode Ray Oscillograph for the Investigation of Nerve Action Potentials, demonstrated a physical device that mimicked the electrical action of a nerve as part of Schmitt’s doctoral research (Schmitt, 1938). Schmitt was a graduate of Washington University in the United States and of the University College London in England with degrees in Zoology, Physics, Mathematics, and a post-doctoral degree in Biophysics.

Julien Vincent of the Center for Biomimetic and Natural Technologies at the University of Bath, UK published a paper entitled Biomimetics: Its Practice and Theory” (2006) in which he states the following:

“Biomimetics is thus a relatively young study embracing the practical use of mechanisms and functions of biological science in engineering, design, chemistry, electronics, and so on.” (Vincent, et al, 2006, pp. 471-482)

According to Bar-Cohen:

“Bionics as the term for the field of study involving copying, imitating, and learning from biology ... Biomimetics ... [the] term itself is derived from bios, meaning life, and mimesis, meaning to imitate. This new science represents the study and imitation of nature’s methods, designs, and processes. While some of its basic configurations and designs can be copied, many ideas from nature are best adapted when they serve as inspiration for human-made capabilities.” (Bar-Cohen, 2006)

In Peter Forbes’ The Gecko’s Foot he states the following:

“Inevitably with a new subject there is some uncertainty about the boundaries of bio-inspiration. Scientists working in bio-inspiration usually fall into one of two camps: Biomechanics or materials science. Biomechanics is concerned with large-scale mechanisms, such as how insects fly, materials science with fine-scale structure and chemical composition.” (Forbes, 2005, p.18)

3.2 Biomimetic Design Methodologies

Two design processes were identified, the problem-driven and the solution-driven. The former starts with a problem definition and the process would then lead to a solution. The solution-driven process starts with a biological example to match it eventually with a problem. In a conducted university workshop, Helms stated that almost half of the approaches followed by the participants were
solution driven although experts mainly focused on the problem-driven approach (Helms, et al, 2009).

Based on the book Mental Leaps, Analogy in Creative Thoughts, written by cognitive scientists Holyoak and Thagard (Holyak and Thagard, 1994), analogy is created when knowledge is mapped from a source domain to a target domain; however, the analogy includes both superficial knowledge, or surface similarity, and deep knowledge or deep similarity (Shu, 2008); furthermore, Shu empirically demonstrates the importance of matching the right level of complexity of the biological phenomena with the corresponding analogy and suggests that the right lingual formulation or skeleton outline of the biological knowledge plays an important part in determining the success of the biomimetic solution (Shu, 2008).

In the field of Hybrid Design, it is of great importance to make use of consulting experts in many fields of biology and often other disciplines like physics, chemistry, material engineering in order to know more thoroughly the biological references that are more adequate and the technologies to be borrowed. This is why a developed methodological approach is specifically required to adhere with the complex identity of the design discipline, an approach that is simultaneously scientific and humanistic (Langella, 2007).

In light of these considerations, a biomimetic methodology more relevant to the design culture is that of hybrid design. This methodology that may be applied either on concrete products or on service design is developed and verified through theoretical and applied research activity that took place within the scope of the bachelor in Industrial Design at the Second University of Naples. The methodological structure is divided in phases:

1. Identification of the design problem to be resolved.
2. Definition of the project brief. In this phase what is requested is made explicit. The definition of the required requisites is a crucial point because from that point starts the research of analogy with the natural world. It is anyway necessary that the project brief is very precise and detailed in order not to fall in confusion.
3. Elaboration of a list of biological systems that comply with possible solutions for the specified problem and the possible analogies. In this phase it is necessary the contribution of the biological knowledge. In all cases, references to database like the one developed by The Biomimicry Institute is possible, but is always preferred to resort to consulting experts.
4. Identification of the concept and the idea, or of design ideas, that is more suitable to be used as references for the solution of the problem.
5. Translation of principles, logic, codes, and strategies extracted from biology in design hypothesis. Although preliminary hypothesis are taken into consideration, it is necessary, from early phases of the project, to investigate on materials and technologies of production that may be applied in the transfer of the identified biological principles, to be able to evaluate and select biological references in function of the design objectives and the production feasibility. Elaboration of final design solutions in which the development of design solutions identified in preceding phases is verified in terms of feasibility.
6. Prototyping, engineering, patenting, and production.

3.2 Biomimetic Research Pavilions

In the more recent period, researchers at the University of Stuttgart have started applying the biomimetics in architecture. These researchers stressed that a sophisticated design accompanied
with simulation and fabrication technologies enable the investigation and transporting of fibrous systems specific to morphology in biology to technology. They created a coreless pavilion design by winding carbon and glass filaments that comply with the morphological principles of arthropod exoskeleton (Knippers, et al, 2012, Lapidot et al. 2012). The mode of arrangement of the filaments indicated a transformation from a helicoidal to the unidirectional fiber pattern in the supporting areas (Knippers et al.2012, Luquet, 2012). The biological principles underlying the invertebrate skeletal composites were found to inspire the researchers in producing the more refined exoskeleton models of arthropods for the pavilion that clearly reflected the principles and assemblies in designing the scaffolds. Hence, the pavilion is a worth significant biomimetic model (ICD/ITKE research pavilion 2012, web).

Researchers at the University of Stuttgart have produced yet another pavilion, ICD/ITKE research pavilion 2013-2014, where the biological model is a structure typical of the forewing of the flying beetles that possess a structure with an integrated border frame and a big middle region (Doerstelmann, et al, 2015, Chen and Wu,2013, Arakane et al.,2012). This structure inspired the pavilion’s shell to be in a double-layer glass fibers and a special process of winding particularly devised for the research (Doerstelmann, et al, 2015).

In the following ICD-ITKE research pavilion 2014-2015, the same researchers based their biological model on a structure typical of the sub aquatic web of water spider (Argyroneta aquatic). The concept of this design was believed to rely on the processes specific to biological construction of structures that are fiber-supported. Here, water spider’s web constructing process had gained much attention. The researchers have tested the water spiders’ web building system and the hidden patterns of behavior, analysed design rules, and then transformed into a process-based on the technological fabrication. In fact, this water spider allot much of its time for the underwater survival. To enable this, it builds a supportive air bubble. The outcome will be a rigid constructed bubble that offer a constant and safe habitat that resists the mechanical stresses in unstable water currents. This mode of natural production demonstrates strategies specific to the adaptive fabrication that could be used to build the reliable fiber-reinforced structures (ICD/ITKE Research Pavilion 2014-2015, web).

The three pavilions built by the researchers have a unique morphology in terms of their structural composition and integrity. The models used in all the three Pavilions belong to invertebrates but difference exists with regard to the taxonomic ‘class’ to which the model animal belongs to. Biologically, each animal model belongs to a different class. Further, the materials employed for the pavilion 2012 and 2013-2014 involved both black carbon fibers and the glass fibers while that used for the pavilion 2014-2015 was ETFE and the carbon fibers.

3.3 Interview with Carla Langella about Diatom Design

Author: In The Evolution of Design, Steadman states, “Honzík is skeptical, however, of Francé’s claim that all forms in nature are perfectly adapted, or that there is a necessary and unique relation between function and form. If so, why should there be 6,000 different species of the unicellular Diatomaceous living under identical conditions?” Referring to Steadman’s quote and the project of ‘diatom design’ carried on by Hybrid Design Lab, what are the potentials in understanding and studying these unicellular organisms to benefit the design discipline?

Carla Langella: In Diatom Design project we experienced that in investigating different species, what emerges is the same principle of intelligence made of nerves, overlapping layers, hierarchical structures, differentiated porosity, and complex details at every dimensional scale. Each of these aspects generally performs more than one function. For example the perforations of the frustules,
namely of the shells, which define their typical ornamentations, simultaneously perform the functions related to nutrition needs, the compressive structural optimization, protection against virus invasion, filtering, conveying of solar radiation useful for photosynthesis.

This is a very interesting principle for design: design details that respond to multiple needs and multiple functions.

At the same time every single species is characterized by individual details such as interlocking, morphology, mode of aggregations in colonies that respond to the specific needs of the environment where they live, the conditions of the waters in which they live, every one of these details might suggest a different design solution.

4. SynBio

4.1 Potentials and Standardization

The design discipline in particular has a role in raising issues that are not often discussed elsewhere such as how the path that a new technology like synthetic biology may develop and what direction we want it to take in favour of the potential users. Some of the potentials of SynBio are producing sustainable fuel, new manufacturing techniques, novel drugs and materials, and medical technologies. Simultaneously Synbio is accompanied by many questions about the ownership of life’s materials and the unintentional or intentional harm that may be caused by biotechnologies.

Synthetic biology presents complex new issues, social, ethical, and legal issues that have been raised and investigated in countless reports by bioethicists, social scientists, and policy makers. The role of design was further found to question how the aims of this new biotechnology align with those of potential users.

Synthetic biologists dream of a Biotechnological Revolution by applying engineering design principles such as standardization and industrialization (Church and Regis, 2012). Existing definitions of SynBio (abbreviation of Synthetic Biology), mostly stress on modularization, standardization, and related engineering concepts- which scientists are trying to apply to the engineering of biological systems- as the principal drivers to speed up and facilitate GMO (Genetically modified organisms) design, manufacture, and utilization (CCS, et al, 2014).

4.2 Precedents of SynBio Artefacts

With the number of people living in this planet continuously increasing and the total value and extent of devastation that humans have so far inflicted to the environment, there is no telling how soon a phenomenon called the sixth extinction would occur. In a futuristic proposal authored by designer Alexandra Daisy Ginsberg who was interviewed in this research, she argued that the only way to reverse the sixth extinction and all of the processes and phenomena that would eventually lead to it is to release synthetic (i.e. artificially made or modified) creatures into the environment and program their purpose of existence (e.g. save endangered species and clean up wastes and pollutants). Examples of species that she proposed in her presentation include but may not be limited to a slug that has the ability to neutralize acidic soils by leaving a trail of alkali wherever it goes and a porcupine that has the ability to disperse seeds of endangered plant species thanks to its biosynthetically engineered sticky rubber spines (Fairs, 2013). This potential change is also where the ethical implications of this project lies. Many would think that no one must be allowed to alter life and they must not have the authority to affect the life of other beings—or so it would be based
on the main ethics-based arguments of the people who would be against this synthetic biology revolution.

The *Stranger Visions* is one of Heather Dewey Hagborg’s most popular and at the same time, disturbing, works. For a brief background about what this thirty two year old bio hacker, information artist, and geneticist can do with *Stranger Visions*, she can basically recreate an individual’s face using only tiny patches of DNAs recovered from basically any form of discarded items, her knowledge in genetics and biotechnology, and a three dimensional printer. This is what she exactly came up with when she first created *Stranger Visions* (Dawsey, 2013). This artefact is basically a series of 3D portraits (of strangers that is) that she created using the DNAs she gathered from practically trashed items such as hair, cigarette butts, and even chewing gums while she was staying in Brooklyn, New York. She then analyzed and modified the DNAs she collected to determine the gender, ethnicity, and other specifics such as the facial features of the individual she was trying to create a 3D portrait of. This opens up many opportunities to make meaning (i.e. semiotics and semantics) and representations in the field of forensic science, particularly when it comes to the use of genetics, facial recognition and generation software, and 3D printer usage.

Dolls have long been used as a toy for children, which fundamentally make them a source of entertainment. This has been the case for centuries now and would most likely continue to be, not unless this long established notion about dolls get challenged by a new doll or doll-like product (i.e. biosynthetic product) such as the semi living worry dolls (Catts, et al). These dolls are made out of hand crafted degradable polymers and are surgically sutured so that the different body parts of the doll would hold together. Another unique feature of the semi living worry dolls is that they are seeded with living cells that will divide and grow. This is based on the notion that it feels lighter to share someone’s worry and anxiety to a living thing (as in a dog or another person), only that in this case, it is a doll that was partially brought to life. With the ability to create partially living beings such as these dolls, those who are against the popularization of products like these are anxious about how the future of this industry would look like.

4.3 Interview with Alexandra Daisy Ginsberg

**Author**: Amidst emerging new biotechnologies, particularly synthetic biology, what is the role of the designer?

**Alexandra Daisy Ginsberg**: It is complicated to define the role of the designer. Design must be both critical and optimistic, the terms that Anthony Dunes used. Critique is a form of innovation. Since a year, I stepped out of Synthetic Aesthetic project. With regards to synthetic biology, design tries to be idealistic, a space to build networks with biologists and other designers. This is where there is an effort to have a critical approach to biotechnologies rather than a more traditional design role. Designers must find clever ways of producing things in the laboratory and through research. Designers often fight for a space to question, for example questioning what does it mean to design living things?

5. Conclusion

5.1 Divergences

The ethical role of design in synthetic biology and biomimetics overlap in many ways. Both are emerging disciplines of science and involve the creation of artificial systems that closely mimic or are derived from natural biological systems. However, whereas the innovations of biomimetics merely
emulate the function and design of natural systems, the products of synthetic biology are themselves living organisms and biological systems so the ethical role in SynBio is more critical. At the moment a large movement is against genetic modification (GM) of seeds and food (Bizarri, 2012). On a deeper level, other motivations based in power politics (corporations versus farmers) are far more controversial.

The use of SynBio necessitates the understanding of natural science at a deeper level than biomimetics so that the synthetic design is well-suited for the purpose to which it is applied. SynBio uses control theory to define the stability, measurability, and controllability. Also, SynBio is used to understand and emulate systematic control processes successfully displaying positive breakthroughs in regeneration therapy (Sekin, et al, 2011). European development under the umbrellas of ERASynBio includes the above ideas and others based upon ethical, multidisciplinary, networked global community offering innovative verified solutions to shared problems (De Lorenzo, 2014). In speculative design, we have seen many artifacts that imagine variety of solutions using SynBio but those are yet to be verified.

Natural selection due to genetic assimilation is accepted as an aspect of Darwinism (Parker, et al, 2004). Darwin’s theory takes preeminence over the cybernetic processes identified as existing from the circular causality of regulatory action, not from some antecedently designed purpose. The success of SynBio is based on opposite assumptions from the cybernetic model because the trajectory of regulatory action is to be determined by humans. The designer’s role as seen in SynBio artifacts are, thus, more assertive than that in biomimetic products.

5.1 Convergences

The problem can be theoretically solved upon a biological system of an organism or its environment in Biomimetics. If the problem is not expected to arise until the future, the purpose of solving a logical non-empirical thought problem remains a practical experiment in speculative design as well. Empirical experiments are based on observations from the physical reality of our world or based on observations theorized from the reported knowledge by other scientists. SynBio is involved with empirical studies to a greater degree than to biomimetics because of the natural way SynBio can readily use genetics to identify a problem and then adapt genes to find a solution.

The approach of Hybrid Design Lab embraces both biomimetics and SynBio. The role of the designer is hence acknowledging the definitions, approaches, and methodologies relative to both fields and their corresponding complexities in order not to fall in trap of the biological fallacy and functional determinism. Besides the technical disciplines like chemistry, physics, engineering and marketing, that contribute to the design of the project, other humanistic skills must also be taken in consideration especially those related to the culture of the project.

Biomimetics and SynBio open new horizons and a variety of possible ways and methods to create potential opportunities, applications, and projects that meet the needs of sustainability. The main point being shared with the reader is that now we have reached a time when even the human species is facing extinction; therefore the positive attributes of SynBio offer new possibilities in the design discipline to meet many global challenges. This research offers a moment to reflect on these new possibilities that bridge biology to design.
References

Arakane, Y., Lomakin, J., Gehrke S.H., Hiromasa, Y., Tomich, J.M., Muthukrishnan, S., Beeman, R.W., Kramer, K.J. and Kanost, M.R. (2012). Formation of rigid, non-flight forewings (elytra) of a beetle requires two major cuticular proteins. PLoS Genet 8.4.e1002682.Print.

Bar-Cohen, Y. (2006). Biomimetics: Biologically Inspired Technologies. Taylor & Francis Group, LLC.

Benyus, J.M. (2002). Biomimicry: Innovation Inspired by Nature, 2nd edition. Harper Collins: New York.

Bizzarri, M. (2012). The New Alchemists, The Risks of Genetic Modification. WIT Press.

Catts, O., & Zurr, I. (n.d.). The Semi-Living Worry Dolls. Dublin Science Gallery

CCS, SCENIHR, & SCHER, 2014. Opinion on Synthetic Biology. Retrieved December 20, 2016 from: http://ec.europa.eu/health/scientific_committees/consultations/public_consultations/scenihr_consultation_21_en.htm [24 January 2016]

Church, G. & Regis, E. (2012). Regenesis. How Synthetic Biology Will Reinvent Nature and Ourselves. New York: Basic Books.

Collins, P. (1959). Biological Analogy. Architectural Review, Volume 126, (pp. 303-306).

Colquoun, A. (1969). Typology and Design Method. Perspecta, Volume 12, 71-74.

Dawsey, J. (2013). Art Emerges from DNA Left Behind Excerpt. The Wall Street Journal.

DeLorenzo, V. (2014). Next Steps for European synthetic biology: A strategic vision from ERASynBio (European Research Area Network for the development and coordination of synthetic biology). European Commission Seventh Framework Programme. Retrieved December 20, 2016 from www.erasynbio.eu [4 Jan. 2016]

Dörstelmann, M., Fibrous morphology in Biology and Architecture. 2014. Retrieved December 20, 2016.

Dunne, A. and Raby, F. (2013), Speculative Everything, Design, Fiction and Social Dreaming. Cambridge, Massachusetts: MIT Press.

Fairs, M. (2013). Synthetic Creatures Could Save Nature says Alexandra Daisy Ginsberg. DeZeen Magazine.

Forbes, P. (2006). The Gecko’s Foot, How Scientists are Taking a Leaf from Nature’s Book, Harper Perennial.

Ginsberg, A. D. et al, (2014). Synthetic Aethetics: Investigating Synthetic Biology’s Designs on Nature. Boston: MIT Press.

Helms, M., Vattam, S. and Goel, A. (2009). Biologically inspired design: process and products, Design Studies, 30(5), 606-622. Retrieved December 20, 2016, from: http://home.cc.gatech.edu/svattam/uploads/7/DS1.pdf

Holden, G. (2012). Looking to nature to catalyze energy. R&D. Res Manag. Jul-Aug.

Holyoak K., Thagard P. (1994). Mental leaps: analogy in creative thought. Cambridge: MIT Press.

ICD/ITKE Research Pavilion 2012. Retrieved December 20, 2016 from web.

ICD/ITKE Research Pavilion 2014-15. Retrieved December 20, 2016 from web.

ICD-ITKE Research Pavilion 2013-14 / ICD-ITKE 2014. Retrieved December 20, 2016 from web.

Kleowitz, J. & Hansen, E.G. (2014). Sustainability-oriented innovation of SMEs: A systematic review. J Clean Prod, 57–75.

Knippers, J., La Magna, R., Menges, A., Reichert, A., Schwinn, T. and Waimer, F. (2015). ICD/ITKE Research Pavilion 2012: Coreless Filament Winding Based on the Morphological Principles of an Arthropod Exoskeleton (pp.48–53). Architectural Design 85.5.

Langella, C. (2007). Hybrid Design, Progettare Tra Technologia e Natura [Hybrid Design, Designing with Nature and Technology]. Milano: FrancoAngeli.
Lapidot, S., Meirovitch, S., Sharon, S., Heyman, A, Kaplan, D.L., and Shoseyov, O. (2012). Clues for biomimetics from natural composite materials. Nanomedicine 7.9. 1409-23.
Luquet, G., 2012. Biomineralizations: insights and prospects from crustaceans. Zookeys, 176. 103–121
Marshall, A. et al (2009). Questioning the Theory and Practice of Biomimicry, International Journal of Design and Ecodynamics. Volume 4, No 1, 1-10.
Nidumolu, R., Prahalad, C.K. & Rangaswami, M.R. (2009). Why sustainability is now the key driver of innovation. Harv Bus Rev. Sept. 1-10.
Parker, S.T., Langer, J. and Milbrath, C. (Eds.) (2004). Biology and Knowledge Revisited: From Neurogenesis to Psychogenesis. Mahwah, NJ: Lawrence Erlbaum Associates. Print
Romei, F. (2008). Leonardo Da Vinci. The Oliver Press, Inc.
Schmitt, O.H. (1938). Cathode Ray Oscillograph for the Investigation of Nerve Action Potentials, Journal of Scientific Instruments.
Sekine, R. and Yamamura, M. (2011). Introduction of Synthetic Circuit Design. Chapter 2 in Natural Computing and Beyond: Winter School 2011, Hakodate, Japan, March 2011 and 6th International Workshop on Natural Computing, Tokyo, Japan, March 2012, ProceedingsY. Suzuki and T. Nakagaki editors. Tokyo: Springer Open.
Shu, L.H. (2007). Biomimetic design through natural language analysis to facilitate crossdomain information retrieval. AI EDAM: Artificial Intelligence for Engineering Design, Analysis, and Manufacturing, Volume 21, Issue 01, January 2007, 45-59.
Steadman, P. (2008). The Evolution of Design. Biological Analogy in Architecture and the Applied Arts. 2nd Edition. Abingdon: Routledge.
Vincent, J.F. et al, (2006). Biomimetics: its practice and theory. J R Soc Interface 3.9, 471-482.

About the Author:

Toufic Haidamous is an architect, educator and researcher in the field of design and architecture with major experience in sustainability and environmental consultancy. Haidamous got his PhD in Design Sciences from IUAV, Italy and is currently a full-timer at AUST, Beirut.