Biomimicry – Where Nature is Changing Innovation

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ABSTRACT

As a highly interdisciplinary field, business management is influenced by many subjects of natural and social sciences. From a new angle, there seems to be an increasingly biomimetic influence. Biomimicry is an applied science that examines nature, its models, systems, processes, and elements to emulate or take inspiration from, in order to solve human problems. This for the reason that nature has proven its ability to teach us about systems, materials, processes, structures and aesthetics. By delving more deeply into the application of biomimicry and how nature solves problems that are experienced today, we will be able to extract timely solutions from it and to build a more sustainable environment. Through the comparison and examination of existing biomimetic applications, this paper elaborates on distinct approaches to biomimicry that have evolved. A framework for understanding the various forms of biomimicry has been developed, and is used to discuss the potential of the various cases. So, this research attempts to specifically investigate strategies for sustainable innovation. Those strategies are inspired by the development of unsophisticated living systems (ecosystem level), their material properties (organism level) and their possibility to adapt to changes in the environment (behavioral level). The results are achieved through an attempt to link the two emerging interfaces: biomimicry and innovation, exploring their potential in developing more sustainable businesses.

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Keywords

Biomimicry, bio-inspired design, innovation management, sustainability, biomimicry levels, nature, business management

1. INTRODUCTION

1.1 Problem Statement

Nowadays, in a rapidly changing environment, companies are forced to be innovative, to bring new products to the market and to keep their management practices up to date to remain competitive and ensure longevity.

The majority of businesses believe that innovation is a priority and that the importance of innovation is increasingly significant. This for the reason that every organization is feeling the impact of globalization, migration, technological and knowledge revolutions, and climate change issues nowadays (Shukla, 2009).

Besides, today's global market place is fiercely competitive and "organizations that fail to bring to market innovative products that create value for their customers will quickly find that their competitors have done so, and that their own existence is in danger" (Reddy, 2014, p. 21). This trend could also be described by using Darwin's theory of evolution, which relies on the principle of survival of the fittest. This theory suggests that organisms that are best able to adapt to their environments, and at the same time are best able to change in response to that environment, are most likely to survive (Farr & West, 1990).

Furthermore, innovation will bring added value and widens the employment base. However, breakthrough innovations are often sensitive to failure due to a lack of resources, high risk, uncertainty and inefficient processes (Hobcraft, 2011). However, there are promising approaches that have the potential for companies to adopt sustainable innovation, one of which is biomimicry. Although biomimicry is mainly known for copying nature for technological applications, this field is also applicable to management concepts. For example, the Keystone Advantage, which translate business networks into ecosystems as found in nature, "laying an emphasis on the interconnectedness and reliance on each other within the network" (Badawy, 2007, p. 287). However, at the moment, it is quite unclear what management concepts are exactly related to biomimicry, as well as which management concepts have already been used in practice ("Biomimicry and its Place in Business Management", 2016). Moreover, "biomimicry can help the development, production and commercialization of new products to be aligned with ecologically, socially and economically sound standards" (Petrig, 2013, p. 1).

1.2 Concept Clarification

Biomimicry, is a new interdisciplinary field, which is about learning from nature and then emulating nature, its forms, its processes, its ecosystems in order to solve human problems (Baumeister, Benyus, Dwyer, Ritter, & Tocke, 2012). The term biomimicry is derived from the Greek *bios*, which means life or nature, and *mimesis*, which means imitation; '*imitating nature'* (Baumeister et al., 2012). Biomimicry strives for using biological concepts in the development of innovative technologies, products, and processes. It aims to better understand successful strategies adopted by nature to better adapt organisms to life, and then mimic and apply such strategies to solve human problems.

1.3 Research Project Motivation

As already explained in the problem statement, in the rapidly changing environment, companies are forced to be innovative, to bring new products to the market and to keep their management practices up to date to remain competitive and ensure longevity. However, a lot of companies remain stuck in running everyday business.

My personal motivation for doing this research is to analyze ways in which we can apply bio-inspired concepts and approaches to solve human problems. This thesis will be mainly structured around the concepts of product innovation and the innovation of organizational processes. Moreover, I will look at creating innovations that are economically, socially and ecologically sustainable. In my opinion, biomimicry is a concept that will cover all the above-mentioned concepts.

1.4 Research Objectives & Research Question

The goal of this research is to bring in perspective the relevance of biomimicry for innovation from the perspectives of both product innovation and the innovation of organizational processes. This will be done by analyzing which biomimetic approaches exist, are being utilized already in practice or have a great potential to be implemented.

The following research question is therefore formulated: *'How can biomimicry contribute to the innovation of products and organizational processes?'*

1.5 Outline of This Paper

This paper is basically structured into three parts. The first part includes the theoretical framework and the subject analysis. The theoretical framework covers the body of knowledge on the relevant subjects of this research; innovation and biomimicry. Every chapter in the theoretical framework is divided in certain sub-divisions, which allows the reader to create an in-depth understanding of the two concepts. The goal of the proceeding methodology section is to explain and justify the applied method to be used for the data collection and data analysis. Moreover, it will show how biomimicry can be integrated at different levels. When all the data is collected and analyzed, and when the results are clear, a conclusion that will answer the formulated research question will be written.

2. THEORETICAL FRAMEWORK

2.1 Innovation

This paper is focused on the relevance of biomimicry for innovation from different perspectives, for example both product innovation and the innovation of organizational processes. This makes the term innovation a crucial element, which needs to be clearly defined. This chapter aims at distinguishing between innovation and invention and determines the importance of innovation in today's rapidly changing environment.

2.1.1 Definition of Innovation

It could be stated that innovation is a hot topic in global business today. However, the term innovation can be interpreted in multiple ways. There is a very generic definition from the Merriam-Webster Dictionary, "the introduction of something new" as "a new idea, method, or device".

Political economist Joseph Alois Schumpeter is considered to be among the first to recognize the process of innovation and its impact on economic development. In 'The Theory of Economic Development', Schumpeter described development as a "historical process of structural changes, substantially driven by innovation which was defined by him in five different ways" (Schumpeter, as cited in Sledzik, 2013, p. 90):

1. Launch of a new product or new species of already known products;
2. Application of new methods or production or sales of a product (not yet proven in the industry);
3. Opening of a new market (the market for which a branch of the industry was not yet represented);
4. Acquiring of new sources of supply of raw material or semi-finished goods;
5. New industry structure such as the creation or destruction of a monopoly position.

In contrast, King and Anderson (as cited in De Jong, 2007, p. 16), define innovation as "something new to the social setting in which it is introduced (an individual, group, firm, industry, wider society) although not necessarily new to the person(s) introducing it". Furthermore, they consider that innovations are "based on ideas, which are a necessary but not a sufficient condition for innovation" (King and Anderson, as cited in De Jong, 2007, p. 15). In this process ideas are just a starting point, but you cannot speak of innovation without further development efforts. Finally, an innovation is aimed at producing some kind of benefit, for example financial gains, improved cohesiveness and increased satisfaction (De Jong, 2007).

There are different types of innovation, such as process, products, market, business and management innovation. For the scope of this research the focus will be on product and business/management innovation. Product innovation can be defined as "the introduction of a good or service that is new or significantly improved with respect to its characteristics or intended uses" (Tiwari, 2008, p. 1). Organizational innovation is "the implementation of a new organizational method in the firm's business practices, workplace organization or external relations" (Tiwari, 2008, p. 1).

2.1.2 Innovation vs. Invention

People often use the words 'invention' and 'innovation' interchangeably, which is incorrect. To clearly differentiate invention from innovation, Fagerberg (2006) stated that invention is "the first occurrence of an idea for a new product or process, while innovation is the first attempt to carry it out into practice", (p. 4). Although, invention and innovation are closely linked, there is a considerable time lag between them in many cases. Furthermore, when a firm wants to transform inventions into innovations, it needs to combine different types of knowledge, capabilities, skills, and resources (Fagerberg, 2006). To provide a clear overview of the differences between innovation and invention, a comparison chart is sketched in Table 1. This comparison chart makes a clear distinction based on the following elements: meaning, concept, skills required, occurrence, occupation and activities.

Table 1. Comparison Chart Innovation vs. Invention (Surbhi, 2017)

Basis for comparison	Invention	Innovation
Meaning	Invention refers to the occurrence of an idea for a product or process that has never been made before	Innovation implies the implementation of an idea for a product of process for the very first time
What is it?	Creation of a new product	Adding value to something already existing
Concept	An original idea and its working in theory	Practical implementation of a new idea
Skills required	Scientific skills	Set of marketing, technical and strategic skills
Occurs when	New idea strikes a scientist	A need is felt for a product or an improvement in existing products
Concerned with	Single product or process	Combination of various products and processes
Activities	Limited to R&D department	Spread across the organization

2.1.3 The Importance of Innovation

Taking the definitions of innovation into account; why is it so important for businesses to be innovative? The answer to this question will be discussed in this sub section.

The majority of businesses believe that innovation is a priority and that the importance of innovation is increasingly significant. This for the reason that every organization is feeling the impact of globalization, migration, technological and knowledge revolutions, and climate change issues (Shukla, 2009). According to Nadler and Tushman (1986), "these rapid changes in the marketplace make it increasingly difficult, and essential, for businesses to think in terms of the future and to constantly anticipate tomorrow's definition of value – the right mix of quality, service, product characteristics, and price" (p. 74). So, to ensure longevity, it is advisable for organizations to adopt innovation as a way of corporate life (Nadler & Tushman, 1986).

Besides, today's global market place is fiercely competitive and "organizations that fail to bring to market innovative products that create value for their customers will quickly find that their competitors have done so, and that their own existence is in danger" (Reddy, 2014, p. 21). This trend could also be described by using Darwin's theory of evolution, which relies on the principle of survival of the fittest. This theory suggests that organisms that are best able to adapt to their environments, and at the same time are best able to change in response to that environment, are most likely to survive (Farr & West, 1990). Freeman formulated it even more drastically in his studies of the economics of innovation: "… not to innovate is to die" (Freeman, as cited in Trott, 2005, p. 5). However, as stated by Weinberger (n.d.), innovation is not the only ingredient for long-term success and in theory it is possible for companies to survive without any crucial developments. This for the reason that you also need long-term favorable relationships with your customers in order to build a successful business. Nevertheless, businesses cannot afford to be living off the former glories of their products or services. "Keeping one step ahead is all about avoiding complacency – one of the biggest silent killers in business" (Petch, 2017).

To summarize, to survive it is essential that companies are able to adapt and evolve to changing business conditions. Furthermore, businesses need to operate with the knowledge that their competitors will inevitably come to the market with a product that changes the basis of competition, which makes the ability to change and adapt fundamental to survival (Trott, as cited in Goyal, Pitt, & Sapri, 2005).

2.2 Biomimicry

Nowadays, in a rapidly changing environment, companies are forced to be innovative, to bring new products to the market and to keep their management practices up to date to remain competitive and ensure longevity. However, innovations are often sensitive to failure due to a lack of resources, high risk, uncertainty and inefficient processes (Hobcraft, 2011). Nevertheless, there are promising approaches that have the potential for companies to adopt sustainable innovation, one of which is biomimicry. This chapter covers the literature in the field of biomimicry, which is mainly based on the models from the Biomimicry Guide.

2.2.1 Origin of Biomimicry

The earth has been developing efficient methods of life for 3.8 billion years and is therefore the oldest and wisest teacher we could ask for (Schreiner, 2018). Moreover, the activity of studying and emulating nature for offering solutions to human needs is not a new practice, because humans have always looked to nature as an inspiration to solve their problems (Vierra, 2016). For example, early humans relied on nature for the provision of food, shelter and alternatives to survive. One more specific example of early biomimicry was the study of birds to enable human flight by Leonardo da Vinci. He very closely observed the anatomy and flight of birds, and therewith made numerous sketches of proposed flying machines (Vierra, 2016). Unfortunately, he never became successful with his own flying machine. However, his ideas lived on and the Wright Brothers finally succeed in creating and flying the first airplane in 1903 (Vierra, 2016).

By the in-depth study of nature, early scientists and innovators have been able to gather information about the sustainable exploitation of resources. “The natural world metamorphoses and sustains itself over the long term by meeting its own needs and providing sustainable remedies to its challenges” (Aigbavboa & Oguntona, 2017, p. 2492).

The specific term ‘biomimicry’ appeared as early as 1982 and was popularized by scientist and author Janine Benyus in 1997 when she published her book: ‘Biomimicry: Innovation Inspired by Nature’ (Smith, 2007).

2.2.2 Definition of Biomimicry

Biomimicry, also called biomimetics, can be defined as “an approach to innovation that seeks sustainable solutions to human challenges by emulating nature’s time-tested patterns and strategies” (Biomimicry Institute, 2018). It is “an interdisciplinary approach that brings together two often disconnected worlds: nature and technology, biology and innovation, life and design” (Biomimicry 3.8, 2015). The purpose is to create products, processes, and policies that are well-adapted to life on earth over the long haul.

The term biomimicry is derived from the Greek *bios*, which means life or nature, and *mimesis*, which means imitation; ‘*imitating nature’* (Baumeister et al., 2012).

Benyus (2011) further argued that “at its most practical, biomimicry is a way of seeking sustainable solutions by borrowing life’s blueprints, chemical recipes, and ecosystem strategies”. Moreover, “at its most transformative, it brings us into right relation with the rest of the natural world” (Baumeister et al., 2012).

Biomimicry aims to better understand successful strategies adopted by nature to better adapt organisms to life, and then mimic and apply such strategies to solve human problems.

To better understand what biomimicry is about and how it differs from other bio-inspired approaches, it is important to understand what biomimicry is not. To make a clear distinction, the concepts of bio-utilized, bio-assisted and biomorphism will be introduced. Those concepts are quite different from biomimicry.

“While biomimicry focuses on the translation of biological principles into human-made technology, bio-utilization directly leverages organisms or biological materials” (Bernett, 2015). In short, it requires harvesting a product or producer, e.g. utilizing fungal mycelium (the vegetative portion of mushrooms) to produce environmentally-friendly products (Baumeister et al., 2012). This approach can be particularly useful in cases where replicating complex biological processes in human technologies is unsuccessful or too difficult to be cost-effective (Bernett, 2015).

Bio-assisted technologies, involves domesticating an organism to accomplish a function, e.g. cows bred to produce milk (Baumeister et al., 2012).

Biomorphism is another form of bio-inspired innovation, which mimics natural forms and patterns, e.g. the ‘Great Room’ with “an array of striking dendriform or ‘tree-like’ columns within this expansive, double story space, creating prospect and refuge conditions not unlike a savannah” (Bernett, 2015). However, it is commonly critiqued for its lack of adherence to biological principles, resulting in designs that do not necessarily perform better or that are sustainable.

Baumeister et al. (2012) argue that biomimics take another approach by consulting organisms; “they are inspired by an idea, be it a physical blueprint, a process step in a chemical reaction, or an ecosystem principle such as nutrient cycling”.

2.2.3 ‘Doing it Nature’s way’

If we want to consciously emulate nature’s genius, it is necessary that we look at nature from different perspectives (Pramatarova, 2011). Therefore, Janine Benyus, suggests looking at nature as a model, as a measure and as a mentor.

Nature as a model – “biomimicry is a new science that studies nature’s model and then emulate these forms, processes, systems, and strategies to solve human problems sustainably” (Elsharkwary, 2011). In short, we would manufacture the way animals and plants do, using sun and simple compounds to produce our own products.

Nature as a measure – besides providing the model, nature is also providing the measure. We consider nature as the standard for the rightness of our innovations. This for the reason that biomimicry uses an ecological standard to judge the sustainability of our innovations (Elsharkwary, 2011).

Nature as a mentor – biomimicry is a new way of viewing and valuing nature. Instead of seeing nature as a source of raw materials, we would see nature as a source of ideas, as a mentor. Biomimicry “introduces an era based not on what we can extract from the natural world, but what we can learn from it” (Elsharkwary, 2011).

2.2.4 *Biomimicry Principles*

Nature is a big thing, both physically and conceptually and there is a lot going on in nature: cycling and recycling, death, birth, cooperation, competition, nurturing, movement etc. (Lozeva & Marshall, 2009). Despite the diversity of nature, Benyus believes "it is important for biomimics to take account of certain basic laws of nature when they engage in the practice of biomimicry" (Benyus, as cited in Lozeva & Marshall, 2009, p. 4). Benyus therefore, formulated nine basic principles of biomimicry, which are focusing exclusively on nature's attributes. Therefore, implying that humans have much to learn from the natural world's evolutionary experience. The nine principles include the following (Benyus, as cited in Lozeva & Marshall, 2009, p. 4-5):

1. Nature runs on sunlight
2. Nature uses only the energy it needs
3. Nature fits form to function
4. Nature recycles everything
5. Nature rewards cooperation
6. Nature banks on diversity
7. Nature demands local expertise
8. Nature curbs excesses from within
9. Nature taps the power of limits

3. RESEARCH METHODS

At the beginning of this research, desk research has been done about innovation and biomimicry to get an understanding of those topics. The sources for this information are websites such as Google Scholar, Web of Science, ScienceDirect, Google and Scopus. The keywords used for the searches are as follows: biomimicry, innovation, bio-inspired design, importance of innovation, biomimicry principles, nature and a few variants of them. Furthermore, the book 'Biomimicry: Innovation Inspired by Nature – by Janine M. Benyus' is used. For the research of innovation, it is decided to use recent resources (starting from 2005) to cover the largest part of the theoretical framework, this for the reason that innovation requirements had constantly changed during the past decades. For the topic biomimicry there is no such limitation as for innovation.

Innovation projects will be more reliable when a systematic innovation method is followed (Reis, 2014). So, for the methodology part, several of those methods were identified and considered to criticize their usefulness in clarifying the potential of biomimicry, one of which was the Input-Process-Output (IPO) Model. The IPO Model identifies "the inputs, outputs, and required processing tasks to transform inputs into outputs" (Schembri, 2012). In such a model, the input is about whatever you need, or have, when you start your project, the so-called ingredients (Reis, 2014). The process is about "whatever you do during the project, which will include various tools and methods" (Reis, 2014). The output is depending on how you define your innovation project, which may be developed concepts, prototypes, etc. (Reis, 2014). Although the IPO Model is a dominant way of thinking about transformation processes, relatively few empirical studies have been devoted to the validity of the model itself (Rogelberg, 2007). In addition, the IPO model assumes "that processes fully mediate the association between inputs and outputs" (Rogelberg, 2007). However, some research has suggested that a purely mediated model may be too limited (Rogelberg, 2007). Furthermore, Forsyth (2010) outlined that some of the 'processes' are not actually processes, but rather characteristics of a process that develop and emerge during the time (Forsyth, as cited in "Input-Process-Output Model of Teams", n.d.). "They are not events that happen, but merely mediators of the input-output relationship" (Forsyth, as cited in "Input-Process-Output Model of Teams", n.d.).

Another approach is to use a framework which identifies the three levels of biomimicry, which are typically referred to as natural form, natural process, and natural ecosystems. (Baumeister et al., 2012). Within this approach each level is concerned with a layer of the design of an organism, which makes it possible to analyze the application of biomimicry from different perspectives. Furthermore, this framework may allow innovators who wish to employ biomimicry as a methodology for improving the sustainability of their products or for improving organizational processes. Given the fact that this framework will provide the most elaborated outline of the application of biomimicry, there is decided to continue using this method.

Afterwards gaining knowledge of the topics of innovation and biomimicry and the method selection, content analysis is adopted to identify the biomimicry levels. However, a framework for understanding the application of biomimicry is proposed in this paper which redefines the aforementioned levels.

The selected content used for the content analysis comes mainly from case studies and practical examples. Those are chosen based on their study about biomimicry approaches and applicable biomimicry levels: the organism level, the behavioral level, and the ecosystem level. (Ismail, Othmani, Rahman, & Yunos, 2018). A visualization of this framework is presented in Figure 1.

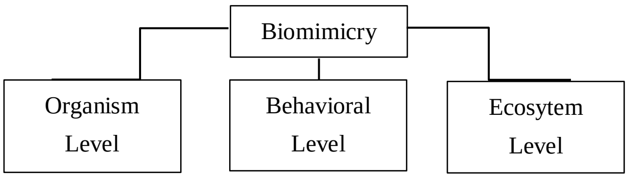

Figure 1. The Division of Biomimicry

The organism level entails the designer looking at the form of a specific organism, like a plant or animal, and at the same time analyzing how it functions; the designer can choose to mimic a part of the organism of the organism as a whole (Ismail et al., 2018).

The behavioral level involves the imitation of how an organism interacts with its immediate environment in order to build a structure or a process, for example an organizational process. In short, it is about how organisms behave or relate to a larger context (Ismail et al., 2018).

The ecosystem level "involves mimicking how an organism interacts with the environment and how many components work together, this tends to be on the urban scale or a larger project with multiple elements rather than a solitary structure" (Ismail et al., 2018, p. 55).

The information embedded in each level can be categorized in many aspects, which are summarized in Table 2.

Table 2. Different Aspects of the Levels of Biomimicry (El-Zeiny, 2012, p. 507).

Levels of biomimicry	Aspects of the levels
Organism level	Formal attributes include shape, color, volumetric treatment, transparency, rhythm
	Organization and hierarchy of parts and systems
	Structure, stability and gravity resistance
	Construction materials and process
	Mutation, growth and lifecycle
	Function and behavior
	Motion and aerodynamics
	Morphology, anatomy, modularity and patterns
	Portability and mobility
	Self-assembly
	Healing, recovery, survival and maintenance
	Homeostasis that balances internal systems while external forces change
	Systems which include organ, digestive, circulatory, respiratory, skeletal, muscular, nervous, excretory, sensory and locomotive systems
Behavioral level	Survival techniques
	Interaction with other creatures
	Transgeneration knowledge transfer and training
	Hierarchy of community members
	Group management and coordination
	Communication
	Collaboration and teamwork
	Self-protection
	Sensing, responding and interaction
	Risk management
Ecosystem level	The contextual fit
	Adjustment to change
	Response to climate by cooling, heating and ventilation solutions
	Response to context by, for example, camouflage, self-protection and self-cleaning
	Adaptation to ecosystems include adjustment to various light or sound levels, shading and self-illumination
	Shelter building
	Limited resource management such as adaptations to lack of water, light or food
	Waste management
	Input/output/process cycling

After the identification of the biomimicry levels and the provided examples fitting each level, their relevance and possible application for business management will be discussed.

After the desk research and the content analysis, the data analyzed using tables in Chapter 5 and their further possible applications in Chapter 6, leads to the conclusion of this research paper and to the answer on the main research question: *'How can biomimicry contribute to the innovation of products and organizational processes?'*.

4. DATA COLLECTION

For the data collection, there is decided to use practical examples or case studies that are already existing. Those are chosen based on their study about biomimicry approaches. Besides, those cases were clearly divisible and match the corresponding characteristics of one of the aforementioned biomimicry levels: the organism level, the behavioral level and the ecosystem level. Furthermore, those cases fit the categorization requirements that will be proposed for the data analysis framework which will be further explained in Chapter 5.

Unless the fact that we use the term biomimicry as early as 1982 (Smith, 2007), the application of biomimicry is still not enough implemented in human life. For this reason, there is not an overload of biomimicry examples available nowadays, they are actually relatively rare. Given this situation, the availability of examples is mainly dependent on what the internet was providing. Therefore, just like most of the information being part of this paper, also those cases are mainly derived from sources like Google, Google Scholar, Web of Science, ScienceDirect and Scopus. Furthermore, a few of them were cited and elaborated on in the book of Janine M. Benyus: 'Biomimicry – Innovation Inspired by Nature'.

However, the hype around biomimicry at the moment made it quite difficult to distinguish between pure scientific literature and novels, which made searching for concepts relatively difficult. Therefore, we could not state that those examples are representative for nature and the application of biomimicry as a whole, because there are undoubtedly more examples that could have strengthen the validity of this paper. However, due to the limited resources and the serious time constraint, research has taken us this far.

Table 3 provides a categorization of the biomimicry levels and their corresponding cases, this makes that the division is clear at a glance.

Table 3. Biomimicry Levels with Their Corresponding Cases

Organism Level (*copying form and shape*)	**Behavioral Level** (*copying a process*)	**Ecosystem Level** (copying *an ecosystem*)
1. WhalePower **2.** Efficient high-speed trains inspired by the kingfisher **3.** Norman Foster's Gherkin Tower **4.** The Eden Project, Cornwall **5.** Waterloo International Terminal **6.** Learning from mosquitos to create a nicer needle **7.** Eiffel Tower **8.** Arab World Institute **9.** Sinosteel International Plaza **10.** Habitat 2020 **11.** National Aquatics Centre, Beijing **12.** Gecko Climbing Feet **13.** Baobab Tree Inspired Treehouses **14.** Bird Skull Shoe by Marieka Ratsma and Kostika Spaho **15.** Orient Station **16.** Spiral Café **17.** UAE Pavilion	**1.** Swarm Logic **2.** Optical Hydrophone **3.** Eastgate Centre, Harare, Zimbabwe **4.** The Qatar Cacti Building **5.** Council House 2 Building, Melbourne, Australia **6.** Learning from dolphins how to send signals underwater **7.** Beijing National Stadium **8.** Rafflesia House **9**. Treescraper Tower of Tomorrow	**1.** Coral Reef Project Haiti **2.** The Cardboard to Caviar Project **3.** The Sahara Forest Project **4.** Lavasa Hill City **5.** Zira Island Master Plan **6.** Biolytix Water Australia Ply. Ltd.

The assumption is made that there will be a degree of overlap between the different levels of biomimicry and that each kind of biomimicry is not mutually exclusive. For example, the Qatar Cacti Building, psychically looks like a cactus (organism level), but on the other hand its functional processes are inspired by the way cactuses sustain themselves in a dry, scorching climate (behavioral level). Finally, the building uses the cactus's relationship to its environment as a model for building in the desert (ecosystem level). Apart from the Qatar Cacti Building, most of the examples at least fit two biomimicry levels. However, due to the scope of this research there is decided to classify each example according to one level; the most suiting one, which will be the level that fits most of the characteristics of the proposed innovation.

Furthermore, it can be noticed that the number of cases fitting each level is not equally divided. Most cases, at least 17, are provided for the organism level, compared to the 9 cases for the behavioral level and the 6 cases for the ecosystem level. This is due to the fact that biomimicry has become a popular topic when it comes to copying nature's form and shape for technological applications, however this field of science is still relatively limited when it comes to the application of biomimicry to behavioral or ecosystem concepts (Mead, as cited in "Biomimicry and its Place in Business Management", 2016).

5. DATA ANALYSIS

As aforementioned in the methods section there is decided to use a framework that divides the application of biomimicry into three categories, the so-called biomimicry levels, which include the organism level, the behavioral level and the ecosystem level. A glimpse of this framework is already provided in Table 3, Chapter 4. Nevertheless, for this section there is decided to create a separate table for each of the levels. Within each of the tables there will be elaborated on the specific cases. To create a more elaborated framework there is decided to create certain sub-elements for each of the cases. This will provide the opportunity to describe each case in more detail. Those sub-elements include the following: the inspiration, the materials used, the application and the added value. The element 'inspiration' provides the possibility to make the linkage between the technology and nature visible, which is very crucial, because this makes that we can speak off biomimicry. Although the second element 'materials used' is the least important element, it shows how humans replicate the materials and structures that nature is actually using, for their own applications. The application of each case is concerned with how we mimic and apply the inspiration from nature in our own designs. So, that we are able to recognize the contribution from nature. Finally, the added value of each case will be discussed, which is necessary for the reason that for its validity and integrality each case needs to contribute something. When a case does not fulfill this requirement, it can be better filtered out.

Although each case will be described in words, it still might be difficult for biomimicry to appeal to our imagination. For this specific reason there is decided to add an image to each case to strengthen its clarity.

5.1 The Organism Level

As already explained before; the organism level entails the designer looking at the form of a specific organism, like a plant or animal, and at the same time analyzing how it functions (Ismail et al., 2018). At this level the designer is able to choose to mimic only a part of the organism or the organism as a whole.

However, a disadvantage of mimicking an organism is that without "mimicking how it interacts and contributes to the ecosystem at a larger context, it has the potential to produce designs that are below average in terms of the impact it will have on the environment" (Reap et al., as cited in Alibaba & Nkandu, 2018, p. 4).

Table 4 provides an in-depth overview of the organism level, by analyzing several cases at aforementioned aspects.

Table 4. The Organism Level with Corresponding Cases

Whale-Power	*Inspiration*	Humpback whales[1]
	Materials used	Iron materials, steel, aluminum, copper, fiberglass, zinc[2]
	Application	♦ New fans and wind turbine blades designed using tubercle technology, which was inspired by the flippers of humpback whales, which have tubercles or bumps on the leading edges[1]
	Added value	♦ The new blades produce more energy more efficiently than conventional smooth blades[3] ♦ The delayed stall doubles the performance of the turbines at wind speeds of about 17 miles per hour and allows the turbine to capture more energy out of lower-speed winds[3] ♦ The tubercles effectively channel the air flow across the blades and create swirling vortices that enhance lift[3] ♦ The tubercles on the blade's leading edge are reducing noise and are increasing its stability[3] ♦ The bumps on the leading edge of the humpback whales' flipper give it a hydrodynamic advantage[3]

Image 1. WhalePower Turbines

Efficient High-speed Trains inspired by The Kingfisher	*Inspiration*	Beak of the kingfisher bird[4]
	Materials used	Steel, aluminum, zinc, plastic
	Application	A streamlined front nose cap modeled after the beak of the kingfisher bird[4]
	Added value	♦ No longer suffering from the loud shock wave known as the 'tunnel boom'; no more structural damage to several tunnels[4] ♦ Increasement of overall aerodynamics[4] ♦ The new trains are 10 percent faster[4] ♦ The new trains consume 15 percent less energy[4]

Image 2. Japan's 500 Series Shinkansen Bullet Train

Norman Foster's Gherkin Tower	*Inspiration*	Venus Flower Basket Sponge[5]
	Materials used	Glass, steel[6]
	Application	♦ An elongated, curved, shaft with a rounded end that is reminiscent of a stretched egg[6] ♦ It is covered around the outside with glass panels and it is rounded off at the corners[6]
	Added value	♦ The open shafts build in between each floor act as ventilation for the building and they require no energy for use[6] ♦ The shafts pull warm air out of the building and use passive heat from the

[1] AskNature Team. (2016, October 1). Tubercle Technology Blades; WhalePower. Retrieved from: https://asknature.org/idea/tubercle-technology-blades/

[2] Made How. (n.d.). Wind Turbine. Retrieved from: http://www.madehow.com/Volume-1/Wind-Turbine.html

[3] Hamilton, T. (2008, March 6). Whale-Inspired Wind Turbines. Retrieved from: https://www.technologyreview.com/s/409710/whale-inspired-wind-turbines/

[4] Adams, D. (2017, January 28). The Best of Biomimicry; Here's 7 Brilliant Examples of Nature-Inspired Design. Retrieved from: https://www.digitaltrends.com/cool-tech/biomimicry-examples/

[5] Wikipedia. (n.d.). Biomimetic Architecture. Retrieved from: https://en.wikipedia.org/wiki/Biomimetic_architecture#cite_note-13

[6] Design Book Magazine. (n.d.). 30 St. Mary Axe: The Gherkin. Retrieved from: http://www.designbookmag.com/thegerkin.htm

		sun to bring heat into the building during the winter[6] ♦ The shafts also allow available sunlight to penetrate deep into the building to cut down on light costs[6]

Image 3. Norman Foster's Gherkin Tower

The Eden Project, Cornwall	*Inspiration*	Soap bubbles and pollen grains[5]
	Materials used	Steel, EFTE-plastic, aluminum[7]
	Application	Geodesic hexagonal and pentagonal bubbles inflated with air, that house thousands of plants that are collected from many diverse climates and environments[7]
	Added value	♦ The use of Green Tarriff Electricity; the energy comes from one of the many wind turbines in Cornwall[7] ♦ Environmental education focusing on the interdependence of plants and people; plants are labelled with their medicinal uses[7] ♦ The massive amounts of water required to create the humid conditions, are all sanitized rain water[7]

Image 4. The Eden Project, Cornwall

Waterloo Int. Terminal	*Inspiration*	Pangolin[8]
	Materials used	Glass, steel[8]
	Application	The glass panel fixings that make up the structure of the terminal building mimic the flexible scale arrangement of the pangolin[8]
	Added value	The ability to move in response to the imposed air pressure forces at trains enter and leave the terminal[8]

Image 5. Waterloo International Terminal

Learning From Mosquitos to Create a Nicer Needle	*Inspiration*	Mosquito's proboscis[9]
	Materials used	Etched from silicon[9]
	Application	♦ Creation of a minute needle just one millimeter long and with a diameter of 0.1 millimeters[9] ♦ Copying a mosquito's seven mouthparts, including a system to steady the needle as it enters the skin[9]
	Added value	♦ Reduced pain for injecting or drawing blood samples[9] ♦ Because of the jagged outer surface, it presents a minimum amount of surface area to nerves in the skin, which makes

[7] Wikipedia. (n.d.). Eden Project. Retrieved from: https://en.wikipedia.org/wiki/Eden_Project

[8] Elsharkawy, A.N.E. (2011). Biomimetic Architecture. Retrieved from: http://biomimicryarch.blogspot.com/2011/05/biomimicry.html

[9] Coxworth, B. (2011, April 5). Moquito Inspires Near-Painless Hypodermic Needle. Retrieved from: https://newatlas.com/mosquito-inspires-near-painless-hypodermic-needle/18320/

		the injection more comfortable[9]

Image 6. A Needle Inspired by Mosquitos

Eiffel Tower	*Inspiration*	Thigh bone head[10]
	Materials used	Exposed iron[10]
	Application	♦ The outward flares at base resemble the upper curved portion of femur[10] ♦ The internal wrought iron braces closely follow the design of original trabeculae within femur[10]
	Added value	♦ Can withstand bending and shearing effects due to wind[10] ♦ Ventilation problem is solved by the unshakable structure[10]

Image 7. The Eiffel Tower Inspired by Thigh Bones

Arab World Institute	*Inspiration*	Iris of eye, diaphragms, moucharabia (Moorish extension with tracery)[10]
	Materials used	Aluminum, glass, steel[10]
	Application	♦ Cladded with screens with automated lenses like metal eyes that dilate according to outdoor light conditions[10] ♦ The kinetic wall that is facing the south controls thermal exposure and interior lightening with a single system[10]
	Added value	Controls the amount of sunlight entering to the building; keeping it cool[10]

Image 8. Arab World Institute

Sinosteel Int. Plaza	*Inspiration*	Bee hive[11]
	Materials used	Concrete, steel[11]
	Application	The façade is made up of five different sizes of hexagonal windows, multiplying and growing across, creating an ever-changing image of the building from each different perspective[11]
	Added value	The honeycomb structure allows the building to be energy efficient by mapping the different air flows and solar direction across the site[11]

Image 9. Sinosteel International Plaza

[10] Virmani, S. (2014, July 30). Biomimicry, p. 35. Retrieved from: https://issuu.com/sahilvirmani07/docs/biomimicry

[11] Virmani, S. (2014, July 30). Biomimicry, p. 39. Retrieved from: https://issuu.com/sahilvirmani07/docs/biomimicry

Habitat 2020	*Inspiration*	Living skin, basic cellular functions, leaf surface[12]
	Materials used	Steel[12]
	Application	♦ Fuses high-tech ideas with basic cellular functions to create ‘living’ structures that operate like natural organisms[12] ♦ The skin behaves like a membrane which serves as a connection between the exterior and interior of the habitat[12] ♦ The skin may be also considered as the leaf surface having several stomata, cellular openings involved in gaseous exchange and transpiration in plants[12]
	Added value	♦ The air and wind would be channeled into the building and filtered to provide clean air and natural air-conditioning[12] ♦ The active skin would be capable of rain water harvesting where water would be purified, filtered, used and recycled[12] ♦ The skin could absorb moisture from the air[12] ♦ The waste produced would be converted into biogas energy that could be put to diverse uses in the habitat[12] ♦ The surface would automatically position itself according to the sunlight and let in light; thus, electricity for lightning would not be needed during the day[12]

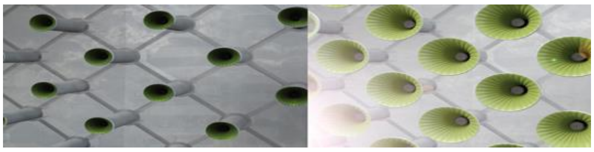

Image 10. Inspiration for Habitat 2020

National Aquatics Centre, Beijing	*Inspiration*	Water bubbles in foam[8]
	Materials used	Steel[8]
	Application	♦ The honey-comb structure appears to be a pool of water from an aerial view, and is created with the intention to host national swimming events[8] ♦ The surface is covered with membrane of light blue bubbles or pneumatic cushions creating a bubble effect[10]
	Added value	♦ The bubbles collect solar energy to heat the swimming pools[10] ♦ Temperature regulation[10]

Image 11. National Aquatics Centre, Beijing

Gecko Climbing Feet	*Inspiration*	Tiny little hairs (setae) covering the toes of Geckos[13]
	Materials used	Plastic, silicone[13]
	Application	♦ Climbing pads capable of supporting a human’s weight[14] ♦ The pads are covered with adhesive tiles bearing sawtooth-shaped polymer structures about the width of a human hair that create an adhesion force when they are pulled on[14]
	Added value	♦ Increases the surface area of the foot[13] ♦ Goal: to help soldiers scale buildings and obstacles more easily or helping astronauts to maneuver themselves[13]

[12] Yoneda, Y. (2008, September 7). Habitat 2020: Future Smart ‘Living’ Architecture. Retrieved from: https://inhabitat.com/habitat-2020-off-the-grid-future-abode/

[13] IFLScience. (n.d.). Gecko-Style Climbing Pads Allow A Man to Climb a Glass Wall. Retrieved from: https://www.iflscience.com/technology/gecko-style-climbing-pads-allow-man-climb-glass-wall/

[14] bySteph. (2014). Nature’s Wisdom: 9 Brilliant Examples of Biomimicry in Design. Retrieved from: https://www.momtastic.com/webecoist/2014/12/31/natures-wisdom-9-brilliant-examples-of-biomimicry-in-design/

Image 12. Inspiration for the Gecko Climbing Feet

Baobab Tree Inspired Treehouses	*Inspiration*	Baobab trees which have large swollen-looking trunks[15]
	Materials used	Cedar shingles, glass, wood[16]
	Application	♦ The threehouses wrap around the trunk like a result of natural growth[15] ♦ The treehouses are intented to blend in with the supporting trees, so that it looks like it grew from the tree itself[16]
	Added value	It has a very small impact on its forest environment, attacking with a set of braces that allow the tree to continue growing without damaging the bark[16]

Image 13. Baobab Inspired Tree Houses

Bird Skull Shoe by Marieka Ratsma and Kostika Spaho	*Inspiration*	Bird skull[17]
	Materials used	3D-printing material[17]
	Application	The design highlights the use of a bird's cranium of the front of the shoe, with the tapered beak as the spike of the heal[17]
	Added value	♦ The lightweight and efficient structure of the skull allowed the shoe to be 3D-printed[17] ♦ Such a structure requires less support material, resulting in optimal efficiency, strength and elegance[14] ♦ The production of unusual, lightweight and strong shoes[15]

Image 14. Bird Skull Shoe

Orient Station	*Inspiration*	Palm tree[8]
	Materials used	Steel, concrete[8]
	Application	Steel and glass 'trees' interlock to form a continuous system of transparent roofs arranged on a 56-foot-grid[18]
	Added value	♦ The sweeping, glazed canopies of the bus terminal rise up to cover an elevated gallery, which provides access to the station above the bus lanes[18] ♦ An important interchange for high-speed intercity trains, rapid regional transport, standard rail services, tram and metro networks[18]

[15] McFadden, C. (2017, February 17). Biomimicry: The Sincerest Form of Flattery. Retrieved from: https://interestingengineering.com/biomimicry-sincerest-form-flattery

[16] Delana. (n.d.). Beautiful Biomimicry: Treehouses Look Like Part of the Trees. Retrieved from: https://dornob.com/beautiful-biomimicry-treehouses-look-like-part-of-the-trees/

[17] Chalcraft, E. (2012, July 17). Biomimicry Shoe by Marieka Ratsma and Kostika Spaho. Retrieved from: https://www.dezeen.com/2012/07/17/biomimicry-shoe-by-marieka-ratsma-and-kostika-spaho/

[18] Santiago Calavatra Architects & Engineers. (n.d.). Oriente Station, Lisboa. Retrieved from: https://calatrava.com/projects/oriente-station-lisboa.html

Image 15. Orient Station

Spiral Café	*Inspiration*	Shape of sea shells and pines cones to fractal patterns within galaxies[8]
	Materials used	Concrete, glass[8]
	Application	♦ Sweeping a Fibonacci spiral to create a shell-like canopy; a simple curved enclosure[19] ♦ Like a shell the exterior of the café is rough, rugged and durable, whereas the inside is smooth and precious[20]
	Added value	♦ It creates a landmark structure, which is part sculpture and part revenue generator[19] ♦ Helps to animate the terraces of the hard landscape in which it sits[19]

Image 16. The Spiral Café

UAE Pavilion	*Inspiration*	Desert landscape[8]
	Materials used	Steel, stainless steel[8]
	Application	The pavilion creates a symbolic reference with the desert landscape over which each of the seven emirates presides[8]
	Added value	As if modeled by prevailing winds, the pavilion mimics the duality between the rough and smooth sides of a sand dune while making the most of its site[8]

Image 17. UAE Pavilion

5.2 The Behavioral Level

To recap, the behavioral level involves the imitation of how an organism interacts with its immediate environment in order to build a structure or a process, for example an organizational process (Ismail et al., 2018). In short, it is about how organisms behave or relate to a larger context.

"The behavioral level is based on the fact that a vast number of organisms have learnt to operate within the capacity of specific environmental conditions and within the limits of energy and material availability, they encounter the same environmental conditions that humans do and therefore need to solve similar issues that humans face" (Alibaba & Nkandu, 2018, p. 6).

Table 5 provides an in-depth overview of the ecosystem level, by analyzing several cases at aforementioned aspects.

[19] SteelConstruction.org. (n.d.). Bullring Spiral Café, Birmingham. Retrieved from: https://www.steelconstruction.org/design-awards/2006/certificate-of-merit/bullring-spiral-cafe-birmingham/

[20] World Architecture News. (2005, July 18). Spiral Café Completed. Retrieved from: https://www.worldarchitecturenews.com/article/1499197/spiral-cafe-completed

Table 5. The Behavioral Level with Corresponding Cases

Swarm Logic	*Inspiration*	The way that social insects like ants, termites or bees communicate and coordinate with each other using simple rules governing individual interactions[21]
	Materials used	Stainless steel
	Application	Wireless power controllers that enable autonomous communication among power-consuming appliances[21]
	Added value	♦ Wireless energy management solution[21] ♦ Reduction of an owner's electric costs with 5-10 percent[21] ♦ Reduction of peak demand usage and smoothing out of demand[21] ♦ To prevent that different types of building equipment operate in isolation from each other. When these loads communicate with each other, they do not have to operate unnecessarily at the same time fulfilling the same demands[21] ♦ It operates in the background and requires no human interaction to maintain or monitor its actions[21]

Image 18. Swarm Logic Sensor

Optical Hydro-phone	*Inspiration*	Orcas[22]
	Materials used	Stainless steel, Delrin
	Application	A highly sensitive underwater microphone that can capture the whole range of ocean sounds[22]
	Added value	♦ Useful for studying underwater ecosystems[22] ♦ Guiding robots to repair leaking undersea oil wells[22]

Image 19. Optical Hydrophone

Eastgate Centre, Harare, Zimbabwe	*Inspiration*	Termite mound[23]
	Materials used	Concrete[23]
	Application	♦ Based on techniques of passive ventilation and temperature regulation observed in termite mounds, in order to create a thermally stable interior environment[24] ♦ Water which is mined and cleaned from the sewers beneath the building is used in a similar manner to how termite species will use the proximity of aquifer water as an evaporative cooling mechanism[24] ♦ The central open space draws more air with help of fans and is pushed up through ducts located in the central spine of the building[23]
	Added value	Temperature remains regulated all year around without using conventional air-conditioning or heating systems[23]

[21] AskNature Team. (2017, September 19). Swarm Logic Technology Reduces Energy Use; Encycle. Retrieved from: https://asknature.org/idea/swarm-logic-technology-reduces-energy-use/
[22] AskNature Team. (2016, October 1). Optical Hydrophone. Retrieved from: https://asknature.org/idea/optical-hydrophone/
[23] Krishnakumar, V. (2011, November 26). Biomimetic Architecture, p. 41. Retrieved from: https://www.slideshare.net/vaisalik/biomimetic-architecture/43
[24] Pedersen Zari, M. (2007). Biomimetic Approaches to Architectural Design for Increased Sustainability. Retrieved from: http://www.cmnzl.co.nz/assets/sm/2256/61/033-PEDERSENZARI.pdf

Image 20. Eastgate Centre, Harare, Zimbabwe

The Qatar Cacti Building	*Inspiration*	Cactus[11]
	Materials used	Glass, steel[11]
	Application	Sun shades on the windows can be opened or closed to suit the prevailing temperature, mimicking the activity of the cactus which performs transpiration at night rather than during the day in order to retain water[11]
	Added value	♦ Temperature regulated[11] ♦ Absorption and loss of heat controlled[11]

Image 21. Qatar Cacti Building

Council House 2 Building Melbourne	*Inspiration*	Termite mound[25]
	Materials used	Concrete, recycled timber[25]
	Application	♦ CH2 uses a ventilation strategy similar to a termite mound using convention, ventilation stacks, thermal mass, and water for cooling[25] ♦ The façade is composed of dermis and epidermis, which provides microclimate[25] ♦ Ventilation stacks are placed on the north and south facades of the building[25] ♦ The ceilings are wavy shaped to optimize the surface area and therefore increase the thermal mass capacity[25] ♦ The west façade is covered with timber louvers to optimize the penetration of natural lights and views[25]
	Added value	♦ The epidermis provides primary sun and glare control while creating a semi-closed change phase material environment[25] ♦ The wavy design helps it efficient collection and channeling out of heated air[25] ♦ The vaulted ceiling allows for more filtration of natural light to the deeper parts of the space[25] ♦ The shower towers provide a reduction of 4-13 degrees Celsius from the top of the tower to the bottom[25]

Image 22. Council House 2 Building, Melbourne

[25] Krishnakumar, V. (2011, November 26). Biomimetic Architecture, p. 42. Retrieved from: https://www.slideshare.net/vaisalik/biomimetic-architecture/43

EvoLogic	*Inspiration*	Physics of dolphin communication[26]
	Materials used	Stainless steel, Delrin[27]
	Application	♦ Development of underwater sensors that can transmit frequencies similar to those emitted by dolphins[26] ♦ Modems built on the S2C technology continuously spread the signal energy over a wide range of frequencies and adapt the signal structure so that the multipath components do not interface with each other[26]
	Added value	♦ The sensors can be used to detect underwater earthquakes and therefore aid in tsunami warning systems. This for the reason that an early detection system can prepare residents to evacuate even sooner, and perhaps take precautions to reduce damage to infrastructure[26] ♦ The beam pattern is optimal for transmissions in horizontal channels[27] ♦ Smaller and lighter build design for size- and weight-sensitive applications[27]

Image 23. EvoLogic Sensor

Beijing National Stadium	*Inspiration*	Bird's nest[25]
	Materials used	Unwrapped steel, EFTE[25]
	Application	There is a so-called 'cushion system' adopted where the facades are filled with translucent EFTE panels, just like a nest of a bird is insulated with small pieces of material[25]
	Added value	♦ Filters sun rays[25] ♦ Reduced dead load[25] ♦ Reduces maintenance costs[25] ♦ Provides acoustic insulation[25] ♦ Protects spectators from elements[25]

Image 24. Beijing National Stadium

Rafflesia House	*Inspiration*	Rafflesia flower[28]
	Materials used	Tensile environmentally friendly fabrics[28]
	Application	♦ The building is constructed on twelve different columns to allow other species to develop around it, trying to change traditional definitions of its characteristics[28] ♦ Concave and convex internal walls to regulate the flow of air inside the building[28]
	Added value	Effective air-conditioning at independent zones[28]

[26] AskNature Team. (2016, October 1). EvoLogics Underwater Sensor. Retrieved from: https://asknature.org/idea/evologics-underwater-sensor/

[27] Evologics.de. (n.d.). S2C M HS. Retrieved from: https://evologics.de/acoustic-modem/hs

[28] Krishnakumar, V. (2011, November 26). Biomimetic Architecture, p. 43. Retrieved from: https://www.slideshare.net/vaisalik/biomimetic-architecture/43

Image 25. Rafflesia House

Tree-Scraper Tower of Tomorrow	*Inspiration*	Growing of a tree[29]
	Materials used	Steel, glass[29]
	Application	♦ The southern facade would be made of photovoltaic panels that convert sunlight into electricity[29] ♦ A combined heat-and-power recycle system. There will be also a tower plant installed, which is fueled by natural gas, to supply the power that the solar panels cannot[29]
	Added value	♦ It uses minimal construction materials, while making maximum use of the enclosed space[29] ♦ All of the water in the building is recycled[29] ♦ All products, from building materials to furniture, could be recycled or returned safely to the earth[29]

Image 26. Treescraper Tower of Tomorrow

5.3 The Ecosystem Level

As aforementioned the ecosystem level "involves mimicking how an organism interacts with the environment and how many components work together, this tends to be on the urban scale or a large project with multiple elements rather than a solitary structure" (Ismail et al., 2018, p. 55). This level is considered as the hardest level as it focusses on a functionally very hard issue to mimic (Aziz & El Sherif, 2016).

The mimicking of ecosystems is an integral part of biomimicry as described by Benyus (1997) and Vincent (2007). Another term that describes the mimicking of ecosystems is called ecomimicry (Russell, 2004).

Considering all the biomimicry levels, mimicking at the ecosystem level allows for the easiest conjunction with the other levels (organism and behavioral) (Alibaba & Nkandu, 2018).

For design to mimic nature on the ecosystem level, it might follow six principles. Ecosystem principles follow that ecosystems (El Ahmar, 2011):

1. Are dependent on contemporary sunlight
2. Optimize the system rather than its components
3. Are attuned to and dependent on local conditions
4. Are diverse in components, relationships and information
5. Create conditions favorable to sustained life
6. Adapt and evolve at different levels and at different rates

However, due to the scope of this research it is decided to not test each ecosystem case against those six principles, because that would take too much time and will be too complicated.

Table 6 provides an in-depth overview of the ecosystem level, by analyzing several cases at aforementioned aspects.

Table 6. The Ecosystem Level with Corresponding Cases

Coral Reef Project Haiti	*Inspiration*	Coral reef[30]
	Materials used	Metal, tropical wood, duplex[30]
	Application	♦ An energy self-sufficient village from standardized and prefabricated modules in order to rehouse the refugees from humanitarian catastrophes[30] ♦ Two passive houses interlocked in duplex around a transversal horizontal circulation linking every unit[30] ♦ The overall project presents itself as a great living structure made of two waves dedicated to house more than one thousand Haitian families[30]

[29] Virmani, S. (2014, July 30). Biomimicry, p. 37. Retrieved from: https://issuu.com/sahilvirmani07/docs/biomimicry

[30] eVolo. (2011, February 14). Coral Reef – Matrix for the Construction of 1000 Passive Houses in Haiti / V. Callebout. Retrieved from: http://www.evolo.us/coral-reef-matrix-for-the-construction-of-1000-prefabricated-passive-houses-in-haiti-v-callebaut/

		♦ Each roof of each module represents an organic suspended garden[30]
	Added value	♦ This canyon is a true tropical ecosystem for the local fauna and flora[30] ♦ The roofs are enabling the families to cultivate their own food and to use their own wastage as compost[30] ♦ The project is eco-designed and integrates all the bioclimatic systems as well as the renewable energies[30]

Image 27. Coral Reef Project Haiti

The Cardboard to Caviar Project	*Inspiration*	How nature uses waste as nutrition[31]
	Materials used	Cardboard[31]
	Application	This project takes cardboard from restaurants, shreds it and sells it as horse bedding to farms. When the horse bedding needs to be replaced, it is composted in a worm farm. The compost is then used onto plant beds and the surplus of worms are fed to the fish that produces caviar. The caviar is then sold back to the restaurants[31]
	Added value	Shows how waste can be transformed into food again[31]

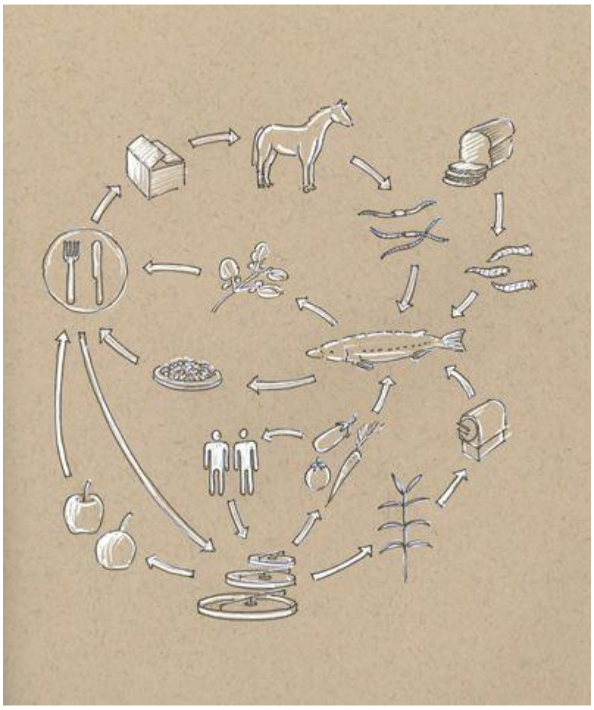

Image 28. Cycle of the Cardboard to Caviar Project

The Sahara Forest Project	*Inspiration*	Nature[32]
	Materials used	Steel, iron, PVC, PE
	Application	♦ A technological system where the waste product from one technology is used as resource for another[32] ♦ Revegetation and creation of green jobs through profitable production of food, freshwater, biofuels and electricity[32] ♦ Combines saltwater-cooled greenhouses with solar power technologies and technologies for desert revegetation[32]
	Added value	♦ Offers opportunities for renewable energy production and agricultural production in low lying desert areas[32] ♦ Bringing out the potential that exist in the synergies between technologies across industry sectors[32] ♦ By using locations below sea level,

[31] Oppenheim, L. (2008, October 28). Lessons in Biomimicry – Part 2 Natural Systems. Retrieved from: https://www.treehugger.com/sustainable-product-design/lessons-in-biomimicry-part-2-natural-systems.html

[32] Bellona. (n.d.). Sahara Forest Project. Retrieved from: https://bellona.org/projects/sahara-forest-project

		pumping costs for seawater would be eliminated[32] ♦ Ensuring there is enough land, fresh water and power for the expected 9.3 billion people on the planet by 2050[33]

Image 29. Sahara Forest Project

Lavasa Hill City	*Inspiration*	Banyan fig leaves, harvester ants and amoebas[34]
	Materials used	Different materials like concrete, metal, tiles, steel, brick, wood
	Application	♦ Development of tiled shingle rooftops that shed water in the same way as the native banyan fig leaf, whose pointed spear shape hastens the water run-off and cleans its surface in the process[34] ♦ A system that is adopted to channel water through the city based on an ant nest that divert water away from their nests through multi-path, low-grade channels[34] ♦ Strategically based catch basins are also used to collect rainwater for irrigating farms in the valley below the hills[34]
	Added value	♦ Restore 70% of the deforested land through detailed landscaping, reforestation and slope greening[34]

		♦ Reduce 30% of carbon emissions, 65% of potable water consumption, and 95% of waste send to landfills[34]

Image 30. Lavasa Hill Station Master Plan

Zira Island Master Plan	*Inspiration*	Natural landscape of Azerbaijan[35]
	Materials used	Different materials like concrete, metal, tiles, steel, brick, wood
	Application	♦ An autonomous ecosystem where the flow of air, water, heat and energy are channeled in almost natural ways[35] ♦ Recreates the iconic silhouettes of the seven peaks of Azerbaijan, which are not only metaphors, but actual living models of the mountainous ecosystems of Azerbaijan[35] ♦ The buildings are heated and cooled by pumps connected to the Caspian sea[35]
	Added value	♦ It creates biotopes and eco-niches, it channels water and stores heat, it provides viewpoints and valleys, access and shelter[35] ♦ The creation of an island that is completely independent of external resources[35] ♦ Provides a high-end living with a minimum usage of resources[35] ♦ The island supports the lush green condition of a

[33] Atlas of the Future. (n.d.). Greening the Sands with the Sea – The Sahara Forest Project. Retrieved from: https://atlasofthefuture.org/project/the-sahara-forest-project/

[34] Elakhya, N. (n.d.). Biomimicry – Better Ideas Inspired by Nature. Retrieved from: http://www.ecoideaz.com/innovative-green-ideas/biomimicry-better-ideas-inspired-nature

[35] Basulto, D. (2009, January 30). Zira Island Carbon Neutral Master Plan / BIG Architects. Retrieved from: https://www.archdaily.com/12956/zira-island-carbon-neutral-master-plan-big-architects

		tropical island, with a minimal ecological footprint[35]
 Image 31. Zira Island Master Plan		
Biolytix Water Australia Pty Ltd	*Inspiration*	Based on how forest litter decomposes[36]
	Materials used	Manufactured from 100% recycled material[36]
	Application	♦ Water filtering systems that cleans without chemicals[36] ♦ It mimics the intricate natural conditions that cause decomposition of debris on a river's edge[36] ♦ Selected worms, beetles, and microscopic organisms covert the waste into structured humus[36]
	Added value	♦ The system removes solid wastes from wastewater immediately[36] ♦ Converts raw sewage, wastewater, and food waste into high quality irrigation water on site[36] ♦ Silent operation[36]
 Image 32. Biolytix Water Filtering System		

[36] AskNature Team. (2016, October 1). Biolytix Water Filter. Retrieved from: https://asknature.org/idea/biolytix-water-filter/

6. CONTRIBUTION TO BUSINESS MANAGEMENT

According to the analysis of Chapter 5, biomimicry has already proven its usefulness in the areas of technology, products, and designs that have adapted concepts from nature and are used to solve more complex human problems. However, the goal of this research was also to analyze what kind of impact biomimicry and its concepts could have on organizational processes, or in other words what could be the contribution of biomimicry, and the aforementioned cases, for business managers.

From the aforementioned biomimicry levels, the behavioral level is most applicable to assess the potential of biomimicry for the innovation of organizational processes. Within this level it is all about the way that organisms behave and therefore best comparable with human actions or behavior, for example in organizations. A great number of organisms have to deal with the same environmental conditions that humans do and need to solve similar issues that humans are facing (Pedersen Zari, 2007). Therefore, humans may gain "valuable insights by looking at how other species are able to change their environments while creating more capacity for life in that system" (Pedersen Zari, 2007, p. 33). On the other hand, the organism level is more applicable to the contribution of biomimicry in the field of product innovation.

For the above-mentioned reasons, there is decided to mainly focus this chapter on the applicability of the aforementioned behavioral level cases to business management concepts. Furthermore, due to amongst other things the time constraint for this research, there is decided to not discuss every case in detail regarding their added value for business managers. Another reason is that some cases dwell on the same basic principles and that will cause to much overlap.

In short, this chapter elaborates on certain theories and concepts indicated by nature, from which inspiration is generated from certain aforementioned cases, and their applicability to business practices. Afterwards, we will be able to draw some conclusions covering the whole paper, to indicate the limitations and to provide some suggestions for further research.

6.1 Inspiration by Termites

Both the Council House 2 Building and the Eastgate Centre, two cases from the behavioral level, have taken their inspiration from termites and termite mounds. Termites could be seen as architects of sort, building nests of complex architecture, that in some instances are several meters high (Soar & Turner, 2008). Those termite mounds have been proposed to optimize different structural features (Andara, Griffon, & Jaffe, 2015). For example, mimicking termite's strategies can drastically improve energy efficiency in buildings (Tonn, 2015). As in the cases of the Council House 2 Building and the Eastgate Centre, termite inspired ventilation systems "allows buildings to breathe freely" (Soar, as cited in Tonn, 2015), while at the same time using only 10% of the energy needed by a similar conventionally cooled building (Doan, as cited in Ahmed & French, 2011). Furthermore, such a structure avoids "multiple crossing of activities and minimizes the overlap of foraging territories" (Andara et al., 2015). However, termites are much more interesting in their function than had previously been discussed within this paper.

Termites are communicating with each other according to simple rules. Those simple rules are of high importance, because when the termite construction needs to be clearly managed, all kinds of mistakes will occur (Tofield, 2002). For example, a lot of termites would waste time waiting for instructions and getting in each other's way, while at the same time 'termite managers' would get a lot of stress (Tofield, 2002). However, this is the way that business organizations have developed over time, because managers decide what needs to be done and how it needs to be done. In this way, managers disable the mechanisms by which people could work together to make a termite-like organization much more than the sum of its parts and therefore achieving only a fraction of their potential (Tofield, 2002).

Jim Donehey, the CIO of Capital One, developed similar simple rules to shape the behavior of its organization and replace the current command-and-control structure. By applying this approach, Donehey came up with four basic guidelines to ensure that everyone in his organization was working towards the same goals (Bonabeau & Meyer, 2001, p. 111):

1. Always align IT activities with the business (that is, keep the company's overall goals in mind)
2. Use good economic judgement (spend the money like it is your own)
3. Be flexible (do not box yourself into one thought pattern)
4. Have empathy for others in the organization (when people ask you to do something you do not agree with, put yourself in their shoes)

Donehey claims "those rules empowered his staff to make decisions on their own and work with little top-down management" (Bonabeau & Meyer, 2001, p. 111). And as a result, "the attrition rate is below 4%, compared with 20% for the IT industry as a whole" (Bonabeau & Meyer, 2001, p. 111).

So, such cultures enable people to work together to generate extraordinary performances, "the so-called human equivalent of termite building" (Tofield, 2002). Moreover, those cultures, where people are enabled to be responsible, are suitable for exceptional teamworking, quality and customer service. Besides, it is important for businesses to become more than the sum of their parts (Tofield, 2002).

Furthermore, the role of termites in water conservation is well recognized (Ahmed & French, 2011). However, there a just a few studies that have examined the behavioral approach of termites in relation to water conservation in order to manage water. So, this will be worth looking at for businesses, because sustainable water management "is a key to every society's survival and development" (Ahmed & French, 2011, p. 573).

To summarize, termites have become a source that could be harnessed for the achievement of our own desired ends (Srinivasan, 2018). However, when it comes to the decentralization part, Hom et al. (2010) found that "when teams self-organize too independently there is a lack of cohesion and complete failure of the system" (Hom et al., as cited in "Biomimicry and its Place in Business Management", 2016, p. 11).

6.2 Inspiration by Swarm Intelligence

The technology of Swarm Logic, a case from the behavioral level, is inspired by the way that social insects, like ants communicate and coordinate with each other using simple rules governing individual interactions. Swarm Logic designed wireless power controllers that enable communication among building appliances to reduce peak electricity demand and costs (AskNature Team, 2017). In this way, Swarm Logic provides a wireless energy management solution (AskNature Team, 2017). Swarm Logic inevitably drew its inspiration from the phenomenon that is called 'swarm intelligence'. Swarm Intelligence can be defined as the collective behavior of decentralized, self-organized systems which are typically made up of a population of social insects interacting locally with one another and with their environment (Agarwal, Balochian, Bhatnagar, Yan, & Zhang, 2013).

Nowadays, there are many examples of where swarm intelligence is being used, especially in the application of information technology, just like the wireless power controllers of Swarm Logic. However, there are also a few results of using this theory linked to management practices within businesses.

Self-organization is a big aspect of swarm intelligence. Social insects are "individually simple, yet collectively brilliant having complex functional systems within their environment, such as the routing of traffic and the allocation of labor and resources" (Fewell, as cited in "Biomimicry and its Place in Business Management", 2016, p. 7). Where "humans require structural management and organizational systems, including hierarchies, social insects are fully capable of doing the same tasks without supervision or any method of centralized control" ("Biomimicry and its Place in Business Management", 2016, p. 7).

Furthermore, the efficiency of logistical operations could be improved by using a model of work allocations inspired by social insects, this phenomenon is called 'the bucket brigade' and was first introduced by John Bartoldi and Donald Eisenstein. This phenomenon suggests that we have to prevent ourselves from using zone approaches, in such approaches each worker is responsible for a specific task and the start of his task is dependent on the completion of a previous task by another co-worker. This is not an efficient way of working for the reason that those approaches tend to underuse the faster people and overuse the slower people (Bonabeau & Meyer, 2001). Using computer simulations, they found out that the optimum sequence of workers is from slowest to fastest and that it makes the whole system 30% more productive (Bonabeau & Meyer, 2001).

Moreover, "the way insects cluster their colony's dead and sort their larvae, for instance, has led to a novel approach for banks to use to analyze their data for interesting commonalities among customers" (Bonabeau & Meyer, 2001, p. 113).

However, research is relatively limited when it comes to the application of swarm intelligence to robotics. Despite the fact that it has a great potential to be implemented. Such robots need to be programmed with an algorithm that tells the robot what basic action it needs to perform in a subsequent order, just like the concept of the 'bucket brigade'. In this way the robots will be able to construct, for example, a wall or a staircase. The input will be based on the input the sensors receive about its environment. Just like the termites themselves those robots need to function without any centralized command or human action. So, amongst other things, the robots need to detect each other to prevent coming in each other's way. Computer scientist Radhika Nagpal and her team have started with the development of such robots, based on the principle of 'extended stigmery': which means that the embedding of the design information needs to be in the robot's environment, instead of in the robots themselves (Nagpal, as cited in Scrinivasan, 2018).

Swarm Intelligence is becoming a valuable tool for optimizing the operations of various businesses. The advantages of the application of swarm intelligence can be summarized into three aspects (Bonabeau & Meyer, 2001, p. 111):

1. *Flexibility:* the group can quickly adapt to a changing environment
2. *Robustness:* even when one or more individuals fails, the group can still perform its tasks

3. *Self-organization*: the group needs relatively little supervision or top-down control

However, the swarm theory and self-organization could also be difficult to implement in companies, especially companies new to the concept of swarm intelligence (Bonabeau & Meyer, 2001). Furthermore, Hom et al. (2010) recommend to include individual self-management and group processes (e.g. cohesion) as elements in the organization, if they want to fully use such systems to their own advantage.

6.3 Inspiration by Bee Hive Selection

From the organism level cases, Sinosteel International Plaza has taken its inspiration from the bee hive. The façade of this building is made up of five different sizes of hexagonal windows, based on the design of a bee hive (Virmani, 2014, p. 39). As aforementioned, this honeycomb structure "allows the building to be energy efficient by mapping the different air flows and solar direction across the site" (Virmani, 2014, p. 39).

However, companies may also use the decision-making process used by bees in the search for leaders. Bees possess a search and decision-making mechanism that can be used and applied for leadership location. It is suggested that the bee's search-and-decision mechanism is most advantageous when the decision-making environment is at a high stake (List & Vermeule, 2010). This is for the reason that "leadership and charisma are scarce resources whose presence or absence can make or break institutions, and because firms and organizations tend to search for new leadership in periods of crisis" (List & Vermeule, 2010, p. 23). Therefore, one could state that the stakes are high and justifying the use of such a decision system. According to List and Vermeule (2010) three conditions seem to favor the use of the bees' type of decision making: (1) an open-ended agenda, (2) high stakes, (3) high opportunity costs.

Furthermore, it is suggested to create a wide range of diversity across organizations, just like the diversity in a beehive. This for the reason that, "the greater the diversity in the bees' DNA, the more sensitive they are to different conditions and circumstances, and the more options the hive is able to gather" (O'Malley, 2012). In other words, more diverse organizations should be better at basically everything and more productive than the less diverse ones (O'Malley, 2012).

Moreover, when a honeybee colony becomes too large – that is, when it reaches a point of diminishing returns – the nest splits in two. This could be a process worth looking at for business managers, because such knowledge could help various organizations determining when to spin off some of their operations or spreading the risk by creating more sub-divisions (Bonabeau & Meyer, 2001).

To conclude, bees have developed procedures that humans can use to prevent catastrophic loss. Furthermore, when we adapt the key features that "keep bees venturing productively, but never gambling catastrophically, businesses might avoid heavy-handed regulation, and everyone will be better served" (O'Malley, 2012). However, the suggestion is emphatically not that "humans should mindlessly copy the hive, or that any decision procedure in use among social insects or other non-human animals can be directly transposed to the human world" (List & Vermeule, 2010, p. 4). Rather, it is suggested that certain structural features of decision-making environments, are common to decision making by both human and non-human animals in certain settings (List & Vermeule, 2010).

6.4 Inspiration by Amoebas

From the ecosystem level cases, Lavasa Hill City is amongst other things inspired by amoebas. However, this is just an example of how people are able to influence design by amoebas. Nevertheless, amoebas also have a great potential to influence how we are conducting business.

A persistent challenge for companies, as they become larger and more established, is how to maintain the high level of dynamism that drove their success in the early days (Adler & Hiromoto, 2012). During the years, management theorists have formulated an array of approaches for dealing with this problem. However, few companies have taken things as far as Kyocera Corporation. A key driver of Kyocera's growth and success has been its distinctive entrepreneurial culture, known as 'amoeba management' (Adler & Hiromoto, 2012). In general, an amoeba is a "type of cell or unicellular organism which has the ability to alter its shape, primarily by extending and retracting pseudopods" (Singleton, as cited in Wikipedia, n.d.).

Amoeba management is about dividing an organization into small units, the so-called amoebas (Inamori, 2009). "The use of the word 'amoeba' is meant to capture the concept of an entity at its smallest, most elemental level, as well as to describe its ability to multiply and change shape in response to the environment" (Adler & Hiromoto, 2012). In short, amoeba management is intended to offer a spontaneous response to a business world characterized by rapid, dynamic change (Adler & Hiromoto, 2012).

The amoebas achieve their goals through collaborative teamworking of all their amoeba members. In such a system, "every employee plays a major role and voluntarily participates in managing the unit, achieving what is known as 'management by all'" (Inamori, 2009). So, amoeba management demands the active participation of all employees. Decentralization, together with employee empowerment, permits companies to adapt quickly to competitive pressures (Adler & Hiromoto, 2012). Like other decentralized management systems, "amoeba management is designed to spur market agility, customer service and employee empowerment, but it is also supposed to reinforce performance management processes such as human resources selection and training, accounting and organizational development to promote positive performance" (Adler & Hiromoto, 2012).

Nowadays, the amoeba management system has been implemented at approximately 700 companies, including Kyocera, KDDI and Japan Airlines (Inamori, 2009).

However, the amoeba management system would function even more productive when there is a more suitable accounting system available. This for the reason that the traditional accounting systems operate on the base of global figures, which are useless for managing amoebas (Urban, 2017). For amoeba management systems it would be more advisable to have an accounting system that provides reliable information about the total expenses of each amoeba (Urban, 2017). So, this would be an interesting research opportunity for organizations that want to adopt such an amoeba management system.

To finalize, "business environments characterized by intense competition and fast technological change are better suited to amoeba management because companies that operate in that type of environment require decentralized structures" (Lawrence & Lorsch, as cited in Adler & Hiromoto, 2012). However, organizations that go too far in fostering competitive activity are likely to run into difficulty if they try to adopt amoeba management (Adler & Hiromoto, 2012).

7. SUMMARY AND CONCLUSION

The objective of the research is to indicate the relevance of biomimicry for both product innovation and the innovation of management concepts in order to answer the aforementioned research question: *'How can biomimicry contribute to the innovation of products and organizational processes?'*. Assessment is necessary in order to validate or disprove the promising potential of biomimicry to solve current innovation and business challenges.

With the literature review this paper elaborated on the importance of innovation and the potential of biomimicry in contributing to this issue. Today's global market place is fiercely competitive and "organizations that fail to bring to market innovate products that create value for their customers will quickly find that their competitors have done so, and that their own existence is in danger" (Reddy, 2014, p. 21). So, to survive, it is essential that companies are able to adapt and evolve. However, innovations are often sensitive to failure due to a lack of resources, high risk, uncertainty and inefficient processes (Hobcraft, 2011). Nevertheless, there are promising approaches that have the potential for companies to adopt to sustainable innovation, one of which is biomimicry. As aforementioned, biomimicry can be defined "as an approach to innovation that seeks sustainable solutions to human challenges by emulating nature's time-tested patterns and strategies" (Biomimicry Institute, 2018).

An explorative research consisting of multiple case studies has been conducted in order to answer the main research question. Those cases were placed in a framework that divides biomimicry into the organism level, the behavioral level, and the ecosystem level. According to the analysis of this framework, it could be stated that most research has already been conducted in the field of the organism level. This for the reason that for this level the most cases were available of which at least 17 are used instead of the 9 cases for the behavioral level and 6 for the ecosystem level. Furthermore, within this analysis, biomimicry has proven its usefulness in the areas of technology, products and design which have adopted concepts from nature.

From the aforementioned biomimicry levels, it could be noticed that the organism level is most applicable to the contribution of biomimicry in the field of product innovation. On the other hand, the behavioral level seems to be most suitable for the application of biomimicry to management concepts. Within this level it is all about the way that organisms behave and therefore best comparable with human actions or behavior, for example in organizations. However, there is still a large research gap when it comes to using biomimicry to tackle management situations. By far the greatest issue that stands between using biomimicry for organizational processes is that human beings are not animals, and thus cannot be treated, dealt with or associated with animals in many principle ways (Mead, as cited in "Biomimicry and its Place in Business Management", 2016).

All the provided research showed that companies are still in the early phase of adopting biomimicry in their organizations and are still in the area of using biomimicry as means to inspire new products or new solutions. The reality is that "using nature as an inspiration is extremely complex and is not nearly understood well enough to simply be applied to situations, especially when considering using it in management and organization" ("Biomimicry and Its Place in Business Management", 2016, p. 20). The issue is not collecting the biological information. However, the complexity lies in putting it into good usage. Furthermore, it is important that the design research and the biology research occur simultaneously, which is often rare in practice. In this way the processes are able to inform one another.

So, the answer the research question *'How can biomimicry contribute to the innovation of products and organizational processes?'*; we could state that biomimicry can stimulate organizations and their managers to think out of the box and find new ways to design their products and manage their organizations.

8. LIMITATIONS AND FUTURE RESEARCH SUGGESTIONS

The research results are based on the input of 32 case studies, which is not the largest sample size possible and therefore can only indicate a general tendency. However, conducting a longer-term study to better prove the applicability of biomimicry was out of scope and time for this paper. In order to increase the validity of the research, one should include more cases. In addition, the cases included in this paper applied to different levels of biomimicry. For the organism level there are 17 cases provided, compared to the 9 cases for the behavioral level and the 6 cases for the ecosystem level. These amounts are unequal and therefore it is more difficult to compare the cases based on the level of biomimicry applied.

Another limitation of this research is that it is focused on product innovation, design and the innovation of management concepts only. For further research, it would be interesting to focus the research and applicability of biomimicry on a wider scope. For example, to test the added value of biomimicry for healthcare or medical solutions.

As aforementioned, there is a degree of overlap between the different levels of biomimicry, which makes that each kind of biomimicry is not mutually exclusive. This ensures that almost each example should fit multiple levels. However, due to the scope of this research there is decided to classify each example only according to the most suiting level. So, for further research it might be suggested to amplify the presented tables, by processing each case on the basis of all the levels it fits. This provides innovators with a more elaborated view of the dynamic commitment of biomimetic technology. Furthermore, especially for the ecosystem level, it could be a suggestion to test each case against the aforementioned 6 ecosystem principles. This allows us to eliminate the cases that are not fully applicable. However, due to the serious time constraint, it was not possible to apply those 6 principles to this paper.

Due to the trend around biomimicry at the moment, it was also quite difficult to distinguish between pure scientific literature, novels and management theorists. This causes a large amount of disturbance in literature, which made searching for concepts quite difficult and might decrease the reliability of this research.

Moreover, there is a serious lack of practical testing and actual implementation of biomimetic concepts to help form a case for biomimicry with reference to management. So, it might be interesting to elaborate on the practical testing that already has been done in Chapter 6. Also, the in-depth relation of the organism level and the ecosystem level with regard to business management might be worth looking at. This for the reason that most biomimetic business applications are retrieved from the behavioral level.

Further research suggestions are relatively easy to point out as there are still a lot of unanswered questions in the field of biomimicry, especially with regard to its application to business management. One specific suggestion would be to conduct interviews with management, organization and biomimicry specialists with regard to the application of biomimicry to business management.

Furthermore, this research is just based on the application of a framework that divides biomimicry into three levels, which could be considered as a viable option. However, a further research suggestion might be to, for example, use The Four Phase Model of Sustainable Entrepreneurship to test the included cases towards sustainability. Another research suggestion might be to reorganize the cases according to a framework that divides biomimicry into the original business departments, like manufacturing, logistics, human resources, marketing etc. This allows us to more specifically address the application of biomimicry to business organizations.

Finally, comparative research will increase the validity of the outcomes. More research can establish a new research based on the comparison of the results from this research and the results from a research with a larger scope and more detailed searches.

9. RESEARCH CONTRIBUTION

This research contributes to existing knowledge by assessing whether a biomimicry approach can contribute to the generation of successful innovations.

First, a framework for understanding the various forms of biomimicry has been developed. Moreover, it is used to discuss the inspiration, the application and the added value inherent in each of the cases as a design methodology. Therefore, this framework is of value for the application of biomimicry at the field of product, technology and design innovation.

Secondly, it fills the gap, mainly in literature and somehow in practical testing, regarding the benefits of using biomimetic concepts to management practices.

Finally, this paper about biomimicry, is not just basic research about biology. It also includes innovation, business, and design research. However, the biology research adds an extra layer of complexity and makes the whole process more rewarding.

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