Biomimicry and its place in business management

(image taken from: http://www.being-here.net/page/2982/the-biomimicry)

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Contents

1. Introduction

The following chapter will go on to introduce biomimicry and explain why this is an area of science that should be considered.

Environmental degradation and the topic of sustainability have become a common theme in organisations on a global scale. 'Companies are considered by many to be the main players in creating environmental and social problems and thus to be a source of a lack of sustainability in society' (Schaltegger & Wagner, 2011). At the same time business and industry are the only institutions large, powerful and persuasive enough to bring change to our current passage of destruction (Hutchins, 2013). However in order to stimulate any form of sustainable development organisations it is essential that first the management of these organisations operates in the best possible fashion (Lueg & Radlach, 2016).There is a vast amount of information and debate on management, and more specifically managements roll on sustainability where scientists and managers are constantly looking for new methods and techniques that can be utilised within their organisation. One such concept that has been gaining the focus of attention in known as biomimicry. Simply defined ''biomimicry is the technological application of designs already used in nature to solve problems in engineering, material science, medicine, and other fields' (Gardner, 2012).

Biomimicry has become a hot topic specifically when it comes to copying nature for technological applications, however the field of science is relatively limited when it comes to the application of biomimicry to management concepts (Ulhoi, 2015; Mead, 2014). A fierce debate is currently ongoing in existing literature between those for and those against biomimicry and biomimetic concepts, especially that in terms of application of biomimicry to management concepts. Currently it is unclear what management concepts have been linked to or based on biomimicry, as well as which concepts have been used in practice or have been specifically researched.

The goal of this research is to bring in perspective what biomimicry concepts have been brought to light in the literature with regard to management concepts and to determine which of the existing concepts have been used in practice, and thus determine their relevance for management concepts. Biomimetic management concepts are currently scattered throughout literature with little reviews and summaries of concepts that exist as well what their applicability is, which is what this research will attempt to achieve; organisation of the material as well as assess the relevance for management concepts. Furthermore, Managers and organisations may be missing key insights that may boost performance, efficiency and sustainability by not looking towards what biomimicry has to offer.

1.1 Research objective & Research Questions

The following chapter will introduce the research objective and research questions with regard to the research.

As aforementioned in paragraph two, a fierce debate is currently ongoing in existing literature between those for and those against biomimicry and biomimetic concepts, especially that in terms of application of biomimicry to management concepts. This debate leads the objective of this research.

The objective of the research is to indicate the relevance of biomimicry for management concepts by analysing which biomimetic management processes exist, are being utilised in practice or have a great potential to be implemented.

- **General research question (GRQ)**

What is the relevance of biomimicry for management concepts?

- **Sub-research questions (SRQ's)**

1. Which management concepts exist within the concept of Biomimicry?

2. What is the potential of biomimetic management concepts in practice?

Making use of the above research objective and questions, the author will attempt to understand what different management concepts exist within BII literature and assess whether or not these concepts are applicable to management processes.

1.2 Report Structure

The report is structured in the following manner; chapter 1.3 will introduce the methodology by which the research has been conducted. Chapter 2 will present the literature that has been found starting with elements linked to the work of Mead (2014) and ending with further information that has been found. Chapter 3 will present the results, chapter 4 will present the conclusion and chapters 5,6,7,8 will represent the discussion, further research, references and appendices.

1.3 Methodology

The following chapter describes how the research was conducted in order to answer the GRQ and SRQ's.

In order to answer the questions at hand the first step that was undertaken was a literature review. According to Kumar (2014) a literature review is done in order to find the main themes and concepts that exist within the literature. From this literature review, the author could familiarise himself with the theory surrounding Biomimicry in general allowing him to come up with the definitions needed for the foundation of this research.

During the initial scan of the literature to familiarise with the topic, the paper written by Mead (2014) came up and contained an elaborate review of concepts and themes that had been identified by Mead and brought into an organised sequence. The paper by Mead will be used as a backbone for this research.

First the concepts by Mead will be placed in order and analysed, after which the author will bring in concepts and theories that have not yet been indicated by Mead. This will be done using the literary sources; www.webofknowledge.com, library.wur.nl and www.scopus.com. The literature will be critically read and any management concepts which may be inherent will be included into this literature overview.

Once all the concepts from the literature have been brought to light, explained and put in order, the methods that have been used in practice will be discussed. After this the author will progress to analyse what the potential is of the mentioned concepts and theories in practice and what the relevance of the concepts are in management processes, which will be presented in the results section.

2.Literature

The following chapter will bring to light the literature on M&O and biomimetic concepts and practices. The goal of this chapter is to answer SRQ 1 namely "Which management concepts exist within the concept of Biomimicry?"

2.1Meads Research

Mead states in his research that management innovations and applications from inspiration such as BII can only be applied after external validation including that of business schools, consultancy agencies and industry associations (Mead, 2014). Although she does not state, in depth, the quality of BII works and also says some BII works are inadequate the following concepts have been brought up by him in his paper: "Biologically inspired management Innovation".

2.1.1 Organisational ecology

Mead indicates that there are number of examples of management innovation dating back as far as 1977 with the theory of 'organization ecology' (Mead, 2014). Organisation ecology (OE) can be defined as 'an approach to the macrosociology of organisations that builds on general ecological and evolutionary models of change in populations and communities of organisations' (Hannan & Freeman, 1993). Hannan & Freeman state that the goal of such a perspective is to grasp what shapes the structures of organisations over a longer period of time.
The theory has a set up of three main aspects namely; the level of individual organisation, the population level and the community level. The basis of the theory evolves around the idea that organisations are able to adapt in goal orientated ways by changing structure, behaviour, etc. accordingly (Hannan &Freeman 1977). For long periods of time this system of thought was seen as a form of Darwinian research programme, where evolution of organisations could teach MO.

Further translations of organizational ecology was done by Gareth Morgan in a book named Images of Organisations (Lawley, 2001). Morgan argued that organizational ecology could be translated into metaphors and that all organisations are based on metaphors, which in terms of MO play a paradoxical role (Lawley, 2001). In this book, Morgan defines eight metaphors; Machines, organisms, brains, cultures, political systems, Psychic Prisons, Flux and Transformation and instruments. Morgan uses these metaphors to frame how the organisation works from which diagnostic readings could be taken in order to critically reflect on what the readings imply for the organisation (Lawley,2001). Although only 2 aspects of Morgan's book are biologically related, the book does represent the successful power metaphors have in helping MO understand how they work. In follow up of Images of organisations, Morgan later states that 'The challenge facing the modern manager is to become accomplished in the art of using metaphor: To find appropriate ways of seeing, understanding, and shaping the situations with which they have to deal' (Lawley, 2001) further emphasizing the power of metaphors, especially in biomimetic terms. This is shown in "Reflections on Images of Organization and Its Implications for Organization and Environment" (Morgan, 2006). In his paper Morgan states that the difference between common metaphors and his metaphors is that he took the paradoxical nature of his metaphors and brought them to a logical conclusion. In this he managed to create a 'dialectic between the strengths and limitations of different metaphorical perspectives to advocate ways of seeing, thinking, and acting that can create a broader, more creative, and more critical mode of understanding organizations than is usually the case' (Morgan, 2006). To further strengthen his idea of metaphorical use he states "I believe that metaphor is the process that drives theory construction and science, generating metaphors that create theories and associated research that always have inherent strengths and limitations because of the creative

insights and distortions that characterize the very nature of the metaphorical process" (Morgan 2006).

The relation between the works of Morgan and Hannan & Freeman do have similarities. They both attempt to take the environment of the organisation into account, and they both attempt to represent the positions of the organisation with the use of metaphorical translations to nature. Hannan & Freeman base their theory more on evolution and Morgan more on metaphors and how they may be interpreted.

The theory of Hannan & Freeman does have its flaws and critics. For long periods of time this system of thought was seen as a form of Darwinian research programme but a later research deemed organizational theory non evolutionary (Reydon & Scholz, 2009). Reydon & Scholz argue that changing of organisations lacking an evolutionary mechanism, and therefore could absolutely not represent organisational diversity (Reydon & Scholz, 2009). Mead indicated that OE cannot not be used because a natural environment to which that the concept of OE is related with, does not exist and is not defined. The theory of Morgan has critics too. Images of organisations often misses fundamental biological connections making the link with BII very small and the metaphorical translations are limited.

To conclude on OE, the theories were ground breaking when introduced however they lack a closer relation to biological models according to the critics. Metaphorical translations are somewhat limited however as is stated above, metaphorical translations are the easiest and best way to help scientist understand MO concepts within an organisation. The mimicking of nature is good justification for the use of metaphors as a source of inspiration but also at the same time means further research is needed to make deeper and better relations between BII and MO theory.

2.1.2 Keystone Advantage

Mead states that the concepts that derive from OE, is the theory of "Keystone Advantage" (KA), due to both concepts making use of metaphors(Mead, 2014). In the book of Keystone Advantage, the authors translate the business networks into an ecosystem as is found in nature, laying an emphasis on the interconnectedness and reliance on each other within the network (Badawy, 2006).
KA was initially coined by Iansiti & Levien in 2004 with a MO book was based on the successful business strategies of companies like Walmart and Microsoft. These organisations metaphorically translated themselves in the market as if they were part of an ecosystem with interconnectedness and reliance on each other within the network, just as is found in nature. Lansiti & Levien (2004) argue that biological keystones maintain the health of their ecosystems through specific behaviours that will have an effect on the entire system, which is what allowed companies such as Walmart and Microsoft to understand what would happen to the system with regard to the actions that they took within their system.
The theory has now been reviewed by Badawy, and his analysis shows that the actual foundation of KA is that "an ecosystem and all its components have a shared fate. The system thrives when everyone is healthy. At the same time, the system becomes unsustainable if significant assets get hurt or if significant segments of the system are out of balance" (Badawy, 2006). This is the precise interconnectedness and reliance intended to be explained by Iansiti & Levien by means of stating that behaviours of companies have effects on the entire system.
The KA theory however does not provide any new theories or contributions to the management field (Badawy, 2006). Mead indicates that this theory does not connect well enough to abiotic and biotic factors needed for sustainable development.

The KA is a concept which has made the step between BII and MO literature closer together, and even though the concept has seen success, the theories are not related enough to further contribute to BII literature in the current state.

2.1.3 Swarm Theory and Swarm Intelligence

The next topic introduced by Mead is that of swarm theory. This is an extremely large theory and the author feels that Mead may have overlooked a few aspects of this theory in his paper.

Swarm Theory also known as swarm intelligence has been defined as the "Collective behaviour that emerges from a group of social insects"(Bonabeau and Meyer, 2001; Krause et al., 2010). When one types swarm theory into the search bar in any of the literature sources used for this study, the results are in their thousands. There are many examples of where swarm theory is being used, more especially in the application of information technology, technology and logistical problems. There are however a few results linked to management and organisation within companies, and therefore also certain management terms come into perspective which will be discussed in the following paragraphs.

2.1.3.1 Self-organisation

Self-organisation is a big part of swarm theory and comes up in may literature pieces related to BII. The concepts of self-organisation derived from swarm theory have been used by many authors and scientists including Elke Michlmayr, Gandomi & Alavi, Holbrook et al., Bonabeau and Meyer, Bensaude-Vincent and Fewell. This concept is common in networking and computer research which do not make part of management literature but are part of information technology. In a recent article, the developments in insect inspired design for humans was brought up putting an emphasis on what there is to be learnt from social insects such as ants, bees, wasps termites etc. especially with regard to management and organisation.

Insects are highly capable of informing mankind's designs as these creatures have integrated societies with millions of members. These members also had to solve many complex problems (Holbrook et al., 2010) much of which can be compared to human problems. Such social insects are individually simple yet collectively brilliant having complex functional systems within their environment such as the routing of traffic, allocation of labour and resources as well as building homes with social and physical services (Holbrook et al., 2010; Fewell, 2015). Where humans require structural management and organisational systems, including hierarchies, social insects are fully capable of doing the same tasks without supervision or any method of centralized control.

Insects, and other colonies, are able to "self-organize, or emerge, due to two things (Fewell, 2015) Local interactions that elicit positive and negative feedback" (Holbrook et al., 2010) meaning coordination is primarily between individual colony members (Bonabeau and Meyer, 2001) and iteration (Repeating patterns). In self-organisation, individuals use information from their surroundings, environment and others around them to strengthen or weaken the interactions (Fewell, 2015). Thus, these creatures are able to design complex algorithms that can be sued for solving optimization and distribution of problems (Holbrook et al., 2010).

Michlmayr compared the self-organising behaviour of ant colonies to that of peer to peer networks based on algorithms (Michlmayr, 2007.). The definition for self-organisation in her thesis is that 'self-organisation is a dynamical and adaptive process where systems acquire and maintain structures themselves, without external control' (Michlmayr, 2007.). There are several indications that when applied to a business organisation, there are systems that could work without the 'external control' or in other words, no hierarchy or central governing system.

Michlmayr however, also states that researchers in computer science tend to use natural phenomena as inputs and metaphors and then end up building their own extensions on top of the model, which is something this thesis does not want to support. As well as this she also says that as most natural phenomena are hardly understood, it is not possible to remodel these phenomena, also known as complex systems, and therefore they are all simplifications (Michlmayr, 2007.).Thus, for as much as these complex insect colonies can be understood; they were eventually renamed to complex adaptive systems as the agents within the complex system are adaptive and any system which is adaptive usually shows signs of self-organising behaviour (Michlmayr, 2007.). This theory further led to the term 'swarm intelligence, which as described by Michlmayr, lays emphasis on the same simple behavioural capabilities, of which the algorithms in ant society is one of. Bonabeau & Meyer simplify this by stating that swarm intelligence is any 'collective behaviour that emerges from a group of social insects' (Bonabeau and Meyer, 2001).

Algorithms derived from social insects have been used widely to solving problems, especially algorithms that have been copied form nature as these algorithms are especially efficient at solving complex problems due to their millions of years of evolution and survival of the fittest (Gandomi & Alavi, 2011, Michlmayr, 2007).The algorithms are inspired by the ants natural mechanism of following each other by using pheromones which will indicate the direction/path in which an ant has followed allowing another ant to pick it up and follow it to the location where the other ants are going, hence the more ants following a path, the more pheromones and the more clear the path becomes. The fact that each ant has incomplete information for the solving of problems (which way to go from hive to feeding location), there is no social control (no commanding cant or hierarchy), data is decentralized (does not go through one centre) and calculation of where to go is asynchronous and they build their results incrementally makes the ant colonies complex adaptive systems (Michlmayr, 2007.). Another example of such an algorithm and method of self-organisation is that used by krill herd (Gandomi & Alavi, 2011) with further examples ranging from fish to birds to microorganisms. This ability to self-organise results in flexibility and robustness which has a large deal of effectiveness when applied in the right manner (Bonabeau and Meyer, 2001) and has been argued to be the working foundation which allows for corporate alliances to function better (Richter, 1994). Here, self-organisation is said to be the success factor when cooperation between companies occurs as there is a collective set of goals which constantly adapts and is best done when a company is organised in a networking fashion, allowing for self-organisation. Finally, as indicated Dargent; When an organisation decentralizes their decision making towards employees, the organisation becomes more able to adapt and sense changes. Supporting this is that diversity within a group is a source of innovation for the company, and the diversity among employee's vs management is much higher, especially in large companies (Dargent, 2011).

2.1.3.2 Autopoiesis
Autopoiesis is a word which pops up regularly in self-organisation texts, and although it is arguably the same as self-organisation, the term does pop up under other search terms. Autopoiesis comes from Greek translation meaning 'self-creation', initially used to describe a phenomenon within the animal kingdom namely; all social systems are based primarily on communication (Schatten & Zugaj, 2011). The common definition which is found for Autopoiesis is 'a system organized as a network of processes of production of components that produces components. When applied to an organisation system the type of communication is special as the 'decisions made are decisions that set up possible future states of the system' (Schatten & Zugaj, 2011). In this paper, it is considered to be the same thing as self-organization.

2.1.3.3Self-Organisation measurement

Saadia Mahmud from the university of South Australia created a model where measurements of a company's self-organisation skills could be studied. By making this model, extensive literature and empirical research was done resulting in the following conclusions.

Measurement of an organisations self-organisation is possible, but is in the beginning of development and needs much more attention and time. Further results of the research showed that organizations are only able to learn how to self-organize under three minimal conditions; 1; high level of trust, open communication and a strong value system (Mahmud, 2009; Krause et al., 2010). These three aspects may seem common sense but they do form the backbone of any self-organisation activity and this thought can be taken with for the rest of the chapter.

2.1.4 Swarm intelligence in management literature

Although the subject is well researched, application to management remains to be difficult to find however there are numerous examples where use has been made from swarm intelligence. These examples will be explained in the following paragraphs, including further theory on swarm intelligence that is necessary to explain how the system works.

2.1.4.1 The Bucket brigade

The "bucket brigade" is an algorithm that is based on seed harvester ants collecting food, and was initially implemented by John Bartholdi and Donald Eisenstein to improve the efficiency of order pickers. "A bucket brigade is a linear production line in which each worker picks up a job and processes it at each station until he gets "bumped" by a downstream worker. Whenever the last worker in the line finishes a job, he initiates a reset of the production line: Each worker takes over his predecessor's job and the first worker starts a new job" (Armbruster et al., 2006). The concept worked around the fact that there are fast and slow workers, and when working in zones, the fast workers become underused and the slower workers overused (Bonabeau and Meyer, 2001). To get the most out of all the employees, they were aligned so that orders were passed onto the next person instead of every employee getting a single order. This system led to the personnel being ordered from slow to fast, allowing for the fast workers to make up for the slow, and therefore making the entire system 30% faster (Bonabeau and Meyer, 2001).

2.1.4.2 Swarm intelligence, simple rules and company efficiency

As the company grows, the need for efficiency will grow at the same time and owners/entrepreneurs may be in dire need to make their company more efficient. One great example of how biomimicry can aid in this area is the example of Capital One IT services whom grow from 150 employees to 1800 in 5 years' time. Based on swarm intelligence (simple rules for complex behaviour) the company came up with a set of simple rules for all employees to be followed in combination with a chip award system that allowed employees to backtrack their own successfulness in following the rules (Bonabeau and Meyer, 2001). After a year of using this system the rules became so natural to employees that the reward system was no longer needed and that personnel were unified and able to make decisions on their own work with little to no top management (Bonabeau and Meyer, 2001).

2.1.4.3 Addition of employees through biomimicry of bee hive selection

Although not related to the addition of employees, executive appointments and searches for leaders can learn a thing or two through biomimicry. In the paper 'Independence and interdependence: lessons from the hive' by Christian List and Adrian Vermeule, the authors explain how companies can use the decision-making process used by bees in the search for leaders (List & Vermeule, 2010). Bees possess an independence and interdependence search and decision making mechanism which can be used and applied for leadership location. It is argued that this type of 'search-and-decision mechanism' works best when stakes are high. As 'leadership and charisma are scarce resources

whose presence or absence can make or break institutions, and because firms tend to look for new leaders in times of crisis' one could state the stakes are high, therefore justifying the use of such a decision system, through the use of independence and interdependence (List & Vermeule, 2010).

The decision mechanism of bees when finding a new location for the hive to settle down is based on interdependence of decision makers and independence in the choice. During the search for the new hive a striking decision process is used involving a 'search committee and scout bees that fly over a large area and report their findings back to the swarm. If a possible suitable site is found, a scout bee will perform a dancing ritual which will invite other bees to assess the possible location. The more bees dancing in an area, the more attention from the hive and the more assessments that will take place which eventually leads to the most popular site being selected. This collective decision process is not part of any high cognitive capacity as bees are not complicated enough for this type of decision, however dependency on the quality of the assessment of the new location by the bee scouts is extremely vital. This process allows the bees to be interdependent in their communication between each other yet independent in their assessment of the quality of any nesting site (List & Vermeule, 2010). According to Vermeule the conditions needed to satisfy this type of decision making are: (1) an open-ended agenda; (2) high stakes; (3) high opportunity costs. A further example of where this type of decision making of bees can be applied to companies when they become to large or when diminishing returns are experienced. When this is the case large corporations can determine when to spin off some operations in the same way bee hives split when they become too large.

When one translates this system in search for a new leader the following is described:' independent agenda setting and independent assessment '. Individual members of the team can individually source and find candidates proposed by other members of the search party and the preselected pool of candidates that is being selected from has been selected interdependently beforehand (List & Vermeule, 2010). Although all of the above could fall under specific context of biomimicry and decision making processes of a company, it has only one example of where it can be used in business and is therefore included under the addition of employee's title. Other examples of where this system can be used according to Vermeule are; Legislative committees, in the supreme courts and in Research and development firms (leading to the invention of post its and masking tape) (List & Vermeule, 2010).

2.1.4.4 Other managerial research
There are several studies in which self-organisation is compared to the standard organisation for example the study done by Lambe et al. (2009) on selling teams and team performance. This study looked at the benefits of self-organization in selling teams and noted the advantages that self-organisation had on performance, however they tend to agree that without some form of upper control or management, results would be disappointing (Lambe et al., 2009).

2.1.5 Critics of Swarm Theory
Self-organisation can also be difficult to implement in companies, especially companies new to the concept of swarm intelligence as people are very unfamiliar to these types of concepts (Bonabeau and Meyer, 2001). Furthermore, there is the argument that insects and humans are not to be, and should not be, compared and described with similar mathematical frameworks as those found in swarms, however Bonabeau and Mayer are convinced that in the future companies will be based on the swarm intelligence system. (Bonabeau and Meyer, 2001).

Self-organisation in teams that form part of multi-team systems were researched by Millikin et al. whom indicated that the largest problem with humans is that we are not exactly the same, and this means that differences in the group will continually cause us to be unable to be fully efficient in adopting the self-organization process. Also, they found that when teams self-organise too independently there is a lack of cohesion and complete failure of the system (Millikin et al., 2010). Further their advice was that should organisations want to fully use such systems to their advantage, group processes (e.g. cohesion, etc.) and individual self-management should be induced by the organisation to ensure the correct basis (Millikin et al., 2010).

According to Krause et al other problems bleaching the bright future of self-organisation are; 1. the lack of clear criteria in defining swarm intelligence (this is seen throughout many BII terms); 2. Differences in human and animal swarm intelligence (Krause et al., 2010). These two aspects are directly supporting of the research done by Millikin et al. Swarm theory is possible to understand when compared to individual intelligence and cognition making it an excellent management opportunity (Krause et al., 2010). They researched what effects diversity of the group had in terms of swarm intelligence together with collective vs. individual cognition, and also here a leadership problem is established but different to the one described before. Their research showed that the diversity of the group generally improves performance of the group (Krause et al., 2010). They also establish that currently companies hire employees through individuals, meaning that there is no group consent in the decision. If organizations are to fully benefit from self-organisation, employment of new employees should then also go through the entire work force, making it a costly and time consuming exercise (Krause et al., 2010). Further research by them distinguished that swarm theory could definitely help organisations in terms of management. They came up with three principles that had to be followed if an organisation was to succeed in utilising swarm theory (Krause et al., 2010):

1. Diversity of opinion throughout the group
2. Truthfulness and trust
3. Un-Biased members

Although these three principles make the concept look simple, they are everything but. Theory pushes us to believe that 'complex adaptive systems' link well all together in the biomimetic theory and probably are the best example to help us fit in the environment (Dargent, 2011). However, if one had to implement the three rules above, this would not mean guaranteed success or that all the personnel would continuously adhere to these rules. One could even question, is it even possible? Biomimicry texts have shown several pieces whereby is argued that certain processes can be run with a set of rules, however critics argue against this as is seen in the discussion section.

Furthermore, decentralisation of decision making and self-organisation would mean that top executives and managers can wave their perks and benefits goodbye, something which is not likely to happen. So, implementation would be a complete nightmare. Company organisation would have to be cohesive and work as one single unit, something which in business terms may be difficult. Dargent even argues that due to people having a will, they may like the benefit of not being a leader and enjoy being led. Something which could turn the entire system around and go all out against the theories from swarm intelligence. Although this situation is deemed impossible, read 'leadership aspects in swarm theory' below.

These are points that have not yet been fully developed and need further research to clarify and empirically test what these aspects can individually do and mean for organisations (Krause et al.,

2010). This research does show that with adequate research and empirical testing results can be achieved and there is more to be learned.

2.1.6 Critics on the leadership aspects in Swarm theory

The core subject of question in the area of self-organization remains to be what the task of the leader is in this self-organized system and as indicated before even though no central control is needed in much of the self-organisational literature. In an in-depth study by Plowman et al. (2007) the questions surrounding leadership and self-organization were analysed including from the perspective of swarm intelligence leading to intriguing results. The conclusion from their research was that leadership was clearly still necessary, although it is different from traditional perspectives, once again leaving room for biomimicry to inspire (Plowman et al., 2007), and at the same time rendering serious questions on the effectiveness of non-hierarchy, non-governed and non-led groups of employees. The lack of empirical backing in this area of science is an area of opportunity in the social sciences.

Another critic of self-organisation with specific reference to the 'Bucket Brigade' system states the same findings as Plowman et al namely; some amount of management intervention is necessary to ensure the efficiency of the system of 'bucket brigades' (Armbruster & Esma, 2006) Krause et al go as far as saying that application of swarm theory does not mean eradication of leadership.

To summarize the above text, we are able to state that there is a large area of opportunity in the field of self-organisation, however there are some serious obstacles in the way as indicated above. The biggest reason that this type of management will struggle to be a benefit to sustainability is as Mead states; any of the previous examples of BII metaphors in the above paragraphs do little to connect business to actual biophysical and social aspects of business environments (Mead, 2014). However, the lack of knowledge and insight should not be allowed to reduce inspiration. This means that until now the practices seen will only lead to further efficiency and benefits for companies but not necessarily the environment. That being said, this paper is based on the help that BII can give management and organisation, and there are enough lessons to be learned. Further reference to leadership will return further on in this thesis.

2.1.7 Industrial ecology

Mead indicates that theories that followed the above namely; "Industrial ecology", are theories which connect biological metaphors with biotic and abiotic factors of sustainable development. "Industrial Ecology" is brought up by Mead as closely related to operations management. However, as the sources referenced to be Mead lead to a paper by Korhonen, the application to management as defined by in the introduction becomes farfetched. The management terms that Kohonen speaks of are industrial and waste management systems (Korhonen, 2001), non-the less, the inclusion of BII literature is closely related to that of Cradle-to-cradle, "The natural Step" and Janine Benyus (1997) which will have dealt with later in this thesis.

2.1.8 Chaordic Organisation

 Gary Hamel's name is one that is familiar in management innovation literature. In his Harvard business review work, he relates to the problems that growing companies are experiencing and says that management innovation is the best way to combat problems (Hamel, 2006). Hamel states that the only way to change how managers work in a big organisation is to reinvent the governing process (Hamel, 2006). Hamel separates actual management from business processes, which he describes as logistics, customer support, etc. and focusses on the management process of the company, which is exactly what the goal of this thesis is. Unfortunately, there was limited amount of BII work involved.

This begs the question why Mead would bother mentioning it in his paper, especially seeing as the example of Visa, where some primary "rules" from nature were used. This example may have been better placed in the first examples of his paper.

2.1.9 Cradle-to-cradle, "The natural Step" and Janine Benyus

Next Mead refers to the "Cradle to Cradle" design from the source of Braungart and McDonough. As explained by Hamel, these activities are focussed more on the business processes rather that the management processes as defined by this thesis. Again, here there is a lack of coherence with the defining terms of management and no further management literature could be found through this source, making the author wonder once again why Mead would include such a source of reference. This is also going for the works from Nattrass & Altomore (2013) and that of Janine Benyus (1997) whom are all established BII authors however until now their works, especially those cited by Mead, lack any relevant managerial solutions with regard to this papers definitions.

2.1.10 The Nature of Business

Summarizing much of the above, and having used his book as a reference for several paragraphs above is the work of G. Hutchins. His book "The nature of Business: Redesigning for resilience" contains a collective work of many concepts in existing BII literature. Hutchins book is a prime example of what Mead calls an interconnected work that includes all aspects of the ecosystem to compare to 'standard business culture'. He indicates that entire culture around business needs to change playing as synergetic partners instead of business partners (Hutchins, 2013).

2.2 BII in management literature outside Mead's work

2.2.1 Leadership

Leadership has by many management and organisation book sand literature sources been deemed to be of essential importance to organisation. Many scientists argue that leadership is possibly one of the most important themes in the social sciences (King, 2010). This together with the fact that much research and interest is being shown in the understanding of leadership in the biological sciences (Smith et al, 2016) leaves room for scientist to query on the applicability of leadership found in biology, to that of management and organisation. Smith et al define leadership to be a 'pervasive phenomenon in social species, organizing behaviours ranging from group movement to complex patterns of cooperation and conflict' (smit et al 2016). Research has shown that when humans are compared to non-human but social animals they both have something in common namely that the emergence of leadership with in a group is based more on individual achievements than on an inherited status (Smith et al, 2016). The aspect of leadership has been emphasized in the chapter of swarm intelligence as well. In the following section the literature that was found with regard to leadership and biomimicry will be discussed.

Hutchins the job of the leader being to sprinkle water on talent and allow it to grow. This creates conditions for co-creation leading to cycles that allow people to develop themselves. This will lead to optimal systems of own value-creation, desire to overcome obstacles, learn and help others to achieve the same (Hutchins, 2013). This will remove burdens of value creation activities from management itself leaving more time and energy to the innovate and create new organisational vision (Hutchins, 2013). Hutchins states that all the theories of self-organisation and self-empowerment, using leadership is more about "empowering, empathizing and encouraging interconnections, innovation, local attunement and an active network of feedback. Hutchins

indicates this is the only way for organisations to revitalize form the bottom up, and strengthens this opinion with the use of metaphors such as a fungal network on the forest floor, it's all connected (Hutchins, 2013).
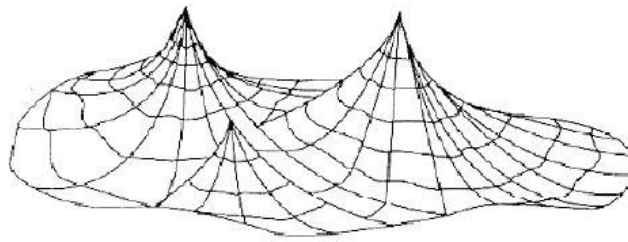
2.2.2 Organisation
There are several examples of organization found outside the paper of Mead and others used so far.

2.2.2.1 The Amoeba organization
It has been found in the literature that there are also arguments against single specific leadership within an organisation. A summarizing example is the theories of Wilbert L. (Bill) Gore who first introduced the 'Amoeba' organisation. Core aspects of this type organisation were that the organization consisted of teams that self-organized, were decentralized, had flat hierarchy and were in fact organizational chaos (Schuppel, 2004.). The structure of such an organisation is taken as an example in the works of M. Schatten and M Zugaj whom describe the system as 'small divisional or operational units consisting of self-organizing teams that have flat or non-existing hierarchy where team leaders are chosen depending on the situation (Schatten & Zugaj, 2011). This leaves the main strength of the Amoeba theory being that it has the ability to adapt and change as is what the metaphor of amoeba is; 'changeability' as used by the Greek language. This having been said they also show that this type of organisation still has to eventually form part of hierarchy therefore once again implying that there is need for leadership either way, even in such an Amoeba organisation. (Schatten & Zugaj, 2011). Supporting this idea of the amoeba design is the example that can be taken from reorganisation of the United States Green Building Council (LEED certificate system) whom had management problems when attempting to connect 80 local chapters together. As is the case with the Amoeba design, the council was inspired by the mycorrhiza fungi and their symbiotic relationship they have their surrounds securing themselves sunlight, water and distribution of nutrients. Based on this symbiotic relationship the council evolved its hierarchy structure to a supportive structure in order to ensure the leverage of local initiatives and the flow of information and resources (Walker, 2010.)This is a prime example of how entrepreneurial management has to be able to sense shifts and changes in opportunities in the business environment to which the organisation can be adapted for maximum advantage as is recognised by Teece leadership is a core aspect in organisational capabilities (Teece, 2016.). Teece also further justifies the concept of the amoeba organisation proving that 'leadership can potentially emerge at all levels of the organisation' and thus not only the positions of formal authority. As well as this, he claims that transformational leadership (motivation and inspirational leadership) is the type of leadership that contributes more to organisational effectiveness (Teece, 2016.). To summarize the above, we can say there is proof of organisational structure and manner as that used by amoeba can also be applied to business organisations successfully coming from both biomimicry and management and organisation literature sources.

2.2.2.2 Neural networks
Neural networks and heterarchies are based on the principle that an organisation consisting of 'organisational units that are mutually connected through information links, are mutually independent, heterarchically organised and operate internally to achieve a common goal' (Schatten & Zugaj, 2011). This leads to a structure of undefined interrelationships but self-regulating and activated. The metaphor described by Schatten and Zugaj is that of a fishnet organisation, which in many ways looks like a spider's web. The net and web may seem flat however when one pulls on one point of the system, hierarchies will be made. Figure below demonstrates that system.

Figure 1. The fishnet organisation - Source Schatten and Zugaj, 2011.

Although the above system does not give us a clear understanding of how this will help a company to organise and manage itself, it does create certain points of similarity with other systems. Creating a hierarchy in certain places in the company will have a different effect every time, depending on where the company wishes to go this could help them figure out and possible foresee what certain actions within the company could do.

2.2.2.3 Fractal company

This is also the case with the example of the Fractal company as described by Schutten and Zugaj being metaphoric to a fern tree. Fern tree twigs look like one another and the twigs on that twig do to and so on and so forth, which is also what the term fractal means namely; a certain degree of statistical self-similarity, self-organisation and self-optimization. When this is metaphorically applied to an organisation one could use this concept to observe individuals, departments, divisions, process flows, decisions and other organizational subsystems (Schutten and Zugaj, 2011.) The combination of the self-similarity, self-organisation and self-optimization means that a company is this form has the ability to share a mutual objective, have working harmony and synergy within the company and are able to keep themselves optimized as possible.
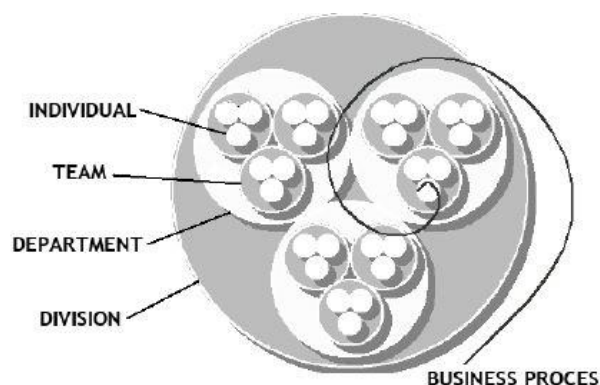
Figure 2. The fractal Principle

2.2.2.4 Genesis and reproduction

Genesis and reproduction is the final example indicated by Schutten and Zugaj and is based on the metaphoric representation that reproduction produces new organisms in nature and in organisations it can be an interesting analogy of strategic alliances, joint ventures, spinouts and outsourcing which are all terms all well known in the industry of entrepreneurship and innovation. The idea behind this system is that animals reproduce on the basis of survival of the fittest and that certain matching in nature creates new offspring which will carry on the strong genes. This is the same for organisations

where strategic alliances, joint ventures, spinouts and outsourcing are offspring and combinations of certain aspects which will hopefully make the end result the fittest for survival.

Of all the options that have been proposed in the paper by Schutten and Zugaj, their most promising concept is that of Bioteaming, which is dealt with in this paper already. Although the above metaphors may seem to be easily used and implementable, they are not. Schutten and Zugaj conclude that the only realistic use for metaphoric forms of biomimicry and organisation are in the form of analysis and not directly applicable in practice (Schutten and Zugaj, 2011.). Schutten and Zugaj conclude that Biomimetics is applicable to organization theory, when organisations are complex and social enough as when organisations are complex their interactions on different levels are similar to that of nature. However, at the same time they also conclude by saying that the use of metaphors is the first and most obvious step that can be used in the field of biomimetics but at the same time they express their doubts whether the metaphors being used are applicable and not just ideological ideas (Schutten and Zugaj, 2011.).

3. Results

The following chapter will present the results of this research and will be presented in the same order as the concepts are presented in literature.

3.1 Results to SRQ 1

The results for SRQ 1; 'Which management concepts exist within the concept of Biomimicry?' based on the literature study above, are the following concepts:

Biomimetic Management Concept	Key Description	Sources in chapters
Organisational ecology	Darwinian school of thought relying on the adaptability aspects of an organisation on three levels; individual, population and community.	Mead, 2014; Hannan & Freeman, 1977; Lawley, 2001; Morgan 2006; Reydon & Scholz, 2009;
Keystone advantage	Keystone Advantage was first derived from practical application, however through a metaphorical translation into a market situation, where all in the market is interconnected.	Badawy, 2006; Mead, 201; Lansiti & Levien, 2004
Swarm theory, Swarm intelligence	'Collective behaviour that emerges from a group of insects' translated in into management terms gives terms as self-organisation, autopoiesis and the bucket brigade where humans work collectively.	Bonabeau & Meyer, 2001; Krause et al., 2010; Michlmayr 2007; Gandomi & Alavi 2011; Holbrook et al., 2010; Fewell, 2015; Richter 1994; Dargent 2011; Schatten & Zugaj, 2011; Krause et al., 2010; Mahmud, 2009; Armbruster et al., 2006; List & Vermeule, 2010; Lambe et al., 2001; Millikin et al., 2010; Plowman et al., 2007; Armbruster & Esma, 2006; Mead, 2014
Industrial Ecology	Close relation to Cradle to cradle and the natural step, industrial ecology aims to combine biotic and abiotic factors.	Korhonen, 2001

Chaordic Organisation	Separation of business processes and management, little ties to BII literature	Hamel, 2006
Cradle to Cradle, 'the natural step'	Cradle to Cradle (and industrial ecology) are big topics in the book by Janine Benyus. Benyus, and others, say that industries must start thinking like ecosystems where the 'circle of life' is closed.	Braungart & McDonough; Nattras & Altomore; Benyus 1997,
The Nature of Business	Interconnectedness between organisations and people, similar to KA. Mainly based on 1 single book.	Hutchins, 2013; Mead 2014
Leadership aspects in biomimicry	Pervasive phenomenon in social species, organizing behaviours ranging from group movement to patterns of cooperation and conflict. Leadership found throughout the ecosystem, compared to leadership in Management.	King, 2010; Smith et al, 2016; Hutchins, 2013
Amoeba Organisation Neural Networks Fractal Company Genesis and Reproduction	Organisational concepts derived from manners in which nature has organised itself. For example, how Amoeba bacteria are organised; and then translated into organisations.	Schuppel, 2004; Schatten & Zugaj, 2011; Walker, 2010; Teece, 2016

Table 1 Results SRQ 1

3.2 Results to SRQ 2

The results for SRQ 2; 'What is the potential of biomimetic management concepts in practice?' based on the literature study above, will be presented in the paragraphs below.

Biomimetic Management Concept	Drawbacks	Feasibility − very bad − bad +reasonable ++ Excellent
Organisational ecology	Organisational ecology was one of the first biomimetic concepts introduced into M&O literature, however, as this research has indicated, until now there is a lack of scientific backing beyond metaphorical translations seen in this concept, leaving these concepts to be only metaphorical and not practical.	- Theories remain to organisational and little link to managerial practices, furthermore little practical testing
Keystone advantage	Keystone Advantage was first derived from practical application, however through a metaphorical translation into a market situation, where all in the market is interconnected. The KA concepts are however far underdeveloped in terms of management and the theory does not provide new insights.	- Nice chain of thought, but a company has to learn to adapt in any case. Not BII specific.
Swarm theory, Swarm intelligence	Swarm theory is largely practiced in algorithm related problem solving, and showed a large amount of literature results for this research. Swarm theory	+ Insects and humans differ far too much, especially in terms of

	however has to cope with the difference between insects and humans, and that the two are not comparable. Thus, swarm intelligence serves as an excellent theme for inspiration, however when applied to humans it is severely limited.	management. May help organisational literature better. Aspects as self-organisation however show big potential
Industrial Ecology	Little relation to BII	- - Too little information
Chaordic Organisation	Chaordic organisation was deemed of absolute no relevance to biomimicry, especially in terms of management.	- - Too little information
Cradle to Cradle, 'the natural step'	Cradle to Cradle (and industrial ecology) are big topics in the book by Janine Benyus however the relevance to actual management concepts was farfetched.	- Is excellent when looking at production/business processes however serves little for management
The Nature of Business	The nature of business resembled more business culture oriented concepts than actual concepts, which means that also this concept has little relevance to management literature.	- - little relevance
Leadership aspects in biomimicry	Leadership Concepts from biomimicry sources all share the same problem namely; their importance is recognised however their practical application and research base from a biomimetic perspective remain underdeveloped.	+ underdeveloped but has potential. Animal human barrier once again a problem.
Amoeba Organisation Neural Networks Fractal Company Genesis and Reproduction	Organisational concepts − Neural networks, fractal company, genesis and reproduction have shown large potential for management with much of the line of thought being similar to other concepts discovered in the literature. The applicability on practical basis has however yet to be developed and tested, however could serve as an inspiration to organizational theory on its own. The Amoeba organisation has been implemented in practice, but once again on a basis of organisational rather than managerial aspects. Also, it is possible to argue whether this was implemented in practice first and later compared to amoeba's. This still remains unclear.	+ Is organisationally useful however still says little about management.

4. Conclusion

In this chapter the answer to the GRQ will be brought forward

The objective of the research is to indicate the relevance of biomimicry for management concepts by analysing which biomimetic management processes exist, are being utilised in practice or have a great potential to be implemented. Below the GRQ and the SRQ of this research are presented.

- **General research question (GRQ)**

What is the relevance of biomimicry for management concepts?

- **Sub-research questions (SRQ's)**

1. Which management concepts exist within the concept of Biomimicry?

2. What is the potential of biomimetic management concepts in practice?

Biomimicry has already proven its usefulness in areas of technology that have adapted concepts from nature and used them to solve complex human problems. The goal of this research was to analyse what the relevance of Biomimicry and its concepts could have for that of management of organisations.
Based on the chapters above, it can be stated that there is not a large amount of work and research that has been done based on using biomimicry to tackle management situations. Literary sources remain difficult to find and any proven tests with concepts are non-existent. Metaphorical translations of situational descriptions or translations to management practices are used in most of the above-mentioned concepts, however the complexity of the translation varies such as in the examples of swarm theory and the Amoeba organisation (chapter 2.1.3 - 2.1.5 & 2.2.2.1).

Chapters 2.1.9 and 2.1.10 both relate to management concepts, but do not go into the depth of management and rather see Biomimicry as a translation of how organisations must think in global manner and not in management term specifically.

By far the greatest issue that stands between using biomimicry for management concepts is that human beings are not animals, and thus cannot be treated, dealt with or associated with animals in many principle ways. For example; as is stated above in swarm theory, colonies achieve great things by combined efforts, standardization and many other properties all of which are virtually impossible to directly translate to a human being. It is the cognitive ability versus the non-cognitive ability of human's vs animals/insects that makes it impossible for us to manage our organisations in the same manner, see chapter 2.1.5 and 2.1.6.

Evidently from this paper and the large number of sources surrounding this work, there is Mead says; "a pattern of usage of biological metaphors and analogies emerging amongst management professionals"(Mead, 2014). Even though all these concepts have popped up and are being conceived globally a critical analysis to the usefulness of these concepts to "innovation or more sustainability-orientated results either for the organisations, the economy or nature." (Mead, 2014)

Many scientists argue that 'if' we can discover a way to harness 'natures chemistry' the human race would become more efficient and especially more sustainable (Goldstein and Johnson, 2014). However, the big question that remains at the end of this thesis is whether or not it is actually possible to copy nature to its full extent especially concerning management.

There are simply large differences with the moral status of humans when compared to the rest of the ecosystem. In an example by Van der Hout (2016), she illustrates an example of how this moral difference is easily seen. Her example compares a human reaction to a drowning child compared with that by the surroundings. Should the human choose not to save the drowning child, the human would be considered immoral, but the animals surrounding the water would not be judged (Van der Hout, 2016). With this she states that nature simply does not have any moral agents (Van der Hout, 2016). Although this a cruel and simple example, Van der Hout (2016) has a good point in that

humans can simply not always mimic natural situations (Van der Hout, 2016). This is especially applicable to the construct of management and organisation as it concerns people working with people and not an ecosystem of living things.

The global use of 'rules' or 'codes' throughout BII texts is seen often and the argument that withstands with all these texts is the question where they are not too simple to apply to humans. Many authors refer to the 9 canon laws, of which the famous BII author Janine Benyus (1997) is a great fan. These laws are however a romanticized and simplified version nature (Van der Hout, 2016). How does one justify using this for human application? Nature is simply too vast and diverse to be translated into some set of rules and then applied to humans (Marshall & Lozeva, 2009). Furthermore, even if these rules would be applicable to any management and organisation problem or situation, there would still be no guidance for inter-human ethical codes of conduct (Van der Hout, 2015). Also, nature does have its flaws too, especially if this has to be applied to humans. Defining principles of nature also have critics with responses indicating that nature itself has laws humans should not trust and caution must be used when approaching it (Marshall & Lozeva, 2009).

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 organisation. Lessons from organisms in nature can help us into deeper trouble, more so when we are not fully aware of the manner in which they work (Van der Hout, 2016). Critical analysis is needed to broaden our knowledge of all the effects that systems could and do have. This combined with the large questionable science surrounding ethics in social sciences when applied to management and organisation may make this area of science farfetched from current reality. Many scientists argue that 'if' we can discover a way to harness 'natures chemistry' the human race would become more efficient and especially more sustainable (Goldstein and Johnson, 2014). However, the big question that remains at the end of this thesis is whether or not it is actually possible to copy nature to its full extent especially concerning management of human beings.

Thus, the answer to the GRQ; What is the relevance of biomimicry for management concepts; is quite simply a source of inspiration. Biomimicry can stimulate managers and organisations to think out of the box and find new ways in which to manage their organisations. The limitations however will continuously be the problematic complexity of nature itself and the inability for the animal kingdom to be compared to human beings.

5. Discussion

There has been a large amount of limitations in this research which need to be introduced for those who would like to carry on in this field of research.

For this research project time was a serious constraint and without the existence of existing literature reviews, much time was needed in collection sufficient data to make a case. Furthermore, 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.

The current 'hype' around the concept of biomimicry makes research more difficult as the difference between pure scientific literature, novels and management theorists or ideologists does cause a large amount of disturbance in the literature making searching for concepts difficult. The term Biomimicry

comes up with a large amount of research and in combination with management a large amount of environmental management aspects come up.

This research could be repeated again with extensive time, however the key results from the conclusion would not be any different, the comparison of humans to nature is simply a difficult aspect.

6. Further Research

Further research suggestions for this topic are easy to point out as there are large amount of unanswered questions. One specific suggestion would be for authors in the field of biomimicry to conduct interviews with management and organisation specialists with regard to the application of biomimicry to business.

Biomimicry is still underdeveloped when it comes to management concepts, however as aforementioned, further research in the application of biomimicry purely for organisational aspects may be fruitful. Furthermore, more research could be done specifically on the claimed benefits that have been made, by for example an amoeba organisation (chapter 2.2.2.1), and put these claims to the test in well-developed scientific analysis.

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