BIOMIMICRY AS A DESIGN REFERENCE

PRO GRADU THESIS

The sustainable potentiality of textile design mimicking nature's ways

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Interior and Textile Design
2015

LAPIN YLIOPISTO,
TAITEIDEN TIEDEKUNTA

Työn nimi: Biomimiikka suunnittelun välineenä – kestävien arvojen toteutumismahdollisuudet luontoa imitoivassa tekstiilimuotoilussa
Tekijä: Anna Uuttu
Koulutusohjelma/oppiaine:
Sisustus- ja tekstiilimuotoilu
Työn laji: Pro gradu -tutkielma
Sivumäärä: 80 +liitteet (2)
Vuosi: 2015

Tiivistelmä:
Tutkielman tavoitteena oli selvittää biomimiikan roolia kestävän ja vastuullisen tekstiilimuotoilun kontekstissa. Tutkielmassa kartoitettiin olemassa olevia esimerkkejä biomimiikan hyödyntämisestä tekstiilimuotoiluun. Lisäksi tutkielman keskiössä oli tarkastella biomimiikan edellytyksiä kestävien arvojen mukaisesti toteutetulle tekstiilimuotoilulle. Biomimiikan *(eng. biomimicry)* käsite tulee latinankielen sanoista *bios*, elämä ja *mimesis,* imitaatio. Kestävä ja vastuullinen tekstiilimuotoilu tarkentui tutkielmassa laaja-alaiseksi käsitteeksi kattaen sosiaalisen, ekologisen, ekonomisen ja eettisen vastuun näkökulman.

Tutkimus toteutettiin laadullisena, ilmiötä selittävänä tutkimuksena. Tutkielman primääriaineistona toimi biomimiikan ja tekstiilisuunnittelun yhdistäville muotoilijoille ja tutkijoille toteutetut haastattelut sekä heiltä saadut artikkelit. Aineiston sisällönanalyysi toteutettiin neljävaiheisen prosessin mukaisesti aineistoa teemoittaen ja luokitellen. Aineiston pääkategoriat *Nature as a design model*, *Platform for Innovations* sekä *Reaching sustainability* vastaavat tutkimuskysymyksiin yhdessä teoriaosuuden muodostaman viitekehyksen kanssa.

Tutkimuksen perusteella biomimiikkaa voidaan hyödyntää luonnosta saatujen toimivien ja ympäristöä kuormittamattomien mallien avulla useissa eri konteksteissa tekstiilitaiteesta käyttötuotteisiin. Kestävät ja ympäristöä kunnioittavat arvot nähdään oleellisena osana biomimiikkaa ja sitä hyödyntävää muotoilua. Luonnon tarjoamista toimintamalleista erityisesti materiaalit ja niiden rakenteet nähdään potentiaalisina, energiaa vähän kuluttavina esimerkkeinä. Biomimiikkaa on mahdollista soveltaa eri tasoilla. Luonnosta inspiroitumisen ohella tavoitteet voidaan asettaa jonkin tietyn luonnosta havaitun toimintamallin soveltamiseen esimerkiksi tekstiilikuidussa, -pinnoitteessa, tai –taiteessa hyödyntäen mallirakennetta kokonaisvaltaisemmin.

Biomimiikan kontekstissa yhteistyö eri alojen ammattilaisten, kuten biologien, insinöörien ja tutkijoiden välillä korostuu. Yhteistyö mahdollistaa potentiaalisten mallien löytämisen ja soveltamisen useisiin eri käyttötarkoituksiin. Yhteistyön lisäksi teknologialla on huomattava rooli innovatiivisten tekstiilituotteiden ja sovellusten kehittymiselle kestävää ja vastuullista lopputulosta tavoiteltaessa.

Avainsanat: *Biomimiikka, bioimitaatio, kestävät arvot, tekstiilimuotoilu, ympäristövastuu, sisällönanalyysi.*

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The title of the pro gradu thesis: Biomimicry as a design reference – the sustainable potentiality of textile design mimicking nature's ways
Author: Anna Uuttu
Degree programme / subject: Interior and Textile Design
The type of the work: Pro gradu thesis
Number of pages: 80+ appendices (2)
Year: 2015

Abstract:
The purpose of the thesis was to clarify sustainable textile design from biomimicry's perspective. The focus of the study was to examine the different ways biomimicry could be applied to textile design. In addition the aim was to study the possibilities biomimicry might have for sustainable textile design. Biomimicry comes from the Latin words *bios*, life and *mimesis,* imitation. In this thesis the term sustainability is regarded as a holistic approach to design including social, ecological, economical and ethical perspectives.

As a qualitative study, the purpose was in explaining a phenomenon. Data for the study consisted of interviews and articles received from branch pioneers abroad. The informants combine biomimicry in their current research and textile design. For analysing the data, a four-step content analysis was used. Answers to the research questions can be found in the developed major categories *Nature as a design model*, *Platform for Innovations* and *Reaching sustainability.*

The study reveals that biomimicry can be applied in multiple contexts from experiments to textile art and commercially available products. Sustainability is seen vital in biomimicry and therefore also in design utilizing biomimicry. Materials and their structures in nature are seen sustainable and potential for their low energy consumption. Biomimicry can be applied in different levels. A certain model from nature can be applied for example in a textile fibre, textile finish or textile art in a coherent way.

In the context of biomimicry, collaboration between biologists, engineers and researchers is highlighted. A collaborative practise enables finding potential models and their usable implications for design outcomes. In addition to the collaborative work also technology has an important role in terms of creating innovative textile products and applications with a sustainable approach.

Key words: *Biomimicry, biomimetics, sustainability, textile design, environmental liability, content analysis.*

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INTRODUCTION

1.1 Velcro

I visited The Design Museum in Helsinki during summer 2013. The museum was exhibiting *Finnish Form* which is an ongoing exhibition presenting the history of applied art and design in Finland from the late 19th century to the present day [1]. What caught my eye was *Takkiainen* (Fig.1) by Com-pa-ny which I immediately related with biomimicry having red Kate Fletcher's *Sustainable Fashion & Textiles, Design Journeys* (2008). *Takkiainen* is a clever piece of clothing; a jacket for two persons to wear and to stick together. The designers of Com-pa-ny, Aamu Song and Jonas Olin say they came up with the idea for people to better get in contact with each other [2].

Takkiainen is made of cotton and Velcro which is perhaps one of the most famous applications of biomimicry. Velcro was invented by a Swiss engineer, George de Mestral, in 1948. As de Mestral was taking a walk outdoors, he noticed burrs attaching to his trousers. Later, de Mestral studied the structure of the burrs more closely. Using a microscope he was able to notice the tiny hooks in the burrs that made the clunging possible. This was the starting point for Velcro as de Mestral created a fabric fastener with hooks on one side and loops on the other. With the help of professional weavers he developed tapes of cotton that fastened similarly to each other as the burrs did with his trousers. The fastener was eventually named Velcro and it was patented by a Swiss company in 1952. [3] Velcro is produced and used even today. This invention was the starting point for textile design mimicking the natural world.

This invention was the starting point for textile design mimicking the natural world.

[1] Design Museum.
[2] Company.
[3] Quinn 2010, 111.

1.2 Background of the thesis

Biomimicry comes from the Latin words *bios*, life and *mimesis*, imitation. It is a science that studies nature's ways and then imitates these designs to solve human problems. [4] In his book, *Textile Futures*, Bradley Quinn highlights the opportunity biomimicry may offer, when nature's ways are being applied for human life. Quinn reckons that it is possible to achieve new groundbreaking aspects for textile design once the secrets of the evolution are being revealed. [5]

The subject for the thesis is based on the challenges nature and the environment face also due textile and fashion design. As Quinn brings up, yesterday's textiles are tomorrow's toxins [6]. In addition to the consumption of natural resources, all the produced waste and emissions play a key role in the challenge of a more sustainable textile production [7]. The continuing growth in world population and the developing high living standards have increased global fibre production in the past few decades. This has led to an extended amount of both post industrial and post consumer fibre waste. [8]

Researcher's own interest in the topic is linked to the question of textile designers responsibility and possibility in working sustainably. How should the responsibility this profession nowadays requires be carried out? Would it even be possible to exclusively work sustainably in this field or are compromises inevitable? Could biomimicry help us to find new, more comprehensive ways of practising this branch even more sustainably and what would that require? If an individual textile designer wanted to work following biomimicry's core idea, how thoroughly could it be done? Our habits of making, producing and consuming nowadays make it vital for responsible professionals to view and to practise textile and fashion design in the most sustainable way.

FIGURE 1

Takkiainen by Com-pa-ny.
In Finnish 'jacket' = *takki*
and 'burr' = *takiainen.*

[4] Benuys 2002, foreword.
[5] Quinn 2010, 111.
[6] Quinn 2010, 109.
[7] Fletcher 2008, 7.
[8] Wang 2010, 135.

1.3 Aim and research questions

The main purpose of this thesis is to clarify the concept of sustainable textile design from biomimicry's perspective. The focus of the thesis is in the different ways biomimicry can be applied in textile design and in the possibilities biomimicry may have for sustainable textile design. The potential of the thesis is in opening and continuing a discussion of the current state of textile design and possibly also in broadening the ways sustainable textile design can be carried out by following the principles of biomimicry. Although studying nature's ways is not something new, only few researchers have considered biomimicry's possibilities in textile design in Finland.

The aim of the thesis is to study the role biomimicry can have in sustainable textile design. The research problem is, whether biomimicry can offer new premises, aspects or solutions in the context of sustainable textile design. The main research questions are:

In which way can biomimicry be carried out in textile design?
What are the benefits for sustainability of using biomimicry in textile design?

Textile designers and researchers working on biomimicry will be consulted for the thesis. The purpose of these interviews is to gain deeper understanding and visceral information directly from the pioneers. The aim is also in broadening the awareness textile design can be accomplished at the moment and in the near future.

1.4 Framework and scope of the thesis

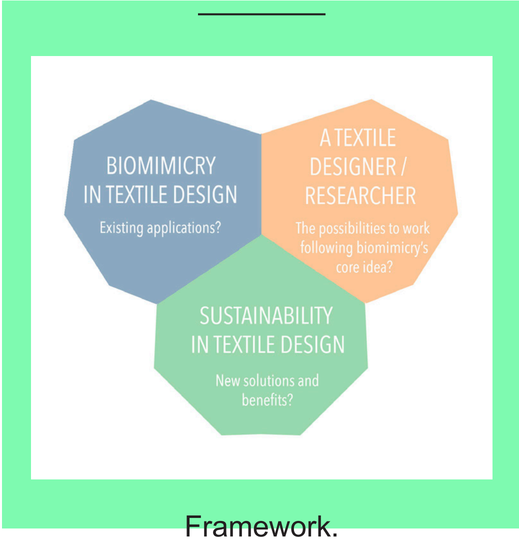
The framework (Fig. 2) indicates the key focus of the thesis. As the aim is to study the potential role of biomimicry in sustainable textile design, the core interest is set in existing examples of textile design mimicking nature. The interviews from branch pioneers make it possible to gain profound understanding of the current relationship between biomimicry and textile design.

Major concerns the environment faces due the field of textiles are mainly caused by mass production, dying and finishing processes [9]. However, the purpose is not to research textile industry or mass production phases as such, but the situation and possibilities before coming to that. Therefore, this research focuses on an individual designer's point of view. The reason for this is based on the researcher's own interest in gaining deeper understanding in textile designers' possible sustainable working methods for the future.

Biomimicry and sustainability are in a key position in the thesis. While sustainability in general has gained a huge popularity among professionals as well as consumers, the amount of different certifications and concepts have emerged. In this thesis, the main sustainability aspect is in the whole life cycle of a textile product regarded from designers' perspective. This aspect is further introduced in chapter 3.4.

Examples of biomimetic textile design in this thesis are focusing on the work of the chosen informants. These examples include textile products, fibres, accessories, prototypes and experiments. In addition, other biomimetic design examples are being studied and presented in detail in chapter 2. These design applications include for example a finishing product for textiles, pigment and color design according to nature and a fabric that improves athletic performances.

FIGURE 2



Framework.

[9] Hethorn & Ulasewicz 2008, 305.

Biodesign is a rather new subject I came across during my research. In his book *Bio Design, Nature, Science, Creativity* (2012) William Myers showcases design combined to biology through various examples. The designs presented in *Bio Design, Nature, Science, Creativity* are biology related, curious and bold. The examples relate to architecture, art and design projects. Myers explains the examples as a reflection to a comprehensive shift in societal priorities. The cases are presented as more sustainable approaches for example in building and producing methods. They also reveal an increasing amount of collaborations between designers and biologists, offering new opportunities for design, art and architecture.[10] Currently, biodesign is gaining more attention and extent at the core of global design tables and events. According to Myers, biodesign reaches beyond other biology-inspired design and manufacturing approaches. He claims that unlike biomimicry, *Cradle to Cradle®* and the common but obscure concept of "green design", biodesign refers to the integration of living organisms as a vital element of improving the functions of the product [11]. In biodesign, it is typical to merge living organisms to the actual design. The outcomes of this can be for example, building blocks, material innovations or product design such as energy generators, digital storage systems or air purifiers.[12]

One of the showcased examples in Myers' book is Amy Congdon's *Biological Atelier* (Fig. 3). In Congdon's project the materials are not made, rather than grown. *Biological Atelier* envisions a fashion industry, where new luxury materials are created from cells and not fabrics. One of the aims is to reach new methods for innovative and renewable fashion.[13] Congdon examines the changing roles of the designer, the craftsman and the scientist placed in the biotechnological future and the imaginary couture atelier of the year 2080. *Biological Atelier* is part of a doctoral research project at Central Saint Martin's College in collaboration with King's College, London. [14]

FIGURE 3

The accessories line from *Biological Atelier*. Amy Congdon.

[10] Myers 2012, 8-9.
[11] Myers 2012, 8-9.
[12] Myers 2014.
[13] Myers 2012, 172.
[14] This is alive.

Despite its indisputable relation to biology and sustainability, a decision was made to not include biodesign in this research more extensively. In order to keep the aim and focus clear and to concentrate on my original research problem that is sustainability in biomimicry, biodesign was excluded. In addition the length of this thesis would not allow a thorough research on both of the concepts. However, biodesign is a theme that deserves its own research as it claims to go beyond biomimicry in sustainability. For the future and further research, biodesign is definitively a subject to continue with.

1.5 Research methods and data

The research is carried out by using qualitative research methods. Qualitative research is recommended when the goal is in explaining real life phenomenons comprehensively [15]. The purpose of qualitative research is to find meanings in the studied phenomena and to develop new theories from the gathered data [16]. According to Pirkko Anttila it is important, that the data for the content analysis can be gathered, observed and/or analysed.[17] The most general forms of data used in qualitative research are interviews, questionnaires, observations and information based on different types of documentaries. The different types of data can be used as alternatives, together or mixed according to the type of the research.[18]

The primary data for the thesis consists of an academic publication and an essay by Dr. Veronika Kapsali together with the completed interviews with Elaine Ng Yan Ling and Jane Scott. The informants are located abroad and are therefore contacted via Skype and by e-mail. In *The SAGE Handbook of Qualitative Research (2011)* Norman Denzin and Yvonna Lincoln present Anssi Peräkylä's and Johanna Ruusuvuori's explanation that by using interviews, new areas of reality can be cov-

The purpose of qualitative research is to find meanings in the studied phenomena

[15] Hirsjärvi, Remes & Sajavaara 2004, 152.
[16] Anttila 2006, 280.
[17] Anttila 1998, 254.
[18] Tuomi & Sarajärvi 2002, 73.

ered. Peräkylä and Ruusuvuori describe interviews to give an advantage in reaching knowledge and experiences better despite the possible long distances between the researcher and the interviewees.[19] The secondarily data for the thesis consists of articles, research and studies, essays and web pages. Collecting of the material started in fall 2013 by gathering the literature and by participating in *Sustainable & Innovative Fashion* -seminar in Helsinki (2.-3.10.2013).

For analysing the collected data, content analysis is being used. Content analysis is a research method that can be used to make repeatable and competent conclusions of the relations between the research data and its context [20]. Referring to Hämäläinen (1987), Burns & Grove (1997) and Strauss & Cobin (1998), Jouni Tuomi and Anneli Sarajärvi describe the aim of analysing the research data. The gathered data describes the studied phenomenon from which the aim is to create a verbal and clear description. By using content analysis the objective is to set the data in an informative and straightforward form without loosing the information it contains. The aim is to add information value, since the unstructured data is intended to come out as as meaningful, precise and coherent as possible.[21]

The process of qualitative analysis is often represented in a form of a spiral. Defined as a hermeneutical spiral, it describes the proceeding of the research step by step through different levels of comprehension [22]. The phenomena in the qualitative research should always be considered as a part of a certain context [23]. According to Tuomi and Sarajärvi, the pre-comprehension of the researcher is always the first step towards the interpretation of the studied phenomenon. The researcher has to specify the main content of the data. The interpretation is developing according to the hermeneutical spiral, from a section to the whole. [24]

[19] Denzin & Lincoln 2011, 529.
[20] Anttila 1998, 254.
[21] Tuomi & Sarajärvi 2002, 110.
[22] Anttila 2006, 280.
[23] Ronkainen & Pehkonen et al. 2011, 83.
[24] Tuomi & Sarajärvi 2002, 103-104.

1.6 Earlier research on the topic

Previously, biomimicry has been studied mostly by biologists, scientists and other, often non-Finnish professionals. However, the topic is brought up to some extent in recent sustainable textile design literature and in few Finnish theses. Obviously, examples of biomimicry in textile design have been around since the famous application, Velcro (p.4) and new examples are currently taking place. Fletcher (2008), Fletcher and Lynda Grose (2011) and Quinn (2010) all introduce biomimicry to us in their textile and fashion design related publications. Each of the writers refer to an American biologist and scientist Janine Benyus and her seminal book *Biomimicry, Innovation inspired by Nature* (2002).

Today sustainable textile and fashion design is becoming more and more popular and an inevitable perspective of viewing this field. As well as the pioneer Fletcher, also Sandy Black (2011), Richard Blackburn (2009), Andrés Edwards (2010) and for example Janet Hethorn and Connie Ulasevicz (2008) have all examined the subject. In Finland, sustainable textile and fashion design has been researched by for example Kirsi Niinimäki (2011). Theses at the University of Lapland from researchers Laura Seppälä (2010) and Jenni Räsänen (2011) include the perspective of sustainability in textile and/or in fashion design.

Heta Kupsala's thesis *Eco-effective fashion theory: How to implement the Cradle to Cradle ® concept into fashion and clothing design? The designer's professional, economic, social and environmental role* (2013, University of Lapland) is a research reveailing *designers' will* to find concrete solutions in terms of applying sustainable methods in the design processes. Maarit Aakko's research about *sustainably changing fashion*, its possibilities and challenges opens the fashion designer's viewpoints to sustainability. The research was carried out in University of Helsinki in 2011.

2

BIOMIMICRY – A CLOSER LOOK

2.1 The core idea

Biomimicry is a science that studies nature's ways and then imitates these designs for human problem solving. According to Benyus, biomimicry is about looking to nature for inspiration in terms of new inventions [25]. Also Julian Vincent, leader of the Centre for Biomimetic and Natural Technologies at Bath University in the United Kingdom conveys that the concept of biomimicry is about taking ideas from the nature and implementing them in other technologies such as engineering, design and computing [26].

Based on Ed van Hinte's reports, John Thackara clarifies that the subject matter of biomimetics is known by several names: bionics, biogenesis, biomimicry, and others [27]. In this thesis, the word biomimicry is primarily used, firstly according to Benyus and secondly, according to the researchers and designers in the field of textiles and fashion using the same term when describing the relations between nature and man-made designs.

Biomimicry can be considered in different levels and according to Benyus, there are three levels to be taken into consideration: *Nature as model, Nature as measure* and *Nature as mentor* [28]. The levels are further explored in chapter 3.5 Levels of mimicking.

[25] Benyus 2014, 1.
[26] Thackara 2005, 270.
[27] Thackara 2005, 270.
[28] Benyus 2002, foreword.

2.2 How nature works

The first found fossils of microorganisms led scientist to a consumption, that there was life on Earth as early as 3.5 billion years ago [29]. Since the very first bacteria, life has mastered for example to fly, to orbit the globe, to live deep under the sea or at the top of the greatest mountains, to light up the darkness and to harvest energy. Living organisms have accomplished to manage in harsh conditions and to adjust that into life-friendly environment with stable temperatures and gently percolating cycles. In brief, life surround us has done all humans want to do without fossil fuels, pollutions or other elements compromising the future life.[30]

As the organization *Biomimicry 3.8* (page 19) indicates, life has developed a range of methods to sustain itself for nearly 4 billion years. This development has been able by adapting new circumstances and creating strategies conducive to life. By learning from these profound design lessons, *Biomimicry 3.8* conveys that humans can form inventive outcomes when benchmarking nature's sustainable examples.[31]

Referring to Ernest Callenbach's book *Ecology, a pocket guide (2008)*, Fletcher and Grose explain that the adaptability of life is in key position for the best evolutionary outcome in which new species arise and from which all life flows. Adaptability makes it possible for species to occupy certain niches of the environment, each with a specific possibility to interact with other species, resources and processes. To be able to adapt constantly, leads to survival in altering situations and even in adverse habitats. [32] Such adaptations are the result of evolution; the transformations of life on Earth from its original beginnings to the rich diversity of organisms living here today [33]. In *Biomimicry – Innovation Inspired by Nature (2002)*,

[29] Campbell, Reese et al. 2008, 507-508.
[30] Benyus 2002, 2.
[31] Biomimicry 3.8.
[32] Fletcher & Grose 2011, 76.
[33] Campbell, Reece et al. 2008, 1.

Benyus describes us nature's masterpieces; photosynthesis, self-assembly, natural selection, self-sustaining ecosystems, talking neurons, natural medicines and more. In a world of biomimetics we would, according to Benyus, manufacture identically the way animals and plants do, using sun and plain combinations to produce completely biodegradable fibres, ceramics, plastics, and chemicals. Benyus explains how our farms would be self-fertilizing and pest-resistant simply designed after prairies. [34]

In his book *In the bubble (2005)*, Thackara highlights Benyus' perception about nature offering us endless examples to design. According to Benyus it is possible to benefit from these design examples and create more efficient solutions to even our basic needs such as keeping warm, finding shelter and getting food. Benyus continues how nature is able to craft materials in a complex and functional way humans can only dream of. [35]

2.3 Research and studies

Scientists, biologists and other professionals in the field of biology, engineering and innovation are leading the current research and education of biomimicry. The research centres, universities, organizations and researchers are located especially in the USA, Australia and the United Kingdom. One of the leaders in biomimetic thinking is the previously mentioned American scientist Janine Benyus. Benyus was one of the first researchers to acknowledge nature's abilities in providing sustainable solutions [36].

Together with biologist Dayna Baumeister, Benyus cofounded the *Biomimicry Guild* in 1998; a research, education and consulting company. Since then, the interest in

[34] Benyus 2002, 2.
[35] Thackara 2005, 187.
[36] Quinn 2010, 111.

biomimicry vastly increased and a wider demand for education took place. In 2006, Bryony Schwan and Benyus co-founded the *Biomimicry Institute*. *The Biomimicry Institute* encourages people to create nature-inspired solutions for a healthier planet through a broad education network and community [37]. Furthermore, the *Biomimicry Institute* also holds global design competitions to solve some of the worlds most challenging sustainability issues. In 2015, the competition is held under the theme *Food security* and is open for both students and professionals. [38]

In 2008, a digital library of nature's solutions, *Ask Nature*, was launched. *Ask Nature* claims to be the most inclusive archive of examples on nature solving human design challenges. This online library is a free database with information on more than 1800 natural phenomena. It gives admirable examples of bio-inspired applications already existing in nature.[39]

In a search of a more competent and connected network, Benyus, Baumeister, Schwan and Chris Allen developed *Biomimicry 3.8*, as a combination of *Biomimicry Institute* and *Ask Nature*. To integrate the work of the two existing organizations, *Biomimicry 3.8* was launched in 2010. *Biomimicry 3.8* is a global leader in consulting, educating and professional training in the field of biomimicry. *Biomimicry 3.8* presents biomimicry as an innovative strategy of discovering sustainable solutions for human challenges, by mimicking nature's well-tested patterns such as a solar cell inspired by a tree leaf. According to the organization, the aim in biomimicry is to create products, processes, and policies that are suitable for life on earth in the long term.[40] Currently, there seem to be no universities offering a degree in biomimicry and design by definition. Instead, there is an increasing amount of academic institutions and universities merging biomimicry in their current courses and degree programs. For example *Biomimicry 3.8* is providing a 2-year *Biomimicry Professional* -certificate, a program described as profound as a Master's degree.[41]

[37] Biomimicry Institute.
[38] Biomimicry Institute.
[39] Ask Nature.
[40] Biomimicry 3.8.
[41] Biomimicry 3.8.

Despite biomimicry is being researched worldwide, the United Kingdom seems to hold a notable position when related to textile design. For example, *Textile Future Research Center (TFRC)* covers researchers from Chelsea College of Art and Design, Central Saint Martin's College of Art and Design at the University of the Arts, London. Many of the researchers there are working on subjects such as biology and science in design, future sustainable materials and process and production systems. The backgrounds of the researchers are in either textile or fashion design and they are productive in both, artistic work and theoretical research.[42] Central Saint Martin's, London, offers a Master's degree in Material Futures. The aim of the studies is to examine the relations between crafts, science and technology by looking beyond the existing boundaries in order to predict our future needs and confrontations [43].

Textile Environment Design, TED, is a research community that develops practice-based sustainable design strategies. Their focus is in reducing harmful impacts on the environment.[44] The research at *TED* is based on the consumption that decisions made at the design table are 80-90 % accountable of a product's environmental impact. Since 1996, *TED* has been developing a set of strategies for sustainable textile and fashion. The strategies called *TED's TEN* include principles for sustainable materials, processes, new technologies and biomimicry.[45]

Since this, the potential interviewees and the design examples for this thesis were discovered mostly via *Biomimicry 3.8, Ask Nature, TRFC* and *TED.*

[42] Textile Future Research Centre.
[43] University of the Arts, London.
[44] Textiles Environment Design.
[45] Textiles Environment Design.

2.4 The informants

The informants for the thesis were selected based on a background research made during summer 2014. A special interest took place in designers and researchers who themselves describe their work to be based on biomimicry.
I started by online search together with reviews on recent publications, newsletters and books. The background research revealed that there is an emerging amount of professionals studying nature's ways and then implementing that into design processes, experiments and final products. Unfortunately, design professionals currently working with biomimicry in Finland were not to be found at the time.

On the basis of the background study, 14 persons were contacted and introduced to this thesis. The persons asked to be interviewed for the thesis were chosen by their deep interest and professional background in biomimicry related textile design. Challenges in timetable played a role in the amount of final participants. The purpose was to interview 3-5 persons. Fortunately, one Skype and one e-mail interview were settled. In addition, one informant kindly sent me her own material related to the theme. The informants are presented in the following.

Elaine Ng Yan Ling is a British Chinese textile designer and a multi-media artist. Ng graduated from Central Saint Martin's in London having studied MA-levels in Textile Futures. During her studies Ng started working with smart materials and focused on for example shape memory alloys.[46] Her art and design research is being featured globally and she continues to give talks at some of the world's best known conferences such as TED, DOIT *(Delivering Innovation for Tomorrow),* Taiwan and Shape Shifting, New Zealand. [47]

[46] Ng 2014.
[47] Elaine Ng Yan Ling.

Ng's recent projects include for example *Climatology* and *Naturology*. *Climatology* is a research project celebrating nature's survival tactics. The project is concentrating on the engineering structures of plants and their ability to self-adapt into change of natural surroundings. One key element is to reveal the survival tactics the plants create in order to increase their longevity. Ng's aim is to translate these skills into textiles to enhance the materials endurance and to propose a new way of creating sustainable material (Fig. 4).[48]

Naturology as a word combines nature and technology. According to Ng, techno '*Naturology'* means the use of artificial technology to activate and stimulate nature's technology in order to create tectonic movement. The project is exploring the functions and relationship between shape memory alloy and polymers and the natural sensing system of wood (Fig. 5). The endlessly evolving patterns of nature, the responsive tectonic structures can be explored in a way that the design can both mimic and create new structures.[49]

Ng is the founder of The Fabrick Lab, which is an experimental art and design studio and a material consultancy. The Fabrick Lab aims to combine textiles, electronics, biomimicry, interiors and installations. The distinctive use of materials in The Fabrick Lab has been described as "materials that move and grow like trees – but faster". The key design philosophy for Ng lies in biomimicry, nature and innovation. The textile experiments are a result from combining traditional craft skills and modern understanding of materials.[50]

FIGURE 4

From the series *Climatology* by Elaine Ng Yan Ling.

[48] Elaine Ng Yan Ling.
[49] Elaine Ng Yan Ling.
[50] The Fabrick Lab.

During Ng's career, she has been working with international design companies such as Nissan Design Europe and Nokia Design Beijing. Her work has been on display at multiple exhibitions and art galleries including V&A and Science Museum in London, Textil Museum in Tilburg, Harbour Front Centre in Toronto, Espace EDF Art Foundation in Paris and Wuhao, Beijing. [51]

Jane Scott has studied her first degree at The University of Leeds and then completed Master of Art degree in Textiles at Manchester Metropolitan University. I was originally recommended to contact Scott by Angela Hartley from Textile Futures Research Centre. Currently, Scott is teaching the BA Textile Design Programme in The School of Design at The University of Leeds. She is also undertaking a PhD through Textile Future Research Centre at Central Saint Martin's. [52]

Specialized in knitted textiles, Scott's PhD research focuses on the design and development of knitted fabrics and technologies. Scott is examining the possibilities to create environmentally responsive knitted textiles for architecture. Her research interest lies in how the structures of knitted fabrics could be engineered following biomimetic models. [53]

Scott's work consists of the intersection of material innovation and smart textile design. She examines systems for actuation based on biomimetic principles seen in botanical systems. Her work has been exhibited broadly in the UK and she has presented research papers at several international conferences.[54] Scott's PhD question is *How can the structure of knitted fabric be engineered using biomimetic models to design environmentally responsive textiles for architecture?* This places biomimicry as the central research method for the investigation. Scott reckons biomimicry to be very appropriate for her current personal work because she is looking for an alternative to technology driven innovation. [55]

FIGURE 5

Techno Naturology
Wooden Velcro
-accessories
by Elaine Ng Yan Ling.

[51] The Fabrick Lab.
[52] Scott 2014.
[53] Textile Future Research Centre.
[54] Textile Future Research Centre.
[55] Scott 2014.

One of Scott's research papers *Hierarchy in knitted forms, environmentally responsive textiles for architecture* (2013) concentrates on the theoretical framework behind the development of a series of knitted prototypes inspired by the biomimetic model of the hygromorph (Fig. 6). The moisture responsive pieces use the inherent properties of wood veneer as an actuator incorporated into complex knitted forms constructed from linen and wool. These textile and veneer assemblies are environmentally responsive, transformable and made from natural and sustainable materials. The experiments represent a new interpretation of shape changing textiles for architecture. The work also illustrates the potential of designing hierarchically organised structures where functionalities are incorporated at different levels of material fabrication. As a conclusion, the paper argues that the implementation of textile materials and processes offer possibilities for developing environmentally responsive architecture through the development of shape changing textile/veneer assemblies. [56]

Dr Veronika Kapsali is a Reader in Biomimetic Systems and leader of the BioExplore subject at the Northumbria University's P3i Studio/Labs. She is the inventor and co-director of MMT Textiles Limited, a research and design company owning the rights for INOTEK TM, a biomimetic fibre based textile technology using moisture in clothing microclimate to create a mechanical response for advanced moisture management (Fig. 7). [57]

Kapsali's background is in fashion and textile design and she has been working in the fashion sector since 1999 as a studio manager and freelance textile designer. In 2004 she started to give lectures in Textile Technology and Design Development at the London College of Fashion, while studying for her doctorate in Biomimetic Textiles at the University of Baths Mechanical Engineering Department. [58]

Truly inspired by nature, Kapsali reckons that nature can help us to create a smarter

FIGURE 6

Smart natural biomimetic textiles by Jane Scott.

[56] Acadia.
[57] Kapsali 2014, 1.
[58] Inotek Textiles.

and more sustainable future.[59] In addition to presenting frequently at international conferences, Kapsali's research also appears on several publications. Her work at MMT textiles has brought multiple awards and gained a great deal of media visibility as well. [60]

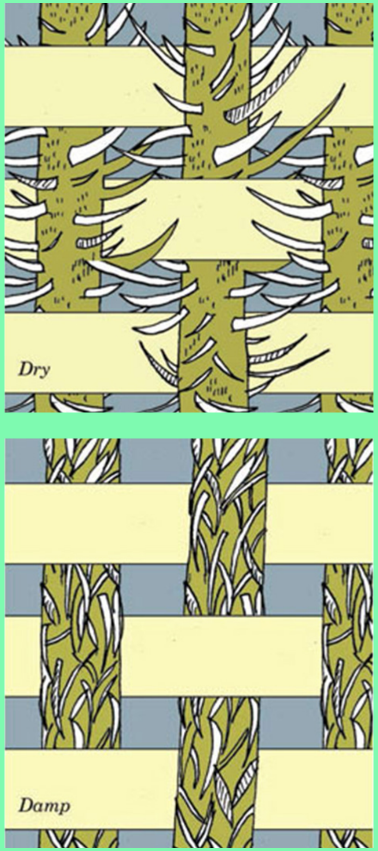
2.5 Design applications

To begin with, biomimicry is not a style of a building nor an identifiable design product. We might for example, have a solar cell not looking like a leaf, but made according to the photosynthesis of leaves, a design method existed for billions of years. Therefore, biomimicry could be described merely as a design process. In this process, the designer seeks the best possible model from an ecosystem or an organism for the current design challenge and starts the problemsolving; how is the ecosystem doing what the designer aims to do and how could that be imitated. [61]

According to Benyus, the very first design examples were found in our native habitats. Beautiful forms and systems existed everywhere around us making life possible. Humans have always had a certain idea of good design. The appreciation we have towards aesthetics and practicality has developed into a will to imitate nature in art and other applications. Our intuition taking design cues from the environment is returning to the practice of biomimicry. It is the manner of learning from nature, adopting designs and approaches that have worked for billions of years [62].

The principles behind biomimicry are not exactly new. As Quinn explains, mankind

FIGURE 7



A drawing explaining the biomimetic invention behind the fabric by Inotek TM.

[59] Kapsali 2014, 1.
[60] Northumbria University.
[61] Kellert, Heerwagen & Mador 2008, 29.
[62] Kellert, Heerwagen & Mador 2008, 27-28.

has long used technologies imitating nature. For example, Leonardo da Vinci's flying machine mimicked wings, and airline jets took their aerodynamic shape inspired from birds bodies and beaks. Quinn continues with an example of a product design, the telephone receiver which was modelled according to the anatomy of the human ear. In addition, the animal dwellings and plants have inspired architects for centuries.[63]

Also Benyus gives us examples from the past; the early Greek mathematicians mimicked nature's measures and proportions thinking it would bring them closer to the cosmos. She continues with vernacular architects (architects relying on local materials and traditions) who may have learned mud-daubing from swallows and termites and the methods of weaving from birds and spiders. Also, when the Hispanic settlers reached the San Valley of Colorado in the 1800's, they were new to the climate and uncertain of how thick to make their adobe walls. They then took example from a local mammal, the Columbian ground squirrel, to estimate the wall-thickness better. Amusing enough, the adobe walls built in the valley still continue to have the same thickness that the squirrels' nests even today.[64]

According to Robert Allen, a professor of biodynamics at the University of Southampton, UK, biology is dependent on materials for the structures it creates. These structures have to be inexpensive and dependable. Allen explains the evolutionary survival being partly value-based, in fact, the survival of the cheapest ones. By this he means that in order to be able to reach success there might be a competition for one's survival due limited resources. [65]

The construction of animals and plants is largely based on materials on hand. These materials include water, carbon, hydrogen, nitrogen, calcium and silicon. Despite iron, zinc and manganese are vital in different ways, only few metals are used. The

[63] Quinn 2010, 111.
[64] Kellert, Heerwagen & Mador 2008, 28.
[65] Allen 2010, 134.

biological materials are built up at the available, surrounding temperatures and use only two polymers (protein and polysaccharide), with two ceramics (calcium salts ad silica), when compared to man-made materials which demand much higher temperatures to be manufactured and hundreds of polymers.[66] For nature, it is only logical to apply the most ecological way of achieving its goals for low energy costs and use of material. [67]

Companies from all over the world, like DaimlerChrysler, Speedo and ESA (an aerospace agency), have already been devoted to nature's examples in some of their projects. Engineers in Bath, England, and West Chester, Pennsylvania, are studying the bumps on the edges of humpback whale flukes in order to manufacture airplane wings in a lighter and more flexible way. In addition, architects in Zimbabwe are looking to termites, to learn from their habits of regulating temperature, humidity, and airflow in their mounds in order to build more appropriate buildings. Also Japanese medical researchers are concentrating to reduce the pain injections might cause by using hypodermic needles with tiny serrations, mimicked from mosquito's beaks, minimizing nerve stimulation. Material scientist Michael Ribner from MIT reckons, that the use of biomimetic thinking is adding an entire new set of tools and ideas to the table.[68]

As an example, the company Daimler-Chrysler made a research on the growth of trees to better understand nature's examples of strength-to-weight issues. The study was made for a boxfish concept car. The research enabled the engineers to reduce 40 % of the car's normal weight, but the process was abandoned due to the total amount of time it took to manufacture. Despite all the examples known already, Allen still thinks that biomimetics has only made few inroads into technology. [69]

[66] Allen 2010, 134.
[67] Allen 2010, 8.
[68] Biomimetic Design.
[69] Allen 2010, 163.

Referring to Benyus, Quinn gives us an example of colour formation in nature. The feathers of a peacock give an impression of multiple colour collection, but instead of an array of pigments, the colours occur because of light-catching barbules. Frankly, the only pigment the feathers contain comes from melanin, which is brown. The other colours are visible due an optical phenomena created by the barbules. In comparison to colour pigments, the barbules never fade. This gives an interesting and valuable option to textile designers, to create colourful fabrics without the need of any dyes or chemicals.[70]

Based on the same notion on peacock feathers, a company called Qualcomm has developed an e-reader display screen. The screen does not need any backlighting, since it takes the advantage of the surrounding light to create the colour pixels to be seen. By doing so, the device's use of energy reduces drastically.[71] The display is called mirasol® and the technology behind it assures it to stay clear and functioning even in bright sunlight.[72]

2.6 Textile design

According to Leslie Eadie and Tushar K. Gosh, we are given marvellous examples of practical systems built with only few materials by nature. Nature has developed to adapt and cultivate remarkable ways of problem solving. Examples of functional surfaces, structures, and self-healing offer us valuable guidelines for the future of textile products.[73]

Few textile designers have already started to look into life sciences in order to design sustainable textiles while examining the possibilities biomimetics and biochemistry can lead to. Designers are studying nature and biomimicry's secrets.

Nature has developed to adapt and cultivate remarkable ways of problem solving

[70] Quinn 2010, 112.
[71] Qualcomm.
[72] Qualcomm.
[73] Eadie & Gosh 2011, prewords.

Researchers in the field of biomimetics are studying processes that animals, insects, plants and microbes use in order to develop materials and techniques that can greatly improve design. As mentioned in previous chapters, plant fibres, pine cones and peacock quills have led the way towards a new group of textiles.[74] The following examples aim to give an insight into the developments already found in the field of biomimicry related to textile design.

2.6.1 GreenShield®

The petals of a white lotus flower give us an example of hydrophobic wax. The flower grows under muddy waters while still blossoming on the surface without any trace of grain or dirt on it. The reason for this is in lotus flowers' ability for self-cleaning. While the droplets run of along the leaves, they pick up the dirt making the flower exclusively non-sticky and water repellent. Following this principle *Lotusan*, a spray-on exterior paint, was developed. The paint creates a rough exterior coating making the surfaces self-cleaning in the rain.[75]

For the field of textiles, the self-cleaning effect of lotus flower inspired the company BigSky Technologies to create a textile finishing product, registered as *GreenShield®* (Fig. 8). The innovation is based on nano-particles and it contains components that have a solid and stated safety confirmation. The technology behind *GreenShield®* relies on microscopic roughness. Basically, *GreenShield®* creates pockets of air on the surface of the fabric making it repellent to water, oil, stains and dirt. This microscopic roughness is something that has existed in nature for thousands of years providing natural water resistance due to the roughness of the leaves. *GreenShield®* was developed in partnership with *The Biomimicry Institute* and continues to feature as one of their case studies.[76]

FIGURE 8

GreenShield® textile finish.

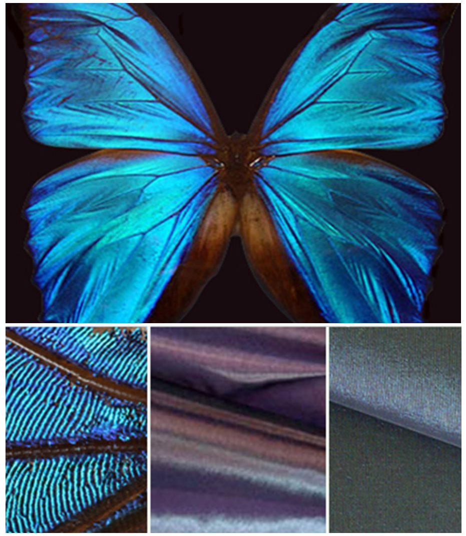
[74] Quinn 2010, 110-111.
[75] Quinn 2010, 114.
[76] GreenShield.

2.6.2 Morphotex®

A Japanese company called *Teijin*, has developed a biomimetic fibre called *Morphotex®* based on the South American morpho butterfly (Fig. 9). *Morphotex®* is an example of a shiny, colourful textile fabricated without the use of any dyes or pigments. Just like the butterfly's wings, also the fibre receives its colours from light difftraction and interaction with the fibre layers increasing certain wavelengths. The structure of the *Morphotex®* fibre consists of multiple layers of polyester and nylon, each with particular refractive proportions. By mastering the thickness of the layers, the variations of colours appear; red, green, blue and yellow, depending on the angle and intensity of light shining on the fabric.[77]

The *Morphotex®* fibres appear in intensive and brilliant colours to the viewer. Without any use of dyeing or other chemicals, *Morphotex®* is a special add to sustainable textiles.[78] Allthough many companies showed true interest in this new invention, the manufacturing of *Morphotex®* was stopped in 2011 [79]. Before this, *Morphotex®* was ordered and used in multiple applications. For instance in 2000, Nissan used it as an upholstery fabric for the front seats of the Silvia Convertible Varietta. As the fabric was pigment-free, there was no danger of colour fading when exposed to UV light. Also a sportswear company called Descente used *Morphotex®* in skiwear designed by the recognised costume designer, Eiko Ishioka. The skiwear was used by the Swiss, Canadian and Spanish Olympic alpine teams.[80] According to Rossin *Morphotex®* reaches sustainability goals by not using pigments. Therefore also dyeing processes can be avoided. This drastically reduces the level of energy consumption and results as a fabric free of toxins.[81]

FIGURE 9



Morphotex butterfly,
fibres and fabric.

[77] Quinn 2010,112.
[78] Fletcher 2008, 138-139.
[79] Ask Nature.
[80] Quinn 2010,112.
[81] Rossin 2010, 6.

2.6.3 LZR Pulse™

For humans, swimming is not considered efficient frankly because our bodies are not shaped for travelling fast through water. Indeed, the learned swimming styles will affect a lot to the speed level we will achieve. An important fact in adding the speed in water is to lower the skin friction drag. In order to gain greater speed, researchers have started to examine the examples given by nature.
A considerable interest has been shown towards sharks and their fast and smooth movement in water. The structure of shark's skin revealed researchers some facts humans have later benefited from.[82]

Scientists and designers have examined fish skins at large to study the molecular levels in order to analyze the small friction levels they have. Surprisingly enough, the shark's skin turned out to have the smallest friction level. The researchers were especially bewildered by this since shark's skin is known to be very rough. In fact, the shark's skin consists of the same material as its teeth. The skin is covered by small, V-shaped protrusions which during the swim, channel the water away from the surface reducing the drag actively. When reproduced in a form of a woven textile, a shark skin imitation of ridges and grooves enables the water to spiral in microscopic vortices, resulting in a hydrodynamic advantage. [83]

[82] Eadie & Ghosh 2011, 768.
[83] Quinn 2010, 113.

Speedo saw the potential of mimicking shark's skin in their products and in 2008 the *LZR Racer®* suit was launched (Fig. 10). Known as *LZR Pulse™*, the fabric was developed in cooperation with NASA and the Australian Institute of Sport. Also Commes des Garcons took part in the project by designing the surface motif. The final swimsuit was made of high tech fabric imitating the skin of sharks in addition to the skin of dolphins and porpoises. The swimsuit is shaped stable at the core, giving the fabric's structure an extra support on the corset area.

The *LZR Racer®* suit has impacted on other areas of sportswear as well; it has led all-in-one suits, seamless surfaces and polyurethane coatings to be of high performance design.[84]

FIGURE 10

The LZR Racer®
suit by Speedo, 2008.

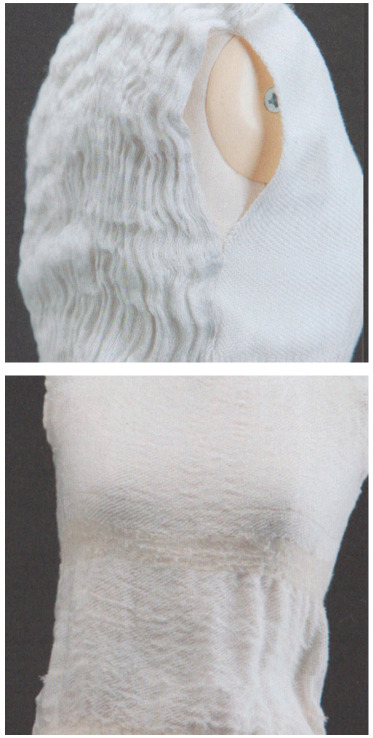
2.6.4 Pine cones

Pine cones have been one of the most inspiring examples for responsive fabrics. As Quinn explains, pine cones mature on tree, remaining their surfaces closed. But as soon as they fall to the ground due ripening, they expand and open releasing their seeds. The pine cones' scales are divided into layers which makes them possible to open. Each layer also has a unique response to moisture. When the pine cone drops, it begins to dry out. The scales are slowly starting to bend and flex, due to their different rate of releasing moisture.[85]

[84] Quinn 2010, 114-115.
[85] Quinn 2010, 114-115.

Kapsali's PhD research led her to develop an adaptive textile (Fig. 11). The textile was inspired by moisture and its way to induce shape changes in the structure of many plants, as briefly presented in chapter 2.4. Kapsali explains that the inspiration for her adaptive fabric came from the notion of moisture causing shape changes in many types of plant structures. She clarifies that the absorbing textile works the opposite way compared to conventional natural fibres. As wool and cotton swell when absorbing moisture, it will reduce the porosity of the textiles they comprise. The system Kapsali has developed actually becomes more porous while absorbing moisture. The resulted textile could be used for example in sportswear, where perspiration would cause the fibres to expand and open, releasing the moisture away from the skin and onto the surface of the fabric, where it quickly evaporates. [86]

FIGURE 11



Moisture absorbing fabric developed by Veronika Kapsali.

2.6.5 Spider silk

One of the strongest fibres in the world, spider silk, is five times stronger than steel. Its most valued qualities are the lightness, flexibility, water-proofness and sustainability. Research has revealed that spider silk can absorb energy before breaking. Spider silk originates from the intricate protein molecules received from the insects they catch and eat. The glands of each spider species varies and produces its own types of silk for the relevant situation.[87] To be more precise, spider silks are protein-based biopolymer filaments. Spider silk is a remarkable example of nature's sustainable making process. The silk is being spun at almost ambient temperature and with water as the only solvent. In addition, the spider silk is an exceptional example of nature's use of protein as an adjusting building material. [88]

[86] Quinn 2012, 198.
[87] Quinn 2010, 118.
[88] Eadie & Gosh 2011, 763.

In Madagaskar, Simon Peers and Nicholas Godley have completed several cloths made of spider silk (Fig. 12 & 13). Together with a group of professionals, they have extracted the silk from spiders, spun the yarns and woven the pieces by hand. The spiders were collected in the highlands of Madagascar with the help of the locals. As Godley describes the process, the spiders are collected, harnessed and then milked. The spiders produce between 30 to 50 meters of thread within about 25 minutes after which they are released back into nature. In 2012, Peers and Godley exhibited the world's largest textile pieces made from spider silk in V&A museum, London. To get the perspective, one brocaded shawl was made from silk of more than one million female golden orb-weavers. The project took three years to complete and the men describe it as a huge challenge from the beginning to the end.[89]

The various examples of biomimicry applied to design and textile design are fascinating in their usability and versatility. The examples exist not just as prototypes, but as trademarked and registered fabrics and finishing products together with unique textile art pieces. In addition to the current experiments and research one can imagine a future of sustainable and practical textile design based more on biomimicry.

FIGURE 12

A detail of a spider silk cape created by Simon Peers and Nicholas Godley.

FIGURE 13

The Woven Web. Trial 1. 2009,
160 x 60,5 cm, Golden Orb spider silk.
Hand-woven by Simon Peers in Madagascar.

[89] Victoria & Albert Museum.

3

SUSTAINABILITY

IN

TEXTILE

DESIGN

3.1 Textiles – an everyday commodity

Nature has provided a variety of layers for animals including bare skin, feathers, hair, fur, scales, shell or hide. The value of these layers is found in the protection agains predators and/or the environment. In addition, they also provide comfort and improvement for an individual animal's aesthetic appeal and attractiveness. Furthermore, prehistoric humans used leaves, tree barks and for example feathers to protect themselves against the environment and/or to enhance their aesthetic appeal.[90]

According to Eadie and Ghosh using materials in order to create clothing may be a habit older than pottery and even farming. The oldest found pieces of various textiles date back to the 7th millennium BC and are found in Nahal Hemar, Dead Sea, Israel. These textiles and fragments of cloths are mostly made from flax with limited mixture of other fibres. The oldest known woven fabric with an advanced and sophisticated design dates back to 3000 BC. This example was found from a lakebed in Switzerland. [91]

The oldest known woven fabric with an advanced and sophisticated design dates back to 3000 BC

According to Hawken, Lovins and Lovins the history of using fibres is comparable to the the history of human development. The starting point for the use of extremely strong fibres dates back in early cultural evolution. The first used fibres were in many case coproducts of food production and they were used to create clothes, baskets, ropes, houses and other artifacts. In the course of time, inventors found out the way of turning cellulose into resin and thereafter into many industrial products. [92]

The word 'textiles' comes from the Latin word *texere,* which means 'to weave'. Therefore, the term textiles has originally referred to woven fabrics only. According to Eadie & Ghosh, textiles today include for example cords and ropes and various fabrics manufactured with multiple different techniques such as weaving, knitting,

[90] Eadie & Ghosh 2011, 762.
[91] Eadie & Ghosh 2011, 762.
[92] Hawken, Lovins & Lovins 1999, 171.

non-wovens and combinations of that mentioned. The structures of textiles can be seen valuable for example due their low weight, flexibility and other extraordinary properties. The current, modern-day textiles are far more than mere clothing. An example form the USA reveals that in 2008, more than 75 per cent of the used fibres were in products other than clothing and home textiles. Indeed, an extended definition that describes textiles as flexible products made primarily of polymeric (natural or man-made) fibres is more than convenient today. [93]

As Clarke explains, textiles have developed beside mankind to alter the material world. The importance of textiles appears in the need for protection in clothes and interior textiles. Furthermore, textiles can be seen convenient in other fields such as in fine art and architectural elements. According to Clarke, some of our most inventive creations are represented by textiles and reflected especially in the marvellous design outcomes of haute couture. [94]

According to Black, Delamore et al. the clothing, footwear and textile sector is the fifth largest industry sector today. Employing up to 40 million people worldwide makes it more than valuable from the economical perspective as well.[95] A drastic change in the consumption of fashion has occurred in recent years. Referring to Allwood et al. (2006), Black, Delamore et al. explain the situation from UK where a 37 per cent increase occurred in the amount of purchased clothes per capita between 2001 and 2005 .[96]

Black, Delamore et al. state that over the past decades, the life cycle of fashion has turned into a growing phenomenon of global manufacturing. For example, materials and garments may travel across the world due most of the production facilities locate in low wage countries. [97]

[93] Eadie & Ghosh 2011, 762.
[94] Clarke 2011, 6.
[95] Black, Delamore et al. 2009, 3.
[96] Black, Delamore et al. 2009, 3.
[97] Black, Delamore et al. 2009, 3.

Even textiles continue to be valuable for humans on a daily basis, the consciousness towards the world's limits in producing them have developed. According to Colchester there is now a growing awareness requiring to change the way we live our lives, the way we shop and the amount we consume. In addition the chemicals and materials involved in textile production and the vague solutions for waste clothing – all need to alter.[98]

3.2 Environmental challenges

The environment is facing a direct impact of the increasing amount of population together with the developing economies and the production amounts and consumption of both fossil and natural resources. Blackburn declares that this has significant capability to influence in the degradation of the environment. He continues on how the consumption level of fossil fuels and natural resources need to be reduced.[99] According to Edwards one of the greatest future concerns the Earth is facing is the decline of ecosystems and the loss of biodiversity. Edwards declares that biodiversity provides a "resilience net" that all species depend on in order to survive. Solutions are needed for balancing the ecological, social and economical needs of people, many of whom live at subsistence levels in the developing countries. [100]

Indeed, governments, organizations and leading environmental specialists are declaring the same threat. In August 2014, the World Wide Fund for Nature announced that the resources of the Earth had been used for the rest of the year. In other words, renewable natural resources are being consumed faster than they can develop back and we are therefore incurring debts for the rest of the year.

Renewable natural resources are being consumed faster than they can develop back

[98] Colchester 2007, 22.
[99] Blackburn 2009, preface.
[100] Edwards 2010, 91.

Currently, 86 per cent of people are living in countries, which consume more than their own ecosystems are producing. In fact we would need 1,5 globes to produce what we now consume in a year. This kind of overconsumption leads to both, environmental and economical catastrophe. As the diversity in nature decreases, forests disappear and the soil decays. Also the air becomes toxic to breath and people are suffering from the lack of food and water. The carbon dioxide emissions create half of the ecological footprint we produce and therefore are accelerating the global warming.[101]

One of the biggest concerns in the field of textile and fashion design is the burden industry and many of the mass-production processes causes. The quantity of manufacturing overmeets the needs of consumption, therefore disadvantage towards the nature is inevitable. Natural resources and the environmental diversity are getting scarce for example due certain fibre and fabric production, fabric dyes and finishings, logistics, decreased quality of the products, disposable consuming habits and the amount of waste not suitable for recycling. Although the current environmental situation is a sum of multiple factors, also the textile and fashion industry have their part in it. [102]

Hethorn and Ulasewicz present Orzada and Moore's explanation that the textile industry is addressing issues of pollution caused especially due the manufacturing processes. The pollutions in the air, land and water are issues that should be truly acknowledged and addressed with a great determination towards more sustainable manners. According to Orzada and Moore designers and manufacturers should therefore first comprehend the situation and then evaluate the processes that are used to grow and manufacture fibres and yarns, including dyeing and other processing of the fibres and fabrics.[103]

[101] Finnish ministry of environment.
[102] Uuttu 2013.
[103] Hethorn & Ulasewicz 2008, 299.

To take nature's valuable examples of building and designing seriously, Kellert, Heerwagen and Mador summarize the critical facts of the environment's fragility when miss-treated. They declare that the dominant approach to design of the modern built environment has drastically added for example, the degradation of natural systems and escalated the human separation from the natural world. According to Kellert & al. we are struggling with unsustainable energy and resource consumption, major bio-diversity loss, widespread chemical pollution and contamination, extensive atmospheric degradation and climate change. Kellert & al. further describe the situation to be a cause of a fundamental design flaw. Fortunately, a more positive future can be reached, as long as we want to design ourselves in it. Kellert & al. explain that this would require an adaptation of a thoroughly different paradigm for designing; we should seek, if not harmony, reconciliation with nature. [104]

3.3 Concepts for sustainability

Sustainability is a broad and multilayered term that consists not only from ecological and ethical aspects but also from the social and economical point of view [105]. The word itself comes from the Latin word *sustinere*, which in English means *to hold, maintain, support* and *sustain* [106]. To look at the subject comprehensively, sustainable development can be described as a development where needs of the current generation meets the needs of future generations, as Joan Farrer states according to Brudtland (1987) in *Shaping sustainable Fashion* (2011) [107].

As the awareness of the environmental risks of manufacturing and producing textiles expands, many manufacturer and designer seek for more ethical and sustainable solutions to produce their collections. One way of accomplishing this is to follow the requirements of different concepts and certifications confirming sustainable and ecological aspects for a product or a production phase defines.

[104] Kellert, Heerwagen & Mador 2008, 5.
[105] Uuttu 2013.
[106] Uuttu 2012.
[107] Gwilt & Rissanen 2011, 20.

Responsible organizations, companies and designers are working hard to advocate environmentally and socially healthy values in their production methods and therefore apply for these certifications. Also a growing amount of consumers are keen to know where, by who and how their products have been produced. Since the production of fashion and textiles is nowadays extremely global and mainly managed abroad, there are limited possibilities for the customer to actually follow the production phases all along. According to Annina Nurmi, the founder of Nurmi fashion label, a certification provided by a noted third party organization is therefore valued from both, the manufacturer's and the consumer's point of view.[108]

Blackburn presents Grose's perception of the importance of different ecolabels, although not all of them define environmental aspects in the same way. Some of the ecolabels and certificates concentrate in securing good working conditions, while some deal with prohibiting the use of toxic chemicals in the final product. According to Grose, the *EU Ecolabel* is a remarkable sustainable textile processing certificate since it contains all stages covering textile manufacturing from raw fibre to finished product.[109] In addition to the *EU Ecolabel*, also *GOTS, Öko-Tex 100, Blue Design* and *Fairtrade* are examples of existing certificates and standards, which highlight the ecological and ethical values of manufacturing. Depending on the certificate, it confirms the manufacturing, used materials and finishing methods to be healthy for the workers, the environment and the user.

Despite the overwhelming amount of complexity, Blackburn explains that there are founding principles that all products conform to. Due this, the developing strategies and philosophies offer alternatives. However, according to Blackburn, the core concepts that seem to underpin and maintain many solutions are *Cradle to Cradle®* and biomimicry.[110]

[108] Nurmi 2013.
[109] Blackburn 2009, 70.
[110] Blackburn 2009,16.

According to Susan Kaiser the *Cradle to Cradle*® concept relies on the environmentally aware cradle-to-grave metaphor. The focus is on design and product development where creating innovative and high-quality products create economic value and also enhance the wellbeing of nature and culture.[111] The core idea behind *Cradle to Cradle*® is to design in a way that enables all material to be used in continual cycles of use and reuse. According to Blackburn, *Cradle to Cradle*® too, is inspired by mimicking the processes of nature. In order to achieve the cycles, it is crucial to focus also in the end of the product's life. For a *Cradle to Cradle*® product, the post consumption use should mean the beginning of a new product life.[112]

Blackburn describes that there are only two basic materials in nature; the materials that grow, biodegrade and re-grow and the materials that are finite which do not grow. The materials that grow are renewable and those that do not grow are non-renewable. In *Cradle to Cradle®,* the main idea is that in nature there is no waste. As the writers McDonough and Braungart (2002) themselves define, 'waste equals food'. This is based on the fact that everything in nature feeds on the remains of a previous form. Therefore, one process leads to another creating a dynamic balance that is the result of cause and effect [113]. To take this approach in fashion or textile design means that one product's life cycle becomes connected with a new product's life cycle. In other words, the grave of one garment's life cycle becomes the cradle of another product's life cycle. Finally, this would lead to a situation where instead of waste, "food" or nutrients for new, quality products would develop.[114]

[111] Hethorn & Ulasewicz 2008, 155.
[112] Blackburn 2009, 17.
[113] Blackburn 2009,16.
[114] Hethorn & Ulasewicz 2008, 155.

Since *Cradle to Cradle®* is about the continuous life cycle of products and materials, diversity in design becomes one key principle. Here, the meaning of diversity refers to both, nature and culture. In design, diversity includes not only how a product is made but also how it is used and by whom.[115] An example of *Cradle to Cradle®* product is *Climatex®* which is the world's first fully compostable industrially produced textile. *Climatex®* was developed in 1995 by Michael Braungart. The material is a combination of ramie, wool and polyester. *Climatex®* is biodegradable and all the processing waste is used for felt or garden mulch. [116]

Hethorn and Ulasewicz present Orzada's and Moore's conclusion that all manufacturing has an effect on the environment. Producing goods for consumers require the use of raw materials, energy, machinery, and labour. When the materials and processes for a textile product are being selected during the design and product development phase, also the environmental impact of that textile is determined. According to these decisions, manufacturing process, usage, maintenance, and disposal of the textile product may contain a variety of environmental impacts from minimal to severe.[117]

Referring to Heely and Press (1997), Orzada and Moore continue how the sustainable future depends on an understanding of the relationship between fibre, yarn and fabric. In addition, Orzada and Moore explain that a holistic and integrated approach to design and product manufacturing is essential. They present the *Life cycle assessment (LCA),* which involves determining the product life cycle, assessing resource inputs and waste outputs during each life cycle stage, calculating the environmental impacts, and identifying options that will reduce the total environmental impact of the product over its entire life cycle.[118]

[115] Hethorn & Ulasewicz 2008, 155.
[116] Blackburn 2008, 17.
[117] Hethorn & Ulasewicz 2008, 301-302.
[118] Hethorn & Ulasewicz 2008, 302.

3.3.1 Materials

According to Fletcher, materials play a key role in our current perception of sustainable fashion and textiles. Materials can be seen as the starting point for change and as an essential commodity for the farmer, designer, manufacturing industry, consumer and recycler. Fletcher explains that materials have also been at the core of both recent waves of interest in sustainable fashion and textiles. The first wave dates back to the early 1990s, when natural and recycled fibres dominated the textile industry. The second wave originates to the mid part of the 2000s, where organic, *Fair Trade*® and rapidly renewable fibres have taken the lead in design innovation.[119]

In general, textile fibres can be divided into two categories: natural fibres and manufactured ones. Natural fibres include fibres grown in nature as such, covering vegetable, animal and mineral fibres. Manufactured fibres include natural polymers (derived partly from natural resources) and synthetic polymers which are fabricated trough different man-made processes.[120] Natural fibres follow the laws of nature. Natural fibres are grown and processed as part of an agricultural cycle. Besides this, natural fibres also biodegrade whereas synthetic materials are not part of this cycle and need to be processed separately [121].

When considering sustainable materials, the most obvious choices may not always contain the most sustainable outcome. It is not just the devouring use of sustainability as a word, but the misunderstanding and misevaluation of what is considered to be ’good’ and ’bad’. As Blackburn explains, terms like organic, natural, and biodegradable are typically recognized as ’good’ whereas GM, synthetic and chemical are commonly perceived as ’bad’. This gives an interesting perspective to the matter, since for example water is actually a chemical (dihydrogenoxide) yet arsenic is natural. [122]

[119] Fletcher 2008, 3.
[120] Fletcher & Grose 2012, 15.
[121] Quinn 2010, 128.
[122] Blackburn 2009, preface.

Nowadays the use of recycled materials is ordinary in addition to the popularity of organic alternatives such as hemp, bamboo and raw silk. Preferred inorganic choices include biodegradable textiles, recycled plastics and renewable meltprocessable fibres. These fibres are made synthetically from corn sugars which are altered into lactic acid and then polymerized into polylactic acid creating an alternative to oil-based polymer textiles that are grown as corn. These materials can be woven into fashion fabrics or into nonwoven interior textiles. The fibers can be composted industrially [123].

According to Fletcher we need to understand, that not a single fibre, despite of its organic, Fair Trade® or recycled feature, can solely answer to the challenge of the polluting industry of fashion and textiles. Fletcher underlines, that the focus should not be alone in the material but on the whole. She still highlights choosing of the fibre to be greatly important due its essentiality to the nature of textiles. However, selecting materials is one step in the process of evaluating and actualizing overall product sustainability.[124]

3.3.2 Manufacturing processes

Processing is a vital part of for example manufacturing raw fibre to fabric and further to a piece of a fashion garment or a textile. According to Fletcher and Grose, processing is also a key contributor from the viewpoint of sustainability.[125] Orzada and Moore clarifies, that the major environmental problems in textile processing develop in dyeing and finishing. These processes require the use of different chemicals and a high amount of water.[126]

[123] Quinn 2010,109; Uuttu 2013.
[124] Flether 2008, 5.
[125] Fletcher & Grose 2012, 33.
[126] Hethorn & Ulasewicz 2008, 305.

The particular sustainability results of a textile process depend on the fibre type, the fabric specification and the final design. However, there are some broad principles to be followed and adjusted in design decisions in order to reach the best possible outcome. Fletcher and Grose explain, that from an environmental perspective, the general aim is to specify processing phases that use fewest resources and cause least impact. Recognising the threats could translate into un-use of a certain finishing in order to prevent impacts from this particular processing step. Importantly, not all processes or chemical treatments can be solely avoided since many are vital in producing functional and wearable products [127].

The principles for best practices presented by Fletcher and Grose are:

GOAL	ACTION
• Make wise use of natural resources	• Minimize the number of processing steps
• Reduce the risk of pollution	• Minimize the number and the toxicity of chemicals used and eliminate harmful processes
• Minimize energy consumption	• Combine processes, or use low-temperature processes
• Minimize water consumption	• Eliminate water-intensive processes
• Reduce load on landfill	• Minimize waste generation at all steps[128]

[127] Fletcher & Grose 2012, 34.
[128] Fletcher & Grose 2012, 34.

3.3.3 Designer's role

According to Blackburn, designers should be able to assimilate the environmental issues in their work. He continues how a designer basically defines the wants and needs of a consumer by the products he or she is creating. Therefore, a designer has a great responsibility in developing new products and defining the materials, production methods and required finishings during their manufacture.[129]

Some designers may struggle with the technical issues of textile processing and face difficulties to understand what is required for a certain look or feel of a fabric. According to Flecther and Grose, the aspects of sustainability have added an extra layer of complexity to this situation. Designers might seek a specific structure or effect and leave the technical decision in the hands of textile scientists. By doing so, the implications the processes have for the environment like for watercourses, air quality, soil toxicity and human and ecosystem health, might leave unnoticed. Fletcher and Grose reckons this is because of the technical side of processing might intimidate designers or for the reason designers might just feel less qualified than the 'experts' [130].

Designers need to be aware of the environmental impacts of the processes involved in manufacturing a fibre into a textile product. It needs to be understood, that the fibre-to-fabric process includes various stages that are environmentally questionable. Air, water and land quality are all influenced by fibre production including dyeing, finishing and other wet processes. [131]

Thackara (2005) refers to Design councils *Annual Review* (2002, 19) where it is announced that 80% of the environmental impact of a product or service is established at the design stage. The decisions made during the process determine for example

[129] Blackburn 2009, 6 & 10.
[130] Fletcher & Grose 2012, 33.
[131] Hethorn & Ulasewicz 2008, 302.

the materials and the amount of energy that is required in manufacture. Early design decisions also partly define the products disposal possibilities.[132] Designers should have a privilege access in the production processes since they are accountable for specifying each product up to 70%. Yet designers lack the power to apply changes in the production phases at least when their design brief is set by an employer. When running an own business, there might be more freedom and flexibility to make groundbreaking changes.[133]

3.4 Taking the holistic view

When speaking about sustainable textile design, there is a lot to consider. Design overall should not affect poorly on nature and should take every actors into consideration starting from designing the product, to its production, distribution, use and the final disposal. Sustainability in textile design also highlights the economical, social and cultural aspect during the products development phases[134].

As Fletcher indicates, there is no single-frame approach to sustainability. Issues which are dealt with univocally will almost automatically lead to undesirable and unexpected results somewhere else. In order to be able to avoid these effects we should be aware about the influence that starts already when choosing a fibre for each use. It is not just the mere production of the fibre, but the whole life-cycle of the created product including cultivation, manufacturing, distribution, usage and mending, to the possible reuse and final disposal [135].

[132] Thackara, 2005, 1.
[133] Blackburn 2009, 3.
[134] Uuttu 2013.
[135] Fletcher 2008, 5.

In her book *Sustainable Fashion and Textiles, Design Journeys (2008)*, Fletcher addresses Benyus' idea of how to evaluate our innovations and whether they are 'good' for us. According to Benyus, a good innovation will reply 'yes' to the following questions:

Will it fit in?, Will it last?, Is there a precedent for this in nature?, Does it run on sunlight?, Does it use only the energy it needs?, Does it fit form to function?, Does it recycle everything?, Does it reward cooperation?, Does it bank on diversity?, Does it utilize local expertise?, Does it curb excess from within?, Does it tap the power of limits?, Is it beautiful? [136]

When speaking about sustainability there is no short cut to the most sustainable results of producing or manufacturing. We can still evaluate the best outcome for each and every step while working on this field. According to Hethorn and Ulasewicz, sustainability means that under a development of a process, no harm is done to people or the planet. Also the chosen manufacture processes will enhance the well-being of the people who interact with it and the surroundings it is developed and used within.[137] As a summary, sustainability in textile design should be considered in a comprehensive and holistic way.

There is no short cut to the most sustainable results

[136] Fletcher 2008, 13.
[137] Hethorn & Ulasewicz 2008, introduction.

3.5 Levels of mimicking

Benyus has defined biomimicry's three levels (2002) presented as following:

1. *Nature as model* – Biomimicry is a science that studies nature´s models and then imitates or takes inspiration from these designs and processes to solve human problems, e.g., a solar cell inspired by a leaf.

2. *Nature as measure* – Biomimicry uses an ecological standard to judge the ”rightness” of our innovations. After 3.8 billion years of evolution nature has learned what works, what is appropriate and what lasts.

3. *Nature as mentor* – Biomimicry is a new way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it.[138]

The three levels of biomimicry are opened by Fletcher as follows. The first level is using nature as a model in order to be inspired from nature and to solve human problems. The second level uses nature as a judge or as a measure of the 'rightness' of our innovations. The third level is about taking a metaphorical look at us designing with values and perspectives present in the natural world.[139]

Benyus explains the levels more in detail. The first level *Nature as model* is about mimicking a natural form. Benyus gives an example of mimicking the hooks and barbules of an owl's feather in order to create a fabric that opens anywhere along its surface. However, copying the feather design is merely the first step, as it will not lead to something sustainable directly.[140]

[138] Benyus 2002, prewords.
[139] Fletcher 2008, 138-139.
[140] Benyus 2014, 5.

A deeper perspective to biomimicry can be found from the second level, *Nature as measure,* which concentrates on mimicking of a natural process and how things are made. To give an example of nature's chemistry, the owl's feathers are known to self-assemble at body temperature without any toxins or high pressures. This for instance, is what the developing field of 'green chemistry' is trying to mimic currently.[141]

The third level *Nature as mentor* refers to mimicking natural ecosystems. When thinking about the owl feather, it is part of the owl that is part of a forest that is part of a biome that is part of a sustaining biosphere. Following this principle, an owl-inspired fabric should then also be part of a broader economy that improves instead of diminishes the Earth and its people. According to Benyus, when making a bio- inspired fabric that uses green chemistry, one should be aware for instance not to have workers weaving it in a sweatshop, distributing it with polluting trucks and shipping it long distances, otherwise the point is missed out.[142]

[141] Benyus 2014, 6.
[142] Benyus 2014, 6.

4 ANALYSING THE COLLECTED DATA

4.1 Content analysis

Tuomi and Sarajärvi present that according to Miles and Huberman (1984) data driven content analysis is based on a process including simplifying the data, grouping the data in categories and finally, creating theoretical concepts from the categorized themes.[143] Tuomi and Sarajärvi further explains this process by referring to Kyngäs and Vanhanen who clarify that content analysis consists of four steps. The first step for analysing the data starts from simplifying the original expressions of the data. The data is being asked questions according to the research problem and research questions. The aim is to identify the most coherent and interesting parts of the data for the research. These sentences are then simplifyed with phrases.[144] As Anttila explains, it is extremely important to read through the data repeatedly in order to identify the content thoroughly. The goal is in understanding the true content of the data. The first reading times are good stages for starting to look for the possible categories.[145]

The goal is in understanding the true content of the data

The second step is to concentrate on the developed phrases. Phrases having the same meaning are grouped together. Groups with similar content are placed in categories and named accordingly. Categorizing can be described as a critical phase of the analysis, as the researcher is deciding whether the different topics are included in the same category or not.[146]

The third step in the analysis is to connect similar subcategories together and to create main categories. The main categories are named according to the content. Eventually, as the fourth step all the main categories are summed up as one major category describing all the categories. Together with the found major category, main and subcategories, the research questions can be answered.[147] In this thesis, the analysing is based on the 4 steps analysis by Kyngäs and Vanhanen.

143 Tuomi & Sarajärvi 2002, 110-111.
144 Tuomi & Sarajärvi 2002, 102-103.
145 Anttila 2006, 276.
146 Tuomi & Sarajärvi 2002,103.
147 Tuomi & Sarajärvi 2002, 102-103.

4.2 Analysing the data

The informants for this research are Elaine Ng Yan Ling, Jane Scott and Dr. Veronika Kapsali, as previously introduced in chapter 2.4. The collected data for the research consists of 11 pages of transcribed interviews. The interviews are from Ng and Scott. Data from Kapsali consists of a short essay *(Bio light 2014)* personally received via e-mail and an article received from Northumbria University *(Impact of Biomimetic principles on sustainability in the fashion industry 2012).* The essay and article consist of 12 pages written by Kapsali.

The interviews were accomplished as structured ones. Structured interview requires preparing interview questions and themes in advance. The questions follow the research problem and research questions. As a result, the interview will most likely consist of the required themes and questions important to the research.[148]

I first contacted the informants in September 2014 via e-mails. With Ng we were able to set up a Skype-meeting, while with Scott we managed to carry out the interview via e-mail. The interviews took place in October 2014. The questions remained the same for both of the informants and can be found in Appendix 1. Also data received from Kapsali was asked the same questions and regarded with the same viewpoint important for the thesis. Data from Kapsali was received in autumn 2014 and in spring 2015.

Analysing the data started by transcribing the interviews. It then continued by reading through the data multiple times. During the third and fourth reading the aim was to identify the most valuable parts of the data for the current research. This was achieved by asking the data similar questions compared to the research questions and research problem. The important sentences were then marked and put aside.

[148] Anttila 1998, 230-231.

After this, the original expressions and sentences were simplifyed with phrases. Phrases having the same content were grouped together in step two. The groups found in the data consist of information regarding the environment, nature and design, textile industry, materials, designer's role, massmanufacturing, background and current interests of the informants, meaning of biomimicry, biomimetic examples, bio-related projects, benefits, challenges, future, research, experiments, technology, engineering, sustainability and customer's role. Groups with similar meaning were placed in subcategories and named according to the content.

Step three consisted of connecting similar subcategories together and creating main categories around them. Also the main categories were named to describe the content correctly. From the main and subcategories certain themes arose and the content of the data became structured and comprehensible.

Steps one to three were first carried out concentrating on analysing the data separately from each of the informants. The main categories from data provided by Ng are *Biomimicry and bio-utilization as a design reference* and *Added value.* The main-category of *Biomimicry and bio-utilization as a design reference* consists of four subcategories which are *Defining biomimicry, Meaning of materials, Mimicking processes in manufacturing* and *Benefits and challenges of applying biomimicry into design*. The main category of *Added value* consists also of four subcategories: *Combining traditional skills with technology, Sustainable aspects in biomimicry, Designer's role* and *Social responsibility.* The main categories and subcategories above include information of biomimicry and design, material behaviour, manufacturing, crafts, technology and a holistic view on sustainability taking multiple actors into account.

Data provided by Scott include the main categories *Following nature's core idea* and *Framework for design research.* The maincategory *Following nature's core idea* consists of three subcategories which are *The meaning of biomimicry, Examples of biomimicry* and *Focus on sustainable outcomes*. The main category of *Framework for design research* also consists of three subcategories which are *Biomimicry's role in current work*, *Innovation and smart textiles* and *Challenges in biomimicry*. The categories concentrate on information regarding mimicking nature's core idea, finding examples from natural structures, using biomimicry as the main framework for design research, placing sustainability center to the work and aim, developing new ideas and also confronting difficulties in implementing ideas from the natural world.

The main categories from data provided by Kapsali are *Natural design solutions* and *Sustainable models from nature.* Both of the main categories consist of three subcategories. The maincategory of *Natural design solutions* consists of subcategories which are *Material properties in nature, Towards innovations,* and *Future possibilities*. The main category of *Sustainable models from nature* consists of three subcategories which are *Nature's examples of sustainability, Consumer behaviour* and *Solutions from technology.* The developed main categories and subcategories contain information on material examples in nature, innovative design outcomes, solutions provided by technology, sustainable models and consumer's role in sustainable development.

After concentrating separately on the data provided by each of the informants, the similarities and differences between the main categories and subcategories could be recognized. The analysis could then continue on as one, combining the categories as few major categories. During the analysis step number four, the main categories were summed up. The first intention was to develop one major category to describe all the main categories, but in this case it would have not serve the research in a coherent way. Instead, keeping the focus of the research closely in mind, three major categories were developed to describe all the categories of the analysed data. The major categories are *Nature as a design model, Platform for innovations* and *Reaching sustainability.* The categories are further explored in chapter 5 together with analysing the results and answering to the research questions.

5

ANALYSING THE RESULTS

5.1 Nature as a design model

The first major category, *Nature as a design model,* developed from the analysis of the collected data. Analysing the data revealed similarities between the main categories including for example defining biomimicry. In addition, the data explains a number of existing design applications based on biomimicry and nature's examples of making. The following presents the results that concentrates on the definition of biomimicry in relation to design and design research.

Biomimicry is an approach to design that draws ideas from nature. Biomimicry is described as a systematic method to translate models from the natural world into sustainable design solutions. Biomimicry is combined with engineering to introduce natural world examples into the man-made world. The importance to be able to translate or transpose the design principle from nature into a design outcome is being underlined. An example of investigating pine cone hydromorph is given:

The aim for the investigation is not to design a pine cone or even a pine cone scale, but to see the underlying process. The more you can distal these concepts into transferable design ideas, the more closely it is possible to mimic the outcomes.
-Jane Scott 2014.

To comprehend natures ways thoroughly, lifecycle principle is seen important to understand. According to Ng, following lifecycle principle in creative processes can be considered as biomimicry. In addition to the previous definitions of biomimicry, Ng presents three ways of looking biomimicry in relation to design. The first one is called *the aesthetical way*, which refers to mimicking the looks and feels of nature without affecting the structures or mechanisms of the design. The second way is described as *the mechanical way,* which means learning how nature engines itself and implementing that system into textiles in order to improve a function and/or inherit a property. The third way is defined as *bio-utilization,* which according to Ng means to use the characteristics of the natural materials to improve design:

When I use wood veneer for example, I create my own smart veneer. I'm actually using the behaviour of the wood itself so I'm utilizing the bio-elements of it. That is why I call it bio-utilization.
-Elaine Ng Yan Ling 2014.

In addition to pine cone also Velcro, spider silk and shark skin (LZR Racer suit) are acknowledged as good examples of biomimicry in textile design. These applications are further presented in chapter 2.6. Ng highlights the examples of thermachromatic ink, lily leaves and waxed cotton while Scott refers to architect Michael Pawlyn and his Sahara Forest project as a very ambitious biomimicry related work. Scott also highlights the *Alive / En vie* –exhibition (Paris 2013) to be full of interesting examples of biomimicry related works. Many of these examples are presented in Myers' book (2012) under the category of biodesign. Also Kapsali gives an example which refers more to biodesign as she presents the London based researcher Susanne Lee and her project *Biocouture*. In *Biocouture*, Lee investigates methods to grow garments and uses cellulose producing bacteria Acetobacter xylinum to create sheets of material that can be cut and made into garments.

5.2 Platform for innovations

The second major category, *Platform for innovations,* was developed according to the analysis of the collected data. The main categories contained information regarding technology, smart materials and engineering in an extent that one major category was created indisputably to combine them. The following presents the results concentrating on the possible innovative design outcomes which can be achieved for example when collaborating with biologists and scientists. On the contrary, also the possible challenges experienced by the informants are cited.

Kapsali is impressed by the impact design can inherit from nature. By looking the way materials and structures are formed, sustained and recycled in nature, we have an apparently simple model that can offer ideas to improve practice in the clothing and apparel industry. Kapsali continues how successful living can be achieved in nature even within limited resources and under hard competition:

In nature, plants and animals live in competition with each other for access to limited resources. Successful species use clever design and optimal distribution of raw materials to evolve ways of living and reproducing using the least possible resources.
-Veronika Kapsali 2012.

Biomimetics describes developments inspired by the functional aspects of biological structures. According to Kapsali the improvements biomimetics can offer us today are the products of collaborative work between biology and engineering. Kapsali explains there is a lot we can learn in terms of functionality seen in natural structures. For instance, multi-functionality is essential for survival in the natural environment. For textile industry, biomimetics can show clever ways of using design to achieve desired functionalities over material properties. For example, insulation qualities can be translated into textiles by using hollow fibres.

Kapsali describes biomimetics as a platform that facilitates the transfer of technology from nature to the man-made world. She highlights examples such as *Lotus Effect* and *Morphotex*® (see chapters 2.6.1 and 2.6.2) to offer useful functionalities which can reduce the impact of textile and garment production on the environment. Advancements in technology have given promising examples in technical textiles. The industry has already started to implement several of these innovations and new properties into textiles and some of the examples can be found in use. For example, smart polymers and gels are used in creating textile scaffolds for medical applications. Kapsali states that these new technologies will alter the relationship between garment and wearer as well as our expectation of future textile performance.

According to Kapsali the key is that new technology must offer a solution or at least improve on a problem that cannot be solved with other, more conventional methods. Therefore, the focus should be in innovations that delivers new, smart or adaptive technologies that could slow down the current pace of fashion.

In the future, further advances in technology will enable the clothing industry to transfer even more paradigms for sustainable manufacture. –Veronika Kapsali 2012.

According to Scott, biomimicry changes the way we think about a problem. She explains how using biomimicry adds rigour to design research. An important matter to benefit from biomimicry is that it can take design away from just the aesthetics. For Scott's current work which deals with smart textiles, the conventional understanding of innovation is that it is driven by material modifications or manufacturing system achievements. Yet biomimicry has provided a completely different framework to use for innovation. Scott continues on how biomimicry has provided inspiration for all elements of her PhD research.

However, Scott states that working with biomimicry as a designer is sometimes challenging in terms of finding the right natural model. Furthermore, biomimicry is a collaborative exercise and as a designer it is important to acknowledge the role of the science behind the design work. One of the challenges Ng describes is the unfamiliarity of the subject. Since biomimetic design at the moment is not very known, it needs to be explained more. Also, being an independent designer doesn't guarantee the possibility to work with scientists the same way working within an institute propably would. One particular challenge Ng highlights, is in the use of materials. She gives the example of therma-chromatic ink, which mimics the chameleon sort of skin but is actually quite toxic due the chemicals it consists of.

When examining materials and structures in nature, functions of interaction, self maintain, reproduce and self-assembly already exists. These examples may lead the way of applying similar functionalities into clothing and textiles with the help of technology. Kapsali states that for the future clothing it is reasonable to expect a new set of properties that can perform alterations by our activity and current environment. For these kind of future requirements, biomimetics is said to offer a promising platform in order to contribute a new perspective in the design and assembly of clothing systems.

In addition, Kapsali is interested in the possibility of whether clothing of the future will adapt, grow, self-repair and change appearance. This would affect into the relationship of the garment and the wearer (or textile product and the consumer) in a symbiosis-like outcome. It would be possible by the innovations in material science where textiles are produced to imitate functionalities of living organisms instead of merely the properties of natural fibres.

As a conclusion, enormous possibilities are seen in biomimicry and technolgy combined with textile design. Ng gives the example of the pine cone which has already led to innovation as a technical smart material (see chapter 2.6.4). According to Ng, we can benefit from the examples given by nature. Nature has often already answered a lot of the questions we are dealing with. Therefore, by looking further into nature can help us solve our problems quicker and easier.

5.3 Reaching sustainability

The third major category, *Reaching sustainability,* was created according to the analysis of the collected data. The developed main categories contain information about the possibilities to benefit from biomimicry and nature's examples. Biomimicry is regarded from the perspective of sustainable design and the opportunities this approach may contain. The following presents the results of the possibilities and challenges a sustainable design outcome based on biomimicry may include.

According to the informants, biomimicry can answer a lot of questions to help people to design in a very condensed way. When using nature as a model for design, sustainability must be central to the system. Scott states that sustainable aspects have to be included in biomimicry related projects since it is a fundamental and an obvious element for natural ecosystems. As natural phenomenons are the principle behind biomimicry, the focus in biomimicry related design should be in sustainable outcomes. Also Ng admits a very close link between sustainability and biomimicry. According to Ng, sustainable design should consider the whole lifetime of the product. Ng explains that the best sustainable design is not trend-related and therefore doesn't go updated. Still, talking about sustainability depends much on the chosen

When using nature as a model for design, sustainability must be central to the system

viewpoint and context. Eventually Ng describes bio-utilization to be even more sustainability related because of the possibilities to upcycle and redesign are in her words better.

In relation to biomimicry and sustainability, the meaning of materials is an important area especially for a textile designer. Materials are often the starting point for designing or at least a vital part of defining the quality and usability of the product. To further examine materials, there are two main types of polymers in nature. In comparison, the man-made world offers hundreds of them.[149] When thinking about materials in nature, they are formed using the minimum amount of energy and therefore rely on the resources found in their immediate environment. For example plants need nutrients from the soil, sunlight and water. Kapsali explains how design in nature appears on the molecular level; structures developed from similar polymers can expose significant variations in mechanical properties for example in stiffness, strength and elasticity.

Kapsali confirms that biomimicry can show us how to create a future that is clever, sustainable and human centred. One especially highlighted area to look for in nature is in the way colours and patterns occur. Kapsali continues how there are two methods of producing colour in nature. The first one is pigment which is defined as a material altering the colour of transmitted light by absorbing specific wavelengths. Pigments can be found in animal skin, hair and eyes as well as in plants' leaves, flower petals and roots. The second one is structural colorations which occur due the morphology of the biological surface using interference of reflected light to generate colour. These mechanisms can be found for example in some butterfly wings (see chapter 2.6.2).

[149] Allen 2010, 134

In terms of sustainable design outcomes, designers play a key role. According to Ng, designers have a huge responsibility to work in a sustainable way. Designers need to be aware of their design decisions which can have a deep impact for the environment. Fortunately, responsible designers can make a difference for example by choosing materials in a way that adds longevity and robustness to the final product. However, the thoroughness of implementing biomimicry into design needs to be discussed with the manufacturers. According to Ng, mass-manufacturing should adapt the system first in order to be able to mimick the natural processes more thoroughly. The prototypes designers are making need to be compatible with the mass-manufacturing systems. To achieve this kind of collaboration and outcome may not be accessible for an individual designer. However, massproduction as such may not be an ultimate goal for a designer. For example, Ng would like to stay in limited editions and to give examples of how biomimicry can be used in design. Ng underlines how a lot of her work requires hand-making, therefore she continues to collaborate with local craftmen.

Ng explains that she is not interested in selling her products according to cheap fast fashion. Instead, she talks about a higher price point, so people would consider when buying and appreciate the value of what they have purchased more. At the moment, Ng claims there are so many clothes and furniture being bought merely because they are affordable. This leads people to buy without thinking and eventually placing the bought items of poor quality into landfill.

In addition to designers, consumers also have a great responsibility in terms of supporting sustainability. A considerable challenge at the moment is the throwaway culture which has partly minimized the will to for example repair clothing. According to Kapsali damaged garments are most likely disposed and replaced than maintained. One reason for this is the lack of resources needed for repairing including cost, time, skill and material availability. Another reason for this behaviour lies in the low cost of new products. For many, it is easier to replace the old and broken items with new ones. Yet in nature self-repair occures involving the redistribution of internal resources to address damage. For a garment, the ability to self-repair would prevent it from an early, unnecessary disposal as the garment would sense damage and act accordingly to repair itself.

Even sustainability, ecological and ethical issues around clothing and textile industry have gained a lot of media attention for decades, the public awareness has lately improved notably from what it was a few years ago. According to Kapsali it is however the consumer, who seals the fate of innovations and determines the faith of new discoveries. Perhaps for this reason, Ng sees potential in educating people. At the moment Ng is organizing a series of workshops around biomimicry and building a community called *Naturetech*. The workshops in Hong Kong introduce people more about biomimicry.

5.4 Examining the possibilities

5.4.1 Nature and design

Nature is seen as a profound model for a designer. A closer look of the results reveals the versatility biomimicry can offer. Natural phenomenons can provide inspiration, knowledge, models and solutions for further developments in multiple design applications. The basic definition of biomimicry relates to the methods of translating models from nature into the man-made world. According to Fratzl nature has developed multiple strategies for successful functional properties with relatively inexpensive materials. This has enabled by hierarchical structuring, adaptive growth and consistent remodelling and healing.[150] As a vital notion, it is not important to merely

[150] Fratzl 2007, 641.

copy nature, but to concentrate on the inner properties natural systems contain and to benefit from these examples on a practical level. As previously cited, Kellert, Heerwagen and Mador further explain that biomimicry does not represent a recognizable design style. Instead, biomimicry is defined as a design process where the designer searches models from the nature.[151]

Biomimicry can be applied in various forms of design including architecture, interior design, industrial design, fashion, textile design and art. Furthermore, biomimicry can be beneficial in engineering, medical applications, smart materials and more. Biomimetic examples in textile design at the moment include commercially available products, textile finishes, fibres, art, prototypes and experiments. In addition to biomimicry, there are many other bio-related concepts available that interest designers currently, for example bio-utilization and biodesign.

Designers are able to follow nature's examples by investigating the elements of natural phenomenons. This notion is explained by the given examples of biomimicry which vary slightly according each of the informants; from pine cones as a starting point to spider silk to materials that are grown in the labs. The different ways of using biomimicry in design is presented by Ng. The first way strongly relates to the appearance and aesthetics of a product, which refers to being inspired by nature. The second way is about learning from the natural mechanisms and their impact to the structures of a design product. The third way is described as bio-utilization, which is Ng's personal approach to the matter. Bio-utilization is defined as a way of using the essentials of natural materials in order to exceed in design outcomes. The first two ways can also be found in Benyus' *Levels of mimicking* presented in chapter 3.5.

[151] Kellert, Heerwagen & Mador 2008, 29.

As a conclusion, nature can be seen as a model for designing in different ways and levels. In addition to biomimicry there are new bio-related concepts rising which too can offer framework for designing. Learning from nature and it's systems can have a deep impact on design. Designers and researchers following biomimicry are showing great respect and deep interest in nature and its almost four billion year old natural system of coping, maintaining and developing. Biological materials and structures are studied and mastered in collaboration with professionals from other branches in order to find new groundbreaking solutions for design developments.

5.4.2 Achievable innovations

To be innovative and to be able to develop in general requires new ideas, methods and manufacturing. The informants show a special interest in smart materials and advanced technology in addition to their determination and motivation in developing the textile branch. In order to reach new outcomes and to benefit from biomimicry, a solid understanding of natural phenomenons is required. Collaborative and determined work between designers, scientists, biologists and engineers is seen as a way of achieving the mentioned goals.

Design that is based on biomimicry is utilizing new technologies and research available in order to reach innovative design solutions. In addition to design applications, using biomimicry as a reference can be beneficial for engineering and technology. According to Bar-Cohen nature is full of practical and durable inventions that have survived the environment's changing circumstances. In addition to the informants, also Bar-Cohen highlights the cooperation between biology and engineering in order to benefit most from nature's examples.[152]

[152] Bar-Cohen 2006, 2-3.

Biomimicry can contribute a solid background for smart textiles and innovations. According to Scott, using biomimicry will open new ways to develop responsive smart textiles. Kapsali is determined in bringing STEM (science, technology, engineering and mathematics) and design closer to each other. The experienced benefits in combining all the branches leeds to new studies and further experiments. Smart materials and new technology are seen as an opportunity for future developments. However, craft skills are also highly appreciated and utilized in the current experiments especially in smaller production quantities.

A link between technology and textiles can be found already at the very root of the term *technology,* as the Greek word *technē*, refers to *weaving*.[153] According to Kapsali it is crucial that technology gives a solution to the problem or at least improves the situation. In other words, it is not useful to add technology into design without a proper reason. The combination of textile design, technology and biomimicry is seen as a promising way to discover something new. According to the study, biomimicry provides a thorough and profound basis for design research. The study affirms, biomimicry encourages designers to rethink their design challenges. Biomimicry is seen as a solid theory base which can offer beneficial and innovative design outcomes, since nature often has answered to our problems already.

However, one particular challenge in using biomimicry in design, is the designer's ability to recognize the right model in nature and to adapt this into a design application in the best possible way. To be able to find the beneficial solutions for the current design task is not obvious. Presented by Abbott and Ellison, Kapsali and Dunamore state that it is common for the biologist to recognize the mechanisms useful for industrial applications. In terms of clothing and textile, designers may have a limited ability to locate the opportunities for biomimetic innovations. Therefore, it is vital for designers and manufacturers to work closely with biomimetic teams in order to develop successful outcomes.[154]

[153] Hawken, Lovins & Lovins 1999 171.
[154] Abbott & Ellison 2008, 133

Kapsali and Dunamore further describe the challenges biomimicry related design contains. Biomimicry may not always be able to provide solutions for human problems since it is based on biology where for example time is an unrelevant term. Yet for the man-made world, timetables can be crucial.[155] In addition, biomimicry needs to be explained more, since it is not yet a very famous concept for designing. The possibility to follow natures examples more thoroughly in a man-made factory facilities remains a question.

5.4.3 Sustainable perceptions

Nature can provide endless ideas for developing clever design including low energy materials and structures. To be able to use the minimum amount of materials according to nature's example of utilizing everything without polluting or risking the environment is a challenge and a goal to achieve for. According to Scott it is vital that when working with biomimicry and design, sustainability must be central to the work. For Ng, the best sustainable design outcomes are those which consider the whole lifetime of the product.

From the viewpoint of sustainability, materials are in key position. When working according to biomimetic thinking, choosing materials becomes vital. For textile designers, there are multiple materials available from natural fibers to man-made. The decisions in material choices should not threaten the environment. Indeed, professional designers are aware of different materials, their cultivation and production, properties and performance in different applications. Furthermore, responsible designers are willing and able to seek sustainable alternatives for each design task at hand. Without a doubt, practical challenges may occure when choosing materials. For example, a material can be biodegradable and therefore sustainably convenient.

[155] Abbott & Ellison 2008, 134.

However, it can also be expensive and therefore not suitable for the considered price range of the product. In addition a promising material structure found in nature may not be accessible to mimick sustainably by definition.

The achieved level of implementing biomimicry into design in a sustainable way is partly dependent on the manufacturing processes and methods implemented in factories. The possibilities to work with scientists may be limited when working in an smaller design company. Independent designers may have limited resources and may only create prototypes. In order to implement biomimicry more thoroughly in a design product, the system in massmanufacturing processes is suggested to adapt a change. However, designers have a huge responsibility in terms of working sustainably. They are responsible for much of what they create.

In addition to the designer, the consumer too has a great responsibility and possibility to change things and to affect in the current situation. Together with the overconsumption, all the pollutions caused by textile industry are issuing threat towards the environment. Products are not bought just for a need but merely for a want. They are abandoned and replaced with new, cheaper items in a fast phase. Therefore, one of the biggest challenges in the design assignment is perhaps to engage the customer with the product for the lifetime of it. This asks creating quality and a special value for the product in a way that makes the end-user take care of the purhased item and avoiding it to end up in the landfill in the first place.

A growing interest in taking social responsibility by educating people is shown. For example, Ng is arrangeing biomimicry workshops for locals in Hong Kong while Kapsali teaches biomimicry to bigger audiences in addition to the academic groups. Ng also explains how she is hiring local craftmen to manufacture some of her work. Therefore, an improvement can be seen in both, the cultivation of local culture and

Designers have a huge responsibility in terms of working sustainably

craft skills and also in the economics of the villages of the craftmen. As the growing amount of population is seen as a worldwide challenge, committing to peoples well-being by employing them can be seen as an act of fairness. Among the informants, social responsibility is shown as a desire and as a way to improve overall sustainability.

As the theory part in this thesis reveals, sustainability is a complex term. It consists of various factors such as the social, economical, ethical and ecological aspect. These factors include issues like manufacturing and mass-production methods, fibre to fabric –production, materials, finishing and dyeing methods, product quantities, locations, distribution, people, education, culture, habits of consuming and ethical working conditions. However, biomimicry is seen as a promising model for sustainable textile design, since nature itself tends to give examples healthy to the environment. The informants admit, that it is crucial to place sustainability at the core when designing according to biomimicry.

Based on the research, biomimicry can be beneficial for design in many ways. For sustainability, biomimicry can suggest a solid background leading to new ways of thinking about design and from which to search innovative solutions from. As there is no single answer to sustainability, the question of whether biomimicry can be beneficial for sustainable textile design can only be answered partly. Eventually, it is the designer or the manufacturer who determines the final sustainability level or perspective for the design product as it is being manufactured according to their vision and within their facilities.

6

CONCLUSION

The starting point for the thesis developed from the notion of the environmental challenges that occur also due the field of fashion and textile design. The current level of producing and consuming textiles globally has its part in the environmental issues including polluting, producing emissions, diminishing natural resources and increasing the amount of waste. As textiles at the moment still are essential commodities for us, a greater responsibility in design principles and manufacturing processes is important to adapt.

Reading about biomimicry for the first time raised many questions. The first thought about it was that since biomimicry is concentrating on phenomenons found in nature, it would be interesting to study it in relation to sustainable design. As the topic of biomimicry was relatively knew to me, a certain hesitation was not avoided. Fortunately a quick online search revealed a solid amount of examples, current research, publications and organizations related to biomimicry giving the final courage and motivation to begin the study.

The main purpose of the thesis was to view sustainable textile design from biomimicry's perspective. The aim was to study the possibilities biomimicry might have for sustainable textile design. The focus of the thesis was in the different ways biomimicry could be applied in textile design. In addition the aim was to concentrate on an individual textile designer's possibilities to work sustainably by using biomimicry as a design reference.

The study was carried out as a qualitative research since the aim was in explaining a certain phenomenon. The primary data consisted of a combination of interviews and articles therefore content analysis was utilised for the reseach method. Each of the informants are concentrating on biomimicry in their current design projects and research. The interviews enabled to receive valuable information straight from the branch pioneers otherwise difficult to reach. Therefore, the interviews served the purpose of this thesis extremely well.

Analysing the data was accomplished via a four step content analysis method by Kyngäs and Vanhanen presented in chapter 4.1. Using the chosen method gave a solid framework to examine the collected data in an organized and systematic way. The method also enabled to analyze each part of the data with a similar approach and for this reason, played a key role in the validity and transparency of the thesis. The research questions were answered based on the results of the content anaysis and the developed categories.

The data revealed new unexpected information regarding biomimicry, technology and engineering in addition to for example the more familiar though complex definition of sustainability. According to the study nature is seen as an endless source for ideas that can be developed into design solutions. Biomimicry can be applied in multiple contexts including design, art, architecture, engineering and science. The various examples reveal products that are or have been commercially available, or that are in their infancy as promising prototypes and/or experiments. However, to be able to utilize biomimicry in design requires learning from and understanding of the natural phenomenons. Furthermore, a favorable biomimetic design solution requires recognising the preferable ’right’ model from nature in order to develope functional outcomes. This is in many cases achieved by combining skills with professionals from other fields such as biology, science and engineering.

The results state that biomimicry can offer sustainable models for human problem solving. When using biomimicry as a design reference, sustainability should be located central to the design. Beneficial sustainable models in nature can be found especially in low energy use, self-repair, material use and structures. However as sustainability itself is a multilayered issue, the benefits from biomimicry to sustainable textile design can only be answered in some extent according to the definition and chosen viewpoint of sustainability.

In an era where the global environmental threats can not be ignored, the priority to design and manufacture sustainably becomes vital. Whether we are working as individual designers or within bigger companies, responsible and transparent design solutions need to be addressed. Biomimicry reveals possibilities in different levels starting from mere inspiration to actual solutions for sustainability, technical innovations and many more. In addition biomimicry brings the designer closer to nature and engage him/her with the environment and natural phenomenons on a new level. However challenges are inevitable and exist in both defining sustainability and also in designing according to it. Despite the ultimate sustainable design solutions may only occure in nature, an effort in reaching them can make a difference.

Biomimicry in sustainable textile design is a potential subject for further studies. The aim could for example be set in the biomimetic design process itself in order to receive models for the actual ways of implementing nature's examples on a textile product. The viewpoint of the study could also be extended by including interviews from biologists and engineers who have experienced collaborative projects with designers. In addition the potentiality of biodesign and bio-utilization for sustainable textile design would be interesting to study as the concepts are presented to reach sustainability in a more profound way.

BIBLIO-
GRAPHY

Lecture notes:

Uuttu, Anna, 2012. Sustainable Design –course. Lectures by Michael B. Hardt. September-October 2012, University of Lapland. Lecture notes in possession of the author.
Uuttu, Anna, 2013. *Sustainable fashion and textiles* –seminar. Presentations by Kate Fletcher 2.-3.10.2013, Aalto University, Helsinki. Lecture notes in possession of the author.

Interviews and articles:

Kapsali, Veronika. *Bio Light* -essay received 16.10.2014. E-mail in possession of the author.
Kapsali, Veronika. *Impact of Biomimetic principles on sustainability in the fashion industry* (2012) -article received from Northumbria University 23.3.2015 via e-mail. Article in possession of the author.
Myers, William. Bio Design -essay received 15.9.2014. E-mail in possession of the author.
Ng, Elaine Yan Ling. Interview 28.10. 2014. Notes in possession of the author.
Nurmi, Annina. Interview 03.10. 2013. Notes in possession of the author.
Scott, Jane. Interview 28.10.2014. E-mail in possession of the author.

Published:

Abbott, A. & **Ellison**, M., edit. 2008. *Biologically inspired textiles.* Cambridge, England, Woodhead Publishing Limited.

Allen, Robert, edit. 2010. *Bulletproof feathers, how science uses nature's secrets to design cutting-edge technology.* East Sussex, United Kingdom, Ivy Press Limited.

Anttila, Pirkko, 1998. *Tutkimisen taito ja tiedon hankinta; Taito-, taide- ja muotoilualojen tutkimuksen työvälineet.* Helsinki, Akatiimi Oy.

Anttila, Pirkko, 2006. *Tutkiva toiminta ja ilmaisu, teos, tekeminen.* Hamina, Akatiimi Oy.

Bar-Cohen, Yoseph, 2006. *Biomimetics—using nature to inspire human innovation.* Institute of Physics Publishing <stacks.iop.org/BB/1/P1> Inc. 8.5.2015

Benuys, Janine, 1997. *Biomimicry, Innovation Inspired by Nature.* Reissued 2002. New York, USA, Harper Collins Publishers Inc.

Benyus, Janine, 2014. *A Biomimicry Primer.* <http://biomimicry.net/b38files/A_Biomimicry_Primer_Janine_Benyus.pdf> Inc. 14.3.2015

Black, Sandy, **Delamore**, Philip, **Eckert**, Claudia, **Geesin**, Frances, **Watkins**, Penelope & **Harkin**, Steven. 2009. *Considerate Design for Personalised Fashion: towards sustainable fashion design and consumption.* <http://www.mckn.eu/wp-content/uploads/group-documents/1/1334929140-Paper2.4.pdf> Inc. 8.5.2015

Blackburn, Richard S., edit. 2009. *Sustainable Textiles, Life cycle and environmental impact.* Cambridge, United Kingdom, Woodhead Publishings Limited.

Campbell, Neil A., **Reece**, Jane B., **Urry**, Lisa A., **Cain**, Michael L., **Wasserman**, Steven A., **Minorsky**, Peter V. & **Jackson**, Robert B., 2008. *Biology.* 8th edition. San Francisco, CA, Pearson/Benjamin Cummings.

Clarke, Simon, 2011. *Textile Design.* London, United Kingdom, Laurence King Publishing Ltd.

Colchester, Chloë, 2007. *Textiles today, a global survey of trends and traditions.* London, the United Kingdom. Thames & Hudson Ltd.

Denzin, Norman K. & **Lincoln**, Yvonna S., edit. 2011. *The SAGE handbook of qualitative research.* Los Angeles California, USA, SAGE Publications Inc.

Eadie, Leslie & **Gosh**, Tushar K. 2011. *Biomimicry in textiles: past, present and potential. An Overview.* Journal of the Royal Society, Interface 2011. First published online 16 February 2011. <rsif.royalsocietypublishing.org> Inc. 4.9.2013

Edwards, Andrés R., 2010. *Thriving beyond sustainability. Pathways to a resilient society.* 2013. Canada, New Society Publishers.

Fletcher, Kate, 2008. *Sustainable Fashion & Textiles, Design Journeys.* London, United Kingdom, Earthscan.

Fletcher, Kate & **Grose**, Lynda, 2011. *Fashion & Sustainability, Design for change.* 2012 edition, London, United Kingdom, Laurence King Publishing Ltd.

Fratzl, Peter 2007. *Biomimetic materials research: what can we really learn from nature's structural materials?* Journal of the Royal Society Interface, Published online 6 March 2007. <http://rsif.royalsocietypublishing.org/> Inc. 21.12.2014

Gwilt, Alison & **Rissanen**, Timo, edit. 2011. *Shaping sustainable fashion: changing the way we make and use clothes. London*, United Kingdom, Earthscan.

Hawken, Paul, **Lovins**, Amory & **Lovins**, L. Hunter 1999. *Natural Capitalism.* New York, USA, Back bay Books, Little, Brown & Company.

Hethorn, Janet & **Ulasewicz**, Connie, edit. 2008. *Sustainable Fashion, why now? A conversation about issues, practices, and possibilities.* New York, USA, Fairchild Books.

Hirsjärvi, Sirkka, **Remes**, Pirkko & **Sajavaara**, Paula, 2004. *Tutki ja kirjoita.* 10th edition, Helsinki, Kustannusosakeyhtiö Tammi.

Kellert, Stephen R., **Heerwagen**, Judith H. & **Mador**, Martin L., edit. 2008. *Biophilic Design, The theory, science and practice of bringing buildings to life.* New Jersey, USA, John Wiley & Sons Inc.

Myers, William, 2012. *Bio Design, Nature, Science, Creativity*. London, United Kingdom, Thames and Hudson Ltd.

Quinn, Bradley, 2010. *Textile Futures: fashion, design & technology.* Oxford, The United Kingdom, Berg.

Quinn, Bradley, 2012. *Textile Visionaries, Innovation and sustainability in textile design.* London, United Kngdom, Laurence King Publishings Ltd.

Ronkainen, Suvi, **Pehkonen**, Leila, **Lindblom-Ylänne**, Sari & **Paavilainen**, Eija, 2011. *Tutkimuksen voimasanat.* 1st edition, Helsinki, WSOYpro Oy.

Rossin, K. J., 2010. *Biomimicry: nature's design process versus the designer's process.* USA WIT Transactions on Ecology and the Environment, Vol 138, © 2010 WIT Press. <www.witpress.com> Inc. 7.5.2015

Thackara, John, 2005. *In the bubble:Designing in a complex world*. Cambridge (Mass.),USA, MIT Press .

Tuomi, Jouni & **Sarajärvi**, Anneli, 2002. *Laadullinen tutkimus ja sisällönanalyysi*. Helsinki, Kustannusosakeyhtiö Tammi.

Wang, Youjiang, 2010. *Fiber and Textile Waste Utilization.* Waste and Biomass Valorization, Springer Issue. Volume 1, November 2010. Springer Science+Business Media B.V. 2010. <http://www.prism.gatech.edu/~yw6/Fiberrecycling/Fiber%20Utilization%20(WBV%202010)10.1007_s12649-009-9005-y%5B1%5D.pdf> Inc. 3.12.2014

Electronic sources:

ACADIA, official websites © 2015. <http://acadia.org/papers/69GN9K> Inc. 6.4.2015

ASK NATURE, official websites © 2008-2015 The Biomimicry Institute. <http://www.asknature.org/article/view/why_asknature> Inc 10.5.2015 <http://www.asknature.org/product/4c0e62f66bcccab-f55a1f189da30acb3> Inc.12.1.2015

BIOMIMETIC DESIGN <https://biomimeticdesign.wordpress.com/2008/08/25/involved-in-biomimetics-involucrados-en-la-biomimetica/> Inc. 9.1.2015

BIOMIMICRY 3.8, official websites © Biomimicry Group. <http://biomimicry.net/about/> Inc. 21.12.2014 <http://biomimicry.net/educating/professional-training/bprofessional/> Inc. 10.5.2015

BIOMIMICRY INSTITUTE, official websites. <http://biomimicry.org/history/> Inc. 10.5.2015 <http://challenge.biomimicry.org> Inc. 10.5.2015

COM-PA-NY, official websites © Design practice by Aamu Song & Johan Olin. <http://www.com-pa-ny.com/exhibitions/takkiainen/takkiainenpage.html> Inc. 26.2.2015

DESIGN MUSEUM, official websites. <http://www.designmuseum.fi/en/nayttely/permanent-exhibition/> Inc. 25.6.2014

ELAINE NG YAN LING, official websites. <http://www.elaineyanlingng.com/#!climatology/c42x> Inc. 6.4.2015 <http://www.elaineyanlingng.com/#!naturology/c1h12> Inc. 6.4.2015

FINNISH MINISTRY OF ENVIRONMENT, official websites. <http://www.ym.fi/fi-FI/Ajankohtaista/Maapallon_varat_loppuivat_talta_vuodelta(30865)> Inc. 16.2.2015

GREEN SHIELD, official websites. <http://www.greenshieldfinish.com> Inc. 9.1.2015

INOTEK TEXTILES, official websites. <http://www.inotektextiles.com/directors/> Inc. 6.12.2015

NORTHUMBRIA UNIVERSITY, official websites. <https://www.northumbria.ac.uk/about-us/our-staff/k/veronika-kapsali/> Inc. 6.12.2015

QUALCOMM, official websites © 2015 Qualcomm Technologies. <https://www.qualcomm.com/products/mirasol/technology> Inc. 10.5.2015 <https://www.qualcomm.com/videos/mirasol-display-demo-video-screens-shine-outside> Inc. 12.1.2015

THIS IS ALIVE, official websites. <http://thisisalive.com/biological-atelier/> Inc. 3.3.2015

TEXTILES ENVIRONMENT DESIGN, official websites. <http://www.tedresearch.net/about/>
Inc 3.4.2015
<http://www.tedresearch.net/teds-ten-aims/> Inc. 10.5.2015

TEXTILE FUTURE RESEARCH CENTRE, official websites.
<http://www.tfrc.org.uk/about/> Inc. 3.4.2015 <http://www.tfrc.org.uk/author/jane/> Inc. 6.4.2015

THE FABRICK LAB, official websites © 2013 THE FABRICK LAB.
<http://www.thefabricklab.com/#!about/c1i22> Inc. 6.4.2015

UNIVERSITY OF THE ARTS, LONDON, official websites.
<http://www.arts.ac.uk/csm/courses/postgraduate/ma-material-futures/> Inc. 3.4.2015

VICTORIA & ALBERT MUSEUM, official websites © 2015
<http://www.vam.ac.uk/content/articles/g/golden-spider-silk/> Inc. 6.4.2015

INTRODUCTION

1. Could you briefly tell about yourself – Your education, current title and position?
2. What are the key elements in your work?

BIOMIMICRY

3. How would you define biomimicry?
4. How did you first become interested in biomimicry?
5. Can you shortly name the design projects related to biomimicry you have worked on?
6. What is the main reason you wish to include biomimicry in your research and design projects?
7. How big part would you say biomimicry has in your work?

THE DESIGNER'S ROLE

8. How would you describe a textile designer's possibilities in applying biomimicry into practice / textile products?
9. In your opinion, what is the designer's responsibility in working sustainably?

BIOMIMICRY RELATED DESIGN:

10. What are the best applications you know in textile design related to biomimicry and why?
11. What are the strength and / or weaknesses of combining biomimicry into textile design?

SUSTAINABILITY:

12. What is sustainable textile design at its best?
13. How would you describe the relationship between biomimicry and sustainability? Is there a connection?

CURRENT RESEARCH & FUTURE:

14. How thoroughly do you think one can mimick nature in design processes and applications?
15. What does it mean in practise to be developing textiles according to biomimicry?
16. What are your future plans or wishes concerning biomimicry related design?

LIST OF FIGURES
Appendix 2