

NORDIC WORKING PAPERS

Biomimicry in the Nordic Countries

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Table of contents

Table of contents.....	1
Summary	2
Sammanfattning – Föregångare inom Biomimicry	4
1. Introduction	6
1.1 Motivations and Background.....	6
1.2 Definitions	7
1.3 Mapping Methodology and Process	15
2. Results of the Mapping	17
2.1 Findings in Sweden	21
2.2 Findings in Denmark	25
2.3 Findings in Norway	26
2.4 Findings in Finland	26
2.5 Findings in Iceland	27
2.6 Presentation of the European Scene	28
2.7 The Nordic Network of Actors and Opportunities for Green Business Development	30
2.8 Findings: Discussion and Conclusions	32
3. Recommendations	36
References	40
Appendix 1: Project Group	41
Appendix 2: List of actors	43

Summary

The awareness of Biomimicry within the processes of design and development in Nordic companies are not well known. As a result, The Nordic Council of Ministers Working Group for Sustainable Consumption and Production in its efforts to contribute to the Nordic Environmental Action Plan 2013 - 2018 has called for this report to highlight Nordic forerunners in Biomimicry. The study conducted by Torben Lenau, Lilli Linkola and Anna Maria Orrù, will present a basis for planning further activities to leverage the possibilities for actors in biomimicry and to disseminate knowledge and methodology on *if* and *how* nature's solutions can provide environmental and competitive advantages in business development.

The report is divided into three sections. Chapter 1 is an introduction into the field, motivations and background into biomimicry, a clarification of definitions into biomimicry and other bioinspired fields. Chapter 2 presents the results of the mapping study and a discussion of current actors and activities. Chapter 3 provides a series of recommendations.

Results showed that over 100 organisations and almost 100 professionals from the Nordic countries are listed in the stakeholder map. Most actors were identified in Sweden (57 % of all actors listed). The number of actors identified and listed in Denmark, Finland and Norway was around the same in all of the three countries (DK 16%, FI 12% and NO 13% of all actors). Only three actors were identified in Iceland. Almost half of the activities were categorized as academic research and development, one third of the activities fell into category industry which includes a wide range of companies from design and architecture to business consultancy. Other two categories of actors were education and training, and forums and innovation platforms. Chapter 2 also provides a presentation of the European scene with approximately over 40 significant actors grouped into two families of bioinspired communities; those related to the Biomimicry Institute (USA), and those that are part of a biomimetic scientific research and development network with four countries leading: Germany, UK, Switzerland, and France.

Analysis outlining opportunities, threats, weaknesses and strengths of biomimicry in the Nordic Countries shows that there is an opportunity to enhance the current activities in biomimetics and circular economy with biomimicry by bringing into the field of biomimetics a more structured approach to sustainability and by providing a concrete methodology to design sustainable systems in circular economy. A great strength in the stakeholder's network is that there are several industry forums and innovation platforms that would be able to foster knowledge sharing between academia and industry.

The Summary of recommendations includes a need for a comprehensive Nordic network for Biomimicry to increase awareness between actors and to strengthen

Scandinavian influence as biomimicry frontrunners connect to the various European alliances. We recommend setting up a Nordic Centre for Biomimicry, Biomimetics and Bioinspiration with representation and key actors from each Nordic region starting with a Nordic summit to bring together actors found in this mapping process. Another recommendation is for education and training, as there is a need for more opportunities to train and study Biomimicry and Biomimetics. As biomimicry is a transdisciplinary process, there is need for cross-institutional collaboration and support in this endeavour.

Public private partnerships are also necessary to leverage the potentials in green business development, in order for companies to be able to share the risk of research and development of novel solutions. A requisite for transdisciplinary collaboration is to provide clearer definitions of Biomimicry and Bioinspired sectors, and attempt to avoid binary relations between biomimicry and biomimetics as seen in the European scene.

We suggest a need to setup, develop, maintain an online presence with a continued mapping of actors, and creation of coordinated platforms: for training, educational opportunities, research, practice and for knowledge sharing and collaboration between identified actors. All such endeavours will require allotted, stable funding, promotion and strong support from the public sector. We believe the effort is both significant and valuable given the immense potential offered from increasing knowledge from nature as an inspiration and model for sustainable solutions and future development.

Sammanfattning – Föregångare inom Biomimicry

Medvetenheten och kunskapen om biomimikry är låg inom nordiska företags design- och utvecklingsarbete. Nordiska ministerrådets arbetsgrupp för hållbar konsumtion och produktion har därför beställt denna rapport för att lyfta fram Nordiska föregångare inom biomimikry med avsikten att bidra till den Nordiska Miljöhandlingsplanen 2013-2018. Studien har utförts av Anna Maria Orrù, Torben Lenau and Lilli Linkola, och den ska ligga till grund för vidare aktiviteter som ger möjlighet för aktörer inom biomimikry att sprida sin kunskap och metoder *om* och *hur* naturens lösningar kan ge miljö- och konkurrensfördelar inom affärsutveckling.

Rapporten är indelad i tre delar. Kapitel 1 är en introduktion till fältet: motivationen och bakgrunden till biomimikry samt förtydliganden av olika definitioner inom biomimikry och andra bioinspirerade fält. Kapitel 2 presenterar resultaten av kartläggningen av föregångare och en diskussion om aktörerna och pågående aktiviteter. Kapitel 3 ger en rad rekommendationer.

Resultaten visar att det finns över 100 organisationer och nästan 100 yrkesverksamma individer i de nordiska länderna inom biomimikry. De flesta aktörerna identifierades i Sverige (57% av alla aktörer). Danmark, Finland och Norge hade ungefär lika stor andel av aktörerna (DK 16%, FI 12% och NO 13% av alla aktörer). Endast tre aktörer hittades på Island. Nästan hälften av de identifierade verksamheterna kategoriserades som akademisk forskning och utveckling, en tredjedel av verksamheterna tillhörde kategorin industrin vilken omfattar ett brett utbud av företag från design och arkitektur till företagsrådgivning. Ytterligare två andra kategorier av aktörer var utbildning samt forum och innovationsplattformar. I kapitel 2 ges också en beskrivning av ca 40 aktörer i Europa vilka är tydligt grupperade i två separata kluster: de som är kopplade till the Biomimicry Institute (USA) och de som ingår i ett biomimetiskt nätverk för vetenskaplig forskning och utveckling där Tyskland, Storbritannien, Schweiz och Frankrike är betydande.

Analysen av biomimikryns möjligheter, hot, svagheter och styrkor i de Nordiska länderna visar att nuvarande verksamheter inom biomimetik och cirkulär ekonomi skulle kunna utvecklas med hjälp av biomimikry och genom att föra in ett mer strukturerat förhållningssätt till hållbarhet och en konkret metodik för att utveckla hållbara system i en cirkulär ekonomi. En stor styrka i nätverket av aktörer är att det finns flera branschforum och innovationsplattformar som skulle kunna främja kunskapsutbyte mellan akademien och industrin.

De sammanfattande rekommendationerna inkluderar ett behov av ett brett Nordiskt nätverk för biomimikry för att öka medvetenheten mellan aktörer och för att stärka det skandinaviska inflytandet när nordiska föregångare ansluter sig till de olika Europeiska grupperingarna. Vi rekommenderar att ett Nordiskt Centrum för Biomimikry, Biomimetik och Bioinspiration inrättas med representation och

nyckelaktörer från alla Nordiska länder, och att det invigs/startar med ett Nordiskt möte som sammanför de aktörer som hittats i denna kartläggning. En annan rekommendation gäller utbildning och kompetensutveckling, eftersom det finns behov av fler möjligheter att träna och studera biomimikry och biomimetik. Eftersom biomimikry är en tvärvetenskaplig process, finns det behov av tvärinstitutionellt samarbete och stöd för detta arbete.

Partnerskap mellan offentliga och privata aktörer är också nödvändiga för att utnyttja potentialen inom grön affärsutveckling så att man kan dela på risktagandet förenat med forskning och utveckling av nya lösningar. En förutsättning för tvärvetenskapligt samarbete är tydligare definitioner av biomimikry och bioinspirerade sektorer och en ambition att undvika den skarpa separationen mellan biomimikry och biomimetik som finns i Europa.

Vi anser vidare att det är en nödvändighet att installera, utveckla och upprätthålla en online-närvaro, med fortsatt kartläggning av aktörer och skapandet av samordnade plattformar: för att därigenom skapa utbildningsmöjligheter, praktik, forskning, övning och kunskapsdelning och samarbete mellan identifierade aktörer. Alla sådana ansträngningar kommer att kräva tilldelad, stabil finansiering, marknadsföring och starkt stöd från den offentliga sektorn. Vi tror att insatsen är både betydande och värdefull med tanke på den enorma potential som erbjuds genom ökad kunskap om naturen som en inspirationskälla och modell för hållbara lösningar och framtida utveckling.¹

¹ Swedish Translation of Summary by Louise Hård af Segerstad (Edit 2: by Fredrik Moberg) from Albaeco, Communications Strategists, Stockholm Resilience Centre.

1. Introduction

1.1 Motivations and Background

The awareness of Biomimicry within the processes of design and development in Nordic companies is not well known. It is an unexploited potential that the Nordic authorities together can contribute to increasing knowledge about nature as an inspiration and model for sustainable solutions.

The Nordic Council of Ministers Working Group for Sustainable Consumption and Production (SCP/HKP) is contributing to the Implementation of the Nordic Environmental Action Plan 2013 – 2018. Dissemination of knowledge and networks on biomimicry in Nordic countries can greatly support the implementation of the plan. Biomimicry as a design and development practice generates innovations and supports

This report creates an overview of actors and activities in the field of biomimicry, biomimetics and biologically inspired design in Nordic countries today. The report highlights the Nordic forerunners in this field and summarises the activities by sector and by country and by the type of bio-related activity. The findings presented in the report are based on a study “Mapping Forerunners in Biomimicry” conducted by Torben Lenau, Lilli Linkola and Anna Maria Orrù (The Project Group - See Appendix 1).

The purpose of the study was to present the Nordic Council of Ministers a basis for planning further activities to leverage the possibilities for Nordic actors in biomimicry and to disseminate knowledge and methodology on *if* and *how* nature's solutions can provide environmental and competitive advantages in business development. A list of recommendations for the Nordic Council of Ministers is introduced at the end of the report. The Nordic Council of Ministers can use the results to evaluate the potential of biomimicry in order to leverage green innovations and support the green transition of Nordic societies as part of the Nordic implementation of Agenda 2030.

1.2 Definitions

A brief introduction to biomimicry and its definition is followed by short descriptions of other bio-related methods (bio-satellites) such as biomimetics.

Biomimicry

from Greek bios (meaning life), and mimesis (meaning to imitate)

Biomimicry is a discipline that takes inspiration from nature to develop sustainable solutions to many design challenges that our civilization is grappling on a daily basis. These challenges span from product design, mechanical engineering, medicine, through to agriculture, business and even architecture. Biomimicry is a heterogeneous approach that involves biologists at the design table to help sift through nature's 3.8 billion years of adapting and evolving to the changing conditions on the planet that has created a knowledge bank of solutions.

Biomimicry as a term first appeared in scientific literature in the 1960's and became more commonly referenced in the 1980's by material scientists. As a field and practice, it has been revived and brought to the fore by biologist Janine Benyus with her book 'Biomimicry: Innovation Inspired by Nature', first published in 1997. She defines biomimicry as the conscious emulation of life's genius, wherein a biomimicry revolution unlike the industrial revolution, is an era 'based not on what we can extract from nature, but on what we can learn from her' (Benyus 1997, p. 2). In the practice of biomimicry, the Biomimicry Institute has developed a biological design template on three levels: form, processes, and systems. The form of an organism adapts to its natural setting over long periods of time. There is a metabolic sequencing in this (process) of evolution, and it relates entirely to the living ecosystem (system) conditions of the place in which the organism resides (Orrù 2015).

The first level of biomimicry concerns the mimicking of natural forms such as the imitation of frayed owl wing edges to achieve silent flight. The second level scopes the transfer of natural processes into technical solutions, for example the way green chemistry is inspired by self-assembly of owl feathers at room temperature. The third level has the highest requirement as it covers the mimicking of natural ecosystems, also named as deep, holistic or eco biomimicry. It implicates the integration of all elements and the relationship between the elements in a more or less closed ecosystem. An example of this is the consideration of the owl feather as part of a forest and a sustaining biosphere. To achieve sustainable solutions, level 3 biomimicry should be aimed for (Lenau et. al. 2018, p. 12).



LIFE'S PRINCIPLES Biomimicry DesignLens

Figure 1 Biomimicry Institute Life Principles Biomimicry Design Lens (Image Credit: biomimicry.net/AskNature.org - Baumeister et. al. 2013)

The Biomimicry institute has specified resources for adapting biomimicry utilizing a series of life principles to bring about a solution that is environmentally-led and sustainable. There are six main categories (Figure 1): evolve to survive, adapt to changing conditions, be locally attuned and responsive, integrate development with growth, be resource efficient (material and energy) and use life-friendly chemistry (Baumeister et. al. 2013). These principles stem from a simple set of nature's guiding laws (Benyus 1997, p. 7):

- Nature runs on sunlight*
- Nature uses only the energy it needs*
- Nature fits form to function*
- Nature recycles everything*
- Nature rewards cooperation*
- Nature banks on diversity*
- Nature demands local expertise*
- Nature curbs excesses from within*
- Nature taps the power of limits*

The complexity inherent with biomimicry is that it involves biology and a keen interest in understanding nature, which is best approached through setting up collaboration with biologists or team members that are capable and willing to carry out the required research. Transdisciplinary collaboration is one of the primary challenges in implementing biomimicry.

In addition to Benyus' vital contribution to the field, other critical contemporary figures have included Professor of Biology Steven Vogel and Professor of Biomimetics Julian Vincent, both of whom use biomimetics as their driving definition. The origins of finding inspiration from nature have been present dating back to Leonardo da Vinci in his early sketches studying skulls, bird's wings, human body, water and many varieties of plants (Cremante 2006). Hence the field has been around for a long time. One of the most famous examples has been the invention of Velcro around 1948 by George de Mestrel who was inspired by the seeds of Burdock plant (cockleburs) that attached themselves to his dog's fur during a walk. He started exploring in detail the tiny hooks of the seed to invent fasteners known now as Velcro, a common everyday item in apparel and other products.

It is important to distinguish between different terms associated with biomimicry but that mandate various forms of approaching nature. The words biomimetics, biomimesis, and biomimicry, though similar, can cause confusion. As already mentioned, the field of biomimicry has a strongly ecologically-centred practice that seeks to find sustainable and environmentally-friendly solutions. Other terms such as biomimesis and biomimetics are also used as nature-inspired practices with a long-standing presence in material science and product design especially, though not always from a perspective of reaching a sustainable solution. Therefore, it is vital to mention differences amongst the various practices in order to denote their environmental intentions.

Biomimicry's use of life principles centres around the goal that life creates conditions conducive to life and it survives by working within its surrounding context seasonally, socially, and ecologically. Hence, such principles use nature as a measure, method and model for reaching ecological results that illustrate the interconnectedness of all species, including humans. Nature as a model is where inspiration is taken from these designs and process and used to solve human problems stemming from harnessing energy, feeding future generations, making things, medicine, conducting business etc. For instance, the design of a solar cell that is inspired by a leaf design. Nature as measure uses an ecological benchmark and standard to find innovations that work and last. Nature as mentor provides a way to view and value nature based on what we can learn from it (Benyus 1997). In essence, in biomimicry the aim is to ask - *how do we contribute to the continuation of life and future generations which is in line with what the sustainability revolution and ecological age is concerned about?*

Sustainability is traditionally described by including three dimensions: the economic, the social and the environmental. The United Nations has recently further concretized these dimensions into 17 sustainability goals. The focus of biomimicry and other types of biologically inspired design focussing on sustainability is in many cases

the *environmental* dimension. Architect Michael Pawlyn in his book on biomimicry and architecture outlines three major changes in heading towards a sustainable future; resource efficiency, a shift from fossil to solar driven economy, and a change from linear to circular processes (Pawlyn 2016, p. 1).

In order to determine if a new product or solution is sustainable, some sort of quantitative measure needs to be used. A widely accepted means is Life Cycle Assessment (LCA) where the detailed sustainability footprint for the full life cycle from creation to disposal is calculated. This is done by estimating the amount of material resources used and the environmental impact. To get a figure that can be compared to alternative solutions, the LCA-results are often expressed as personal equivalents which means the fraction of an average world citizen's share of all used resources and pollution on the earth. For practical purposes new products or solutions can be compared with existing products or solutions using so-called functional equivalents where the impact of similar performances is determined. An example is the impact of daily transportation for a single person traveling to work using either public transportation or a private car. If a new product or solution can demonstrate a lower impact, then it will be more sustainable. Biomimicry does not make such sustainability assessments redundant, on the contrary they are very important for the successful implementation of the methodology.

Other Bio-related Methods

There is an array of methods that are practiced alongside biomimicry which some of them have been included in the project mapping. Some examples of these include:

- Biomimicry
- Biomimetics
- Bionics
- Bioinspired/ Bioinspiration
- Biodesign
- Biotechnology
- Bioutilization
- Biomorphic/ Biomorphism
- Biomedical / Biopharmaceuticals
- Biomanufacturing
- Biomaterials
- Biophotonic
- Biophilia
- Bioeconomy
- Bioreplication
- Biorobotics
- Nature based solutions
- Circular economy

There are some terms however that are worth clarifying further given that this mapping report has extended the bio-inspired definition to include actors also within some of these fields (Figure 3). One of the most interchangeable terms used with

biomimicry is biomimetics. In Germany biomimetics, or Bionik as it is named in Germany, has been around for many years with professor chairs in many of the Universities. Examples are Werner Nachtigal at the University of Saarlandes (biomechanics), Ingo Rechenberg at TU Berlin (flight and liquid flow), Wilhelm Barthlott at the University of Bonn (the lotus effect) and Thomas Speck at the University of Freiburg, who is a central person in the BLOKON-organisation (see Section 2.6). BLOKON bridges academia and industry by bringing research insights from the technical understanding of nature into application in industrial products. Examples are Festo's elephant trunk inspired robots and Daimler's boxfish inspired concept car. (figure 2)

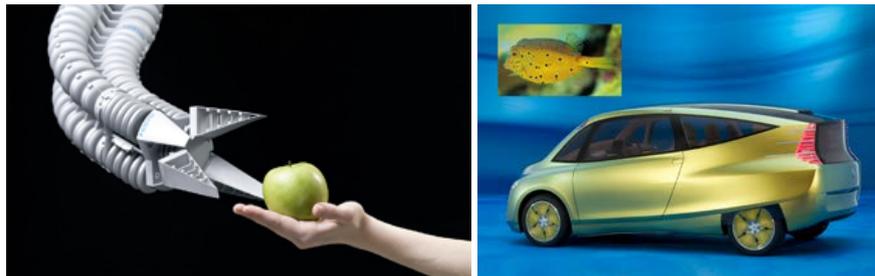


Figure 2: Elephant trunk inspired robot by Festo and boxfish inspired concept car by Daimler (*Image Credit: www.festo.com and media.daimler.com*)

On the teaching side, the aim at some universities has been to educate hybrid biological engineers that possess biology competence but are also trained in engineering. Other universities focus on cross-disciplinary courses where different departments and faculties collaborate. Examples include Georgia Tech in the USA that has collaboration between biology, mechanical engineering, computer science and medicine. At TU Delft in the Netherlands they integrate biology and biomimicry in the training of mechanical engineers and industrial designers. At DTU in Denmark biomimetics is taught as a design topic integrating students from engineering design, material science, mechanical engineering and biology.

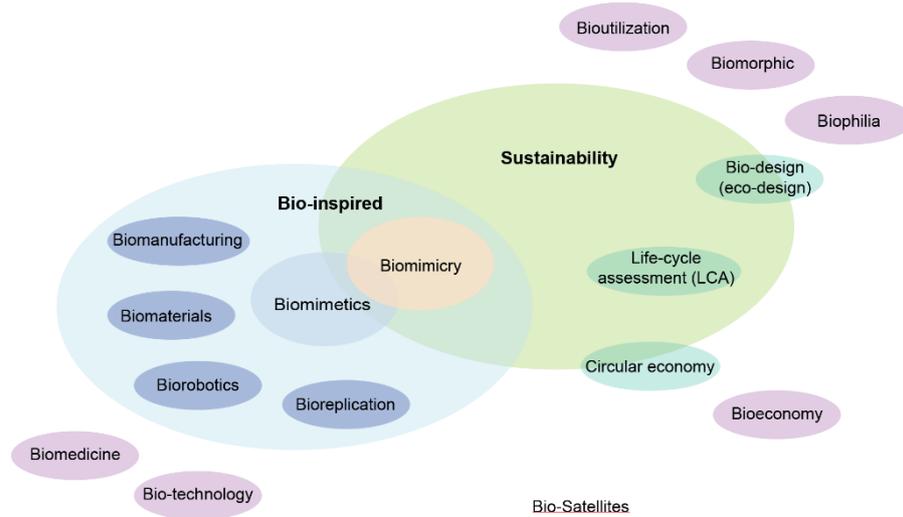


Figure 3: Bio-Satellites - a range of different bio-terms at a first sight reminds of biomimicry. The diagram explains their relation to biomimicry and sustainability. The purple bio-satellites are not related to biomimicry (e.g. bio-technology). (Image Credit: Orrù/Lenau 2018)

Key practices that are Biomimicry-inspired include biomimetics, bioinspired and bio-design. The difference that can be noticed between the first two and the latter is that the first two suggest copying using biological research, whereas bio-design or bioinspired bio-design intends to include the potential for developing something beyond what exists in biology (Pawlyn 2016, p. 2). An important aspect that biomimicry takes into consideration is also an ethical approach to nature manipulation such as gene manipulation. One such approach is the genetic modification of goats to produce milk which contains the same protein found in spider's silk, which ounce for ounce is five times stronger in its strength to steel. Biomimicry includes the consideration of ethical appropriateness for example of such bioinspired alterations of living organisms. Within the frame of biomimicry and finding sustainable solutions, it is therefore important to distinguish and discuss when nature is being manipulated or modified for research purposes, or when nature is used solely as a form of inspiration.

Another interesting field which has resulted in numerous research output is biorobotics. As explained below, biorobotics is the bio-related area within literature that attracts most attention. This is understandable when considering that a robot can be seen as a machine that mimics aspects of the behaviour of human beings. In films, robots are often visualised with two legs, two arms and a head like the human equivalent, despite that most industrial robots have less similarity to man. However, robots are made to perform the same type of handling and movement of objects, and robotic researchers are therefore looking into biology to get inspiration for how to achieve lightweightness while making accurate and gentle motions. The dexterity of elephant trunks has for instance been mimicked as shown in figure 2. Another interesting area within biorobotics is the attempt to make robots acceptable, friendly

and even cute to humans. Japan makes robotic pets that are used to bring calmness to people suffering from dementia. In general, biorobotics can be characterised as biomimetics, since in most cases, the focus is on inspiration from nature to get better performance, not on sustainability.

Case: Biomimicry in Architecture and the Built environment

There seems to be a trend to use biomimicry as a term to denote different forms of bioinspired design which leads to some confusion. These bioinspired designs include Bioutilisation, Biophilia and Biomorphic. To elaborate, Bioutilisation is the direct use of nature for ecological benefits. Examples can include landscape planting around a building, inside or on site for evaporative cooling or for bringing on a microclimate effects. It also includes food production in, on or around the structure as a means of bio-design. Another important term is biophilia as used in the built environment. Biophilia as a term was coined by Biologist E.O.Wilson and illustrates an instinctive bond between humans and living organisms (Wilson 1984). Stephen Kellert has explored and developed the term to produce a niche of biophilic design as a means of reconnecting people to the natural world through architectural design.² Finally, there is also biomorphic architecture in which nature becomes a source of form and symbolism (Feuerstein 2001).

These forms of Bio-Architecture, though critical, are not biomimicry in its intended process and true form. They are however a means to make sustainable efforts in the built environment and it could be said that they take components and levels of biomimicry into consideration: Bioutilisation and biophilia (process/system), biomorphic (form). It should be said that, just because a building is filled with plants, does not make it biomimicry. Additionally, there are attempts to classify bioinspired design on a systems level through ecosystems services and ecological urban systems design which again are a vital endeavour at sustainable development and interconnectedness using a systems approach. They are considered components and levels of biomimicry on the system level.

Growing Interest in the Field

There is a growing interest in bioinspiration within the scientific community. This can be seen from the number of papers published in scientific journals. Twenty years ago, only a few hundred papers were published on the topic. Today, the number is higher than 2500 papers a year (Lenau et al. 2018). In another recent study, 18.000 scientific papers related to biologically inspired design was analysed. It was found that five distinct communities with recognisable themes could be identified. They were robotics and control, ethology-based robotics, biomimetic actuators, biomaterials science and structural bioengineering (Lepora et al 2013).

² <http://www.biophilicdesign.net/>

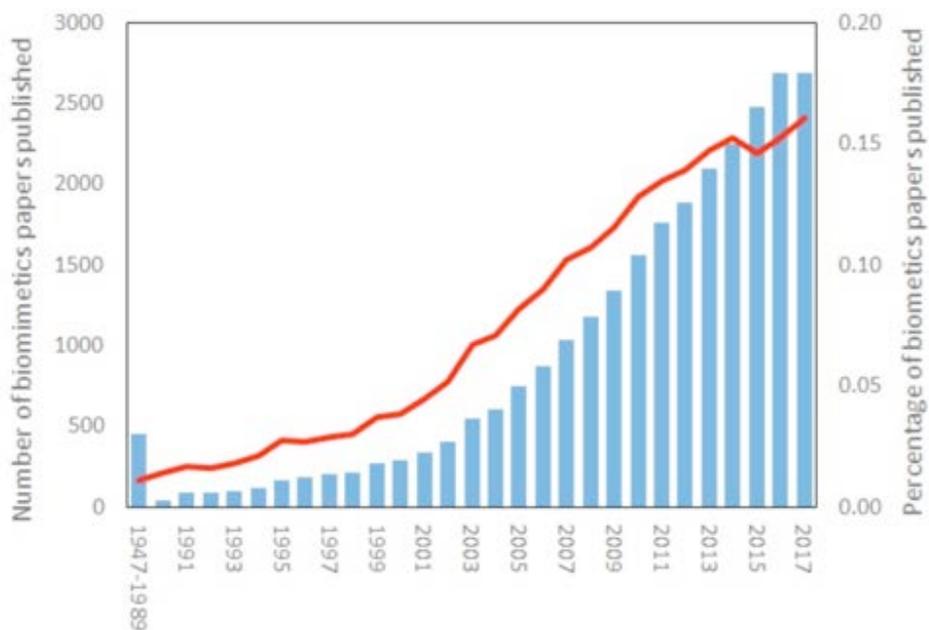


Figure 4. The number of published biomimetics papers in ISI Web of Science. The search was done on articles in the Web of Science core database using the search terms 'biomim*', 'bionic*' and 'biologically inspired' (TS=(biomim* OR bionic* OR biologically inspired)) in the title, keywords or abstract. To get proportional data the number of hits was divided by the total number of published papers (which were assumed to be found searching for 'a' or 'the' in the title, keywords or abstracts - TS=(a OR the*)). The bars indicate the number of published biomimetics papers, while the line indicates the proportion of these papers out of the total of all published papers. (Lenau et al 2018, p3)

In the literature, research and development work involving inspiration from nature is referred to using many different terms with slightly different meanings. Much of the work focuses on the clever solution to technical problems, but do not necessarily involve a focus on sustainability. However, the deep understanding of how nature functions and works is necessary for successful application of biomimicry, and future work should therefore include people from a broader range of disciplines with expertise in biology and the various forms of biologically-inspired design, as well as expertise in the assessment of sustainability. In addition to scientific papers, there are a number of publications ranging from engineering and architecture to nature's design and material science.

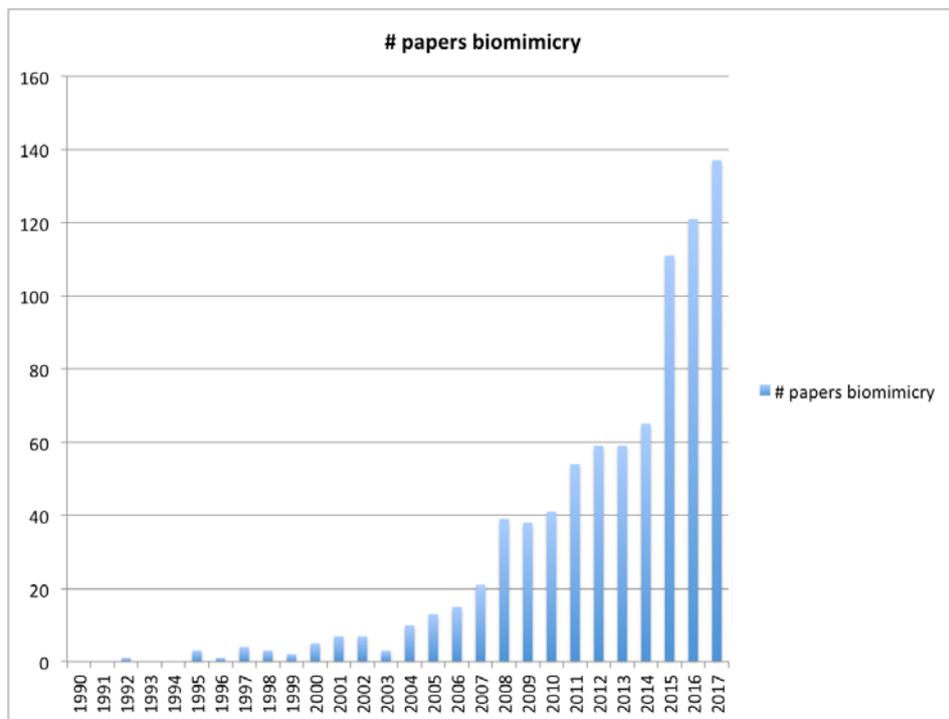


Figure 5. The number of published biomimicry papers in ISI Web of Science. The search was done on articles in the Web of Science core database using the search term 'biomimicry (TS=(biomimicry)) in the title, keywords or abstract.

1.3 Mapping Methodology and Process

The project is a result of a call from the Working Group for Sustainable Consumption and Production (SCP/HKP) of the Nordic Council of Ministers for a pre-study project aimed at mapping Nordic actors within Biomimicry. Once the group was informed about their successful application, the study was carried out during 2018 by four experts that are based in three Nordic countries: Sweden, Denmark and Finland. Anna Maria Orrù and Torben Lenau are leading experts in biomimicry in their fields of architecture and engineering in the Nordics and both work in the interfaces between practice and research. Lilli Linkola is a circular economy expert at Ethica ltd.

The project began with a kick off meeting together with the steering group and the project group at the end of January 2018. The mapping of actors and ongoing activities was conducted during the months of February, March and April 2018. During this period, results and findings were discussed on two occasions with the steering group before the project group completed the recommendations and finalized the report for the Nordic Council of Ministers in end of May 2018.

The information on ongoing activities and actors was mapped primarily through an online questionnaire that was distributed via email to potential practitioners of biomimicry in Denmark, Finland, Iceland, Norway and Sweden. In addition, major

practitioners and nature-inspired platforms in the rest of Europe were also contacted and invited to the survey. The project group approached the topic pragmatically by opening the mapping to all actors working with nature's sustainability, circular economy and/or inspiration from nature, and not only ones that used the term biomimicry or biomimetics to describe their work. The information was gathered via the online questionnaire which included the following parameters: name (respondent/organisation), country, sector, field, description of activities and description of and some metrics related to the activity. Approximately 100 responses were received via the online questionnaire, with further responses directly via email.

The project group started by identifying the actors in their respective networks and expanded the mapping to actors identified by the respondents. The survey was also distributed to environmental and industry interest groups based in Denmark, Finland, Norway and Sweden. Online inquiries with keywords related to biomimicry, biomimetics and bioinspiration were used as a complementary source of information regarding activities in the Nordics. The project group did not receive a response from all identified actors, but nevertheless included all relevant ones in the mapping.

The results of the mapping were compiled into a stakeholder map using the Kumu data visualization platform.³ The results are also represented through graphs in this report. The project group designed the stakeholder map to be dynamic and easily expanded for future use by the Nordic Council of Ministers or other parties. The map gives an overview of activities in the Nordics but does not claim as such to be an exhaustive map. Further map editions and additions can be suggested to the SCP/HKP.

The activities were clustered in four categories: Academic research and development/ industry/ education and training/ forums and innovation platforms. In addition, the activities were associated with tags that describe the sector and field in more detail and the type of bio-related activity in question.

The project group members were responsible for their respective Nordic region(s) in the mapping and in writing a description of their country's specific findings.⁴ Additional information on state of art in biomimicry in various sectors and potentials of disseminating knowledge was gathered through interviews and discussions with the identified actors. The project group organised a workshop in April 2018 to analyse the opportunities and strengths in the Nordics related to biomimicry and green technology and business development.

Based on the results, discussions and prior knowledge and experience, the project group identified the key opportunities in the Nordics to disseminate biomimicry in order to leverage green development. The project group generated ideas and recommendations for further activities for the SCP group and in addition to this report, will present the results and recommendations to the SCP/HKP group in Stockholm in September.

³ <https://kumu.io/Linkola/frontrunners-in-biomimicry-in-the-nordics#actors-in-biomimicry-in-the-nordics/nmbu-norwegian-university-of-sciences>

⁴ Project group members Nordic summary: Anna Maria Orrù-Sweden, Torben Lenau-Denmark, and Lilli Linkola-Finland, Norway and Iceland. The European findings were conducted by Anna Maria Orrù.

2. Results of the Mapping

Altogether over 100 organisations and almost 100 professionals from the Nordic countries are listed in the stakeholder map (Figure 6). The organisations are companies, research groups and institutes, universities, industry or sustainability advocacy groups and governmental organizations. In addition, the project identified and included in the stakeholder map the most important actors, organisations and professionals, related to biomimicry and biologically inspired activities in the European Union (circa 40 actors). Please refer to Appendix 2 for the full list of actors.

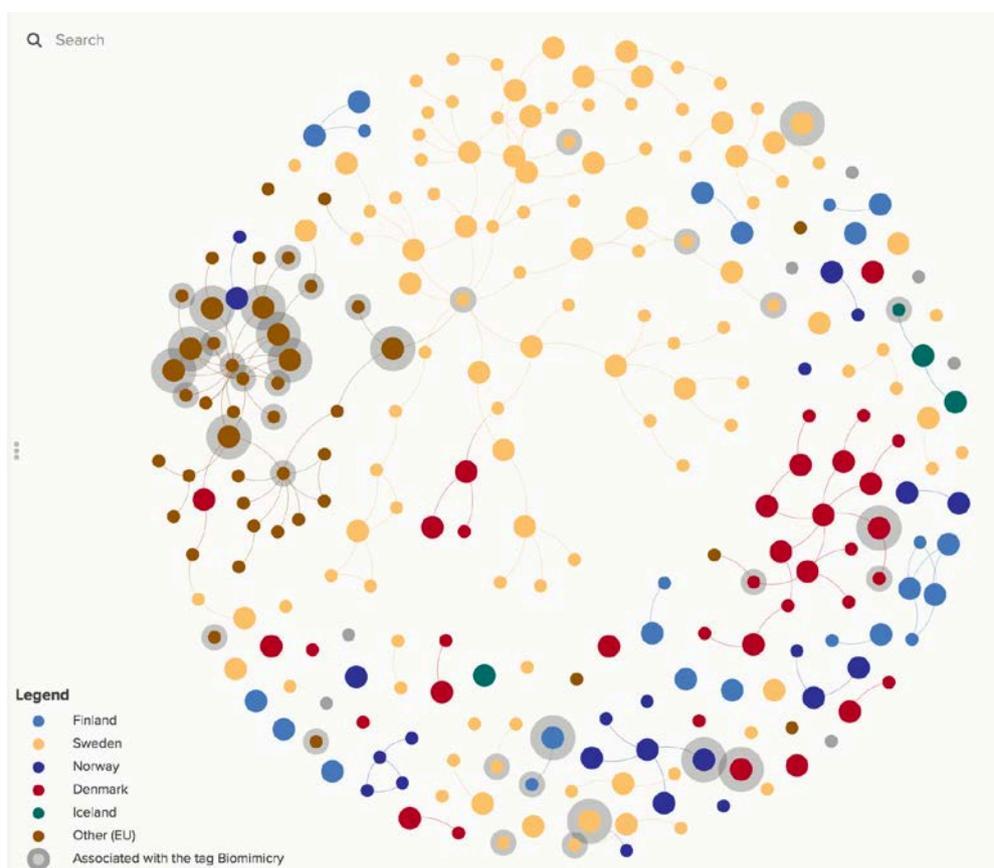


Figure 6: Stakeholder map of actors and activities related to biomimicry or biologically inspired activities in the Nordics. Print screen of the interactive online map.

Most of the actors were identified in Sweden (57 % of all actors listed). The number of actors identified and listed in Denmark, Finland and Norway was around the same in all three countries (DK 16%, FI 12% and NO 13% of all actors). Only three actors were identified in Iceland.

The findings were placed into four categories: academic research and development/ industry/ education and training/ forums and innovation platforms. Many of the identified actors are related to universities and research institutions. Almost half of the activities were categorised as academic research and development (Figure 7). One third of the activities fell into the category of industry. This category includes a wide range of companies from design and architecture, to business consultancy.

In the category education and training, we listed all actors who give training to professionals in industry or other organisations, or their main focus in activities is disseminating knowledge by other means such as writing and public speaking. In this category, we found actors who are directly involved with biomimicry as such. We also listed actors who are active in circular economy and sustainability with focus on nature-based solutions.

The fourth category of actors is forums and innovation platforms (figure 7). All organisations, that have a function to build and maintain industry networks, foster innovation and knowledge sharing between research and industry are listed in this category. All listed organisations in this category have either ongoing activities or an interest to work more with the theme biomimicry or biomimetics. There were around thirteen organisations identified in this category (Figure 7).⁵

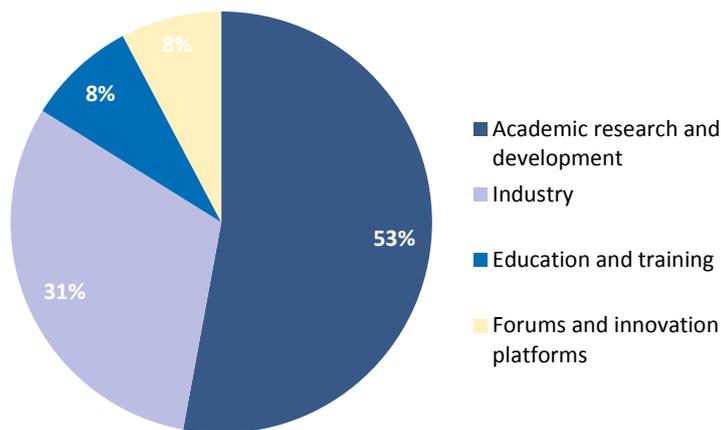


Figure 7: Percentages of identified actors and activities by categories: academic research and development/ industry/ education and training/ forums and innovation platforms.

⁵ Due to lack of information some actors are not classified into a category.

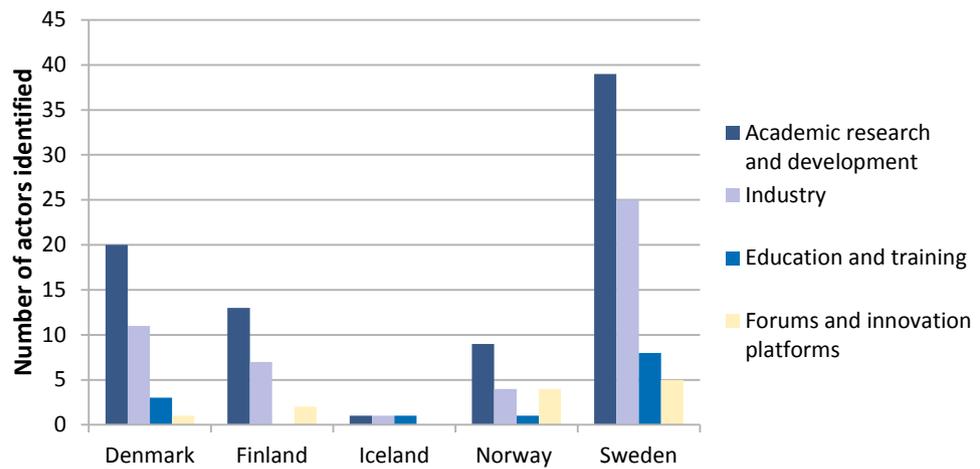


Figure 8: Number of actors identified per category by country.

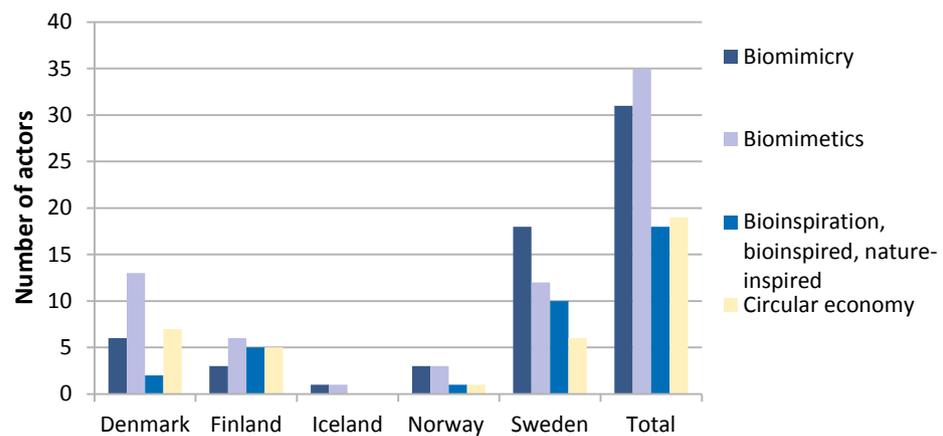


Figure 9: Number of activities and actors related to biomimicry and other bio-satellites by country and in total.

Figures 8 and 9 demonstrate differences and similarities between the Nordic countries, Denmark, Finland, Iceland, Norway and Sweden, in the types of activities. The distribution between academic research and other activities, especially activities in industry, is similar in all countries, academic activities being most dominant. Interestingly, the occurrence of the term biomimicry and other most commonly used terms biomimetics and bioinspiration varies between countries. Most practitioners of biomimicry were found in Sweden and in Denmark. What is unique in Sweden compared to other countries is that several universities there offer a course or workshops in biomimicry, yet, they are not part of the formal curriculum. This is the case at Chalmers University of Technology in the Department of Architecture, at CEMUS in Uppsala University, and at KTH in the School of Architecture, which some have offered annual course(s), lectures and/or workshops to students since 2011. Refer to following sections 2.1 - 2.6 for more detailed descriptions for each country.

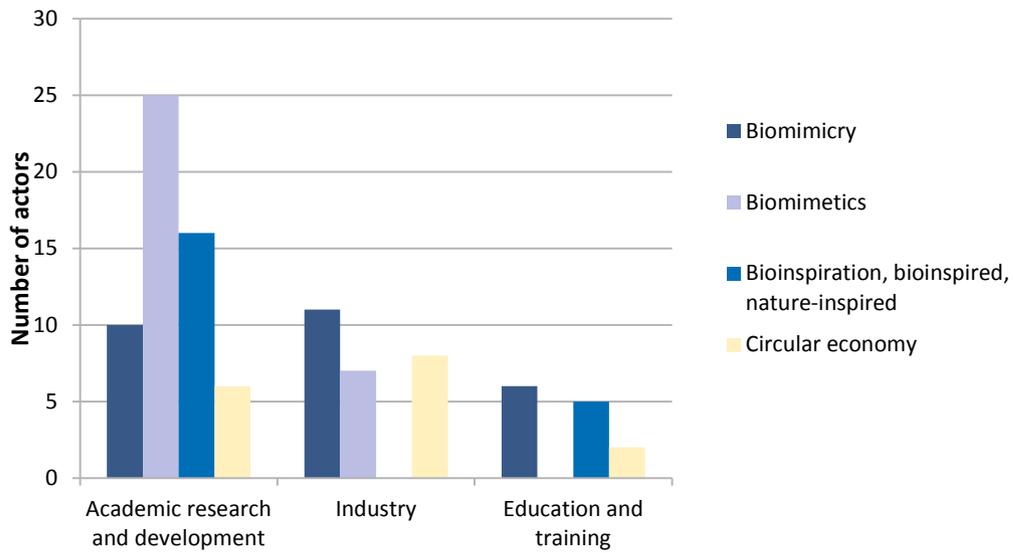


Figure 10: Number of activities and actors related to biomimicry and other bio-satellites by category.

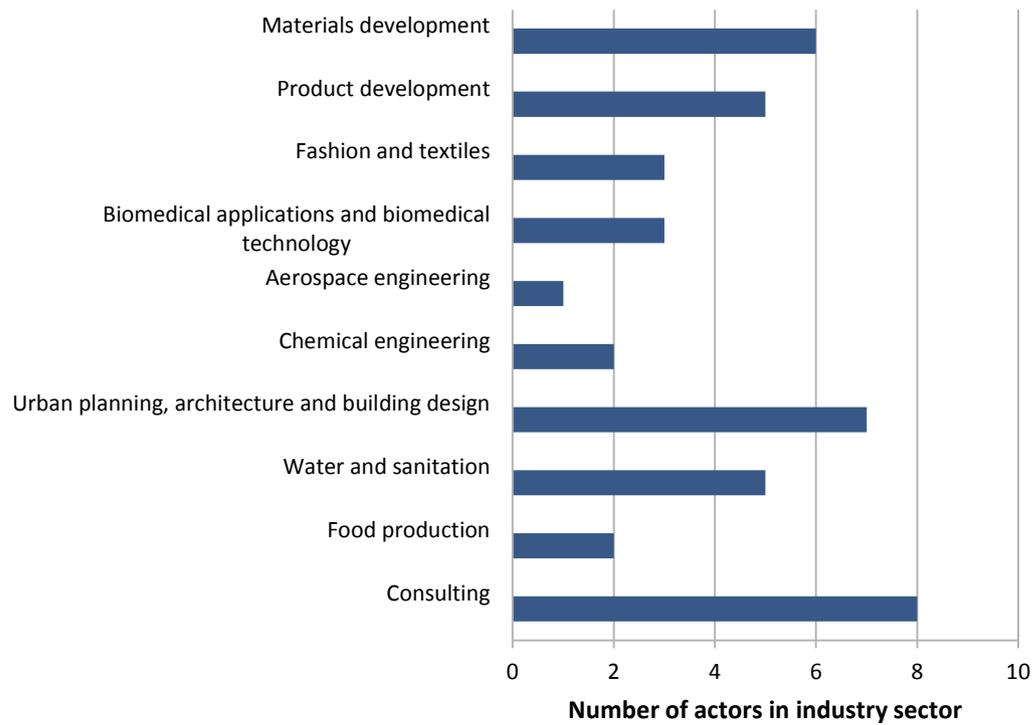


Figure 11: Types of sectors and activities in the category industry

Figure 10 demonstrates that the approach most common in academic research and development is biomimetics, whereas amongst the actors in industry biomimicry was more commonly a used term to describe the activity. This might be due to the fact that the terminologies are less recognized in industry and therefore the terms biomimicry, biomimetics and bioinspired are used synonymously. The academic actors tended to be more careful with the terminology when responding to the questionnaire. On the other hand, many of the actors, that were placed in the category industry, were consultancy companies or from the sector of architecture, urban planning and building technologies (figure 11). These sectors were identified to have most practitioners in biomimicry.

2.1 Findings in Sweden

Based on findings, a majority of the bioinspired and bio-related work in Sweden was being conducted within university research and development and within the field of biomimetics. Sweden has no established biomimicry network, however there have been attempts at training biomimicry by larger corporations such as Interface who also support such efforts in the UK and abroad.⁶

The terminology 'biomimicry' was mostly present in architecture and built environment discourses, that extended into design research. The next sector with a considerable number of actors was found in industry, followed by a number of public platforms that promoted biomimicry as a form of sustainable method and approach. Furthermore, there were a series of actors highlighted who were either training biomimicry, providing lectures, or promoting the field to the public and/or private sectors, including education, industry and culture such as a science centre and museum.

Academic Research and Development

Altogether, approximately 16 universities (academic research and development) with several diverse research institutes were listed. The universities listed were Chalmers University of Technology, Blekinge Institute of Technology, KTH Royal Institute of Technology, Linköping University, Lund university, Malmö University, Stockholm University, Swedish University of Agricultural Sciences SLU, University of Skövde, Umeå University, Uppsala University, KKH The Royal Institute of Art, Konstfack - University of arts, crafts and design, Beckmans College of Design, Gothenburg University HDK Academy of Design and Crafts and Valand Art Academy and Karolinska Institute. The listed research institutes included RISE Research Institutes, Biomime⁷, Umeå Plant Science Centre, Wallenberg Wood Science Center, Centre for Environmental and Climate Research (CEC), and the Centre for education science and teacher research. RISE itself is a merging of RISE-institutes Innventia, SP

⁶ <https://www.bio-uk.org/urblondon2018>

⁷ The Biomime centre might be closed for now but we have understood from interviews that their work continues into new initiatives.

and Swedish ICT to build research and innovation partnerships and collaboration programmes with academia, industry and the public sector and is government owned.

Amongst the universities, the departments in which biomimicry and biomimetic related research was undertaken included biology, architecture (including urban studies, civil engineering and landscape architecture), engineering, chemistry, sustainable development environmental science and engineering, Industrial Biotechnology, industrial design, design and art, geography, environmental and climate research, and clinical and experimental medicine and neurobiology. Lund University has quite significant ongoing activity in the Department of Chemistry, Physics and Department of Molecular Biomimetics into Bioorganic Chemistry looking into renewable energy research, molecular biomimetics and material development. They also have cross-over collaboration with industry actor Swedish Biomimetics 3000. In the department of Architecture, there are further bio-inspiration fabrication work from termites. Further actors were mapped from the Centre for Environmental and Climate Research (CEC) looking into bioeconomy and urban nature for nature-based solutions for urban challenges. Also, at the Department of Biology, Functional Zoology, there is an active research group studying vision and visual navigation in animals from extremely dim habitats (nocturnal and deep sea).

Important bioinspired material innovators, researchers and development centres comes out of KTH in Stockholm, at the Schools of Biotechnology and Chemical Science and Engineering (Biomime) and at Chalmers University at the Department of Chemistry and Chemical Engineering (The Wallenberg Wood science centre – this centre collaborates also with other universities)⁸. Both are involved in materials development, materials research into 'Eco-friendly materials from renewable resources.' Furthermore, at Chalmers University we found actors at the Department of Architecture and Civil Engineering, at the department of Chemistry, and at the Division of Industrial Biotechnology, all working in broad topics related to bioinspired work.

At Linköping University, there is activity in engineering design into the design of products and services inspired by biology. At Malmö university, K3 School of Arts & Communication, there are efforts into product design that explore biomimicry through materials and natural manufacturing processes on the PhD research level.

Further, at the Blekinge Institute of Technology, there are endeavours to include biomimicry in the development of sustainable products and leadership. These include several efforts at the Master level to evaluate the potential of the biomimicry toolbox against the Framework for Strategic Sustainable Development (FSSD) in order to improve the toolbox at the Faculty of Engineering in the Department of Strategic Sustainable Development.

At Uppsala University, at the Department of Chemistry and Molecular Biomimetics, there are numerous parallel projects running that focus on H₂ production using biological and/or biomimetic systems financed by Swedish and European funding agencies. For instance, we found research into photosynthesis for the development of

⁸ The Wallenberg Wood science centre has collaborations between three universities; KTH, Chalmers and Linköping university.

artificial catalysts and devices for solar fuels production. In addition, The Centre for Environment and Development Studies (CEMUS) at Uppsala University has held an annual lecture on biomimicry since 2014. Uppsala University is also known to have a strong presence in circular economy research as part of the Baltic University programme and Department of Life Sciences.

At SLU - Swedish University of Agricultural Sciences ALNARP, both the Department of Aquatic Resources has been teaching biomimicry.org principles, and the Landscape Architecture division has held biomimicry training as part of its Landscape Architecture day in the past.

At Karolinska Institute, there has been a strong attempt to develop immersive workshops for PhD students on biomimicry and circular design at the Department of Neurobiology for their Doctoral Programme in Development and Regeneration (DEVREG) and Gendered Innovation Alliance.

At Stockholm University, Albaeco at the Stockholm Resilience Centre are an independent group working with strategic science and environmental communication, science communication and education. Fredrik Moberg, one of the directors, had already brought up the term biomimicry into environmental discourse back in 2008 when he spoke about it on an environmental radio show and wrote on the subject. Both Moberg and his co-director Louise Hård af Segerstad have been involved as guest biologists/ecologists on the 2011-2012 Biomimicry elective course taught at KTH School of Architecture.

At the University of Skövde, biomimicry has been taught in the design engineering and industrial design departments with Niclas Norrström as the biologist at the table teaching and researching in ecology and evolution. They are also beginning a collaboration with Industrial Development Centre (IDC) / Material ConneXion Skövde. Other universities where biomimicry lectures or workshops were either being taught or were present in the past, included; KKH The Royal Institute of Art, Konstfack - University of Arts, Crafts and Design, Beckmans College of Design, Gothenburg University HDK Academy of Design and Crafts and Valand Art Academy, and also at the GU Centre for education science and teacher research.

Industry

In industry, there is a number of developments within the wastewater treatment, water production and HVAC areas. Medicine and pharmaceuticals also have a wealth of research and product development in areas such as dentistry, pharmaceutical manufacturing technology, synthetic cornea, and protein aggregation in disease. One actor, Swedish Biomimetics 3000, work with academia such as with Lund University and also commercialize innovative biomimetically inspired platform technologies whose strategic focus is exploring Biomimetic concepts as a Venture Philanthropic Organisation (VPO).

In terms of textiles with ties to cradle to cradle and circular economy thinking, there are a number of actors in fashion and carpet manufacturing, but also in industry textiles within materials technology and green chemistry (materials development). In terms of viewing biomimicry on a systems level thinking, there are actors particular to the

agroforestry and ecoforestry sectors, but also ones which view cities as urban ecological systems. Within urban field and approaches, there are a number of architects that do biomimicry-related work, including Anders Nyquist who has a long-standing relation to the field of biomimicry and has been contributing since the 1990's. Most of the mapped architects work within the area of practice and research including White Architects and Phenotype Studio, who specialize in Digital/Parametric Design. On the particular subject of Biomimicry, teaching is scarce in universities but there are several courses/lectures and workshops taught by the author in this report – Anna Maria Orrù. At Lund University, there are also efforts at fabrication for architectural scale applications based on Macrotermes - Termitomyces symbiosis using 3d printing at the Department of Architecture connected to two past doctoral theses, ongoing research applications, and an investigative and experimental design studio.

Agriculture also brought up actors in algae production and products. This area can also encompass food production such as permaculture, natural farming etc. Activities that took on a bio-related form included also tax accounting, peak innovation and leadership training. In addition, there were actors found within the fields of cleantech innovation and electronics manufacturing for speakers.

In the area of circular economy, there are several efforts to both bring together actors (cradle net) and map significant others (SB insight), including research dedicated to the field which seems ongoing at Uppsala University. There is also research into Bioeconomy at Lund University that has created a collaborative learning platform between academia and industry to meet and identify, carry out and communicate innovative, analytically advanced and yet problem-oriented research for a sustainable future circular bioeconomy covering the whole biomass value chain. This includes also the communication/education/trendwatching circulareconomy group who take a broad take on circular economy, within main fields that include architecture, furniture, packaging, "circular living", circular business models, circular economy for cities/regions, regenerative agriculture.

Training

A few actors in Sweden have been found to train Biomimicry both to private and public sectors including museums, universities, schools and design. One actor, Universeum – a public science centre and museum in Gothenburg, has held training into biomimicry programmes for primary and secondary schools for several years.

Forums and Innovation Platforms

There are approximately 11 forums or platforms identified that have national and/or international influence. These actors include both biomimicry, circular economy, cradle to cradle thinking and other forms of sustainable consultancy and/or platforms for sustainable knowledge. Some platforms are directly linked to academia, while other focus on business and industry as their main audience. One platform called BioInnovation in particular has strong connections both with private and public sectors, and is linked to research ongoing at the Wallenberg Wood Centre. BioInnovation is a strategic innovation programme financed by VINNOVA, The Swedish Energy Agency

and The Swedish Research Council Formas, and by the participating organizations that transform ideas into innovation involved with several ongoing projects which takes inspiration from nature, resulting in biomimetic solutions. They connect organizations from different industries and sectors and give support in creating these projects. In this sector, we identified the Natural Step group as an international platform operating also in other Nordic Countries. Many of the identified actors in this sector are geared towards design, development, materials, and innovation.

2.2 Findings in Denmark

Biomimicry in the sense of bioinspiration being integrated with considerations of sustainability is mainly found within the educational institutions. There are university level courses at DTU (the course is part of the curriculum of the engineering master education in design & innovation), Aalborg University, The Royal Academy and Kolding Design School. However, there are many places in academia and industry where there is a profound interest either in bioinspiration or in sustainability, paving the way for a more widespread use of biomimicry through collaboration.

At DTU there are biomimetic research groups working on very detailed research within lubrication mechanisms in animal joints for reduced wear and long life movable products, on the study of micro flow patterns in shark scales for reduced energy consumption in sea vessels, study of the structural colour mechanisms in beetle and butterfly surfaces and in diatom algae to produce long lasting fade proof pigments, the mimicking of mosquitos stinging for making disposable polymer needles, and on artificial muscles based on electrically and magnetically controlled polymers. There are also strong research groups within LCA and circular economy with comprehensive industrial collaboration on sustainability.

At the Royal Academy the Flora Robotica project explores how plants grow and to what extent they can be manipulated using natural stimuli like light to control growth direction.

In industry, the large company Novozymes uses biological inspiration for the production of their industrial enzymes and is actively involved in circular economy initiatives like the Launch Nordic. Unsilo produces computer software that can do intelligent text searches – originally made to search biology texts to find functional analogies to be used in technical development in biomimetics. 3xN Architects are very actively promoting and exploring circular economy to achieve buildings that easily can be dismantled and reused for new houses. In Odense there is a strong robotic research community with a number of large companies and a large research group at SDU.

Within consultancy, there are Innovation Lab and Teknologisk Institut offering courses on biomimetic innovation.

Denmark has no established biomimicry network though there is some initial intent and desire from an actor who is going to collaborate with Biomimicry UK on their workshop further on this year.

2.3 Findings in Norway

Academic research and development related to biomimetics and nature inspired applications is active at least at the Norwegian University of Science and Technology (NTNU), Norwegian University of Sciences (NMBU) and at the Oslo School of Architecture and Design. At NTNU in the Department of Engineering Cybernetics, biomimetics is applied in robotics. The research challenge is to control snake robot locomotion in challenging outdoor environments. At NMBU, the protein engineering and proteomics group (PEP) is working with enzymes to establish green chemical transformation processes.

The SINTEF research division SINTEF digital is doing interesting research in IT and in the internet of things applications and enhancing them with properties derived from natural systems. They are researching whether it is possible to increase robustness, security and privacy within IT infrastructures by introducing diversity and evolution to software.

In the industry sector, we identified Thales group as an international company operating also in other Nordic Countries. The company has utilized biomimetics in product development e.g. mimicking butterfly's wings tiny comb-like structures to create low energy communications technologies. Another company identified is Abalonyx AS whose goal is to produce a super-tough material mimicking the Red Abalone structure.

Consultancies were also identified in the industry sector. One of the most important to mention is BiomimicryNorway (established in 2014) that is offering biomimicry consultancy and education and training services, and has several ongoing development projects with different actors e.g. City of Oslo. BiomimicryNorway is a member of the European Biomimicry Alliance.

BiomimicryNorway also aims to build the Norwegian Biomimicry network. The term biomimicry was quite well recognized within the government owned innovation platforms Innovation Norway and the associated industry clusters Norwegian Centres of Expertise. The request to participate in the mapping was received with great interest on behalf of these organizations, and the response was that these organisations wish to leverage the biomimicry methodology in green innovation development within industry. Another organization in the category forums and innovation platforms is Circular Norway, an association that was established in 2017 aiming to advance circular economy in Norway.

2.4 Findings in Finland

In Finland, the term biomimicry was not commonly used, and most identified activities found were related to biomimetics or bioinspiration. On the other hand, there were a lot of activities related to circular economy in industry and other sectors. The leading organisation in this field is Sitra. Yet, even though the fundamental analogy to

circular systems comes from nature, the activities in this field are not profoundly tied to mimicking natural systems in the creation of industrial circular systems.

Research related to biomimetics was found in two universities; Aalto University and University of Oulu. At both universities, research is related to materials development and molecular level biomimetics. Aalto University hosts the Centre of Excellence in Molecular Engineering of Biosynthetic Hybrid Materials Research (HYBER) of Academy of Finland. Leading research groups in biomimetics at Aalto University are; Professor Olli Ikkala, Professor Markus Linder and Professor Orlando Rojas. In addition, Åbo Academie has offered courses in biomimetics and biologically-inspired design. At the University of Oulu and at the Tampere University of technology, there is research related to biotechnology and biomedical technology and mimicking of natural conditions in vitro process conditions.

Examples of applications of biomimicry or bio-related examples in business and industry were hard to find in Finland. In the category industry, we listed three consultancy companies, one research and development company related to antimicrobial technology, one company related to materials development, and one related to plumbing. None of the technology companies were currently found to directly apply biomimicry or biomimetics in product development. The consultancy Biomimita Ltd. (established in 2017) is a biomimicry consultancy and has the aspiration to become an official member of the Biomimicry Institute. Ethica Ltd and Natural Step Finland are sustainability consultancies with a broader scope in circular economy and nature-inspired solutions.

The Finnish Environmental Institute has a strong research focus in nature-based solutions. Biomimicry or bioinspiration, according to their definition, is seen as a sub-category of nature-based solutions. Most of the current research in nature-based solutions focuses on bioutilization, i.e. using nature as a beneficial component in human systems.

Finland has a strong focus in circular economy and bioeconomy, and there are a lot of activities in these fields, which are not registered in this listing. One actor listed related to circular economy is Motiva which facilitates a platform called Finnish Industrial Symbiosis System (FISS).

It seems that there is a growing interest towards biomimicry or biomimetics in Finland, which is demonstrated by a recent study by Business Finland on the opportunities of biomimetics within the cleantech sector. One of the findings in this report too is that biomimetics and biomimicry is very little used in the Finnish cleantech sector. Overall, there is a lot of confusion amongst actors on the bio-terminology and of its translation into Finnish. It should be said that the term Biomimicry is still rather unrecognized.

2.5 Findings in Iceland

Only a few actors were identified in Iceland. The best source of information related to Icelandic activities was a master thesis by Sigríður Anna Ásgeirsdóttir 'Biomimicry in

Iceland: Present Status and Future Significance' (Ásgeirsdóttir 2013). The thesis concluded that biomimicry is largely an unknown concept in Iceland and that true biomimicry applications in Iceland are relatively rare. The thesis suggests that the main reasons for this are fourfold: the lack of funding for experimental research, the lack of structured governmental policy, segmentation of the educational system and the lack of communication between different scientific fields that hamper the creation of an interdisciplinary approach as suggested by the founders of biomimicry. However, the attitude towards the idea behind the concept was positive by all actors interviewed for the thesis once they learned about it. Increased focus on biomimicry solutions in the future can be anticipated if structured efforts are put in place to increase awareness about biomimicry.

The actors mentioned in the thesis were contacted during the mapping process but some of them announced that they are not active in the field anymore and some were not reachable. The remaining few identified actors were at the Reykjavik University and the medical technology company Ossur who design and manufacture bionic prosthetics. At Reykjavik University, nature and especially intelligence in natural systems is used as a model in the design of artificial intelligence in the Centre for Analysis and Design of Intelligent Agents. On the other hand, biomimicry is recognised in the research related to technology development.

Two potential forums for disseminating knowledge in Iceland are the Iceland Innovation Centre and the Iceland Design Centre.

2.6 Presentation of the European Scene

In mainland Europe, there seem to be two families of bioinspired communities; those related to the Biomimicry Institute, and those that are part of a biomimetic scientific research and development network.

The first community stems from the Biomimicry Institute, a non-profit organisation, is based out of the Montana in the USA.⁹ It was founded in 2006 by biologist Janine Benyus and social entrepreneur Bryony Schwan, who has subsequently developed educational training with educators in schools, universities and non-formal environments (museums, zoos, aquariums) to expand biomimicry into the educational systems. As a result, they offer a range of courses through the global community of educators called BEN (Biomimicry Education Network).¹⁰ In 2008 they launched an online catalogue called AskNature which contains a wealth of information from nature's solutions to design challenges.¹¹ In 2010, they combined entities with the Biomimicry Guild, a consultancy started by Janine Benyus, to formulate Biomimicry 3.8 which is a bio-inspired for-profit consultancy that offers biological intelligence

⁹ <https://biomimicry.org>

¹⁰ <https://asknature.org/groups/biomimicry-education-network/gpages/#.WvSY3ci-l24>

¹¹ <https://asknature.org>

consulting, professional training/certification and inspiration to biomimicry enthusiasts.¹² Biomimicry 3.8 and the Biomimicry Institute are under the holding company, The Biomimicry Group.

Over the past decade, the above biomimicry organisations have trained a number of actors around the globe in 21 countries (2018 figure) with 6 officially website-listed institutes connected to the Biomimicry Institute in Europe: Biomimicry Iberia, Biomimicry Italy, Biomimicry Switzerland, Biomimicry Germany, Biomimicry Netherlands and Biomimicry UK. In the USA, they have 36 regional networks and worldwide over 12,000 participants in their network.

The second community consists of the scientific community of Biomimetics which has had a long-standing presence in Mainland Europe, and in some countries such as Germany and the UK, has already existed for 25 years with pioneers such as Julian Vincent and George Jeronimidis (UK), and Werner Nachtigal and Thomas Speck (Germany).

Overall, there are four countries that are leading the Biomimetic-inspired fields: Germany, UK, Switzerland, and France. In Germany, biomimetic networks already appeared in the early 2000's with a central centre of BLOKON, supported by the government. BLOKON, hosting over 28 main actors in the field of bionics and biomimetics in Germany. They have grown to be one of the most efficient networks in the world, and have as a result created the most prestigious research centre with approximately 120 million euros year budget and an accepted and fundamental field of biomimetics. Over the past years, BLOKON has grown into a series of localized and regional networks and Germany is also a leader in higher education with at least 20 curricular master's degree programs. In Germany, we have also identified the Deggendorf Institute of Technology/Biomimetics, who look into Biologically-inspired design (BID)/innovation, biomimetics, surface technologies and methodologies of BID for the application in industry. Bionikum in Austria is very connected to the network in Germany.

In France, one of the largest networks in Europe is the Biomimicry European Centre of excellence (CEEBIOS), soon predominantly funded by the French government. CEEBIOS has been producing a significant dynamics in bioinspired fields launched in 2014 to coordinated academic research with over 200 laboratories dedicated to biomimetics in France, including over 50 large companies. They are currently in negotiations with the ministry of research and ministry of industry to receive governmental support. Their method stemmed from bottom up initiatives to gradually formalized structure, which rely on the state to continue operating. In addition, architecture in biomimicry is a huge topic in France with currently the first PHD dedicated to biomimicry and multi-functional envelopes.

The UK was early involved in the field of biomimetics with pioneers Julian Vincent and George Jeronimidis. Currently the main centre of research for nature-inspired manufacturing is being created at Heriot-Watt University in Edinburgh by Marc

¹² <https://biomimicry.net/>

Desmulliez. In Switzerland, there is an emerging dynamics in biomimetics with a bio-inspired material centre (NCCR).

Other Biomimicry-related entities that do not have formal ties to the Biomimicry Institute but bring together a variety of actors and activities across Europe are also present. An example is the European Biomimicry Alliance (EBA), a loose group of NGOs (organizations, not individuals) focused on bio-inspired innovation from all over Europe. The EBA gathers a few times per year to discuss the state of biomimicry in Europe. Both Biomimicry Norway and the authors from this report are involved from the Nordic regions.

In addition, there are several other biomimicry/bio-inspired networks in Europe also vital to mention: Biomimicry Belgium, Biomimicry Europa (France/Belgium), Biomimetic (France), the Centre for Biomimetics and Natural technologies (UK), Exploration Architecture (UK), Schumacher College (UK), Biomimicry Greece, phi360 (Germany) and Bioversum (Austria). Bioversum is also a consortium that connects many of these actors mentioned above together. In the Netherlands, Ingrid de Pauw and Conny Bakker have worked with biomimicry and sustainability in academia and in NGO's. We have also been informed that there is Biomimicry activity taking place in Turkey, Cyprus and across the former Yugoslav countries, although these seem to be in early stages. Both Bioversum and Biomimicry Iberia are conducting exhibitions into the bioinspired topics this year, 2018.

From discussions with a number of these actors, we see that there exists a dichotomy of approaches between the biomimicry and biomimetics in which a tension has arisen between the two fields. In this friction, the community surrounding the Biomimicry institute work seems to be discredited by the more hard-core biomimetics as not being rigorous enough, non-legitimate, nor scientifically supported. This discord need to be addressed when developing the future Nordic scene. In response to this division, the EU commission has chosen to classify biomimicry and biomimetic related topics under the wording 'nature-inspired Solutions' in order to merge the diverse methods and approaches.

2.7 The Nordic Network of Actors and Opportunities for Green Business Development

Most of the direct connections between activities and actors are found within a country. As stated earlier, the only country having an active organisation promoting and building a biomimicry network is Norway. However, in Sweden the actors are quite connected. This observation underlines the necessity for creating a more organized network and network activities. The biomimicry scene in Sweden has gained a degree of maturity, and support is needed to pursue these activities and leverage their full potential in green innovation development given the already existing and interesting knowledge base. The strength in the networks, in Sweden and in the Nordic Countries in general, is that there is a lot of diversity in the activities and ideas of biomimicry and biomimetics are applied in many sectors (see figures 10 and 11 in the beginning of

chapter 2). Collaboration between sectors and between Nordic regions is not yet very extensive.

The pioneering technology companies in all countries working with biomimetics have close collaboration with universities but there are still only a few such cases. In the mapping we identified for example Aquaporin A/S and Swedish Biomimetics 3000 AB. One respondent in this study underlined that biomimetics, especially in molecular and materials level, requires quite often long research efforts before commercial applications can be developed. The risk in R&D for a company is quite high. Research in universities is prerequisite for green technology development around molecular and materials level biomimetics.

There is stimulating and exciting research in universities in all of the Nordic Countries. Despite some good examples, it seems though that there is a knowledge gap between research and industry. In Denmark, Technical University of Denmark (DTU) is a major Nordic hub for research related in biomimetics in terms of their diversity of research activities. In Sweden, both Uppsala University and Lund University have various research tracks into Biomimetics (See Swedish Findings for further details). The observation they have is that companies in general are not familiar with the concepts biomimicry and biomimetics and do not recognize the related opportunities. Similar observations are made by Business Finland in their recent study on opportunities of biomimetics in cleantech sector and other respondents.

One respondent pondered if research and industry are using biomimicry to its full potential in the field of wood science and engineering. The applications of cellulose and better understanding of the plant cell wall is something the Nordic countries excel in due to extensive research into wood materials (Wallenberg Wood Centre, Biomime, Umeå Plant Centre, Aalto University, Technical Research Center of Finland). Another respondent stated that the application of biomimicry or biomimetics in lubrication has a fairly long history, but visible industrial outcome (including biomedical applications) is still in its infancy and requires further attention and support.

The most prominent sectors regarding green business development based on current activities seem to be activities related to product and materials development in general, and applications in urban planning, architecture and building solutions and water, sanitation and the heating, ventilation, and air conditioning (HVAC) (see figure 11 in the beginning of chapter 2). Also, fashion and textiles, biomedical and medical technology applications have ongoing activities.

Many of the identified forerunners in biomimicry are practitioners in urban planning, architecture and building solutions. Bringing these actors together could potentially create a very attractive knowledge pool that would support the very urgent transition in the building sector towards more greener practices.

Biomimicry-led solutions to save, collect or treat water and sanitation, as well as ventilation strategies, are much needed globally as solutions cannot keep relying on energy consumption and need to be sustainable. Seeing, that there are already very interesting commercially viable biomimicry applications in these sectors including applications for HVAC and water treatment (e.g. Aquaporin A/S, Watreco / H₂O vortex), the water and HVAC sectors could be key actors to embrace biomimicry in product and

systems development. Biomimicry could potentially provide a very powerful design and innovation tool for the whole water sector in the Nordics.

Regarding medical technologies, one respondent made a note that biomimetics or biomimicry is being exploited in the research of pathogens and related diseases by studying different organisms and their ability to fight the pathogens. The biomedical field, including pharmaceuticals, should exploit academic studies more on their R&D projects, because it is well known that the pipeline of new drugs and antimicrobials has waned during the past few decades and led to a global crisis especially on antimicrobial resistance (including drugs).

Algae production and nutrition needs its own mention as potential runner up in green business development and biomimicry as it is used for a variety of practices; for food, for filtering light, for mimicking and filtering. There are actors identified in Sweden - Fredrika Gulfort (Simris Alg) and Fredrik Gröndahl (KTH).

There are also several actors in the stakeholder map that work with agriculture, food, forestry or permaculture for example. Though these are fundamental fields in terms of creating natural processes and systems by for example 'growing food in nature's way' – we do not consider them to be 'biomimicry' per say.

We also identified certain small companies who have capitalised on the biomimicry field seeing that there is an opportunity for product development. Though, we do not see that there is research going into the actual design processes.

2.8 Findings: Discussion and Conclusions

There is an identified confusion on the different definitions between biomimicry, biomimetics and other bio-satellites. We have also received feedback from some actors in this study with a request not to mix the terms and to be cautious of not rendering all bio-related activity as biomimicry or biomimetics.

In terms of forerunners in biomimicry, Norway seems to be most well-organised and has set up the only biomimicry organization in the Nordic region (BiomimicryNorway). However, Sweden has the most activity based on the mapping findings and more identified actors practicing biomimicry. The forerunners in biomimicry and actors that train biomimicry in various contexts in the Nordics are; In Norway, BiomimicryNorway. In Sweden, Anna Maria Orrù (Chalmers University, KTH, Uppsala University and other academic contexts), Karolina Netterlund (Equidesign), Alexina Thorén Williams (GU/Universeum), and at its beginnings of promoting the field, Material ConneXion Skövde. In Denmark, Torben Lenau (DTU), Henrik Riisgaard (Aalborg University), Vibeke Riisberg (Kolding Design School) and Birgit Bonefeld (Tekstilbiologi), in Finland Biomimita Ltd. and Finnish Environmental Institute (Nature Based Solutions).

We have also identified several biologists/ecologists that support biomimicry workshops; In Sweden there is Fredrik Moberg and Louise Hård af Segerstad (Albaeco group), Niclas Norrström (University of Skövde), Noël Holmgren (SLU- Alnarp).

The main potential for disseminating biomimicry in the Nordics is in filling up the information and knowledge gap between research and industry, fostering cross-disciplinary and transdisciplinary collaboration within research and other practitioners, and integrating biomimicry into existing research and innovation programs and initiatives related to circular economy, bioeconomy and biomimetics. A suggestion from a respondent was to involve the natural history institutions towards these efforts (e.g. Universeum in Gothenburg, Sweden already has been promoting/training biomimicry).

Many of the respondents proposed a Nordic interdisciplinary networking seminar or a series of other events that would bring together researchers and industry, demonstrate the practical applications and increase the general knowledge in the field. Some of the respondents even offered their contribution to hosting events. Some of the respondents and the authors of this report suggest establishing a Nordic biomimicry and biomimetics network and society to coordinate such efforts.

Some of the respondents in academia emphasized the challenge of interdisciplinary research and development, especially bridging biologists with designers and engineers. Biomimicry needs to be taught in universities at both Bachelor and Master levels especially in design and engineering in order to pave the path for innovations. Respondents underlined the need for workshops and summer schools where designers and biologists would be brought to the same table to share ideas and adopt tools that could facilitate collaboration. The EBA already runs a series of such events and could be an interesting network to collaborate efforts with. Forming a common language is not easy. One respondent stated, that engineering students have trouble understanding scientific papers and discussions with biologists. Hence there is a need for individuals that can bridge these gaps of knowledge and help make the biology understood and transferable. Some of the respondents made the observation that better, easier and more practical tools need to be developed to make the threshold lower for designers and engineers to use biomimicry. Here too the benefits of a Nordic network and Nordic collaboration and disseminating knowledge within existing practitioners comes in, as there are universities such as DTU in Denmark and Chalmers University in Sweden that are developing processes and tools for implementing biomimicry into architecture, design and/or engineering.

Many of the respondents saw the potential for some industry sectors to take more advantage of the academic research in the industry R&D projects. In order to increase the general knowledge and interest towards biomimicry and biomimetics, respondents insisted on highlighting Nordic champions, along with practical and inspiring case examples that exist in research and industry. The respondents and the authors of this report identified some fields that are particularly interesting from the green business development point of view. These were materials development and endeavours in molecular level biomimetics, architecture and product design (incl. mechanical engineering) and applications in built environment, HVCA and water sector. Relation of biomedical development and data sciences to biomimicry were thought to be interesting and should be explored further. Sustainable and circular materials have a central role in circular economy and cradle to cradle thinking. The authors of this report

note that there are overall interesting research efforts related to materials development (molecular tailoring of materials) in the Nordic universities, of which many base their research into biomimetics. The research could greatly benefit from biomimicry methodologies in assessing the systems level sustainability for material applications. Biomimicry could be used as a tool to ensure that new materials development is per definition circular economy fit.

Some of the respondents expressed a concern for the limited methods that are available to ensure that biomimicry solutions for product development can lead to enhanced sustainable performance, avoiding potential rebound effects. They emphasized the importance of using a science-based assessment in order to reach an environmental sustainability using biomimicry strategies or types. This entails evaluating their strengths and weaknesses in terms of environmental sustainability when viewed from a life cycle perspective. Working with Biomimicry requires an understanding at the life cycle scale, including a life cycle analyses.

The authors of this report conclude that biomimicry as methodology and design approach has a great potential to contribute to the Nordic implementation of the global agenda 2030. Universal tools are needed, and biomimicry may be the most natural and ecological way to solve sustainability problems. Table 1 on the following page summarizes the opportunities and strengths of biomimicry in the Nordic Countries and of the Nordic network of actors.

Table 1: SWOT-analyses of Biomimicry in the Nordic countries

Strengths	Weaknesses
<ul style="list-style-type: none"> • Connection with nature in Nordic Countries, knowledge of species, and easy access to nature. People in general have a nature underpinning • Diverse ongoing research activities and university education already in place in many of the Nordic Countries • Growing interest (recently founded BiomimcryNorway and aspiration to put up similar organisations in Finland, Sweden and in Denmark). • Existing successful Nordic examples of applying biomimicry and biomimetics in business 	<ul style="list-style-type: none"> • Similar to any complex methodology, biomimicry needs investment - time, money, education etc. • There are no shortcuts towards sustainability in biomimicry • Biologists are not present in some of the design tables • Research in biomimetics does not always have a strong connection in sustainability • Confusion in terminology, misuse, misunderstood
Opportunities	Threats
<ul style="list-style-type: none"> • Method for reaching a truly sustainable society • Holistic approach on form, process and systematic level • Cross-disciplinary (widely useful, common language across discipline) • Transdisciplinary (biomimicry is truly a transdisciplinary process, bringing a biologist to the design table is unique and involves more interlaced forms of collaborative work). • Nature as a solutions and knowledge bank • Constant learning and expansion of the discipline • Inexhaustible knowledge bank taken from 3.8 billion years of R&D • There is interest in sustainability and to looking to nature for inspiration. There is opportunity to join them together, such as seen in biomimicry 	<ul style="list-style-type: none"> • Competing methodologies (biomimetics vs biomimicry) • Silo-thinking, narrow-minded use. Do not think how your particular area effects other areas/processes. A lack of systematic approach and thinking • Unsustainable processes, assessing the sustainability (LCA. etc) • Lack of Political support, and support from the public sector • Lack of funding • Not enough training or trained leadership to promote biomimicry • Use of the term because it is a trend with no research underpinnings or biological thought

3. Recommendations

The Summary of recommendations are as follows based on our findings:

- Nordic Centre for Biomimicry, Biomimetics and Bioinspiration
- Nordic Summit 2019 collecting the mapped actors in this report
- Education platform for opportunities to train and study Biomimicry and Biomimetics
- Continuation for the online presence/stakeholder mapping
- Support for the transdisciplinary process: facilitation and programs for cross institutional collaboration
- Funding towards biomimicry and biomimetics, both in academia and industry
- Biomimicry promotion and support for industry from the Public Sector through identified forums and innovation platforms
- Clearer definitions of biomimicry and other bio-related methods
- Avoid binary relation between biomimicry and biomimetics
- Distribute the report to the actors and through various conferences/symposiums

It is clear from the mapping results that there is a need for a comprehensive Nordic network for Biomimicry given that there are many actors in place in the different Nordic regions but little awareness of one another. Therefore, in order to strengthen Scandinavian influence as biomimicry frontrunners and connect to the various European alliances, setting up a Nordic Centre for Biomimicry, Biomimetics and Bioinspiration is recommended with representation and key actors from each Nordic region. There has been interest from the authors of this report and the Albaeco group connected to the Stockholm Resilience Centre at Stockholm University to investigate such a collaborative effort with help from the Nordic Council of Ministers. Such a centre would bring together several existing and upcoming biomimicry institutes from the different Nordic regions, as well as key actors in the field of biomimetics. Currently, only one official established institute exists in Norway (BiomimicryNorway) set up in 2014.

In discussion with a European actor, there is an identified challenge in most European partnerships to federate and animate their networks. To this endeavour, thus far Germany, Switzerland France and UK have been the only ones to really succeed. Though there exists both a rift and struggle between the two approaches of biomimicry and biomimetics, as seen in the Mainland European partners, we believe that both bring important perspectives, methodologies and tools of using nature for inspiration. The future, expressed by one European partner, is that at some point these two approaches will merge. The issue is that they are also opposing scientific approaches, perhaps labelled as hard and soft science. As such, the authors in this report validate both

methodologies and believe that the endeavour must be transdisciplinary, however, we also believe that both efforts must strive towards sustainable means. One relies on the other also in order to bring about a behavioural shift both in the research community, industry and education. And as such, the variety of approaches need each other to disseminate and communicate with and to wider audiences. We also recommend that in the set-up of a Nordic Centre for Biomimicry, Biomimetics and Bioinspiration, we should contact the main European networks (i.e. CEEBIOS, BIONIKON etc) for assistance in structuring the Nordic network based on their experiences.

If such a network was to be established, it is important to first compose a Nordic summit, which would bring together actors from the different regions that have been found in this mapping process. This summit would include the European alliances described in chapter 2 as a way of linking up to long-standing networks in Europe. Rather than looking only to the Nordic Region for pioneering environmental work, we recommend expanding ties to international collaborations. Our recommendation is that the summit takes place in Spring 2019. This recommendation also came as a wish from actors who were mapped who stated a desire to meet others in the field.

In terms of education and training, there is a need for more opportunities to train and study Biomimicry and Biomimetics given the evidence of a gap between research and industry. Education and the teaching/training is a large challenge in most Nordic countries and as such a significant effort should be made and funded with institutional input. Such efforts need to occur both in primary and secondary levels, which is an achievable potential given the close-knit education already into nature in Nordic schools, and at the level of university education (Bachelor and Master levels) tailored to diverse sectors and their transdisciplinary overlaps. As seen from the European landscape, Germany already has 15 allotted degree courses (licenses and masters) in biomimetics, wherein there are 25 listed in the whole of Europe.¹³

We recommend a stronger educational platform for training biomimicry in different sectors and for knowledge dissemination and further activities. For instance, we have located a platform based in Germany for finding Biomimetic education and networks.¹⁴ There should be a Nordic platform that highlights similar opportunities for studying and training biomimicry in the Nordic regions. Hence, we also recommend a comprehensive online presence for the state of Nordic actors in Biomimicry. As such, there is opportunity to continue the mapping process of biomimicry actors online. Though we have to the best of our knowledge mapped key players in the Nordic field, we are aware that this appendix list may not be comprehensive including all actors.

In line with education, there is a need for cross-institutional collaboration as Biomimicry is a transdisciplinary process, which involves different fields at the table in collaboration with biologists. In Biomimicry, a biologist or similar actor is needed in order to be considered a true bioinspired design. We find many actors who shortcut through this important step. This collaborative effort requires training, funding and time in order to be successful.

¹³ CEEBIOS report 2018 (Ceebios 2018).

¹⁴ <http://www.biokon.de/en/bionics/education/>

Such endeavours would mean that there is a need for more funding opportunities for the Biomimicry field both in education and industry, and a way to promote and support biomimicry. Already in 2014, then Swedish environmental minister (Miljöminister) Åsa Romson highlighted the need for providing further funding to biomimicry research.¹⁵ In this case, the importance to distinguish biomimicry from the other bio-related terminology is especially important in terms of distributing funding to appropriate education, research and industry potentials that need support and development.

The public sector needs to get involved and take a stronger role in promoting biomimicry. There is a need to push biomimicry as a sustainable practice and therefore a move for clearer definitions and relations to sustainable processes through Biomimicry. We also recommend integrating biomimicry in existing publicly funded programs and initiatives related to circular economy and green development. We see that public private partnerships are necessary for companies to be able to share the risk of research and development of novel solutions. In order to induce green business development, it would be interesting to explore the idea of running a Nordic accelerator program within sectors that have currently most biomimicry related activities.¹⁶ The accelerator program would be run by the Nordic innovation platforms.

There is a lot of interest in the field from all Nordic countries but not many actors who consider themselves working in the field. The mapping process has highlighted a strong desire for biomimicry, we found many actors interested that would like to get more active in the field which again highlighted a need to network and mobilize them. Actors who already work in areas that come close to biomimicry, can with a little help, go closer to the field and find better connections and collaboration.

In summary, the next steps are to distribute this report to the actors who have been part of the mapping process, present results at various symposiums/conferences, and gather interest for a common centre and a symposium in 2019 as we recommend a structure and more institutionalized effort between and within the Nordic Region. As such, we have already interest from the authors in this report and from the Albaeco group at the Stockholm resilience centre in Stockholm to embark on such an effort with help and allotted funding from the government. There is also interest on part of these actors to apply for further funding from the Vetenskapsrådet (Swedish Research Council) in collaboration with European actors CEEBIOS in France to help develop such a centre. The European actor has expressed both the effort and desire to help the Nordic Region to structure such a centre and to build more sustainable practices in biomimicry and biomimetics. Such a centre could also be a strategic effort to coordinate the multi-actors already involved in projects throughout, and also consult them on reaching more sound and ecological solutions. Furthermore, there is a need for developing and coordinating a database, platforms for biological models and examples/case studies of biological innovation. These recommendations are taken from research conducted by CEEBIOS in France.

¹⁵ <https://sverigesradio.se/sida/artikel.aspx?programid=406&artikel=5990889>

¹⁶ Such as Nordic LAUNCH (launch.org) or other programs bridging research and business.

One further recommendation is to provide a platform for the merging of biomimicry and biomimetic efforts in the Nordic Region in order to avoid the binary relation between these two efforts that seems to be occurring in the European scene. As such, both these communities of research and practice could combine efforts into bioinspired education, institutional structures and ecological endeavours towards the outlined goal of sustainable development.

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Appendix 1: Project Group

Torben Lenau

Torben Lenau has a profound interest in nature and in engineering and in the way the two can meet. He has many years of experience from academia and industry within design & innovation, product development, materials & manufacturing, eco-design and bio-inspired design. In a project on eco-design within product families in a collaboration between 6 larger Danish companies he acted as project manager demonstrating how the use of LCA-analyses could be extended from single products to much wider product families thus making the assessment of sustainability more realistic. He has been active in several projects on bio-inspired design including bio-photonic structures for structural colours inspired by beetles and diatom algae and plant movement inspired robust and autonomous solar trackers. Mosquitos and other biting animals has given input for new ways of drug delivery and has formed the basis for the development of disposable medical polymer needles. He has also developed the biocard method for bio-inspired design and teaches a master course on bio-inspired design where 60+ students each year are trained in searching for biological analogies to specific functional problems and in acquiring sufficient knowledge of the biological equivalents.

Lilli Linkola, MSc

Lilli is a circular economy consultant at Ethica Ltd., a Circular Economy Consultancy operating internationally across private and public sectors. Lilli is specialized in industrial ecology and systems modelling. She works mostly with sustainability in built environment and urban development but is comfortable advising any sector towards circular systems. Lilli has been studying and working with circular economy since 2008. In her previous roles, she used to work as a Project Manager at the Green Building Council Finland, Project Manager at Open Knowledge Finland, Open data specialist at City of Helsinki, Sustainability Expert at the Finnish Innovation Fund Sitra and as private entrepreneur and consultant. Lilli believes all humans can live in abundance. If we study carefully how ecosystems work and apply those principles in developing our economy and industries, we will soon find ourselves in a society that is regenerative by definition: consumption of goods and services creates raw materials and resources. A regenerative society enables renewable growth. Lilli believes that natural ecosystems are a perfect model of circular economy and thus, leveraging biomimicry in systems level – in systems design – is a great opportunity for the Nordic societies.

Anna Maria Orrù PhD SAR/MSA

The foundation of Anna Maria Orrù's work is embedded in biomimicry, natural system design, food and in curating research, providing an innovative approach in the field of sustainable design, art, urbanism and architecture. She has been practicing, teaching and researching biomimicry since 2003 when she met Janine Benyus. She behaves as a connective tissue, working in the interstitial spaces between fields by bringing a variety of diverse disciplines, including biologists, and talents to the table to creatively tackle issues around climate change and environmental sustainability. Her projects and PhD from Chalmers Technical University cover the distinct topics of food, architecture, embodied methodologies, biomimicry, senses and urbanism, explored through the study of organoleptic qualities, encounters and interfaces in urban-making as a way to explore food systems and ecological behaviour. Prior to embarking on the PHD in 2012, she has worked in London, for Ove Arups where her bio-inspired work began in 2003, for Shigeru Ban, Grimshaw Architects and Exploration Architecture. She is a researcher, lecturer and teacher at a number of Swedish Universities since 2010 on the topic of biomimicry, architecture, design, artistic research, feminist spatial practice and urbanism.

Appendix 2: List of actors

Organisation/Contact	Country	Category	Tags
Design School Kolding/ Vibeke Riisberg	Denmark	Academic research and development	Fashion Textiles Circular economy
DTU Chemical Engineering/ Anne Ladegaard Skov	Denmark	Academic research and development	Energy transducers Biomimetics Biomimicry
DTU Environmental Engineering/ Claus Helix-Nielsen	Denmark	Academic research and development	Water technology Biomimetic membranes Biomimetic resource recovery Biomimetics Membranes
DTU Management Engineering, Division of Quantitative Sustainability Assessment/ Michael Hauschild	Denmark	Academic research and development	Sustainability assessment Technology Biomaterials Biochemicals Food Energy systems Transportation Buildings Built environment Electromechanical products Nanotechnology Environmental technologies
DTU Mechanical Engineering & Aalto University School of Engineering/ Johan Rindmar	Denmark	Academic research and development	Product development solar energy energy technologies
DTU Mechanical Engineering/ Daniela Pigosso	Denmark	Academic research and development	Product development Biomimicry Circular economy
DTU Mechanical Engineering/ Lars Drøgemüller Kjeldsen	Denmark	Academic research and development	Medical applications biomimetics
DTU Mechanical Engineering/ Nicklas Werge Svendsen	Denmark	Academic research and development	Medical technology Bioinspired Biomimetics
DTU Mechanical Engineering/ Seunghwan Lee	Denmark	Academic research and development	Tribology Mechanical engineering Biomedical Biomedical applications Biomimetics
DTU Mechanical Engineering/ Torben Anker Lenau	Denmark	Academic research and development	Industrial design engineering material sciences design work education biomimicry biomimetics
DTU Nanotechnology/ Anders Kristensen	Denmark	Academic research and development	Biophotonics bioinspired surfaces Bioinspired
DTU Physics/ Kirstine Berg-Sørensen	Denmark	Academic research and development	Microfluidics Fluidics Biomimetics
Professional/ Birgit Bonefeld	Denmark	Academic research and development	Material functionalization Materials development Textile fibres Textiles Biomimetics
Royal Academy of Arts Copenhagen, CITA (Centre for Information Technology and Architecture)/ Mette Ramsgaard Thomsen	Denmark	Academic research and development	Architecture Computation Building structures Materials development Actuation Sensing Bionics Biotechnology Robotics robotic fabrication
University of Copenhagen Department of Plant and Environmental Sciences/ Marianne Ellegaard	Denmark	Academic research and development	Diatom algae, biophotonics
Aalborg University/ Henrik Riisgaard	Denmark	Education and training	Engineering
Teknologisk Institut, Industrial Biomimetics/ Claus Bischoff	Denmark	Forums and innovation platforms	Biomimetics Biomimicry Forum Platform Materials development Technology Cleantech
Vugge til Vugge/ Annette Hastrup	Denmark	Industry	Circular Economy Consulting

3XN architects GXN innovation/ Kasper Guldager Jensen	Denmark	Industry	Products Buildings Master Planning Product development Design Materials development Architecture Circular economy
Aarhus University Hospital/ Susanne Backer	Denmark	Industry	Recycling Plastic packaging Circular economy
Aquaporin A/S/ Dr. Jörg Vogel	Denmark	Industry	Cleantech water water treatment water filtration membranes biomimetics
Sarah Gregersen	Denmark	Industry	Consulting Urban plant social innovation Product innovation Living system leadership
Innovation Lab/ Anders Sahl Hansen	Denmark	Industry	Industrial al development
Novozymes A/S/ Claus Stig Pedersen	Denmark	Industry	Chemical engineering Enzymes microorganisms production sustainability bioutilisation
Professional/ Caroline White	Denmark	Industry	Construction Housing Natural building
Professional/ Christina Okai Majborn	Denmark	Industry	Biomimetics, co-development seminar, sanitation, developing countries
Symbiosis Center Denmark/ Per Møller	Denmark	Industry	Industrial symbiosis PPP PPI triple helix policy Circular economy
Unsiilo/ Thomas Laursen	Denmark	Industry	Datamining, Computer search engines,
Åbo Academie/	Finland	Academic research and development	Bioinspiration Biomimetics
Biobased Colloids and Materials research group/ Orlando Rojas	Finland	Academic research and development	Art Sustainable development Materials development
BioMediTech/ University of Tampere	Finland	Academic research and development	Bioinspired bioinspiration materials development robotics biomeditech
Centre of Excellence in Molecular Engineering of Biosynthetic Hybrid Materials Research (HYBER) of Academy of Finland/	Finland	Academic research and development	Materials development Molecular biomimetics Biomimetics
Finnish Environmental Institute/ Eeva Furman	Finland	Academic research and development	Urban planning Food Health Nature Based Solutions Circular economy
Natural Resources Institute Finland/	Finland	Academic research and development	Nature Based Solutions Circular economy Biomimetics Virtual nature Sustainability
Professor, Molecular Materials laboratory, Aalto University/ Olli Ikkala	Finland	Academic research and development	
Professor, Research group of Biomolecular materials, Aalto University/ Markus Linder	Finland	Academic research and development	Biotechnology Materials development
Tampere University of Technology/ Pasi Kallio	Finland	Academic research and development	Biotechnology Biomedical applications
University of Oulu/	Finland	Academic research and development	Biotechnology Biomedical Medical applications Physical sciences Bioinspiration Materials development
University of Oulu/ Wei Cao	Finland	Academic research and development	Physical sciences Bioinspiration Biomimetics Materials development
VTT/	Finland	Academic research and development	Circular economy Water treatment Sustainability water
Business Finland/	Finland	Forums and innovation platforms	Biomimetics
Motiva/ Paula Eskola	Finland	Forums and innovation platforms	Circular economy Resource efficiency Industrial symbiosis
Betulium/	Finland	Industry	Materials development

Biomimita Ltd/ Niina Kuusanniemi-Abbotts	Finland	Industry	Biomimicry Consulting
Ethica ltd./ Lilli Linkola	Finland	Industry	Circular economy Consulting
Lillklobb Permaculture/	Finland	Industry	Food production Education Landscape planning and design Permaculture
Nolla Antimicrobial Oy/ Jani-Markus Malho	Finland	Industry	Biotechnology Biomedical Antimicrobial technology Pharmaceuticals Biomimetics
Suomalainen Putkimies Oy/	Finland	Industry	Plumbing Decoration
The Natural Step (in Finland)/ Outi Ugas	Finland	Industry	Strategic sustainability Biomimicry Consulting
Reykjavik University/ Center for Analysis and Design of Intelligent Agents	Iceland	Academic research and development	Natural intelligence Artificial intelligence Information technology
Reykjavik University/ Ólafur Andri Ragnarsson	Iceland	Education and training	research education technology trends social sciences
Ossur/	Iceland	Industry	Bionics biomeditech
NMBU - Norwegian University of Sciences/ PEP Group	Norway	Academic research and development	Biotechnology Molecular biomimetics Biomimetics
NTNU Department of Engineering Cybernetics/ Filippo Sanfilippo	Norway	Academic research and development	Search and rescue Robotics Biomimetics
SINTEF Digital/ Jakob Høgenes	Norway	Academic research and development	IT infrastructures IoT Nature-Inspired
The Oslo School of Architecture and Design (AHO)/ Birger Sevaldson	Norway	Academic research and development	Architecture engineering
The Oslo School of Architecture and Design (AHO)/ Michael U. Hensel	norway	Academic research and development	Architecture engineering
The Oslo School of Architecture and Design (AHO)/ Research Centre for Architectural Tectonics	Norway	Academic research and development	Architecture
University of Oslo, Institute of Clinical Dentistry/ Staale Petter Lyngstadaas	Norway	Academic research and development	Medical applications Medical technology Dentistry
Circular Norway/	Norway	Forums and innovation platforms	
Innovation Norway/ Claus Gladyszak	Norway	Forums and innovation platforms	Innovation advise Innovation facilitation Innovation development Platform Circular economy
NCE Aquatech Cluster/	Norway	Forums and innovation platforms	Innovation development Platform
NCE EYDE Norwegian Center of expertize, sustainable process industry/	Norway	Forums and innovation platforms	Biomimicry Innovation development Platform
NCE Seafood Innovation Cluster/	Norway	Forums and innovation platforms	Innovation Development Platform
Abalonyx AS/ Rune Wendelbo	Norway	Industry	Materials development Materials Biomimetics
BiomimicryNorway/ Michel Wolfstirn	Norway	Education and training, Industry	Education Consulting Design Management Engineering Urban planing Food production Academia Biomimicry
Professional/ Baard Røsvik	Norway	Industry	Consulting Product development Technology Innovation counselling Innovation development
Thales group/	Norway	Industry	Aerospace engineering Biomimetics
Sareh Saeidi/	Norway	Architecture Parametric	

Albaeco (Stockholm Resilience Centre - Stockholm University)/ Fredrik Moberg, Louise Hård af Segerstad	Sweden	Academic research and development	Biomimicry, Science communication, Policy
Beckmans College of Design/	Sweden	Academic research and development	Biomimicry Design
Blekinge Institute of Technology/ Lisa Ohlander	Sweden	Academic research and development	Biomimicry Sustainable development Management
Blekinge Institute of Technology/ Sophie I.Hallstedt	Sweden	Academic research and development	Sustainable product development
Chalmers Department of Chemistry and Chemical Engineering/ Simon Isaksson	Sweden	Academic research and development	Sweden Water Water treatment
Chalmers University, Department of Architecture and Civil Engineering/ Lars Marcus	Sweden	Academic research and development	Urban systems
Chalmers University, NASA/ Larry Toups NASA	Sweden	Academic research and development	Urban systems Extreme climates
Gothenburg University - Centre for education science and teacher research/ Alexina Thorén Williams	Sweden	Academic research and development	Biomimicry education
Gothenburg University/ HDK / Valand	Sweden	Academic research and development	Biomimicry
K3: School of Arts & Communication, Malmö Uni/ Charlotte Asbjørn Sörensen	Sweden	Academic research and development	Product design Biomimicry
Karolinska Institute, Division of Neurogeriatrics, Department of Neurobiology, Care Sciences and Society/ Janne Johansson	Sweden	Academic research and development	Medical research and innovation
Konstfack University of arts, crafts and design/ Industrial Design, Experience Design Group	Sweden	Academic research and development	Biomimicry Biomimetics Experience Design Industrial design
KTH Royal Institute of Technology in Stockholm, School of Architecture/	Sweden	Academic research and development	Biomimicry
KTH, Department for Sustainable Development Environmental Science and Engineering (SEED) - Seafarm/ Fredrik Gröndahl	Sweden	Academic research and development	Marine resources macro algae bio-based economy
Linköping University, Department of Clinical and Experimental Medicine (IKE)/ Per Fagerholm	Sweden	Academic research and development	Medical Synthetic cornea
Linköping University/ Tomohiko Sakao	Sweden	Academic research and development	Design engineering Product design Service design Bioinspiration
LU - Swedish University of Agricultural Sciences, Department of Aquatic Resources - Aqua/ Noël Holmgren	Sweden	Academic research and development	Biomimicry Ecology
Lund School of Architecture, CITA/ Ana Goidea	Sweden	Academic research and development	Architecture Biomimetics
Lund University, Centre for Environmental and Climate (CEC), Urban nature Nature-based solutions for urban challenges/ Katarina Hedlund	Sweden	Academic research and development	Nature-inspired urbanism Environmental and Climate Research

Lund University, Centre for Environmental and Climate (CEC)/ Deniz Koca	Sweden	Academic research and development	Bioeconomy Circular economy
Lund University, Department of Analytical Chemistry/ Charlotta Turner	Sweden	Academic research and development	Packaging Lotus inspired Material development
Lund University, Department of Architecture/ Anna Petersson	Sweden	Academic research and development	Design Aesthetics
Lund University, Department of Biology, Functional Zoology/ Eric Warrant	Sweden	Academic research and development	Visual science Biomimetics
Lund University, Professional/ David Andréen	Sweden	Academic research and development	Architecture Biomimetics biophysics ventilation building physics
Lund University/	Sweden	Academic research and development	Visual science Biomimetics Bioeconomy Value chain Architecture Multidisciplinary
Molecular Biomimetics, Department of Chemistry - Ångström Laboratory/ Anders Thapper	Sweden	Academic research and development	Renewable energy research Molecular Biomimetics Materials development Biomimetics
Molecular Biomimetics; Photosynthesis group/ Johannes Messinger	Sweden	Academic research and development	Solar Fuels Renewable energy Molecular biomimetics Biomimetics
Nordic Agroforestry/ Johanna Björklund, Christina Schaffer	Sweden	Academic research and development	Agroforestry
Professor, Wallenberg Wood Science Center/ Lars Berglund	Sweden	Academic research and development	Materials development Materials research Bioinspired
RISE Innventia AB/ Mikael Lindström	Sweden	Academic research and development	Materials development Design Experience Perception Processes Packaging Biomimetics
RISE Research Institutes/ Thomas Nyström	Sweden	Academic research and development	Design product development Business development Materials development Product design Resilient systems studies Nature-Inspired adaptive systems
The Swedish Center for Biomimetic Fiber Engineering (Biomime™)/ Vincent Bulone, Professor	Sweden	Academic research and development	Biotechnology Materials development
Treearch/	Sweden	Academic research and development	Bioeconomy Biochemicals Materials development
Umeå Plant Science Centre/	Sweden	Academic research and development	Biomimetics Bioinspiration Materials development
Uppsala University, Department of Chemistry - Molecular Biomimetics; Photosynthesis group/ Gustav Berggren	Sweden	Academic research and development	Chemistry Renewable energy research Biomimetics Bioinspiration Molecular Biomimetics Photosynthesis
Uppsala University, The Centre for Environment and Development Studies (CEMUS)/	Sweden	Academic research and development	Biomimicry
Professional / Chalmers University, Department of Architecture Civil Engineering)/ Anna Maria Orrù	Sweden	Academic research and development, Education and training	Architecture Urban Development artistic research design sustainability design work consulting seminars science communication Biomimicry
CircularEconomy.se/ Tobias Jansson	Sweden	Education and training	circular economy architecture furniture packaging life style circular business models urban development regenerative agriculture Communications Trends Technology trends

equiDesign/ Karolina Netterlund	Sweden	Education and training	Biomimicry design facilitation
Professional/ Ivar Inkapööl	Sweden	Education and training	Biomimicry design furniture
Universeum/ Alexina Thorén Williams	Sweden	Education and training	Biomimicry business innovation
University of Skövde/ Niclas Norrström	Sweden	Education and training	Education Research Ecology Evolution Biomimicry
BiolInnovation/ Oscar Högberg, Anna Wiberg	Sweden	Forums and innovation platforms	Innovation development Bioeconomy
Bioinspired Forum/ Mats Brodén	Sweden	Forums and innovation platforms	Science Communication
Ax Foundation/ Carolina Sachs	Sweden	Forums and innovation platforms	Science Communication
Cirkulär Visionär, Inspirationsbyrå/ Carina Sundqvist	Sweden	Forums and innovation platforms	Circular economy Urban living Sustainable production Sustainable industry Biomimicry
Cradlenet/ Michiel van Noord	Sweden	Forums and innovation platforms	Circular Economy Cradle2Cradle Network creation Innovation facilitation Communications
Green Leap KTH/ Teo Enlund	Sweden	Forums and innovation platforms	research design
SVID - Stiftelsen svensk Industridesign/ Anna Velander Gisslén	Sweden	Forums and innovation platforms	research design
The Natural Step, Sustain In Time/ Outi Ugas	Sweden	Forums and innovation platforms	Circular Economy Sustainability
Stena recycling	Sweden	Industry	Waste management
Arkitektkontor AB, EcoCycleDesign/ Anders Nyquist	Sweden	Industry	Biomimicry Architecture Urban Planning
Biora AB, Straumann AG/ Stina Gestrelus	Sweden	Industry	Medical applications Medical technology Dentistry Biomimicry
Bonkeli Design/ Jeppe Larson	Sweden	Industry	Clothing
ByDemand, Vargbroskolan/ Charlotta Berggren	Sweden	Industry	HVAC Energy Indoor Climate ventilation
CAREX of Sweden AB/ Stanislaw Lazarek	Sweden	Industry	Water wastewater water and food security R&D Biomimicry
Ecoforestry Foundation/ Mikael Karlsson	Sweden	Industry	Ecoforestry
H2OVortex, Watreco/ Håkan Grönlund	Sweden	Industry	Biomimicry water purification
Harvest Moon/ Karin Habermann	Sweden	Industry	Sanitation design Industrial design Circular economy
IDC West Sweden AB, Material Connexion Skövde/ Christian Bergman	Sweden	Industry	Product Development Biomimicry Materials Materials research Materials development
Interface Carpets/	Sweden	Industry	Biomimicry textiles carpets materials development buildings Cradle to Cradle
Matilda Wendelboe/ Annika Wendelboe	Sweden	Industry	Fashion Cradle to cradle
OrganoClick AB/ Mårten Hellberg	Sweden	Industry	Cleantech Materials technology Green chemistry Materials development Chemistry Biomimetics Textiles
Peak Innovation (MYCELIUM CoLab)/ Joel Svedlund	Sweden	Industry	Outdoor industry Sustainable Sports
Phenotype Studio AB/ Kayrokh Moattar	Sweden	Industry	Architecture Urban Planning Biomimetics
SB Insight/ Eva Seignette	Sweden	Industry	Consulting Sustainability Circular Economy Market Research
Simris Alg/ Fredrika Gulfort	Sweden	Industry	Algae food production

Society Beyond/ Michael Lind	Sweden	Industry	Education Leadership training
Sustainable Leadership Lab/ Stuart Pledger	Sweden	Industry	Circular economy Leadership
Swedish Biomimetics 3000® AB/ Lars Uno Larsson	Sweden	Industry	Biomimetics
Transparent Speaker/ Martin Willers	Sweden	Industry	Consumer Electronics Cradle2Cradle Product Development
TrustWeaver/ Christiaan van der Valk	Sweden	Industry	accounting
White arkitekter, Chalmers University - Department of Architecture and Civil Engineering/ Jonas Runberger	Sweden	Industry	Architecture Design Education Biomimicry
DIT - Deggendorf Institute of Technology/Biomimetics/ Kristina Wanieck	Other (EU)	Academic research and development	BID biologically inspired design Biomimetics bioinspired surfaces surface technologies Innovation
Heriot-Watt University, HS Rhein-Waal; Clemson University/ Julian Vincent	Other (EU)	Academic research and development	Biomimicry Biomimetics Ontology Methodology
Heriot-Watt University, School of Engineering, Nature Inspired Manufacturing Centre/ Marc Desmulliez	Other (EU)	Academic research and development	Biomimetics Nature-Inspired Materials development
phi360/ Arndt Pechstein	Other (EU)	Academic research and development	Biomimicry
Professional/ Conny Bakker	Other (EU)	Academic research and development	
The Bio-Inspired Photonics group in Cambridge/ Villads Egede Johansen	Other (EU)	Academic research and development	Structural colours photonics bioinspiration
University of Oxford, Department of Zoology/ Thomas Hesselberg	Other (EU)	Academic research and development	Biomimetics Bioinspiration Materials development
University of Reading, Department of Zoology/ Julian Vincent	Other (EU)	Academic research and development	Biomimetics Bioinspiration Materials development
University of Veterinary Medicine - Department of Integrative Biology and Evolution, Orsa Predator Park/ Johanna Painer	Other (EU)	Academic research and development	Biomimicry Biomimetics
Rhine-Waal University of Applied Sciences, Faculty of Technology and Bionics/ Julian Vincent	Other (EU)	Academic research and development, Education and training	Biomimetics
/ Schumacher College	Other (EU)	Education and training	Biomimicry
Biomimicry Belgium/ Jean-Michel Scheuren, Sebastiaan de Neubourg, Caroline Zaoui	Other (EU)	Education and training	Biomimicry
Biomimicry Germany/ Arndt Pechstein, Fabian Feutlinske, Kristina Wanieck	Other (EU)	Education and training	Circular economy Product design Biomimicry
Biomimicry Greece/	Other (EU)	Education and training	Biomimicry
Biomimicry Iberia/ Millard Theresa, Carlos Sáez	Other (EU)	Education and training	R&D Education Innovation Innovation Development
Biomimicry Institute (USA)/ Janine Benyus	Other (EU)	Education and training	Biomimicry
Biomimicry Italy/ Alessandro Villa	Other (EU)	Education and training	Biomimicry
Biomimicry Netherlands/ Saskia van den Muijsenberg	Other (EU)	Education and training	Circular economy Architecture Dairy sector Climate change Social innovation Built environment Agriculture Finance Design Biomimicry

Dedicated Institute/ Fredrik Wikholm	Other (EU)	Education and training	Education Leadership training
EBA European Biomimicry Alliance/ Regina Rowland	Other (EU)	Education and training	Biomimicry
Ellen MacArthur Foundation/ Planeta Biomimético España/ Manuel Quirós	Other (EU)	Education and training	Circular Economy
University of Freiburg/ Thomas Speck	Other (EU)	Education and training	Biomimetics Biomimicry Network Innovation development sustainable development development projects
University of Oxford, Wixia Web/ Thomas Hesselberg	Other (EU)	Education and training	Biomimetics zoology comparative biomechanics Materials development Biomaterials
BIOKON - Forschungsgemeinschaft Bionik-Kompetenznetz e.V./ Rainer Erb	Other (EU)	Forums and innovation platforms	Biomimicry Bionics
Biomimethic/	Other (EU)	Forums and innovation platforms	Biomimicry
Biomimicry Europa/	Other (EU)	Forums and innovation platforms	Biomimicry
Bioversum/ Regina Rowland	Other (EU)	Forums and innovation platforms	Innovation development Design Technology Biomimicry Circular economy
Circular Economy Club/	Other (EU)	Forums and innovation platforms	Circular Economy
Bionikum/ Kalina Raskin	Other (EU)	Forums and innovation platforms, Education and training	Biomimicry Biomimetics
CEEBIOS Biomimicry European Centre of excellence/ Kalina Raskin	Other (EU)	Forums and innovation platforms, Education and training	Biomimetics Biomimicry
Biomimicry Switzerland/ Jacques Chirazi, Patrick Baumann	Other (EU)	Industry	Finances Market Research Commercialization of Biomimetic Technologies Biomimicry
Biomimicry UK/ Richard James MacCowan	Other (EU)	Industry	Workshop presentations textiles product design water management computer science
Exploration Architecture/ Michael Pawlyn	Other (EU)	Industry	Architecture Biomimicry
MANGROVE/ Alessandro Villa	Other (EU)	Industry	Desalination Regenerative agriculture Nature- Inspired Bioinspiration Product Development
NCCR Bioinspired Material Centre/ Professional/ Ingrid de Pauw	Other (EU)	Industry	Biomimetics
Professional/ Lilian van Daal	Other (EU)	Industry	product development design engineering circular economy sustainable development Biomimicry
Studio Transitio/ Leen Gorissen	Other (EU)	Industry	Design Product development
w.r.yuma/ Sebastiaan de Neubourg	Other (EU)	Industry	Innovation R&D al development Regenerative design regenerative development
			Fashion Circular economy Biomimicry Materials Business development