Biomimicry Toolbox, a strategic tool for generating sustainable solutions?

Lisa Ohlander
Miranda Willems
Paul Leistra
Simon Damstra

Blekinge Institute of Technology
Karlskrona, Sweden
2018

"Biomimicry Toolbox, a strategic tool for generating sustainable solutions?"

Lisa Ohlander, Miranda Willems, Paul Leistra and Simon Damstra

Blekinge Institute of Technology

Karlskrona, Sweden

2018

Thesis submitted for completion of Master of Strategic Leadership towards Sustainability
Blekinge Institute of Technology, Karlskrona, Sweden

Abstract:

The goal of this thesis is to understand how the Biomimicry Toolbox (BT), a practical tool for applying biomimicry, currently supports strategic thinking in order to create sustainable solutions. A pragmatic qualitative research approach was used, in which the BT was analysed through the lens of the Five Level Framework (5LF), a tool for planning and analysing in complex systems and the Framework for Strategic Sustainable Development, the application of the 5LF for sustainability endeavours. Interviews were conducted with people experienced with the BT. Results show that the BT has several aspects of strategic thinking. It supports the application of a systems perspective, provides a success goal to move towards and offers tools for a strategic process to follow. The authors conclude that the BT could benefit from including understanding of the patterns and structures of the social system in relation with the earth system. Also, it can benefit from including a section on upstream thinking helping users of the BT consider root causes. Lastly, it could benefit from a strategic approach for evaluating how sustainable solutions are and include a simple and clear prioritisation process. The improvements can make the BT more impactful in supporting societies transition towards sustainability.

Keywords

Biomimicry, Sustainable Design, Strategic Thinking, Social Sustainability, Systems Thinking, Nature's Unifying Patterns

Statement of contribution

The research is executed by the thesis team; Simon Damstra (Bachelor of Science, Environmental Science), Lisa Ohlander (Bachelor Mechanical Engineering), Paul Leistra (Bachelor Engineering Industrial Design: Human Product Interaction) and Miranda Willems (Bachelor of Business Administration, Track for Social Innovation). The whole group contributed by bringing in their energy, passion and insights into this thesis. Each member brought their own diverse perspective, but the overall perception of this thesis is representing our shared mental model. During this process we have discovered our personal and group "groan- and grow zones" from which we have grown and come out stronger.

Lisa has been strong in setting research boundaries on what we can and cannot research. What is realistic, what is useful and necessary to research and what is not. Lisa's calm presence has kept us grounded as a group. She has been very supportive of the group in her mediating role by summarizing what was happening and giving her balancing and professional opinion. She brought professionality to the group and this thesis, being highly dependable with regards to doing the work.

Miranda has brought a positive process approach into the group. She has livened us up and reminded us that the way we do our work is as important as the actual work. From her background in social innovation we learned to support the group process in delivering results. She supported the team with feedback and tribe processes to reach a higher level of performing. Miranda was the main contact in communication around our interviews and made a big contribution by making sure our interviews got scheduled, designed and performed in time.

Paul has contributed with his interest in biomimicry that started this thesis and connected us to the Biomimicry Institute. He is a highly strategic and effective team member and was valuable in connecting the FSSD framework with the Biomimicry Toolbox. He contributed with clarity and structure for the groups progress and made sure our hard-working days were mixed with times of fun and good companionship. He also brought a sense of vulnerability to the group which has made it easier for all of us to share what is going on, thereby creating a safe space.

Simon has been invaluable by bringing in his academic thinking and helped us to learn and appreciate the particularities of that way of thinking and writing. He has also helped us in keeping our focus on building the shared mental model, where some of us were still in "working" mode. Simon has contributed by keeping attention to governance and creating decision-making processes as well as making sure those processes were adhered to. Simon has the ability to question assumptions and create discussions that have deepened our understanding of the subject of the research.

We as a team are very grateful in this learning journey we co-created together. Learning academically while developing sustainable leadership skills, to turn our diversity into a high performing team for this master's degree thesis! Thank you for all of the contributions.

Lisa Ohlander   Miranda Willems   Paul Leistra   Simon Damstra

Acknowledgements

Executive summary

Introduction
Achieving a sustainable society is one of the biggest challenges of the 21st century. Progress towards a sustainable society has over the decades been slow. A reason for that is that it has not been properly understood that society within the biosphere is a complex dynamic system. This results in downstream problem solving, where only symptoms are addressed, instead of addressing the structural obstacles that occur upstream and trigger the thousands of negative impacts occurring downstream. One of the main explanations of why this is so, is the reductionist approach. This is the idea that interaction between cause and effect is not influenced by its environment and that the whole can be understood by analysing the individual parts that it consists of.

An alternative to the reductionist approach is a strategic thinking approach. Important aspects of strategic thinking are identified by Baumgartner and Korhonen as Strategy Context - the conditions surrounding the strategy, Strategy Content - the output of the strategy and Strategy Process - how to develop the strategy. This description correlates with the way Robert et al. describes a strategic planning process which includes; applying a systems perspective, having a clear success goal to strive for, and having a clear process for how to move towards that goal.

In order to strategically address the sustainability challenge, it is important to have a clear understanding of what a sustainable society looks like. Sustainability has been defined differently through the years. One of the most common definitions is from the Brundtland Report:
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."

Even though this definition describes what sustainability is, it does not provide clear guidance of which actions to take today in order to achieve sustainability and it does not help addressing the systemic issues society is facing. The Framework for Strategic Sustainable Development (FSSD) gives a definition of sustainability through eight Sustainability Principles (8SPs) that explain the unsustainable actions that currently prevents society from moving towards sustainability and that needs to be stopped. A strength of this definition of sustainability is that it is specific enough for users to identify if they have achieved sustainability or not and that it focuses on upstream causes of unsustainability. The 8SPs are detailed below:

In a sustainable society, nature is not subject to systematically increasing:
1. concentrations of substances extracted from the Earth's crust;
2. concentrations of substances produced by society;
3. degradation by physical means;

and, in that society, people are not subject to structural obstacles to:
4. health;
5. influence;
6. competence;
7. impartiality;
8. meaning-making.

One of the moments when it is possible to intervene to help society move towards sustainability, is at the moment when design happens since designers are involved in shaping the physical world. Many of the tools for sustainable design are evaluative with the goal of minimizing the environmental impact of the solution under investigation, for example Life Cycle Analysis. Some tools also analyse the social dimension of sustainability. Most of the tools focus on making products less bad in comparison with other products but fail to offer support in creating innovations where totally new solutions with big sustainability wins are generated. Designers need tools and practices that support adopting a strategic perspective for the generation of solutions that are sustainable and not merely less unsustainable.

Biomimicry, 'Imitation of Life', is an approach to design that offers large potential for being a source of inspiration for sustainable design of systems, processes and products through looking at how nature solves problems. Biomimicry is explained to be different from other bio-inspired design approaches through not only be inspired by how natures solves problems, but to also learn from nature how to be sustainable. Even though studies have shown that biomimicry has the potential of generating more sustainable solutions, it does not always manage to do so.

Integrating strategic thinking into the application of biomimicry might make the field more effective in achieving its goal of realizing a sustainable and thriving society. In this research a specific biomimicry tool has been reviewed namely the Biomimicry Toolbox (BT). The BT is a quick start guide to biomimicry. It is an open source, online tool that is provided by the Biomimicry Institute mainly as support for participants in the Biomimicry Global Design Challenge (BGDC). In this thesis, the authors aim to determine how the BT currently supports its users in thinking strategically in order to create sustainable solutions and further elaborates on how the BT possibly can be improved. This lead the authors to construct the following research question:

"How might the Biomimicry Toolbox better support its users in applying strategic thinking in order to create sustainable solutions?"

Methods

In order to answer the research question, a pragmatic qualitative research approach was used. The Conceptual Framework of Five Level Framework (5LF) and FSSD together with understanding of strategic thinking informed the research and provided a structured way to evaluate the BT and its ability to strategically support users to create sustainable solutions. The 5LF is a conceptual framework that aids in analysis, decision making and planning in complex systems and can be used to analyse what a tool is good for and weather it is successful in delivering on its intended purpose. The FSSD is structured in the same way as the 5LF but is specifically made for planning for sustainability in complex systems. The FSSD includes a scientific understanding of both the ecological and social system of the earth and an understanding of the systemic causes that currently prevent sustainability. The FSSD also includes a definition of sustainability through the 8SPs as explained above, and strategic guidelines that support decisions towards sustainability. Since the FSSD is a clear framework to define, design and evaluate what is sustainable and what is not, it can be used to analyse if and how a tool is supporting its users in moving towards sustainability. The 8SPs as defined by FSSD was used as the definition of sustainability.

Three different methods were used to inform the understanding of the BT and to answer the research question. The first was an analysis of the written content of the BT, based on the structure of the 5LF and FSSD. The second was an 8SP analysis of the presentations of

solutions created for the BGDC, with the support of the BT. The third method was doing semi-structured interviews with designers of the BT, mentors of teams in the BGDC and former participants of the BGDC.

Results and Discussion
The Results and Discussion are structured by three major themes, that were identified in the Introduction and the Conceptual Framework, as important in order to strategically support users in how to create sustainable solutions. Those themes are strategic context, strategic content and strategic process.

Strategic context
Understanding the strategic context, or in other words, applying a system perspective, has been identified as important in order to address sustainability issues. The BT provides understanding of the strategic context through a section in the BT that explains the 'Earth's Operating System' and through ten patterns called Nature's Unifying Patterns (NUPs). Interviews with designers and mentors confirm that adopting a system perspective is considered important in order to create sustainable solutions. Both the section 'Earth's Operating System' and the NUPs are explanations of how the natural ecosystem function. The BT considers humans as integrated in nature and does not specify the interrelationship between the social system and the ecosystem in the way that the FSSD does. It is also noted that the NUPs do not cover all social and ecological aspects vital for sustainability as defined by the 8SPs. There are gaps when it comes to explaining the social structures that are unique for humans but also in explaining the need to prevent systematic degradation of physical means as described by SP3. Implications of this can be that the system explanation of the BT is probably not complete enough in order to support users in creating fully sustainable solutions. The authors recommend that the system description in the BT is further expanded on, in order to include all aspects of the social and ecological system.

One of the gains of adopting a system perspective is that it provides the ability to identify and address issues upstream. Addressing issues upstream implements addressing them at the cause of the problem where the structural obstacles are that causes thousands of problems occurring downstream, thereby making the intervention more impactful. Through analysis of solutions and through interviews it was found that many of the solutions coming out of the BT mainly address symptoms of problems and not the structural obstacles that caused them. From this the authors see indications that the section explaining how to apply system thinking probably could be improved by explaining the concept of upstream vs. downstream problem solving and thereby encourage users to address problems more upstream. This may make the solutions coming from the use of the BT more impactful in addressing the sustainability challenge.

Strategic content
Having an understanding of the strategic content, or a clear goal, have been identified as important in order to strategically move towards that goal. The BT encourages evaluation against the NUPs as a way to ensure implementation of sustainability in the solutions. At the same time the NUPs are explained and stated as an explanation of how nature works and thereby can be understood as explanations of the earth system. It is also found that the NUPs are open for interpretation which can make it harder for the user to understand what is really needed in order to apply to the NUPs and how to evaluate against them. An unintended consequence of this can be that the user is satisfied or even considers that the goal is reached even if only a few of the NUPs are implemented. Partial implementation of the NUPs can be a stepping stones in the right direction, but it should be clear that the goal is not yet reached. The

authors find that the description in the BT, on what a clear goal for sustainability is, could be improved and thereby making the BT more capable of supporting its users in creation of sustainable solutions.

Strategic process
Having a strategic process to follow has been identified as important in order to strategically move towards a goal. The BT provides a process to follow through the 'Biomimicry Design Spiral'. In the sections 'Define' and 'Evaluate fit and function' of the design spiral, strategic elements were identified. The process within the BT encourages users to apply system perspective, use the NUPs for evaluation and encourages prototyping. Though, through interviews it was found that the BT does not provide any explicit decision-making support in how to prioritize between different options in order to make sure that the solution becomes most optimal in addressing the sustainability challenge. The authors find that the strategic process of the BT could probably be improved by introducing decision making support, possibly in the way similar to the three prioritization questions that the FSSD provides.

Connection to global sustainability challenge
Through the research it was noted that few of the solutions from the BGDC, supported by the BT, are actually implemented in society. One can question if the BT itself really is an important leverage point to investigate, in order to support societies transition towards sustainability. Though, as indicated by interviews, the BT is focusing on students and people new to biomimicry that are most likely in the beginning of their career. The BT and the BGDC has the potential to influence the users thinking and thereby guide their actions in all future work they perform, even after the project for the BGDC is completed. Thereby, the authors think that making the BT more strategic in its support for the creation of sustainable solutions may have a positive impact on the global sustainability challenge.

Limitations of the research
Due to limited amount of time to perform the research, selection of interviewees was made mainly based on availability. The result of this was that only three participants were interviewed and all of them had ended up in top placements in the BGDC. Since the number of participants interviewed were so few in regard to the entire population, the findings may not be representative for the larger population. It should also be noted that a large portion of the results are based on the analysis performed by the authors and thereby may be biased by the authors previous experience and understanding.

Conclusion
The BT provides elements of strategic thinking in all of the three sections identified to be important to strategically guide users in how to create sustainable solutions. All three sections could be improved in order for the BT to be even stronger in its support. The strategic context can be improved by inclusion of the interrelated activities between the social and ecological system and by inclusion of patterns unique to the social system. Strategic context could further be improved by including encouragement of upstream problem solving. The strategic content could be improved by providing a clearer explanation of the goal when it comes to sustainability that is more suitable to use for evaluation of solutions. The strategic process can be improved by providing support on how to prioritize between different options in order to be more efficient in reaching the goal of creating sustainable solutions.

Further research could be beneficial in order to confirm the conclusions above and to best understand how to implement the suggested improvements.

Glossary

ABCD Strategic Planning Process: A four step process designed to implement the FSSD in a real world, organizational context. (Robert et al., 2015)

Accelerator program: a follow up program for winners of the Biomimicry Global Design Challenge, that is meant to guide the solutions to market/implementation

Authors: where "the authors" is mentioned we refer to the thesis team unless other specified.

Bio-inspired: That which takes inspiration from nature, but without it being aimed at being more sustainable. (Biomimicry Institute, 2018)

Biologize: To take a human need or function and rephrase it so that an answer may be found in biology, e.g., "How can I make the fabric red?" becomes, "How does nature create color?" (Biomimicry Institute, 2018)

Biomimicry: The conscious emulation of life's genius. Learning from nature and then emulating biological forms, processes, and ecosystems to create more sustainable designs. (Biomimicry Institute, 2018)

Biomimetic: Created through use of the nature's patterns and lessons. (Biomimicry Institute, 2018)

Creating conditions conducive to life: Establishing practices and strategies so that the existence of other species, communities, and systems is not threatened but rather enhanced. A goal of biomimetic design. (Biomimicry Institute, 2018)

Design (noun): The way something has been made; the way the parts of something are formed and arranged for a particular use, effect, etc. verb: To plan and make decisions about (something that is being built or created); to create the plans, drawings, etc., that show how (something) will be made. *Note: The word "design" implies intent and forethought in both its noun and verb uses. For this reason, the Biomimicry Institute refrains from using "design" to refer to nature and to biological strategies, except in poetic usage. Biological strategies are not "designed," rather they are a result of evolutionary processes.* (Biomimicry Institute, 2018)

Emulate: To mimic patterns or principles rather than directly copy them. (Biomimicry Institute, 2018)

Five Level Framework: A conceptual framework that aids in analysis, decision making, and planning in complex systems. It consists of five distinct, interrelated levels: Systems, Success, Strategic, Actions and Tools.

Framework for Strategic Sustainable Development: The application of the Five Level Framework for Planning in Complex Systems to a planning endeavour with sustainability as the desired outcome.

Leverage point: Places in a complex system where a small shift in one thing can produce big changes in everything. (Biomimicry Institute, 2018)

Life Cycle: the combination of the different phases in the life of a product, for example: design, production, distribution, use and discarding.

Life-friendly solutions: Sustainable solutions that are fitting to the constraints of the planet earth system.

Life's Principles: A list of persistent patterns exhibited by organisms and living systems which contribute to life's ability to survive and thrive. The prototype for these principles was first drafted by Janine Benyus in her book *Biomimicry: Innovation Inspired by Nature.* The current version is published by Biomimicry 3.8 (formerly the Biomimicry Guild).

Nature as model, measure, mentor: Three ways that biomimicry values nature. Model – applying, imitating or taking inspiration from nature's designs and processes in order to solve human problems; Measure – using an ecological standard to judge the "rightness" of our innovations; and Mentor – valuing nature for what we can learn from it and not what we can extract from it. (Biomimicry Institute, 2018)

Natures Unifying Patterns: A simplified list of 10 patterns exhibited by living systems that have profound implications for what and how humans design. The list was created for use in the Biomimicry Institute's design challenge competitions. (Biomimicry Institute, 2018)

Pattern: A reoccurring form, strategy, or principle. Often an indicator of especially effective solutions. (Biomimicry Institute, 2018)

Reductionism: The scientific attempt to provide explanation in terms of ever smaller entities. (Biomimicry Institute, 2018)

Regenerative: Of, relating to, or marked by regeneration; tending to regenerate. (Biomimicry Institute, 2018)

Strategic decision-making support: A strategic guideline that provides decision makers support to make strategic decisions towards success.

Strategic thinking: A mental or thinking process applied by an individual in the context of achieving success in an endeavor. In this thesis it is defined as consisting of three aspects, namely that of strategic context, strategic content and strategic process.

Strategic content: The output of the strategy, i.e. the result of strategy activities. In the Five Level Framework and the Framework for Strategic Sustainable Development, this aligns with the success level. In Liedtka (1998) it aligns with being intent focused.

Strategic context: Conditions surrounding strategy activities. In the Five Level Framework and the Framework for Strategic Sustainable Development, this aligns with the systems level. In Liedtka (1998) it aligns with applying a systems perspective.

Strategic process: The way to develop the strategy. Those parts of the process as a whole that clearly help the users of the BT make steps toward the desired goal. In the Five Level

Framework and the Framework for Strategic Sustainable Development, this aligns with the strategic guidelines level. In Liedtka (1998) it aligns with thinking in time, applying intelligent opportunism and being hypothesis driven.

Sustainable solutions: Solutions that comply with the 8 Sustainability Principles, defined by the FSSD.

System: An interconnected set of elements that is coherently organized in a way that achieves something (a function). (Biomimicry Institute, 2018)

Upstream and downstream thinking: Upstream thinking means to look in the system where the structural obstacles are, that trigger the thousands of negative impacts occurring upstream in the system.

List of Abbreviations

BT Biomimicry Toolbox

BGDC Biomimicry Global Design Challenge

5LF Five Level Framework

FSSD Framework for Strategic Sustainable Development

LP Life's Principle

MSLS Master's in Strategic Leadership towards Sustainability

NUP Natures Unifying Pattern

SSD Strategic Sustainable Development

SP Sustainability Principle (also 8SP as there are currently 8 in total)

Table of Content

List of figures and tables

List of figures

List of tables

1 Introduction

1.1 Purpose

The goal of this thesis is to understand how the Biomimicry Toolbox (BT), a practical tool for how to apply biomimicry into design endeavours, currently supports its user in creation of sustainable solutions and how the BT may be further improved. It is the authors hypothesis that integrating support for strategic thinking into the application of the BT might make the tool more impactful in supporting societies transition towards a sustainable society. It is the hope of the authors that insights from the research will influence future development of the BT.

1.2 The sustainability challenge

Over the last century, the world has become increasingly complex. A dynamic of interrelated, ecological, social, cultural, economic and psychological issues interact and converge, thereby causing a multitude of challenging complex issues throughout the world (Wahl and Baxter, 2008; Loorbach, 2010). Examples of these issues are climate change, water scarcity, decreasing resources, dependence on fossil fuels for energy production, and a build-up of toxic substances are contaminating the air people breathe, the water people drink and the food people eat (Galaz et al, 2012; Robert et al, 2012). Dealing with the challenge of taking into consideration the increasing complexity of society and its relationship to nature, while ensuring we are moving towards a sustainable society, constitutes to the global socio-ecological sustainability challenge (Robert et al, 2017). To address this challenge, it is important that we, as a society, improve our thinking, the tools we use and take action to address this systemic challenge (Wahl and Baxter, 2008).

1.3 Reductionism and complexity

Why has progress towards a sustainable society over the decades been so slow? The fact that the focus of sustainable development of 'society operating within the biosphere', is a complex and dynamic system that has not been properly understood (Baumgartner and Korhonen, 2010; Robert et al., 2015). Managing a complex dynamic system includes risks, such as developing actions and measures that are conflicting with each other and suboptimal in terms of improvement of the system. Isolated cause-and-effect chains between two system components are often the focus of study, neglecting connections to other components (Baumgartner and Korhonen, 2010; Wardman, 2011). Other phenomena are downstream problem solving instead of upstream problem solving, closer to the source of the problem (Robert et al., 2015). One of the main explanations for this is the reductionist approach, which often leads to problem shifting and problem displacement instead of problem solving (Baumgartner and Korhonen, 2010). The reductionist approach is the result of cause-and-effect thinking. It is the idea that the interaction between cause and effect operates in a vacuum, without influence from its environment. Also, it is the idea that if a system is segmented and understood at its most basic elements, that we can understand the whole from there (Wardman, 2011).

Reductionism leads to situations where existing problems are handled within certain elements or parts of the system while new problems are created in other areas (Baumgartner and Korhonen, 2010). Therefore, sustainability is a system property and not a property of individual system elements and sustainable development is a global and long-term challenge (Allais, Roucoules & Reyes, 2017). There is a risk for problem displacement if the wider system is not considered in sustainable development work. Nevertheless, also within the field of sustainable development practitioners have to work with limitations such as time, funding, availability of sustainable materials and production etc. Thus, a balance needs to be struck between the deep analysis of a particular challenge and inclusion of the wider system.

1.4 Strategic thinking

An alternative to the reductionist approach is a strategic thinking approach. Different authors describe strategic thinking differently. Liedtka (1998) describes that strategic thinking is characterised as incorporating the following five elements into the approach to challenges:
  1. holding a systems perspective,
  2. being intent focused,
  3. thinking in time
  4. being hypothesis driven,
  5. applying intelligent opportunism

As opposed to a reductionist approach, holding a systems perspective is a way of looking at the world by focusing on the interactions between elements within complex systems, rather than looking at those elements separately. Baumgartner and Korhonen (2010) describe this strategic thinking as consisting of three dimensions; strategic content, strategic process and strategic context. Strategic context is described as the conditions surrounding the strategy such as the socio-economic context. Strategic process is about how to develop the strategy, that considers which stakeholders to include and what process structures to use. Strategic content is about the output of the strategy, the added value and the results of the activities.

Robert et al (2017) describes a strategic planning process that includes applying a systems perspective, having a clear success goal to strive for, and having a clear process of prioritization, process design and actions. All these activities are related and must be present for making good strategic decisions. Each must be individually attended to in the planning process. An overlap between these different approaches to strategy is further detailed in the conceptual framework section of this thesis.

1.5 Definitions of sustainability

As identified in the previous section, having an understanding of what success look like is important in order to strategically move towards that goal. Sustainability has been defined differently by different authors and institutes over the years. Parris and Kates (2003) for example, have defined a transition to sustainability as stabilizing the world's population, meeting its needs and reducing poverty and hunger while maintaining the planet's life support systems. Similarly, a report from the Third World Academy of Sciences explains sustainability

as meeting current human needs while preserving the environment and natural resources needed by future generations (Hassan, 2001). One of the most used definitions worldwide, is from the Brundtland Report to the United Nations World Commission on Environment and Development
"Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs." (Brundtland, 1987):

Even though these definitions describe what sustainability is, it does not provide clear guidance on what is needed for action today in order to achieve sustainability. Another challenge with these definitions is that it does not help in addressing the systemic issues that society is facing. As the challenge is systemic, meaning it affects the whole system, systemic solutions are also needed to address it. This means addressing the root causes of the problems the system faces.

1.6 Sustainability definition of the Framework for Strategic Sustainable Development

Another definition of sustainability is the definition from the Framework for Strategic Sustainable Development (FSSD), in consulting circles widely known as the The Natural Step Framework. Its definition of sustainability is not about preserving resources, a product, a company or an organization, but rather about not systematically degrading the global socio-ecological system so that it cannot longer sustain the socio-ecological services that we as humans need to survive (Hallstedt et al., 2013). It describes what society complies to once a sustainable society has been achieved.

The FSSD has been derived from research identifying the basic mechanisms of unsustainability. By identifying those mechanisms, principles for sustainability could be designed to define what society must stop doing in order to preserve the socio-ecological system. To do that, *enough* must be known about the system - the environment around us (the biosphere), human societies, and the interactions and flows of materials between the two. In what principal ways is society destroying the biosphere's ability to sustain life? This question is answered by looking *upstream*, where the structural obstacles are, that trigger the thousands of negative impacts occurring *downstream*.

The FSSD's sustainability definition consists of eight Sustainability Principles (8SPs), that allow for an assessment of what is sustainable and what is not (Robert et al., 2017). The Sustainability Principles explain what a sustainable society would look like and what unsustainable action stops it from moving towards a sustainable society (Cook, 2004; Robert et al, 2017).

In a sustainable society, nature is not subject to systematically increasing:
1. concentrations of substances extracted from the Earth's crust;
2. concentrations of substances produced by society;
3. degradation by physical means;

and, in that society, people are not subject to structural obstacles to:
4. health;
5. influence;
6. competence;

7. impartiality;
8. meaning-making. (Robert et al, 2015, p40)

The term systemically increasing, in the ecological SPs refers to an increasing deviation from the "natural" (pre-industrial) state of the ecological system due to society's actions. The ecological SPs do not prohibit use of materials from the earth's crust as long as the concentrations in the biosphere of those materials do not systematically increase. This could be done by closing the material loop for example (Robert et al, 2015).

The term structural obstacles in the social SPs, refers to structural obstacles within the patterns and structures of society, that;
- prevent people from being able to live healthy fruitful lives;
- have influence on the systems they are part of;
- grow in their competence;
- undermine impartial treatment;
- undermine meaning-making for people and organisations. (Robert et al, 2015)

A strength of this definition is that it is specific enough for users to identify whether they have achieved sustainability or not. Another strength is that it focuses on the upstream causes of unsustainability, compared to focusing on downstream symptoms. (Robert et al, 2017)

1.7 Design

One of the moments it is possible to intervene to help society move towards sustainability, is at the moment when design happens. Designers and engineers are involved in shaping our physical world. Their involvement has resulted in both an abundance of materials and physical products, however also the damaging of our environment (Wahl & Baxter, 2008, p. 5). Indeed, all products that have been created have some impact on the environment in some or all the phases of their life cycle, such as at the phases of raw material acquisition, production, distribution, use, maintenance, and final disposal of the products (Bovea and P'erez-Belis, 2012; Senge, Carstedt & Porter, 2001). This is described as the take-make-waste model in 'The Ecology of Commerce' by Paul Hawken (1993).

The influence of the design process on the final product is crucial. It has been identified that early integration of sustainability aspects into the product design and development process is important (Bovea & -Belis, 2012). The way products are designed affects all stages of a product life cycle thereby making the design phase an important leverage point for creating sustainable products. If sustainability considerations are made at a later stage, after important design decisions have already been made, the possible positive impact the product may have on society's ecosystem is smaller (Bovea & -Belis, 2012).

But besides negative indirect impacts of designers, their positive role and impact on the sustainability challenge our world is facing has also been recognised (Papanek 1995; Manzini 2009). In order to reach the goal of creating a sustainable society there is a need for systemic changes in the way human society creates the products, process and systems that it relies on. Design can serve as one of the important leverage points for bringing that change forward.

1.8 Sustainable Design

Generally, in is no emphasis on a whole-systems-perspective, nor does it define that success look like for being in line with socio-ecological principles (Ketchie, Shapira and Nehe, 2013). Yet, Mead and Jeanrenaud (2017) claim that products, services, technologies or organisations individually cannot be defined as sustainable or unsustainable and they should be considered within the systems they are embedded. Only if the systems of concern are sustainable, then the products, services and technologies therein can be regarded as sustainable.

Design and innovation for sustainability firstly, should adopt a system thinking approach as a reference to evaluate product/service concepts within the system they will be produced and consumed (Mead and Jeanrenaud, 2017). Secondly, designers need to define or adopt conditions that describe when a product is assessed to be truly sustainable (Pauw, Kandachar and Karana, 2014; Robert et al, 2013).

The design approaches most commonly used in sustainable design are mostly of analytical character such as Life Cycle Design and Life Cycle Assessment (Marseglia, 2017). When using Life Cycle Design or Life Cycle Assessment, the full life cycle of the products is analysed to find out the effect of a product on the ecosystem. Design for Environment and Eco-Design approaches aim to meet consumer's requirements but in a more sustainable way by reducing the environmental impacts of product and services (Vallet et. al., 2013). The LCA tools focus on the evaluation of products and only offer limited support for product innovation since they are evaluative rather than generative (Kennedy & Marting, 2016).

Also, a shift is needed in the aim of design from 'reducing unsustainability' towards 'achieving sustainability', to think beyond efficiency (Robert et al, 2013; Pauw, Kandachar and Karana, 2015). It is the authors understanding that most design approaches available for supporting sustainable design, focus on reducing unsustainability by making sure that products are less bad compared to other products. This may be a side effect of not knowing what sustainability exactly is. Unless the goal is clearly defined, it is not possible to aim for it, thus reducing unsustainability is the next best option. The authors have the hypothesis that in order to create sustainable solutions, there is a need for tools and practices that support adopting a system perspective and the generation of solutions that move towards a vision of sustainability and not merely reducing unsustainability.

Lastly, there is a need for a shift in the thinking of design from a linear paradigm that is focused on take-make-waste thinking to think with a circular approach, where materials are kept in closed loops (as discussed in section 1.5) in such a way that materials from society are not increasing in the biosphere. Circular thinking could be an approach for creation of solutions more in tune with how the earth's system operates and how it could be sustained for next generations. According to Rebecca Earley (2017), it is when designing products, systems and services by circularity, design could create the approach towards success. In her perspective Circular Design differs from Sustainable Design in that the objective is ultimately measurable – one either closes the loop, or one does not. In creating circular systems and products new social innovation models, communities and businesses may be created, and work together towards a common goal (Earley, 2017). Circular design as an emerging field needs new frameworks and tools to help others establish innovative solutions across sectors. In her research 'Circular Design Futures' she includes that we can design and lead research to create

more resource efficient models in order to plan future material loops and circularity. She encourages to engineer new processes and systems which will require designers to embrace these expanded roles for circular design (Earley, 2017).

1.9 Biomimicry

Society needs an alternative lens for design to effectively change the current pathway from unsustainability to sustainability (Mead and Jeanrenaud, 2017; Pauw, Kandachar and Karana, 2014). Also, there is a need for society to move towards a closed loop approach to product design and a shift towards a circular model of design (Earley, 2017). Biomimicry is an alternative approach within design that shows large potential for inspiring the creation of sustainable design of systems, processes and products that may meet these needs (Kennedy et al., 2015; Kennedy & Marting, 2016).

Biomimicry literally means 'the imitation of life'. The word has Greek roots and is a combination of bios (life) and mimikos (imitation) (Benyus, 1997).

Janine Benyus, one of the founders of the biomimicry movement (1997) describes three pillars of the biomimicry practice:
1. *Nature as model.* Biomimicry is a science that studies nature's models and then takes inspiration from these designs and processes to solve human problems.
2. *Nature as measure.* Biomimicry uses an ecological standard to judge the "rightness" of innovations. After 3.8 billion years of evolution, nature has learned: What works. What is appropriate. What lasts.
3. *Nature as mentor.* Biomimicry is a way of viewing and valuing nature. It introduces an era based not on what we can extract from the natural world, but on what we can learn from it. (Benyus, 1997)

Already in 1997, Benyus (1997) claimed that biomimicry has the potential to change for example the way we grow food, make materials, harness energy, heal ourselves, store information, and conduct business. By using nature's way of solving problems, the solutions that are created should then already be well adapted to coexist with life on earth.

An example where inspiration from nature was used in innovation, is in how the shape of the fins of the Humpback whale provided inspiration on how to make the wings of a wind turbine more effective (Biomimicry Institute, 2018, 1). The wind turbine blades require lower wind speeds, increasing the amount of time they can produce energy and the number of locations where they can actively generate electricity. This is an example of using nature as a model, but not nature as a measure as it is not yet fully sustainable and circular in design.

Figure 1.8.1 Humpback whale inspires wings of wind turbine (Biomimicry Institute, 2018, 1)

Other synonyms for biomimicry that are used are, biomimetics, bionics, biognosis and bionical creativity engineering. There are also disciplines bordering biomimicry for example biomechanics and biophysics (Volstad and Boks, 2012). The purpose of those disciplines is to use the learnings from nature to create solutions to technical challenges.

What makes biomimicry different from those models of imitating nature, is the respect for nature at the heart of biomimicry and its aim to solve problems in a sustainable way. This is an example of using nature as a mentor.

Kennedy and Marting (2016) suggest that biomimicry, is particularly valuable for its focus on inspiration, as opposed to validation. This makes biomimicry a design approach that has the potential of generating sustainable designs, processes and systems and by that play a role in effectively addressing the global socio-ecological sustainability challenge.

1.10 Challenges of the biomimicry field

Even though studies have shown that biomimicry has the potential of generating more sustainable solutions, it does not always manage to do so. From exploratory interviews with practitioners (Mead, 2017; Hoeller, 2018) it seems that from the multitude of biomimicry projects, few of these actually end up in production and the market. The examples that receive attention in media are mostly related to the company Interface and some smaller successes.

Also, there is criticism in literature that biomimicry lacks a unified evaluation system estimating the sustainability of the solutions (de Pauw, et al, 2014; Kennedy & Marting, 2016; de Pauw, Kandachar, Karana 2014). Many of the biomimicry inspired products lack an integration within the larger (eco-) systems they are part of. As a result, it is therefore hard to assess whether they contribute to sustainability on the larger scale (Marshall and Lozeva 2009, 1-10). This means there is a need for a unifying biomimicry framework for evaluating the sustainability impacts of the design derived from using biomimicry approaches.

1.11 Tools in biomimicry

The challenges within the socio-ecological sustainability challenge are plentiful. As has been elaborated above, strategic thinking is needed within the sustainable development field in order to successfully achieve its end goal of a sustainable world. This also applies to biomimicry as a design approach that aims for this same end goal.

It is beyond the scope of this thesis to study the entire field of biomimicry on its current application of strategic thinking. However, analysing whether and how a set of tools used within the field of biomimicry are supporting strategic thinking is within the scope of this thesis. It has therefore been chosen to analyse one of the primary sets of tools that are being used within the field of biomimicry.

There are different tools applied within the biomimicry field, such as 'Cradle to Cradle', the 'Biomimicry Toolbox', the 'Biomimicry Innovation Toolkit', 'Ask Nature', 'IdeaInspire', 'BioTRIZ', and 'Biocards'. Appio et al. (2017) researched a number of tools ('AskNature', 'IdeaInspire', 'Engineering-to-Biology thesaurus', 'DANE', 'BioTRIZ', 'Knowledge based CAD systems' and 'Biocards') and came to the conclusion that out of those, 'Ask Nature', a web-based inspirational catalogue, was the most known and used amongst the participants of the study. However, 'Ask Nature' is a data base of idea's, not a set of tools and processes that biomimics use to create sustainable solutions.

The 'Biomimicry Institute' is a non-profit organisation with the goal of sharing natures design lessons with the world through education on how to use biomimicry. To do this they run several initiatives. One of them is the 'Biomimicry Global Design Challenge'(BGDC) and 'Ask Nature' is another. The Design Challenge is run yearly and invites students and practitioners worldwide to solve critical sustainability challenges using biomimicry. As support for both those who are participating in the challenge and for those who want to incorporate insights from nature into their solutions, The Biomimicry Institute provides The 'Biomimicry Toolbox' (BT). (Biomimicry Institute, 2018)

The BT is a quick-start guide to biomimicry and includes a set of tools and core concepts for how to implement lessons from nature into design (Biomimicry Institute, 2018). We will focus our research on the BT for a number of reasons:
  - The BT is intended to be used in the design phase of developing products, processes or systems;
  - The BT is a widely used tool by both practitioners and students all over the world both for the BGDC, and for separate work;
  - The BT is open source, and therefore easily accessible for the research team;
  - No prior scientific research has been performed on the BT, and our research is therefore at this point unique;
  - The designers of the BT indicate on the website that they are open to suggestions for improvement and want the BT to develop.

1.12 Research question

It is believed by the authors of this thesis that the BT can significantly contribute to societies transition towards sustainability. The goal of this research is to identify how the BT supports its users in strategic thinking towards sustainability and what improvements can be made to make it even more impactful. The research question that we will aim to answer through our research is the following:

> *"How might the Biomimicry Toolbox better support its users in applying strategic thinking in order to create sustainable solutions?"*

The BT is then considered a tool that could provide support for users to cultivate their strategic thinking, thereby possibly producing more strategic thinkers within the field of biomimicry. This in turn would support strategic leadership towards sustainability.

2 Methods

In order to answer the research question and to facilitate the analysis and the structure of the research, guiding questions have been determined that each focus on one of the three main aspects of the main research question (sustainable solutions, strategic thinking, better support):

- *"How well does the BT support strategic thinking?*
- *"How well does the Biomimicry Toolbox (BT) support its users strategically in achieving its own goal?"*
- *"How well does the BT support its users in creating sustainable solutions?*
- *"How can the BT be further evolved to better support strategic thinking for the creation of sustainable solutions?"*
- *"How is the BT a stepping stone towards sustainability?"*

The selection of the datasets used in answering these questions was based on the datasets availability and the different perspectives they provided on the BT. The ones that were selected were the BT itself (its contents), the solutions (output of the BT) and the intent and experiences with the BT (design intent and user experience).

One of the key drivers for the thesis team was the desire to do research that would also have a direct effect on the practice for biomimicry. For this reason, the approach of a pragmatic qualitative research was selected as according to Savin Baden and Howell Major (2013). This approach is well suited for research that is "*practical and often related to practice*". In general the duration of pragmatic research is shorter than with other research approaches, which fits with the narrow timeline of this research. And finally, pragmatic qualitative research allows for the combination of various data collection methods to answer the research question, which will facilitate the analyses of the different types of datasets used. In the following chapters the methods used in the research will be further detailed.

2.1 Conceptual framework

To be able to answer the first guiding question, it was needed to first clarify what is meant by strategic thinking. Strategic thinking was introduced in the introduction and will be further described in this section. Strategic thinking has guided the way the results and discussion have been structured. Additionally, there is a need to have an approach that minimizes the probability that the research team takes on a reductionist perspective while analysing. For this reason, a literature review was done to find an appropriate conceptual framework to place the study in.

2.1.1 Strategic thinking

As described in the introduction, to successfully move towards a sustainable society, it is important that a strategic thinking approach is being applied. Liedtka (1998), Baumgartner & Kornhonen (2010), and Robert et al. (2017) each describe aspects of what can be called strategic thinking. The authors found a general overlap between the description of strategic thinking in this review. This overlap on strategic thinking models is presented in table 2.1.1 and is further described in the section below.

Table 2.1.1. Overlap between the different descriptions of strategic thinking

Overlap between the different descriptions of strategic thinking		
Baumgartner & Korhonen, 2010	Robert et al., 2017	Liedtka, 1998
Strategic Context	System	Systems perspective
Strategic Content	Success	Intent focused
Strategic Process	Strategic Guidelines	Thinking in time
	Back casting	Hypothesis Driven
	Prioritisation questions	Intelligent opportunism

One thing these articles have overlap on is that strategic thinking includes applying a systems perspective. This is related to having a clear sense of the context in which the initiative is operating. Another item has to do with having direction. Direction can be provided by having a clear intention to what you want to achieve. In Robert et al (2017), this is described as having a clear success definition and is provided with the 8 SPs as a set of principles to direct actions within. Lastly, there is an overlap between the different articles in that three of them describe the need for a strategic process of achieving the end goal. Robert et al. (2017) provides a prioritization process and also a planning process called the ABCD process. Liedtka (1998) describes particularly the process of being hypothesis driven and applying intelligent opportunism and thinking in time. Now the Five Level Framework (5LF), and the Framework for Strategic Sustainable Development (FSSD), two frameworks described in Robert et al. (2017) will be described in more detail.

2.1.2 Five Level Framework

As will be explained below in further detail, the Five Level Framework (5LF) is a conceptual framework that aids in analysis, decision making, and planning in complex systems. It consists of five distinct, interrelated levels: Systems, Success, Strategic, Actions and Tools (Robert et al, 2017).

The Five Level framework is a mental model meant to structure information in ways that make that information useful for planning, contextualising and understanding in a complex system. The 5LF has been developed to help solve complicated problems in complex systems and is designed for problem analysis, decision making, and used when planning for investment programs or strategic action plans (Robert et al, 2015). It can be used not only to analyse organisations and systems, but also to analyse tools. What a tool is good for and whether it is effective in delivering on its intended purpose, looking at it from a systems and strategic perspective. The five levels of the framework are described as followed by Robert et al. (2017):

System. The system that is relevant to the overall goal (success).

Success. The overall goal that is to be attained by using the tool or the intended. purpose of the designers of the tool that is to be achieved.

Strategic Guidelines. The strategic guidelines used to select actions that move towards success in the system.

Actions. This level was not used for this research since it did not overlap with strategic thinking.

Tools. This level was not used for this research since it did not overlap with strategic thinking.

Using this framework minimizes the probability that the research team takes on a reductionist perspective while analysing the BT. It allowed the thesis research team to take a systems perspective, striking the balance between going in to the depth of the BT and connecting it to the wider system that the BT is part of.

2.1.3 Framework for Strategic Sustainable Development

The Framework for Strategic Sustainable Development (FSSD) has already been shortly introduced in the introduction. It offers one of the most comprehensive principle-based definitions of sustainability and has been used in most sectors of society to give direction and drive organizations towards sustainability (Robert et al., 2017). It consists of a clear framework to define, design and evaluate what is sustainable and what is not.

FSSD builds on a scientific understanding of how the earth system level operates and the underlying systematic causes of the ecological sustainability challenge. It also includes a scientific understanding of how the complex social structures of human society operate and the structural obstacles in society today that currently prevent society from sustaining itself. Through this understanding of both ecological and social structures, the FSSD defines 8 Sustainability Principles (as explained in section 1.5) that, if complied to, will ensure global sustainability of planet earth (Robert et al., 2015).

The FSSD consists of a variety of supporting elements that enable strategic planning. This approach can support strategic thinking. The different elements and objectives each level (structured in the same way as the 5LF) can be found below:

System. The system level of the FSSD consists of an understanding of the overall socio-ecological system, its interaction with the lithosphere and the social- ecological sustainability challenge. In the system level the authors analyse if the BT's description of the system is in alignment with the system level of the FSSD.

Success. On the success level the FSSD provides a definition of sustainability consisting of 8 Sustainability Principles (8SP's), as described in section 1.5. Compliance with the 8SP's is needed in order to achieve sustainability. On the success level we analyse the BT to find out how the BT's definition of success contributes to socio-ecological sustainability as defined by the 8 Sustainability Principles.

Strategic Guidelines. The FSSD provides two complementary strategic guidelines for choosing between different actions: (1) Back casting from success principles, this is a process that is opposed to forecasting where based on a definition on success (as stated by achievement of the 8SPs) a course is planned towards achieving that success. (2) Three prioritization questions to use in order to choose the most strategic actions to achieve sustainability: Does this action proceed in the right direction with respect to the Sustainability Principles? Does this action

provide a stepping stone for future improvements? Is this action likely to produce a sufficient return on investment to further catalyse the process?

Actions. This level was not used for this research since it did not overlap with strategic thinking.

Tools. This level was not used for this research since it did not overlap with strategic thinking.

2.1.4 Definition of sustainability and strategic thinking

Throughout this research the 8 Sustainability Principles (8SP) as the definition of sustainability has been used. Within the FSSD these 8SPs are found at the success level.

2.1.5 Choice for conceptual framework

It is beyond the scope of this thesis to include all these presented ways of looking at strategic thinking in our thesis. However, it is possible to research the toolbox on aspects that are mentioned in the description of strategic thinking.

For this research the conceptual frameworks; the Five Level Framework (5LF) and the Framework for Strategic Sustainable Development (FSSD) have been used primarily. The 5LF and FSSD are two frameworks the authors are proficient in and can therefore effectively apply in the thesis. Additionally, a few elements of Liedtka (1998) were included to enrich the perspective this thesis can provide on how the BT supports strategic thinking. The authors wanted to make sure they were not biased in applying the lens of the 5LF and FSSD, without having a proper review of what the general literature on being strategic in a sustainable development context states. Which aspects of Liedtka were included is described at the data sets used in the methods below.

The descriptors for strategic thinking, used in Baumgartner & Kornhonen (2010) were used as an overarching framework to place the results coming from the 5LF and FSSD analysis and the analysis based on Liedtka (1998) in. These descriptors are strategic context, strategic content and strategic process as headers for the different sections of the results and discussion.

2.2 5LF and FSSD analysis of the Biomimicry Toolbox

As stated at the beginning of this chapter, the main research question has been divided into guiding questions. In this analysis the focus was on the four guiding questions of:
- *"How well does the BT support strategic thinking?"*
- *"How well does the Biomimicry Toolbox (BT) support its users strategically in achieving its own goal?"*
- *"How can the BT be further evolved to better support strategic thinking for the creation of sustainable solutions?"*
- *"How is the BT a stepping stone towards sustainability?"*

The lens of the *Five Level Framework* and the *Framework for Strategic Sustainable Development* from Robert et al. (2015) were applied for the analysis of the BT itself. These strategic frameworks are, as mentioned in the introduction, widely used within the field of sustainable development, sustainable design and transition management (Robert et al, 2017). The 5LF analysis assists in answering to what extent the BT is achieving its purpose and it shows in what way the BT is already being strategic. The FSSD analysis showed in what way the BT is supporting sustainability. This analysis covers all the levels of the conceptual framework of strategic thinking: strategic context (system level), strategic content (success level) and strategic process (strategic level).
The focus in this analysis is on the dataset as published on the website of the BT. The reason for this is that those sections are the full representation of the BT itself. The text was captured in documents as PDF's and analysed from there. During the analysing process, all the authors read through the complete BT documentation, and placed relevant sections of the BT within the respective level of the framework. Lastly, the authors analysed the data sets, while using triangulation in order to answer the research question.

2.2.1 Procedure

For this analysis, two members of the thesis team read through the entire BT and copied relevant sections with references to a document, within the respective levels of the 5LF. This process was facilitated by having a set of questions related to the respective levels. List of questions are provided in Appendix A1. The results visualised how and to what extent each level of the 5LF was represented within the BT. In order to be as objective as possible, the two other authors checked the results and unclarities were discussed and resolved.

Then in a second step, all the data that was collected in the 5LF framework and was analysed through the lens of the FSSD. The information gathered for each level of the 5LF analysis was reviewed by two of the authors and placed in the FSSD framework document. Here again a set of questions related to that level of the FSSD was created. List of questions used are available in Appendix A1. Two other authors checked the data and unclarities were discussed and resolved. As a final step, a summary of the information of each level of both the 5LF and FSSD was created and the key points were distilled into the results section.

Supplementary, based on the conceptual framework: being intent focused, hypothesis driven and using intelligent opportunism from Liedkta (1998) was also used as a lens to the data from the BT. The reason for this is that the BT may have met these dimensions of strategic thinking, even if they are not represented that strongly in the 5LF and FSSD. In this way, a broader perspective on strategic thinking was given with regards to the BT. Then the main trends and

points were added to the results section in the next chapter, under strategic context, strategic content and strategic process respective to points made that fit that section. Results that related to the objectives and purpose of the BT were introduced at the start of the results sections.

2.3 8SP analysis of solutions derived from the Biomimicry Toolbox

How effective the BT is in producing sustainable solutions also offers some understanding in how strategic its users are in creating sustainable solutions. The assumption here is that the more effective users are in strategic thinking, the more effective they are in achieving their goal. One of the ways to analyse this was to look at the dataset consisting of the outcomes of the BT, the solutions. This dataset was chosen to check in what ways the outcomes of the BT represent its intention and content. In the Biomimicry Global Design Challenge (BGDC) the BT is used to create sustainable solutions. In order to assess the sustainability of the solutions, the 8SPs were used to analyse the possible contributions and violations of the solutions on these principles. Fourteen of these solutions were analysed based on the following guiding questions:

-   *"How well does the BT support strategic thinking?*
-   *"How well does the Biomimicry Toolbox (BT) support its users strategically in achieving its own goal?"*
-   *"How well does the BT support its users in creating sustainable solutions?*
-   *"How can the BT be further evolved to better support strategic thinking for the creation of sustainable solutions?"*
-   *"How is the BT a stepping stone towards sustainability?"*

Although it is not a requirement for participants of the BGDC to use the BT, it is the assumption of the authors that the BT was used when the solutions were developed. Another assumption is that while the solutions are created by using the BT, previous knowledge and experience of the users themselves also influences the quality of the solution. For the purpose of this research it was assumed that participants are relatively new to the field of biomimicry and therefore the results are comparable enough. The focus on the award winners was based on another assumption that as award winners, these solutions are most in line with the intent of biomimicry and the BT. The solutions were analysed to identify in what way they contribute to- or violate the 8SP's.

The authors had access to the online presentations of the solutions and not to the full product documentation. Due to this limited information there was not a complete understanding of the contribution or violations of the solutions. A detailed analysis would require complete product documentations and more time in order to fully understand the sustainability impacts of the solutions. This was determined as being beyond the scope and time limits of this research. The authors reasoned that taken this into account, an indication could be obtained of what the designers of solutions have thought about and taken into consideration in terms of sustainability (also, in terms of what they have considered important enough to mention in their presentation).

Out of a total of 254 solutions presented on the website fourteen were investigated. Six solutions from the student challenge and eight from the open challenge, aimed at professionals. Solutions originated from all the years the competition was held: four from 2015, four from 2016 and six solutions from 2017. Only top placed (and award winner) solutions were chosen since our assumption is that these are the solutions that the Biomimicry Institute considers most

in alignment with their definition of success. From the student challenge all first and second place winning solutions were analysed. From the open challenge eight random solutions out of the total twenty award winners were investigated (in the open challenge the solutions were not rated with any positions). A list of the solutions analysed including links to the presentations of the solutions is provided in Appendix A2.

On its own, this analysis would not be sufficient in answering the research question, but it was considered complementary to the other methods as it could give nuance to other findings. With regards to the interviews, it could offer direction in the interviews and give an opportunity to validate the insights themselves. Lastly, it could provide inspiration for improvements on the BT to better support its users to design sustainably.

2.3.1 Procedure

This analysis was done by reviewing the online presentations (consisting of an introduction text and short video) on the gallery page of the Biomimicry Design Challenge (GBDC, 2018).

In order to achieve a more balanced evaluation of analysis firstly two solutions were analysed individually, by two authors. After this, the results were compared and discussed in order to create a better common understanding of the approach. All the solutions were analysed by two of the authors. The results were then checked on reasoning by the remaining two authors.

An understanding was sought as to what the designers had considered for making the solutions sustainable. This information was connected to different phases through the entire life cycle of the solutions. In our analysis we divided the life cycle into three stages. (1) Production (2) Use and (3) End of life. Because the authors worked with limited information about the solutions, a more detailed division of the life cycle would not provide any extra value. The information presented was further analysed to identify where the solutions had potential violations of the 8 Sustainability Principles (as presented in the introduction) or where there were effects that were potential contributions. Other elements that were investigated by the authors: in what way the solutions considered the source of energy (in the use of the solution), the materials used and in what way social aspects were mentioned.

The results were summarised in a table and analysed in discussion amongst the authors for verification. Then the main trends and points were added to the results section in the next chapter, under strategic context, strategic content and strategic process respective to points made that fit that section. Results that related to the objectives and purpose of the BT were introduced at the start of the results sections.

2.4 Interviews with practitioners, mentors and designers

With this method answers are sought to all of the guiding questions from an experiential perspective of the designers and users of the BT.

- *"How well does the BT support strategic thinking?*
- *"How well does the Biomimicry Toolbox (BT) support its users strategically in achieving its own goal?"*
- *"How well does the BT support its users in creating sustainable solutions?*
- *"How can the BT be further evolved to better support strategic thinking for the creation of sustainable solutions?"*

While the BT in itself can appear clear to the authors, some level of interpretation is unavoidable. In order to deal with this interpretation, it was decided to interview the designers (for more clarity on the intent of the BT) and the participants (for more clarity on the user experience of the BT) and the mentors (for a third person perspective on the experience of the users). This analysis covers all the levels of the conceptual framework of strategic thinking: strategic context (system level), strategic content (success level) and strategic process (strategic level).

The interviews were semi-structured, and the protocol and questions asked in the interview can be found in Appendix A2.5. Within this interview style, the interviewer was guided by a set of structured questions but has the freedom to ask further probing questions based on the responses of the interviewee (Savin-Baden and Major, 2013). The strength of using this method is that while there are structured questions to receive comparison data across the interviews, there was also the possibility of discovering new questions and fields of interest. This combination makes this method relevant to our research as we needed comparative data from the interviewees on how the BT functions as well as a range of explorative questions to help in creating ideas for improvement of the tool.

The semi-structured approach to asking questions offered the possibility to investigate further when the interviewer sensed there was more information to be gained from the interviewee. A downside of a semi-structured approach is that while this approach leads to interesting side paths with worthwhile information, this new data is difficult to compare across the population as these questions are not necessarily asked to other interviews. This is not a problem for possible improvements of the BT, as they can be individual recommendations, but it can be a problem if new important factors are discovered that were not considered by the thesis team. In the latter case, these new factors can be seen as limitations to the research and inform further research of the BT.

The interview questions were partly open and investigative questions, designed to provide answers to the research question. Based on the guiding questions, the interview questions were created in an iterative process where two members made a draft of the questions after which the other two reviewed and further developed the questions to make sure no area was neglected and that the questions made sense to inform the research question. These questions were then checked again by the other authors.

2.4.1 Procedure

For the procedure for the interviews, three main sections have been determined: the interview selection, the creation of the interview protocols and the analysis of the data. Below these are described in more detail.

2.4.2 Interviewee selection

Three main groups that are important to the BT were defined: the designers of the BT, the mentors of teams participating in the BGDC and the participants in the BGDC. In the section below is explained what the interview selection was and what selection criteria were used.

Three Designers of the core design team of the BT out of N=3. Designers of the BT could contribute with sharing the intent of the BT and provide insights about feedback they have received on the BT. Criteria for selection was that the designer has been part of the design team of the Biomimicry Toolbox and actively worked with developing the BT for the minimum of one year.

Three mentors of teams in the Biomimicry Global Design Challenge out of N ≈150. The mentors provide guidance throughout the challenge for teams to stay on track. For instance, by directing them to information and tools. The purpose of mentorship is guiding and coaching the participants through the challenge. It was considered that mentors contribute to our research through their relatively broad insights about the BT, gained through mentoring multiple teams. Criteria for selection was that the mentor had experience in at least one completed challenge and for a minimum of two teams. These criteria were shared with the Biomimicry Institute and they send out requests to several mentors that fit this description. Due to time constraints, the first three that connected with the thesis team with this profile, were selected and interviewed.

Three former participants of the Biomimicry Global Design Challenge out of N ≈420. Participants of the challenge are the users of the BT and through interviewing their opinion and experience of the BT process and content is analysed. Criteria for being selected is that the participant has finalized the challenge in 2017 and has used the BT to a significant extent. The reason for using the 2017 group is that they have worked with the latest updated version of the BT. Also, participants had to come from different teams. The selection and contact were done similar to the mentors, via the Biomimicry Institute and based on the first contacts that matched this profile for research.

2.4.3 Interview Protocol

The interview questions were generated based on the main themes of the research questions in combination with the findings from the solution analyses and the 5LF/FSSD analyses. These questions were tested and discussed within the thesis team in terms of relevance and phrasing. A selection of interview questions was made based on this discussion and the questions were adapted to the different groups. The full protocol and questions can be found in Appendix A3.

All interviews were held by two authors consisting of a main interviewer and an observer with the task of checking for completeness of the answers and to pick up on possible interesting statements for further questioning. Interviews were recorded only in audio in order to improve

the privacy of the interviewees and after, transcribed. As only audio was recorded for the transcribing, visual and sensory information about deeper levels of communication of the interviewee were lost. This was partly covered by having an observer present during interviews.

The interviews were transcribed using YouTube to create the text, after which a member of the thesis team listened to the interview and corrected the transcription where needed. To immerse the authors in as much of the data, all the different authors performed: interviewing (two authors), transcribing (one author) and coding (one author).

2.4.4 Data analysis

A combination of open and systematic coding was applied. The first coding step was to define to which of the three guiding questions the text speaks, by highlighting those sections in designated colours. During this, themes that were discovered were gathered in a conceptual coding list. These themes were discussed by the authors and compared to the relevance in relation with the research question, in order to generate a shared "coding table" for the research. In this process sixteen out of the original 37 codes were taken to the next phase of the coding. These codes can be found in Appendix 2.4. During the coding of the interviews there was always a second author checking the first coding. The coding was done digitally in the original transcript, by adding the codes at the end of the (highlighted) related sentences.

The findings from the coding phases were summarized in a table in order to more easily identify themes and patterns across interviews. These themes and patterns were discussed, and a list of key findings was generated.

This insights from the interviews were combined with the insights discovered in the other two research methods of the 5LF/FSSD analysis and the 8SP analysis of the solutions and presented in the results section in the next chapter, under strategic context, strategic content and strategic process respective to points made that fit that section. Results that related to the objectives and purpose of the BT were introduced at the start of the results sections.

2.5 Ethical and normative aspects of the research

2.5.1 Ethical considerations

As far as the ethical dimension in our research Savin-Badin and Howell Major (2013) argue the importance of decreasing the possible risk of harm done to participants of the research. They state there are various varieties of harm: physical, psychological, social or economic.

In this research the risk is mainly at the level of the interviews. The participants in this research are either working professionals or students at bachelor and masters level, which lead to the assumption of the thesis team that they are not vulnerable individuals, but well consenting adults. The risk perceived by the authors for this research is low and at mostly at the psychological level. We have taken several steps to decrease this risk:

- The goal of our research was shared upfront
- Interviews were only recorded in audio

- Informed consent was asked for both in first contact and at the beginning of the interviews
- Questions were framed to be open and explorative
- Transcripts of interviews were shared for confirmation
- Transcripts are not shared in full in this thesis and quotes are anonymously used
- Results were made anonymous (designer#, mentor#, participant#)
- Records and transcripts of interviews will be deleted after 3 years

To be ethical in contact with the Biomimicry Institute, clarity was given around the intent and content of the research and the view of the designers has been included in the interviews. The final report results was shared with the interviewees before publishing to make sure we are not sharing any proprietary, conflicting or confidential data.

2.5.2 Normative changes

In looking at the normative aspects of our research, there has been an interesting movement in our own "normative development". At the start of the thesis, these were shaped by an interest in biomimicry from a philosophical standpoint but have been fully immersed by SSD thinking. Then in doing research and interviewing biomimicrists, a fascination for the "thriving" mentality of the model (thriving as in going way beyond "doing no harm") grew. During these "movements" the authors have been aware of this "shift" happening and realized the awareness it takes to stay as objective as possible in working with these two frameworks of SSD and biomimicry. This has in part been solved by using the conceptual framework and in part by creating time to discuss and the different This has in part been solved with the use of the conceptual framework and in part by making time for discussing and evaluation, using the different perspectives of the authors.

3 Results

In this chapter we present the results from our research in order to answer the research question

> *"How might the Biomimicry Toolbox better support its users in applying strategic thinking in order to create sustainable solutions?"*

The results are generated from the 5LF and FSSD analysis of the Biomimicry Toolbox (BT), the 8 Sustainability Principle (SP) analysis of solutions and the semi-structured interviews.

When the BT is quoted in this section, a code is provided to identify in what part of the BT the quote was found. Explanation of the codes and the link to the online BT is provided in appendix A4. Whenever there is a reference to a section of the BT, this set of data comes from the 5LF and/or FSSD analysis of the BT.

The solutions are online presentations of solutions created for the Biomimicry Global Design Challenge (BGDC). A list of the solutions that were analysed are presented in Appendix A2. Interviews were held with designers of the BT, mentors of teams in the BGDC and participants of the BGDC. A matrix with questions for the interviews can be found in Appendix A3.

As explained in the introduction and the conceptual framework of this thesis, three important elements in order to be able to strategically move towards a goal are:
1. Strategic context – applying a system perspective
2. Strategic content – having a clear understanding of the goal
3. Strategic process – guidance from a process on how to reach the goal

The authors have structured the result of the research under these three themes, while having a primary focus on the data provided with the lenses of the 5LF and FSSD, in order to investigate in what way these strategic themes are present in the BT.

3.1 Objectives of the Biomimicry Toolbox

What does the BT aim to do? To what degree is sustainable solutions within its objectives? To answer this the purpose of the BT was investigated. Throughout the interviews and from analysis of the BT, information was gathered on what the purpose of the BT is. The purpose, vision, mission and goals of the BT are elaborated on in the section below.

3.1.1 Mission and goals of the Biomimicry Toolbox

Through the 5LF analysis of the BT it was identified in the section '*About the Toolbox*' that the purpose of the BT is:
(1) To provide an orientation to biomimicry;
(2) To help problem solvers incorporate insights from nature into their solutions and;
(3) To support participants in the Biomimicry Global Design Challenge (BGDC). It is intended as a quick-start guide to the biomimicry thinking process and is directed at those who are new to biomimicry or have little previous experience. (BT 4.0)

The purpose of the BT was confirmed by the interviews with the designers of the BT. Designer 1 describes the purpose of the BT as providing a comprehensive resource to support the challenge initiative. Designer 2 further describes it as intended as an introduction to biomimicry. Designer 1 mentioned that the BT is open source and is therefore not restricted to participants of the BGDC but can be used by anyone who wants to learn about biomimicry.

From the 5LF analysis of the BT is was found that the BT intents to provide an orientation to biomimicry to the users of the BT.

"This toolbox provides an orientation to biomimicry and introduces a set of tools and core concepts that can help problem-solvers from any discipline begin to incorporate insights from nature into their solutions." (BT 5.0)

Then, it is found through the BT analysis that it shares the mission to support the target group of participants in the BGDC.

"We have assembled the toolkit to support individuals and teams participating in design challenges organized by the Biomimicry Institute and/or our affiliates, ..." (BT 5.0)

The BGDC describes its mission and goals as, to:
(1) Help motivated problem-solvers around the world to learn how to look to nature for design and business inspiration; and
(2) Create a pathway for more biomimetic products to come to market (Biomimicry Institute, 2018, 2).

Interviews with mentors and participants also confirm that the BT helps to understand biomimicry. Participant 2 states that even if she is already well familiar with biomimicry, the BT is good as reference to go back to in order to keep track of the biomimicry thinking process.

3.1.2 Mission and goal of biomimicry

As stated in the section above, the purpose of the BT is to enable users getting involved with learning about biomimicry. From the 5LF analysis of the BT it was found that the BT *'Introduction'* section describes the purpose of biomimicry itself: to build a life-friendly world within the constraints of the planet.

"In the practice of biomimicry, we set our sights on an audacious goal: to build a more life-friendly world – one in which human technologies meet the same 'design constraints' that the rest of life on Earth works within." (BT 1.1)

In the *'Introduction'* section of the BT, it is also explained that biomimicry is different from other ideologies that look to nature for how to solve problems, such as bio-inspired design. This is through aiming at not only being inspired by nature, but also to create sustainable solutions.
"Biomimicry is unique among other bio-inspired design approaches in its emphasis on learning from the capacity of living systems to arrive at sustainable solutions to specific functional challenges" (BT 1.1)

The BT has a goal of creating not only sustainable but even regenerative solutions. In the section *'Introduction'* the following statement is made:

"With care and focus, we can learn to emulate nature's successful strategies. Now is the time to begin creating designs, materials, and technologies of our own that are not only sustainable, but also regenerative and restorative—supporting the fabric of life on Earth." (BT 1.1)

Lastly from the 5LF analysis, three aspects of biomimicry were defined in the '*Introduction'* section of the BT explaining biomimicry as the conscious emulation of life's genius.

"Conscious": being intentional
"Emulation": learning from living things, then applying those insights to the challenges humans want to solve.
"Life's genius": recognizing that life has arrived at well-adapted solutions that have stood the test of time, within the constraints of a planet with finite resources." (BT 1.1)

Being intentional was confirmed to be an important part by Designer 2 but was not present in the interviews of the Mentors and Participants. All of the Interviewees mentioned the remaining two elements. 'Emulation' in terms of the inspiration coming from looking at Nature. 'Life's genius' in terms of the Natures Unifying Patterns (NUPs).

3.2 Strategic context

This section presents the findings on how the BT provides understanding of the earth system and supports its users in identifying strategic context from which solutions are to be created.

3.2.1 Description of the earth system

Through the 5LF analysis it was identified that the BT includes an explanation of the earth system that solutions should be adapted to and operate within. The constraints of this system are described in the BT section "The Earth Operating System". In table 3.2.1.1 it is outlined how the BT describes the system in relation to the description from FSSD.

Table 3.2.1.1 Description of the earth system as explained by the BT and the FSSD.

Earth system as described in the BT	Earth system as described by the FSSD
Earth has limited water. Earth has limited atmosphere. Earth has limited sunlight, from which all energy ultimately is derived. Earth has gravity. Earth is cyclic. (BT 2.3)	The Earth is a closed system where matter stays on earth, but energy enters as solar radiation and leaves as heat. Society does not consume matter, only its concentration, structure and purity. Photosynthesis is the primary producer in the system and thereby the engine that drives the biological cycles of nature. Humans are social species. Key elements for adaptive capacity of social system is: diversity, learning, self-organization, trust and common meaning. (Robert et al, 2015, p34, p108)

In the section of the BT *'Earth's Operating System'* it is further described that earth has a dynamic equilibrium and maintains a chemical balance, although it is constantly changing. *"Earth exists in a state of dynamic equilibrium; it maintains an ecological and chemical balance, despite being in a constant state of change, much as our bodies maintain homeostasis despite being in a constant state of flux."* (BT 2.3)

3.2.2 Natures Unifying Patterns as description of the earth system

From the 5LF analysis of the BT and the interviews with the designers it was identified that Natures Unifying Patterns (NUPs) are used as descriptions of the earths system that fit well within the strategic context theme. In the BT section 'Natures Unifying Patterns' it is described that the NUPs are the most essential lessons from the natural world that should be considered when creating solutions. *"Nature's unifying patterns is our attempt to identify the 10 most essential lessons from the natural world that should be considered as part of a design process."* (BT 2.4)

The interviews support the understanding that NUPs are descriptions of the system. One of the designers explains that the NUPs are overarching patterns on an overarching system level: *"These are overarching patterns, it's kind of a grand scale on high level."*

NUPs are presented in the section "Natures Unifying Patterns" of the BT in the following way:
- *Nature uses only the energy it needs and relies on freely available energy.*
- *Nature recycles all materials.*
- *Nature is resilient to disturbances.*
- *Nature tends to optimize rather than maximize.*
- *Nature provides mutual benefits.*
- *Nature runs on information.*
- *Nature uses chemistry and materials that are safe for living beings.*
- *Nature builds using abundant resources, incorporating rare resources only sparingly.*
- *Nature is locally attuned and responsive.*
- *Nature uses shape to determine functionality. (BT 2.4)*

The BT state in the section "Natures Unifying Patterns", that the NUPs support implementation of nature's lessons in a system context and that they are essential in order to build a sustainable world and thereby should be implemented when creating solutions. *"These patterns are worth paying attention to because they can have profound implications for human design. If we aim to build a world that is sustainable (i.e. compatible with life on Earth over the long haul), we need to consider nature's lessons in a systems context."* (BT 2.4)

3.2.3 Ecological and social system

The FSSD analysis of the BT detailed how NUPs correlate with the 8SPs as shown in table 3.2.3.1. It is shown that the NUPs are mostly supporting the ecological SPs.

Table 3.2.3.1 Description of how the NUPs supports sustainability as defined by the 8 SPs

	Sustainability principles as defined by FSSD	**NUPs that supports the SP principle**
In a sustainable society, nature is not subject to systematically increasing…		
1	…concentrations of substances extracted from the Earth's crust	Nature uses only the energy it needs and relies on freely available energy Nature recycles all materials Nature builds using abundant resources, incorporating rare resources only sparingly Nature uses shape to determine functionality
2	…concentrations of substances produced by society	Nature uses only the energy it needs and relies on freely available energy Nature recycles all materials Nature uses chemistry and materials that are safe for living beings Nature builds using abundant resources, incorporating rare resources only sparingly Nature uses shape to determine functionality
3	…degradation by physical means	Nature tends to optimize rather than maximize Nature uses shape to determine functionality
and, in that society, people are not subject to structural obstacles to…		
4	… health	Nature uses chemistry and materials that are safe for living beings
5	… influence	-
6	… competence	-
7	… impartiality	Nature is resilient to disturbances
8	… meaning making	-

From the 8 SPs analysis of the solutions it was identified that several of the solutions do not address social sustainability as defined by the 8 SPs. For example, the solution "Balcony Cultivator" is presented as a way to enable people to grow their own food even though they are living in a city. From the analysis of this solution, it was seen that there could possibly be positive contributions on SP4 '…health'. Contribution to other social SPs could not be identified. (Appendix A3.2)

2/14 of the solutions analysed were mainly focused at addressing social issues. "Polisnack" has the intent of encourage healthier life styles through providing a healthy snack option. "Cool down be more" connects people with cold places in hot cities. Through interviewing one of the participants who created "Cool down be more", it was found that the participant who created this solution had previous background in social design. (Appendix A3.2)

Mentor 2 explains the experience of the BT as being weak on the social parts and its main focus is on ecological issues.
"We have always been weak on the social parts. I don't think on the toolbox they do a lot of stuff with social issues it's more of an environmental" (Mentor 2, 2018)

Designer 2 mentioned that social aspects are addressed by the problem that users are working on and that it is important for the user to state the social and environmental goals they want to achieve.

"Users have to outline social and environmental impacts, so there is the problem they are working on." (Designer 2, 2018)

3.2.4 Importance of system perspective

The BT includes encouragement of adopting a systems perspective to contextualize the design problem that a user aims to solve. All of the designers (3/3) interviewed, as well as all of the mentors (3/3) and 2/3 participants agree on the importance of having a "whole systems perspective" when creating sustainable solutions. All of the designers agree on that adoption of a systems perspective is an important part of how the BT supports creation of sustainable solutions.

Designer 1 explains how biomimicry has the goal of creating thriving communities and ecosystems and operation in a way that is sustaining the whole system:
"I think it is all a pretty interesting perspective on thinking how we can operate in a way that is sustaining a whole and not just maximising benefit for one piece or part." (Designer 1, 2018)

Mentor 3 explains his perspective about the importance of adopting a systems perspective and not just focus on the solution:
"I think it is really important that you think about the system you're in. I think, when you look really at the things that come before what you´re doing and what comes after you have done something and really see the whole system that you´re in with everything that is surrounding you, then you see the impact much better. If you understand that you want to create benefits for everybody, that's when sustainability is the result." (Mentor 3, 2018)

Mentor 2 explains how system perspective influences strategic thinking towards sustainability within the planetary context:
"Sustainability is a goal, an aspiration, a thing we're moving towards and it means living within the regenerative capacities of the Earth's system. So, the earth is continuously regenerative and if we leave enough of it alone, then we can use those ecosystems services without impairing that regenerative ability to recover."

Participant 1 reflects on how biomimicry encourages adapting a system perspective and how that contributed to support the sustainability of the solution:
"The solution is a system (not a product) and aims at solving system issues.", "Biomimicry is encouraging to focus on the system and looking at this solution in nature in a broad section and looking at the super system, subsystem and the interactions. The idea of looking at our design from a bigger perspective helped us to go to a more sustainable solution." (Participant 1, 2018)

3.2.5 Support in the Biomimicry Toolbox for adopting a system perspective

From the 5LF analysis of the BT it was found that the 'The Systems View' section of the BT gives an introduction to system thinking. In that same section, the BT introduces two resources, a book called 'Thinking in Systems' by Donella Meadows and the 'The Systems Explorer' worksheet, in order to support users in how to apply a system perspective when creating solutions. (BT 2.2)

In the System Explorer Worksheet, it is explained that the worksheet aims to help users identify the interconnections, the sub- and super systems of the context that solutions are intended for.

"The Systems Explorer tool is a template for diagramming a system that can help you to illustrate the known and potential interconnections, resources, and sub and super-systems of a particular design or organism. Doing so in the context of biomimetic design will help you come to a deeper understanding of the situation you are designing for, or the organism or natural model you are looking to for inspiration." (BT 2.2)

3.2.6 Downstream vs. upstream thinking

One of the gains of adopting a system perspective is that it provides the ability to address upstream issues. In this section we present the results that describes how the BT support its users in thinking upstream.

In the 8SP analysis of the solutions it was identified that there are solutions that address symptoms of problems instead of addressing problems more upstream where the problem was created. For example, the solution "Refish" (Appendix 3) aims at collecting particles from exhaustions in the air through attaching a particle collector to public transportation. The particle collector will not decrease the amount of exhaustions released from traffic but mainly limit the problem after it as already occurred.
The solution "Extraction" (Appendix 3) is a solution for extracting carbon dioxide from the air and it is suggested to be placed close to traffic. This solution is not designed to stop the exhaustions from happening, but to limit the problem once it has already occurred.
The solution "Balcony Cultivator" (Appendix 3) is a greenhouse for balconies where people can grow their own food at home. It was part of a challenge to address food systems. From the presentation of this solution it was not clear how this solution would be able to have a noticeable effect in addressing the food challenge.

In interviews it was identified that there are also indications that the solutions coming out of the BT have a tendency to address downstream problems. Designer 3 discusses how it is important to move up from product level to process- and system level in order to better address sustainability. She mentions that solutions came from the BGDC that were not great sustainability wins. She also mentions that the BT could be clearer on addressing the system level.
"We talk in the toolbox about the different levels that you emulate. You can emulate at the product level. You can emulate at the process level. And you can emulate at the system level. Over time I, and others, have been really kind of wanting to get away from that product level and encourage people to go deeper, into that process and the system. And it's for that same reason we're ending with all these kinds of products, but they really weren't great sustainability wins. And you almost have to go to the process and system levels for that. I'm wondering if the toolbox needs to be a little more explicit about that. A little clearer." (Designer 3, 2018).

Designer 1 further verifies that the BT might need improvement in the system section to better teach the users in how to think deeper and not only address problems at the surface.

"We have been trying to figure out how to strengthen that portion of the training. That students can better articulate the depth that they could be thinking about. There are a lot of projects that are sort of only at the surface." (Designer 1, 2018)

In the interviews we also found one example of a participant who had addressed a problem more upstream at a system level. Participant 3 had worked on a solution that is a system aiming at connecting people in low-income areas to cool places during hot summer times. She also explains that she considered it as more impactful to design a system.

"In my own opinion, I found it more impactful (to design a system). I guess it has a bigger impact, comparing to a single product.", "Cool down project, which is a system that connects the communities in Baltimore in low-income areas, to the coolest places during the hot summer times. Because, in Baltimore not all people have access to AC, so we defined a system." (Participant 3, 2018)

Participant 2 elaborates on the limitations in current society, when it comes to providing materials that are appropriate to use in order to be able to mimic nature.

"When you mimic a strategy for example, you sometimes realize that we don't have the materials in the human world to actually do what we need to do and there's a lack of technology to actually mimic that strategy." (Participant 2, 2018)

3.3 Strategic content

Having a clear goal with strategic content that supports to be intent focused is one of the elements identified as important for strategic thinking. In what way does the BT provide a clear goal to aim for sustainability with regards to sustainable solutions? This section presents the findings on how the BT supports its users to create sustainable strategic content.

3.3.1 Definition of sustainability in the Biomimicry Toolbox

As sustainability is an essential part of the BT it was investigated how the BT defines sustainability. From the 5LF and FSSD analysis of the BT, a definition of sustainability is identified in the BT section *'Glossary of Terms'*:

"Creating and maintaining the conditions under which humans and nature can exist in productive harmony, that permit fulfilling the social, economic, and other requirements of present and future generations. Sustainability is based on the principle that everything we need for our survival and well-being depends, either directly or indirectly, on the natural environment" (BT 4.3)

In the interviews when asked what sustainability is, the answers were diverse and not always according to the description within the BT. Participant 2 says that it is about ensuring that next generations have the same resources and benefits of current generations. Participant 1 speaks about being environmentally friendly and to consider all aspects when producing a product, materials energy etc. Mentor 3 speaks about sustainability as an aspirational goal to move towards, living within the regenerative capacity of the earth. Mentor 2 refers to the 3 P's; people, planet, profit. Mentor 1 speaks about taking care of the system and creating benefits for everyone.

From the 5LF analysis of the BT, it was found that the BT does not use the definition of sustainability (as mentioned above) throughout the BT, as mentioned in the glossary. Instead, the NUPs are used with the intent to explain what is needed in order to create the strategic content of sustainable solutions.

"The intent behind applying nature's unifying patterns to biomimetic design is to create more sustainable solutions." (BT 2.4)

3.3.2 Natures Unifying Patterns to set design constraints

As mentioned in the previous paragraph, the NUPs are used to explain what is needed to create sustainable solutions. It was investigated how well the NUPs define the goal of sustainability and how these supports its users to create the content of sustainable solutions. This is important because this informs the research question on how the user is supported to strategically think with this content in mind. The results about the NUPs as clear goal for sustainability are presented in this section.

All designers (3/3) mention the importance of using the NUPs as a way to create the strategic content of more biomimetic solutions. 3/3 Designers agree that a better understanding and application of the NUPs will lead to more sustainable designs. 3/3 Mentors also agree that applying the NUPs is an important part of the BT when creating sustainable solutions. However, the participants state that they find it difficult to apply the Nature Unifying Patterns.

Through the interviews it is found that the instructions for how the user should integrate the NUPs is not commonly understood and supported in the BT. It was found that the standards and methods for integration is differently articulated by users and designers. This implies that the user methods for the NUPs is perceived differently. Therefore, the way the NUPs are being used was further investigated.

The use of the Natures Unifying Patterns was first mentioned to set the design specifications and constraints for the strategic content by designer 3, 3/3 mentors and 2/3 participants. In the interviews all the mentors (3/3) and participants (3/3) mentioned the importance of setting specifications and constraints for sustainability of the design.

"We use life principles at the beginning to incorporate in on the design brief of the design. So, at the beginning we can create these boundaries and structure of what the design needs to be and what not. Kind of a big problem, because life principles is not really a measure because theirs is no quantitative. You cannot say I'm 45 percent Biomimicry." (Participant 2, 2018)

Using the NUP to set design constraints was further described in the BT.

"The goal is to translate these lessons into design specifications, quality control metrics, material selection, and other manufacturing or process choices. Although it may be impossible to fully apply all 10 patterns within a design given current limits in human-made materials and systems, replicating all of these patterns is an excellent aspirational goal." (BT 2.4)

3/3 Mentors and 1/3 participant are using the NUP's as a guiding force for the design of the solutions. 1/3 Mentor mentions that participants tend to be under strong time pressure and therefore tend to forget to look at the NUPs. They tend to often look just at the end of the design

process as a checklist whether the design meets the NUPs. At the same time, these strategies from nature are experienced to be hard to fully apply in the designs, given the material and technological limits of todays' world.

It was found through the interviews that the designers and mentors find it important to integrate the NUPs when designing solutions. The NUPs are encouraged to be used as evaluation for sustainability of the solution. However, there are indications that it is not considered as necessary to integrate the NUPs fully. When applying the NUPs for the strategic content of sustainability, according to the designers, the patterns are open for interpretation, more suggestions and inspiration than critical for the design. In the interviews mentor 1 explains that the deeper the integration of the earth system functions and strategies in the design, the better in terms of sustainability. At the same time, not full compliance is considered as sufficient too.

"Living organisms comply with all the unifying patterns and so really good design should do that too. But if you meet some of them it's really good. The more you can meet, the better is your design" and *"Ideally your design would meet all of those life's principles or unifying patterns, because in nature they do". (*Mentor 1, 2018*)*

"I really think they are more suggestions then have to haves." (Designer 2, 2018).

*"Instead of stating a design direction, nature's unifying patterns are more like this is something nature does." (*Designer 1, 2018*)*

*"We don't say that NUP is the definitive list of anything rather we're saying here are some patterns in nature" (*Designer 2, 2018*)*

This implies that the strategic content of sustainability with the application of the NUPs is more of an option than a clear goal that needs to be strived for.

Then, through the interviews it was suggested that the more you integrate the NUPs into the solutions, the better it is considered to be for achieving the strategic result of sustainability. Designer 3 and mentor 1 mentioned that ideally you would meet all of the NUPs and this is used as a quality control for sustainability.

"The more Unifying Patterns you meet, the more sustainable you are." (Mentor 1, 2018)

"If all you do is try to meet life's principles, you know that to me is the most important, because in the end you'll actually end up emulating nature and you actually make it more of a systems approach. Where does your product fit into a whole system?" (Designer 3, 2018)

*"I invite students to meet natures unifying patterns, the more the better but not all need to be met, I use them as a quality control" (*Mentor 1, 2018*)*

Also, mentor 1 and 3 and participant 2 worked with the NUPs to set boundaries for the design, whereas mentor 2 and participant 3 mentioned that actually they were used at the end of the process to check the outcomes rather than at the beginning or throughout the process.

3.3.3 Nature's Unifying Patterns to evaluate sustainability

In the interviews designer 1 stated that within the current BT there is no possibility of assessing how life friendly or life unfriendly the solution is. The practice of LCA (Life Cycle Analysis) was mentioned by mentor 3 and participant 1 as a possible way to address this.

"There's nothing directly in the Biomimicry Toolbox to say how good something is in terms of sustainability". (Mentor 3, 2018)

On the other hand, in the 'Evaluate Fit and Function' section of the BT it guides the user to assess the design concept(s) for how well they meet the criteria and constraints of the design challenge and how well they fit into the earth's systems. This includes a checklist that is used to evaluate the solutions with the NUP's. (BT 3.7)

One of the participants who already had more of a background in biomimicry mentioned that their team used Life's Principles to align their solution with natures principles, instead of using the NUPs provided by the BT. Life's Principles are a collection of lessons learned from nature, published by and intellectual property of Biomimicry 3.8. The NUPs were inspired by the Life's Principles. The second participant explains how she finds it hard to apply to NUPs:

"We use Life Principles. Because I think the patterns are good to understand the patterns, but not really to apply them. Sometimes they are really hard to understand. If you don't understand them they can be very general. We just use Life Principles for design, because they feel more complete for the project." (Participant 2, 2018)

This suggests that the NUPs are open for interpretation and application by participants, which limits the possibility of participants to produce and evaluate the strategic content with regards to sustainability.

However, the NUPs are able to inspire more sustainable solutions. By iteration of the design and integration of the NUPs throughout the process, the NUPs give the opportunity and possibility to improve designs in terms of sustainability. The third designer mentions how this is a constant learning curve that improve sustainable designs.

"I said let's look at these nature's unifying patterns, and she came up with some really great improvements on that project by just doing that. So, I think it's really important, and maybe that's what the role of the mentors is also. Those of us who have more training is to really help people see that." (Designer 3, 2018)

3.4 Strategic process

In this section, the elements of the BT, that fit on the strategic process theme of the conceptual framework are shared. What fits under strategic process are those parts of the process as a whole that clearly help the users of the BT make steps toward the desired goal as described on the strategic content theme.

Examples of such elements are, as described in the conceptual framework, having strategic guidelines such as applying back casting and having prioritization questions and also thinking in time, being hypothesis driven and applying intelligent opportunism.

This section provides a short understanding of what the phases of the process are, provided with the BT. Then it goes into which parts of those have elements of strategy in there and which are focused on specifically strategic process.
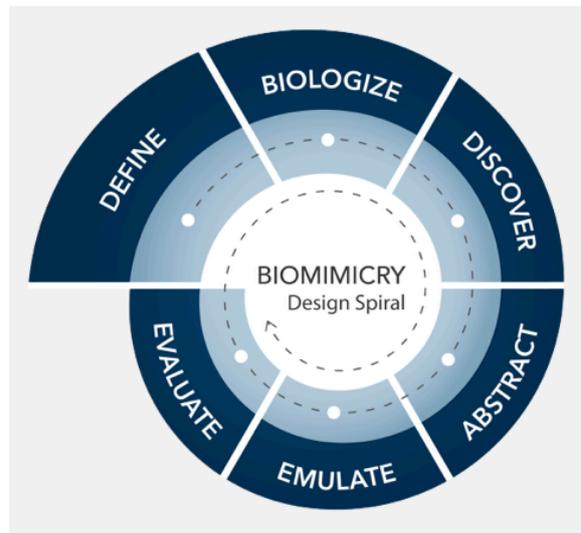
Figure 3.4.1 Design Spiral (BT 3.0)

It was identified in the 5LF analysis of the BT, that the *'Methods'* section describes the process of how to implement a biomimicry approach to design (BT 3.0). The different steps users go through are shown in the Design Spiral in figure 3.4.1. The sections that are relevant for this research are the *'Define'*, *'Emulate'* and *'Evaluate'* sections of the BT, as these provide elements of strategy. Specifically, the 'Evaluate' section has some elements to support strategic process (BT3.7).

3.4.1 Define

Through the 5LF analysis it was found that the *'Define'* section of the BT encourages users to define the problem or opportunity that users want to address. It encourages users to consider the context of the solution and to *"Take a systems view and look for potential leverage points"* (BT 3.2). It provides several tools to take a systems perspective such as the *'systems explorer'* and the *'identifying leverage points'* worksheet. This section provides mostly tools for clarifying the strategic context to fit the solution within.

3.4.2 Emulate

In the *'Emulate'* section of the BT, the actual design concepts based on the abstracted design strategies of the prior process step are created (BT 3.6). In this section, users of the BT are invited to make their design strategy visual, apply brainstorming, and consider Nature's Unifying Patterns (BT 3.6). It was identified in the 5LF analysis that to make the design strategy visual, supports in creating a systems perspective, thereby further clarifying and adapting to the strategic context. As this section includes NUPs, it refers the reader back to the strategic content and the use of the nature's strategies into the design concept.

3.4.3 Evaluate fit and function

In the *'Evaluate fit and function'* section the BT encourage users again to *"Consider the whole system"* (BT 3.7*)*, users are encouraged to take a system perspective and consider how the solution interacts and is dependent on other systems around it.

"Think about how the design concept is part of a system and how that system is impacted by it. How does your design concept interact with material and energy systems? What about human relationships and behavior? Are there adjacent or super-systems that should be considered, too?" (BT 3.1)

The BT also states that when evaluating users should "*Use Nature's Unifying Patterns*". Users are encouraged to incorporate or embody the NUPs in order to create 'successful life-friendly' design (BT 3.7). This is already described at the strategic content section of 'Results'. These are elements of strategic context and content.

A *'Nature's Patterns Checklist'* worksheet of the NUPs is provided in the 'Evaluate Fit and Function' section in order to support that the NUPs are considered when designing the solution (BT 3.7). Also, a 'Business Model Canvas' is offered to identify feasibility constraints (BT 3.7). In this section, users are also suggested to *"Make a Prototype"(BT 3.7)*. The section suggests using IDEO's Design Kit as a resource for rapid prototyping: *"IDEO.org's Design Kit is a great resource for learning about various methods for rapidly prototyping and testing ideas." (BT 3.7)* These three elements are considered being part of the strategic process and are further discussed in the discussion section.

3.4.4 Prioritization process

It was identified in the interviews and the 5LF and FSSD analysis, that what comes closest to being a prioritization process in the BT is the use of the NUPs for evaluation.

During the interviews, interviewees were asked whether the BT provides any form of decision making support. None of the interviewees (9/9) experienced the BT to have any explicit decision-making support. Interviewees (2/9) felt that what came closest to being decision making support towards sustainability were the NUPs.

Designer 2 stated that to some degree the NUPs provide decision making support, but only in a superficial way.

"I don't know whether the toolbox really gets at that. To some degree the NUPs support, but I'd say only in a superficial way maybe would it get at that. I think it's that the NUPs are pretty high level and it's a little bit up to how participants interpret and apply the Nature's Unifying Patterns" (Designer 2, 2018)

Mentor 1 mentions that the NUPs could be considered as something providing DMS, but he does not think students are using it that way necessarily.

One participant mentioned she found it challenging to prioritize between design strategies.

"We could find lots of species and lots of strategies but, which one can best help us and which one we need to pick, was a big challenge." (Participant 3, 2018)

Additionally, it was identified in the 5LF and FSSD analysis that the section 'Identifying Feasibility Constraints' in the BT, is a section which addresses whether solutions created with the help of the BT might provide a sufficient return on investment. It thereby also addresses constraints relevant for prioritizing (BT 3.2).

3.5 Other strategic support

Throughout the interviews, interviewees mentioned elements from outside the BT which appear to also provide support in strategic thinking for the participants of the BGDC compared to general users of the BT. It is beyond the scope of this thesis to address these elements beyond results. However, it was considered relevant to include the fact that these aspects of the BGDC are there in our report and speak to them, to give a fuller picture of the intersystem in which the BT resides. These elements are mentors, judging criteria, webinars and the accelerator program. What the results of the interviews state on each of these elements of the Biomimicry Global Design Challenge, is shortly mentioned below.

3.5.1 Mentors

3/3 Participants described that the mentors help the team to stay on track. Participant 3 mentions that mentors know the process very well and helps them pay attention to what they need to pay attention to at that moment. Mentor 1 states that the mentors opinion has a lot of weight to it and can influence the team quite a lot. Mentor 3 mentions that mentors are helpers that should not direct the work or tell them what to do. It depends on the team asking. The other two mentors say that mentoring is a way of supporting decision making. Sometimes the mentors refer the students back to the NUPs as is described by two of the three mentors.

3.5.2 Judging criteria

In the 'judging criteria section' of the BT, the criteria by which applications of the design challenge get judged are described. The applications are judged on biomimicry process (25%), context and relevance (15%), social and environmental benefits (15%), creativity (10%), feasibility (15%), communication and presentation (10%), and team (10%).

Around social and environmental benefits, the questions that are asked are:
- *Will adoption of your design lead to significant social, cultural, and/or environmental wins? E.g., does your design concept improve accessibility for a percentage of the population; help low income populations meet basic needs; address product lifecycle effects on the environment; address issues of toxicity, reduced material usage, and waste reduction; etc.*
- *How well do you understand and address the underlying sustainability problems you aim to solve?*
- *Have you articulated and defined any sustainability problems?*
- *Have you provided more than shallow evidence of how your design concept will address sustainability concerns?*

- *How have you applied nature's unifying patterns in your design?* (Biomimicry Institute 2018, 3)

3/3 Mentors state that the judging criteria help support them in guiding the participants of the global design challenge in creating better solutions. As the judging criteria are used to grade the solutions coming out of the BGDC, the participants are probably looking to meet these criteria. The judging criteria could thereby influence the team in making more sustainable solutions and cultivate their strategic thinking towards sustainability.

3.5.3 Webinars

The BT and 3/3 designers, 2/3 participants and 1/3 mentor described the use of educational webinars as part of the GDC. The webinars are educative in nature. The webinars could be suggesting the use of certain strategic tools within the BT, thereby giving direction to the participants and possibly cultivating their strategic thinking. The authors of this thesis only looked at one webinar and are not fully aware of the contents of the webinars.

3.5.4 Accelerator program

After the BDGC, participants who ended up in the top tier of the challenge get the opportunity to participate in an accelerator program to bring their solution to market. In that program they get immersed in an ecosystem of biomimicry specialists and other participants wanting to achieve the same goal. Based on the answers of one participant sparring with all these parties appears to help the participants to cultivate an accurate systems perspective of their challenge and helps them identify how feasible the ideas are. This suggests that they might receive a lot of strategic support, cultivating their strategic thinking during this accelerator program.

4 Discussion

As explained in the Introduction and Conceptual Framework sections, from strategic thinking and the FSSD framework, three important factors were identified in order to strategically move towards an intended goal. This is strategic context, strategic content and strategic process. This discussion is structured based on these themes in order to answer the research question:

"How might the Biomimicry Toolbox better support its users in applying strategic thinking in order to create sustainable solutions?"

In the result section 3.1 it was identified that creation of sustainable solutions is within the purpose of biomimicry and the BT. It was also found that emphasis on creation of sustainable solutions, and not only solutions inspired by how nature solves challenges, is what makes biomimicry different from other bio-inspired design approaches. This is explained within the BT and confirmed by the designers. From this the authors learn that sustainability is a vital part of biomimicry and the BT and that the ability to strategically guide users to create sustainable solutions could be beneficial for the BT in order to deliver on its purpose.

It was also identified that the BT supports creation of sustainable solutions through applying systems perspective, considering NUPs and follow the methods as explained in the Biomimicry Design Spiral. We see that the BT has elements of all three important factors (strategic context, strategic content and strategic process) that are needed to strategically move towards the goal of sustainability. Deeper discussion of these individual themes follows in this chapter.

4.1 Strategic context

In this section it will be discussed how the BT defines the strategic context, how it explains the earth system and supports adaptation of a systems perspective when addressing challenges in order to create sustainable solutions.

4.1.1 Ecological and social system

As explained in the result section 3.2, the way that the earth's system is described in the BT is through the section 'Earth's Operating System'. The NUPs are also explaining the earth's system by describing patterns observed in nature. There are similarities in the way the earth system is described in the BT and how the FSSD describes the earth system, although a vital difference can be identified. As understood by the authors, the BT considers human society as integrated in the ecological system and does not recognise human society as a separate system with separate patterns. The FSSD also recognises that human society is nested within the ecological system, but takes into consideration that there are structures within human society that are unique for humans and that need to be understood in order to address the sustainability challenge.

From the comparison of the NUPs with the 8SPs from FSSD we see that the social sustainability principles are not well addressed in the NUPs. Only one of the NUPs could be related to address the social context, namely the pattern '*Nature is resilient to disturbances*'. In the description of this pattern, resilience is described by the attributes of diversity, redundancy, decentralization, self-renewal and self-repair. To some degree this pattern could

support understanding of items important for social systems. Generally, the authors would argue that a more complete understanding of the human social system is missing in the NUPs, which makes it difficult to produce biomimetic solutions that are fully sustainable.

NUPs are described as patterns observed in nature that can teach humans how nature is able to be sustainable. As described in the BT, humans are part of, and not separate from nature. Since humans are part of nature, the authors think that also the social system should be studied and influential when describing the patterns that are important for sustainability.

When it comes to explaining the ecological system of earth, NUPs are better equipped. As indicated in the table 3.2.3.1., applying the NUPs can support the creation of solutions that contribute to the sustainability principles SP1 (In a sustainable society, nature is not subject to systematically increasing concentrations of substances from the earth's crust) and SP2 (In a sustainable society, nature is not subject to systematically increasing concentrations of substances produced by society). Although, the SP3 (In a sustainable society, nature is not subject to systematically increasing degradation by physical means) is not directly addressed through the NUPs. Depending on the interpretation of the NUP *"Nature is locally attuned and responsive"*, there could be some coverage of this principle. In the description of this pattern it is explained that: *"Chances of survival increase when individuals are good at recognizing local conditions and opportunities and locating and managing available resources."* (BT 2.4) Although preventing physical degradation could be seen as 'managing local resources', neither the elaboration on the NUP in the descriptive text, nor the examples given in the BT are providing a description that would prevent degradation of physical means.

Due to this, the authors reason that the NUPs might not be able to fully explain the earths system and the interactions between social and ecological systems of the earth, in a way that enable addressing the systemic issues that cause the sustainability challenge. As has been elaborated in the introduction, experience shows that when certain aspects of sustainability are not taking into account during the design process, this usually leads to sub optimal design solutions that perpetuate the problem. In the analysis of the solutions created for the BGDC, there were indications that social aspects (as described by the social sustainability principles of the FSSD) were not considered in some of the solutions.

The authors, and the FSSD framework, consider it important to understand the interrelationships between the social and ecological systems and how human society is degrading the earth's ability to support life, in order to be able to strategically address the sustainability challenge and create fully sustainable solutions. The BT could benefit from including the social system into its systems perspective and further elaborate on the understanding of the ecological system. Thereby solutions from the BT could better address all aspects of the sustainability challenges. This could for example be done through insights from how the FSSD describes the social system and its interrelationship with the ecosystem. The authors encourage further research in order to understand how to best expand on the understanding of ecological system and integrate social system understanding within the BT.

4.1.2 Upstream versus downstream

As identified in the introduction, adopting a system perspective provides the ability to identify and address issues upstream, where the structural obstacles are that create thousands of problems occurring downstream. This is also in line with the importance of a systems approach taken from the conceptual framework. In the results section 3.2 it is explained how the BT supports applying a system perspective through the section 'Systems View' and through providing the 'System Explorer worksheet'. It is also explained that the designers of the BT, mentors and participants recognize the importance of adopting a system perspective when creating sustainable solutions.

Even though the intention of the BT is to support users in applying a system perspective, the authors recognized through the analysis of the solutions and the interviews, that there are solutions coming out of the BT that focus on solving symptoms of problems instead of addressing problems at the root cause. It is noticeable that the solutions analysed are the ones that have achieved a top position in the BGDC and in that sense are considered as good examples of biomimetic solutions. It is also important to be aware of that many of the participants of the BGDC are students and new to the topic of biomimicry and possibly system thinking. Also, as explained by mentors, students have limited time in order to complete their solutions for the BGDC, which could make them want to grapple with a challenge on a simpler, product level. More experience might be needed in order to fully understand the complexity of systems and where the most impactful leverage points are. Still, if upstream thinking was elaborated on in the BT, it could possibly encourage participants to come up with more impactful solutions, both in the challenge and in future work.

From this the authors reason that the system description of the BT possibly could be strengthened when it comes to encouraging users to address problems upstream, where the structural obstacles occur. The authors suggest that this could be done by for example including an additional section on upstream thinking and by that encourage the users of the BT to address problems at the source. Further research can be beneficial in order to understand how to best integrate upstream thinking within the BT.

4.2 Strategic content

In this section it will be discussed how the BT supports its users in creating sustainable solutions by incorporating the element of strategic content: Is there a clear aim and goal for what success means when creating sustainable nature-inspired solutions?

4.2.1 NUPs as clear goal to comply with for sustainability

For effective strategic thinking, as clarified in the conceptual framework section, it is important to have a clear idea of what the success goal is that you want to achieve. As identified in 'Results (3.3)', NUPs are explained by the designers of the BT and in the BT itself, as the patterns in nature to learn from. They are described as "general suggestions" and "ways in which nature works". They can be understood as descriptions of the earth system. At the same time, the NUPs are used for the evaluation of the sustainability of the solutions. From the interviews it was found that when all NUPs are abided by, a solution would be considered sustainable. The more the design is integrated with the NUP's, the more it complies with the patterns of the

earth system. The more the solution fits in the operating system of the earth, the more the goal of a biomimetic solution is achieved. In that sense the NUPs can be considered as a description of what success for sustainability implements. The authors reason from their results that within the BT the NUPs are used to both describe the earth system and at the same time used as evaluation of the sustainability of the solutions.

There are differences between the way that the BT describes success through the NUPs and the way that FSSD describes success when it comes to sustainability. The 8SPs from the FSSD are created to define the boundary conditions of what is needed to achieve sustainability. It is also made clear that all 8SPs need to be complied to in order to reach the goal. From this the authors reason that the BT may not be strong enough in supporting its users on defining a clear goal with the use of the NUPs.

The authors consider criteria as valuable and needed when designing principles or patterns for success. Using scientifically created criteria that are clear in what to comply with could strengthen the NUPs as a tool to reach sustainability. This implements clarity for the user on what it is the design needs to comply with and on what goals it is evaluated. Therefore, the authors suggest that the NUPs in the BT could be further improved by operating as boundary conditions. To share an example of how the authors suggest working with boundary conditions; when creating the 8SPs the following criteria were used:

Boundary conditions should be….
   a) *… based on a <u>scientifically</u> agreed upon view of the world*
   b) *… <u>necessary</u> to achieve sustainability*
   c) *… <u>sufficient</u> to achieve sustainability*
   d) *… <u>concrete</u> enough to guide action and serve as directional aids in problem analysis and solutions*
   e) *… <u>non-overlapping</u>, or mutually exclusive, in order to enable comprehension and structured analysis of the issues. (Robert et al, 2015, p38)*

As explained in the previous section, the NUPs are not presented in the BT with the same clarity as the 8SPs are in what is needed to achieve sustainability. This makes it hard to evaluate against them. For example, in the NUP checklist of the evaluation sheet there are questions that are repeated and the questions in the checklist are open to interpretation. For example, in the NUPs checklist of the evaluation sheet there are questions that are repeated and the questions in the checklist are open to interpretation. As an example, the following pattern uses several statements that are open for interpretation. *"Nature builds using abundant resources, incorporating rare resources only sparingly."* What is an "abundant" resource? What is a "rare" resource? How much is "sparingly"? Statements like these can make it hard for the user to understand what is really needed in order to apply this pattern into the design criteria. An unintended consequence of this can be that the user is satisfied, or even believes that the goal is reached, even if only a few of the NUPs are implemented. Partial implementation of the NUPs can be a stepping stone in the right direction, but it should be clear that the goal is not yet reached.

Therefore, the authors reason that the way the NUPs are created as explanations of the earth system, can suggest that they are less clear in defining what success for sustainability really means. Thereby they are less valuable when used for the evaluation of the solutions. It could be helpful to be clearer on what the NUPs are intended for when achieving success. It would be helpful to develop a list of criteria for success that are better adopted to be used for

evaluation. Lastly, it might be most helpful to implement the Sustainability Principles of the FSSD. These principles are specifically meant as boundary conditions for sustainability. This would mean that the 8SPs will be adopted and used for evaluation of sustainability of the solutions. The authors recommend further research in order to further understand how criteria for sustainability could be implemented in the NUPs and in the BT. This is especially needed as the framing from these sets is significantly different. Where the SPs are framed from a "stop doing" stand point, the NUPs are framed from a "do more" standpoint.

4.3 Strategic process

In this section it will be discussed how the BT supports its users to achieve the goal that is described in the strategic content section through its strategic processes.

Parts of the process that the BT provides could be considered as being elements of strategic process. What fits under strategic process are those parts of the process as a whole, that clearly help the users of the BT make steps toward the desired goal as described on the strategic content theme. Examples of such elements are, as described in the conceptual framework: having strategic guidelines such as applying back casting and having prioritization questions, thinking in time, being hypothesis driven and applying intelligent opportunism.

4.3.1 Prioritisation process

Having a prioritisation process to choose the most fitting actions to get to the desired goal is an important element for achieving the goal. At this moment, the BT lacks a clear and simple prioritization process that helps users identify which steps are most worthwhile to take. There are some elements that can support decision making in the 'Evaluate' phase of the BT. The NUPs are used as an evaluation tool with the *'Nature's Patterns Checklist'* and the *'Business Model Canvas'* come closest to what can be considered prioritization tools. The first could be considered as a checklist to help solutions to be more in the direction of sustainability, where the *'Business Model Canvas'* mostly helps develop what is feasible for business.

The NUPs are what most interviewees had identified as giving some sense of decision making support. Each NUP has several descriptions of evaluation criteria attached to it. The total number of criteria for the NUPs is 47. This makes this list hard to work with when having to consider them for all the different aspects of a design concept. To add to that, imagine if the NUPs were to be used as a concrete list of criteria of which each criterion has to be met in order for a solution to be considered sustainable. It could mean that this would be very time intensive and very hard to comply with.

A benefit of the 8SPs is that in using them it becomes clear what obstacles need to be solved in order to function within the design constraints of socio- ecological sustainability. Once the violations of the ecological and social principles have been analysed, there is a sense of what has to be done in order to solve them and what principles are being violated the most. This clarity on the application for the design is currently not present in the NUPs. If the intention for the NUPs is to do "more of", then when does a user know he/she has done "enough"?

For a prioritization process to work where the NUPs are used in the same way as the FSSD uses the SPs, the NUPs could benefit from being more concrete. They could either be concrete

qualitative criteria meeting the five criteria as described in the strategic content section above for instance, or a quantitative assessment tool is to be used.

The impact can be measured quantitatively with a tool such as a Life Cycle Assessment (LCA). It is commonly known in designer circles that one of the downsides of applying a LCA, is that it is costly and time consuming. Using qualitative measures can save time, maintaining more money for actually addressing the problem compared to spending that on measurements.

Another way of prioritization is by identifying feasibility constraints and prioritize aspects of the design concept based on what is feasible is by evaluating it in a business sense. In order for a concept to be successful, it not only needs to be ecologically and socially sustainable, but it needs to make business sense as well. The Business Model Canvas provides a way of identifying feasibility constraints with regards to creating a business around the idea. It is helpful in that it provides quite a clear one-pager to make sense of whether the concept as a whole is feasible. But it could benefit from a simpler way of evaluating the feasibility of a concept in earlier steps in order to quickly identify whether a part of the concept makes sense or not.

The FSSD provides three prioritization questions that function as criteria that an action or concept needs to meet in order for it to be worthwhile to execute. Having such a simple list can help to quickly see which concepts are more worthwhile than others and they are already being applied in some practices of sustainable product design. The BT could benefit from a similar simple set of questions that help identify worthwhile steps to take. Using prioritization questions can support the user in deciding which option to choose.

The three prioritisation questions of the FSSD are:
1. Does this action proceed in the right direction with respect to the sustainability principles?
2. Does this action provide a "stepping stone" (flexible platform) for future improvements?
3. Is this action likely to produce a sufficient return on investment to further catalyse the process? (Robert et al, 2015, p44)

Such questions are useful as a preliminary step to quickly identify whether an action makes sense. After that a more elaborate process, such as the BT already has to an extent in the evaluation phase, would be needed to get to the details. If the users of the BT would have similar simple questions, this could help prioritize them throughout the Design Spiral and help them make sure the end product they will evaluate in the evaluate phase is already more aligned with the NUPs and the Business Model Canvas.

That does come with a further note, which is that when one is working with an extensive list of choices as long as 50 or more, that even though the three prioritization questions are helpful, they tend to end up not being sufficient in and of themselves to help get to the best set of actions. Often, there is still a more elaborate process such as a multi-criteria decision-making process needed, to get to the best set of actions which are more supportive of achieving sustainability. When having many options, the users of the BT can also benefit from a tool that can help them prioritize amongst many options.

Another possible improvement could be to update the NUPs checklist in the "Evaluate" section. A way to make users think more deeply about the NUPs could be to, instead of a checklist provide a worksheet where users are asked to explain in what way the solution they are working on contributes to or violate each of the NUPs. The existing checklist simply asks "Can you

close a technical or biological loop?" (BT 4.1). Then the user can answer yes or no. If instead the question was asked "In what way are you implementing this pattern?", as well as "Why, or in what way have you not implemented this pattern?", that would make the user think more deeply about them and make the checklist more impactful.

4.3.2 Prototyping

Liedtka (1998) defines intelligent opportunism as setting out a strategy without losing sight of alternative strategies that might become relevant in the near future. It is about maintaining adaptability. Being hypothesis driven is about having a theory and then testing it. Both are elements of strategic process as defined by Liedtka (1998).

As was mentioned in the result section, prototyping is one of the tools that is being introduced in the BT. The purpose of prototyping is actually to test assumptions, thereby by definition being hypothesis driven. It is also about rapid learning and iteration, allowing for intelligent opportunism to take place. Because of this, prototyping as a tool, addresses two aspects of strategic process.

Prototyping is introduced in the evaluate fit and function section. This is the most logical section for it to be introduced, as once the user of the BT has a concept to test, they are suggested to test it by talking to their potential clients and other stakeholders. With our rapidly changing world, tools such as prototyping become increasingly useful to learn quickly and being effective in creating valuable outcomes for sustainability. Additionally, as soon as the strategic content becomes clearer, then prototyping will become more valuable.

4.4 Impact of the Biomimicry Toolbox

What was discovered about the impact of the BT on the global sustainability challenge during this research? And what was discovered about the effectiveness of the BT on achieving its intended goals. To start with, part of the focus of this research was to understand how the BT supports creating sustainable solutions, as it was discovered as one of the criticisms on the biomimicry field in general that, it does not always enable generation of sustainable solutions.

There are indications that few solutions created in the BGDC with the use of the BT, actually end up in society. No examples of solutions brought to market were given by the designers, mentors or participants, although some of the award winners are pursuing to bring their solutions to the market through the Accelerator program that the Biomimicry Institute offers. Another reason could be that the BGDC only started in 2015 and it is still too early to see the effects. And finally, in this research we did not cover solutions created outside of the BGDC. Possibly there are people who have used the BT outside the BGDC who could have created viable solutions that are already brought into society.

The BT is also intended as a learning tool to explain the basics of biomimicry and get people started in working with biomimicry. This is a goal that it is delivering on quite well. The authors found the BT in itself full of information on the core concepts of biomimicry and many supportive theories around for example working in teams of business models. All of this is also presented in different and engaging ways: theory, worksheets, examples and videos were all used. And from the interviews it became clear the participants were appreciative as well, both

the ones that were new to biomimicry as the more experienced biomimics that was interviewed. Besides this, the various other supportive elements based around the BGDC such as webinars, mentors and the accelerator program for winning solutions are also valuable tools in deepening the knowledge and practice of biomimicry.

As mentioned, most of the users of the BT for the BGDC are students. These students will graduate, get involved in a career and in this career, they will potentially bring their learnings from this challenge. An interesting question for further research is how this experience with the BT will shape their way or working. This is where the BT might actually have its most current impact on sustainability. The number of solutions entered into the BGDC (and thereby the number of participants has been growing with around 15% per year since its start. It is estimated that around 1.000 participants have used the BT for the BGDC. And as the BT is also open for anyone to use, the total amount of people using it and implementing elements in their work is unknown but higher than what is registered. The Biomimicry Institute is sending out a yearly evaluation sheet that gives them basic information. It could be interesting for the Biomimicry Institute as a first step to see in what way they can use results from that evaluation to get a better estimate of the total amount of people looking at (and thereby potentially) working with the BT. This also could be an important factor in increasing their funding (and thereby increase their impact). A second and more complicated step would then be to better monitor how much more sustainable the solutions have become as a result from working with the BT.

This leads to another criticism of the field of biomimicry, that it lacks a unified evaluation system. It is the authors opinion that parts of the BT have the potential to be used as first steps towards such an evaluation system, especially in the creation of the NUPs and in the evaluation phase of the Biomimicry Design Spiral. And at the same time, some of this criticism still holds true as these elements are still mentioned in this discussion section as subjects for improvement. Improved measurability of the sustainability of solutions based on the BT, is needed to visualize the current effectivity of the BT and to define improvements

With the above discussion points in mind, one of the perceived strengths of biomimicry in having an impact on global sustainability lies in the combination of the three elements of Nature as Mentor, Measure and Model. This were explained in the introduction of this thesis as: *"Three ways that biomimicry values nature. Model – applying, imitating or taking inspiration from nature's designs and processes in order to solve human problems; Measure – using an ecological standard to judge the "rightness" of our innovations; and Mentor – valuing nature for what we can learn from it and not what we can extract from it.* (Biomimicry 2018, 4)

For this research the focus has been largely on Nature as Measure as this was where the most overlap was with the focus on strategic thinking and the evaluation of sustainability. But it could very well be that the combination of these three elements is where the leadership potential of biomimicry as a global movement becomes visible.

By offering inspiration for solutions to challenges (model), setting an ecological standard for the evaluation of these solutions (measure) and last but not least (re)connecting society to the ecosystem they are a part of (mentor). It is in this last aspect of the mentor role where biomimicry is aiming to move humans from looking at nature as merely an "ecological service system" to an integral relationship where society is a part of ecology.

4.5 Critical assessment of findings

To validate the research, the authors reflect and critically asses the research work that has been done. By explaining critical reflection on the validation of the work, the authors acknowledge and show the validation of the thinking and the findings.

4.5.1 Continuing refinement of the research

The final refinement of the definitions used for strategic decision making and strategic thinking has only come in the last quarter of the research. This also entailed changes in the research question. It is therefore likely that results from the interviews, which were already done at that point, are not optimally assessing the latest research question and insights.

There were two main reasons for the authors for still applying these changes into the research. On one hand the consequences of this change were negligible for the other two analyses, as that data was easily accessible for reinterpretation. And on the other hand, it was the opinion of the authors that the benefit of the deepened understanding outweighed the effects on the interview analysis.

4.5.2 Findings from the interviews

The external validity of the interviews is limited for the following reasons. During the interviewing of the participants, it was discovered that not all of them used the BT as main source of information during their process. Two of the three already had prior biomimicry experience within their teams and did not need the BT as much. This means that the assumption that participants used the BT was probably only partially true. However, their findings on the BT are still interesting as they did use the BT and gave insights to how the BT also facilitates more experienced users.

In the interviews, due to time constraints only very few users of the BT were reached and interviewed. Therefore, it is likely that those findings are not representative for the entire population of users. This was partially covered by adding mentors to the interviews, who could share insights from their experience in mentoring multiple teams. A stronger source of data was the interviews with the designers of the BT, where we had access to the entire core team that created the BT. Due to this, valuable and strong data could be collected around the intention of the BT.

In the end all participants that we were able to interview were award winners of the BGDC and in general the mentors and participants that participated in interviews had positive relations to the Biomimicry Institute. This created some form of bias, making the selection of interviewees less representative of the total population. This is a limitation of this research that could not be fully solved due to time constraints.

4.5.3 Lenses used

During this research the authors were aware of the concept of reflexivity. Reflexivity means that the researchers position or perspective has an influence on that which is being researched. It affects what methods that are used, what is deemed relevant to mention and how to structure the chapters. Thereby the position or perspective of the authors also shapes the results (Savin-Baden and Major 2013). Keeping this in mind, the authors examined their different perspectives in shared discussions around the content. Also, the authors considered the designers perspectives of the BT. Analyst triangulation was applied, using our different backgrounds optimally. For example, during the interviews one of the authors interviewed and another checked for inconsistencies/missing information, then another author transcribed and yet another coded. These different ways of using reflexivity increased the internal validity of the results.

Still, many of the findings have been made with the use of the 5LF/FSSD model. A downside of mainly applying this lens is that the authors primarily looked at those sections of the BT that fit our lens of what sustainability is, excluding others. It is probably not a coincidence that the authors ended up suggesting many aspects of what the FSSD provides as ways to improve the tool, while for instance hardly addressing the Biologize, Discover and Abstract phases. These three phases are actually most central to the biomimicry process. The fact that these sections of the BT have hardly been addressed is noted. While the authors are quite confident in the value of using this "lens", other lenses could also have been applied more and could have generated other/extra findings. In order to take in a broader approach, the authors have added strategic thinking to the conceptual framework.

Also, since the authors of this thesis do not have extensive knowledge of biomimicry there might be parts of the BT process that are not clearly understood. For example; most of what is stated here is based on the authors understanding of the NUPs and what is presented online, but there might be more nuance in them that was not discovered. At the same time, this also provided the ability to look at biomimicry from an outside perspective and develop different insights from what a Biomimetic professional would have, which can be seen as a strength of this research.

In order to improve the reliability of this research, clear descriptions of the process used in this research were included; either in the methods section or in the appendix. However as mentioned in the description of reflexivity, the selected results, discussion and conclusion are also shaped by the authors interpretation of the results.

5 Conclusion

In this chapter the authors crystallise the key findings of the research and conclude what is found to inform the research question: *"How might the Biomimicry Toolbox better support its users in applying strategic thinking in order to create sustainable solutions?"* The Biomimicry Toolbox (BT) includes elements needed in order to support its users in the application of strategic thinking for sustainable solutions. It includes a systems perspective, provides a goal to strive for and offers some elements of a strategic process to follow. All those parts can still be improved in order to make the BT more effective and more strategic in supporting the creation of sustainable solutions and thereby be more impactful in addressing the sustainability challenge.

From the research the authors conclude that the system view of the BT does not explain the structures specific to the social system or how society interacts with the ecosystem. Implication of this can be that elements of social sustainability is not considered when creating solutions. Since humans are also part of nature, the authors argue that understanding of the human society can be part of how the BT describes the earth system. The authors think that the BT could improve the explanation of the earth system description by including human society. The authors also think that including human social aspects in the NUPs and Earth's Operating System will make solutions from the BT more capable of addressing not only ecological but also social sustainability challenges. A possible way to integrate social aspects in the BT could be by learning from how the FSSD describes human society and its interaction with the ecosystem. Furthermore, by learning from how the social sustainability principles of the FSSD are explained as a clear goal for success to comply with. Further research is needed in order to understand how human society can best be included in the system understanding of the BT.

The BT encourages system thinking through providing an explanation of what system thinking is and providing worksheets for users to understand the interrelated systems that the solution is intended to operate within. There are indications from both analysis of solutions and from interviews that some of the users of the BT mainly address downstream problems, addressing symptoms of problems, instead of creating solutions that address causes of the problems. Going to the root of a problem and address it where the structural obstacles are, that trigger thousands of negative impacts occurring downstream. Upstream thinking would make the solutions more impactful in addressing the sustainability challenge. The authors suggest that an explanation of upstream verses downstream thinking is included in the BT in order to make users aware of how they can be more impactful when addressing sustainability issues.

A clear goal is an element of strategic thinking. The goal of biomimicry is to create biomimetic solutions fitting within the constraints of the earth system and the BT supports that by providing NUPs. The NUPs state what nature does and it is assumed that it is needed to learn what nature does in order to produce sustainable solutions. Some of the NUPs provide clear boundaries and others are descriptions of the system. The NUPs in and of themselves may not be the best tool for evaluation of the sustainability of the solutions. Currently, they are suggestive and created to describe the earth system. The NUPs as they are right now, are not well suited to evaluate sustainability against and an unintended consequence of that can be that, only parts of the NUPs are implemented in the solution. Partial implementation of the NUPs can be a stepping stone in the right direction but, it should be clear that the goal is not yet reached. In order to improve this in the BT, the authors recommend that the goal for what is needed in order for solutions to be sustainable is clarified in the BT. This could be done through updating the 'Natures Patterns Checklist' or include other principles, such as the 8SPs, that better fit to be used for assessment

of sustainability. Improving the BT's definition of what success looks like for sustainable solutions might make the BT more impactful in addressing the global sustainability challenge.

At this moment the BT lacks clear and simple guidelines for prioritising between options for the design concepts and also does not have a clear decision-making process when working with many options. What comes closest to providing support for prioritization of actions and concepts, are the 'Natures Pattern's Checklist' and the 'Business Model Canvas'. The prior is there to encourage users of the BT to consider aspects of the NUPs so that solutions coming from the BT may be more sustainable and regenerative. The latter is there to identify feasibility constraints. Unless the Natures Pattern's Checklist becomes more specific as described in the discussion, it is hard to use them for determining whether a solution is sustainable or not. This also makes it difficult to use them for prioritization of design concepts and actions. The application of prototyping is a strong strategic process element of the BT. If the BT wants to be more strategic towards sustainability, it could be helpful to provide a simple process that users can use, to help them identify logical next steps in each phase throughout the process. The three prioritization questions of the FSSD could provide inspiration for this.

It is the authors hope that with this research they have contributed insights for the Biomimicry Institute that will help them to make the BT more strategic and that thereby more sustainable solutions will enter the market.

5.1 Recommendations for further research

During the discussion, several subjects requiring further research have been identified. In this section these will be summarised and recommendations given on how to proceed.

Further research could be done around the relation of the NUPs with regards to social sustainability principles as defined in this research. Possible questions could be: What patterns in nature are similar to the social system and can be better integrated into the BT? Or: Are other fields of study (for example Anthropology) needed to define patterns that are specifically found in society? The authors reason that case could be made for not including specifically human aspects, as it is currently not included in the scope of biomimicry. In that case the missing elements that are specifically human could be addressed by including reference to the FSSD in the BT.

Further research could be done on what is holding participants back in creating more upstream solutions. The authors reason that besides previous experience, clarity of the teaching, time pressure and other themes might be preventing this. From this, research for possible improvements could be based on those points that are defined as leverage points for improvement.

There is a significant difference between NUPs and SPs in the way they are phrased. Where NUPs are based around "do more" the SPs are structured around "do not". The authors believe that both perspectives have their benefits and that NUPs 'do more' perspective is best used for inspiration when setting the goal of what a biomimicry project wants to reach. Further research is needed to validate the reasoning of the authors that the same criteria could be used to reframe the NUPs, while staying true to the "do more" ethos. And the benefits/downsides of each way of framing could be investigated more deeply in order to make the right improvements.

As it was suggested that the learning aspect of biomimicry could potentially be the biggest impact of the BT, research could be done to the effect of this. How much are the participants of the BGDC influenced in their future work from using the BT in the BGDC? Are they able to create biomimetic or sustainable solutions? And what has influenced that? Answers to these questions can be used to strategically change the BT to enhance the learning, retention and use of biomimicry in the future careers of the participants.

And lastly research could be done on what prioritization process could be most beneficial to implement in the BT. What are the processes that are commonly used? And an interesting 'Biomimetic' research question could be: "How does nature prioritize?"

References

Allais, R., Roucoules,L., Reyes,T. 2017. "Governance maturity grid: a transition method for integrating sustainability into companies?" *Journal of Cleaner Production* 140 (1): 213-226.

Appio, F. P., Achiche, S., Martini, A., & Beaudry, C. 2017. "On designers' use of biomimicry tools during the new product development process: an empirical investigation." *Technology Analysis & Strategic Management*. 29 (7): 775-789.

Baumgartner, R.J., Korhonen, J. 2010. "Strategic Thinking for Sustainable Development." *Sustainable Development.* 18 (2): 71–75.

Benyus, J. M. *Biomimicry, Innovation Inspired by Nature*. New York: Harper Collins, 1997.

Biomimicry Institute. 2018. "Biomimicry Institute" Accessed on May 22nd, 2018
https://biomimicry.org

Biomimicry Institute 1. 2018 . "Stories of the Field" Accessed on May 22nd, 2018.
https://biomimicry.org/biomimicry-examples/

Biomimicry Institute 2. "About the challenge". Accessed on May 22nd, 2018.
https://challenge.biomimicry.org/en/page/about-en

Biomimicry Institute 3. "Judging Criteria". Accessed on May 22nd, 2018.
http://challenge.biomimicry.org/en/page/judging-criteria-en

Biomimicry Institute 4. "Glossary of terms". Accessed on May 2nd, 2018.
https://toolbox.biomimicry.org/references/glossary/

Bovea, M. D., and V. Pérez-Belis. 2012. "A Taxonomy of Ecodesign Tools for Integrating Environmental Requirements into the Product Design Process." *Journal of Cleaner Production* 20 (1): 61–71.

Bruntland, Gro Harlem. 1987. *"Report of the World Commision on Environment and Development: Our Common Future"*, UN

Cook, David. 2004. *The Natural Step: Towards a Sustainable Society*. Schumacher Briefing, no. 11. Totnes, Devon: Green Books for the Schumacher Society.

Earley, R., 2017, "Circular Design Futures." *The Design journal* 20 (4): 421-434

Galaz, V., Biermann, F., Crona, B., Loorbach, D., Folke, C., Olsson, P., Nilsson, M., Allouche, J., Persson, Å., Reischl, G., 2012, "Planetary boundaries"—exploring the challenges for global environmental governance." *Current Opinion in Environmental Sustainability* 4 (1): 80-87

Hallstedt, S., Thompson, A., Lindhal, P. 2013. "Key elements for implementing a strategic sustainability perspective in the product innovation process." *Journal of Cleaner Production* 51: 277.

Hassan M., 2000, "Transition to sustainability in the twenty-first century: the contribution of science and technology, Report of the World Conference of Scientific Academies held in Tokyo, Japan, 15–18 May 2000*." Internal Journal of Sustainability in Higher Education* 2 (1): 70–78

Hawken, P. 1993. *The Ecology of Commerce*. New York: Harper Business.

Hoeller, Norbert. Interview with Norbert Hoeller on Biomimicry. January 8, 2018.

Kennedy, Emily, Daphne Fecheyr-Lippens, Bor-Kai Hsiung, Peter H. Niewiarowski, and Matthew Kolodziej. 2015. "Biomimicry: A Path to Sustainable Innovation." *Design Issues* 31 (3): 66–73.

Kennedy, Emily Barbara and Marting, Thomas Andrew, 2016, "Biomimicry: Streamlining the Front End of Innovation for Environmentally Sustainable Products." *Research-Technology Management* 59 (4): 40-48

Ketchie A., Shapira, H., Nehe M., 2018, "For the Creative Problem-Solver: An Integrated Process of Design Thinking and Strategic Sustainable Development." Master's Degree Thesis School of Engineering Blekinge Institute of Technology, Karlskrona, Sweden .

Liedtka, J. M., 1998, "Strategic Thinking: Can it be Taught?" *Long Range Planning* 31 (1): 120-129.

Loorbach D., Rotmans J., 2010, "The practice of transition management: Examples and lessons from four distinct cases." *Futures* 42 (3): 237 – 246.

Manzini, Ezio., 2009. "New Design Knowledge." *Design Studies* 30 (1). 4–12.

Marseglia, Marco., 2017. "Design Process and Sustainability. Method and Tools." *The Design Journal* 20 (sup1): S1725–S1737.

Marshall, A and Lozeva, S., 2009 "Questioning the theory and practice of biomimicry." *International Journal of Design & Nature and Ecodynamics* 4 (1): 1–10.

Mead, Taryn. Interview with Taryn Mead on Biomimicry. November 30, 2017.

Mead, Taryn, and Sally Jeanrenaud. 2017. "The Elephant in the Room: Biomimetics and Sustainability?" *Bioinspired, Biomimetic and Nanobiomaterials* 6 (2):113–21.

Parris TM, Kates RW. 2003. "Characterizing a sustainability transition: goals, targets, trends, and driving forces. Ecology." *Science and Technology for Sustainable Development Special Feature* 100(14): 8068–8073.

Papanek, V. 1995. *The green imperative: ecology and ethics in design and architecture*. London: Thames & Hudson.

Pauw, de I.C., Kandachar P. and Karana E. 2014 "Assessing sustainability in nature-inspired design*" International Journal of Sustainable Engineering* 8 (1): 5-13.

Pauw, de C. I., Karana E., Kandachar P., Poppelaars F. 2014 "Comparing Biomimicry and Cradle to Cradle with Ecodesign: a case study of student design projects." *Journal of Cleaner Production* 78 Sida: 174-183.

Peterlin, J., Pearse, N.J., Dimovski, V. 2015 "Strategic Decision Making for Organisational Sustainability: The Implications of Servant Leadership and Sustainable Leadership Approaches." *Economic and Business Review* 17 (3): 273-290.

Robert K. H., Broman G., Waldron D., Ny H., Byggeth S., Cook D., Johansson L., Oldmark J., Basile G., Haroldsson H., MacDonald J., Moore B., Connell T., Missimer M. 2012 *Strategic Leadership towards Sustainability* Karlskrona: Psilanders grafiska.

Robert K. H., Broman G., Waldron D., Ny H., Byggeth S., Cook D., Johansson L., Oldmark J., Basile G., Haroldsson H., MacDonald J., Moore B., Connell T., Missimer M., Johnson,P., Daly E. 2015. 2017 "*Strategic Leadership towards Sustainability*". Karlskrona: Psilanders grafiska.

Savin-Baden, M. and C. Howell Major. 2013. *Qualitative Research: The Essential Guide to Theory and Practice*. New York: Routledge.

Senge, P.M, Carstedt, G., Porter, P.L. 2001 "Innovating Our Way to the Next Industrial Revolution." *MIT Sloan Management Review* 42 (2): 24.

Vallet, Flore, Benoît Eynard, Dominique Millet, Stéphanie Glatard Mahut, Benjamin Tyl, and Gwenola Bertoluci. 2013. "Using Eco-Design Tools: An Overview of Experts' Practices." *Design Studies* 34 (3): 345–77.

Volstad, Nina Louise, and Casper Boks. 2012. "On the Use of Biomimicry as a Useful Tool for the Industrial Designer: Biomimicry as a Tool for the Industrial Designer." *Sustainable Development* 20 (3): 189–99.

Wahl, D. C., & Baxter, S. 2008. The Designer's Role in Facilitating Sustainable Solutions. *Design Issues*, *24* (2), 72–83.

Wardman, K. T. 2011. "From Mechanistic to Social Systems Thinking. A Digest of a Talk by Russell L. Ackoff." *The Systems Thinker* 22 (7): 7-10.

Wit, M. de, Hoogzaad, J., Ramkumar, S, friedl, H. and Douma, A. 2018 "The Circularity Gap Report" Circle Economy and Shifting paradigms

Appendix

A1. 5LF and FSSD analysis of the Biomimicry Toolbox

Questions that guided the 5LF analysis of the Biomimicry Toolbox

System
- What is the BT?
- What is the historical context?
- How was the BT developed?
- What is the target audience?
- What is the scope of the BT?
- What type of tool is the BT
- What assumptions are present in the BT?
- In what way does the BT describe the larger systems?

Success
- What is the BT's overall definition of sustainability?
- What is the overall purpose of the BT, what is it designed for?
- How does BT define success?
- How does a user of the biomimicry BT achieve success?
- What internal goal does the biomimicry BT aim for?
- What external goal does the biomimicry BT aim for?
- Does the BT deliver on its full scope and/or its intended purpose to enable users to create solutions conductive to live (success as described by BT)?
- Are there any unintended consequences when using the tool?

Strategic Guidelines
- Does the BT offer any methods to help decision makers decide?
- How to make the success happen?

Questions that guided the FSSD analysis of the Biomimicry Toolbox

System
- In what way does BT contribute to the understanding of the system as described by FSSD?
- Does it help users of the BT to understand more of the system under study and how it relates to society within the biosphere?
- Does it offer, describe or measure further information to understand more about earth, the biosphere, the socio-ecological system or any aspects of their subsystem?
- How does it do this?
- Does it state any assumptions at this level? Are the assumptions accurate?
- How do those assumptions relate to how FSSD defines the system level?
- Does it include any additional system levels?
- Are there any gaps between the system of the BT and that defined by the FSSD?
- How does the BT describe its boundaries to the Earth and society globally?
- How does its understanding of the Earth and its subsystems differ from a SSD perspective?

Success
- What is the BT overall definition of sustainability?
- How does the success of the BT contribute to socio ecological sustainability as defined by the 8 Sustainability Principles?
- Does the BT's definition of success cover the full scope of sustainability as defined by the 8 Sustainability Principles?
- If a user complies with this definition, how close can the user get to addressing sustainability?
- Is global sustainability integrated in the tool's overall long-term success definition?
- Which sustainability aspects does the BT address?
- Does the BT's definition of success go beyond sustainability and move towards a restorative society? If so how?
- Given what the BT is designed to do, are there any 'bind spots' or areas where it cannot help users achieve success in relation to the 8 SP's
- What sustainability aspects are not addressed by this tool or concept?
- What aspects of the Sustainability Principles would be better addressed using other methods or tools?

Strategic Guidelines
- How do the strategic Guidelines of the BT support decision making in deciding on actions to use to generate sustainable solutions?
- How do the strategic Guidelines of the BT support decision making in deciding on actions to use to generate sustainable innovations?
- How do the Strategic Guidelines as defined within the 5LF review assist decision makes in deciding on actions that can bring them towards sustainability?
- Do the strategic guidelines of the 5LF cover more or less than the 3 Prioritisation questions of the FSSD?
- Do they take a strategic perspective?

A2. 8SP analysis of solutions derived from the Biomimicry Toolbox

Overview of solutions used for the analysis

Windchill - a food preservation unit
Preserves food in hot environments without using electricity
Theme year: Food systems 2015
1st place Winner, Student challenge
https://challenge.biomimicry.org/en/custom/gallery/view/2576

Stillae
Fresh water source - distiller to catch water in the air and use to water crops
Theme year: Food Systems 2016
1st place winner, Student challenge
https://challenge.biomimicry.org/en/custom/gallery/view/8114

ExtrACTION
Product that extracts and collects carbon dioxide from the air.
Theme year: Climate change 2017
1st place winner, Student challenge
https://challenge.biomimicry.org/en/custom/gallery/view/15804

Happy Soil
Weed supressing agricultural solution
Theme year: Food system 2016
Award winner, Open challenge
https://challenge.biomimicry.org/en/custom/gallery/view/8183

Nucleario - Geoengineering Concept
Biodegradable tree planter
Theme year: Climate change 2017
Award winner, Open challenge
https://challenge.biomimicry.org/en/custom/gallery/view/15877

Balcony cultivator
A greenhouse to be placed on the balcony for growing food at home and decompose food waste.
Theme year: Food systems 2015
Open challenge, Award winner
https://challenge.biomimicry.org/en/custom/gallery/view/2577

Thermo Smart
System for energy reduction for heating or cooling a building.
Open Challenge, Award Winner
Theme year: Climate change 2017
https://challenge.biomimicry.org/en/custom/gallery/view/15876

Refish
Particle collector to be attached to public transportation that collects particles from the air.
Theme year: Climate change 2017
Open Challenge, Award Winner
https://challenge.biomimicry.org/en/custom/gallery/view/15874

Next loop
Increase urban food production in homes watered by rainwater.
Theme year: Food systems 2016
Open Challenge, Award Winner
https://challenge.biomimicry.org/en/custom/gallery/view/8131

Oasis aquaponic food production system
System that allows growing of fish and vegetables where the plants withdraw nutrients from the excrement's from the fishes and thereby clean the water.
Theme year: Food Systems 2015
Open Challenge, Award Winner
https://challenge.biomimicry.org/en/custom/gallery/view/2556

Bioinspired electric patch
Membrane that creates electricity out of heat
Theme year: Climate change 2017
Student challenge, 2nd place winner
https://challenge.biomimicry.org/en/custom/gallery/view/15828

Polli Snak
Bag with healthy snacks aimed at changing people's eating habits.
Theme year: Food Systems 2015
Student Challenge, 2nd place winner
https://challenge.biomimicry.org/en/custom/gallery/view/2517

COOL DOWN B'MORE
System solution for city in hot environment that aims to connect people with cool places during extreme heat.
Theme year: Climate Change 2017
Student Challenge, Award winner
https://challenge.biomimicry.org/en/custom/gallery/view/15885

Home Food Garbage Decomposer
Product that enables decomposition of organic household waste at your home.
Theme year: Food System 2016
Student challenge, 2nd place winner
https://challenge.biomimicry.org/en/custom/gallery/view/8150

A3. Interviews with practitioners, mentors and designers

Interview Protocol

Project: The Biomimicry Toolbox as a tool for generating sustainable solutions
Time of interview
Date
Interviewer
Place
Interviewee

Interview procedure
You are being asked to participate in a Master research study on the topic of biomimicry, the research is focused on how the Biomimicry Toolbox supports its users in creating sustainable solutions. The goal with this research is to propose improvements for the BT to make it even better in supporting the creation of sustainable solutions.
We would love to learn from your perspectives, opinions and experience. By participating in this topic, you will be able to support our understanding of the strengths and gaps with regards to the tools support in creating sustainable solutions.
This interview will take maximum one hour and the information conducted in this interview, will be handled confidentially. This interview is on voluntary basis and we are most grateful to be learning, understanding and working with you. Once we have identified the parts of the interview that we would like to cite in the report, we first send an e-mail with these parts to you to make sure you are okay with us using these sections as planned.

Informed consent
May I ask you if you are willing to participate in this research? Please, could you repeat this line to consent on the conduction of the interview?
'Yes, I am willing to participate in the interview protocol of research project 'The Biomimicry Toolbox as a tool for generating sustainable solutions'.
The audio files of the interviews are stored on google drive and only the research team of this thesis has access to them. The transcriptions will also be stored on google drive. The benefit of this is that if something happens to any of the researchers laptops, the documents are stored in the cloud. Google uses 128-bit encryption on documents that enter its servers. That means only we can access the documents. We will destroy the data 3 years after obtaining it.

Interview questions
see interview questions for participants, mentors and designers below

Closing
Thank you for your attention, time and sharing of your experiences and perspectives. Please let us stay in touch and you will receive the parts of the interview we want to use for confirmation within 7 days.

Interview questions for designers

Introduction
1. Could you please introduce yourself?
2. We understand that you are part of the design team of the BT is that correct?
3. For how long have you been working with the development of the BT?
4. Can you please tell us about why the BT was created and what you wish to accomplish with it? (intent behind it)
5. To the best of your knowledge, by whom is the BT used? Only by participants of the challenge or beyond that?

Sustainability
1. Can you describe how the BT defines sustainability? (Regeneration?)
2. How were the natures unifying patterns created?
3. Do the natures unifying patterns still evolve and if so how?
4. How does the BT define success when looking at the solutions Does the BT have any way of evaluating the success of the solutions coming out of it? If so, how?
5. How is success for sustainability evaluated? What are the evaluation/monitoring criteria?
6. Are you familiar with TNS or the FSSD? Are there other sustainability definitions and or frameworks that you use? Are you open for influence from other parts?
7. How does the BT support its users to deliver sustainable solutions in each element of the BT? Define biologize discover abstract emulate evaluate
8. Do you have any examples of any good sustainable solutions that has come from using the BT? How big is the impact of the solutions coming out of the BT?

Decision making support/Strategy
1. In what way does the BT provide decision making support towards sustainability? (For example when handling trade-offs?)
2. What are the different steps where wise decisions are made?
3. During the design process one has to decide between different options, how does the BT support wise decision making (in each element)?
4. How does the BT contribute to societies transition towards sustainability In your perspective?
5. What is the success you expect/aim for with the judging criteria?
6. How are the judging criteria being considered, contextualised, used and taken into consideration by mentors and participants?
7. How do you achieve the success? How do these criteria support the development of sustainable solutions, wise decisions.
   What is your experience designing these? Does it do what it aims for and why?
8. How are these designed and delivered for the GDC? Where are they derived from?
9. How does the promise of regeneration come into play here, or doesnt?

Challenges, strengths and gaps
1. Are there any parts of the BT that you consider as the strongest and if so why?
2. (If the answer is not connected to sustainability, ask a sub question on that subject)
3. Are there any parts of the BT that you have noticed that could be improved and if so why?

4. What are the biggest challenges in using/growing the BT to its best use? What burning questions do you hold regarding the topic of wise decisions for sustainability?

Improvements
1. Could you describe to us how you work with the development of the BT? And how can we play a part in this, by supporting your development and learning?
2. In what form could our understanding of the BT; proposal for improvements be delivered to you?
3. What is your vision for the BT?
4. Where are you interested in? What do you see as valuable?
5. How to best go about proposing meaningful improvements for the use of the tool? How to fit and integrate new practice for and of the BT from this project? What (form) would be meaningful and what could work? How would it make sense to suggest hands-on (findings for) improved practice? How to be strategic for the outcome of integrating improved support in sustainability practice for the BT?

Interview questions for mentors

Introduction
1. Could you introduce yourself?
2. What is your connection to the BT?
3. What is your background and experience, what is your experience with the BT?
4. What is sustainability to you?

Sustainability
1. How is your experience with mentoring through the BT?
2. What is the goal of the BT? How is success defined and achieved?
3. Does the BT offer a description of sustainability?
4. How are solutions evaluated when it comes to being sustainable (regenerative)?
5. How does it support the delivery of sustainable solutions?
6. Does it or not? How is that?
7. (How) are you mentoring to support sustainable solutions?
8. What are the strengths in the BT when creating/designing for sustainable solutions?
9. What are the gaps in the BT when creating/designing for sustainable solutions?
10. Can you please explain how the participants work with the Nature's Unifying Patterns?
11. FSSD - do you use other sustainability concepts?

Decision making support/Strategy
1. Definition of decision making support: enabling choices that make sense and move towards success
2. How are wise choices being supported within the BT?
3. How does this relate to sustainable solutions?
4. In what way does the BT provide decision making support towards sustainability? (For example when handling trade-offs?)
5. How are the judging criteria being considered by mentors and participants?
6. (How) do these criteria support the development of sustainable solutions and wise decisions for this desired outcome?
7. Did you consider the judging criteria, how did you work with it? What is your experience? How do these serve its purpose and the purpose of the BT…..?

Challenges, strengths and gaps
1. Are there any parts of the BT that you consider as the strongest and if so why? (If the answer is not connected to sustainability, ask a sub question on that subject)
2. Are there any parts of the BT that you have noticed that could be improved and if so why?

Improvements
1. What questions do you hold regarding the topic of wise decisions on sustainability?
2. What would you like to see improved?
3. What would make an important difference for your role and responsibility as mentor?

Interview questions for participants

Introduction
1. Could you shortly introduce yourself?
2. What do you work with, what is your field of expertise?
3. When did you participate in the challenge?
4. Were you participating as student or professional?
5. How did you experience the challenge?
6. Did you use the BT during the challenge?
7. What is your understanding of what sustainability is?

Sustainability
1. In what way did your solution have a positive impact on sustainability?
2. How did the BT support you in making a sustainable solution?
3. What elements in the BT supported you to create life-friendly solutions?
4. How did you determine and assess the sustainability of your solution?
5. What other things/conditions supported you in your project to be sustainable?
6. What has to happen in order for your solution to be fully sustainable?
7. Did you use the NUPS's?
8. How did you use the 10 NUP's in your process?

Decision making support/ strategy
Definition of decision making support: enabling choices that make sense and move towards success of creating a biomimetic solution
1. How have you experienced being supported in making decisions when using the BT?
2. How did the BT enable you in making decisions (for biomimetic design)?
3. Did you find the support useful?
4. What other things/conditions/persons helped you in making right choices and decisions?

Strengths, challenges and gaps
1. What were the biggest challenges in your project in working w the BT?
2. What gaps have you/are identified? What is needed for you within the BT?
3. Are you still using the BT or any (parts) of it? Why? Why not other parts
4. There is more than the BT to the experience of the BGDC:

5. About your experience in the BGDC; what have you found useful working w your project?
6. How did support of mentors, webinars, 'out in nature' help you?
7. Was there anything that you were missing during the BGDC process or anything you think would have been useful for you?

Improvement
1. If there is anything you could change or adjust what would it be?
2. What could be done more and/or better? Do you have any ideas for improving the BT?
3. What would you propose and why?

List of codes used for the analysis of the interviews

BT general
1. Purpose] What is the intent / purpose for creating the BT?

Guiding question 1: How does the BT and its definition of sustainability support users of the BT in creating sustainable solutions?
2. [SustDefPer] Personal definition of sustainability
3. [SustDefBT] What is the definition of sustainability from the BT, as experienced by the interviewee
4. [BTtext] How is the BT (text) of the BT helping to create sustainable solutions?
5. [SustContribution] How is the solution of the interviewee (coming out of the BT) contributing to sustainability?
6. [Social] Talk about social sustainability

Guiding question 2: What strategic support does the BT offer in order to create sustainable solutions?
7. [System] How do they speak about the systems perspective, and what is their viewpoint on that?
8. [Evaluate] How do you evaluate the sustainability of your solution?
9. In what way does the interviewee consider the systems perspective relevant and worthwhile for creating sustainable solutions.
10. [NUPm] measure/quality control. What does the interviewee say about using Natures Unifying Patterns as a measure/evaluation tool for sustainability? As a guide for decision making?
11. [DM] Decision making assistance in the BT for example evaluation, choice making, deciding, Evaluation sheet,
12. [No DM] Decision making support not present in BT. Experience from interviewee that the BT is not providing or designed for providing decision making support.
13. [OthSupport] Other decision making support, besides the BT. (webinars, Mentors...)

Guiding question 3: How can the BT be further evolved to better support decision making and creation of sustainable solutions?
14. [ID] Improvement ideas and what would the interviewee like to see more of
15. [-] Gaps/irritations/limitations/frustrations when it comes to creating sustainable solutions.
16. [+] Strengths of the BT

A4. Biomimicry Toolbox content overview

Web page of the Biomimicry Toolbox where the information was downloaded from:
 https://toolbox.biomimicry.org

The BT was investigated during the time 1st of January 2018 until 30th of April 2018.

Sections that the Biomimicry Toolbox consist of and codes used to reference in what section of the BT a specific quote was found.

BT 0.0 Biomimicry Toolbox
BT 1.0 Introduction
       BT 1.1 What is Biomimicry?
       BT 1.2 What is Design?
       BT 1.3 Introductory Videos
BT 2.0 Core Concepts
       BT 2.1 Function and Strategy
       BT 2.2 The Systems View
       BT 2.3 Earth's Operating System
       BT 2.4 Nature's Unifying patterns
BT 3.0 Methods
       BT 3.1 The Biomimicry Process
       BT 3.2 Define the Challenge
       BT 3.3 Biologize Function & Context
       BT 3.4 Discover Biological Strategies
       BT 3.5 Abstract Design Strategies
       BT 3.6 Emulate Nature's Lessons
       BT 3.7 Evaluate Fit & Function
       BT 3.8 Other Pathways to Biomimicry
BT 4.0 References
       BT 4.2 Reading List
       BT 4.3 Glossary of Terms
       BT 4.4 Case Studies
       BT 4.5 Biology Research
       BT 4.6 Reading a Scientific Paper
       BT 4.7 Interdisciplinary Collaboration
       BT 4.8 Business Planning for Biomimicry
BT 5.0 About the Toolbox

Master's Programme in Strategic Leadership towards Sustainability
Blekinge Institute of Technology, Campus Gräsvik
SE-371 79 Karlskrona, Sweden

Telephone: +46 455-38 50 00
Fax: +46 455-38 55 07
E-mail: sustainabilitymasters@bth.se