Reconnect to our life-giving systems:

The potential of biomimicry for urban planning

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MSc Thesis Urban Environmental Management - Land Use Planning

Organisms don't think of CO_2 as a poison. Plants and organisms that make shells, coral, think of it as a building block

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Janine Benyus

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Abstract

Natural systems fulfill the basic needs for all life on our planet. Water, soil, air, energy cycles and weather systems are fundamental to our existence. Yet, it is those systems that we are damaging and degrading. As a result, the built environment experiences hazards such as droughts and heat waves. There is increasing interest in urban planning to adopt approaches that are able to sustain both natural and human systems and their quality. The purpose of this research is to explore biomimicry and its potential contribution for urban planning. This study analyzed the potentials and barriers of using biomimicry in planning by means of a qualitative research, using semi-structured interviews. This study shows what biomimicry is, how it is practiced and what it could contribute to urban planning. The results suggest that biomimicry is of value as a planning approach in several ways, however this is put in contrast to a variety of barriers. The results identified grounded criticism on the concept and its methods and tools and gives prerequisites that need to be complied with in order to operationalize biomimicry in planning. Further studies are needed to establish a deeper understanding of the identified values and barriers for using biomimicry in planning.

Key words: biomimicry | urban planning | natural systems | function | systems thinking

Summary

It is an increasing concern that we damage and degrade natural systems, as we depend on these systems to sustain our fundamental needs of life. The built environment faces hazards, relating to the disruption of water, energy and air cycles and soil formation and weather systems. Urban planning needs to adopt approaches that account for the fragmentation and deterioration of natural systems and their quality. There is increasing interest within urban planning in bio-inspired approaches that are able to sustain both natural and human systems.

This research focuses on biomimicry and its potential contribution for urban planning. Biomimicry looks at nature in order to seek answers and possibilities and imitates or takes inspiration from natural designs and processes to solve human problems. With a focus on function and an underlying ethos that sees humans as nature, biomimicry moves beyond the mere mimicking of forms, patterns and structures that are found in nature. Instead, biomimicry aims mimicking nature for the purpose of designing a built environment that performance like nature. There is increasing interest in biomimicry and its contribution to urban planning, however this potential is undefined and unexplored. This research moves forward in our understanding of what biomimicry is, how it is practiced and what it can contribute as a planning approach.

A qualitative study was used to explore the potential of biomimicry for urban planning. This research is explorative as there are only few cases and few people that practice biomimicry, let alone on an urban scale. By means of semi-structured interviews, an international group of biomimicry experts and biomimicry planners was interviewed using Skype and audio recording, which allowed expanding the geographical access to interviewees. To assure structured data analysis, the software tool NVivo was used to analyze the data.

The results of this research show what biomimicry is and how it is practiced. More importantly, it reveals that biomimicry is of value as planning approach in several ways. Biomimicry is of value when planners are stuck in finding answers and solutions to design challenges, it can be used as conflict-resolution process, it encourages planners to realize sustainable designs and it enables planning for complexity. However, the results of this research show a variety of barriers to using biomimicry as a planning approach. Biomimicry is not sufficiently operationalized, the outcomes of biomimicry in terms of efficiency and performance are uncertain, the values underlying a biomimicry design process are different from a planning process and better ethical reflection is needed on the underlying assumption. In sum, this research has shown the potential of biomimicry for urban planning, however puts this in context of grounded criticism on the concept and its applicability. Therewith, this research gives unambiguous prerequisites that need to be complied with in order to use biomimicry as planning approach.

Chapter 1 Introduction

As noted by Whitford et al. (2001), one of man's defining characteristics is that rather than adapting to the environment, he changes it. Consequently, we have replaced forests, grasslands and savannahs by buildings, roads, gardens and parks (Gill et al. 2007). As mentioned by Carter et al. (2018, 1535), unlike grass and woodland, 'hard surfaces have the potential to aggravate weather and climate hazards'. Not only is the quality of life in urban areas affected, but also ecosystems and evolutionary processes are distressed at high rates and in multiple ways (Zari 2007, 3; Carter et al. 2018).

It is increasingly recognized that urban planning and land management need to adopt more sustainable approaches to account for 'the fragmentation and deterioration of the quality of natural systems' (Panagopoulos et al. 2016, 140). Amongst others, Han et al. (2015), Wootton-Beard et al. (2016) and Fernandes and Guiomar (2018) suggest that bio-inspired approaches to urban planning can have a positive effect on sustaining both natural and urban systems. For example, Fernandes and Guiomar (2018, 1925) argue that the aim of nature-based solutions is to reintroduce natural processes and functions in the built environment, as this helps to develop a more creative relationship between humans and natural elements, processes and functions.

A fairly recent approach that takes nature as inspiration is biomimicry. Ivanić (2016, 21) and Cohen and Reich (2016, 6) define biomimicry as 'studying nature's most successful developments and then imitating these designs and processes to solve human problems'. Biomimicry suggests looking at nature in order to seek answers and possibilities. This includes an investigation of natural and environmental features of a specific site, whereby ecological standards are developed to judge the rightness of human actions and innovations (McGregor 2013, 58). And as stated by Buck (2017, 136), 'given biomimicry's philosophy that people and nature inhabit the same socio-ecological system, urban biomimicry could realign economic, environmental and social factors for greater quality of life'.

1.1 Background: urban planning and biomimicry

Planning has the goal of creating a better living environment and ensuring sufficient quality of life. Allmendinger (2017) sees planning as based upon a theory that the world will be a better place (however defined) with planning than without it. An example is the argument of Handy et al. (2002, 64), who state that 'urban design, land use patterns and transportation systems that promote walking and cycling will help create active, healthier and more livable communities'. However, it is inevitable that these changes in the environment affect local ecosystems. The urban environment increasingly faces hazards such as droughts and floods, whereas, as argued by Panagopoulos (2016, 140), land use plans are a non-structural measure that should decrease harmful patterns and improve sustainability.

The spatial dimension of sustaining natural systems creates 'processes and relations between different land uses, ecosystems and biotopes at different scales and over time' (Panagopoulos et al. 2016, 141). This awareness has resulted in a variety of new concepts within planning that have the goal of incorporating knowledge of the natural world, such as ecosystem services, green infrastructure, nature-based solutions, industrial ecology and biophilia (Kellert et al. 2011; Ndubisi 2014; Panagopoulos et al. 2016). For example, planning for ecological networks is a fairly new. As stated by Zari (2007, 4), it is impossible to look at humans as separate from ecosystems and there are

valuable observations we can make in the creation of our habitats that are able to integrate with, rather than damage the ecosystems they are part of.

Despite the use of ecological knowledge for increasing overall performance in the built environment, this effort is often based on a superficial understanding of the way nature works. Aziz and El Sherif (2016) make clear how throughout history, designers have looked at nature as an inspiration source for different forms, techniques and structures. However, the designs that resulted from natural inspiration were a superficial way of imitating and mimicking forms of plants and animals (Aziz and El Sherif 2016, 708). As argued by Zari (2007), there is a need to thoroughly integrate spatial design with global biochemical cycles through a deeper understanding of ecology and its function. However, as argued by Stone et al. (2014, 8), there is 'a knowledge divide of non-biologically trained engineers, architects, product designers, planners, chemists, material scientists and even policy makers for whom nature's strategies would be a revelation'. This is where the interest in biomimicry for urban planning comes in.

Biomimicry approaches a problem from nature's perspective, asking the question 'What would nature do here?' Biomimicry argues that 3.8 billion years of life evolution can serve as refined inspiration for our built environment (Buck 2017). With a strong focus on natural *function*, biomimicry moves away from the mere mimicking of natural forms, patterns, and structures (McGregor 2013; Aziz and El Sherif 2016). Biomimicry is applied on three different levels: the organism level, the behavior level and the ecosystem level (Kennedy et al. 2015; Baumeister 2014). A promising example can be found on the organism level, where beetles were investigated for their successful way of harvesting water from the air in the Namib Desert. The result was a small machine that mimicked the beetles' body position and body surface structure for harvesting water in the desert (AskNature 2018). Another example can be found in architecture, where professionals explore the elements of water, sun and wind as a means to achieve interior thermal comfort. The three elements are used proportionally and consistently with natural features and need to function in a processual relationship to the ecosystem (Abaeian et al., 2016). Although biomimicry is used for innovations ranging from R&D and building and architecture to policy and management (Vogelzang 2018), on a larger spatial scale its application is rather unexplored. Only a few examples can be found that used a biomimicry approach on an urban scale, such as the Eden Project in the UK realized by Exploration Architecture, or the Lavasa Hill Station Project in India, realized by an alliance between HOK Architecture and the Biomimicry Guild (HOK 2019).

1.2 Research objective and questions

The research objective is explained in terms of the scientific and societal relevance of the research.

Scientific relevance

Although the last couple of years show increasing interest in biomimicry and a development of the concept within different fields of study, the application of the concept is fairly unexplored on a larger urban scale. Andersson et al. (2014) point to the potential of urban spatial designs that integrate natural systems in the built environment. Specific knowledge on how to apply biomimicry and its potential contribution to the field of urban planning is scarce. Kenny et al. (2012), Royall (2010), and Toor and Kaur (2017) state that biomimicry explores the balance between economic and environmental aspects and suggest that it is the best potential option for architecture and urban planning, however it remains a relatively new and untapped area of ecological science. Specific

scientific knowledge on how the application of biomimicry within urban planning, its barriers and possibilities offers huge potential for realizing more sustainable urban designs that account for natural systems and processes. The scientific objective of this research is to provide more knowledge on what biomimicry is, how it could be applied as planning approach, what it could contribute to urban planning and designing and what barriers need to be overcome.

Societal relevance
Investigating how biomimicry could be applied in urban planning is socially relevant, as it has become clear that contemporary approaches of city planning are not able to sustain natural and human systems in a way that is mutually supportive (Béné et al. 2018; Ndubisi 2014). Not only is the quality of life in urban areas affected, but also ecosystems and evolutionary processes are distressed at high rates and in multiple ways (Zari 2007, 3; Carter et al. 2018). As humans are dependent on natural systems (Braje 2016; Sala et al. 2017; Comberti et al. 2015), there is an urgency to come up with other ways of planning and designing. An approach such as biomimicry that takes inspiration from nature and natural processes and functions can prove a viable approach to planning that accounts for and reconnects the built environment to the natural systems surrounding it. The societal objective of this research is to provide knowledge on the ways in which biomimicry could be of use for urban planning and contributes to urban plans and designs that sustain both natural and human systems.

Following from the scientific and societal relevance, the objective of this research is to explore what the potential of biomimicry is for urban planning. The main question for this study is:

What is the potential of biomimicry for urban planning to contribute to planning for a future that sustains both natural and human systems?

This question is operationalized into four sub-research questions:

Q1 *What is biomimicry and how is it practiced?*
Q2 *What is the added value of biomimicry for urban planning?*
Q3 *What aspects of urban planning form a barrier to using biomimicry?*
Q4 *What is needed to secure a role for biomimicry in the future of planning our cities?*

1.3 Outline of the report

The subsequent chapters are structured the following way. In chapter 2 the theoretical framework of the research will be discussed. It gives an understanding of what urban planning approaches are, what a biomimicry approach is and it gives insight in how planning and biomimicry have been connected in literature thus far. Chapter 3 elaborates on the research methods and instruments. Chapter 4 presents the results of this research and chapter 5 discusses the results in the context of the research objective, the theoretical framework and earlier studies. Lastly, chapter 6 presents the conclusions of the research by answering the main research question and gives recommendations for future research. Additionally, the bibliography and appendices can be found at the end of this report.

Chapter 2 Theoretical framework

The theoretical framework is made up of three parts. If we are to explore how biomimicry can be applied as planning approach, we must get a grip on what a planning approach is and how it works. Therefore, the first section conceptualizes the planning approach. The second section focuses on conceptualizing biomimicry. It makes clear what biomimicry is, how the approach is practiced, and finishes with giving some critical viewpoints towards the concept as found in literature. The third section conceptualizes biomimicry in the context of urban planning.

2.1 The conceptualization of urban planning approaches

In search for the potential of biomimicry as a planning approach, it is important to give critical attention to what planning approaches are. Zandvoort et al. (2018, 184) give a comprehensive definition of a planning approach:

A planning approach is a combined set of tools in a coherent framework, which planners can use to structure planning processes and deal with multifaceted planning situations, akin to policy packages.

This definition embraces different facets: 'a coherent framework', 'planning processes' and 'policy packages'. In order to arrive at an understanding of a planning approach, these facets deserve further elaboration.

2.1.1 A coherent framework

In order to grasp what is meant with a coherent framework we turn to the crossroads at which planning approaches occur, namely that of a voracious debate on planning *theory* and *practice*. The purpose is not to arrive at a definition of the latter two as this proves to be a never-ending debate (Alexander 2016). Rather, the purpose is to reveal how a coherent framework is formed out of the need to operationalize the concepts that emerge from the interplay between planning theory and practice.

Different scholars have taken the effort to come to terms with planning theories, practices and approaches. Allmendinger (2002a) made an influential attempt to define and situate planning theory in relation to planning practices and approaches. To situate theories and approaches within the planning profession, he gives insight in the different views held on planning theory: some scholars argue that planners only theorize to justify certain practices, while others see planning theory as essential foundation to help develop planning practices (Allmendinger 2002a). In his book, *Planning Theory*, Allmendinger (2017) talks about certain 'Welltanschauungen', or ways of understanding and looking at the world. According to Allmendinger, these Welltanschauungen encompass and frame planning theories. But it seems that opposing views are held. As said by Thompson (2000, 130), 'it is a mistake to expect that there is such a thing as unified planning theory that offers single principles, laws or ideals that guide planning practice to a coherent solution'.

Thompson (2000, 126) goes on by saying that 'one of the features of urban planning is its openness to external influences: it is always in a state of some change'. This open character of planning can work in favor of planning outcomes by incorporating theories from both the natural and social sciences. However it also means that planning theory is an accumulation of theories from

several other disciplines, applied to urban planning. Thompson (2000, 130) argues: 'it has no first principles of its own but draws upon certain foundation disciplines including law, architecture, design, geography, sociology and economics'. This includes that the professional and non-professional doubt what planning actually is, and more specific, what planning theory and practice are. Also Gunder (2010, 37) acknowledges that planning theory has failed to develop 'a unified body of knowledge'. He argues that one of the reasons for this failure is that fact that planning theory relies on conventional social science, which fails to explain complex human action such as that of spatial planning (Gunder 2010, 37). Couch (2016) stresses that planning theory is sub-divided into two categories: theories 'of' and 'in' planning. Theories of planning refer to the procedural issues in planning and methods and processes of decision making and theories in planning refer to the substantive content of plans: what are planners trying to achieve by making plans (Couch 2016, 3). As argued by Healey (1997), the most convincing answers are found by looking at planning practice. Alexander (2016) takes this even further by saying that there is no such thing as 'planning'. Rather, only 'planning practices' exist. As rightly concluded by Brooks (2002) in his book *Planning Theory for Practitioners*, theorists do not practice and practitioners are more interested in using planning to achieve identified objectives and to not spend a lot of time immersed in theoretical literature (Cuthill 2003, 2324). Thus, this two-way relationship between theory and practice is not effectively sharing the benefits of both sides. What remains, undeniable, is the gap between theory and practice that many scholars attempt to bridge. It is the question if this debate on planning theory and practice will ever be resolved, or needs resolving. Without drowning in the fierce debate on defining planning theory and practice, it can be concluded that there is no unified understanding of what planning theory and planning practice are.

In the wake of such debate, there is a need for coherent frameworks that enable application of the concepts that emerge from theory and practice. What is a coherent framework? This research argues that a coherent framework is a structure of meaningful concepts and tools to apply these concepts. To reach an understanding of the coherent framework, an example of the sustainability concept, that has become a huge influential realm within urban planning, is illustrated. The Millennium Ecosystem Assessment brought ecosystem service concepts to the forefront, providing a way to critically make trade-offs between the different services that nature has to offer (Lester et al. 2013, 80). This fits the contemporary tendency in planning to move from a more instrumental look on nature, in which nature is used for human preference satisfaction, to a more intrinsic look on nature, whereby nature is seen as independent of human valuation (Ndubisi 2014; Chan et al. 2016). However, ecosystem services have proven difficult to operationalize in planning, and therefore the concept of green infrastructure emerged as a means to apply the ecosystem service concepts in planning (Duvall et al. 2018, 487). Green infrastructure is seen as a way to (re) generate a diversity of ecosystem services in cities. Gill et al. (2007, 116) define green infrastructure as 'an interconnected network of green space that conserves natural ecosystem values and functions and provides associated benefits to the human population'. Land is often planned in small patches, however green infrastructure promotes to look at the landscape level in order to connect many urban land-use patches. This will create a green network of infrastructure that is able to promote social as well as ecological resilience. Today, the concept of green infrastructure has developed into a reliable way of planning with specific tools that can be used. Jayasooriya and Ng (2014) stress that there are over 20 tools that can be used to implement green infrastructure, such as a cost benefit analysis or other modeling tools. We see that, within the realm of sustainable urban planning, green infrastructure forms a coherent framework of meaningful ecosystem service concepts and tools.

Another but more detailed example can be found at Wageningen University and Research Centre (WUR), who started a research program in 2006 to develop a coherent framework for ecosystem service assessment (De Groot et al. 2010). As there existed a lack of practical applications of ecosystem and landscape functions in planning, management and decision-making, there was a need for a coherent framework that could provide useful tools to implement the concept. The goal was to link ecosystem and landscape characteristics to services, values, trade-off instruments, planning tools and financing mechanisms (De Groot et al. 2010, 261). Their research led to the coherent framework as can be viewed in figure 1. This is a way of coming to a practical application of concepts. These two examples illustrate how the need to operationalize certain concepts results in the formation of a coherent framework, a structure of meaningful concepts. Although such a coherent framework is leaning more towards a conceptual basis than a practical one, it can be used to develop a combined set of tools for the planner to work with in the everyday practice of planning.

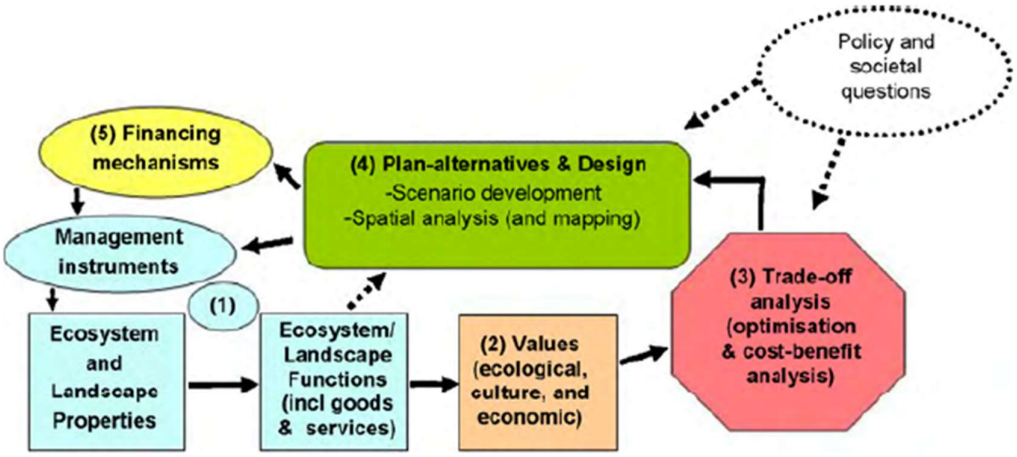

Figure 1. The coherent framework of ecosystem service assessment. Source: De Groot et al. (2010)

This section showed that the interplay between theory and practice encourages shaping a coherent framework: a structure of meaningful concepts. A coherent framework is formed out of the need to operationalize certain concepts that emerge from the interplay between planning theory and practice. In this way, also biomimicry could form a coherent framework for implementing meaningful concepts of nature-inspired design in planning.

2.1.2 The planning process

As mentioned by Couch (2016), a planning process is a guide to action and not an end in itself. However, typically a planning process goes through the following stages (Amado and Ribeiro 2011, 13; Yigitcanlar and Teriman 2015, 2):

1) Intervention aims definition: a definition of strategic goals is set up that take into account natural, economic and social needs.
2) Reference situation analysis: a complete data survey on local scope and regional scope of the environmental, economic and social urban features. Restrictions and potentialities are also identified.

3) Plan design: an urban proposal is realized in the form of a design to satisfy the intervention aim as defined in step 1. This step also aims involving the population, referencing the process transparency and efficiency.
4) Implementation and evaluation: lastly, implementing and evaluating the plan design will validate the strategic goals and the achievement of principles. Technical sheets and indicators are used to execute evaluation.

Instead of elaborating on these general steps in the planning process, it is more valuable to conceptualize the planning process by its characteristics. Contemporary planning processes are influenced by a shift from positivist to post-positivist thinking, which started in the 70's (Allmendinger 2002b). Post-positivist approaches do not strive to find reality but look for varied explanations. An example of this thinking is the article of Rydin (2007). Rydin (2007, 54) argues that knowledge is inherently multiple, with multiple claims to represents reality and multiple ways of knowing. Pinson (2004, 6) adds that this results in planning nowadays being conceived as an iterative process of conception and realization aimed at elaborating concrete plans of action, rather than planning only being regulation, master planning or architectural mega-structures. This brings with it a lack of prescription in the planning process (Allmendinger 1998, 246). Many scholars and professionals argue for an integrated planning process that is able to deal with a multitude of planning situations (Albrechts 2006).

In order to deal with a multitude of planning explanations, the agenda of spatial planning seems to expand more and more, aimed at arriving at a holistic view on problems or ideas. Different discourses are integrated such as the social, cultural, political, ecological and economic, using a combination of bottom-up and top-down approaches. As a result, planning processes are more associative in character. This associative character fosters a transdisciplinary process and advocates the involvement of people from different professions. In addition, a shift in the governance structure of planning is visible. Stakeholder involvement is not only considered of interest to government bodies, but also to communities and businesses (Duvall et al. 2018, 488), which advocates planning through collaboration among a diverse set of people. The work of Jürgen Habermas, Patsy Healey and Lawrence Susskind are important contributions to the collaborative turn in planning and were a reaction to move away from the traditional conception of a plan as spatial blueprint. The degree to which a planning process makes use of collaboration differs, as this is dependent on the urban governance, policy and stakeholder context in which planning operates.

In sum, contemporary planning processes can be characterized by a shift from positivist to post-positivist thinking. This results in the following characteristics of the planning process: it is collaborative, iterative and preferably multi-disciplinary. The process of planning is sensitive to, and shaped by, paradigmatic shifts and existing tensions between discourses and frames in society.

A planning process does not stand-alone and is influenced by the larger planning system in which it operates. It goes without saying that the different facets of this system influence the planning process. The article of Eliasson (2000) investigated when and how knowledge about the climate is used in the urban planning process. Although his conclusion is that climate knowledge had a low impact on the planning process, the result of their study is a framework that shows which variables are of influence to a planning process, so-called explanatory variables: technical, conceptual and knowledge based, policy, organizational and the market. The identified constraints give a more detailed explanation of the explanatory variables.

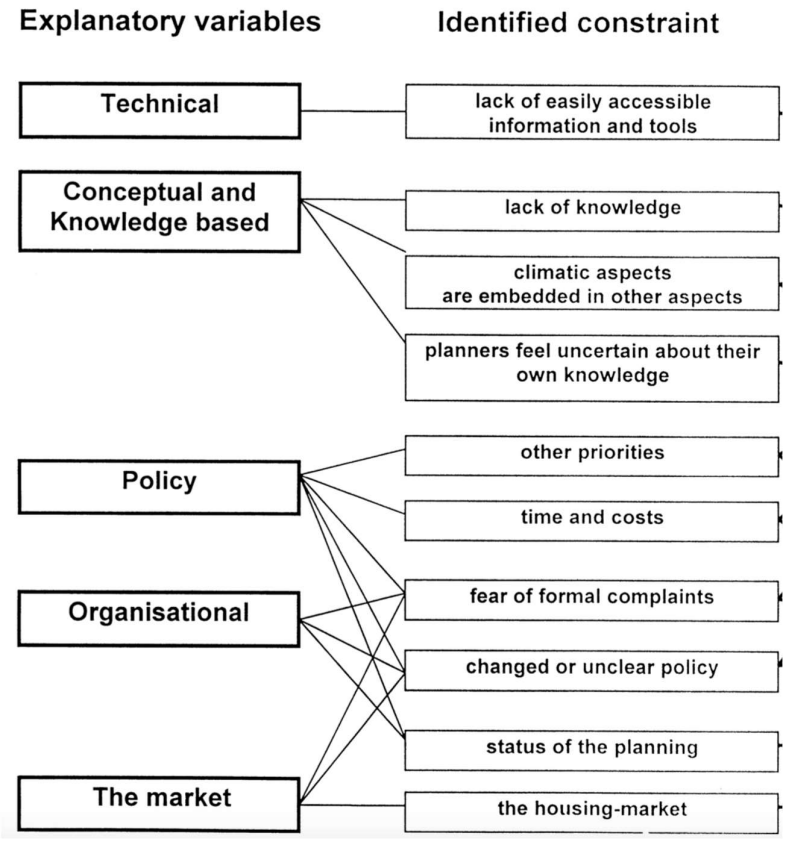

Figure 2. Framework with explanatory variables that influence the planning process. Source: Eliasson (2000)

2.1.3 Policy packages

Now that the coherent framework and the planning process are conceptualized, let us turn to 'policy packages'. Urban planning is part of the process of governing cities and is a way of the state to exercise central or local authority (Couch 2016, 55). As planning is concerned with the allocation of resources and affects the use and value of land, it is evidently a political process that would operate to the benefit of some groups in society and at the cost of others (Couch 2016, 4). Givoni et al. (2013, 2) also describe this as 'an intentional policy intervention upon a corresponding policy objective'.

Givoni et al. (2013, 4) conceptualize a policy package as follows: 'a combination of policy measures designed to address one or more policy objectives, created in order to improve the effectiveness of individual policy measures […]'. The realization of the complex nature of planning that needs to deal with multifaceted planning situations, requires spatial plans that are able to deal with different environmental, economic and social facets through use of a multi-stakeholder process. Implementing policy goals in these multifaceted situations requires the use of policy packages. This reveals how a policy package is better able to grasp the complexity of spatial planning in which policy objectives are implemented, believing that a combination of policies is better able to effectively deal with the policy objective than a single policy measure would. Howlett et al. (2015, 291) also refer to policy packages as a way 'to address multiple goals in more complex multi-policy and multi-level design contexts'. In other words, policy packages arrange multiple instruments and multiple governments to enable to implementation of certain policy goals.

2.1.4 Defining urban planning approaches

Now that a coherent framework, planning process, and policy packages are defined, we arrive at a thorough understanding of a planning approach. Looking at the conceptualization of Zandvoort et al. (2018, 184) once more:

A planning approach is a combined set of tools in a *coherent framework*, which planners can use to structure *planning processes* and deal with multifaceted planning situations, akin to *policy packages*.

The coherent framework of a planning approach allows planners to work within a set of meaningful and reasoned concepts. The interplay between planning theory and practice encourages shaping a coherent framework, which is formed out of the need to operationalize certain valuable concepts. Such a coherent framework in turn shapes and structures the planning process. Looking at planning processes shows they consist of general steps: defining the aim of the intervention, doing a situation analysis, creating the plan design and implementing and evaluating the design. Such planning processes are characterized by post-positivist thinking, showing the following characteristics: they are collaborative, iterative, and are preferably multi-disciplinary. Such multi-character planning processes reflect the diverse planning situations for which a planning approach is designed. Policy packages allow planners to deal with multiple goals, in multi-level design contexts.

2.2 Conceptualizing biomimicry

In order to grasp biomimicry, the concept is delineated. First, it is clarified what biomimicry is. Second, the biomimicry approach is explained by its three core values: scoping, creating and evaluating. Lastly, some critical viewpoints are highlighted on the concept.

2.2.1 What is biomimicry?

Most of the literature on biomimicry devotes its origin to the year 1997, when Janine Benyus published the book *Biomimicry: Innovation inspired by Nature*. As this book coined the term, the etymological origin of the term can be related to earlier history. Going back 3000 years in time, we see that the idea of imitating nature is not new (Gamage and Hyde 2012). As said by Bar-Cohen and Breazeal (2003, 14): 'throughout history humans have attempted to mimic the appearance, mobility, functionality, intelligent operation and thinking process of biological creatures and imitating them offers potential improvements of our life and the tools we use'. Especially marine and flying animals were taken as an inspiration for technological design, such as the streamlined shape of a fish that results in minimal resistance in the water (Ivanić 2016). Ivanić (2016, 20) makes clear how, in 1957, the term bionics appeared including both cybernetics and bionics, describing the science of creating artificial limbs and parts of the human body, and in 1974 the term biomimetics first appeared in the Webster's dictionary. With the book of Benyus, the term biomimicry was popularized.

Benyus defines biomimicry the following way (Ivanić 2016, 21): 'biomimicry refers to studying nature's most successful developments and then imitating these designs and processes to solve human problems'. As mentioned by McGregor (2013, 58), 'the term biomimicry is from Greek bios, life and mimesis, imitation'. Designers learn to look at nature in order to seek answers and possibilities and as stated by Cohen and Reich (2016, 6): 'imitates or takes inspiration from natural designs and processes to solve human problems'. An investigation of natural and environmental

features of a specific site, also called *genius of place*, is central to the approach. By doing this, ecological standards are developed to judge the rightness of human actions and innovations (McGregor 2013, 58). Nature is consulted as a model, mentor and measure. As a model, it helps emulate natural designs in relation to forms, processes and ecosystems; nature as mentor guides a way of screening nature for design; nature as a measure uses ecological criteria to evaluate designs (Gamage and Hyde 2012, 228; Wahl 2006). It is believed that 3.8 billion years of life evolution can serve as a refined inspiration for our built environment (Buck 2017).

In 1998, the Biomimicry Guild was founded by Janine Benyus and Dayna Baumeister and served as a biological consultancy for design teams at Nike, NASA, Shell, Gensler Architects and others (Peters 2011). The goal of this guild is to develop performance metrics from natural technologies and processes for assessing aspects of ecological and sustainable design (Peters 2011, 3). Besides, the Biomimicry Institute was founded to promote biomimicry through resource sharing and training. In order to specify what it means to practice biomimicry, the *Biomimicry Resource Handbook* was published in 2014. The book gives guidance and provides tools on how to apply a biomimicry approach for anyone interested. The book clearly emphasizes what distinguishes biomimicry from other approaches that replicate nature (Baumeister 2014, 81): 'The shift from learning *about* nature to learning *from* nature requires a new method of inquiry, a new set of lenses, and above all, a new humanity'. It focuses on what can be learned from nature instead of what can be taken from nature. The book stresses that biomimicry is a way of working that can be applied to any field and any scale.

Patel and Metha (2011, 218) clarify how 'the laws of nature are embodied in life principles, a framework developed by the Biomimicry Institute to inspire, inform and benchmark sustainable design'. The life principles are central to biomimicry and are seen as design lessons from nature that can be used as a tool to achieve strategic design (Baumeister 2014, 109). As all life is interconnected and interdependent, 'the principles represent the overarching patterns found amongst species surviving and thriving on earth' (Baumeister 2014, 45). In other words, they tell us nature's strategies for sustainability, i.e. how life evolved over 3.85 billion years. Figure 3 gives an overview of the life principles. As can be observed, there are six principles that every design should follow. These principles are adopted from Baumeister (2014)[1]:

1) *Evolve to survive*: the design's success is based on whether or not it contributes to the continuity of life;
2) *Adapt to changing conditions*: the design adapts to temporal and spatial changes and co-evolves with other parts of the system to increase the rate of adaption;
3) *Be locally attuned and responsive*: the design fits into and integrates with the surrounding environment;
4) *Integrate development with growth*: both development and growth are optimized;
5) *Be resource (material and energy) efficient*: the design skillfully and conservatively takes advantage of resources and opportunities, and meets its functional needs with minimal outlay of material and energy;
6) *Use life-friendly chemistry*: the design uses chemistry that supports life processes.

These principles are based on basic laws of nature (Lenau et al. 2018; McGregor 2013, 59): 'nature runs on sunlight, uses only the energy it needs, fits form to function, recycles everything, rewards

[1] A more detailed explanation of the principals can be found in annex 1.

cooperation, banks on diversity, demands local expertise, curbs excesses from within and taps the power of limits'. A design is considered successful when it is able to integrate all life principles. The principles make sure that mimicking nature is not done in a shallow way but is fully inspired by, and fits within, the larger natural system. Thereby the principles provide a set of high standards, and are not only used to integrate ecosystem insights in design but can also help evaluate and measure the success and nature-friendliness of a design. As summarized by the Biomimicry Resource Handbook: *'Life principles can provide a visioning tool and help guide a project's priorities. During design, life principles can be inspirational and provide a framework for choosing among design options. After a design is completed, life principles can be the basis for continuing assessment on how the final outcome of a project performs'.*

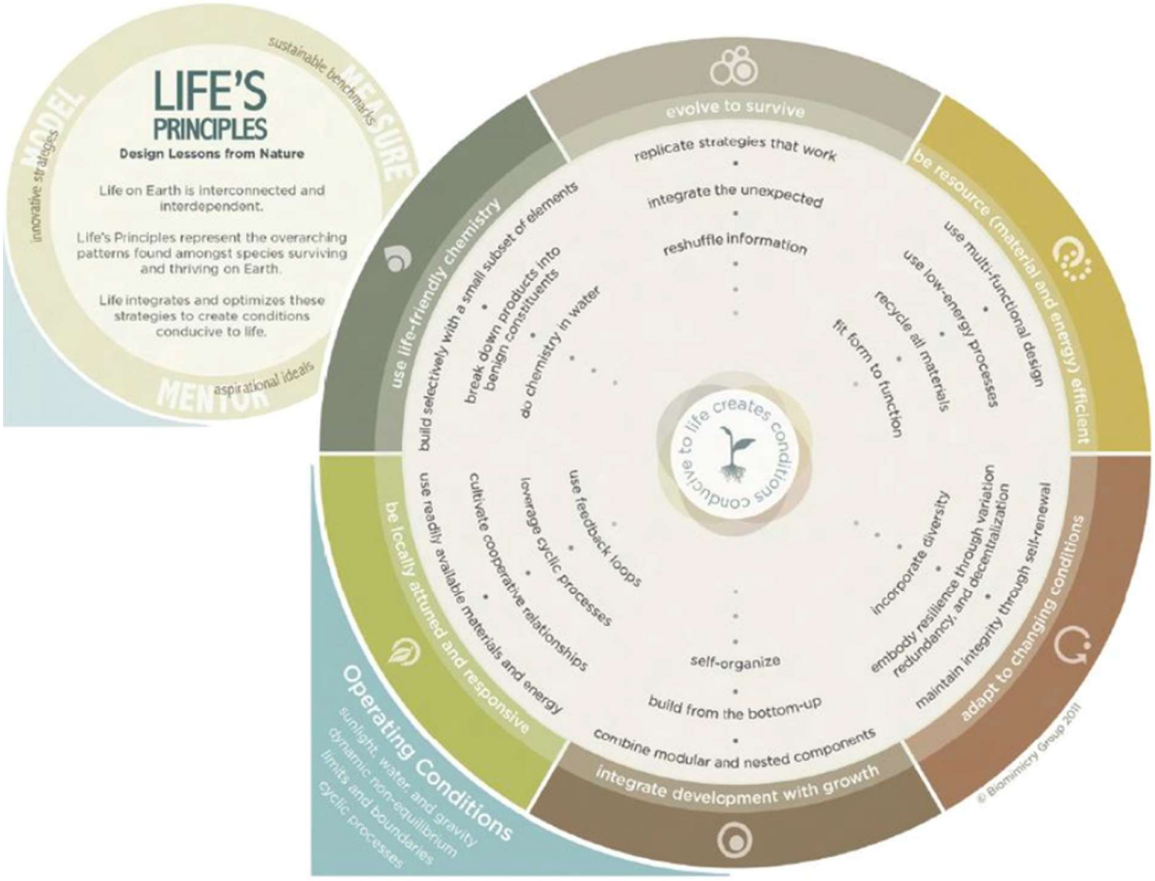

Figure 3. Life principles. Source: Baumeister (2018)

Biomimicry levels

As mentioned earlier, the biomimicry approach can be applied to three different levels: organism level, behavior level and ecosystem level. It must be noted that these levels are by no means separable in their relation towards one another; they are in symbiosis. As species have been evolving for millions of years, the ones that are present today have survival mechanisms that are able to withstand and adapt to constant changes over time. Mimicking organisms and their strategies for

living in a particular context can teach humans a lot, as organisms have often already addressed the problems we face. Organisms must be mimicked according to their participation and contribution in the larger context of their ecosystem. An example on the organism level is the *Stenocara* beetle. This beetle was investigated for its successful way of harvesting water from the air in the Namibian desert. Zari (2007, 32) explains how 'droplets form on the alternating hydrophilic-hydrophobic rough surface of the beetle's back and wings and roll down into its mouth'. Using a biomimicry approach to uncover the strategies behind this function resulted in a small machine that mimicked the beetles' body position and body surface structure for harvesting water in the Namib Desert (AskNature 2018).

Secondly there is the behavioral level. Zari (2007, 32) explains how 'organisms encounter the same environmental conditions that humans do and need to solve similar issues that humans face'. Organisms operate within an ecosystems' carrying capacity, which means there are limits and pressures that create ecological niche adaptations with only those organisms surviving that know how to adapt (Zari 2007, 32). Therefore, looking at the behavioral level is of great importance in creating sustainable designs. A behavior-based inspiration is the beaver. As an ecosystem engineer, the beaver changes his environment while creating more capacity for life in that system (Rossin 2010, 33). The beaver creates wetlands whereby he promotes nutrient retention, which allows more plant and animal diversity.

The last level to apply biomimicry is the ecosystem level. Very little projects have been carried out based on ecosystem biomimicry. An example can be found in architecture, where professionals explore the elements water, sun and wind as a means to achieve interior thermal comfort. The three elements are used proportional and consistent with natural features and in addition, must function in a processual relationship to the ecosystem (Abaeian et al. 2016). The result are ecosystem-inspired architectural solutions (Abaeian et al. 2016). The advantage of the ecosystem level is that it can be coupled to the other two biomimicry levels (Zari 2007). It can be applied to a range of temporal and spatial scales, and thereby operates at the metaphoric level (developing general ecosystem principles) and the practical functional level (Zari 2007, 32).

2.2.2 The biomimicry approach

Trying to get a grip on the biomimicry approach appears a chaotic task. As mentioned by Baumeister (2014) and Goel et al. (2014, 4), the biomimicry approach is interpretative and knows iterative design steps. After Janine Benyus published her book in 1997, different disciplines have tried to come to terms with the approach. As a consequence, literature reveals varying explanations to how biomimicry is practiced. For example, the article of El Zeiny (2012) came up with its own framework for understanding the application of biomimicry in architecture. Their frameworks use slightly different terminology and slightly altered the design steps according to an architecture design process. It seems that people try to provide fellow practitioners tools to engage with the biomimicry approach. As this may foster the adoption of the approach, it may also indicate that the steps, methods and tools remain too generic. To avoid confusion and for purpose of clearance and origin, here the methodology is drawn from its original source, the *Biomimicry Resource Handbook: a seed bank of knowledge and best practices*.

As explained in the *Biomimicry Resource Handbook* (Baumeister 2014), central to the approach are three core values: ethos, (re) connect and emulate. The figure below gives an explanation of each of these values.

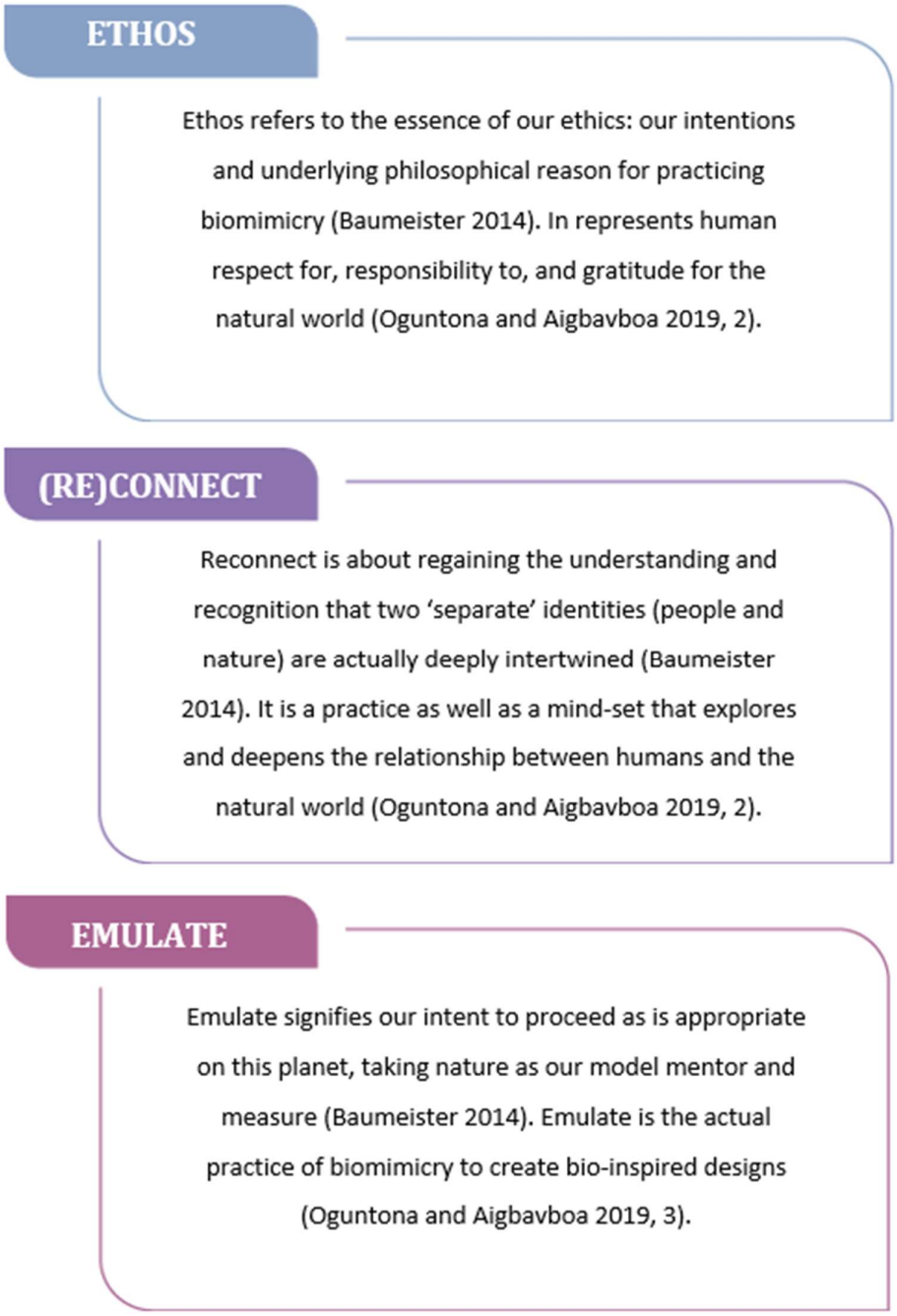

Figure 4. The three core values of the biomimicry approach

The *Biomimicry Resource Handbook* refers to the third step, emulate, as the actual practice of biomimicry. Emulate consists of three steps: scoping, creating and evaluating. A graphical representation of this design process is unified in the *design spiral*. The design spiral, which is illustrated in figure 5, provides a helpful tool for designers to ensure biomimicry-informed practice. It must be noted that these steps are set up to simplify what is in reality a non-linear and iterative process (Baumeister 2014). Interestingly, as the Biomimicry Resource Handbook only shortly

mentions the design spiral, other scientific literature refers to the spiral for practicing biomimicry. This is logical as it comprehensively summarizes the approach. It becomes clear that the biomimicry approach is somewhat challenging to grasp, but following the steps of the spiral leads the designer through scoping, creating and evaluating her design. Let us turn to scoping, creating and evaluating in order to understand the different steps of the spiral.

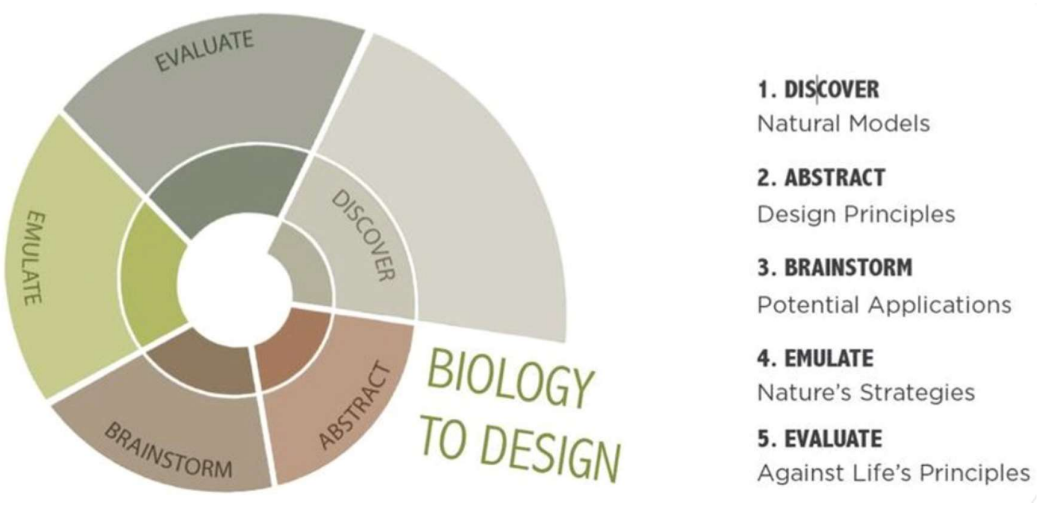

Figure 5. Biomimicry's design spiral. Source: Baumeister (2014)

Scoping

The purpose of the scoping phase is to identify the problem to be solved together with its context, criteria, and constraints. In other words, a design brief is created which involves prior research before the actual designing starts. Nature is seen as mentor, setting the expectations for living and designing (Baumeister 2014). First, the focus is on function, what do you want your design to do? It is important to ask how nature would perform that function. However, that function must also be viable in its context. So second, the focus is on context: under what conditions, circumstances, scenarios, constraints, laws or systems must the solution meet its defined function (Baumeister 2014)? The life principles are used as non-negotiable laws that are also used in the creating and evaluating phase (Baumeister 2014). The scoping phase changes mind-sets by looking at nature as a mentor, broadens the potential solution space, deepens the understanding of context, and supports meeting needs in a life-sustaining manner (Baumeister 2014).

Creating

The creating phase also incorporates biology into design by asking how nature would solve a particular problem. It consists of four important steps.

1) *Biologize*
   The first the step is to biologize the function that was identified in the scoping phase. The aim is to formulate a question that asks how nature would solve the problem, which leads to finding a system to learn from and become inspired by (Nagel et al. 2013, 2). The basic

question is: 'What would nature do here?' (Gebeshuber et al. 2010, 322). AskNature.org is mentioned as a good website that is able to help find design principles from nature (Baumeister 2014). The website classifies how organisms meet different functions with certain strategies.

2) *Discover*

The second step is to discover natural models that meet the function studied for a design and find strategies that are used to meet that function (Baumeister 2014). In addition to studying literature and consulting biological and ecological experts, a very important practice is *genius of place*. Genius of place is an exploration of the ecology of a specific site. This exploration leads to a report that looks at the various site-specific functions of a place, such as how and where water is stored and purified, how waste is managed, local economic development, local plant and animal life and other factors (Peters 2011, 47). This investigation of nature goes beyond making a checklist, rather, it looks at the specific ecological culture of a place and observes, measures and discovers local life (Peters 2011, 47). As mentioned by Buck (2017, 132), 'genius of place goes beyond traditional site analysis, as it incorporates a deeper understanding of local ecologies'. Based on genius of place, a design team should formulate *Ecological Performance Standards* (EPS). These are standards that are set up to meet the performance of nature. In order to make them measurable, they are translated into metrics. This challenges cities to provide the same level of ecosystem services as the native ecosystem (Benyus, 2014). For example in South Africa, the Durban Umbilo River Catchment Project carried out a genius of place. Discovering the geniuses of a place, Ecological Performance Standards were formulated to meet local water qualities and quantities. Metrics were set up based on the local habitat: runoff (gall/min), albedo (%), carbon sequestration (tons/acre), soil created (mm), and so on (Buck 2017, 133).

3) Abstract

As genius of place is carried out and EPS and metrics are formulated, a design team makes sure that a design fits within local natural systems. The third step is to abstract the biological mechanisms and translate them to design principles (Baumeister 2014). As explained in the article of Kennedy et al. (2015, 67), biologists are key players in the biomimicry design process. Abstracting biological strategies into applicable design principles demands a translation of expert knowledge on the natural world, gathered by biologists and ecologists in particular. Kennedy et al. (2015) claims that the aim is not to create an exact replica of a natural form, process, or ecosystem; instead, it is to learn from design principles from nature and use those principles as stimulus for ideation.

4) Emulate

Baumeister (2014) states that the last step is to emulate the translated abstractions of the natural model(s) into a human adaptation of the natural solution, which would be the most creative phase of incorporating biology into design. However it is not very obvious how emulation must take place, as design principles from nature can be emulated in many ways (literal or conceptual), in many circumstances (physical, communicative, etc.) and at different scales (at the same scale as the original example or at a larger or smaller scale). According to

Baumeister (2014), emulating the abstracted design principles would result in a design that used nature as a model, mentor and measure.

Evaluating

The last but very important step is evaluation, which can be done at the end but is encouraged to do throughout the design process. Again, life principles are central in the evaluation phase as they are used as metrics for judging the sustainability of a design (Vierra 2011; Baumeister 2014). To test the feasibility of a concept or idea, it is very useful to determine if goals and metrics are met or to solicit and incorporate feedback on the success of an implementation. Evaluation also identifies if the design brief needs refinement (Vierra 2011). If so, the design team can go through the design steps again.

2.2.3 Critical viewpoints

There are critical viewpoints towards the biomimicry concept as found in literature. The first critical point concerns the way that biomimicry conceptualizes nature. For example, Blok and Gremmen (2016) argue that biomimicry does not conceptualize nature *qua* nature, but nature is conceptualized in technological terms. They refer to the technical-engineer perspective that founder Janine Benyus used to develop the concept. Nature is almost seen as a machine that already solved the problems we are struggling to solve (Blok and Gremmen 2016). Fisch (2017) argues that the approach of Benyus is problematic as it emulates nature in technological apparatus. Fisch (2017) mentions: '[…] such an approach is problematic, I argue, for its valorization of organic form, which results in both a rigid system of ethics demanding absolute separation of nature and technology'.
Also Goldstein and Johnson (2015) state that, as biomimicry may seem to value nature in a less violent and exploitative way, it produces nature in new ways. Goldstein and Johnson (2015, 61) argue: 'biomimicry produces nature through well-worn logics of resource enclosure and privatization, focusing upon two fundamental shifts in how nonhuman life is put to work: the production of nature as intellectual property (as opposed to raw materials) and the production of nature as an active subject (as opposed to a passive subject or vehicle)'. Leonardi (2017, 183) also suggests that 'biomimicry sets in motion a twofold process of enclosure: on the one hand, nature is reduced to intellectual property; on the other hand, nature ceases to be portrayed as passive raw material/waste disposal'.

The second critical point concerns the philosophical underpinning of the concept. Many scholars mention the concept to be philosophically underdeveloped. An example is the argumentation of Mathews (2011), who states that biomimicry is indeed a revolutionary concept but one that remains descriptive and ad hoc in its approach. Inspiration is taken from nature by mimicking design principles from nature by using the life principles. However these principles remain descriptive and are not explanatory. For example, the principle that nature runs on sunlight gives designers a rule of thumb, but an understanding is only formed when designers also know *why* nature runs on sunlight (Mathews 2011, 368). Mathews says that ambiguous thoughts are inherent to the concept, and she calls for a deeper philosophy of biomimicry to really avoid the powerful anthropocentric mentality. A later study of Mathews (2018) even states that, 'unless the modes of contemporary practice are not reformed, the value-orientation of biomimicry will remain anthropocentric'. She argues that biomimicry could become an eco modernist-type scenario. Also Goel et al. (2014, 128) argue that, 'although biologically inspired design is rapidly growing as a design

movement, its practice is ad hoc'. Meaning there is little systemization of biological knowledge from a design perspective, neither is there systematization of the processes of biologically inspired design. Goel et al. (2014) conclude that rigorous development is needed to create precise theories of biologically inspired design. The argument that the approach is ad hoc is seen in the attempt of many articles to detail the approach. Other authors even criticize the innovativeness and new perspective that biomimicry claims to foster, and even call it a weak approach. Therefore, many articles compare the biomimicry approach to other approaches. So do the articles of Goel et al. (2014) and Lim et al. (2018) compare biomimicry to BioTRIZ, a methodology that aims dealing with the contradictions between biology and technology (Bogatyrev and Bogatyreva 2014). Another example is the article of De Pauw et al. (2014), who compare the biomimicry design process with that of cradle to cradle and eco design.

Another critique is that there is a lack of clear methods and tools to apply biomimicry. As mentioned by Appio et al. (2017), the challenge for designers when using biomimicry is the unfamiliarity with tools and methods. They argue this is caused by 'a lack of appropriate documentation to understand the best practices of successful applications in biomimicry' (Appio et al. 2017, 95). Wanieck et al. (2017, 53) also argue that one of the reasons why biomimicry is not widely applied is because of the lack of a clear method. The study of Wanieck et al. (2017) investigated the different existing tools to practice biomimicry. They found that many tools exist but are scarcely used in biomimicry projects because people have no knowledge of their existence or their use. Moreover, the existing tools are developed separately in different disciplines, causing fragmentations of tools. Sharma and Sarkar (2019, 95) specify that especially the transfer from biological systems to design principles is very challenges and requires 'a clear-cut methodology for analogical transfer'.

Lastly, a critique is that several articles easily interchange the concept of biomimicry with other concepts such as biomimetics or eco-design. Oguntona and Aigbavboa (2019, 2) state the following:

'However, multiple terms such as biomimetics, biognosis, bionics, bio-inspiration, biomimesis, bioanalogous design, and bio-inspired design are used interchangeably by different researchers and authors in literature. There is, therefore, no fundamental and significant difference between the terms and biomimicry. They all represent the creation of sustainable designs and solutions through the study and conscious emulation of natural forms, processes and ecosystems.'

The article of Lenau et al. (2018) also stresses the important difference between biomimicry and related bio-inspired sectors. Biomimetics is also a nature-inspired practice with a strong presence in material science and product design, however it is mostly used for increasing performance and not for achieving sustainable solutions (Lenau et al. 2018, 9). The concept is mostly applied in Germany, where technical understandings of nature are used as input for industrial product development. Biological analogies are sought based on functional similarities at different levels of biological organization (Hacco and Shu 2002). This concept thus holds a strong technical and engineering emphasis. This means that, contrary to biomimicry, biomimetics is much more often includes looking at smaller levels than the organism level; to molecule, organelle, cell, tissue and organ level (Hacco and Shu 2002). Using the terms wrongly may indicate a lack of knowledge on what biomimicry and its methodology is. For example, the article of De Pauw et al. (2014, 2) highlights there is a lack of

knowledge on how biomimicry differs from, or adds to, existing validated and well-established approaches such as eco design.

2.3 Biomimicry in the context of urban planning

This section aims to provide a framework of biomimicry in the context of urban planning. A distinction is made between biomimicry and planning literature. The result is an overview of weaknesses and strengths of using biomimicry in planning, as can be found in table 1.

2.3.1 Urban planning literature on biomimicry

The article of Lee (2017) investigated how well biomimicry could serve as an approach to design complex adaptive systems in the built environment. He formulated three conclusions that indicate weaknesses in the biomimicry concept. First, 'biomimicry requires time to exhibit or utilize the inherit potency, and therefore, application within a limited time frame may not yield positive results or might even be harmful' (Lee 2017, 228). Second, 'there is an absence of linearity or clearly defined cause-effect relationships, which are considered to be vital for clear and rational decisions' (Lee 2017, 228). Put differently, the complexity in natural systems and processes challenges to identify causal relationships in natural systems, which makes it hard to make concrete decisions. And third, 'it is very difficult to spot similarities between the biological mechanism that was found in nature, and the current design problem' (Lee 2017, 229). In other words, designers can find a large amount of biological mechanisms in nature, but it is difficult to determine which mechanisms fit the design challenge best.

The article of Hadfield-Hill and Zara (2017) criticizes the empirical outcome of using a of the first urban-scale biomimicry project in India, Lavasa. Based on an extensive in-depth research, one of their conclusions is that citizens felt disconnection to their ancestral land. The project took away nature and replaced it by buildings and parks whereby the access of residents to nature was limited (Hadfield-Hill and Zara 2017). It must be noted that the project in Lavasa was only partly based on a biomimicry approach, so it must be interpreted with caution that a biomimicry approach could result in relocating nature.

Biomimicry is approached in several planning studies as a sub concept of existing planning concepts such as nature-based-solutions and circular metabolism. Duvall et al. (2018) refer to nature-based solutions as an overarching concept that reimagines the relationship between nature and the urban, as it addresses environmental, social and economic challenges in sustainable ways. It encloses green infrastructure, blue and green infrastructure and biomimicry as urban design and planning tools. Spiegelhalter and Arch (2010) point to circular metabolism[2] as an overarching term for biomimicry and industrial ecology. They argue that biomimicry is best seen in the context of a city's lifecycle planning, implying all potential environmental impacts caused by a product, system or building project during its life cycle. 'This includes raw material extraction and processing, manufacture, use/operation, maintenance, re-use, and recycling as new circular resource input process' (Spiegelhalter and Arch 2010, 217). Also Geisendorf and Pietrulla (2017) agree that creating a circular city includes other concepts with a circular approach, such as blue economy, cradle-to-

[2] 'Circular metabolism: 'open loop systems in which resources and capital investments move through the system to become waste can shift to closed loop systems where wastes and other products become inputs for new processes' (Spiegelhalter and Arch 2010, 217).

cradle, industrial ecology and biomimicry.

Although planning literature on biomimicry is scarce, many articles refer to the potential of using a biomimicry approach in planning, such as those of Klein (2009), Kenny et al. (2012), Brown and Kellenberg (2009), Toor and Kaur (2017) and Royall (2010). Unfortunately, a detailed research and explanation of this potential is missing. Planning literature seems to make hypothetical reference to what could result from using biomimicry as planning approach. An example is the article of Royall (2010), which explains how a city can be modeled after a cell according to three characteristics of the cell: self-sufficiency, porosity and adaptability. The self-sufficiency of a cell in terms of its organization means that a cell is contained (its contents spread only to the plasma membrane limits), components of the cell do not have to commute large distances to achieve their purpose and resources are localized and organized without unnecessary repetition of infrastructure. This idea serves as an example for cities to design in a reusable and recycling manner. Also Brown and Kellenberg (2009, 60) state that applying biomimicry at a broad spatial scale might be more effectively confronting ecological degradation and climate change adaptation. These are examples of the way planners see opportunities for using biomimicry in urban planning, based on a vision of what the city could look and perform like using biomimetic principles.

Another potential that is mostly based on hypothetical reasoning, is the opportunity that biomimicry brings to support the planning and designing of urban infrastructures. As mentioned by Wootton-Beard et al. (2016, 28), 'a move away from the mimicry of form, towards the mimicry of function and its underlying mechanism is a trend in biomimetic research, and one that can provide a significant opportunity for interaction between biological scientists and urban infrastructure planners'. They argue that elements of plant science such as biological control mechanisms, organism and community symbioses and adaptive responses could offer new opportunities for biomimicry in the built environment. A main example is solar tracking, the ability of a plant to change its position in relation towards the sun (Wootton-Beard et al. 2016, 9). A biomimetic design could be a whole range of buildings that are adaptive to the position of the sun by rotating their walls and windows. Also Kenny et al. (2012) point to the potential of biomimicry to support infrastructure planning. They argue that, as water and energy infrastructures are faced with environmental issues such as GHG-emission, water and land pollution and resource consumption, planners try to take measures to create more sustainable infrastructures, however without significant effect. Kenny et al. (2012) conclude that biomimicry indicates a clear opportunity to design infrastructure systems. They give an example of Biolytix, a water treatment system that does not use chemicals. This system mimics the way the forest floor decomposes leaf litter to clean household sewage, wastewater and food waste without the aid of chemicals (Kenny et al. 2012, 9). More research in this area will assist infrastructure planners, according to the article. Also Toor and Kaur (2017, 255) point to urban infrastructure as an arena of planning that could be supported by biomimicry: 'biomimicry can be used by planners to reduce embodied energy in construction products, reduce material use, and reduce maintenance'. They say the major efficiency in biomimetic designs for planning is the concept of adaptability to various scenarios (Toor and Kaur 2017, 256). However, Kenny et al. (2012) rightly argue that, in order to use biomimicry as a consistent design approach in planning, a framework is needed for considering biomimicry informed urban infrastructure design.

Many planning scholars see an opportunity for biomimicry to help design more resilient and adaptive cities. Unfortunately these articles do not detail how looking into nature exactly helps to design adaptive and flexible cities. For example, as said by Collier et al. (2013), biomimicry is a way to create cities that are more resilient and adaptive. The article of Broto et al. (2012) also argue there is

a need to design cities that are changeable and flexible enough to maintain growth and transformation, which leads to an increasing interest in biomimicry. By looking at nature, biomimetic principles are seen as a way for urban planning to design these changeable and flexible cities by focusing on transport, food, waste, energy, and communications (Broto et al. 2012, 853).

No articles except a few are able to clarify the potential of biomimicry for urban planning, based on an extensive study. The research of Buck (2017) forms a complete and detailed investigation in the way biomimicry could contribute to plan the future of our cities. First, Buck (2017) found that biomimicry stimulates positive individual behavioral change and can help develop a shared vision for the future of our city. Biomimicry does this by aligning people around a positive message, and creating awareness of our relationship with the natural world. Second, as biomimicry crosses disciplinary boundaries, 'it challenges contemporary urban planning and design approaches and breaks the trend for splintered service provision' (Buck 2017, 135). Third, Buck (2017) explains how biomimicry has the potential to open up horizons for thought and action, as it expands the dialogue and exploration of urban challenges in the planning profession by looking at nature. Fourth, Buck (2017, 136) found that biomimicry could easily be coupled to existing city paradigms such as the smart city, which will result in an easier adoption of biomimicry in planning. Lastly, the most detailed finding from the article is that Ecological Performance Standards (EPS) of the biomimicry approach are seen as a powerful tool, 'to guide the development of future cities, providing a solid design framework for how infrastructure should perform in a particular place' (Buck 2017, 136). Also Chen et al. (2014) carried out a more extensive study in which they investigated how mimicking coral reefs could be a viable application to the built environment. For example, one of their conclusions is Chen et al. (2014, 6):

'Coral reefs' spatial relationships with their surroundings could improve the buffering effectiveness of shoreline stabilization structures, such as jetties and breakwaters. Biomimicry considering climate and wave patterns can lead us to more effective structures that are culturally- and environmentally appropriate.'

It is interesting that several planning studies looked at contemporary building projects through a biomimicry lens. This points to the evaluative value that the biomimicry principles can have for planning. Oguntona and Aigbavboa (2017) examined biomimicry principles as critical success criteria for sustainability in the construction industry. Based on a quantitative study in which they used biomimicry principles for evaluating sustainability, the article concludes that the principles are especially relevant for energy and material efficiency at different stages of construction (Oguntona and Aigbavboa 2017, 2496). Also Ariffin and Gad (2017) used the life principles of biomimicry as a lens and framework to evaluate the presence of these principles in the contemporary Green Building Index (GBI). By doing content analysis they found that a synergy between GBI and life principles can help improve and further develop the green building rating tools that are widely used by professionals to help them define and produce a sustainable building (Arrifin and Gad 2017, 189).

2.3.2 Biomimicry literature on urban planning

Looking at biomimicry literature it becomes clear there is very little known about applying the concept on a city scale. There are two main books that can be considered original biomimicry literature. They are the first published book of Janine Benyus in 1997, *Innovation Inspired by Nature*

and a second book written in 2014 that comes to terms with the practical application, *Biomimicry Resource Handbook: a Seed Bank of Knowledge and best Practices*. Besides, the Biomimicry Guild has created websites that guide practitioners to their designs or provide information, such as Ask Nature[3]. Other than that, there is little 'original' biomimicry literature. Most research takes off when different disciplines research the possibilities of the subject and try specifying the approach for their discipline. This section focuses on those original biomimicry sources and their reference towards urban planning.

Several efforts are made within biomimicry literature to foster the research on a biomimetic approach to planning. Klein (2009, 2) mentions how biomimicry gained a lot of attention from environmental designers after McLennan and Berkebile (2004) identified it as one of the most important principles of sustainability in their book *The Philosophy of Sustainability Design: The future of Architecture*. Shortly after, founder of biomimicry Janine Benyus stated that 'the built environment is the most fertile ground for biomimicry' (Klein 2009, 2). As planning works at larger and smaller urban scales, Benyus believes planning is able to have a larger scale impact to bring sustainability to society at large. This can be seen by the many efforts of different biomimicry organizations over the world to research local ecosystems for the sake of larger spatial designs. An example is the Urban Greenprint, an organization that tries to apply biomimicry to revitalize cities. Researching the local Northwest Forest in Seattle, the organization was able to provide a document, or a so-called 'SeedKit', that informs designers on the strategies of the forest to reduce polluted runoff (Urban Greenprint 2019).

In the *Biomimicry Resource Handbook,* Baumeister et al. (2014) explain how, during the scoping phase of design, nature provides the team benchmarks for how the native ecosystem is capable of performing. This is especially valuable for site-specific challenges, including urban planning. As one of the steps in the biomimicry approach is the creation of metrics from the local ecosystem, this can be used to generate project goals that stakeholders can agree upon (Baumeister 2014, 164). Overall, the book promotes bringing the biomimicry ethos to the local planning and policy level by networking. The article of Wahl (2006, 293) argues that biomimicry is able to bring a new worldview that acknowledges the complex interactions and relationships between systems by integrating multiple perspectives. They conclude that changing the intention behind design with biomimicry will ultimately create a sustainable civilization (Wahl 2006, 296). A more recent attempt was made by Vogelzang et al. (2018), who formulated a 'knowledge agenda' to spark the interest of studying biomimicry in planning. The agenda mentions how biomimicry offers an interesting approach to use nature as benchmark in building projects. For example, biomimicry could teach planners how trees deal with material flows and this could be applied to water management of the city. They propose several questions that require future research, such as: what methodology can be applied when urban planning engages with biomimicry?

Also, it seems that biomimicry literature realizes there is lack of tools available for applying the concept on an urban scale. An alliance between HOK Architecture and the Biomimicry Guild led to one of the first urban-scale biomimicry project in Lavasa. In order to use the biological mechanisms that were found in nature, HOK and the Guild developed the FIT-tool: Fully-Integrated-Thinking. This tool enabled designers to integrate biological knowledge in their designs of the built environment. Spiegelhalter and Arch (2011, 225) conclude that the future challenge is to develop a

[3] www.asknature.org

publicly easy accessible and commonly understandable eco-balancing tool or model that will have a direct input into the structural planning process and that can be benchmarked against global resource balancing levels according to IPCC targets. Overall, it become clear there is increasing interest in the subject of biomimicry and planning. However, as rightly put by Spiegelhalter and Arch (2010, 216): '[…] biomimicry largely presents us still with mysteries beyond our comprehension to improve sustainable practice'.

Table 1. The identified strengths and weaknesses of biomimicry as found in literature

Strengths	Sources	**Weaknesses**	Sources
Biomimicry has potential to be used in urban planning, however this potential is vaguely specified and mostly based on hypothetical reasoning.	Klein (2009); Kenny et al. (2012); Brown and Kellenburg (2009); Toor and Kaur (2017)	There is a lack of a clear method and tools to apply biomimicry in planning.	Spiegelhalter and Arch (2011); Appio et al. (2017): Chayaamor-Heil and Hannachi-Belkadi (2017); Sharma and Sarkar (2019); Wanieck et al. (2017)
Applying biomimicry on an urban scale more effectively confronts ecological degradation and climate change adaption in comparison to smaller scales such as architecture or product design.	Brown and Kellenberg (2009); Lennon and Scott (2014)	The concept is philosophically underdeveloped.	Mathews (2011); Goel et al. (2014)
Biomimicry stimulates positive behavioral change by creating a shared vision in the design team.	Buck (2017); Baumeister (2014)	It is difficult to translate the language used in biological concepts into potential application.	Lee (2017); Sharma and Sarkar (2019); Wanieck et al. (2017)
Biomimicry opens up horizons for thought and action, as it expands the dialogue and exploration of urban challenges in the planning profession by looking at nature.	Wahl (2006); Buck (2017)	Evaluating an urban-scale biomimicry project, it was found that citizens felt disconnected to their ancestral land as nature was relocated.	Hadfield-Hill and Zara (2017)

Most potential is seen for using biomimicry in infrastructure planning.	Wootton-Beard et al. (2016); Kenny et al. (2012); Toor and Kaur (2017)	Biomimicry does not conceptualize nature qua nature, but conceptualizes nature in new ways, i.e. in technological terms.	Blok and Gremmen (2016); Goldstein and Johnson (2015); Leonardi (2017)
Biomimicry can be used to create resilient and adaptive cities, however it is not specified how biomimicry exactly realizes this.	Broto et al. (2012); Collier et al. (2013)	Biomimicry requires investment in terms of time, money, education etc.	Lee (2017); Lenau et al. (2018)
Biomimicry principles can be used to evaluate the performance of existing designs in terms of their sustainability.	Ariffin and Gad (2017); Oguntona and Aigbavboa (2017)	The biomimicry concept is often wrongly interchanged with other bio-inspired approaches.	Lenau et al. (2018); De Pauw et al. (2014); Sharma and Sarkar (2019)

Chapter 3 Methods

This chapter describes the methods for data generation and analysis. The methodological design is discussed, as well as the trustworthiness and validity of the chosen research methods in the context of the research objective, which is to explore the potential of biomimicry for urban planning. Lastly, this chapter reflects on the limitations of the methodical choices.

3.1 The methodological design

This research takes a post-positivist standpoint to explore the potential of biomimicry for urban planning. Looking at the objective and the research questions, the methods for the research should be qualitative. As mentioned by Ritchie et al. (2013, 2), qualitative research is used as an overarching category, as it covers a wide range of approaches and methods found within different research disciplines. Despite the diversity in approaches and methods, there is common agreement among scholars on several characteristics of qualitative research. McCusker and Gunaydin (2015, 537) state how qualitative research aims to understand experiences and attitudes of people by using methods that answer questions about the 'what', 'how' or 'why' of a phenomenon. This suggests research methods to be sensitive to the social context in which data is generated and implies that qualitative research rarely follows a smooth trajectory from hypothesis to findings (Silverman 2016). As mentioned by Flick (2018, 16), 'the subjectivity of the researcher and of people being studied becomes part of the research process and the researcher's reflections upon his or her actions and observations in the field – as well as his or her impressions, irritations, feelings, and so on – become data in their own right, forming part of the interpretation'. Accounting for the iterative character of qualitative research, this research approached the research design as part of a learning process, allowing adjustments according to new insights during the research process (Schwartz-Shea and Yanow 2012).

I used an interpretive approach. In an interpretive approach, the researcher is sensitive to multiple interpretations among interviewees, in which the role of the researcher and the individuals from whom data is collected plays a central role (Lewis 2015, 3). Interpretive research is an on-going and iterative process until it reaches a point of understanding or saturation. This means that when new data is gathered and does not add new insights to the problem but only validates what is already known, saturation has been reached (Botes and Smit 2015).

Very few projects have been carried out based on biomimicry and the concept only recently gained more attention in different fields of study. Therefore, this research was explorative in nature. As argued by Reiter (2017, 144), 'an explorative research is not about discovery, but about a gradual expansion of conceptual tools of perception that allow a better or deeper understanding of the world based on what we already know'.

3.1.1 Research methods

Based on the objective of the research and the main question: *What is the potential of biomimicry for urban planning to contribute to planning for a future that sustains both natural and human systems?,* the main method for data collection were semi-structured interviews. Based on the limited studies on biomimicry and urban planning, a thorough document analysis was impossible. As only a few urban-scale projects have been realized that partly used a biomimicry approach and the people who were involved in these projects are scattered across the globe, a (comparative) case study was not a

viable option. Also, making use of a survey as a research method was perceived as generating little depth on the subject, because it has the risk of narrowing possible answers to questions.

The aim of my research supported the use of semi-structured interviews as the main method of data collection. A semi-structured interview allows depth in the data because of its flexible character, as the interviewer has the opportunity to probe and expand the interviewee's responses (Alshenqeeti 2014). As argued by Cypress (2018, 304), the semi-structured interview allows phenomenon of interest to emerge from the respondent's perception to the issues raised by the inquirer; the interviews are informal, in-depth, specialized and exploratory. A major advantage of interviews is that they enable respondents to move back and forth in time to reconstruct the past, interpret the present and predict the future (Cypress 2018). It allows the interviewer to ask a set of key questions in each interview and do some probing for further information (Ritchie et al. 2013, 111). As stated by Flick (2018, 211), the semi-structured interview allows the interviewer to give thematic direction to the interview questions. Moreover, the respondents' viewpoints are more likely to be expressed in an open-ended interview than in a standardized interview or a questionnaire (Flick 2018, 150).

The semi-structured interviews were designed to answer the main and sub-questions of this research. First, a list was made of different topics that covered the sub-questions. From the list of topics, the sub-research questions were formulated. A complete and detailed overview of the topics and related interview questions can be found in Annex 1. Two question lists were developed to account for the two different groups of interviewees: one question list was tailored for urban planners and the other for biomimicry experts.

3.1.2 Data collection and instruments

Because this research explores the potential of biomimicry for urban planning, there are two groups on which data collection was focused: biomimicry experts and urban planners. The study is thus not limited by only interviewing urban planners, but offers a holistic view by including biomimicry experts. The biomimicry experts were carefully chosen based on their involvement in urban scale biomimicry projects. Urban planners, on the other hand, are familiar with the possibilities and barriers of planning. Only planners were interviewed that worked with biomimicry projects and thus have familiarity with the concept.

To select interviewees, I made use of snowball sampling. Specifically, exponential discriminative snowball sampling was used, which means that every interviewee indicates another possible interviewee, although not necessarily in every case (Etikan 2016; Schwartz-Shea and Yanow 2012). Before selecting respondents, BiomimicryNL (the Dutch biomimicry organization) was contacted to address their well-established network of international biomimicry practitioners. This contact provided the first three respondents. Discriminative snowball sampling was used to further expand the list. The interviewees were reached by mailing and calling and due to the fact that biomimicry experts and biomimicry planners are scarce and widespread, the list of respondents consisted of international experts. A total of 14 interviews was carried out with biomimicry experts and planners. Table2 gives an overview of the interviewees and their expertise.

Table 2. List of interviewees and their background expertise

Interviewee	Specification
1	Biomimicry expert (systems expert)
2	Urban planner
3	Biomimicry expert (systems expert)
4	Urban planner
5	Urban planner
6	Urban planner
7	Urban planner
8	Biomimicry expert (urban planner)
9	Biomimicry expert (urban planner)
10	Urban planner
11	Biomimicry expert (innovation consultant)
12	Biomimicry expert (engineer)
13	Biomimicry expert (architect)
14	Urban planner

The main instrument for data collection was the video call tool in Skype. As mentioned by Seitz (2016), interviews via video internet technologies such as Skype broaden the geographical access to interviewees and are also less disruptive in terms of scheduling and carrying out the interviews. For that reason, Skype was the best option for carrying out the interviews of this research. Comparable to face-to-face interviews, Skype establishes a synchronous visual interaction between the researcher and interviewee (Seitz 2016, 230). Although mediated interviews are not face-to-face interactions, they work as viable alternative data collection instruments (Lo Lacono et al. 2016). To record the interviews, the Dictaphone application was used. Traditional pen and paper were also used to mark important comments during the interview, or related thoughts as they occurred to me.

3.2 Data analysis

The interviews were recorded and developed into interview transcripts. For the analysis of the transcripts, the qualitative data analysis software tool NVivo was used. NVivo establishes researchers to systematically and rigorously synthesize findings, thereby enhancing the trustworthiness of the research (Houghton et al. 2017). NVivo provides a robust and pragmatic way to manage the complexities and imprecise reality of conducting qualitative analysis (Houghton et al. 2017). Although software packages such as NVivo provide excellent data management and retrieval facilities, they do not fully scaffold the analysis process (Maher et al. 2018). In their conclusion, Maher et al. (2018)

argue for use of traditional tools such as colored pens, paper and sticky notes in combination with NVivo to ensure a valid and tested analysis method. This research used these insights by first going over all transcripts by hand. Using pen and paper, the larger themes and insights from the interviews were identified and written down. After all interviews were traditionally analyzed, NVivo was used to re-code the transcripts with more detail and precision. The result was a list of themes, or so-called 'nodes'[4]. Creating these nodes revealed differences in main and sub nodes, as some themes were considered more prominent and important than others. The nodes are accompanied by coding stripes that mark at which point the nodes were attached to the transcripts. A detailed overview of all nodes and an example of the coding stripes can be found in Annex 3.

As the codes provide a distinction between main and subthemes, complex relationships were found among the themes and different themes related to multiple other themes. NVivo was used to get a grip on these complex relationships by ranking the themes by the amount of references coded. This allowed me to systematically analyze the main and subthemes. NVivo was used to create a hierarchy chart of the different elements that belong to the biomimicry approach (figure 6). For example, for the biomimicry approach, multidisciplinary working and genius of place are the most important (figure 6).

Figure 6. Hierarchy chart based on the amount of references for the different elements of the biomimicry approach (The darker green the color and the more space it takes up in the hierarchy chart, the more references it received and the more prominent a theme is)

[4] Nodes provide the storage areas in NVIVO for references to coded text (Bazeley 2007). Node is an NVIVO term for what would be more commonly referred to in research as codes signifying themes and subthemes (Houghton et al. 2016).

3.3 Credibility, trustworthiness, ethics and limitations of the research

This section explains how the credibility and trustworthiness of the research were ensured. In addition, it describes the ethical considerations of the research and its methodological design and looks critically at the limitations of the chosen methods.

3.3.1 Credibility and trustworthiness

The credibility of qualitative research relates to the representativeness of the findings in relation to the phenomena. As mentioned by Twining et al. (2017, 7), the researcher must be reflective by giving insight into assumptions and decisions in order to account for the credibility of the research. As I used an interpretive approach, I acknowledge that my values and predispositions are inseparable from the research process (Roulston and Shelton 2015). As argued by Roulston and Shelton (2015, 335), the researcher is one of the research instruments and is subject to (accusations of) bias given the difficulties of controlling the personal attributes of the researcher in interaction with interviewees. I had an active role in making judgments about what is of interest to this research and what not and access (and likeability) to interviewees directed the research and my choices. As there are only a few biomimicry practitioners and biomimicry planners to be found, separated over different geographical locations, the access to interviewees limited the amount of choice for the research. Also, my prior knowledge on the subject and the professional background of the interviewees influenced my choices, since interpretative research looks for interviewees that matter to the study. For example, a biomimicry expert who works on a system level was prioritized over an expert that practiced biomimicry on a Nano or micro level, to match interviewees with focus on the contribution of biomimicry on an urban scale.

Trustworthiness means that research methods have been undertaken in a transparent manner (Noble and Smith 2015). Twining et al. (2017) mention that giving insight into the analytical process of the research ensures the trustworthiness of the research. For that reason, this chapter gave as much transparency as possible on the steps undertaken in collecting, managing and analyzing data. The NVivo software tool assisted in enhancing the rigorous process of data storing, coding, and analyzing (Houghton et al. 2017). This ensured that interpretations of data were consistent and transparent (Noble and Smith 2015, 2).

3.3.2 Ethics

Consideration of ethical issues is important in every study. For this research, ethical issues involve protecting the rights of the interviewees and properly using and disseminating findings (Cypress 2018, 303; Flick 2018). There are two kinds of ethical issues in research, namely the individual values of the researcher and their honesty, frankness and personal integrity in regard to the research and the researchers' treatment of other people involved in the research relating to informed consent, confidentiality and anonymity (Walliman 2010, 43).

The first aspect that raises ethical issues is the researchers' treatment of interviewees. Working with people means you treat them with respect before, during and after the research (Walliman 2010). Participants were fully informed of the purpose of the study before the start of the interview via an email with a short explanation of the research. This was accompanied by an overview of the interview questions. This allowed interviewees to ask clarifying questions and they were able to prepare for the interview if desired or needed. I interviewed the selected interviewees

from home using Skype. All interviews were held in English as the selected interviewees were of international origin, except for two Dutch-speaking interviewees. Consent for recording the interview was asked before the start of the interview and the anonymity and confidentially of the interviewees and their answers were ensured. I tried to create a comfortable environment by introducing myself, the research purpose and asking questions relating to the interviewee's job and interests regarding the topic. After the interviews I sent a thank you note to the interviewees for sharing their insights and devoting their time to my study. I will also share the findings of my study with all interviewees, as they were interested in receiving the results of my research.

The other aspect that raises ethical issues is the way I dealt with my own values relating to the honesty and personal integrity of the research. As stated by Flick (2018, 41), ethics are of importance to all aspects of the research process, from deciding on a topic to disseminating the findings. It follows that analyzing the data and the interviewees' answers is ethically just. Thus, my interpretations of the data are firmly grounded in the data without including judgments on a personal level and without subjecting interviewees to a diagnostic assessment, for example of their personalities (Flick 2018, 42).

3.3.3 Limitations

There are limitations to the chosen methods and instruments of this research and using a semi-structured interview as a method has its limitations. Interviews cannot be standardized and are difficult to replicate because the sole instrument of study is the researcher. Moreover, the interviewer can influence the outcome of the interview through cues (Cypress 2018, 304). As mentioned by Seitz (2016), using Skype has the benefit of limiting the ability to read facial expressions and cues, thereby limiting the influence of the interviewer compared to face-to-face interviews. The downside of using Skype as a video medium to conduct interviews is that it poses several risks and limitations to the data collection and analysis: calls can be dropped or paused, there is a risk of inaudible segments, there is an inability to read nonverbal cues and a loss of intimacy compared to traditional face-to-face interviews (Seitz 2016, 230). Accounting for these limitations beforehand, I tried to ensure a good internet connection by running test video calls with interviewees. Also, the setting of the interviews was carefully considered by both the researcher and the interviewee in an effort to ensure a quiet and undisturbed room to conduct the interview. Despite my efforts to account for the abovementioned risks, the setting of the interviews is not within total control of the researcher. Examples are sudden changes in the interview setting, which caused noise in the audio records or an unexpected bad internet connection which faded parts of the interviews (Seitz 2016). I experienced a disturbance of video calls by other people and loss of internet connection. I dealt with the loss of internet connection by moving to phone calls instead and immediately after the interviews I made notes in case data was lost due to connection errors. To prevent a loss of information, I started transcribing the interviews immediately after recording them.

Another limitation is the small number of biomimicry experts and biomimicry planners around the world, which restricted the number of potential interviewees. One the one hand, this limits the bias that can occur when a researcher subjectively select interviewees. On the other hand, the research was very dependent on these few interviewees to conduct the interviews and collect a sufficient amount of data. Another limitation to the possible scope of the research is the timespan, as this research was carried out in a time period of 8 months, from October 2018 till May 2019. A last limitation is that all interviews were held in English. For several interviewees and for myself, this

meant that the interviews were not held in our native language. This did pose some language limitations to communicating effectively.

Chapter 4 Results

This chapter presents the results of this study.

4.1 What is biomimicry and how is it practiced?

The interviewees in general demonstrated that biomimicry is described with three terms: function, mimicking and wide applicability. Interviewees unanimously defined biomimicry by function. One interviewee stated that *'biomimicry is about understanding how nature functions and applying those functions to our own designs to become more sustainable'.* And another interviewee commented that *'people try to maximize the effect of a certain function, whereas biomimicry encourages you to look at that function in relation to all other functions'.* With a focus on function, biomimicry goes beyond bringing nature in the city by adding more greenery. As stated by one interviewee: '*I often describe biomimicry as a history of collective intelligence; a whole bunch of solutions already exist in nature that we can explore as humans to solve our own challenges'.* Most of those interviewed indicated that in nature functional problems are solved in a myriad of ways, many being more efficient than human-engineered processes or solutions. All interviewees agreed that biomimicry is *'[…] a radically different way for people to think, and it can change hell of a lot'*.

Mimicking is a second element that is used by a majority of interviewees to describe biomimicry: *'Looking at the way nature performs and functions, we try to mimic the system'*. Mimicking form, process and system, *'biomimicry emulates nature's beauty and intelligence to find solutions to challenges in society'*. One interviewee explained how we expect nature to provide natural system services but we do not demand such services from architecture. Participants echoed the view that our built environment should provide the same services as nature, for example, storing carbon, water and providing clean air.

> *How can we rethink the way we make things, and use resources that take on the same principles as nature does?*

A third way that interviewees described biomimicry is by its wide applicability. Many interviewees suggested that the approach could be applied to a wide variety of subjects. As one interviewee put it: *'Biomimicry is an approach and not a field of expertise in itself, and therefore it can be applied in any sector'*. Participants revealed that biomimicry could be applied to a wide variety of subjects, ranging from engineering, architecture and planning, to product design and organizational structures of companies. This simultaneously caused interviewees to describe biomimicry as non-scalar. For example, one interviewee said: '*You can start working at any scale, it is totally un-scalar'*. So, biomimicry is a way of thinking and working that can be applied to any desired field.

4.1.1 The approach

A second issue was the definition of a biomimicry approach. Participants explained the biomimicry approach in terms of the life principles (see section 2.2.1), multidisciplinary working, ethos and specific design steps.

Life principles

Participants unanimously referred to the life principles as the core principles of a biomimicry

approach: *'The life principles are central and everyone should know them'.* One interviewee clearly echoed how the majority of interviewees defined the life principles: *'Life principles are the attributes and traits that all species that have developed over time, have in common'*. The principles apply to every living thing on the planet: to plants, water, organisms, and also to humans. As one interviewee commented: *'Life principles can be used to design anything: you can use it to design a city, a country, a campus, a building, or furniture!'* The principles are used to formulate a design brief and to evaluate the performance of a design. One interviewee reported: '*Life principles can be used as aspiration-set to determine your ambition level, and also as evaluation to determine the sustainability of your design'*. The principles provide a holistic perspective to problems or solutions, as they take into account all elements that enable and sustain life.

Multidisciplinary working

A majority of interviewees suggested multidisciplinary working as an important aspect of a biomimicry approach. As formulated by one interviewee: *'What biomimicry really is, it's a team endeavor'.* Participants mentioned how important it is to have ecologists and biologists at the design table. Especially biologists have a vital contribution for using a biomimicry approach, as they are able to help translate the natural world into design principles. One interviewee explained how their design team depends on the expertise of biologists to realize designs: *'You cannot do everything, you need specialists such as a biologist'.* The interviewees on the whole argued that biomimicry differs from contemporary multidisciplinary team endeavors, as it fosters real collaboration between disciplines. For example, one interviewee said: *'Using a biomimetic approach you create a purpose for the engineer to understand the environmental impact rather than environmental people constantly telling you what you can't do'.* Another interviewee commented that biomimicry engages different disciplines: *'If you are a planner you learn to think more as a biologist, and if you are a biologist you learn how to think more like a planner'.* In this way, interviewees expressed that biomimicry encourages cross-disciplinary thinking.

Ethos

All interviewees revealed that there is a lot more to the biomimicry approach then the mimicking of nature's functions and processes, that is ethos. Ethos is driven by a certain mind-set that, according to interviewees, distinguishes itself from contemporary beliefs about the relationship between man and nature. One interviewee explained how, in design circles, people talk about sustainability a lot. However, they often describe nature as an amenity: *'Nature holds our fascination, it has cognitive benefits, we like natural patterns, certain sounds, the smell of fresh rain; we talk about what is does for ME'.* Commenting on this ethos, many interviewees stated that it requires a mind-shift to see humans as nature. One interviewee clarified: *'The thing that life teaches us that we don't yet understand, is that we act separate but actually we are part of the system'.* Another interviewee said: *'It is more than a tool in the designers toolbox, I've come to understand that it's a lens, a worldview'*. Several interviewees argued that ethos does not only apply to nature but also to human beings. As commented by one interviewee: *'If your city is upstream from another city it is your ethical responsibility to clean the water you use before sending it downstream'.* This reveals that individual

> *Unless you don't change the man's mind, you don't change anything*

intentions and the goal you want to achieve when using biomimicry must be ethically just. Many interviewees reported that biomimicry is distinct from contemporary sustainable approaches in planning because of this ethos, which teaches planners to understand humans as nature. The comment below illustrates this:

> '*The idea is ironic that people get very upset about nature and people not caring for it, whereas that actual framework is very human-dominant centric versus saying that you are respectful of nature's power and its brilliance. The only way for humans to be sustainable is for human survival, because nature is fine!'*

Three interviewees gave a critical remark to the biomimicry ethos. They argued that, when using biomimicry, you censor which solutions to use or not to use from nature to solve your problems. Talking about this issue, an interviewee said: *'There are also mechanisms in nature that are meant to kill your prey or direct enemy'.* These participants however agree that some ethical decisions have to be made along the way to decide what to incorporate in a design and what not, in order to achieve sustainability in the long term.

4.1.2 Design steps

Interviewees revealed a concern towards the existing confusion on the biomimicry approach. Several interviewees felt that the design steps are too generic and specific tools need to be developed to apply the design steps, while a minority of interviewees argued that the contemporary design steps are sufficient but require a practitioner to take the time and resources to thoroughly understand them. Although opinions differed as to whether the design steps are clear or not, most interviewees explained the biomimicry approach by three specific design steps: tune to place, fit to place and give back to place (figure 7).

The interviewees reported that the first step, tune to place, is about figuring out the ecological dynamics of a place. For this step it is necessary to hire ecologists who are able to reveal the key conditions to resilience in that place. The story of a place is the first thing that should be studied, which not only involves getting to know the biological local reality but also learning about the way people relate to a place in terms of meeting their needs. One interviewee reported: *'You can never state general guidelines because you make changes in a specific content and context, so you first have to know the area'*.

Participants explained that the second step is fit to place, which has the goal to discover geniuses of a specific place. Going out in the field to discover these genii is very important and is called *genius of place*. All interviewees stressed the importance of genius of place:

> *'It is very important to learn from the place you live in, you want to look into it deeply enough to see what rises to the top that could have a meaningful impact on development*. *Genius of place can give people an idea of what biomimicry is and it teaches them how to learn from nature and listen to* nature.'

Many interviewees stated that fit to place is the hardest step of the approach, as it involves a thorough investigation of the local context and all processes and functions that make up a place. Half of those interviewed reported that going out in the field to examine the genius of place is feasible,

whereas the other half reported that genius of place is very important but is not feasible for every design team. Because there is complexity of finding genii of a place and there are associated extra time and financial supports to examine these genii. All interviewees agreed that, once the genius of a place is discovered, it is important to look at the way these deep patterns can be mimicked and translated into design principles. Having a biologist present to make the translation from biology to design principles is necessary. In most interviews, interviewees reported that mimicking should be applied to three different levels: form, process and ecosystem. Biomimicry aims to mimic natural structure and function with the goal to reduce human impact on earth. One interviewee explained how you could mimic a whale's flipper to make a wind turbine, but if you do not pay attention to the process of manufacturing, selling and disposing, you do not bring biomimetic design to the entire process. Interestingly, one interviewee commented that *'the form of for example a buildings may not look anything like a tree but it could function like a tree'*.

Participants reported that the third step is to give back to place. Based on the design principles that were created in step two of the approach, step three sets a goal of how the design must perform. This last step involves asking questions whereby the question is rephrased to how nature would do it. One interviewee exemplified: *'If it was a mature ecosystem how would it function, how much phosphates and how much nitrogen would it cycle, and how does nature deal with waste and stores water?'* Participants unanimously agreed that these are questions we have not yet asked but are vital in sustaining natural and human systems. A majority of interviewees revealed that the performance of a design is determined by using Ecological Performance Standards (EPS). EPS allow you to set a normative framework in which to design: one that makes sure your design meets the same performance standards and functions as the local ecosystem. One interviewee clarified: *'EPS show to what extent your design exceeds the carrying capacity of an area'*. In order to make EPS measurable, metrics need to be created. As one interviewee argued: *'The idea is to make the concept measurable, otherwise it is just a concept, right?'* Several interviewees commented that EPS are challenging. For example, one interviewee said: *'When we do EPS people often say that we are never going to meet those standards as they are very high'.*

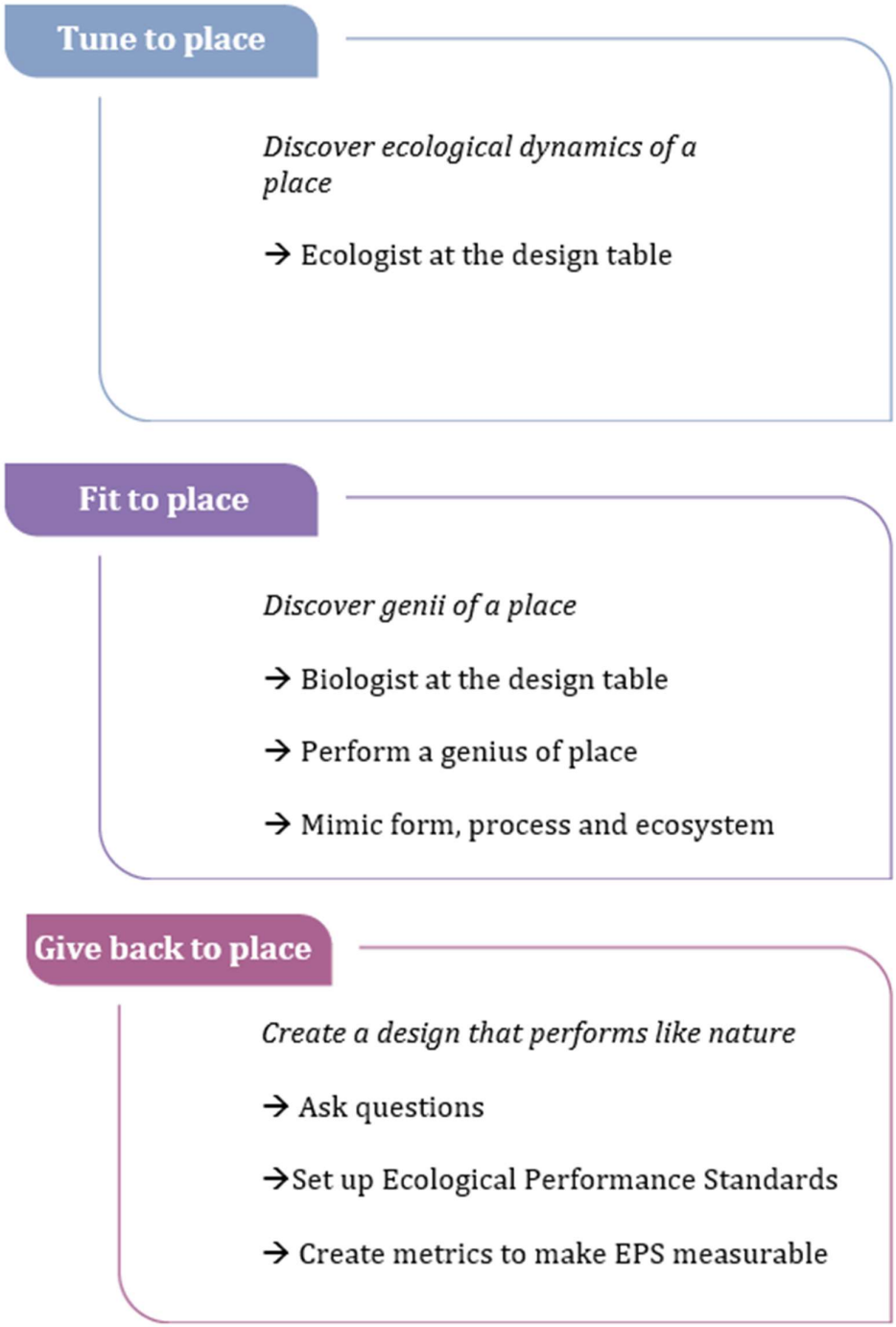

Figure 7. The three steps of practicing biomimicry: tune to place, fit to place and give back to place

4.2 What is the added value of biomimicry for urban planning?

Turning now to the added value of biomimicry for urban planning, a number of aspects were found. A common view amongst interviewees was that biomimicry broadens people's thinking. One interviewee commented: '*The added value of biomimicry is that it allows people to extract themselves from their normal day-to-day roles and normal day-to-day professional languages to think in a completely different and fresh way'.* And another commented: '*Looking into nature and natural processes certainly gives you clues that are not typically found when you just look for metrics and technical solutions'*. The interviewees explained how biomimicry introduces nature's design thinking and principles, which broadens people's thinking. One interviewee added: '*It opens people's eyes to a variety of things that otherwise would have never been considered and therewith unlocks creativity'*. One interviewee described the way he experiences the value of biomimicry:

> *'One of the great lessons I learned from Janine* [Janine Benyus, founder of biomimicry] *had to do with being a landscape architect and learning in your training that you are the ultimate designer with all the answers. But in fact what Janine thought me was to quiet my cleverness and listen to nature and natural systems. That really changed the way I approached projects and the way we practice.'*

Second, a majority of interviewees stated that biomimicry helps planners to deal with the complexity of city planning by making spatial and temporal scale interactions when planning and designing. Several interviewees clarified that the city is a lively phenomenon and city planning is a subject that relates to many different concepts. It follows that planners do not have all the answers to the questions that city design raises. One interviewee clarified: *'An aspect as economy is very hard to control in city design, whereas happiness and certain indices are subjective and so wide in understanding'*. Comparing this to product design, another interviewee commented: *'Planning and design is not as simple as product design, that once you understand the functionality you need one clue that becomes a solid way of designing your products'.* A common view amongst interviewees was that contemporary city planning has the tendency to grasp this complexity as a linear cause-effect relationship, creating a squared, grey, and blocked city structure that has adverse affects on the environment. Participants pointed to biomimicry as an approach that is better able to grasp this complexity by making spatial and temporal scale interactions.

Several interviewees commented that planners must be switching between scales all the time, thinking about the way a design effects the larger and smaller scales it is embedded in. One interviewee said: *'You can start from a cell structure, from a cell you start developing the organism, the community, and the community connected to other communities'.* Another interviewee explained how biomimicry approaches the city as a system that consists of multiple smaller and larger scales: *'The scale of the city is made up of many small projects or phases'.* Three interviewees made clear how, building up the city from smaller elements, makes change on a larger scale better manageable. A number of interviewees also argued that, as biomimicry approaches the city as a system, it shifts the time frame of planning: '[…] *ecological processes take longer and that forces us to think beyond a 3, 4 or 5 year framework that most planning process are stuck in, to planning for 10-15 years'.*

Third, a common view amongst interviewees was that biomimicry enables to design an adaptive and resilient city. Participants pointed to nature: *'Nature doesn't have a plan and doesn't work with a to-do list'.* Rather, interviewees mentioned that nature is a system in which all living and

non-living things are interdependent and respond to each other by adapting. Several interviewees noted how all elements in this system work together and are subject to variability and chaos. One interviewee argued: *'By understanding that a city grows and evolves over time, planners can help in designing modular and flexible infrastructures which will adapt to new conditions instead of having fixed infrastructures'.*

Fourth, a majority of interviewees explained that biomimicry is able to internalize expert knowledge that is normally outsourced in the planning process. Participants pointed to the multidisciplinary character of the biomimicry approach. One interviewee reported that biomimicry is able to bring together a variety of people from different worlds, which is seen as a huge strength and opportunity: *'[…] it brings together very technical people but also very holistic people, these two worlds are very rare to bring together and that is what biomimicry does'.* Many comments of interviewees referred to comparing biomimicry with contemporary ways of planning. It was stated that contemporary planning processes are made up of someone who does a social analysis, someone who does an environmental analysis, etcetera. Oftentimes, different stakeholders are involved that are brought in and left out at different stages of the planning process. Participants mentioned biomimicry as a way to internalize knowledge and expertise from different professions from beginning till the end of the planning process, as setting an aspirational goal to make your design function and perform like nature really fosters collaboration between disciplines. Another interviewee was convinced that using biomimicry will redesign the planning process: *'Redesign the way people work together, redesign the way people think, and redesign rules and regulations'.* And as added by one interviewee, it even allows other people to be engaged: '*It brings the opportunity for the arts, the creative, and other people that would normally not play a role in the urban planning space. We want these places to be beautiful and not only effective, right*?'

When asked about what expert knowledge needs to be internalized in the planning process, interviewees all stressed the importance of having a sustainability and biomimicry expert present throughout the planning process. One interviewee commented: *'It's their job to […] understand the latest technologies and approaches to sustainability, which includes biomimicry as a concept'.* Those experts help translate biological knowledge to planners, which is crucial for creating common language and common goals. Two interviewees also referred to the website Ask Nature[5], which is very useful for non-biology experts to understand nature properly and ask the right questions to tackle design challenges.

Three interviewees also argued that it is important to have people involved in the planning process that understand the financial side of development. One interviewee explained how developers often disqualify sustainable designs by disregarding it as too expensive: *'To have someone within the planning process that understands finances and development appraisals'* will bypass the issue of making trade-offs against sustainability. One interviewee critically commented that this requires a planning department to be better resourced: '*You need more planners, who are better informed on sustainability and biomimicry, and they need more time to be better involved in the whole design process'.*

Fifth, many interviewees suggested that biomimicry could serve as conflict-resolution process in urban planning. Over half of those interviewed reported that biomimicry could be used when a design team is stuck with ways of defining problems. As highlighted by one interviewee: *'It facilitates processes between people to do collective decision making, which enables people to move*

[5] www.asknature.org

along with their development'. Another interviewee commented how biomimicry offers a potential framework that anyone can relate to:

> *'It does not matter what professional background you have because everyone has seen caterpillars crawling in trees or seen birds nesting while they were children. So it is a way to harmonize all different practices and professions that make up the planning and design process.'*

Two interviewees gave an example of the project in Durban, South Africa, where they had a direct role. The large planning project of 9.000 ha had gone into deadlock, as the landowner and the municipal department of Climate Change and Environment got into conflict. Biomimicry was brought in to unlock development. Innovation and planning were proposed as a conflict-resolution process. The deadlock was resolved in six months by writing new policy of how to do trade-offs between policy, infrastructure and development. As said by the interviewee: *'It was pretty ambitious, we got into a place where they were no longer in conflict and were able to set up a partnership and developed policy for them to move forward with'.* Another interviewee explained how her design team uses biomimicry as conflict-resolution process:

> *'When we do team meetings with for example engineers at the table, they come in with a set idea of what we are going to talk about. Then we ask them to tell us their first memory of being in nature. Everything dissolves. Going into a memory child-like connection of watching the ants or being muddy, makes the engineer side disappear and it becomes about a heart connection to nature: an intimate connection.'*

When the interviewees were asked to clarify the ability of biomimicry to serve as conflict-resolution process, they mentioned biomimicry is able to create a feeling of alignment among people, building a foundation for thinking and working successful in a multidisciplinary way. It reduces the risk of conflict and thereby fosters to come to solutions that serve multiple goals and functions.

Lastly, almost two third of interviewees saw potential in the regulatory framework within which planning operates. One interviewee noted: *'I believe we can rewrite our building codes and our urban policies to align with ecological systems, and recreate a more fair and healthy world'.* Participants saw opportunities from both top-down as well as bottom-up stakeholders. There were some suggestions that local authorities can rewrite policy as top-down stakeholder. For example, one interviewee explained how a local authority could set up a guidance document that reviews biomimicry projects. This might spark interest for the use of biomimicry in urban planning. As policy trickles down and sets targets and restrictions to what we plan and design, policy helps to shift expectations in a more sustainable direction. One interviewee added: *'Policy sends a very powerful message and can encourage people to start thinking in a different way'.*

There was also a sense of agreement amongst several interviewees that bottom-up efforts are able to rewrite policy that favors sustainable approaches to planning. For example, one interviewee exemplified that a university can also go to the city with a proposal to make an exception on existing rules and policies that obstruct their work. If bypassing certain policies proves to benefit the community at large, chances are that the city is willing to make exceptions more often in the future. After the outcomes and effects of bypassing existing policies is considered effective and

safe, it might result in policy rewriting that fosters sustainable approaches such as biomimicry. According to the interviewee, *'the community, city and policy makers need to be on board with trying something different'.* Another interviewee argued how policies could be influenced from the bottom up through projects. It regularly happens that planning projects run into rules and regulations that obstruct the development of a project. These projects have the strength to go against the grain of what these policies prescribe. One interviewee pointed to the circular economy concept that has shown its benefits to society and is now more and more embedded in local and regional policy.

Table 3. The added value of biomimicry for urban planning

Added value
1. By turning to nature, biomimicry expands the set of answers and solutions to design challenges, as it unlocks creativity and extracts people from their normal day-to-day roles and professional languages.
2. Biomimicry helps in dealing with the complexity of city planning by making spatial and temporal scale interactions.
3. Biomimicry gives the ability to design adaptive and resilient cities by taking a systems perspective that acknowledges that a city grows and evolves over time.
4. Biomimicry offers a multidisciplinary approach that internalizes knowledge that is normally outsourced in the planning process.
5. Biomimicry offers a conflict resolution process by creating a feeling of alignment among different stakeholders.
6. Biomimicry brings the opportunity for top-down as well as bottom-up efforts to rewrite building codes and urban policies that better align with natural systems.

4.3 What aspects of urban planning form a barrier to using biomimicry?

Although this study focused on the potential of biomimicry for urban planning, almost all interviewees expressed a variety of barriers to using biomimicry in planning. When the interviewees were asked to clarify and define these barriers, the majority commented that the financial dependence of biomimicry is the largest barrier. More barriers were found in the structure of the planning process, the regulatory framework and the market.

4.3.1 Financial dependence

A recurring theme in the interviews was a sense amongst interviewees that biomimicry is limited because of its financial dependence, from individuals who sustain the different biomimicry organizations around the world and also from sponsors or clients who are willing to fund biomimicry projects. Almost all biomimicry experts and practitioners expressed they are member of a biomimicry organization. To name but a few, there is BiomimicryTX (Texas), BiomimicryNL (Netherlands) and BiomimicrySW (Switzerland). These organizations depend on their members, who work half time for the biomimicry organization and half time for their own companies or jobs. There is no market (yet) for using bio-inspired approaches such as biomimicry, which requires a lot of individual effort to receive funding. One interviewee explained that members of their organization give up 5% of their own companies' non-commercial profit to sustain the organization.

When asked about the financial dependence of biomimicry projects, most interviewees argued that clients have a certain budget allocated for a project that is not big enough to take biomimicry to the next level and clients are not willing to pay for bringing biologists in design teams. One interviewee argued: *'From my own experience in city projects, it depends on funding, clients, and sponsors'.* While other interviewees expressed more concern towards the fact that urban planning often works within competition projects. This not only brings financial restrictions to a project but also puts a limited time frame on a design. One interviewee gave an example of Interface, a carpet company that designed an innovative carpet tile using a biomimicry approach. Once funded, the company was able to start doing research on the way that leaves form a 'natural carpet' on the forest floor. The first phase of the project was finished in which they identified metrics and strategies to move the factory towards functioning more like a forest. The interviewee said: *'Then they've done a little bit of work on actually implementing it'.* However, it turned out to be a start-stop-process, as the profit margins of Interface in the market determined if they received funding or not. Participants explained this by arguing that stakeholders see a financial implication in risk; as the outcomes of biomimicry are not known, clients and developers find it hard to take the risk to invest in these projects. For example, one interviewee said: *'Companies are used to doing things their way, which is very efficient in their eyes; they are not likely to change, as they see financial implications of change and taking risks'.*

4.3.2 The planning process

Another reported barrier for using biomimicry in planning was the structure of the planning process. There was a sense of agreement amongst interviewees that the contemporary planning process needs to be organized in a different way. One interviewee explained that, before going into public meetings or design shreds, planners and anyone involved in the design process should do extensive up front research on the biological and ecological context of a place to avoid that biomimicry becomes an add-on rather than a strategy. Another interviewee commented that the contemporary

planning process is organized based on old notion of who makes the city: *'Challenge their minds: who makes the city, is it an urban planner or what?'* Two interviewees believed that other parties outside official governmental bodies could have a great involvement in urban planning. As stated by one of them: *'Keep challenging those notions of the way things are done!'* This will foster planning processes to integrate other ways of working, with different stakeholders.

Second, concerns were expressed regarding the regulated character of the planning process. One interviewee commented: *'The challenge at the moment is the very regulated and regimented system of planning that doesn't accommodate innovation easily'*. Another interviewee explained: *'Urban planning is made up of the word planning'.* There was general consensus amongst interviewees that planning relies on control mechanisms of regulation, which results in a static and restricted planning process that does not allow things to unfold spontaneously and iteratively. For example, one interviewee explained how planners use certain policies, tools and methods that in turn lead to scientific answers. Participants unanimously agreed that planning drives on established and proven facts, which is a very different mind-set than biomimicry follows. In contrast, several interviewees argued that the organized character of planning favors biomimicry, which in their eyes needs more structure and could benefit from more regulation to make its design steps more concrete.

As commented by several interviewees, another reported barrier is that it is difficult to introduce biomimicry in planning. When talking about introducing a new approach in planning such as biomimicry, the outcomes are uncertain. With any new approach there exists the risk of failure and failure is expensive. One interviewee put that, as biomimicry is not as measurable and quantifiable as people would like to, it is not easy to introduce the approach in planning. The interviewee explained how contemporary city planning measures everything against quantitative units: *'Every design challenge is formulated into a mathematical problem, so is climate change now identified as CO_2, a unit that we can measure'*. Therefore, two interviewees argued that biomimicry should look at very proven methods for understanding ecology and biology, in a way that planners can use scientific understanding of biomimicry in planning. Most interviewees agreed that biomimicry should be introduced by relying on the existing planning framework. One interviewee said: *'We have to leverage what's already there, because change doesn't happen without a framework'.* Participants stated that it would be more beneficial for the adoption of biomimicry to connect it to other concepts and approaches that are already used in the planning field. Biophilia is often mentioned by interviewees as a concept that biomimicry can easily relate to.

Lastly, the concern was expressed that planners often get stuck in the concept of ecosystem services when thinking of biomimicry. The reference below illustrates this:

> *'That is a wonderful place to start but it's still only the beginning of the conversation. The problem is that we out-engineer our city problems and use technology to concur every possible constraint. We are not using those constraints to our benefit'.*

Participants agreed that those constraints should be used to benefit our designs. For example, one interviewee exemplified that glasshouses should not be built in the desert. Instead, planners need content and context specific designs. Participants mentioned this would not be without a hurdle. Biomimicry requires a long-term commitment from all stakeholders to really make it work: *'This is time consuming as it takes practice to integrate biomimicry thinking […]*'.

4.3.3 The regulatory framework

Many interviewees expressed that policy is an obstacle for using biomimicry in planning. One interviewee saw a problem in the relationship between policy and planning: *'Policies tend to drive planning'.* Participants argued that policy tends be very regulated and therewith promotes an organized way of city planning. Policies set boundaries and regulations that result in neatly organized structures in the city. For example, one interviewee pointed to the large units and building blocks that are designed in the city that do not seem to account for social, societal and educational aspects of city design:

> '*We have very neatly organized policy for all these aspects; there is social policy, economic policy, social welfare, and special mobility departments within the city. However, policy should support much more fluid and variable design principles. The whole interplay of these different aspects that come together in city design should be taken together, then we arrive at a very scary word: a holistic interpretation.'*

Two interviewees stated that policy can change in a more sustainable direction over a longer period of time, however this is mostly when society runs into severe problems such as resource depletion. In the wake of such problems, policy might be changed to allow for an ecological design process in the future. One interviewee gave an example of hurricane Sandy, which changed local policy to focus on resilience: *'That really impacted urban planning and design here in New York City'.* Another interviewee added that contemporary policies do not fully consider the value and benefits of nature: *'People aren't fully aware of the benefits so they don't regulate the benefits and don't demand the benefits'.* A small number of interviewees argued that contemporary policies do not fully account for limitations of natural systems and processes. As one interviewee said: *'By using these old codes we resist change'.* However, several interviewees realized this is easier said than done, as it takes a huge rewrite to make transformative changes in policy in order to set up rules and regulations that account for natural systems and their limits.

4.3.4 The market

A reported barrier for using biomimicry in planning was the influence of market forces on what we plan and design. Participants put forward that the economic model forms a big barrier. One interviewee said: *'Economy is almost some sort of religion that hangs on to the belief that economy must always grow'.* Another interviewee commented that, for example in the business world, many environmental and ecological services of nature are not valued as should be: '*A developer doesn't have to pay attention to some of the attributes like storing carbon'.* Another interviewee supported this by saying that there is a lot of value creation in for example the biomimetic approach that is not taken into account: '*[…] it is safer, healthier, non-toxic, and more efficient'.* Participants were not surprised that decisions are made against sustainability because people see profit in making less sustainable decisions. There existed general consensus amongst interviewees that, as long as the economic system does not include the value of nature and natural systems, it will be hard for a concept like biomimicry to be used properly in planning.

Another reported barrier was found in the housing market. For example, one interviewee stated that a local authority may include drastic sustainability elements in the design of urban areas,

but all a developer has to do is declare the design financially impossible. Another interviewee exemplified how the UK housing market started an initiative called Code for Sustainable Homes, which had the goal of moving to zero carbon houses by 2016. The initiative started in 2006 but the house building industry lobbied successfully to keep the initiative at bay until the government completely dropped the zero-carbon standard. The government was pressured under the motto: *'If you want to deliver the houses you need, then make it easier for us to build them, which means not damaging our profits and make it less sustainable'.*

However, interviewees also turned their criticism towards governmental bodies. As revealed by one interviewee, governments like techno-fixes: *'It is a lot easier to try and fund a technology than it is to try and fund cultural change'.* That is why a concept like the smart city is so popular and catches the market so easily. Two interviewees see the smart city as a distraction; according to them it is not a concept that leads to true sustainability. For example, Amsterdam Smart City was mentioned as a gimmick: a combination of good marketing and great profits that does not lead to true sustainable living. Participants on the whole demonstrated that a fundamental change still does not take place.

Lastly, a suggested barrier of the market was green washing: *'Instead of white-washing, they green wash, saying you are sustainable if you have one electric car for the entire city'.* One interviewee explained how sustainability has become a market asset with which different stakeholders create economic interest. In this way, sustainability is misused and misinterpreted. Another interviewee added that planners could use a checklist where they can tick the 'sustainable' boxes to get their profit. Participants realize that biomimicry could easily be green washed in the same way.

Table 4. Aspects of urban planning that form a barrier to using biomimicry

Barriers
1. Biomimicry projects and organizations are highly financially dependent.
2. The structure of the planning process forms a barrier to adopt biomimicry in planning: its regulated character, biomimicry is difficult to introduce in planning and planners often get stuck in the concept of ecosystem services.
3. The national policy framework has a presumption in favor of development and contractual policies put time and financial restrictions to development, making it hard to use biomimicry as it is a relatively time consuming approach.

4. The economic model is based on growth and development and often does not account for natural values that an approach such as biomimicry brings.

4.4 What is needed to secure a role for biomimicry in the future of planning our cities?

It becomes clear from the results that interviewees were critical towards the biomimicry concept and its application. Most interviewees expressed their criticism in a positive way, and referred to the changes that could be made for improvement of the concept.

4.4.1 Critical opinions

Some interviewees commented that many people do not follow the biomimicry approach correctly. People get really enthusiastic when they hear about biomimicry: *'We all feel the potential, it all feels so grand'.* However, three interviewees stressed that the approach is often superficially interpreted and used, as people do not take the time to look deeply into the design steps: '*There is a genius of place process but people don't know how to do it, […] we talk about it and give away our stuff freely in describing how to do it!'*

In contrast, a majority of interviewees expressed there is a lack of knowledge available to thoroughly understand the approach. For example, one interviewee argued: *'[…] the lack of information and the few people that practice biomimicry is a challenge'.* In several interviews, criticism was reported towards the lack of tools available for planners to use biomimicry. For example, one interviewee said: *'It requires more research and development to generate a specific methodology of biomimicry, that is adapted to urban planning'.* The majority of interviewees agreed that more development of the biomimicry approach is needed to use it in planning. Three interviewees pointed to environmental impact assessment and cost benefit analysis as useful tools that can be applied alongside a biomimicry approach.

Almost all interviewees were critical towards genius of place. Two interviewees very clearly mentioned that genius of place must not become a distraction.

> *'I now call it entertainment…we ask how nature does it but in the end we often still ask the same questions. Genius of place is wonderful but must remain focused on the deeper functions and processes conducive to life.'*

The interviewee went on by saying that biomimicry is otherwise used to design a better widget: *'How do we do bad things a little less bad?'* Another interviewee made a critical remark towards the scale at which genius of place can be applied: *'At a little project scale it's not feasible because you are not likely to get a project developer to fund that, but if you do it at a big biome level it might'*. There was general consensus amongst interviewees that genius of place is very hard to do. One interviewee said: *'They are hard to do because they are never-ending; trying to find the things that are graspable*

for others, that will give them the translation ability in design is what you ultimately want'. Many interviewees associated genius of place with a longer design process, as designers need enough information to translate knowledge of the natural world into a feasible design. One interviewee even stated that he would rather turn to landscape architects than do a genius of place, as *'genius of place is not always helpful and not always needed'*. He mentioned that landscape architects already have a lot of the knowledge and information that genius of place strives to gather. One interviewee even argued that biomimicry is not always useful: *'People sometimes create things that were replicated a hundred times before, but they came with the idea by looking at nature and they think it's better'.*

A small number of interviewees saw danger in the fact that biomimicry is easily labeled as an approach for tree huggers. For example, a concept like ecosystem services, which is already used in planning, puts human needs more central and is easier to bring into the conversation than biomimicry. One interviewee explained: *'It is easier to say that nature needs saving so it can provide us with oxygen, than saying that nature on its own needs to be benefited'*. Another interviewee said that placing nature central as biomimicry does might trigger negative reinforcement towards biomimicry, which is also bad from a business perspective. For those reasons, several interviewees saw the use of the word biomimicry as territorializing: *'Biomimicry is not the word we want to use in urban planning, it's an alienating word'.* Another interviewee argued that it is very important to use explanatory language and not loaded terminology: 'W*e really need to break it down into what it is'.* Another interviewee added that biomimicry may come across as cultish: *'If you aren't within this particular branch or you haven't subscribed to this very rigid kind of thinking and language, then you don't qualify'.* Another interviewee went even further by saying that the Biomimicry 3.8 organization comes across as evangelical, almost preaching:

> *'I do not really prescribe or work the way that Biomimicry 3.8 says it because it can become a bit evangelical, preaching almost. People think you are an eco-warrior but actually you try to solve complex engineering solutions, that 99.9% of the time turn out to be biomimicry or biomimetic'.*

Lastly, interviewees commented on the unexplored potential of biomimicry. Biomimicry strongly focuses on what nature would do, whereas in contrast, two interviewees argued that the relationship between man *and* nature should be more central in the concept. This relates to the reported interest of many other interviewees to also investigate the social side of biomimicry. Three interviewees mentioned they have already taken action in this direction, seeking collaboration with social experts. Although interviewees were critical towards the human-centered focus of biophilia, many interviewees pointed to biophilia as an example of a concept that focuses more on the social side. One interviewee said: *'Biophilia is more about human health and wellbeing'.*

4.4.2 The future of biomimicry

In order to use biomimicry in urban planning, interviewees commented that biological intelligence needs to be incorporated in the tools that planners use. Four interviewees argued for a scenario-planning tool that is able to model biological and ecological information from a site. One interviewee commented that this tool must not only give information, but must enable planners to draw different scenarios by adding elements or leaving elements out: *'Put permeable pavement on a road and then immediately see what the effects of that are on water storage'.* One interviewee clarified: *'You can*

show a group of people what design is the most sustainable in terms of clean water, clean air, wildlife, and less toxic-chemicals'. Another interviewee supported this by saying that contemporary urban plans are very hard to replicate and simulate. Modeling allows planners to analyze complex systems. Testing can be done through modeling. One interviewee stated that the contemporary challenge is that modeling is already done, but not all the models are known and these need to be site specific by including local biological and ecological information.

All interviewees revealed they do not see biomimicry as the only solution for the future. One interviewee argued: *'A non-biomimetic but sensible urban design can be equally beneficial than solely applying biomimicry'.* There are a lot of similar fields that celebrate biomimicry, but do not claim to practice biomimicry: *'They are yielding very similar outcomes'.* So, interviewees agreed that biomimicry is just another way of influencing design solutions. Participants mentioned that biomimicry was never used in projects on its own, no matter on what design scale it was used. For example, one interviewee commented: *'I did not fully back on biomimicry as the one singular concept because we learned from earlier biomimicry city projects that one concept is not able to justify all the answers that we needed for city design'*. Rather, the majority of interviewees stated that the life principles could be used to set up a feasible framework.

Overall, these results indicated that interviewees see a hopeful future for biomimicry. They believe biomimicry will impact the way we plan and design our world and the way we think about ourselves. The challenge is to open people's minds to the practice: *'Once they understand how nature filters water there is nobody who is going to argue with that'*. One interviewee made an interesting remark. He hoped that, in the future, we do not talk about biomimicry anymore: *'I hope it becomes second nature to integrate natural systems and adapt a systems' approach into cities'.* However, futures are unpredictable and so is the future of biomimicry. By revealing criticism on the biomimicry approach and suggesting changes for future improvement, interviewees stressed the importance of further research and development on the concept.

Chapter 5 Discussion

The purpose of this study was to investigate the potential of biomimicry for urban planning. This study found that biomimicry could be of contribution as a planning approach. The claimed added value of biomimicry is that it expands the set of answers and solutions to design challenges, it is able to realize resilient and adaptive urban plans, it helps planners to deal with the complexity of city planning, it can serve as a conflict-resolution process and it fosters an integrative planning process. However, genius of place is perceived as a challenge, the design steps of the approach are claimed to be too generic, biomimicry organizations and projects are financially dependent and more obstacles are found in the planning process, the regulatory framework and the market. This chapter answers the sub research questions by discussing the results and linking them to the scientific objective of the research, the chosen theoretical framework and to findings of other research projects. In addition, this chapter discusses the chosen research methods.

5.1 Defining the concept and the approach

Prior studies have shown that biomimicry demarcates itself from other concepts by a strong focus on function (e.g. Dicks 2016, Baumeister 2014 and De Pauw et al. 2014). Many articles (e.g. Van Vuuren 2014, Kennedy et al. 2015 and Fisch 2017) also state how *mimicking* function is at the core of biomimicry. The contemporary study supports this and found that biomimicry is described in terms of function, mimicking and wide applicability. The aim of biomimicry is to understand how nature functions and applying those functions to human designs to become more sustainable. Mimicking form, process and ecosystem, biomimicry emulates nature's intelligence. This study has found a third way in which biomimicry is described: wide applicability. The approach is a way of thinking and working that can be applied to a variety of subjects and to many scales, from Nano-scale to urban scale. The literature confirms this, for example, Myung et al. (2018) reveal how biomimicry can be used in Nano-technologies and Amer (2019) shows the possibilities of biomimicry for architecture. This research is more general in outline and found that biomimicry is indeed applicable to many fields of study and at different scales.

As mentioned in in the literature review (section 2.2.2), there exists confusion on how to practice biomimicry. There are design steps with accompanying tools, but these tools remain very generic. The designer can only use interpretive design steps (Goel et al 2014, 4) and as a consequence, the application of biomimicry shows a wide diversity in practice (Appio et al. 2017, Sharma and Sarkar 2019 and Wanieck et al. 2017). This research supports the finding that biomimicry is practiced in varying ways. This study specifies that the approach be best grounded in three different steps: tune to place, fit to place, and give back to place. The only source to describe the approach by these three steps is the Biomimicry Resource Handbook (Baumeister et al. 2014). In contrast, prior studies refer to the design spiral steps for practicing biomimicry (e.g. McGregor 2013, Fayemi et al. 2015 and Buck 2017). Although the design steps are an expanded version of tune to place, fit to place, and give back to place, the discrepancy between the results of this research and existing literature is explained by De Pauw et al. (2014, 2). They clarify that there is a lack of knowledge on how biomimicry differs from or adds to existing validated and well-established approaches (De Pauw et al. 2014, 2). This may indicate a lack of precision and guidance in the biomimicry approach, resulting in attempts of practitioners to clarify how their discipline could justly apply biomimicry.

This study has found that the life principles, multidisciplinary working and *ethos* are core aspects of the approach. These results are consistent with many other studies (e.g. Patel and Metha 2011, Gamage and Hyde 2012 and Chayaamor-Heil and Hannachi-Belkadi 2017). An unexpected outcome of this study is that the life principles are often considered more important than the design steps of the biomimicry approach. It was found that the life principles are easier to apply than the generic design steps are to plans and designs, as they provide stricter guidelines that can be turned into metrics.

5.2 Biomimicry's added value for urban planning

The research shows there are several ways in which biomimicry has added value for urban planning. First, biomimicry expands the set of answers and solutions to design challenges in urban planning. This result reflects that of Buck (2017) who also found that biomimicry has the potential to open up horizons for thought and action, as looking into nature expands the dialogue and exploration of urban challenges in the planning profession.

A recent study of Zari concludes that a biomimetic approach to the built environment could enable adaptive and resilient urban designs (Zari 2018, 73). The results of this research indicate that biomimicry is indeed able to realize resilient and adaptive urban plans and designs; unfortunately this study was not able to show in detail how biomimicry realizes resilient and adaptive plans. It was found that biomimicry teaches planners to view the city as a system whereby inspiration is taken from natural systems to look at interactions, dependencies and processes within systems. This systems perspective allows planners to accept the city as complex, unpredictable and changeable system, instead of viewing the city as static and predictable, which can reveal some interesting clues to resiliency.

Biomimicry helps planners to deal with the complexity of city planning by make spatial and temporal scale interactions when planning and designing. As biomimicry takes a systems perspective, it looks at the city as a system made up of smaller systems. This promotes planning to look at the different scales and levels of the city and constantly reflecting how a design impacts the larger and smaller scales it is embedded in. As natural processes (such as ecological or geomorphological processes) are taken as an example, the time frame with which planners plan and design expands. Zari (2007) does mention how biomimicry can be applied to a range of temporal and spatial scales. Also the study of Chen et al. (2014) found that mimicking coral reef could serve as inspiration at the material scale, component scale, systems scale and regional scale. My findings show that the systems perspective of biomimicry encourages looking at spatial and temporal scale interactions. This helps planners to deal with the complexity of cities. This is consistent with an earlier observation of Wahl (2006, 293), who states that biomimicry offers a new worldview that acknowledges the complex interactions and relationships between systems, in contrast to city planning from a prediction and control mind-set which ignores the complex interplay of diverse social, cultural, economic and ecological factors. These findings provide support for the argument of De Roo and Hillier (2016), who advocate embracing complexity and chaos in the world using a non-linear planning approach to create flexible and adaptive cities that co-evolve with global and local changes. Biomimicry shares this direction and can strengthen the advances of non-linear, adaptive planning.

Several reports have shown (e.g. Toor and Kaur 2017, Broto et al. 2012 and Kenny et al. 2012) that biomimicry benefits planning by enabling planners to create adaptive and flexible urban *infrastructures*. For example, Wootton-Beard et al. (2016) argue that biomimicry creates a significant

opportunity for interaction between biological scientists and urban infrastructure planners. My study does not support this finding. A possible explanation for this might be that these reports specifically focused on urban infrastructure and this study on urban planning in general. However, looking at the amount of articles that reference the opportunity for biomimicry to be of use in creating adaptive and resilient urban infrastructures, it proves an important and promising issue for future research.

The *Biomimicry Resource Handbook* argues that biomimicry allows stakeholders to unite behind a common inspiration and thereby harmonizes the project team (Baumeister 2014, 161). This is consistent with the finding of Buck (2017, 130), who states that biomimicry is able to align design and planning teams around a common goal by discarding all preconceptions whilst eroding traditional disciplinary siloes. My findings confirm this and show that, besides a harmonizing effect, biomimicry can even be implemented as a conflict-resolution process. When development is in deadlock or planners are stuck with ways of defining problems, biomimicry has the potential for people to start working along the same lines, putting aside professional interests and values. It reduces the risk of conflict and fosters integral solutions that serve multiple goals and functions.

Prior research of Buck (2017, 135) concludes that, as biomimicry crosses disciplinary boundaries, it challenges contemporary urban planning and design approaches and breaks the trend for splintered service provision (Buck 2017, 135). Baumeister (2014) highly recommends consulting biology and ecology experts for this and Gamage and Hyde (2011) claim that identifying accurate biological information in the enormous number of answers found in nature is difficult. Here, each of these findings is confirmed. Biomimicry fosters an integrative planning process by internalizing expert knowledge that is normally outsourced. Bringing biology and ecology experts at the design table, expert knowledge of the natural world is integrated throughout the planning process. Experts help translate biological knowledge to planners and enable them to understand nature properly. Interestingly, this study adds that there should also be people involved in the planning process that understand the financial side of development. In this way, financial considerations are made within the planning process rather than outsourced to external stakeholders, which will bypass the issue of making trade-offs against sustainability. Oguntona and Aigbavboa (2019, 4) do reveal financial constraints as a barrier to the implementation of biomimicry, however based on this study I argue that internalizing financial expertise in the planning process could solve this problem.

Few studies have looked into the way that policy plays a role in the adoption of biomimicry. This study reveals that both bottom-up as well as top-down efforts have the ability to change the regulatory framework within which planning works, which may spark the interest for using more sustainable approaches to city planning such as biomimicry. Local authorities are seen as a top-down stakeholder that can set up targets and restrictions based on biomimicry principles, which can shift expectations in a more sustainable direction. Also bottom-up efforts of interest groups are able to influence the built environment by demanding a change in policy. It regularly happens that interest groups run into rules and regulations that obstruct the development of a project. If bypassing certain policies proves to have beneficial outcomes, chances are that exceptions are made more often in the future. This might result in policy rewriting that fosters sustainable approaches such as biomimicry. Previous research has not looked at the way the regulatory framework influences the adoption of biomimicry in urban planning.

5.3 Urban planning barriers to biomimicry use

Prior research of Kenny et al. (2013) concludes that the key barrier to using biomimicry for water infrastructure design is the financial risk associated with biomimicry projects. Oguntona and Aigbavboa (2019) are able to specify that the associated financial risk of biomimicry projects is largely a consequence of the uncertainty on performance, efficiency and effectiveness of biomimicry. This study confirms that biomimicry projects are associated with financial risks. Clients and developers find it hard to take the risk to invest in biomimicry projects as urban scale biomimicry projects, which makes the outcomes and effectiveness of a biomimicry approach are uncertain. In terms of performance and effectiveness, my study reveals that biomimicry projects do not yield the performance and effectiveness that clients and developers are directly concerned with. For example, clients and developers may be willing to invest in sustainable projects as long as this investment is accompanied by short-term profits. In contrast, biomimicry results in performance and effectiveness that is valued less in the economic model: biomimicry supports the creation of other values such as a healthier, safer and non-toxic urban environment that is more efficiently accounting for natural systems. Therefore, clients and developers see a financial risk in investing in biomimicry projects. As a result, my study shows that biomimicry projects are almost seen as experiments that are most often not taken further than the design table. Governments or private clients have a certain budget allocated for a project but this is often not sufficient enough to take biomimicry to the next level, i.e. to start building. This study also found that city planning often works with competition projects, which not only brings financial restrictions to a project but also puts a limited time frame on a design. The result is that biomimicry projects are financially dependent on sponsors and clients, who are willing to fund biomimicry projects. This forms a barrier to using biomimicry in planning.

Another finding of this study is that the planning process forms a barrier to using a biomimicry approach in planning. First, different stakeholders are involved that are brought in and left out at different stages of the planning process. It would be beneficial for the use of biomimicry, to protect it from becoming an add-on rather than a strategy, to internalize knowledge and expertise from different professions from beginning till the end of the planning process. This will foster planning processes to integrate other ways of working such as biomimicry. Second, this study reveals that the regulated character of the planning process forms a barrier to using biomimicry. The planning process relies on using certain policies, tools and methods that lead to scientific answers to problems. In that way, the planning process relies on established and proven facts. A biomimicry approach embraces that answers can be unpredicted and are found in an unstructured way, just as processes in nature unfold iteratively and spontaneously. It becomes clear that introducing biomimicry in a planning process may result in friction. However, my study also shows that biomimicry could benefit from the organized character of the planning process to make its design steps more concrete and pragmatic. Third, as the planning process drives on regulations and is keen on creating a design that is based on scientific understanding and facts, an urban plan is measured against quantitative units. For example, climate change is now defined as CO_2, a unit that planners can measure. Biomimicry is not as measurable and quantifiable as planners would like to and therefore is hard to introduce in planning and does not easily fits the current planning process.

Oguntona and Aigbavboa (2019) state that governments should encourage the use of biomimicry in construction practice by putting in necessary legislation and policies. This study found that policies tend to limit the use of biomimicry in planning. A lot of national policies have a presumption in favor of development, as do world-renowned institutes such as the World Bank and the UN, which makes it hard for planners to advocate true sustainable designs. Policies that are of

concern to city planning and design, such as zoning policies that divide the city in residential or commercial areas, are often based on technical-engineering information. In this way, policies do not fully consider the value and benefits of nature and ignore the limitations, but also the possibilities, of natural systems and resources.

An expected but new finding of this study is the barrier that the market forms to using a biomimicry approach in planning. Our economic model is focused around profit and growth in which there is little room for true sustainable decisions. For example, many environmental and ecological services of nature such as clean air are not (yet) valued equally to for example timber, which can be expressed in terms of money and is therefore considered to be of higher economic value. The housing market also forms a barrier. Local authorities may enforce sustainability targets to what is planned and designed, but developers easily declare a sustainable design financially impossible.

5.4 A critical future

The results of this study indicate that there is a lack of tools available for planners to start using the approach and that a specific methodology of biomimicry, that is adapted to urban planning, is needed. This is consistent with the conclusion of Spiegelhalter and Arch (2011, 225), who argue that the future challenge for biomimicry is to develop a public, easy accessible and commonly understandable tool or model that will have a direct input into the structural planning process. This research showed that the adoption of biomimicry would improve if easy access to biological research would be enlarged. Biological information needs to be incorporated in the tools that planners use. This research specifies that a scenario-planning device that models biological and ecological information is a sound method to analyze complex designs. The research outcomes show that existing planning tools can be used to support the biomimicry approach. Especially a (social) cost benefit analysis is mentioned as a useful tool to support a biomimicry approach.

Second, this research found that many practitioners do not follow the biomimicry design steps as meant to. When planners try to get a grip on biomimicry and apply the design steps, they often mistakenly return the concept of ecosystem services. Planners run into the obstacle that there is a little amount of information on biomimicry and this is also scattered among and interpreted differently by a variety of disciplines. Third, this research found that it is important to introduce biomimicry in planning by relying on the existing planning framework, whether one has the intention to transform this framework or not.

A fourth finding of this research was that biomimicry is easily labeled as an approach for tree huggers, which may lead to negative reinforcement towards the concept. A validated concept in planning such as ecosystem services is easier to bring into a conversation than biomimicry, as ecosystem services puts human needs central. A critique is that biomimicry strongly focuses on nature and natural needs and is less concerned with human needs. Planning has the goal to ensure sufficient quality of life. It follows that biomimicry is harder to introduce than a concept like ecosystem services, which values natural sources as a service to humans. The result is that biomimicry is sometimes seen as a niche. Therefore, to bring biomimicry into use, it is important to use explanatory language instead of loaded terminology when introducing biomimicry in planning. For urban planning, it is not useful to portray biomimicry as something that is really distinct from contemporary ways of sustainable planning.

5.5 Discussion of the research methods

This section discusses to what extent the findings might have been influenced by the chosen research methods. I will elaborate on possible barriers, shortcomings and special circumstances of my research methods.

There was diversity in data richness of the interviews. Some interviews provided a relatively large amount of information, while others proved to be scarce in data richness. Some interviews therefore weighted more than others in the research. This was resolved by checking if the statements in the interviews were commonly shared or were rather considered a distinctive finding. For example, it appeared that less informative interviews supported the general outcome of the combined interviews rather than stating opposing viewpoints. In that way, these less informative interviews were used to check the general outcome of the interviews.

Another limitation can be found in the fact that this research required interviewing people from different countries and regions of the world. There was a huge time difference with interviewees located in for example India, the United States, or Mexico, which sometimes caused interviews to be cancelled or rescheduled. More importantly, this diversity in origin of interviewees may have impacted the findings of this research. Planners and biomimicry experts most likely had context specific views and answers to questions. It follows that a planner from the United States has a different experience and opinion on this research topic than a planner from London. As a result, some findings of this research may have been influenced by context specific phenomena or situations.

Since the topic often related to complicated and very detailed expertise of the interviewees' work and knowledge, interviewing via Skype hampered full connection during the conversation. It sometimes occurred during interviews that interviewees explained themselves or exemplified their description by drawing or making small sketches. Using video calls for the interviews limited interviewees as they sometimes had to overdue their descriptions to make their opinions clear. On the one hand this was beneficial as it allowed me to probe additional questions and receive detailed explanations. On the other hand it proved a shortcoming as the dialogue could have otherwise taken a more visual direction. For example, one interviewee turned to unparalleled screen sharing to show PowerPoint slides and drawings to support his story.

The qualitative analysis software tool NVivo might have influenced the interpretation of data. Although NVivo enabled me to differentiate main themes from sub themes by ranking the themes by the amount of references coded, complex relationships between themes still required me to interpret these relationships. It occurred that a theme in NVivo was ranked as one of the main themes because of the many references coded for that theme, but in reality this was not a prominent theme in the interviews. Thus, there existed discrepancy between the amount of references that belonged to a code, meaning that my interpretation played a role in confirming if a densely referenced theme was indeed an important outcome of the interviews. As NVivo is a pragmatic way to manage data, I acknowledge that there is always some form of interpretation from the researcher when a 'raw' finding is coded under a certain theme. In order to make sure that my interpretations did not influence the analysis of the data, I ran through the interview transcripts with an open mind. This meant that I did not look for expected patterns that might have emerged from the literature study nor did I search for themes that related to my research questions. This allowed any theme to emerge from the data. After all interview transcripts were coded, I used additional tools in NVivo to confirm the created themes and their belonging references. For example, NVivo allowed me to create charts, tables, mind maps and diagrams from the information coded. I used these visual tools to manually go through my interview transcripts once more to make sure that I created themes that were true to the data.

Chapter 6 Conclusion

This study explored the potential of biomimicry for urban planning. This study investigated how biomimicry is practiced and what its added value is for urban planning. Barriers were identified to using biomimicry as a planning approach and it was found what is needed to secure a role for biomimicry in the future of planning cities. The main research question was: *What is the potential of biomimicry for urban planning to contribute to planning for a future that sustains both natural and human systems?*

6.1 The value of biomimicry for planning

I conclude that biomimicry is of value when planners[6] are stuck in finding answers and solutions to design challenges. By turning to nature for inspiration, biomimicry broadens people's thinking and allows people to extract themselves from their professional roles. Planners can approach current design challenges of urban areas, such as droughts or floods, by looking at a wide range of answers and solutions already present in nature. This encourages planners to think creatively and expands the set of answers and solutions to design challenges that are not typically found when looking for metrics and technical solutions. In other words, biomimicry generates alternative design options.

Building on the work of Lawrence Susskind, Innes and Booher (1999, 412) already stated how 'consensus building among stakeholders is increasingly common as a way to search for feasible strategies to deal with uncertain, complex and controversial planning and policy tasks'. This is also in line with the work of Healey (1997), who arguments for collaborative planning by focusing on relation-building processes within planning. My study has found that biomimicry could even be deployed as conflict-resolution process, especially when developments run into deadlock. Biomimicry has a strong focus on multidisciplinary work, which encourages collaboration between stakeholders and enables planners to come to solutions that serve multiple goals and purposes. In this way, biomimicry supports consensus building from an integral and holistic perspective. Besides, I conclude that biomimicry must not be viewed as the one and only solution to design challenges. Rather, the concept lends itself to be used besides existing concepts and approaches in urban planning. The life principles are seen as a useful framework that allows planners to work with other approaches and concepts in planning. My study identified environmental impact assessment and (social) cost benefit analysis as tools that could be used when applying biomimicry as planning approach.

When planning and designing, planners inevitably need to make trade-offs between different aspects of a design, such as environmental, social or economic, as not all aspects can be equally accounted for (King et al. 2015). I conclude that biomimicry encourages planners to realize sustainable designs, as the multidisciplinary character of the biomimicry approach internalizes expert knowledge that is normally outsourced. By including biological, ecological, sustainability and financial experts from beginning till end of the planning process, planners can give foundation to their decisions in favor of sustainability. In this way, fundamental decisions regarding sustainability are internalized rather than outsourced, which bypasses the issue of making trade-offs against sustainability.

I moreover conclude that biomimicry enables planning for complexity. As said by Boelens and de Roo (2016, 46): 'There is growing interest among planners to address complexity and its ongoing

[6] Or anyone involved in city planning and design

fluid, open, non-linear and unpredictable development considering this to be more in line with reality'. My study found that biomimicry approaches the city as a complex system, which enables planners to deal with the complexity of city planning by accounting for (sub) systems and their relationships by making spatial and temporal scale interactions. When planning and designing, biomimicry enables planners to switch between scales because it examines the effect of a plan within the larger and smaller scales it is embedded in. Approaching the city as a system also shifts the time horizon of a plan, since trying to understand natural processes forces planners to think about the impact of their plan on the long term. Thus, accepting that a city as a complex system that grows and evolves over time enables planners to design modular and flexible infrastructures that can adapt to and be resilient to new conditions. This resonates with the work of Batty (2013, 8), *The New Science of Cities*, who embraces complexity theory to explain that 'cities can be constructed in modular form, as hierarchies that reflect subsystems of interactions on which processes of change take place and evolve'.

6.2 Biomimicry as a planning approach: barriers to overcome

I conclude that biomimicry has the potential to be used as a planning approach, yet many barriers need to be overcome. Zandvoort et al. (2018, 184) define a planning approach as 'a combined set of tools in a *coherent framework*, which planners can use to structure *planning processes* and deal with multifaceted planning situations, akin to *policy packages*'. Looking at the different facets this definition embraces, I conclude that biomimicry can serve as a coherent framework for a planning approach: a structure of meaningful concepts and tools. However, biomimicry is not sufficiently operationalized. The design steps remain generic and planners miss tools to use biomimicry as planning approach. Genius of place, whereby design teams gather information from the natural, local context (preferably by going out in the field) is a challenging exercise that requires sufficient knowledge, time, preparation and resources that are not (yet) in place in planning teams. More research is needed on biomimicry and urban planning to create a specific methodology with applicable tools adapted to urban planning. My study has found that biomimicry is best introduced by relying on the existing planning framework. Biological information and expertise needs to be incorporated in the tools that planners use and the processes that lead up to design decisions. Instead of flipping through a design catalogue that consists of separate sections, planners need to have a playbook of nature that shows all interrelated elements of the system and their functions. Based on my study, I conclude that a planning tool that models biological and ecological information from particular sites could be of contribution to using biomimicry as planning approach. Computer modeling will encourage the adoption of biomimicry in planning, as contemporary planning is hard to replicate and simulate without actually building. Contemporary planning tools lack certain biological and ecological information, which could be resolved by using a biomimicry approach.

Looking at the planning process, I conclude that the values underlying a biomimicry design process and a planning process are different, which complicates the adoption of biomimicry as planning approach. The design steps of a planning process and biomimicry are quite similar, as both design processes go through aim definition, situation analysis, design and implementation and evaluation. However, my study has found that the values underlying a biomimicry design process are different from a planning process. A planning process is guided by regulations and relies on using certain policies, tools and methods that lead to scientific answers to problems, whereby a design is measured against quantitative units. Biomimicry is not as measurable and quantifiable as planners would like to and embraces that answers can be unpredicted and are found in an unstructured way,

just as processes in nature unfold iteratively and spontaneously. A biomimicry design process has a strong focus on understanding nature's functions. A validated concept in planning like ecosystem services is easier adopted because it puts human needs central, in contrast to biomimicry that mostly focuses on nature. I conclude that, in order to encourage the adoption of biomimicry in planning, it is relevant to use explanatory language and not loaded terminology. As biomimicry uses specific terminology, it may come across as a niche. This is not only bad from a business perspective but will also hinder planners from learning more about the concept. It may even be beneficial to not label projects or ideas as biomimetic, but rather introduce planners to the content of the approach.

Looking at policy packages, I conclude that multi-policy objectives that account for multifaceted planning situations, i.e. for environmental, economic and social facets, encourage the adoption of biomimicry as planning approach. A current barrier is formed by the limited amount of biomimicry projects, which is holding back the adoption of biomimicry in planning. As urban-scale biomimicry projects are scarce and the ones that exist only partially used biomimicry, the outcomes of biomimicry in terms of effectiveness and performance are uncertain. Therefore, clients and developers see a financial risk in investing in biomimicry projects. This financial dependence of biomimicry projects on clients who are willing to devote their resources to it is the largest barrier to using biomimicry in planning. This is complicated by the fact that the effectiveness of biomimicry is mostly expressed in natural values, such as healthier, safer and non-toxic urban environments that are more efficiently accounting for natural systems. More projects need to be carried out that implement (part of) a biomimicry approach to encourage the adoption of biomimicry as planning approach. I conclude that policy packages could encourage urban-scale biomimicry projects, as policy packages stress the need to grasp the complexity of urban planning by means of multiple policy objectives. This encourages using biomimicry as a planning approach, as policy packages are more likely to align with the objective of biomimicry than a single policy objective, to solve urban design problems in a systemic and holistic way.

Mathews (2011) and Goel et al. (2014) stated that biomimicry is philosophically underdeveloped. My study compliments this, as I conclude that better ethical reflection is needed on the underlying assumptions of biomimicry. When using a biomimicry approach, the designer censors which solutions to use from nature and which not, to solve design challenges. My study has found that ethical decisions have to be made to sustain natural and human systems when using a biomimicry approach, as a designer must decide what aspects to incorporate in a design and what not. Whereas in nature, there also exist processes and functions that are meant to kill a prey or enemy. Put differently, the underlying ethos of biomimicry must be called into question, as not the entire spectrum of nature's processes and functions is considered. The result of the philosophical underdevelopment of the concept is also reflected in the difficulty of practitioners to decide what mechanisms in nature fit a particular design challenge. Better ethical reflection is needed on the underlying assumptions of biomimicry and the concept must be philosophically developed in order to provide a foundation for applying biomimicry as planning approach.

Overall, I conclude that biomimicry has the potential to be used on an urban scale, as found in several values that a biomimetic planning approach could offer, to realize urban plans and designs that sustain natural and human systems. Biomimicry could be used as a planning approach, however some barriers need to be overcome to operationalize a biomimetic planning approach.

Chapter 7 Significance of the findings and recommendations

The implications of this study are that when we embrace biomimicry as a planning approach, the possibilities of finding solutions to our design challenges is expanded. Although this study focuses on urban planning, the findings are relevant to other fields of study where there is an interest of using biomimicry. For example in (landscape) architecture, environmental governance and civil engineering. The barriers and opportunities of biomimicry can be translated to, and accounted for, in any other field of study.

The study adds to the rapidly expanding field of bio-inspired approaches to planning and designing. The insights gained from this study may be of assistance to planners or anyone involved in city planning and design who is looking for an approach that can sustain all forms of life and provide a thorough understanding of the natural world. The empirical findings provide a new understanding of the potential role of biomimicry as planning approach and lay the groundwork for future research into biomimetic urban planning.

Although this research gave a deeper understanding of the potential of biomimicry as planning approach, several questions remain. I recommend future research to focus on the way biomimicry can be operationalized in planning. A specific methodology must be created for biomimetic planning with applicable tools. This research showed that developing a modeling-planning tool that incorporates biological and ecological knowledge is a promising method; especially since computer modeling is becoming more prominent in planning and designing cities. Before biomimicry is introduced, such a planning tool must be usefully explored. As more studies are investigating the concept, it is important to create unambiguous methods and design steps to secure the future of biomimicry. I recommend the Biomimicry Guild to develop specific design steps and tools that clarify the contemporary confusion and variation regarding the biomimicry approach.

Implementing urban scale biomimicry projects is a way to test the biomimicry design steps and tools in planning. Cases are missing that are able to give clearance on the outcomes and effectiveness of using biomimicry. Implementing cases might spark the interest in biomimicry as it develops more insight in the outcomes and effectiveness of a biomimicry as planning approach. My research provided a general insight into the potential of biomimicry for urban planning. Future research must focus on investigating specific cases from beginning to end with all its involved stakeholders. A (comparative) case study deepens the findings of this research and the knowledge about the contribution of biomimicry in general. However, significant resources and networks are needed, as urban scale biomimicry projects are scarce and people involved in them are scattered around the globe.

I also recommend investigating the policy uptake of biomimicry in planning. Put differently, how the adoption of biomimicry in planning could be promoted by the uptake of certain policies. My study found that biomimicry brings the opportunity for both top-down and bottom-up efforts to rewrite building codes and urban policies that better align with natural systems. The interest of a local authority in biomimicry might trickle down more sustainable targets and restrictions that will influence what planners plan and design. On the other hand, projects and interest groups are bottom-up efforts that bring the opportunity to rewrite policies by showing the benefits to the larger community. Therefore, I recommend that biomimicry be taken forward by investigating policies that sufficiently consider natural systems and their relationship to human systems.

An aspect of my research was to investigate a biomimicry approach set against a planning approach. My research found that biomimicry is best introduced by connecting it to the existing

planning framework (approaches, concepts, methods and tools). Future research must detail how biomimicry connects to existing planning approaches. Think about other sustainable or bio-inspired approaches such as green infrastructure or nature-based solutions.

I recommend future research to focus on the different facets of planning to investigate how biomimicry can be applied as planning approach. This will detail how biomimicry fits planning practice, what needs to change and how in order to use a biomimetic planning process. Think about aim definition, situation analysis, plan design, and implementation and evaluation. Besides, future research should account for the different scales of planning and the way biomimicry can be applied to each of these scales. Questions remain relating to the value and effectiveness of biomimicry on a local, meso, regional or national level.

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Annex 1

The following two lists show the questions of the semi-structured interviews. Two question lists were set up for the two focus groups of this research, biomimicry experts and biomimicry planners.

Question list for urban planners Duration 60 min.

[Ask for permission to record interview & assure anonymity of interviewee]

[Shortly introduce myself & my research interest]

[Allow interviewee to introduce him/herself]

Starting questions

- On what level are you applying biomimicry, mostly on systems level, form or more on processes?
- How would you describe biomimicry and the biomimicry Approach?
- What do you understand by urban planning? And what do you understand by a planning approach?

Theme: **description**

Q1 *What is your impression of the usability of biomimicry as a planning approach?*

Theme: **added value**

Q2 *What added value do you think a biomimicry Approach offers to urban planning? And why?*

Theme: **scale**

Biomimicry is mostly used on a smaller scale in businesses for product development, innovation and for example in architecture.

Q3 *How do you see scale and scale issues related to using biomimicry in urban planning, do you see challenges that need to be overcome?*

Q4 *What would make a biomimicry Approach particular (noteworthy) for urban planning? How can biomimicry inform planners?*

Theme: **comparison**

Q5 *How do you compare a biomimicry Approach to existing eco-based*

planning approaches? Do you see differences, similarities or both? For example Green Infrastructure or the Ecosystem-based Approach.

Q6 *Could biomimicry be coupled to your existing planning processes and approaches? Which issues concerning feasibility of a biomimicry Approach in your day-to-day practice might arise? Did you experience barriers for such implementation? How where they solved?*

Theme: **planning process - transition**

Q7 *Which consequences would biomimicry have for your normal planning process?*

Q8 *Do you believe that biomimicry is ready to be implemented in urban planning,* or *are there preconditions that must be put in place to use a biomimicry Approach in urban planning?*

Q9 Can you be more specific: does the contemporary planning process offer sufficient knowledge and concepts to apply biomimicry in the planning process and why?

Q10 *How do you see policy in relation to the planning process and outcomes?*
Do you think the contemporary interaction between policy and planning allows for a biomimicry approach to planning? Yes, no, what needs to change?
(other priorities, time and costs, fear of formal complaints, changed/unclear policy)

Q11 If we look at the contemporary way that the planning process is organized, *do you think changes are needed in these organizational aspects to apply a biomimicry approach?* For example look at the way that funding, clients or sponsors influence the planning process.

Q12 A last aspect of the planning process is the market, *how do you view the market in relation to using biomimicry in the planning process?*

Q13 *How do you think that planners can gather knowledge from nature? What do you think of the Genius of place method?*

Part of the biomimicry Approach is to create metrics that set a benchmark to what we plan and design: it challenges cities to provide the same level of ecosystem services as the native ecosystem.

Q14 *What is needed to incorporate ecosystem insights in urban planning? How can this be organized and by whom?*

Biomimicry is formed out of concepts and definitions from biology.

Q15 *Do you think there is a need to make the translation from biology to planning in order to use a biomimicry approach in planning, and why?*

Q16 *How would you compare this way of working to existing eco-based planning approaches?*

Theme: **ethics**

Q17 *Do you experience ethical assumptions in biomimicry, for example concerning the relationship between humans and nature? Do you see ethical dilemmas or opportunities for a biomimicry Approach to planning? If negative, how -are you dealing with/would you deal with- this?*

Theme: **prospects**

Q18 *What developments do you see in the field of biomimicry? How do you see the future of biomimicry in the context of urban planning?*

Q19 *In your opinion, how can planning practices be altered or adjusted to facilitate these future developments?*

Q20 *What parties or stakeholders should be involved in the future development of biomimicry?*

[Thank interviewee for taking part in the interview]

Question list for biomimicry experts Duration 60 min.

[Ask for permission to record interview & assure anonymity of interviewee]

[Shortly introduce myself & research interest]

[Allow interviewee to introduce him/herself]

Theme: **description**

Q1 *How would you describe biomimicry and the Approach?*

Q2 *What do you understand by urban planning?*

Theme: **scale**

Biomimicry is mostly used on a smaller scale in businesses for product development, innovation and for example in architecture.

Q3 *How do you see scale and scale issues related to using biomimicry in urban planning, and do you see challenges that need to be overcome?*

Q4 *Do you think the biomimicry Approach is ready to be applied on an urban scale? And how can biomimicry inform planners?*

Theme: **added value**

Q5 *What added value do you think a biomimicry Approach offers to urban planning? And why?*

Theme: **comparison**

Q6 *How do you compare a biomimicry Approach to contemporary ways of sustainable city planning? Do you see differences or similarities or both?*

Q7 *Which issues concerning feasibility of a biomimicry Approach in urban planning might arise? Did you experience barriers for such implementation? How were they solved?*

Theme: **planning process**

Q9 *How do you think that planners can gather knowledge from nature? What do you think of the Genius of place practice?*

Part of the biomimicry Approach is to create metrics that set a benchmark to what we plan and design: it challenges cities to provide the same level of ecosystem services as the native ecosystem.

Q10 *What is needed to incorporate ecosystem insights in urban planning? How can this be organized and by whom?*

Q11 *How would you compare this way of working to existing ways of sustainable city planning?*

Can you be more specific: does the contemporary planning process offer sufficient knowledge and concepts to apply biomimicry in the planning process?

Q10 *How do you see policy in relation to the planning process and outcomes?*
Do you think that the contemporary way that policy in relation to planning allows for a biomimicry approach to the planning process? Yes, no, what needs to change?
→other priorities, time and costs, fear of formal complaints, changed/unclear policy (you cannot influence it only minor details)

Q11 *If we look at the contemporary way that the planning process is organized, do you think changes are needed in these organizational aspects to apply a biomimicry approach?* For example look at the way that funding, clients or sponsors influence the planning process.
→fear of formal complaints, changed/unclear policy, housing market.

Q12 A last aspect of the planning process is the market, how do you view the housing market in relation to using biomimicry in the planning process?
→fear of formal complaints, changed/unclear policy, the housing market.

Theme: **ethics**

Q13 *Do you experience ethical assumptions in biomimicry, for example concerning the relationship between humans and nature? Do you see ethical or moral dilemmas or opportunities for a biomimicry Approach to planning? If negative, how -are you dealing with/would you deal with- this?*

Theme: **prospects**

Q14 *What developments do you see in the field of biomimicry? How do you see the future of biomimicry in the context of urban planning?*

Q15 *In your opinion, how can planning practices be altered or adjusted to facilitate these future developments?*

Q16 *What parties or stakeholders should be involved in the future development of biomimicry?*

Any last questions or remarks?

[Thank interviewee for taking part in the interview]

[Close interview]

Annex 2

Evolve to Survive	Be Resource (Material and Energy) Efficient	Adapt to Changing Conditions	Integrate Development with Growth	Be Locally Attuned and Responsive	Use Life-friendly Chemistry
Continually incorporate and embody information to ensure enduring performance.	Skillfully & conservatively take advantage of local resources & opportunities.	Appropriately respond to dynamic contexts.	Invest optimally in strategies that promote both development and growth.	Fit into and integrate with the surrounding environment.	Use chemistry that supports life processes.
Replicate Strategies that Work Repeat successful approaches. **Integrate the Unexpected** Incorporate mistakes in ways that can lead to new forms and functions. **Reshuffle Information** Exchange and alter information to create new options.	**Use Multi-functional Design** Meet multiple needs with one elegant solution. **Use Low Energy Processes** Minimize energy consumption by reducing requisite temperatures, pressures, and/or time for reactions. **Recycle All Materials** Keep all materials in a closed loop. **Fit Form to Function** Select for shape or pattern based on need.	**Maintain Integrity through Self-renewal** Persist by constantly adding energy and matter to heal and improve the system. **Embody Resilience through Variation, Redundancy, and Decentralization** Maintain function following disturbance by incorporating a variety of duplicate forms, processes, or systems that are not located exclusively together. **Incorporate Diversity** Include multiple forms, processes, or systems to meet a functional need.	**Combine Modular and Nested Components** Fit multiple units within each other progressively from simple to complex. **Build from the Bottom Up** Assemble components one unit at a time. **Self-organize** Create conditions to allow components to interact in concert to move towards an enriched system.	**Use Readily Available Materials and Energy** Build with abundant, accessible materials while harnessing freely available energy. **Cultivate Cooperative Relationships** Find value through win-win interactions. **Leverage Cyclic Processes** Take advantage of phenomena that repeat themselves. **Use Feedback Loops** Engage in cyclic information flows to modify a reaction appropriately.	**Build Selectively with a Small Subset of Elements** Assemble relatively few elements in elegant ways. **Break Down Products into Benign Constituents** Use chemistry in which decomposition results in no harmful by-products. **Do Chemistry in Water** Use water as solvent.

Figure 8. Detailed explanation of the life principles. Source: Baumeister (2014)

Annex 3

Name	Files	Referen...
Mind-shift	0	0
Paradigm	9	16
Relationship with nature	7	16
Obstacles	0	0
Societal obstacles	7	13
Biomimicry obstacles	10	39
Planning obstacles	10	39
Implementation	1	1
Financial dependence	11	24
Stakeholders	11	34
Nice examples	4	5
Methodology	6	7
Design Spiral	2	4
Asking questions	4	5
Metrics	4	7
Ecological Performanc...	6	8
Life's Principles	5	10
Function	5	12
Mimic	5	13
Ethics	9	14
Genius of Place	12	25
Multidisciplinary	9	26
Systems' thinking	11	33
Developments	8	35
B. not THE solution	9	18
Definition	13	27
Scale	11	27
Urban planning	9	29
Organisation	4	5
Complex	5	8
Market	5	10
Policy	7	19
Planning process	8	25
Critique	10	32
Future	11	36
Added value	13	38

Figure 9. Overview of the nodes as created in NVivo