Revisiting the human-nature relationship through biotech architecture

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Chiara Juriatti

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Introduction

Buildings in the European Union are responsible for approximately 36% of the union's greenhouse gas emissions and use around 40% of the produced energy.[1] Similar numbers can be found in the statistics about buildings in the United States: There, they consume 48% of the nation's energy and produce 45% of the carbon dioxide emissions.[2] These statistics show the impact of building construction and use in the Western world and how powerful their ecologization[3] could be. Moreover, the rising world population and consequently increasing demand for buildings require a higher consumption of natural resources, resulting in the consumption of 60% of raw materials worldwide by the construction sector alone.[4] Contrary to energy supplies, materials are not infinitely producible.[5] However, the material that is chosen for a building can also determine its environmental impact, due to differing levels of energy consumption and CO_2 emissions that arise during the production of the materials. For example, wood as a building material is strong, renewable and serves as a carbon sink. Another material that proves useful for 30% of the world's population is soil. It is the most available material in every country. Building with earth requires little energy and it regulates temperature inside the edifices.[6] This statistical outline exemplifies the common approach to sustainable architecture, namely addressing their materiality. As the architectural projects presented in this thesis will show, to strengthen the human-nature relationship through architecture, it is necessary to change the discourse about nature and materials. Architecture that is not dominated by a certain material but that regards nature as an equal part of the living space has to be created.

In Western design practices, using low-impact materials, reflects an arising awareness of citizens for sustainability and in a way, integrates nature into architecture. Architecture has a special predisposition to connect the natural and human environment since it is able to shape both realms. Buildings are placed in the natural environment, therefore, contributing and altering the appearance of nature. From the perspective of human habitation, architecture is located on the threshold between nature and culture, seemingly dividing the two. Hence, it is

[1] https://ec.europa.eu/energy/topics/energy-efficiency/energy-efficient-buildings/energy-performance-buildings-directive_en#energy-performance-of-buildings-standards [Accessed 25 April 2021]
[2] Cogdell, *Toward a Living Architecture?,* 11.
[3] Ecologization not only means to make architecture more sustainable but also change the way architecture is thought of. As Erich Hörl states, ecologization reconceptualises the relation of humans and nonhumans. It acknowledges the complexity of the environment and defines the world as a cooperation between the multitude of nonhuman and human entities. (Hörl, 3).
[4] Surnam, "Materials: A Major Component of Green Building", 2.
[5] Van den Boomen eds., *Urban challenges, resilient solutions*, 45.
[6] Surnam, "Materials: A Major Component of Green Building," 9-12.

through architecture that humans look out into the environment and differentiate between being in a human or a natural space. Furthermore, the way humans interact with nature in their everyday life is fundamentally shaped by the architectural environment; for instance, if the building provides access to natural space or considers natural light in the design. The aspect of architecture as an intermediary between humans and nature gives buildings potential for incorporating nature on a larger scale. Different laboratories already use new technologies to generate compostable building materials out of renewable resources or waste. Introducing new materials and methods of construction offer solutions for severe environmental problems. However, as the discussion in this research will show, this step is not sufficient to tackle the structure that lies behind environmental problems – namely capitalism, the economic system that lets humans view nature as a commodity –, based on the lack of incentive behind the designs to change the way humans perceive and engage with nature.

The objective of this research is to describe the performative qualities of building techniques that incorporate nature in its living form and investigate how this can recalibrate the human perception of nature. Thereby, the performative potential of different "bio-technologically" produced materials for sustainable building will be evaluated based on their ability to influence human beings' interactions with nature. The research intends to highlight the capacity of biotech architecture to mediate between humans and nature and therein to raise awareness for environmentally conscious living through the bio-technology's inherent performance. In light of this discussion, the research aims to answer the following question: To what extent can bio-technologically produced materials and forms and their inherent performative character in the context of architecture contribute to a non-materialistic, appreciative perception of nature? To better explore the significance of this new approach to architectural design, the following sub-questions will be posed and investigated:

- How do the bio-technologically produced materials and forms relate to the natural environment?
- How can bio-technology influence the performance of a building? What impact does this have on the interaction of the building with the human perceiver?
- To what extent can biotech architecture place the building in the context of a greater ecosystem and sensitise humans to ecological concerns?

Incorporating nature into architecture with the help of technology has already been examined by Christina Cogdell in her book *Toward a Living Architecture?: Complexism and Biology in Generative Design*. In her research about, what she calls, "generative architecture", i.e., architectural practices that utilize digital technologies, Cogdell especially focusses on design projects that explore the possibility of using DNA or even living cells as a material.[7] Due to the extremely controversial topic of genetics, especially in context of eugenics, Cogdell also deals with ethical aspects of genetic designs. Similar to Cogdell, this research will analyse the design projects on the basis of the concept of sustainability and investigate how technology supports or undermines ecological considerations. However, I will concentrate on possible effects of biotech architecture on the perceivers' attitude towards the environment.

In order to provide context for this inquiry, the first chapter will give a definition of the concept of "biotech architecture" as it is used in this research and, on the basis of the biophilic hypothesis, explain the ethical and moral considerations that inform design practices. Moreover, as sustainability is a broad term that is frequently employed to designate eco-friendly building, this concept will be scrutinised to give a better understanding of the way biotech architecture is situated in the discourse. To answer the research question the thesis will be divided in three chapters, each following one sub question and one thematically framed case study.

Chapter two titled "Composing – Decomposing" will examine materials and forms of biotech architecture and their relation to nature. This chapter explores compostable or recycled materials as new materials in architectural design. In this respect, it will also be highlighted that aesthetic and ethical considerations are essential for creating a truly sustainable architecture. Central for this chapter is Roger Paden's text *Aesthetics and Sustainable Architecture*, in which he argues for an architectural aesthetic that is informed by natural processes and that reflects the immediate environment. Departing from Paden's argumentation, two approaches to aesthetic implementation of nature and natural processes in material design will be juxtaposed, to analyse the different effects of aesthetic representation of nature in architecture. The presented case study will consist of analyses of two new materials: on the one hand, the bioreceptive panels of Marcos Cruz and Richard Beckett; on the other hand, Neri Oxman's biopolymer materials, whose composition is mainly driven by the idea of decay. Composing with the possibility of decomposing serves as an example for sustainable design that is influenced by nature, in a mimicking sense, but at the same time aims to change the way nature is perceived.

In chapter three, architectural practices will be investigated that employ nature itself as the constructing entity. The case study focusses on living trees as architectural materials, exemplified by the project *Fab Tree Hab* by Terreform ONE. As the natural processes of trees

[7] Cogdell, *Toward a Living Architecture?,* 17.

are utilised to generate living space, the case study will be observed under the guiding principle "Growing". The basis for this discussion is provided by Humberto Maturana and Francisco Varela's theory of autopoiesis, which describes the self-organizing character of natural organisms. By connecting autopoiesis to architectural design, the building's agency is foregrounded to examine the performative characteristics of self-growing architecture. In doing so, biotech architecture is disclosed as a design process that acknowledges not only human but also nonhuman needs, making nature experienceable as a coequal entity in an ecosystem.

Lastly, in the fourth chapter named "Biodiversifying", the positioning of biotech architecture within a greater environmental context will demonstrate the ability of buildings to materialise intricately entangled ecosystems. This examination will be made on the basis of M. Beth Dempster's and Donna Haraway's texts about sympoiesis. This concept forms an expansion of the notion of autopoiesis and describes the necessary exchange between entities to maintain the ecosystem. The works discussed in this chapter are the *Monarch Sanctuary* by Terreform ONE, which creates a co-habitational space for both nonhumans and humans, and the project *Dune* by Magnus Larsson, which aims to generate living space in the Sahara Desert and therefore provides a solution for the issue of growing desertification. By observing biotech architecture through the lens of sympoiesis, it will be highlighted how architecture responds to problems arising in a multispecies network and how this could benefit the human-nature relationship.

1 Architecture in consideration of nature

1.1 Biotech Architecture

Chris Abel, design theorist in the field of architecture and technology, defined the concept of "biotech architecture" for the first time in his manifesto in 1997.[8] In this concise text, Abel presents an approach to biotech architecture through 20 arguments, mainly concerning the relationship of designers, technology, architecture and nature. Although already composed more than 20 years ago, the aspects brought forward by Abel are still valid. First of all, he clarifies that biotech architecture "is *not* a style", but, "a computer-centred *process* of architectural design, production and use.", furthermore the concept "is *information* based, not *form* based. It does not prescribe what a building should look like, but rather how it should *behave*."[9] Thus, biotech architecture, rather than identifying a certain aesthetic form, relates to the technological design of architecture in order to create a building that performs in a desired way. While these aspects leave the architectural intention of biotech architecture open, the following points of the manifesto – which will be touched upon in the succeeding chapters – illustrate the grounding principle of biotech architecture. Abel explains that the term biotech architecture is intended as a synonym for sustainable design. He further remarks that "the designer's remit covers the entire *foreseeable life cycle* of the building, from the production to the recycling of materials."[10] Thus, Abel's biotech architecture manifesto offers guidance that underlines the importance of technological solutions for sustainable architecture, but that does not dictate an artistic style. However, multiple aspects can be detected that support certain implementations and exclude others.

With the term "biotech", Abel does not refer exclusively to the scientific field of biotechnology. In his definition "biotech" relates to the technological enabling of architecture that is based on organic processes. Thus, a multiplicity of technological practices can generate biotech architecture. Amongst others Abel names molecular engineering, nanotechnology and biotechnology.[11] In her work about living architecture, Christina Cogdell summarizes a multitude of technological solutions that work with nature and biological processes as an inspiration or a material, namely "material computation", "biocomputing" and "programming matter".[12] The definitions Cogdell gives of those methods are all very similar to each other. All three techniques use technology to gain information about natural phenomena, processes or

[8] For entire manifesto see Appendix
[9] Abel, *Architecture, Technology and Process,* 243.
[10] Ibid.
[11] Ibid., 9.
[12] Cogdell, *Toward a Living Architecture?,* 70.

materials and digitally translate those into the design.[13] For example, designer Achim Menges, inspired by sea urchins' structure, created a wooden pavilion (Fig. 1) by translating the data he got from investigating sea urchins into computer simulations to then achieve a construction that utilizes adaptable lightweight plates.[14] Thus, the performance of nature is mirrored by architecture, making them biomimicking constructions.

Material computation, programming matter and biocomputing all relate to the practice of "natural computing", which is interpreted in two different ways: on the one hand, natural computing is seen as a form of biomimicry, meaning that computer-based technologies simulate natural processes; on the other hand, natural computing describes the action of natural processes, hence, nature being the actor of its own computing.[15] To not only achieve a technological paternalism over natural forms and processes, the merger of both interpretations of natural computing has to be the aim of biotech architecture. Thus, "biotech" serves as a comprehensive term that includes all environmentally-based technologies that meet the characteristics mentioned in Abel's manifesto.

However, some ethical considerations have to be made in order to achieve the premise of "a sustainable life on Earth"[16], as Abel calls it. It has to be kept in mind, Cogdell notes, that "[b]iomimicry has no definitional requirement to be sustainable, although it is often presumed that if one mimics a natural solution, it will de facto be more sustainable than a solution that does not mimic nature."[17] Searching for architectural inspiration in nature alone does not suffice to create a sustainable building. Biotech architecture, therefore, should not only be seen as a technoscientific approach to tackle climate change and modify our planet; in combining technology with environmental aesthetics, it can raise awareness for the relationship between humans and other living things. Biotech, in that sense, should not be seen as the solution for the problem that merely has to be applied in order to achieve a desired aim. It has to be regarded as an intermediary that allows humans to attain a sense of inclusion in the natural environment. This utilisation of bio-technology, too, has to be monitored closely. As Nora Vaage notes, bioart questions technology as a solution both in its own right and in the wider context of human handling of the environment. The application of biotechnology on other living things reflects humans' unguarded attitude towards nature.[18] Thus, the designs should not support the

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[13] Cogdell, *Toward a Living Architecture?,* 69.
[14] Achim Menges, "ICD/ITKE Research Pavilion 2011", Accessed 7 August 2021, http://www.achimmenges.net/?p=5123
[15] Cogdell, *Toward a Living Architecture?,* 70.
[16] Abel, *Architecture, Technology and Process*, 244.
[17] Cogdell, *Toward a Living Architecture?,* 63.
[18] Vaage, "What Ethics for Bioart?", 87-88.

commodification and perception of nature as a mere resource. Cogdell remarks that to achieve a sustainable interaction between all entities on Earth, which sustains all lives equally and through all generations, the destructive ideology of the Western world has to shift from domination of the environment to cooperation.[19]

Phil Ayres, therefore, proposes “bio-hybrid” practices instead of biomimicry in architectural design. Bio-hybrid architecture emerges from a coupling of “living biological complexes” with artificial objects. The artistic research project *Interwoven* (Fig. 2), by Diana Scherer, serves as an example of what this hybrid combination of artificial and natural matter might look like. Since the various computing practices enable the inclusion of living entities in human artefacts as well as the modification of living processes to generate human artefacts, they make the dynamic processes of nature visible. Scherer’s project is a material study that investigates the possibilities of woven structures simultaneously produced by humans and nature. Scherer creates textile-like materials through controlling the growth process of freshly seeded plants through digitally fabricated templates. Those templates modify the patterns of the root growth, but do not contribute to the stability of the material; stability is solely achieved by growth.[20] Therefore, the main aspect of roots, namely stabilizing, is maintained and becomes an important part of the design. The way the roots grow adapts to the environmental circumstances. Thus, through altering these, the growth can be influenced. For instance, dryer soil leads to elongated roots and the utilisation of artificial gravity can change the direction in which the roots grow.[21] The growing phase of the plant, therefore, lets perceivers observe the development of the design, making the production of the artefact and the process of growing nature graspable at the same time.

That this connection to natural process is especially enabled through Scherer’s bio-hybrid design becomes apparent when contrasting it with a design example that mimics roots and their growth. In the course of the Amsterdam Light Festival 2016, the architect group DP architects developed the *Rhizome House* (Fig. 3), which mimics the root structures of natural organisms. The composition consists of RGB light diodes, changing in colour, and weather-resistant, translucent high-density polyethylene material, which forms tube-like installation. Its shape appears as an interwoven network that has no beginning or end; the tubes extend to every possible direction and are open at the edges of the design, adding to the impression of a growing structure. That the work is only meant to resemble root growth is noticeable due to the platform

[19] Cogdell, “From BioArt to BioDesign”, 28.
[20] Zhou et al., “Digital biofabrication “, 112.
[21] Ibid., 113.

it is presented on: a steel construction in the shape of typical Dutch houses frames the design, preventing its destruction. Thus, because the artwork is in need of exterior stabilisation, it does not work as a root system itself. Furthermore, a contextualisation of the design is missing because nature is not made part of the work or explicitly referenced. Therefore, the *Rhizome House* can be interpreted in multiple ways, for instance as the interconnectedness found in the environment or as a metaphor for the interaction between art and technology.

Scherer's work also visualises the entanglement of nature and culture. In an architectural setting, one could name it inside and outside. This distinction is addressed in Abel's manifesto:

> Biotech architecture presents *no artificial boundaries between architecture and nature*, or between human and organic growth and development. It embodies the same principals of *energy efficiency and dynamic balance* between different forms of life as those governing nature's own ecosystems.[22]

Exactly because biotech architecture's aim is to sensitise people to question their concept of nature, the implementation of nature through technological means calls for a blurring of the boundaries between culture and nature, between the built and the natural environment. The design should create a feeling of enclosure of humans in the ecosystem. Although Abel did not conceive this aspect literally, but rather in reference to the simulation of natural energy efficiency in the architectural realm, the interpretation of this quotation in a literal way can open up a new form of architecture.

In that sense, biotech architecture undermines what is regarded as a basic requirement of architecture: it merges nature with culture and outside with inside. In his theory of autopoiesis of architecture – which describes architecture as a self-regulating field that creates its own structure and components –, Patrik Schumacher explicates the principle of architecture as follows: "It is this distinction of inside vs. outside that is constitutive of architecture as a very specific design discipline. There can be no architectural design that does not produce this difference."[23] Schumacher, here, points not only to the architectural discourse as an inside differentiated from an outside societal system, but also to the literal inside of the architecture that separates itself from an outside environment. The introduction of living entities into the architectural design through technological tools challenges this differentiation and aims to overcome it. Roger Paden, too, stresses the potential of a new aesthetics to overcome this distinct boundary: "An environmental aesthetics […] would emphasize connection and interpenetration [of inside and outside], differences in scale, and fortuitous juxtaposition."[24] As

[22] Abel, *Architecture, Technology and Process,* 243.
[23] Schumacher, *The autopoiesis of architecture*, 168.
[24] Paden, "Aesthetics and Sustainable Architecture", 25.

will be illustrated on the basis of the analysis of the case study in chapter 3, biotech architecture does not constitute an inside space as the refuge from an outside anymore. Rather, the architecture removes the artificial boundary between culture and nature, that could only be generated by architecture, and transforms the outside environment into an inside space that does not detach humans from the environment but supports undisturbed daily routine in nature. This entanglement of the two spheres allows for a bodily engaging experience of the environment (that includes both the architecture and nature), as Paden accentuates.[25] In order to better understand the significance of the connection of the built and the natural environment and its influence on human values, the next chapter will introduce the biophilic hypothesis.

1.2 Biophilic design

Biologist Edward Wilson describes the concept of "biophilia" as "the innate tendency to focus on life and lifelike processes."[26] Wilson argues that for the survival of humanity it was of essence to focus on life – no matter in what form. Thus, the emphasis of the quotation lies on the word "innate", because the human species evolved in – and its survival was dependent on the knowledge of – the natural environment, as Kellert explicates:

> This reliance on nature reflects our biological origins as a species. We evolved in a natural world, not an artificial or human-created one. For more than ninety-nine percent of our history, our fitness and survival depended on adaptively responding to the ongoing demands of the natural environment, which drove the development of our senses, emotions, intellect, and spirit.[27]

Kellert, here, points not only to the development of the complex human mind, that is conscious and highly intelligent, but also of humans' affective states, that enable them to feel emotions and be sensitive to their environment. Biophilia can therefore be expanded into the field of aesthetics: our aesthetic aversion or attraction to different kinds of living beings can be explained on the grounds of the knowledge about their advantages or disadvantages in an evolutionary context.[28] Hence, Kellert argues that humans are more aesthetically attracted to certain animals or non-animated natural scenes than to others. For example, to argue on the basis of Kellert's observation[29], a widespread aversion towards rats but an appreciation of squirrels can be observed – although they both belong to the family of rodents. Due to the fact that those seemingly arbitrary aesthetic judgements exist across cultures and history, Kellert

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[25] Paden, "Aesthetics and Sustainable Architecture", 23.
[26] Wilson, *Biophilia,* 1.
[27] Kellert, *Birthright*, x.
[28] Ibid., 3.
[29] Ibid., 1.

concludes that they reflect human evolution, thus, are passed down from generation to generation according to adapted responses.[30] Moreover, the aesthetic appeal of the environment had (and could continue to have) the function to bring order into a chaotic world. It helped early humans to concentrate on important things and through recognising and reiterating nature's patterns a sensually appealing order could be established.[31] This special bond between humans and the environment on an aesthetic level suggests a great potential for architecture because it justifies sustainable design not only on an instrumental level but an evolutionary-driven one.

Biophilic design, therefore, aims to reintegrate this innate bond of life and natural processes into architectural designs. Due to the diversity of natural forms and patterns, biophilic design, too, is not limited to a specific set of attributes. There is, however, one rationale that dominates biophilic design practices. It is what Boomen et al. call the "[fading of] the boundaries between culture and nature and between cities and ecological systems."[32] Because the entanglement of natural and humanmade materials is intrinsic to biophilic design and it is inspired by nature as a self-sufficient system, the term is commonly expanded to biophilic cities. The objective is to create an urban cityscape that is reminiscent of an ecosystem. As Timothy Beatley remarks, biophilic cities have to integrate nature both in outside areas and the inside of buildings, as people spend more than 90% of their day inside.[33] By paying attention to both outdoor and indoor spaces, the blurring of the boundaries between the natural and the built environment can be realised. This can be achieved by embedding living entities into the interior design, such as green walls, or non-living processes taken from nature – as can be observed in Fig. 4. This study hall located at Leiden University designed by Tjeerd Dijkstra offers working places surrounded by plants and illuminated by a roof-encompassing skylight that does not detach the visitors from the sense of time but enables experience of time's passage by means of natural cues.

This biophilic design example shows that the integration of nature is not restricted to plants but can include the development of a design according to natural processes. In this respect, Kellert makes a subdivision of natural experience: direct experience of nature (which includes every immediate contact with nature, for example, light, animals, water and plants), indirect experience (referring to the experience of nature in the form of materials or artworks as well as the possibility of experiencing the passage of time), and lastly, the experience of space and place (this means the perception of specific natural spaces in a positive way, for

[30] Kellert, *Birthright,* 7.
[31] Ibid.
[32] Van den Boomen eds., *Urban challenges, resilient solutions*, 11.
[33] Beatley, *Handbook of Biophilic City Planning & Design*, 20.

instance, as a place that allows mobility).[34] All three aspects of experience of nature presuppose a human perceiver. Thus, although they aim to reconnect humans and nature, the design incentive is solely shaped by a human subject. By introducing biotech architecture through the moral interpretation of the biophilic hypothesis, those guidelines for biophilic design will be expanded in order to include the natural environment as a subject in design processes.

Surrounding oneself with nature, interacting with natural environments and relocating humans in the ecosystem, can lead to effects on the moral and ethical attitudes of humans towards nature. With his biophilic hypothesis, Wilson concludes that "to the degree that we come to understand other organisms, we will place a greater value on them, and on ourselves."[35] This is easier said than done – as Wilson further explicates, the development of a valuing or moreover moral attitude towards something is highly dependent on the experience of immediate time and space.[36] That means that humans place a greater value on something if it is temporally and spatially connected to their survival and well-being and that of their family. That makes thinking about successional generations or places that are far away from one's own living area extremely difficult. Nevertheless, that implies that when integrating immediate natural environments into humans living spaces, so that they can experience nature as a valuable part of their lives, they will develop a sense of ethical obligation to care for it.

However, humanity currently shows a behaviour that exploits and destroys the environment, which has grave implications on a social and ecological level: we are in the midst of the sixth mass extinction, resources are rapidly decreasing and diseases are spreading faster and more easily.[37] Governments answer to this with "sustainable development" – this concept should support humans' urge to develop and at the same sustain the environment in that way that it keeps on providing resources and habitats for all species. Ironically, one of the 17 sustainable development goals of the United Nations includes economic growth.[38] As Holden et al. point out, if humans have to recognise resources as finite and the environment as limited, economic growth cannot be a viable development.[39] The return to biophilic practices can therefore pose as a corrective to the capitalist notion. This is also acknowledged by natural philosophy, as Wilson remarks:

> Natural philosophy has brought into clear relief the following paradox of human existence. The drive toward perpetual expansion – or personal freedom – is basic to the

[34] Kellert and Calabrese, *The Practices of Biophilic Design*, 9.
[35] Wilson, *Biophilia,* 2.
[36] Ibid., 2.
[37] Kellert, *Birthright,* xi.
[38] United Nations, "Sustainable Development Goals", Accessed 25 March 2021, https://www.un.org/sustainabledevelopment/sustainable-development-goals/
[39] Holden et al., "The Imperative of Sustainable Development", 213-214.

> human spirit. But to sustain it we need the most delicate, knowing stewardship of the living world that can be devised.[40]

He goes on noting that in order to be able to solve this paradox, its premise has to be changed "into forms more suited to ultimate survival, by which I mean protection of the human spirit."[41] The protection of the spirit refers to the approach to solving the environmental problems by reviving a biophilic human behaviour. Due to the paradox of modern society presented in the quotation, it seems inevitable for human behaviour to change. In the following chapter the urgency of a different approach to sustainability than the one relying on development will be discussed.

1.3 Sustainable architecture

The attempt to describe what sustainable aesthetics are is an inherently difficult one. There is no definite right answer to this question because it very much depends on the social and environmental circumstances for what is aimed to be sustained. In the following chapters, the use of the words "sustainable" and "sustainability" are intended to illustrate a "bottom-up" principle that does not presuppose a specific environment that has to be sustained and at the same time does not impose a certain aesthetic on the environment when introduced in architecture. This "bottom-up" rationale is also supported by Boomen et al., who remark that instead of conducting research before designing an object, viewing speculative design as the research per se could demonstrate to humans what their future could look like and mobilize them.[42] In that way, the laboratory and studio spaces open their doors to the outside world and conduct their research together with the people for those people. In architecture as well as in the sustainability discourse it is important to take on a bottom-up approach instead of top-down thinking. Unfortunately, both concepts are currently dominated by a top-down behaviour under the burden of the capitalist system.

In her theory about a posthuman urbanism, Debra B. Shaw remarks that contemporary cityscapes are the materialisation of the capitalist system. The structure of such cities supports the aggregation and the flow of capital.[43] The financial crisis in 2008 showed that capital and housing, especially in the United States, are intrinsically tied. Even European cities were deeply affected by this crisis, leading to privatization of public transportation and budget cuts for public

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[40] Wilson, *Biophilia,* 140.
[41] Ibid.
[42] Van den Boomen eds., *Urban challenges, resilient solutions*, 15.
[43] Shaw, *Posthuman Urbanism*, 4.

institutions.[44] These findings suggest that modern cities are primarily designed for – and controlled by – elites to satisfy their needs. Shaw notes that this capitalist paternalization of the urban space leads to architectural top-down solutions that do not consider the urban inhabitants as their subject.[45]

The definition of "sustainability" is dominated by capitalist notions in a similar way. As the discussion above already showed, economic growth is a key aspect in the sustainable development goals of the United Nations. In 1987 the UN's definition of sustainability was as follows: "Sustainable development is development that meets the needs of the present without compromising the ability of future generations to meet their own needs."[46] Human needs play the central role in their definition and objective. Making economic growth one of the 17 aims, too, shows that this interpretation of sustainability builds up on the same system that has sparked the crisis, namely capitalism. In other words, sustainable development promotes constant changing of the outer, material world by disregarding systematic, ideological change. To resolve the problem of fulfilling human and environmental needs at the same time, the capitalistic system that supports growing consumption and economic inequality has to be reconsidered and ultimately replaced by a less exploitive way of thinking and acting.[47]

On these grounds, the imperative of sustainability should be to deconstruct a materialistic perspective on the world. The goal is not to replace the rational, instrumental thinking with mere intrinsic valuing of the non-human world but to create a balance between the two. In the context of economy, Max Weber differentiates between four different approaches to social action: instrumental, intrinsic, affectional, and traditional[48]; whereby he especially takes up instrumental and intrinsic valuing to describe social relations, which should consist of a counterbalanced existence of both factors.[49] According to Weber, someone who thinks instrumentally in a social situation, constantly weighs up their aims with the means it takes to reach those goals and the possible consequences arising from achieving it.[50] In contrast, intrinsic behaviour is characterised as action that is based on one's own beliefs about what is right and important.[51] Thus, in a social interaction, Weber notes that instrumental valuing points

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[44] Turcu et al., "The impact of the global financial and economic crisis on European cities", March 2015, Accessed 26 April 2021, https://www.ucl.ac.uk/public-policy/sites/public-policy/files/migrated-files/Crisis_briefing.pdf
[45] Shaw, *Posthuman Urbanism*, 4.
[46] United Nations, "Report of the World Commission on Environment and Development: Our Common Future", 1987, Accessed 19 March 2021, http://www.un-documents.net/our-common-future.pdf
[47] Van den Boomen eds., Urban challenges, resilient solutions, 50.
[48] Weber, *Wirtschaft und Gesellschaft*, 12.
[49] Ibid., 21.
[50] Ibid., 13.
[51] Ibid., 12.

to the expectations someone's has on the other, whereas intrinsic valuing relates to one's own liability.[52] Regarding the sustainability discourse, Weber's argumentation signifies that to engender a well-balanced social relationship between humans and nature, the behaviour of humans towards the environment should not only incorporate expectations concerning nature's material worth but also the responsibility of humans to act rightfully without thinking about their own benefits.

Design-based research constitutes an approach that functions as a bottom-up practice. This aligns with the theory of aesthetic sensibility as formulated by Arnold Berleant. He notes that every idea and practice is only measurable in a human context, concluding that every assertion is based on the "physical, social and historical conditions of a human environment."[53] Berleant makes evident that the human environment directly correlates with human thinking. Thus, by shaping the human environment aesthetically, human thinking will also be influenced. The significance of aesthetics becomes more apparent when looking at its etymology: the term "aesthetics" is derived from the Greek words *aisthetikos* meaning "of or for perception by the senses" and *aisthanesthai* meaning "to perceive, to feel".[54] Hence, aesthetic in that sense points not solely to the beauty of an object, it also includes how the object is perceived and sensed.[55]

Sensual perception is the most immediate way humans can experience their outside world. Senses make contact with the environment possible and therefore function as an intermediary between the object that is perceived and the abstract concepts that humans create in their minds. In other words, the idea humans have of the world around them is shaped by their perception. This assertion can furthermore be reversed, so that it can be argued: The way humans shape their environment influences how they perceive it and, hence, how they think about it. This directly follows Berleant's reasoning when he remarks: "[…] for there is nothing to which we can appeal that is outside or beyond the domain in which we think, live, and act. This domain is inevitably the ground condition of all inquiry."[56] It can therefore be reasoned that aesthetic experience might be subjective, but in no regards irrelevant or inferior to quantitative approaches for gaining insights into the world. If the proclaimed goal is to create a sustainable society, one that lives, acts and thinks sustainably, changing the way it perceives

[52] Weber, *Wirtschaft und Gesellschaft*, 22.
[53] Berleant, *Sensibility and senses,* 9.
[54] "aesthetic", Online Etymology Dictionary, Accessed 25 February 2021, https://www.etymonline.com/word/aesthetic#etymonline_v_5184
[55] Berleant, *Sensibility and senses,* 15.
[56] Ibid., 9.

the environment is of great importance. Thus, a sustainable aesthetics can function as a bottom-up principle by making nature visible as a mutual part of the environment.

2 Composing – Decomposing

The number of innovative materials for a more ecological building practice seems to be increasing exponentially. Solutions vary from bricks made out of mycelium or demolition debris, to panels consisting of recycled clothes or hemp fibre. The project *The Exploded View* (Fig. 5) by the design group "New Heroes" combines various biobased and recycled materials in one architectural design. The fabricated walls made out of food waste, fungi and sewage water, amongst other materials, display the designers' research progress, whereas the voided spaces of the house show that there is still potential for further research with different materials. An important characteristic of the materials that the designers used and created is that they can be placed in a so-called "circular economy" – either because they are biodegradable or they create new products out of waste, or in other words, material that already exists. It seems as if with such innovations two problems can be solved: reducing CO_2 emissions due to production of low energy materials and reducing waste. From a mere constructional point of view, this criterion seems to be sufficient – so current materials merely have to be substituted by circular ones. Nevertheless, an aspect of circular economy that has to be criticised, especially in the context of the sustainability discussion above, is that by solely tackling the problem at the end of the value chain the bigger problem is kept out of sight, namely the reconsideration of the economic system creating the huge amount of waste. Thus, instead of trying to reuse waste products, solutions for the avoidance of waste production have to be developed and the relationship between humans and the object they use have to be strengthened – turning away from overconsumption and a throwaway mentality.

To escape this vicious circle of innovation, Bruno Latour proposes a concept of composition. The procedure of composing, according to him, points to a cautious and attentive state of remodelling the world. Latour defines compositionism as a task "of searching for universality but without believing that this universality is already there, waiting to be unveiled and discovered."[57] A compositionist does not rush their composition but pays attention to the task and the dynamic circumstances around it.[58] In that sense, the compositionist does not take any knowledge for granted or impose presupposed knowledge on the composed world.[59] This idea of composing describes a bottom-up approach that serves as a basis for sustainable design because in its definition it includes the need of a designer who is considerate of all individual parts without disregarding the desired whole solution. This can be related back to biotech

[57] Latour, "An Attempt of a 'Compositionist Manifesto'", 474.
[58] Ibid., 487.
[59] Ibid., 488.

architecture, more precisely to the fifteenth point of Abel's text: "Biotech architecture implies integrated design. It involves designing building, subsystems and components all together in a collaborative process to achieve the highest possible performance for the whole."[60] Abel, like Latour, highlights the significance of designing buildings whose parts are equally important as the whole composition. This signifies the composition of biotech architecture is not dominated by a hierarchy of the parts but forms a harmonious unity of the building, its parts and nature.

2.1 Environmental aesthetics of sustainable materials

In context of architecture, Roger Paden points out that sustainability must not only be considered when discussing the function of architecture, but also its form.[61] As the discussion of the biophilic hypothesis and Berleant's theory about aesthetic sensibility illustrates, aesthetics play an important role in how humans perceive their environment. Paden points out that sustainable aesthetics, as he calls it, should not only reflect the building's function but should "tell us about nature and our relationship with it."[62] Bringing this into agreement with Berleant's view on perception, sustainable aesthetics should enable a perceptual and sensual experience that contributes to a better understanding of the human-nature relationship. In order to achieve that, the design, when incorporating the environment into a building, has to engage more senses than just the visual. The study of architecture as opposed to paintings and sculptures relies on an embodied perceiver. Paden highlights the importance for sustainable aesthetics to break with the concept of the viewer as an outside observer. Thereby, Paden equates the reduction of architecture to its visual appearance with the over-emphasis of a building's façade.[63]

To heighten this intricate relationship between the perceivers and nature, another feature has to be included in sustainable aesthetics, namely, as Paden argues, the integration of the building in the environment.[64] Thus, sustainable aesthetics should also include the entanglement of the natural and the built environment, the blurring of boundaries between what is broadly called nature and culture. This aspect of sustainable aesthetics would enable the destruction of the clear separation of inside and outside space carried out by architecture. Paden notes that if the architect strives to create a building with sustainable aesthetics, those buildings "should not be given 'frames,' separating them from the environment and making them into isolated self-referential objects. […] Rather than making their own statements, buildings should echo those

[60] Abel, *Architecture, Technology and Process,* 243.
[61] Paden, "Aesthetics and Sustainable Architecture", 13.
[62] Ibid., 26.
[63] Ibid., 23-24.
[64] Ibid., 25.

made by the surrounding environment."[65] Buildings should therefore not only work as sustainable systems by themselves, their design should refer to the environment that surrounds them. However, the aesthetic reference to the environment can take two forms, according to Paden, depending on the concept of nature on which the design is based. On the one hand, the aesthetics can be dominated by clear lines, harmony and regularity, stemming from the character of science as explaining nature with the help of laws and rules. On the other hand, science can also lead to another understanding of nature that underlines its complexity and imperfection, leading to aesthetics that implement those features.[66]

To better illustrate the significance of these characteristics, the idea of green walls with the example of the "vertical garden" in a shopping street in Palm Beach, Florida (Fig. 6) can be consulted. This particular green wall, although called vertical garden by the local tourist information website[67], rather resembles an abstract painting. The forms that the plants create are inherently artificial, imposed on them by a steel grid. In this way, the green wall does not offer a space for a natural ecosystem but instrumentalises nature for human pleasure. Quoting the company that designed the green wall, the wall was built to "restore [the street's] charm and attract shoppers."[68] Attached on an outer wall of a shopping centre, the green wall functions as a tool for aggregating costumers and generating cash-flow. In that sense, the façade covers up a capitalist building, the sustainable idea behind the design is lost and is not an imminent part of the architecture's design Besides ideologically re-interpreting the sustainability of the green wall, the façade in Palm Beach illustrates the strict border that exists between culture and nature as the piece is attachable but detachable at the same time – the incorporation of the building into the natural environment is not a notion that shapes the architecture's form. Rather, the green wall is a construction element that can be added and subtracted to keep up with shifting consumer taste.

This begs the question: can a building practice that is merely incorporated as an "afterthought" [69] (to borrow Paden's term) truly be considered sustainable architecture? Because sustainability is an issue that is so frequently utilised by politicians and one that initially appeared in a scientific context, it is denied any aesthetic value, in that sense that the

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[65] Paden, "Aesthetics and Sustainable Architecture", 25-26.
[66] Ibid., 26-27.
[67] Hilda Mitrani, "Vertical Garden at Shopping District in Palm Beach, FL", *Visit Florida*, Accessed 25 April 2021, https://www.visitflorida.com/en-us/things-to-do/outdoors-nature/vertical-garden-at-shopping-district-in-palm-beach-fl.html
[68] Gsky, "Palm Beach – Worth Avenue", Accessed 25 April 2021, https://gsky.com/portfolio/palm-beach-worth-avenue/
[69] Paden, "Aesthetics and Sustainable Architecture", 7.

imperfect side of nature is not aesthetically appreciated but only the pure one. Ascribing a high level of significance to aesthetics, i.e., aesthetics that underline the complexity of natural processes, in the context of sustainable design could prove to be beneficial for the ecologization of architecture. As Berleant describes aesthetic sensibility: "For aesthetic appreciation is not sensory delectation but an entrance into domains of understanding that lie outside the boundaries of empirically verifiable scientific knowledge, of linear rationality, as it were."[70] Hence, it can be concluded that green façades – or similar tools – do not suffice for sustainable aesthetics. In the following chapters, examples that meet the presented requirements will be presented.

2.2 Comparing concepts of nature used in new architectural materials

The same can be said for certain biotechnological, architectural solutions. Bioreceptive materials are proposed by Marcos Cruz and Richard Beckett as both a solution for environmental problems and an aesthetic for sustainable architecture. Together with the Bartlett School of Architecture, theses designers researched the possibility of bioreceptive architecture in the form of panels (Fig. 7). Those panels are receptive to species like mosses, fungi and lichen – which are enormously important for the biosphere, in that they absorb pollutants, such as carbon dioxide or nitrogen oxide,[71] they regulate nitrogen intake for other plant species and serve as nutrition for animals (a fact which was disregarded by Cruz and Beckett in their description).[72] Their designs represent a mixture between a top-down and bottom-up approach: firstly, bricks are produced – which primarily consist of cement, however, Cruz and Beckett also propose materials like sandstone or cellulose – which in a further step are colonised with algae cells and moss spores. The panels are then placed outside to develop a first state of growth. According to the researchers, their bioreceptive panels are functionally inspired by tree barks. The tree bark as a model for architectural design can substitute the common notion of architecture as skin because the bark mediates between "internal and external conditions"[73] and allows growth on its surface.[74] Furthermore, they remark: "The architectural bark is not to be understood solely as a biomimetic extrapolation from nature to architecture. In design terms, it is a concept that derives from a specific phenomenon in nature but goes beyond its formal or

[70] Berleant, *Sensibility and senses*, 82.
[71] Cruz and Beckett, "Bioreceptive design", 52.
[72] Turetsky et al., "The resilience and functional role of moss", 51.
[73] Cruz and Beckett, "Bioreceptive design", 51.
[74] Taking these aspects as differentiation of bark and skin is epistemologically false. The characteristics Cruz and Beckett list to distinguish between the two can actually be found in both those types of protective and regulative surfaces.

functional mimesis."[75] Their architectural bark expands on the notion of functional and formal mimesis because the panels are bioreceptive, meaning that the panels support the growth of other species on the building. Thus, their design not only mimics a certain environment but also tries to integrate an ecosystem into the architecture. Both those aspects resonate well with Paden's criteria that sustainable architecture should give information about nature and at the same time connect both spheres.

Nevertheless, the aesthetic appearance – also in the extended notion of sensory perception – of the bioreceptive panels as Cruz and Beckett propose them cannot be seen as an example for a sustainable aesthetics. In fact, on the basis of their descriptions of the panels' aesthetics, it seems as if they cannot decide on a specific aesthetics. On the one hand, they argue for an "impure aesthetics"[76], criticising the common practice of removing growth from buildings to "maintain the integrity of materials while safeguarding a much desired 'aesthetic of cleanliness'."[77] On the other hand, their scaffolds incorporate aesthetics of the twentieth century, resonating with Art Nouveau and Art Deco motifs – as they remark themselves and defend by bringing forward the possibility of a negative perception in case of uncontrolled, ugly growth.[78] The design incentive of Cruz and Beckett, namely accentuating impure, natural patterns, and the developed panels contradict each other.

The panels clearly reflect patterns and forms found in Art Nouveau buildings, for example, the *Frison House* by Victor Horta (Fig. 8). In the inside of the house multiple glass surfaces can be found that are decorated with delicate iron braces. Those braces are arranged in both geometrical shapes and more natural, contorted lines. The pointed forms that dominate the bioreceptive panels can also be found in the acute glass ceiling and the herringbone structure of the floor of the *Frison House*. Inspiration from nature was taken in the fin de siècle in order to support human needs. As Hector Guimard, an architect from that time, remarked: "Nature is a big book from which we can draw inspiration, and it is in that book that we must look for principles, which, when found have to be defined and applied by the human mind according to human needs."[79] This illustrates the utilitarian view that architects had of nature during the ascendancy of Art Nouveau aesthetics. Aspects of nature were deemed appropriate for architecture if they were useful for satisfying human needs. Such a notion of nature, as implemented by Art Nouveau architects and Cruz and Beckett, heavily imposes familiar

[75] Cruz and Beckett, "Bioreceptive design", 52.
[76] Ibid., 63.
[77] Ibid., 53
[78] Ibid., 55.
[79] Grady, "Nature and the Art Nouveau", 188.

aesthetics on nature that are artificial and negates the ability of natural environment to develop its own aesthetics that can be appreciated by humans. The aesthetics Cruz and Beckett inflict on nature, when seen through Paden's differentiation of sustainable aesthetics, reflect a concept of nature as harmonious and dominated by human actions. The understanding of nature as chaotic and dynamic, however, would suggest giving nature the freedom to unfold its own aesthetics and therefore, enable an appreciation of nature that is based on natural pattern-forming.

In that sense, the aesthetics of the panels do not resemble tree bark or offer information about nature and the human relationship with it. In contrast, they mimic the environment and convey this in an aesthetic manner produced by humans for humans. Even if this seems like a minor problem compared to the (apparent) great benefit of fostering the settlement of those species in an urban environment, this aesthetic paternalism over nature reflects the general relationship between humans and nature. The bioreceptive designs originate from and support the utilitarian perception of nature imposed by capitalism. They are based on a disembodied nature as an architectural object, whose aesthetics are guided by functional considerations. The design is reduced to one utilitarian advantage of mosses, lichen and fungi in the urban landscape: the absorption of CO_2. They not only leave out the species' important role in the whole ecosystem (that seems at first detached from humans) in their description but also in their design. The mosses, are purely reduced to one beneficial aspect out of their natural metabolism, entirely striped from their other functions in the ecosystem.

Another example that works with bio-technology in designing new materials for architecture and at the same time tackling humans' view of nature are the designs of Neri Oxman with her team *Mediated Matter*. Her and her teams' work is profoundly shaped by what Oxman calls "material ecology"[80]. This theoretical concept emerged from Oxman's observation that in industrial design practices objects are made out of standard parts which consist only of single materials that are given specific functions. Criticising those procedures, material ecology "aims to establish a deeper relationship between the design object and its environment."[81] Environment, here, is meant as the specific environment the object is located in. Furthermore, an aspect that frequently is addressed in the group's practice is the object's ability to integrate itself back into the natural cycle after its use by decomposing. Oxman, for example, remarks: "Organic structures embody more efficient and adaptable material properties compared with

[80] Oxman et al., "Material ecology", 1.
[81] Ibid.

human-made ones, and leave no marks."[82] Leaving "no mark" is inspired by the earth's ecosystem where every waste material is reused by another entity in the ecosystem. In a time in which microplastic is already detectable in the Arctic ice, humans have to question themselves how far their waste production and handling with waste can go. Especially in a field where single-use materials are still the main materials used, creating sustainable architecture calls for the idea of decomposing as a principle for the designs – either in the sense of decaying materials, or objects that can be taken apart into reusable elements. Acknowledging the finiteness and life sustaining significance of raw materials must be the point of origin for sustainable architecture.

Both those points, on the one hand, the relationship between the design and the environment and on the other hand, the aspect of decomposing, then have an influence on the composition of Oxman's design; the aim of her practice is to inform people "how buildings and products are made and how their shape and material composition may perform in harmony with the ecosystems they inhabit."[83] Oxman's material study *Aguahoja* (Fig. 9) displays how aesthetic features can be informed by natural conditions of the surrounding environment. The object is a pavilion measuring five meters, consisting of a white core structure that divides the pavilion into sections. Those sections are filled in by the biopolymer material ranging in different hues of brown. The overall shape and colour of the pavilion might remind the viewer of a dried, involute leaf, which not only reflects the origin of the material but also its demise – the aesthetic of the pavilion is therefore spatial and temporal at the same time, combining past and future in a present design. However, what the designers focus on with this object is not its holistic aesthetic but its material, which is made out of 5740 fallen leaves, 6500 apple skins and 3135 shrimp shells. Resulting from this mixture of organic matter is a biopolymer. Therefore, the material was primarily composed as a substitute for plastic.

The composition of the objects is produced by a 3D printer, which prints lattice-like structures that are constructed to incorporate considerations about adaptation to external conditions, such as sunlight and humidity. Through evaporation after the completed printing of the composition, the object gains its rigidity. This relation to air conditions makes the object sensible to humidity and heat, so that the perceiver attains information about outside conditions through the adaptation of the material. In the case of *Aguahoja*, its aesthetic appearance can be adapted to preferences about densely or coarsely meshed structures, opacity or transparency, flexibility or rigidity. Not only can the design then be holistically perceived as a whole

[82] Oxman, "Aguahoja", Accessed 01 March 2021, https://oxman.com/projects/aguahoja
[83] Neri Oxman, "Neri Oxman", Accessed 01 March 2021, https://oxman.com/

sustainable building but it also – in line with Paden's argumentation – intertwines the natural and built environment through aesthetic interaction of the material. Here lies the potential of biotechnologically produced materials: because the materiality is so inherently entangled with the aesthetic features, the perception of the material can contribute to the understanding of the architecture's design principles. Unfortunately, it seems as if the material studies of *Aguahoja* have not been able to program the material so that its decay can be controlled by the user. It is stated in the object's description that upon contact with rain, the material will start decomposing itself.[84] This makes the material, to this point, still unusable for architectural practices. Nevertheless, the aspect of decomposing that is the inspiration and source of the object gives it a temporal frame that places the human back into the centre of a circular environment – even if the object deteriorates after the first rain, that only accentuates the circular movement of ecosystems and demonstrates how more attention to composition and decomposition could possibly transform architecture.

Oxman's object makes apparent the ways in which form and function must be entangled to create a truly sustainable architecture. The principle of composing for decomposing is reminiscent of the famous phrase of modern architecture and industrial design "form follows function". However, the difference between the modern notion and Oxman's ecological version of "form follows function" lies in the source that creates functional needs. Whereas modern architecture was focused on the development of buildings that fulfil the new needs and satisfy the high standard of living of modern society, ecological architecture is more concerned to also include the needs of the ecosystem in the designs. Therefore, the function that influences form does not only emanate from human needs but also from environmental ones; a part of human functional needs, nevertheless, also originates from environmental circumstances, such as temperature regulation or capturing of daylight. As the analysis of Oxman's biopolymer showed, the composition is amongst other things shaped by environmental conditions and therefore relocates humans into an ecosystem through aesthetic perception of said environment. Considering environmental conditions when creating materials then not only becomes important for guaranteeing the longevity of a building but also for influencing the aesthetic appearance of the material.

[84] N. Oxman, "Aguahoja"

3 Growing

Through the illustration of biotech architecture's characteristics of "growth", the following chapter argues that merging environmental and architectural performance leads to a higher sensitivity towards natural processes and therefore, elevates the biotech architecture from an object, that is perceived, to an equal subject that possesses agency. This argumentation is based on point ten of the Biotech architecture manifesto, which states: "Biotech architecture is self-organizing. It is not a fixed or final product, but is more like a biological organism, continuously learning about itself and its surroundings, adapting to changing conditions and improving its own performance."[85]

The following architectural designs will spawn an extension of this aspect by not merely being "like a biological organism" but actually being a biological organism and constituting a performance that is perceived in terms of agency of a living entity. The importance of recognizing the agency of natural entities can be illustrated with the example of artificial plants. Such plants imitate the aesthetics of their natural opponent meticulously. However, what they cannot adopt are the plant's needs. On one hand, this can be an advantage because they can be placed in every corner of the room regardless of solar irradiation and irrigation. On the other hand, because of their independence from humans, they can easily be forgotten. Whereas the artificial plant exists mostly detached from human action, a real plant, through its domestication, is in need of human care. An interaction emerges whereby exercised human actions, like watering the plants, results in an observable reaction that shows either positive or negative effects. Moreover, natural movements of the plants according to the passing of the sun discloses their livelihood. The plants, therefore, display agency which is detached from humans but shows their life processes, which, according to the biophilic hypothesis, humans can relate to. Putting this into the context of architecture, the introduction of bio-hybrids shifts the design from biomimicry towards an active, self-referential architecture.

3.1 Autopoiesis

The notion of agency in a bio-hybrid architecture directly leads to the idea of autopoiesis – not in the sense of Schumacher, as discussed above, but in its initial definition. First introduced by Humberto Maturana and Francisco Varela, autopoiesis describes a system that "continuously generates and specifies its own organization through its operation as a system of production of its own components."[86] Therefore, an autopoietic system consists of a network of processes that

[85] Abel, *Architecture, Technology and Process*, 243.
[86] Maturana and Varela, *Autopoiesis and Cognition,* 79.

disclose the system as a unity. According to Maturana and Varela, when humans encounter an autopoietic system they regard it as a living system:

> In our common experience we encounter living systems as unities that appear to us as autonomous entities of bewildering diversity endowed with the capacity to reproduce. In these encounters autonomy ap[p]ears so obviously an essential feature of living systems that whenever something is observed that seems to have it, the naïve approach is to deem it alive.[87]

This inclusion of autonomy in the definition of Maturana and Varela focuses more on the autopoietic system as distinct from its environment. In his analysis of the autopoietic theory, Ezequiel di Paolo further explains the significance of adaptivity for autopoietic systems: "If autopoiesis in the present analysis suffices for generating a natural purpose, adaptivity reflects the organism's capability […] of evaluating the needs and expanding the means towards that purpose."[88] In summary, autopoiesis describes a system that is firstly, self-generating and self-maintaining, secondly, a unity separate from its environment and lastly, responsive to environmental factors.

Those aspects of autopoiesis, when applied to architecture, can satisfy the call for a function-form relationship that was proposed in chapter 2. By introducing living entities that can still exercise their inherent autopoiesis, humans can perceive the specific entity as a living unity that possess its own agency and shows its independence from other entities. This is what expands autopoietic systems, and also biotech architecture, from what Di Paolo calls "simply a physical pattern" to a "self-distinguishing concrete unity".[89] An autopoietic architecture becomes a subject that through its own ability to act not only creates decorative patterns but a distinct performance. Furthermore, this performance is charged with meaning. Di Paolo, here, makes the distinction between a "movement of meaningful action", which can be artificially fabricated, and a "system acting meaningfully".[90] Thus, if a prerequisite for biotech architecture is to "tell" the perceiver something about the environment and the relation between the three entities, as was argued above, then the inclusion of living entities' immanent autopoiesis has the potential to convey meaning.

3.2 Trees as autopoietic architecture

A leading architecture research group in the field of biotech architecture is the collective Terreform ONE. The name derives from the words "terre" (earth) and "reform" (in the sense of

[87] Maturana and Varela, *Autopoiesis and Cognition*, 73.
[88] Di Paolo, "Autopoiesis, adaptivity, teleology, agency", 445.
[89] Ibid., 433.
[90] Ibid., 443.

rebuilding), insinuating their design principle to create an environment that is inhabitable for all species of the world for generations to come. With their project *Fab Tree Hab* (Fig. 10) the group designed a habitat for humans inside a network of plants. Trees, like elm, live oak or dogwood, can be used as load-bearing parts, that create the walls and the roof of the house (it is imperative for the project that the used trees are native to the environment the house is built in). The outside walls are supplemented with vines as an additional layer of protection and soil pockets for other plants. A mixture of clay and straw is used on the interior walls to insulate the house. To bring the trees into an inhabitable form, a practice called "pleaching", which describes the technique of weaving tree branches with the help of a structure that modulates their growth, is employed. In early stages of the trees' growth, a prefabricated, reusable CNC (Computerized Numerical Controlled) plywood scaffold is attached to guide the growth process and achieve a desired, inhabitable shape.[91]

The utilization of pleaching techniques in architecture is not a new invention of the twenty-first century. Early realizations of tree architecture in form of "living root bridges", that are still extant and created to today, can be found in the territories of the indigenous Khasi and Jaintia people in India. These people systematically planted branches of *Ficus elastica*, a native tree of the ecosystem, on both sides of a river. Aerial roots, which the tree develops in the adult stage of its growth, are controlled with the help of a scaffold made out of deadwood, such as bamboo. Through years of growing, the aerial roots develop a strong, interwoven structure that can safely be used as a bridge. The entire process, from the planting of the branches to the utilization of the finished structure, takes up to two decades.[92] However, the growing process is only a fraction of the bridge's lifetime: The Rangthylliang bridge (Fig. 11) is estimated to be 200 years old and still is adequate to use. The Living Root Bridges made by indigenous people enhance life in the communities in many ways. First of all, they connect the community with the farmland and therefore, are vital for their survival.[93] Moreover, the construction of the bridges is rooted in local tradition, making the passing on of the constructional knowledge from generation to generation an important moment to strengthen the identity of the people.[94] Lastly, living root bridges, as opposed to bridges made out of artificial materials, support the sustenance of local biodiversity and absorb carbon dioxide.[95]

[91] Joachim and Aiolova, *Design with Life,* 273.
[92] Middleton et al., "Characterizing Regenerative Aspects of Living Root Bridges", 3.
[93] Ibid., 4.
[94] Ibid., 14.
[95] Ibid., 13.

These examples of architectural practices utilizing the growth of trees illustrate two important aspects: first of all, in turning to nature to find solutions for ecological and architectural problems, designers return to century-old crafting methods. In the context of the biophilic hypothesis, the discovery of a prospective “new” design technique by reinterpreting indigenous constructions shows the great potential of a mutually beneficial affiliation of humans with nature. This affiliation is characterized by a close observation of natural processes and the utilization of the very same processes to benefit human activities without harming the ecosystem. Secondly, the potential of research by design and consequently, through bottom-up approaches is demonstrated. While the *Fab Tree Hab* by itself seems inherently speculative and hard to implement, by placing it in the context of living root bridges, it becomes more realistic and feasible because the successful implementation of the used technique is apprehensible. This, furthermore, accentuates the practicability of bottom-up designs. The bridge is generated by the people who use it themselves. Thus, the design does not exist before its locality is chosen, but it originates from the actual conditions of the environment, directly answering the problems that arise on site. It is created with locally disposable materials and techniques that do not necessitate extraordinary tools.

In the case of the *Fab Tree Hab*, the design is also realisable in different environments. Due to the fact that the building depends entirely on a living, growing tree, the environmental and social conditions have to be considered. Moreover, the availability of native malleable trees has to be taken into account. Regarding the weaving process, it can be questioned if the use of digital technology to produce the scaffolds is even necessary, since the root bridges show that scaffolds can also be made by hand. Creating scaffolds through technology provides an opportunity to capitalize on the design. But utilizing technology enables a bottom-up designs in a multitude of environments: the scaffold used for shaping the tree can be designed and altered according to needs and desires observed in the community and the natural ecosystem. The relationship between technology and the natural material, therefore, is subtle. The CNC scaffolds are guiding the growing process, in a way imposing a form on the trees. However, the imposed form differs considerably from the aesthetics the bioreceptive panels impose on nature. It does not reflect a form that has roots in human pattern-making but it generates a shape that is reminiscent of other species’ creation of habitats, for example, the excavation of trees by birds or of the soil by foxes. Thus, contrary to the material studies by Cruz/Beckett and Oxman, nature itself is not computed, only the scaffold that shapes the trees is. By not co-opting the natural computing system, but rather working with it symbiotically, the trees can still perform as an autopoietic system.

The *Fab Tree Hab*'s materiality is closely tied to nature's autopoiesis. Although the growth is influenced by the scaffold, the material and form of the house are produced by nature itself – unfortunately, making the design susceptible for diseases and termites. The tree is not robbed of its self-sustaining processes, such as developing roots in the ground or photosynthesis. Due to the perpetuation of nature's distinct agency, the tree's performance is transferred onto the building. The grown roots of the tree are also rooting the house to the ground, making it sturdy. Furthermore, the steady photosynthesis and seasonal change maintain the structure of the tree and the house equally. Those aspects underline the circular qualities of intertwining the building's and nature's agency: It is not a circularity that is based on creating materials for commodities, it rather searches for a space of cohabitation that is localisable in a closed loop of natural composing and decomposing. In other words, the *Fab Tree Hab* evolves in a natural system that already exists in one way or another and modifies it; no new product is fabricated but two habitats are merged with each other.

The specific entanglement of technology and nature as composing entities allows for the experience of all three biophilic experiential dimensions. First of all, perceiving the *Fab Tree Hab* is a direct experience of nature, in that it mainly consists of living plants and, ideally, if the building is placed directly into a larger natural context – as can be seen in Figure 10 – the treehouse is seen as a part of a natural community. Inhabiting the building, then, not only makes the direct experience of the tree as part of a network possible, but it is also possible to imagine oneself in this network. Secondly, the building offers an indirect experience of nature because the appearance of the plants changes in time due to the growth process and seasonal climatic conditions. Therefore, the perceiver can observe the dynamic transformation of natural patterns and forms. Because the aesthetics of the building are mostly produced by nature itself, the aesthetic appreciation of the architecture aligns with the appreciation of environmental aesthetics, hence, nature. Thirdly, through the architecture, nature is experienced as a space of refuge and safety as well as a place of relaxation and comfort. Because the design makes it seem as if the house was built as part of a tree, the clear architectural distinction of inside and outside vanishes. The building does not function as a divisive layer that allows the differentiation between being in nature or looking at nature from a detached space. It rather shifts the space that is protected from natural conditions into the natural environment, therefore, making the experience of nature as a safeguarding place possible.

As was already mentioned in chapter 1.2, the three experiential dimensions of biophilic design are developed around a human perceiver; the architectural requirements all derive from human needs. When incorporating nature as an autopoietic system into the building, thus emphasising its growing and changing feature, biotech architecture offers an architectural design that can satisfy the needs of both humans and the environment. Furthermore, it makes the inhabitants more aware of processes in natural ecosystems and strengthens the bond between humans and their surroundings owing to the transformation of nature into inhabitable space, which leads to its valuation on an emotional level.

4 Biodiversifying

As the following chapter will demonstrate, the final step in describing the qualities of biotech architecture as a sustainable design practice is to take the network-like characteristics of the environment into account. In the environment, all entities are interrelated; they form an ecosystem whose perpetuation depends on the flows between its parts. Gilles Deleuze and Felix Guattari described such a network in nature as a rhizome and opposed it to the metaphor of the tree as a hierarchical structure. A rhizome is firstly defined by the interconnection of its parts. There is no beginning and no end; there are only lines of connections. Therefore, the rhizome is characterised by the dissolution of hierarchy. Contrary to the tree, which according to Deleuze and Guattari is characterised by a hierarchical composition that is committed to order, no higher dimension regulates the rhizomatic network because it is solely constituted by the interrelated bonds between entities.[96] Based on such a concept, the integration of autopoiesis into design practices is not enough, on its own, to achieve sustainability. Because the maintenance of the natural environment is not only performed by the entity's own process of sustenance but also by the exchange with other entities, biotech architecture has to be composed in the context of a rhizomatic network itself.

Thus, I turn away from the metaphor of the autopoietic tree as a model for sustainable architecture in this section and look to what Donna Haraway calls "sympoiesis"[97]. As Thomas Schröpfer argues:

> Ecological projects should form part of the larger inhabitable environment rather than remain limited showcases of environmental science. To achieve this, new design methodologies and tools cannot be based primarily on performance terms, as projects will be successful only when they exceed the sum of their environmental technologies […][98]

Schröpfer stresses that the mere focus on performance-related aspects of architecture, which he mostly identifies with energy or water consumption, leads to an accentuation of the technological characteristics of the building. However, sustainable architecture as presented in the chapters above has to create a predominantly ecological design that utilizes new technologies but is not dominated by them. That does not mean that the proposition made in chapter 3, namely the integration of self-regulating elements into the design, is nullified through this refocusing. The acknowledgement of the autopoietic tendencies of biotech architecture illustrated that architecture can develop dynamic characteristics. Because the environment

[96] Deleuze and Guattari, *A thousand Plateaus*, 7-9.
[97] Haraway, *Staying with the Trouble*, 5.
[98] Schröpfer, *Ecological Urban Architecture*, 198.

consists of multiple agencies rather than static entities, the attainment of vitality then makes it possible to distinguish the building as a natural system.

To enable the experience of the world as an entangled space through the built environment, biodiversity has to be supported. Schröpfer notes that growing urbanization is a threat to biodiverse ecosystems, turning them into homogenous habitats that favour only a minority of species, whether it be plants or animals.[99] Cities therefore often actively create green spaces. However, as Schröpfer examined, this leads to an urban flora that is alien to the environment and is similar across a multitude of cities, which further accelerates the loss of biodiversity.[100] Moreover, he points to the importance of creating inclusive green spaces, thus, of actively designing green architecture that is accessible for every member of the society, rather than a private company building, since nature cannot be privatised.[101] Because the environment is regarded as a network that is formed through interacting entities, sustainable architecture should take on the same principle to be aware of environmental, social and cultural concerns.[102] Hence, it is important to not only strive to engender a connection between the natural and the built environment, which creates a biodiverse habitat, but also to respond to environmental, social and cultural circumstances of the surroundings to support the thriving of the multiple, interconnected species that find residence in the architecture.

4.1 Sympoiesis

In order to establish a theoretical framework for sustainable planning, M. Beth Dempster coined the notion of "sympoiesis" to describe the complexity of the natural and social world.[103] The development of the term was made in contrast to the concept of autopoiesis, as can be seen in Figure 12. In this table, Dempster differentiates between auopoietic systems, which are characterised by defined boundaries and are temporally finite, and sympoietic systems, which possess no boundaries and are temporally infinite. Dempster defines sympoiesis as a collective production inside a system. Contrary to autopoietic systems, no boundaries are produced in the sympoietic system that separate different components. Rather, boundaries are substituted with ties between the components.[104] Such a sympoietic system is therefore not hierarchically structured or controlled by a higher order, which aligns with Deleuze/Guattari's notion of the rhizome.

[99] Schröpfer, *Dense + Green Cities*, 88.
[100] Ibid.
[101] Ibid., 287.
[102] Schröpfer, *Ecological Urban Architecture*, 195.
[103] Dempster, *A Self-Organizing Systems Perspective on Planning for Sustainability*, 2-3.
[104] Ibid., 28.

Sympoiesis gained further recognition through the work of Donna Haraway, who used the concept to trace the complexity and interrelatedness of the Earth and its species.[105] Haraway notes that sympoiesis is an expansion of autopoiesis, in that sympoiesis encloses autopoietic systems in itself.[106] In the table, Dempster assumes organisms to be autopoietic systems and ecosystems to be sympoietic systems. Thus, on the basis of Haraway's argumentation, the sympoietic ecosystem is in need of autopoietic organisms for its proper function. To expand autopoiesis with sympoietic networks also signifies that a potential "ongoingness", as Haraway calls it, opens up.[107] That means that because no boundaries between entities exist, they strive to support and sustain each other; thus, the extermination of an entity is unlikely. Even if an entity disappears, the grief provoked by the loss of a valuable member of the sympoietic system results in the understanding of the problem and therefore can enable an appropriate response to solve the problem.[108]

Haraway makes this concept conceivable by bringing forward the example of the monarch butterfly.[109] The migration and survival of those insects is strongly dependent on a specific natural environment. Both larvae and adults of the eastern monarch butterfly in North America feed of a plant called "milkweed". Industrial agriculture threatens the existence of milkweed because of excessive herbicide use.[110] During their migration to the South, the monarchs typically rest and sleep in woodlands located in mountain areas. Those woodlands are being destroyed through illegal logging.[111] This particular interdependent existence of the monarch illustrates the importance of biodiversity for the functioning of a sympoietic system. If one of the entities in the system ceases to exist, the other entities are threatened as well. Such concerns are also taken up by designers. Especially architecture is suitable for counteracting the destruction of inhabitable spaces for other species, in that it can turn the human habitat, which it normally constructs, into a habitat of multispecies encounter.

Terreform One's *Monarch Sanctuary* (Fig. 13) provides one example of what a biodiverse, sympoietic architecture might look like. This design combines office spaces with a breeding and habitation ground for the threatened monarch butterfly. It accommodates a green façade, that consists of various plants and forms, shielded by a lattice-like construction and a green roof terrace; both serving as breeding areas for the butterflies. Equipping the building

[105] Haraway, *Staying with the Trouble*, 33.
[106] Ibid., 58.
[107] Ibid., 125.
[108] Ibid., 38.
[109] Ibid., 141.
[110] Ibid., 141-142.
[111] Ibid., 142.

with a green roof is especially important in relation to biodiversity of the city. Through an investigation of a multitude of green urban spaces, Schröpfer concluded that green walls do not suffice to support a multitude of species, particularly when an increase of flying species, such as birds and butterflies, is desired.[112] Unfortunately, the architects do not elaborate on the specific environment the building should be situated in, as Schröpfer notes that the immediate surroundings of green walls and roofs determine their success, i.e., they can rather biodiversify the city if they are placed close to other green areas.[113]

As can be seen in Figure 14, the roof terrace also features an entrance to an inside area for the monarchs, bringing the insects closer to the humans using the building. The rooftop is equipped with nectar plants and milkweed.[114] To guarantee optimal temperature and humidity for the thriving of the insects, EFTE (fluorine-based plastic) foil is added to the inside of the outer grid and algae are added to the green wall in order to filter air and water. The material itself, although long-lasting, does not suffice with the criteria of sustainable materials developed above. This project uses non-compostable materials that do not reference or incorporate nature. Furthermore, technology is deployed to monitor the well-being of the monarchs: butterfly-shaped drones continuously measure the climate and LED screens are placed at street level to display live recordings of the monarchs inside the building and raise awareness of the sympoietic system's ongoing activity.[115]

Primarily, the design appears as an attempt to help recover the monarch butterfly population and increase the existence of green spaces in the cityscape, thus, biodiversifying the urban region. The architecture demonstrates the potential of green technology to imagine and create an urban environment that serves as a multispecies cohabitation. However, the designers are aware of the fact that the building alone is not going to save the monarchs from extinction. Hence, the work is rather a demand for attention for the dramatic processes taking place in the environment. In bringing the monarchs in immediate proximity to humans, it strengthens the bond between the two entities and sharpens the knowledge of the interdependencies that exist in the natural environment. Therefore, the building turns the built environment into a sympoietic system and at the same time situates humans in this multispecies network, in that it accentuates the necessity of human action in building such habitats and the significance of conserving them.

Because this biotech design mainly focusses on tackling an environmental problem and thereby disregards the material of the building, it has to be challenged if this is because of

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[112] Schröpfer, *Dense + Green Cities*, 90.
[113] Ibid., 94.
[114] Joachim and Aiolova, "Design with Life", 69
[115] Ibid.

practical or economic reasons. Building without bio-hybrids, whose growth would have to be awaited, is faster and easily reproducible, therefore benefitting the designs capitalisation. Thus, from the analysis of the *Monarch Sanctuary* it could be reasoned that connecting two environmental challenges – on the one hand, unsustainable construction materials and on the other hand, extinction of a species – in one design leads to the favourability of solving the problem that is closer to our hearts. This means the predominance of affectual and intrinsic valuing in Terreform One's design that appeals to humans' moral beliefs to prevent a species extinction. Instrumental values, such as the consequences of building with unsustainable materials or bringing monarchs into the city on a larger scale, are not addressed by the architects.

However, there are also approaches to architecture that try to mitigate a problem through utilizing bio-hybrid technologies, for example *Dune* by Magnus Larsson. Essential for such an architecture is the adaptability to natural surroundings. Translating the notion of interrelated networks between self-regulating entities into the design practice means regarding architecture as a process itself.[116] The building should not be considered as a fixed, delimited object, but as an entity that responds and adapts to its social and environmental context. Nevertheless, as the discussion of this project will show, designing sympoietic architecture on a larger scale can lead to ethical problems.

4.2 Biotech architecture in its environmental context

Designed for the Sahara Desert, Magnus Larsson's project *Dune* (Fig. 15) aims to make the ever-expanding desert landscape inhabitable and cultivatable. With his project, Larsson answers to the advancing desertification of the Earth, especially the African continent. 6,000,000 ha of agricultural land are lost annually due to desertification and approximately 850 million people are at risk of losing their homes and livelihood.[117] As Hirche et al. bring forward, concomitant with the loss of land is also the vanishing of nonhuman species: in under forty years, the number of species decreased by more than 50 percent, making the desertification a threat for biodiversity.[118] Although Hirche et al. measure a regreening trend in the Sahel zone, they also remark that the flora richness is still in decline.[119] *Dune* is designed as a 6,000 km long inhabitable structure, built into and with sand dunes of the Sahara, that stretches over the whole width of the continent. Larsson envisions that the top of the architectural dune should be

[116] Schröpfer, *Ecological Urban Architecture,* 195.
[117] Larsson, "Dune", 434.
[118] Hirche et al., "The Maghreb (North Africa) Rangelands", 74.
[119] Ibid., 94.

transformed into a green shelterbelt, preventing the desert's expansion. Through the planting of trees, the sand will be stabilised even more, natural shade is generated and water can be harvested. However, due to the high rate of poverty in African countries, trees are chopped down for firewood and building material.[120] Thus, a strong bond of the inhabitants and the greenery on the architecture has to be formed in order to prevent their logging.

Larsson throughout his argumentation remarks that the architecture has to support the local population, demanding a bottom-up design that takes human and natural needs in consideration:

> The structure would have to support local habits and building traditions, and would need to find ways of braiding one such tradition into the next, possibly across national and religious borders. The three things the different potential adaptations would hopefully share is a connectedness within the architectural refuge, a common materiality—a seamless plasticity—as the microbes close some of the gaps in between its grains and turns it into sandstone, and a shared opportunity to use the structure to improve the local economy.[121]

The project aims to create a space for the daily life of African people and simultaneously enhance the economic situation of the population. Diana Davis' reflection about the role of deserts for the Western world demonstrates that especially the first idea of "supporting local habits" is problematic and based on colonial thoughts. For instance, in the early twentieth century, the French colonisers viewed livestock breeding by nomad people critically and framed it as one of the sources of desertification. Davis remarks that the French thereby forced nomads to settle, which made governing and taxing them easier.[122] On the other hand, because the design is intended to range over the whole width of the continent, it would also encourage nomadism. As Alvarez Gila et al. note, nomadic movement in the Western Sahara does not adhere to national borders, it rather is determined by environmental conditions.[123] Therefore, a cross-border architecture could prove useful for the migration of nomads. As this discussion illustrates, the implementation of projects, such as Larsson proposes, have to be made extremely cautiously without imposing any idea on the population that they do not agree with and respecting sovereign decisions of the Maghreb nation-states.

The second incentive of Larsson's project seems controversial at first glance. Aiming to improve the local economy gives way for capitalist interpretations. However, Larsson does not intend to bring economic growth to the Saharan Desert, much less wants to create an opportunity to financially profit from their land; rather, he proposes a change of agriculture that

[120] Larsson, "Dune", 455.
[121] Ibid., 456.
[122] Davis, *The arid Lands*, 128.
[123] Alvarez Gila et al., "Western Sahara", 151-152.

could answer a growing demand for water in the desert and offers potential for supporting biodiversity. The main agricultural product in the Saharan area is livestock. According to Hirche et al., the huge demand for livestock cannot be covered because reduced rainfall leads to a decreased barley harvest.[124] Larsson's design opens up the possibility of water harvesting through planted trees. The architecture aims to support both nature's and humans' thriving and through the connection of both entities makes them interdependent, as Larsson explains: "Once the structure is in place and the permacultural network begins to support water harvesting and habitable thermal comfort zones, the economical sustainability of regions in dire need of such improvements could be increased."[125] The trees, that have to be native to the environment and diverse to prevent monoculture (which Larsson unfortunately does not address), are dependent on humans that guard them from being chopped down and humans need the trees to enhance the weather conditions for the improvement of their livelihood. A sympoiesis is created that is not based on a hierarchical differentiation of the parties but that works as a network.

The material that is used for the architectural structure is the sand on-site. Larsson's design works with the dynamic movement of the sand. Even though sand is inanimate, it possesses autopoietic features: in every environment where sand plays a part, in rock formations or deserts, the creation of the environment is generated through a cycle of aggregation and erosion. Environmental conditions disaggregate rocks, turning them into grains of sand. This sand accumulates and in a span of time, the grains become "glued" together again, forming sedimentary rocks.[126] To use this natural cycle in the design, Larsson employs the calcifying effect of the bacterium "Sporosarcina pasteurii". This bacterium occurs naturally in soils. When coming in contact with a calcium-rich environment, it creates calcite, which binds the loose soil particles together and solidifies them.[127] Because the bacterium is in need of carbon and energy to sustain its autopoiesis, its growth and proliferation can be controlled.[128]

Inhabitable structures can be generated through two different building techniques. One practice that could be used is pneumatic balloon precipitation, whereby a balloon filled with the bacteria and the necessary nutrients is placed into the sand. When the sand fully covers the balloon, forming the desired shape, the solution is distributed by opening apertures on the balloon. After the solidification process is completed, the balloon is removed.[129] Another possibility is to use injection pile precipitation. Here, piles are inserted into a dune that solidify

[124] Hirche et al., "The Maghreb (North Africa) Rangelands", 96-97.
[125] Larsson, "Dune", 456.
[126] Ibid., 442.
[127] Ibid., 432.
[128] Ibid., 452.
[129] Ibid., 448-449.

an initial area of sand, serving as the basis of the structure. Then, like a 3D printing arm, the piles are moved upwards, solidifying parts of the sand as needed, allowing for, as Larsson claims, the fabrication of any structure.[130] Afterwards the loose sand inside the space is either blown away by the wind or manually removed.

Larsson proposes to base the architecture's form on tafone structures (Fig. 16). Tafone refers to erosional processes in rock formations that are spawned by water transporting minerals to the surface of the rock.[131] Because this is not how Larsson creates the design, this aesthetic imposition on the dune can be called geo-mimicry. The bacteria and sand are formed in a way that is unnatural to them and that merely mimics the performance of rock processes. However, because the movements of wind are utilized to help engender the excavations, it could be argued that the architecture is a materialisation of the wind's performance. Larsson recommends this honeycomb pattern because, when applied on the sand construction, it serves as an ideal form that regulates the temperature inside the building.[132] The hollow spaces that are created in a tafone structure provide living space that is protected from the sun. By paying attention to local wind conditions, the structure can be composed in order to achieve sheltering from sandstorms and at the same time ventilation of the inside space.[133] The structure's form also accommodates multiple inhabitable spaces in one design. The tafone-like composition spans over the entirety of the architecture, uniting the inhabitants and the environment. This melding-together indicates the design's sympoietic quality because the building has no boundaries, the structure can therefore always be expanded.

The architecture can furthermore be described as sympoietic in two different ways: First of all, the project connects three autopoietic entities, namely humans, sand, and bacteria, in the design process. In doing so, it secondly reacts to social and environmental conditions in a specific place and tries to create a solution for those issues. Therein, the design acknowledges the position of humans and architecture in a larger environment. This aspect was already discussed above, namely in context of agricultural benefits of the greenery on top of the architecture. In utilizing the notion of the network, both the formal and the functional aspects of the design blur the boundaries of inside and outside, of what is culture or nature.

The inhabitable space is placed inside a natural ecosystem; the threatening environment of the desert therefore turns into a safe shelter. Although the incentive of the architectural work

[130] Larsson, "Dune", 449.
[131] Ibid., 453.
[132] Ibid., 454.
[133] Ibid.

is to mitigate desertification by creating a green threshold, it is not meant to form a wall, as Larsson remarks:

> Dune fundamentally opposes this view through the creation of a wall that never existed before, the opposite of a wall. The word ‘wall’ usually connotes a membrane that demarcates space, that divides one space in two. We think of a surface that prevents us from entering the next space. But dare to think big, allow the wall to straddle an entire continent, place the habitable spaces inside of it, and we get a stretch of architecture that could bind places, villages, people, even countries together.[134]

Hence, the building is not a distinct unity separate from its surroundings that restricts movement. *Dune* only functions as a wall when trying to restrict undesired actions, namely the spread of desert area.

From the discussion of the Dune project, it gets evident that the attempt to apply biotech architecture on a scale that extends to a whole ecosystem entails various obstacles. Desertification is a worrying issue caused by climate change that affects many people and continents, making its prevention even more intricate. Therefore, the danger of designing an architecture that intends to create or recreate an environment is that not every factor that guarantees an inclusive design can be considered. Addressing many environmental problems simultaneously – because desertification goes hand in hand with the topics of biodiversity and climate change – perhaps makes maintaining the balance between intrinsic and instrumental valuing inherently difficult. Larsson’s argumentation and design show a predominance of intrinsic valuing, where ecological values prevail over instrumental values, i.e., considering possible consequences that arise from the design or evaluating problematic means. Thus, the *Dune* project appeals to emotional and moral beliefs people have towards nature, partly disregarding the social and political situation on-site. Although the architecture works as a sympoietic building, since it connects the environment, humans and nature without creating boundaries, it is not specifically designed for the local humans and environment. Larsson fails to address the essential aspect of using native and a multitude of different plant species to create a biodiverse environment near the desert as well as the special migration behaviour of Saharan nomads.

4.3 Relating to the Environment

The discussion of the two case studies in context of sympoiesis and biodiversity shows that although the rethinking of the human-nature relationship is important, it can overshadow significant parts of the relationship. Both the *Monarch Sanctuary* and the *Dune* accentuate the role of humans in the ecosystem as caregivers and preservers. Biodiversifying the urban

134 Larsson, “Dune”, 445.

landscape or the desert is based on the perception of humans that something has to be cared for. Desiree Förster remarks that the word "care" insinuates that an entity is deficient in its current state and therefore is in need of attention and support to attain an ideal state.[135] Because of that, she further argues, defining an ideal is highly dependent on another entity's norm, opening up the possibility of inadequate measures.[136] That defining an ideal state is highly problematic was shown with the analysis of Larsson's work. It exemplified the danger of merely turning around the relationship of care: while the current human-nature relationship has as its subject of care human life, therefore, endorsing the exploitation of nature in order to attain a certain state, for instance the logging of trees to nourish one's family, the dune project focusses on the importance of nature's well-being and subsequently subordinates human needs.

However, what the case studies illustrated is that the introduction of biotech architecture as a simulation of an interrelated ecosystem, the relationship that is formed between humans and nature is not a unilateral one, but one that is based on co-dependency. Contrary to the notion of biophilia that suggests returning humans to a sensually appealing, natural environment, Pauliina Rautio remarks: "Being with the world […] is not about humans single-handedly forming and developing a relation to the world."[137] In her article, Rautio criticises the use of the word "anthropocentric" in a negative sense, i.e., to identify human behaviour towards nature as inherently bad and to create a distinction between good nature and bad humans.[138] Thus, reconnecting humans and nature means to break down this distinction and connotation of the word anthropocentric. Relating to the environment requires more than just a localization of humans in the natural world. Recognizing and understanding the bonds that connect humans to the world as well as the aspects that make humans part of nature themselves, is essential for a more attentive cohabitation with other species.

While the biophilic hypothesis approaches nature from an anthropocentric perspective that shows how nature is useful and necessary for humans' survival and well-being, sympoiesis describes the environment as an interrelated network from multiple perspectives that offer space for humans and their anthropocentric actions. Hence, sympoietic designs not only bring together multiple species for the sake of human habitation, they rather reveal interconnections between the species and accentuate the significance of human actions that serve other species' thriving. In that way architecture, that is designed in a sympoietic way, creates a shared reality, or what Förster calls "intersubjectivity". Förster notes that a space of shared existence can be perceived

[135] Förster, *Aesthetic Experience of Metabolic Processes*, 104.
[136] Förster, *Aesthetic Experience*, 104.
[137] Rautio, "Being nature", 448.
[138] Ibid., 448.

because entities act near and with each other.[139] Being aware of this intersubjectivity that is generated by the entities' spatially and temporally close activity, enables adapting one's behaviour according to the other entities of the network, Förster argues.[140]

Rautio summarizes the perception of an environment as a shared reality and the behavioural adaption as follows:

> The logic of this unfolds roughly as follows: the relation that I have to my surroundings, the ways in which I am nature, are relative to the actions and existence of all of the other things that share this relation with me. As I am not the sole author of my relationship with my surroundings, yet as this relationship is a significant source of well-being and balance in my daily life, it is both my interest and my responsibility to make sure that the beings in my surroundings are able to uphold their part of our relations. In other words, I am to act in ways that uphold and preserve the independent and unique nonhuman entities that condition my existence.[141]

Again, this description of the human-nature relationship is based on intrinsic valuing – Rautio addresses the interest and responsibility that humans have towards the upholding of the ecosystem. But, relating to the world, as Rautio describes it, is not meant as favouring the maintenance of natural processes. The quotation displays the world as a rhizome, to come back to Deleuze/Guattari, where every entity has the responsibility towards other entities to guarantee their existence.

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[139] Förster, *Aesthetic Experience*, 96.
[140] Ibid., 97.
[141] Rautio, "Being nature", 453.

Conclusion

Sparked by alarming news about climate change and the worrying state that nature is in, this research aimed to look at new approaches in the field of architecture through the lens of ecology. “Revisiting” the human-nature relationship, as the title of the thesis suggests, proved to be highly intricate due to the diverse concepts of nature that prevail not only in the field of architecture but all other discourses. Whether one views the environment as a resource that has to be cultivated in order to sustain human life, or perceives it as a complex network that has to be intrinsically valued against all odds, plays a huge role in the composition of biotech design, since the way nature is perceived determines the manner in which technology is utilized to incorporate non-human entities into architectural designs.

Due to the critical situation the Earth is in at the current point of time, the emphasis of the investigation lay on accentuating a non-materialistic, appreciative perception on nature in biotech architecture. As the discussion showed, the designers used performative characteristics of nature, either in the form of information that was digitally translated into materials, seen in Oxman’s material studies, or in their most natural and autopoietic form, illustrated with the example of living tree architectures. Introducing nature as bio-hybrids into buildings, rather than in the form of biomimicry, gives the environment its own “voice”. Nature is not prevented from performing in its immanent way and much less reduced to an aesthetic object. This is what was called “sustainable aesthetics”, namely aesthetics that support the integration of nature’s agency. Sustainable aesthetics do not derive from culture; a building’s aesthetics have to be taken from or developed by nature, in order to engender an encounter between humans and nature that does not subordinate the latter to an object or material status.

Biotech architecture therefore helped to situate humans in the environment, demonstrating that people have a role in nature and are impacted by natural processes. While applying the multispecies entanglement on the scale of a building was feasible without ignoring every entity’s needs, designing an architecture that functions as an ecosystem or as part of it proved to be difficult and to some extent problematic. If such designs address a specific environmental problem, such as the extinction of a species, it is likely that the focus lies solely on the resolution of that very problem and the designers lose sight of the well-being of other entities. Thus, the goal to biodiversify through architecture in an appreciative and sustainable manner is generally desirable, but utterly intricate to implement due to its large context. The architecture could then run the risk of not strengthening the human-nature relationship, but sabotaging it because one or more entities are neglected.

Therefore, if architects designing with nature in the form of bio-hybrids are aiming to go beyond the recalibration of the human-nature relationship and try to provide solutions for ecological issues, more in-depth research about social behaviour of local communities and about qualities of threatened ecosystems has to be conducted. These field-overarching considerations are frequently missing from the discussed design research, which rather concentrates on the peculiarities of the used technology. By putting too much emphasis on the technology, it is easy to forget that technology in biotech architecture is supposed to enable the introduction of natural processes into the design or regulate the performative movement of nature. Another challenge is to avoid the use of technology in a way that aligns with capitalist tendencies. If scaffolds, which are often used in biotech architecture, are mass-produced with the help of technology, allowing the capitalisation of the design, this would undermine all sustainable advances made in the field. Undoubtedly, this also signifies that biotech architecture works on a temporally large scale, which does not fit into the fast-paced world of the twenty-first century, calling for revisiting human relationships with products and altering the throw-away mentality prevailing the consumer sector.

This does not imply that biotech architecture has to always stay speculative. Rather, it signifies that a bottom-up approach is essential for the success of the designs on a sustainable level. To create an equally appreciative human-nature relationship the architecture has to stay true to the particular human and non-human entities affected by the construction. This cannot be achieved by prefabricated parts that are based on a fictional, idealised image of human and natural life, but only by designing with the information found on-site and learning from local habits and processes. As Chris Abel emphatically phrases it: "Biotech architecture demands radical changes in education and practice!"[142] Reconsidering practices in design and production that resemble capitalist notions poses an obstacle that has to be overcome in order to create truly sustainable architecture.

[142] Abel, *Architecture, Technology and Process*, 244.

Appendix

Appendix 1:

Abstract from *Biotech Architecture: A Manifesto*

WHAT IS BIOTECH ARCHITECTURE?

1. Biotech Architecture is not a style. It is a computer-centred process of architectural design, production and use.
2. Biotech architecture combines global technologies with local responses to site and social conditions.
3. Biotech architecture is information based, not form based. It does not prescribe what a building should look like, but rather how it should behave.
4. Biotech architecture uses smart technologies to achieve a dynamic, interactive relationship between a building, its users and its environment. In the near future, smart materials will be used to help achieve the same result.
5. Biotech architecture aims for customized design from the molecular level to the rooftop!
6. CAD + CAM Craftsmanship. Biotech architecture takes the art and craft of building onto a new plane. It resolves the alienation between humanity and machines, which has plagued architectural ideology and practice since the industrial revolution, through customized automation and human centred production systems.
7. Biotech architecture presents no artificial boundaries between architecture and nature, or between human and organic growth and development. It embodies the same principals of energy efficiency and dynamic balance between different forms of life as those governing nature's own ecosystems.
8. Biotech architecture is synonymous with sustainable design. In Biotech architecture, the designer's remit covers the entire foreseeable life cycle of the building, from the production to the recycling of materials.
9. Customized architectural form and space – no matter how aesthetically pleasing they might be - without a related customized response to the local climate, is like a tree without roots. In Biotech architecture, energy conservation is as central to the architect's work as gravity is to the engineer's.
10. Biotech architecture is self-organizing. It is not a fixed or final product, but is more like a biological organism, continuously learning about itself and its surroundings, adapting to changing conditions and improving its own performance.
11. Biotech architecture is integral to the electronic ecologies of the future, upon which the very survival of the human race depends.
12. Self-organization does not mean 'out of control'. It means no centralized control! Evolutionary planning, which is based on self-organizing systems, comprises multiple forms and levels of control and feedback, providing mutual checks and balances dispersed throughout the affected population, both human and non-human. Like Biotech architecture, evolutionary planning is holistic in conception and responsive in application.
13. Biotech architectural design is a total design approach with continuous feedback from the production process to the design process and vise versa.
14. Biotech architectural design is multi-disciplinary and network-based. It entails coordinating a number of simultaneous dialogues with different people in different locations using complementary skills, covering all aspects of design, production and use, including clients and future users as far as possible.

15. Biotech architecture implies integrated design. It involves designing building, subsystems and components all together in a collaborative process to achieve the highest possible performance for the whole.
16. The heart of the Biotech design process is the virtual prototype, which is both a design and communications medium. Used together with rapid prototyping and virtual reality technologies, Biotech architecture actively encourages full and open participation in design.
17. Biotech architecture embraces both the ‘two cultures’. In Biotech architecture, art, science and technology are all enlisted toward achieving the same ultimate goal: sustainable life upon Earth!
18. Biotech architecture is not dictated by architectural fashion or limited to any cultural or professional niche, elitist or otherwise. It embraces all forms of building and construction, grand and humble, large or small, and all forms of use. Biotech architecture aims to raise the general standard of environmental design for the benefit of all.
19. Diversity is to Biotech architecture as bio-diversity is to nature. Innovation in design requires the parallel development of alternative approaches and cross fertilization of ideas, no less than evolution requires the multiplication and cross fertilization of biological species.
20. Biotech architecture demands radical changes in education and practice!

Abel, C., *Architecture, Technology and Process*, Amsterdam [i.a.]: Architectural Press, 2004

(*Numbering done by me)*

Illustrations

Fig. 1: Achim Menges, ICD/ITKE Research Pavilion 2011, Stuttgart University

Fig. 2: Diana Scherer, Interwoven #14, 2018, photography, textile from woven plant roots, 50 x 60 cm, ed. 5 + 2 AP

Fig. 3: DP Architects, Rhizome House, 2016, Amsterdam

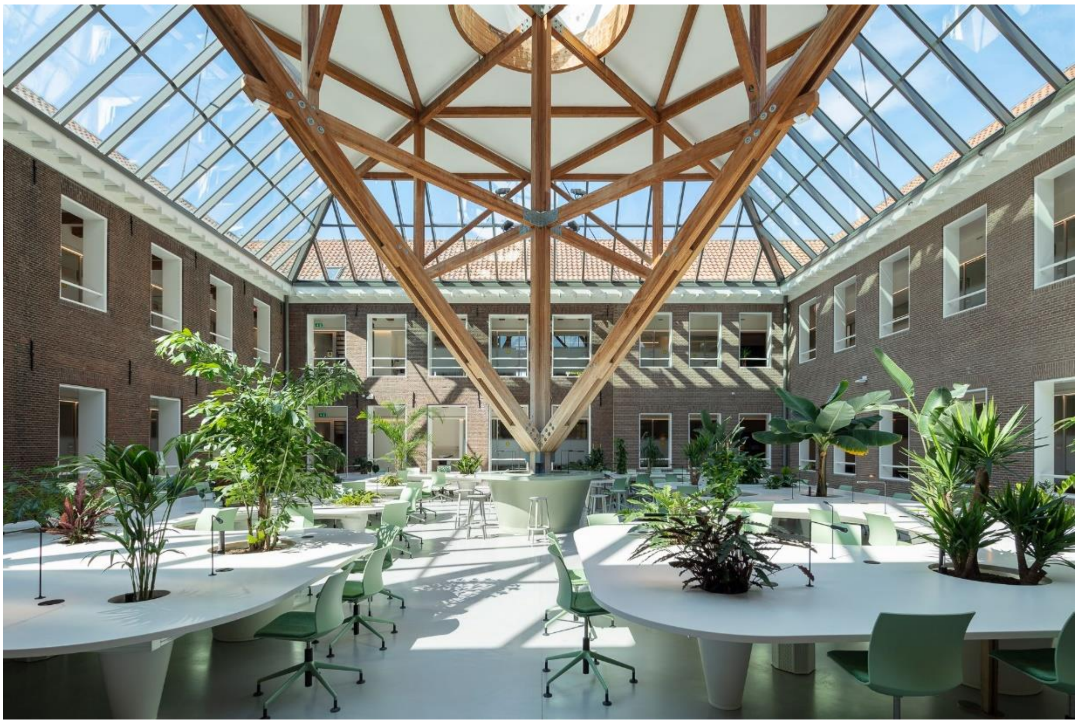

Fig. 4: Tjeerd Dijkstra, Arsenaal building, Leiden University, Atrium

Fig. 5: New Heroes, The Exploded view, Central House, 2020

Fig. 6: Green wall, Worth Avenue, Palm Beach, Florida

Fig. 7: Marcos Cruz, Richard Beckett, Bioreceptive walls

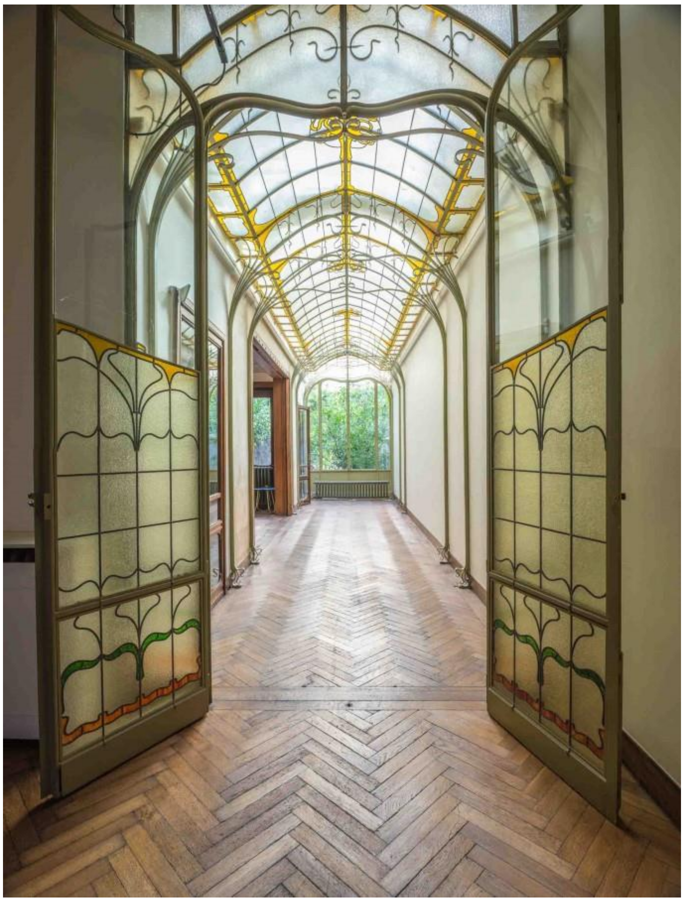

Fig. 8: Victor Horta, Hôtel Frsion, 1894, Brussels, Belgium

Fig. 9: Aguahoja, Neri Oxman

Fig. 10: Terreform One, Fab Tree Hab

Fig. 11: Rangthylliang bridge, Meghalaya, India

AUTOPOIETIC SYSTEMS	SYMPOIETIC SYSTEMS
Defining Characteristics	
self-produced boundaries	lacking boundaries
organizationally closed	organizationally ajar
external structural coupling	internal and external structural coupling
Characteristic Tendencies	
autonomous units	complex, amorphous entities
central control	distributed control
'packaged,' same information	distributed, different information
reproduction by copy	amorphous reproduction
evolution between systems	evolution within system
growth/development oriented	evolutionary orientation
homeostatic balance	balance by dynamic tension
steady state	potentially dramatic, surprising change
finite temporal trajectories	potentially infinite temporal trajectories
predictable	unpredictable
Examples	
cells, organisms	ecosystems, cultural systems

Fig. 12: Table by M. Beth Dempster, Comparison of poietic systems, 1998

Fig. 13: Terreform One, Monarch Sanctuary, Modell

Fig. 14: Terreform One, Monarch Sanctuary

Fig. 15: Magnus Larsson, Dune, 2010

Fig. 16: Tafone, San Mateo, Californian coast, 2006

Illustration sources

Title Figure: Downloaded 02 February 2021. https://terreform.org/fab-tree-hab

Fig. 1: Downloaded 08 June 2021. http://www.achimmenges.net/?p=5123

Fig. 2: Downloaded 02 May 2021. http://dianascherer.nl/page/2/

Fig. 3: Downloaded 08 June 2021. https://www.dpa.com.sg/projects/rhiz0meh0use/

Fig. 4: Downloaded 02 May 2021. https://www.universiteitleiden.nl/humanities-campus/deelprojecten/arsenaal

Fig. 5: Downloaded 02 May 2021. https://theexplodedview.com/materials-methods/

Fig. 6: Downloaded 25 April 2021. https://gsky.com/portfolio/palm-beach-worth-avenue/

Fig. 7: Downloaded 02 February 2021. http://www.richard-beckett.com/projects/

Fig. 8: Downloaded 02 May 2021. https://screen.brussels/nl/film-commission/filmset/hotel-frison

Fig. 9: Downloaded 01 March 2021. https://oxman.com/projects/aguahoja

Fig. 10: Downloaded 20 April 2021. https://terreform.org/fab-tree-hab

Fig. 11: Middleton et al. 2020, Fig. 16(b).

Fig. 12: Dempster 1998, Tab. 2.1.

Fig. 13: Downloaded 15 May 2021. https://terreform.org/monarch-sanctuary

Fig. 14: Ibid.

Fig. 15: Larsson 2010, Fig. 8.

Fig. 16: Downloaded 02 May 2021. https://de.wikipedia.org/wiki/Tafone#/media/Datei:Tafoni.jpg

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