Thesis: Bioreceptive Habitats
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Reflection

The present thesis involves several stages in order to develop what was learned through literature, experiments, simulations and research-by-design. Seemingly disparate subjects were investigated in order to cultivate a deep understanding of their synergies. The possible benefits of bioreceptivity and bryophytes, the support of surface topology in bioreceptivity, the underlying properties of bioreceptive materials and the introduction of a bioreceptivity-oriented design approach in the evolving industry of additive manufacturing are only some of the explored topics.

The fact that more and more scientific papers related to bioreceptivity highlight its potential as a material property in combination with the abundance of bioreceptive materials within the locality of my studies in Delft, Netherlands, have initiated this research work.

Throughout the course of my research, it has become evident that bioreceptive materials are mostly colonized by cryptogams, organisms who are reproduced by spores (and not with flowers or seeds). Cryptogams are highly adaptable non-vascular plants (with no roots but rhizoids) which do not need soil as a substrate because they absorb moisture and nutrients directly into their cells through osmosis. Cryptogams uptake more than 3.9 Pg. carbon and 49 Tg. nitrogen per year globally (W.Elbert et al, 2012) which strongly indicates that they can contribute to urban greening and promote environmental and social sustainability.

What is more, cryptogams' absence of roots emphatically supports their integration in building elements and materials because they cannot cause biodeterioration through their roots' pressure. In order to create a successful interaction between the material and the living organisms, three are the main variables that should be considered; material properties, surface topology and environmental conditions. The majority of the existing studies focus on the material properties which boost biological growth or on the pattern-making of bioreceptive elements which supports the entrapment of biological content within their substrates. This thesis has as a starting point the identification of the requirements which are essential for an organism's growth. In order to do so, a case study is run on a specific moss species, Tortula Muralis, a popular cryptogam easily found in the Netherlands. This choice is fundamental for the research and differentiates my thesis from the existing methodologies, because even though a material can be prone to bioreceptivity it will not be biocolonized if the appropriate conditions do not occur.

Consequently, the ultimate goal of the present thesis is to engineer a strategy for producing surfaces which support bioreceptivity and express a new architectural vocabulary through bioreceptive materials. The research is examined both in digital and physical space which come as one through digital fabrication and prototyping at the very end of the process. The research starts in digital space, by identifying the environmental conditions which are in favor of bryophytes' growth. By determining several climatic variables in an advanced climate-finder, (such as high relative humidity, high rain frequency, air temperature ranging between -5 and 25°C etc.), potential locations where mosses thrive are found. This first step comes to be validated by my empirical viewpoint since several locations in the Netherlands have appeared. As a location for further investigation Amsterdam is selected, because of its proximity and thanks to the accessibility of its climatic data on the internet.

Moving on, bryophytes' survival requirements dictated the following steps. They cannot tolerate direct sunlight because it dries out their rhizoids and leaves. Instead, high levels of moisture and water can help them grow and propagate. For these reasons, the research is explored in two level. One seeks for the creation of shaded spaces which are easily accessible by water, whereas the second one attempts to identify a material which could be placed in these shaded spaces and offer a high water content for a considerable amount of time. The first case is investigated in-silico[1] and the second one in-vitro[2].

The impetus for the study in-silico originated from several structures and patterns which are often found in nature and create self-shading to tackle heat and sunlight-related issues. For instance, termites create their settlements in such a way that several shady spots are made because they cannot survive in direct sunlight. In order to make some observations but also compare several geometries, a script was set up successfully capable of evaluating the levels of sun and shadow. Solar exposure simulations are quite common in architectural projects and their contribution could support majorly bioreceptive applications. The script begins with the topology of a vertical flat surface which represents the external side of a wall. Vertical building elements consist of the largest area of building envelopes. By setting several control points and manipulating its topology and orientation in digital space, several conclusions were made. Firstly, in the case of Amsterdam (=north hemisphere), north orientation has the lowest levels of sunlight and therefore moss would probably grow in that direction. Indeed, this assumption can be considered as accurate since it is an old concept among hikers that mosses grow in the north orientation of the tree barks helping them to understand their orientation. What is more, by applying an optimization solver, it was concluded that the size of the deflections' and the number of the moved controlled points of the surface topology determines proportionally the amount of shadow that is created but also directs water towards these self-shaded spots. The same script was then applied in a dome's topology, a geometry which faces all directions in order to understand its full potential in 3-dimensional objects. Even though the script needs more advancement for a wider use and requires a multidisciplinary input from other fields, like botany, biology, engineering and material science, it can act beneficially already. For example, in the comparison of design alternatives or by identifying where bioreceptivity would more likely be efficient. The fact that the script suggests different optimized topologies in every location/orientation makes each produced element unique and that is why additive manufacturing is chosen as the means of fabrication.

Moreover, in order to produce a final design approach and a prototype, a bioreceptive material was necessary to be selected. In that fashion, lime-based mortars were chosen among others, as the most suitable material. Their high bioreceptivity performance in combination with their capability of being casted/molded, and hence be applied easily over and inside complex geometries, helped this decision. Then, based on an existing experiment that deals with bioreceptive lime-based mortars, new mixtures were made in order to evaluate if their water transport behavior could be improved and thus benefit their bioreceptivity performance. In order to observe this relation between bioreceptivity and water transport behavior, numerous experiments which required a high level of precision were conducted in the Heritage and Technology Lab at TU Delft. Even though the existing experimental proof indicates that high

[1] "in-silico" : Experiment which is performed on a computer or via computer simulation. (source: Wikipedia.org)
[2] "in-vitro": Studies which are performed with microorganisms, cells, or biological molecules outside their normal biological context. (source: Wikipedia.org)

open porosity, high surface roughness, high water retention and high permeability support bioreceptivity, it becomes apparent that a considerable amount of time is required in order to observe clear results. In this framework, several mortars were examined in terms of moss growth and during the first five weeks signs of fungi growth were observed on a mortar due to the availability of moisture and nutrients. This phenomenon known as symbiosis is the early biocolonizing phase before moss appears. Nevertheless, it could be assumed that the developed mortars have a bioreceptive character because of their high water absorption capacity and retention in combination with their surface roughness. Mortars with smaller grain size distribution were proven to be the most promising because they had a higher water capacity and retention in comparison with the rest.

Finally, in order to showcase how these two can act synergistically by increasing the effect of bioreceptivity, three design approaches were made. This was achieved through a research-by-design experimental approach by prototyping in the Laboratory for Additive Manufacturing in Architecture at TU Delft. Their common design principle is the placement of a material prone to bioreceptivity in the self-shaded parts of a surface which are indicated by the generated script. These are not the only possible designs that can be made, but definitely they demonstrate a tangible method of combining the topology and material research expressing a new architectural vocabulary and act as a source of inspiration for future researchers. In any case, there is a growing need for a multiscientific approach in order to evaluate and improve this new concept, but also testify to what degree this approach could benefit the urban landscape.

In conclusion, conducting research on the intersection of bioreceptivity, mosses, mortars and additive manufacturing can create new design applications in the urbanscape. As designers and engineers we need to think how we can contribute to a better quality of living through the use of new materials and technologies on different scales and conditions. From my personal point of view this can be achieved by incorporating nature in the urban environment. A deep understanding of natural complex phenomena, like bioreceptivity, can help us resolve many environmental issues and lay the foundation for innovation and a more environmentally benign coexistence.

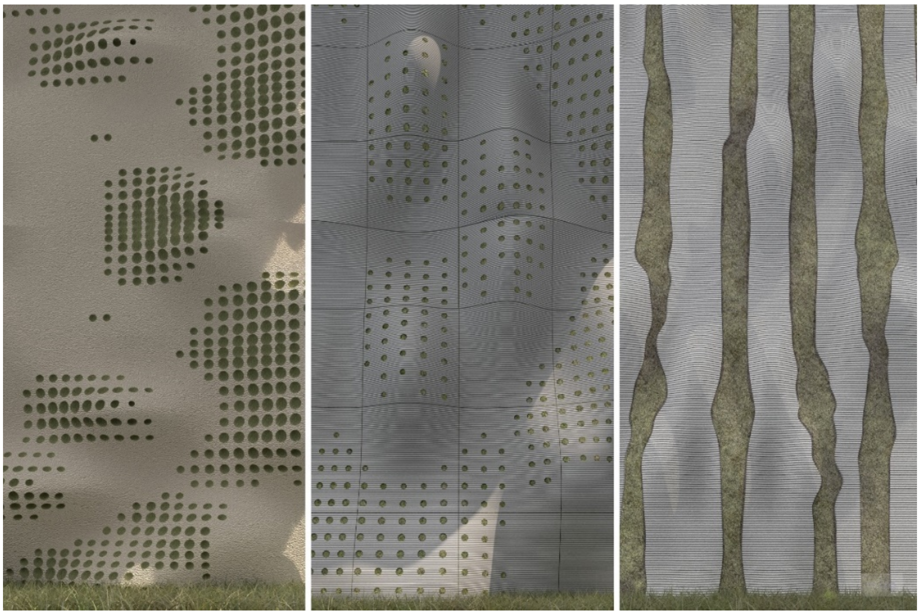

Figure: Renderings of the three preliminary design approaches that were developed (own source)