**REFLECTION – P4**

Maurits Stoffer

This reflection is part of the sustainable design graduation of the master Building Technology at the faculty of architecture in Delft. This will give an analysis on the graduation process, as well as a reflective overview of the several steps that has been taken throughout the project. Lastly a brief elaboration is given on the societal impact and relevance of this graduation.

**Graduation Process**

1. Introduction

This graduation was all about biomimicry with a specification in structural design. Biomimicry and the translation from natural design to structural design will be a new point of view. In the last few decades various living organisms have been analysed in terms of structure. Several architects and engineers have already studied the confluence between nature and technique, the confluence between biology and structural design: Frei Otto with his tensile and membrane structures, Félix Candela with his anticlastic thin shell structures and Buckminster Fuller with the geodesic domes are a few examples.

2. Objective

The main objective is to find a new structural principle that is emulated by the design by nature. Observing, analysing and transforming the natural design principles and laws could derive a new application in the field of structural design. The first step was to observe. Observe biological processes we can find all around us in the realm of nature. There are many concepts, approaches and directions to translate biology to architecture. It is all depending on what the final design is asking. In my case, with the goal to find a new structural principle, it needs to be integrative with the environmental exposures. The way to get from biological observations, to physical phenomena, describing these mathematically in the hope to come up with an integrative innovative structural principle for architecture is done through different levels of mimicry. This goal was achieved since the final structure is based on two physical phenomena that are combined.

3. Methodology

After the categorization into physical phenomena, the following levels of the transformation methodology are based on partial mimicry. Every level has its unique grade of abstraction. Beginning with similarity. This is a classification of several biological categories, which can be mimicked for the transformation to architecture. After the selection of one of two focus groups, the filtering will take place. This will be done on scaling – the ability to overcome the problem of scale mentioned earlier, the form stability, and the constructability when it comes to the ability to build with components. The next level of transformation is to analyse the biological categories and to find analogues. Examples of analogues can be self-optimisation, self-organisation, and self-forming. After the selection of the type of analogue, the level of abstraction and mutation is next. This is the part where the fields of science come into play; this level encloses the structural analysis, the math-based design and material selection. A last potential level can be to learn from pioneers with similar approaches and the analyse precedents. This can be useful but is not a necessity for the transformation. In the end, after having walked through all the separate levels of the methodology, the derived information will form the basis for the design direction. An important note with this methodology is that it has practically infinite possibilities of combinations, all resulting in a different design direction. A different outcome of the first step – selecting a few of the categorized physical phenomena, gives already a total different input for the following levels in the transformation. Besides, there is a pretended hierarchy in the levels and definitions, but this does not assume to be the absolute truth. There are various ways to interpret the methodology. Looping, skipping or going back a few steps can therefore often be very useful, resulting in more in depth concepts.

4. Research

Research by design was firstly done on analysing the natural laws. From there on an overview and categorization of twelve physical phenomena was made. It is a necessity to mention that firstly, these are definitely not the only twelve and secondly, these twelve are not in a specific order or hierarchy. Some phenomena overlap others. To give an example, the core natural principle of symmetry can be found in many of these phenomena. These twelve phenomena were then mathematically described in order to get a better understanding on how these could be translated into Once a selection of the phenomena was made, the further research was mainly done on the structural characteristics of trees, what the advantages are of the use of branching structures and how this could be integrated into the design.

**Societal Impact**

1. Relevance

There is still a lot to gain from our observations towards nature and phenomena that are all around us. Today, each element of nature continues to be studied for creating more lightweight, durable, flexible, economical and high-performance architectural structures. The relevance of this study is clearly articulated in the article Influences of the living world on architectural structures'. *"Structures in the nature motivate innovation in architectural and engineering disciplines in terms of aesthetical, functional and structural advantages. Using efficient, lightweight structural forms similar to those in nature reduces material and energy usage and waste amount. In this sense, it can be clearly seen that based on learning from nature in relation to meeting gradually increasing and changing requirements through limited resources and creating modern structural designs, biomimicry will provide much more contribution on architecture and related fields."*

2. Application

The results are directly applicable in practice and when it comes to the projected innovation, this goal was achieved since the final structure, which is based on two physical phenomena combined, has never been done before. With both phenomena separately several structures are built and have been proven to work. However, a combination of example fractals and minimal surface has not been done before, which gained my interest for further research in the first place. In the end it did lead to the results that I aimed for, since there was enough time for the design development. The final result can be seen as a method statement with detailing and several design intents on how this structural principle can be used.

3. Sustainability

Using nature as inspiration combined with mathematics enables us to come up with structurally rational designs. These rational designs are because of its simplicity appropriate for smart solutions on detailing as well. Besides, the research on the structural performance of natural dendriforms contributed to the sustainable development in such a way that material usage was minimized. Ludwig Glaeser rightfully state in his book on the work of Frei Otto that by applying his minimal theories to support elements and space frames, Otto arrived at lighter structures by reducing the buckling lengths of their compression members. This reducement of buckling lengths is also what happens when a branching structure is used. When a comparison in percentage is done between the resultant bending moments in the branches with a flat roof and the resultant bending moments in the branches with a roof of hypars, it is given that on average the branches of the double curved surfaces have a resultant bending moment of only 70% of that of the branches with a flat roof. In about seventy percent of all the cases, this percentage is even below 50%. In general, these bending moments are replaced by axial forces, which is often the case if a branching structure is used correctly. Thus, it is structurally more efficient to use a roof that consists of hypars compared to using a flat roof. Also, a branching structure also enables us to use large span surfaces.

Finishing off, if I could have done something different during this graduation process, it would have been to start making physical models in an earlier stage. The digital and parametric design was in the first month of the application phase a priority. Consequently, it resulted in having less time for further analysis on the structural performance of the structure as a whole. However, by spending a lot of time in the parametric design of the structure, I was able to broaden the range of applications that are possible with this principle.