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Architectural Engineering
Robotic Building*

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RESEARCH REPORT
workshop 01



Workshop introduction

During the first semester of 2019/2020 one workshop has been conducted that introduced the design to robotic production process. In this workshop we were encouraged to develop a design that informs our own thesis design.

The starting point of this workshop were the random beams as seen in figure on the right. These beams could be seen as the main structure of a building whereas the challenge was to make certain add-ons to these beams to make it a complete 'building'. The main objective was to design a panel for a building envelope that has multiple functions integrated. The main driver behind the concept of integrating different functions into one envelope is that it will become possible to use less materials and is overall a smarter skin compared to the facades that are built right now. To see the implications of integrating different functions we started with only two aspects. These aspects were chosen out of personal preference and are respectively acoustics and structure.

This research report consists of three parts:

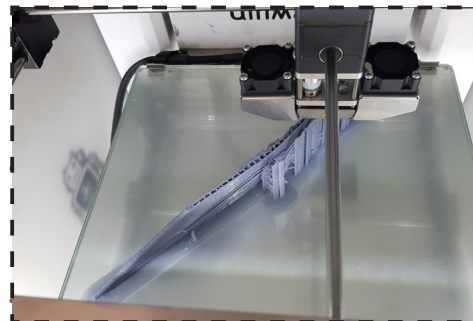
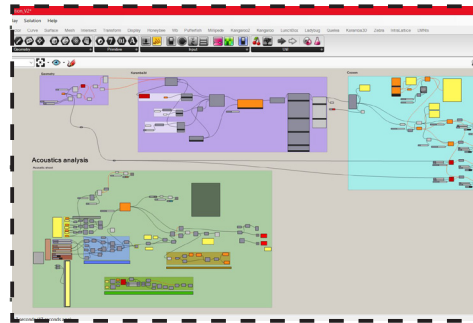
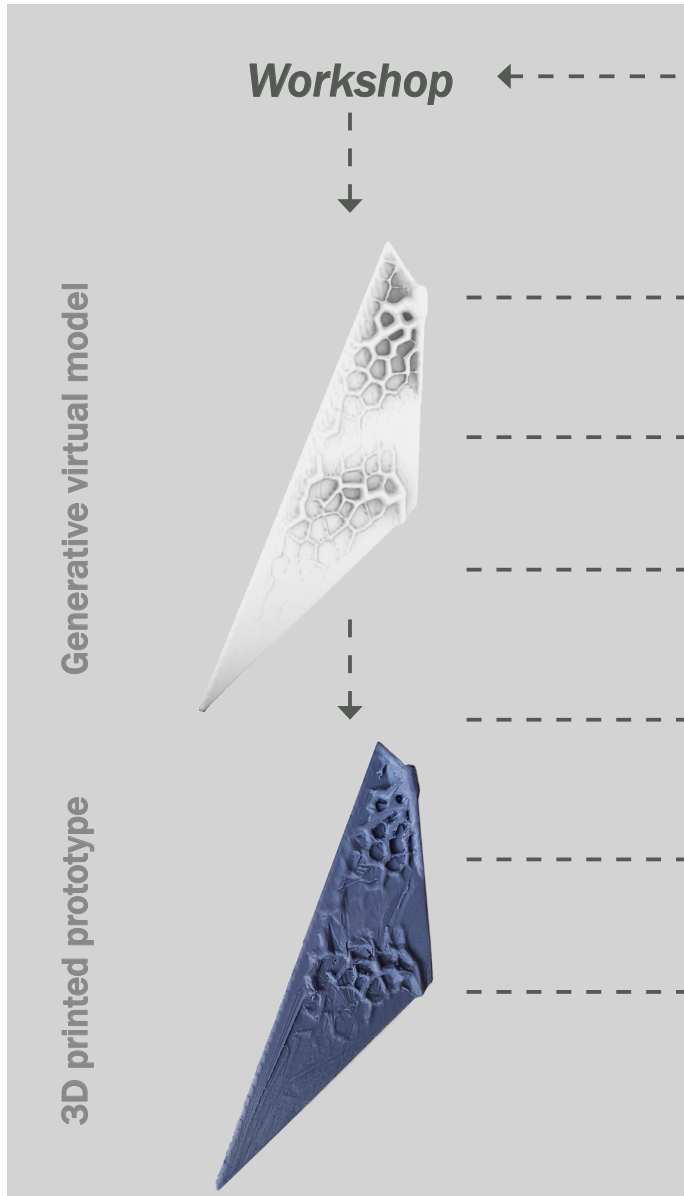
- A. Relation with thesis
- B. D2RP process + discussion
- C. Reflection

Whereas this introduction and part B. is co-authored with Thomas Geraedts



Relation with Thesis

A



How to integrate different functions into a mono material envelope that uses the potential of the 3D printing technique?

→ Computational knowledge about generative design in grasshopper

→ Integrating different functions, but also systems in envelope

→ Until what level should functions be integrated?

→ 3D printing technique for on site printing (layered, lattice, etc.)?

→ Mono-material printing for different types of functions

→ Porosity of structure tiny house?

Thesis

Workshop 01

Sound quality or acoustics can be divided into direct and indirect sound coming from a sound source. The combination of direct, first order and second order reflections of sound determine the overall quality of acoustics. The sound source produces energy, which is traveling towards a surface, then transmitted, reflected or absorbed. The energy which hits the surface is distributed into one of the three mentioned [...], the extent is dependent on the material's acoustic properties. Relating this to architectural terms, large flat surfaces generate strong specular reflection, which refers to second order delayed sound waves hitting the receiver (Cox & d'Antonio, 2016). This is unwanted and can be optimized through morphology. Diffused or scattered sound waves are pleasant in combination with the necessary absorption in a room. Hence, creating dispersed sound waves is the aim, which loses energy in the process of scattering and transform into background noise.

In architecture the term acoustics refers to the performance of sound based on reflection, absorption and diffusion in a room. To increase interior comfort it is eminent to decrease direct reflection and thus, create a scattering geometry in order to transform noise sources into ambient background sound (figure 1, Cox & d'Antonio, 2016). Furniture (e.g. sofa, carpet, curtains, etc.) is capable of absorbing a part of the emitted sound waves, because of its porous material properties these waves keep 'bouncing' and thus losing significant energy. Hence, researching diffusion as integrated functionality is interesting in order to determine the effects of different surfaces in architectural scope in order to increase the acoustics while having optimized structural features.

Acoustic Research

Figure 2 (Cox & d'Antonio, 2016)

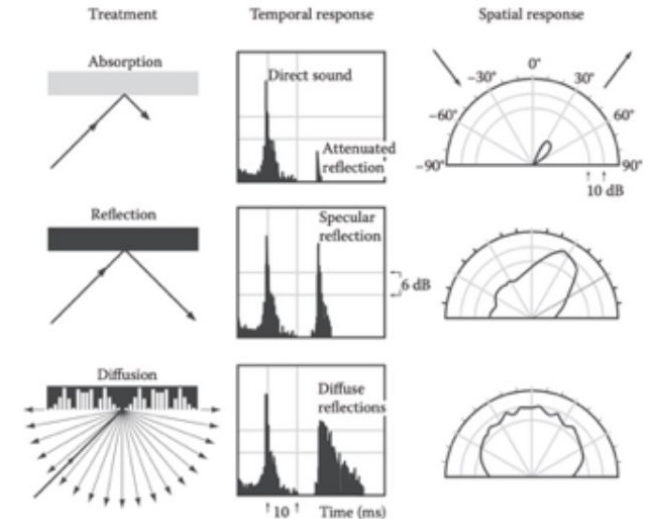
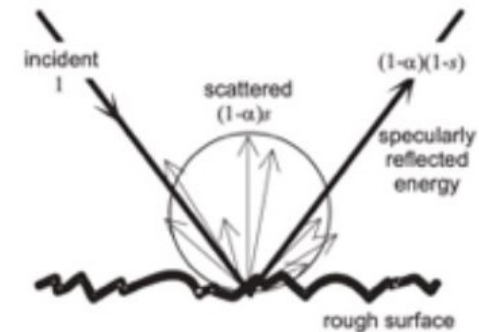


Figure 1 (Cox & d'Antonio, 2016)

Workshop 01

B

The difference between structural optimization with conventional methods and new, additive techniques is the level of complexity and the different amount of possible solutions. Current practices rely primarily on the use of concrete, steel and wood. These are manufactured in predetermined sizes and dimensions. The 3D printer changes this approach completely because it can print almost any form on demand. In doing so, it places only precious material on places where needed without losing performance. This structural optimization is only possible with additive manufacturing technologies. To know how much material is needed in what place, an analysis of the possible forces should be conducted. The manner in which these forces are transported from the panel to the main structure defines the local thickness the panel needs.

Structure Research



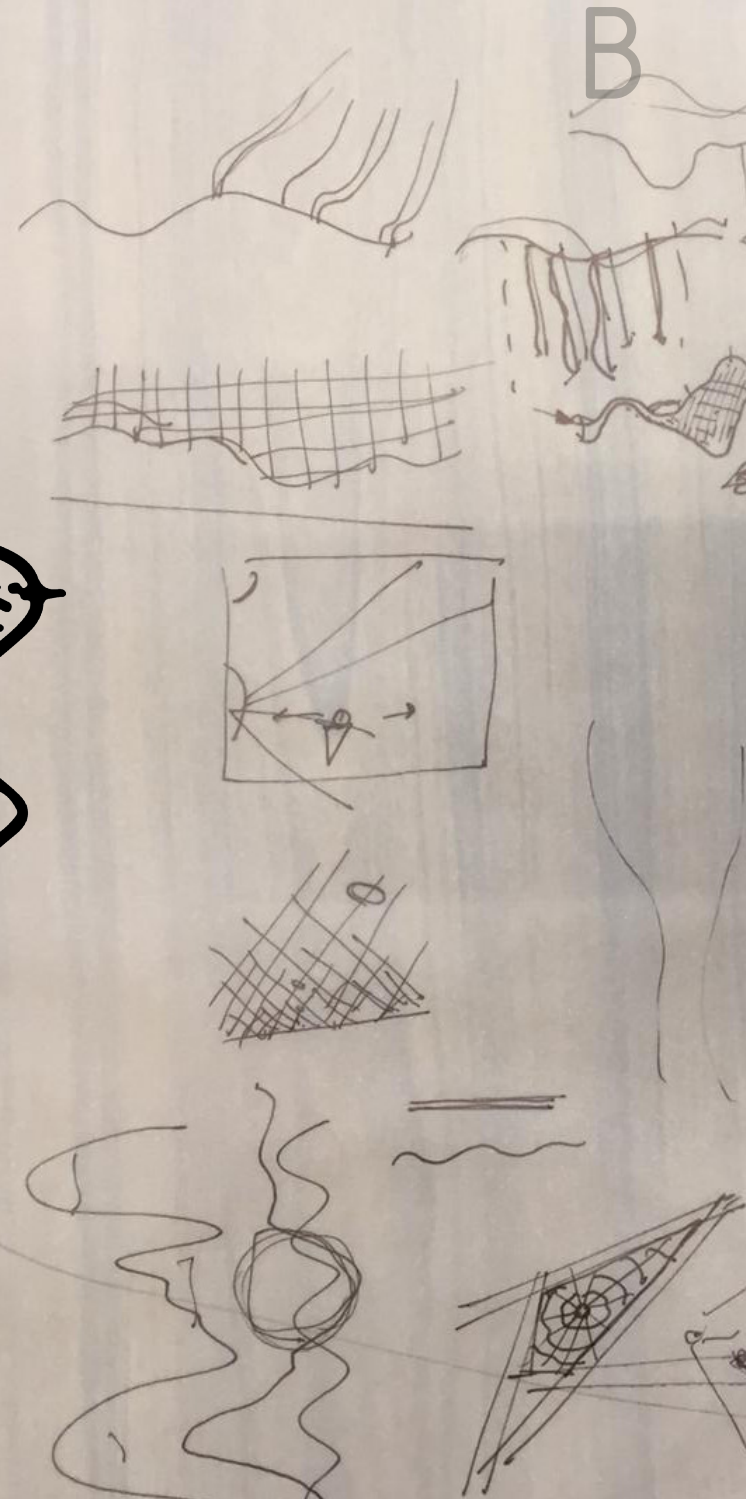
Figure 3: Optimization of structure in nodes (Galjaard et al., 2015)

Workshop 01

Considering the research about both structural and acoustic design as our starting point we developed some design principles. Firstly these functions should be integrated by using only one material, because that material is the leading factor in our thesis design, namely plastic. This is a hard material, so in order to design an acoustic panel the surface should be rippled. A rippled surface means for the structural design that it should have many different small sized beams that form the structure of the panel. This way the concept would have both used the requirements of the acoustic research, as well as the possibilities and potentials of the structural research. We started sketching these principles into a lot of different variants.

Eventually after sketching for a while we discussed them based on the level of integration, complexity and the feasibility. The concept should be simple and straightforward to communicate and to develop further into a prototype. We chose the concept as seen in the drawing. This drawing has the highest potential of integrating the two functions into a single panel element because it relies primarily on an irregular surface that is created by thickened stress lines of possible forces.

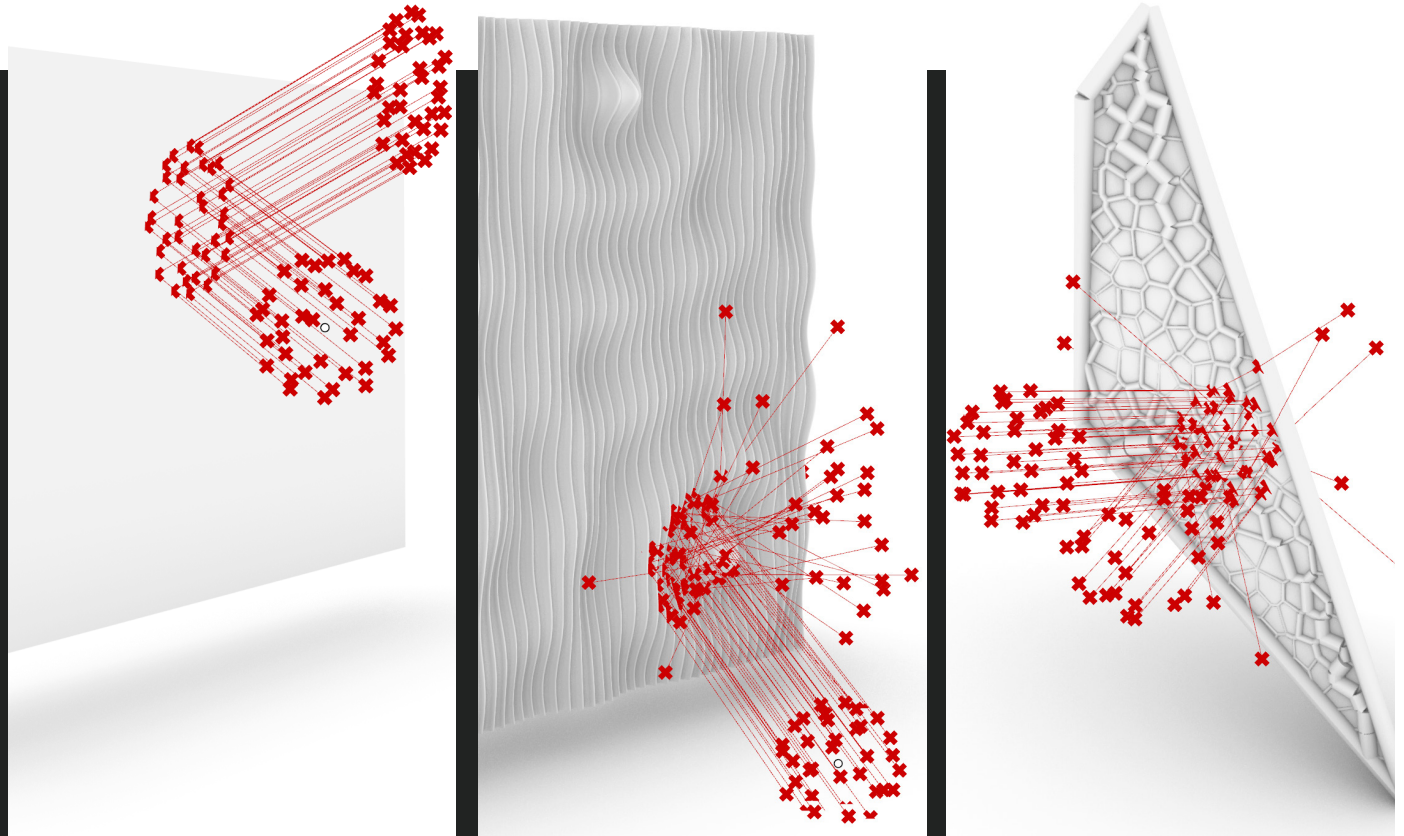
Conceptual Design
Section integrated panel



Workshop 01

B

The research on acoustics explained theories on acoustics state the importance of creating scattered sound waves. Parametrically modeled surfaces will analyze the scattering rays of sound in three simulations. Research through design, based on analysis by the forward ray tracing component in Ladybug, can project the scattering potential of a surface. The more dispersed pattern in reflection is wanted, in contrast to the direct reflection by a flat surface like the left figure. The geometry acquainted from the structural optimization model is the basis for creating random scattering (see right figure). The ray tracing component shows the results in crosses, which start at a point based source, hitting the irregular surface, scattering in high degree of randomness and are smaller because of the decrease in energy (see figure in the middle).



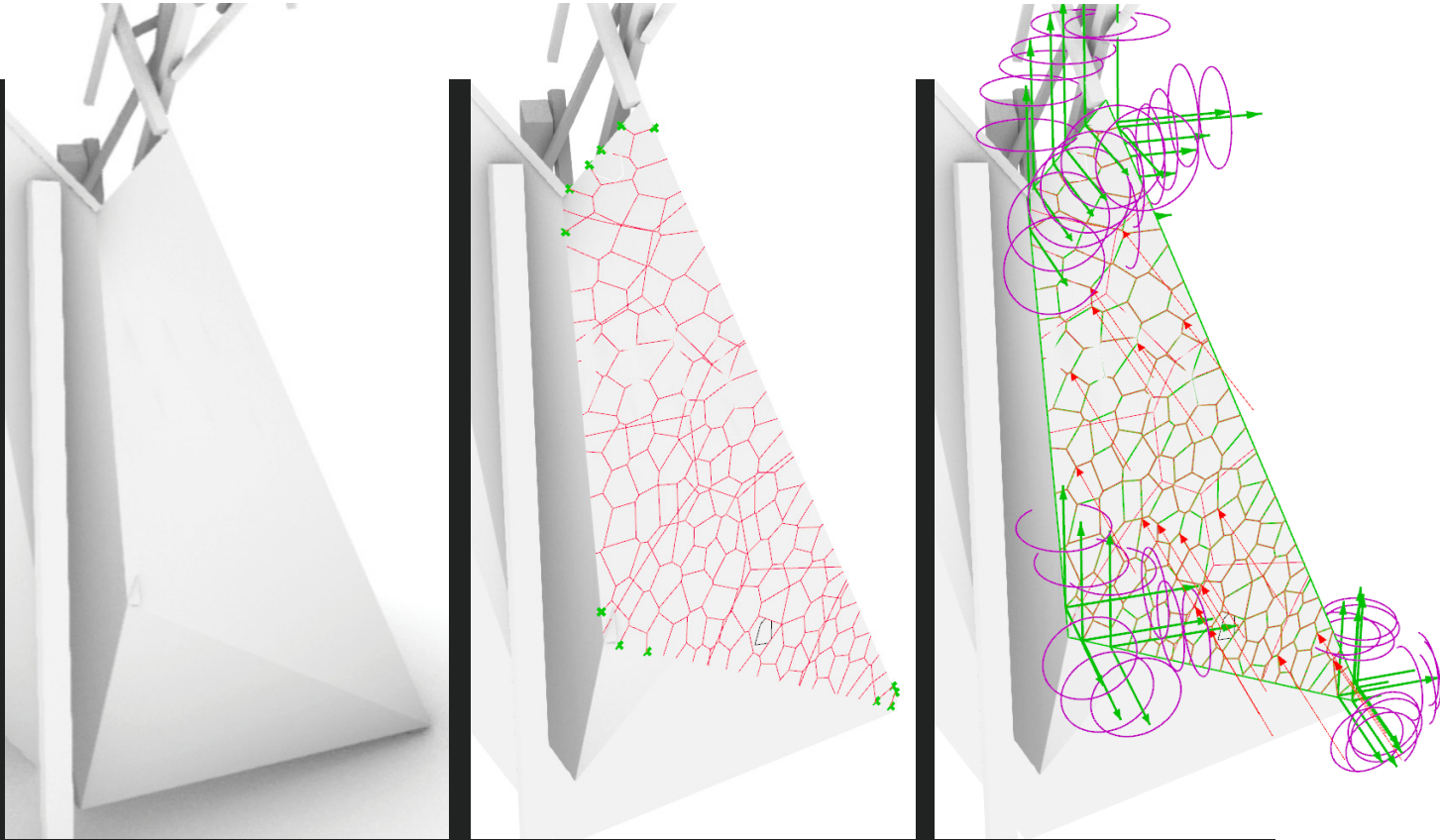
Computational Design: Acoustics

Workshop 01

B

To transform the preliminary sketched concept to a fully working prototype grasshopper is used to parametrically design the panel. A parametrically adjustable voronoi pattern is used to divide the surface into smaller sub segments. These voronoi lines are used as stress lines in the solver script of Karamba to get their supposed thickness. The panels are attached to the main structure on the corner points and they correspond with the overlaying voronoi pattern. A gravity load and a wind force are applied on this particular panel.

The integration with acoustics comes forward when looking at the voronoi lines. The higher the level of stress lines, the applied forces can be more evenly distributed to its determined support points. That means that there will be more different types of irregular surfaces that can scatter the sound.

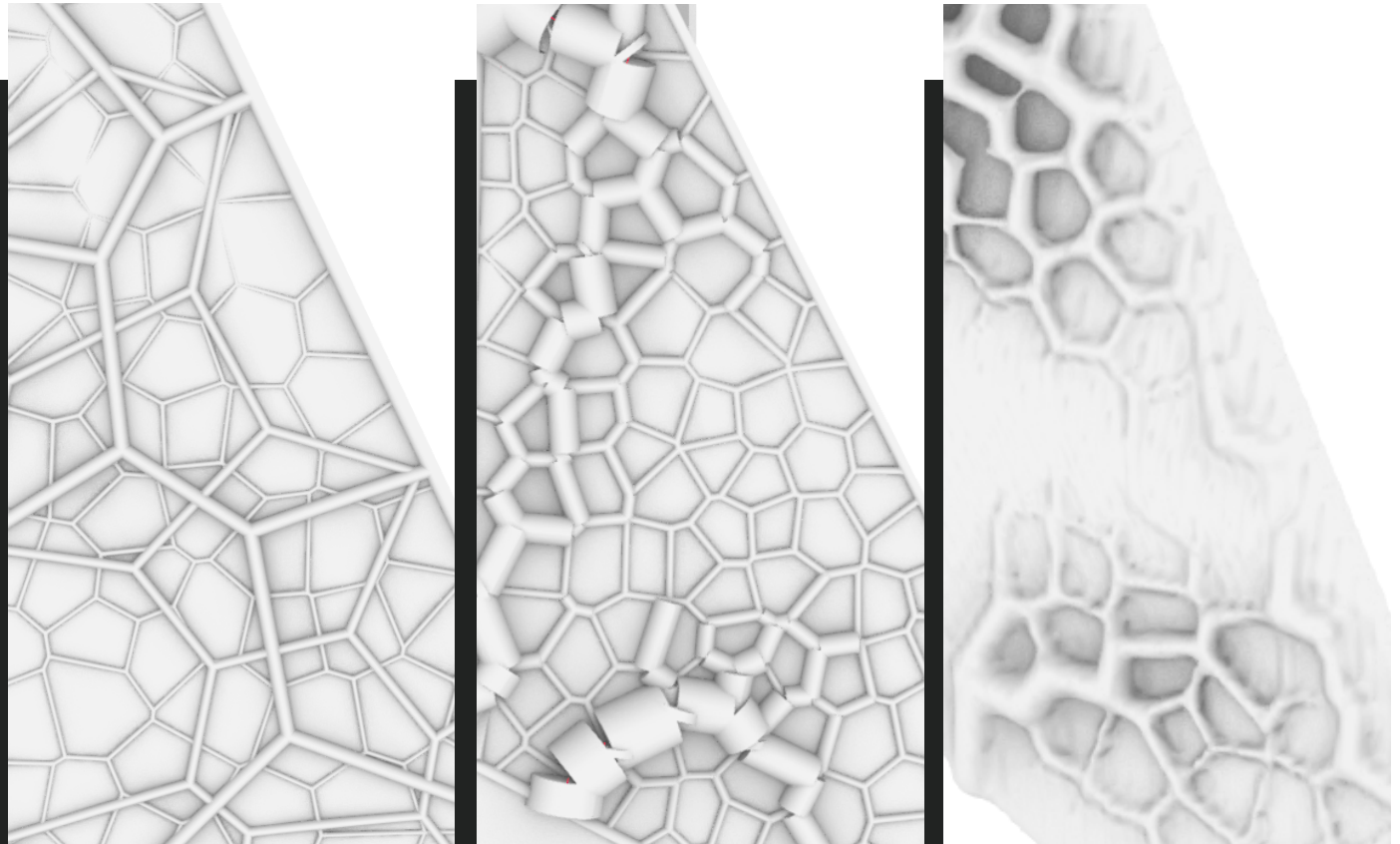


Computational Design: Structure

Workshop 01

B

The idea of using multiple heights according to both stress lines and the best acoustic scattering can be seen in the figure on the left. This figure shows the main concept virtualized without any optimization. The second one shows the optimization of the stress lines according to the applied different forces gravity and wind. The last image shows the integration between the optimized forces of the second image and the implementation of the acoustical requirements, like rippled and irregular surfaces, as described before. This procedure is done with a marching cubes algorithm plugin for Grasshopper named cocoon.



Computational Design: Integrating Functions

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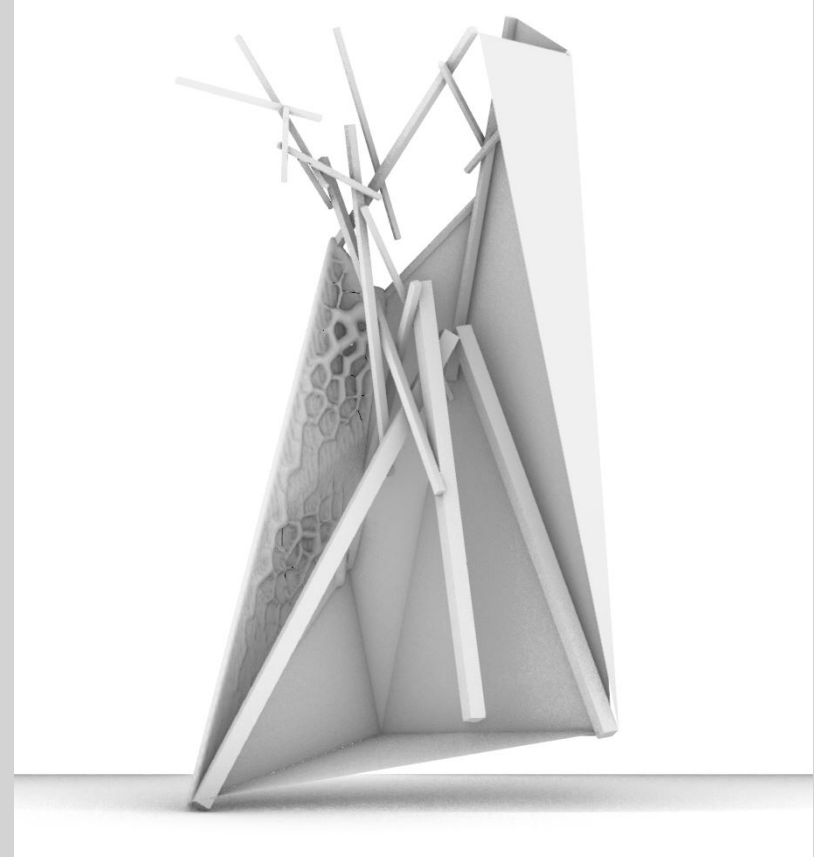
B

Final Design Panel

Optimized acoustical and structural panel



Without any context



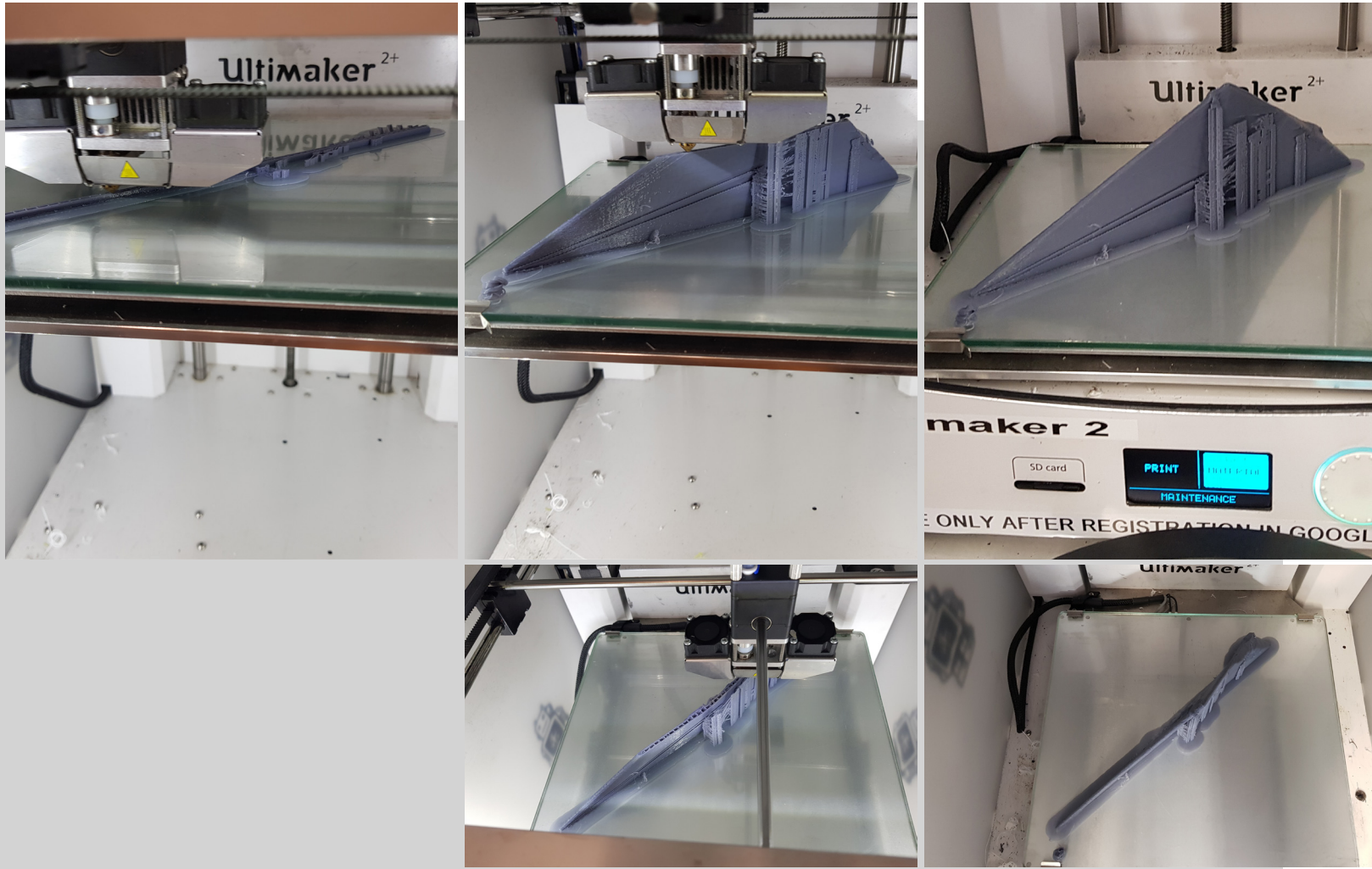
Attached to main structure

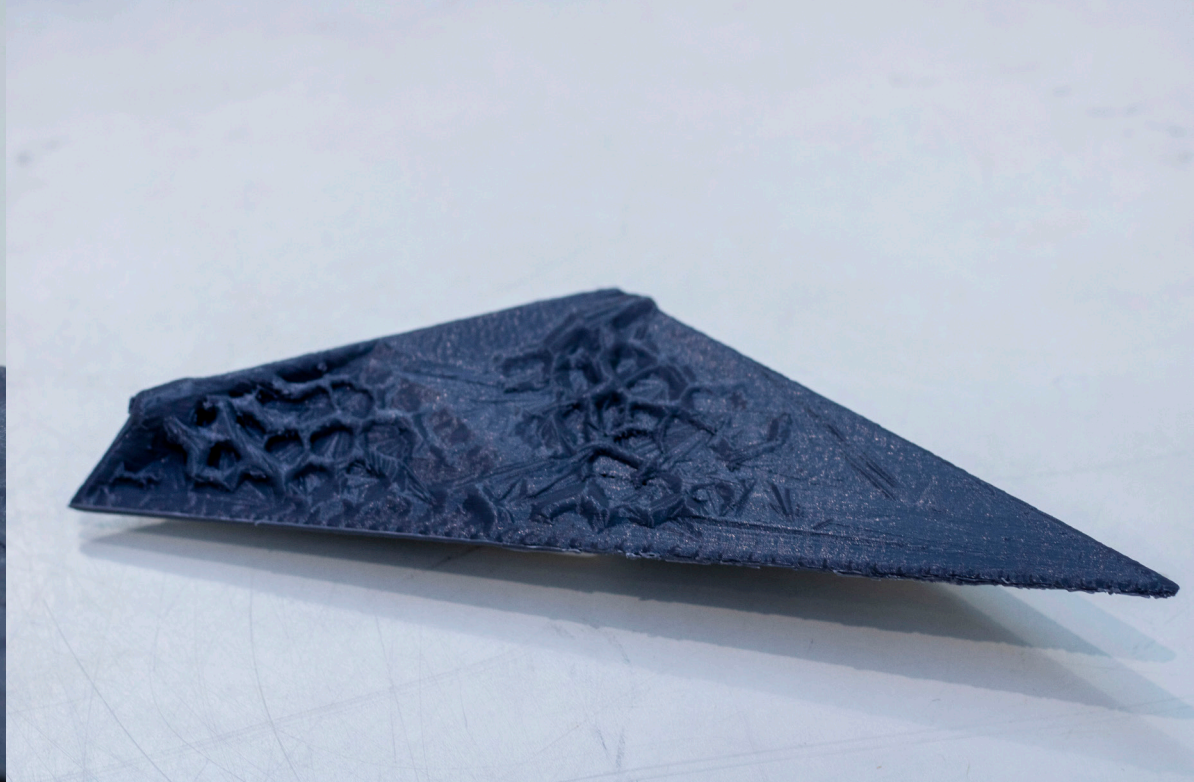
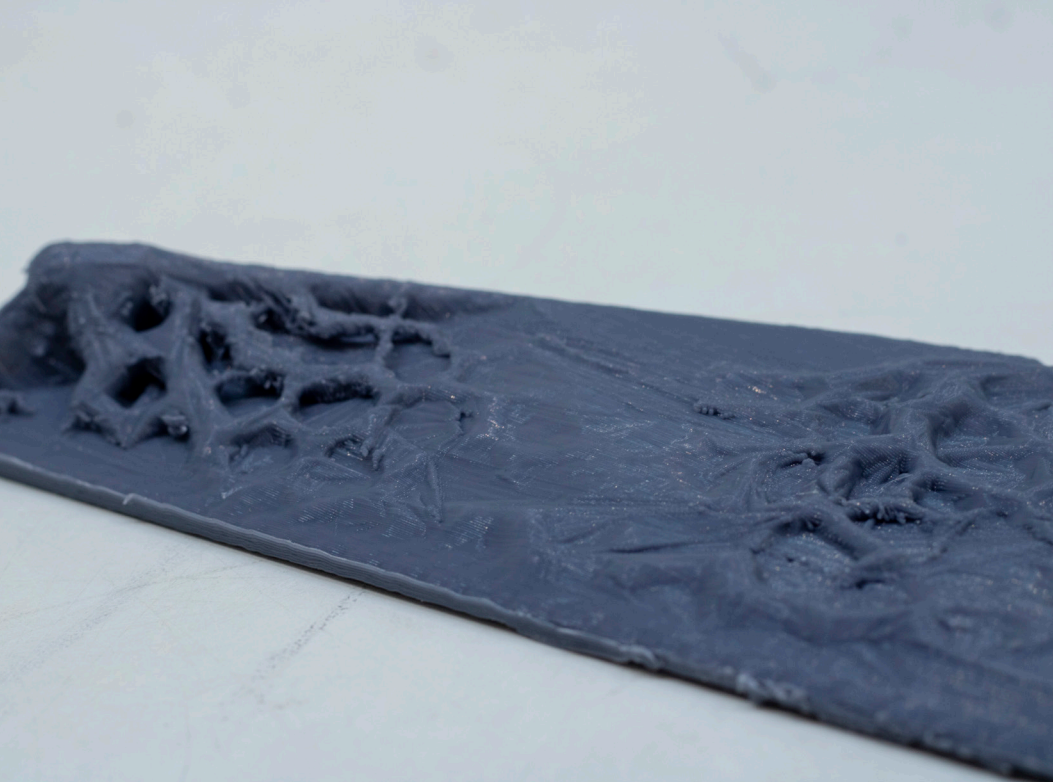
Workshop 01

B

Overview D2RRP

3D Printing Process



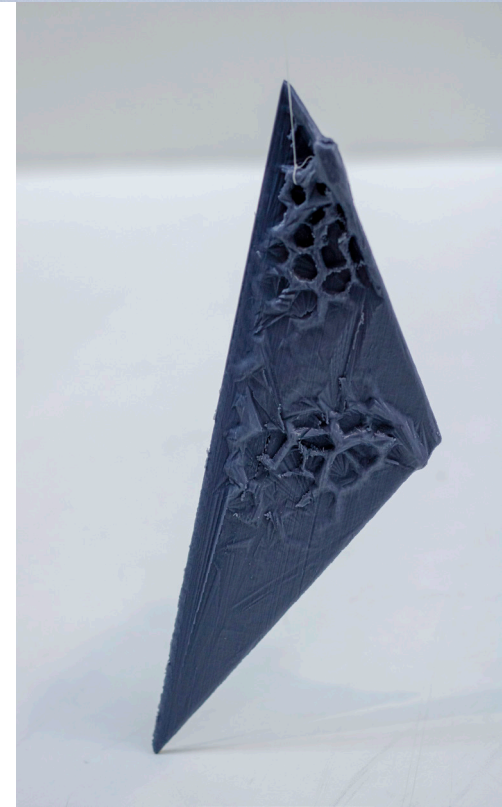


The prototype is printed with a layer height of 0.25mm and is a scaled version of the original virtual model. However this prototype certainly shows the proof of concept of the design, even when the print is not at high quality. The printing result is not everywhere as good as one would hope for, but this can have multiple causes, like the orientation of the print, print speed, layer height and the used material. It should be stated that the prototype panel is still too flat on certain places, while in the virtual model there is almost no flat surface. Scale can play an important role in this aspect because there is a ruled surface on the prototype, but it is not that visible. Probably when printing a 1:1 prototype this problem will be resolved.

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Physical Prototype

B

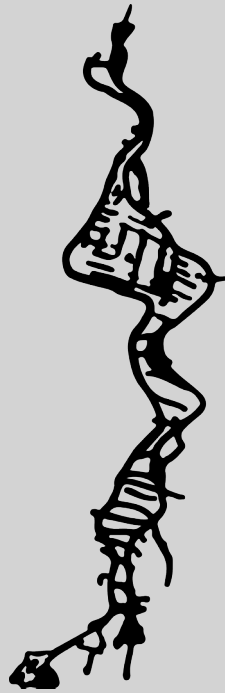


Workshop 01

B

Overview D2RP

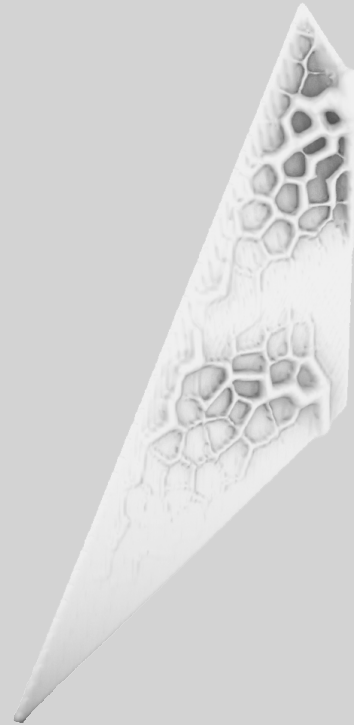
From concept to prototype



Conceptual (sketched) idea/design

Design Principles:

- Mono material
- Integration of functions
- Stress lines as acoustic panel



Virtual prototype

Design Execution:

- Dense voronoi
- Irregular surface
- Tree structure



Physical Prototype

Proof of concept:

- Plastic material
- Conventional 3DP
- Structure = Acoustic panel

Reflection workshop/thesis



During this workshop I gained a lot of knowledge to support, evaluate and improve my thesis design. During the design process I gained a lot of computational knowledge about the possibilities of grasshopper to generate a lot of design proposals. But also the process of actually printing the virtual model to a physical prototype raised a lot of questions that I did not consider in the first place regarding my thesis design. The layer height, printing speed, printing technique and the porosity of the prototype made me wonder about these aspects in my thesis design, how they can be used in a positive manner to proof that future building can be 3D printed.

Other insights appeared to me when the workshop and the integration process took place. It should be possible to also add sensor actuators in the designed panel to enhance the functions one panel could have. This insight is roughly translated in the thesis design, whereas there is a strong preference for innovation in the current building systems. The workshop shows that integrating different functions is possible, but that these interventions can be very hard. However integrating several functions does lead to a more innovative design that can be aimed towards a sustainable constructed building.