WS 1 - HYBRID COMPONENTIALITY 2.0 - D2RP & D2RO
structural optimization and acoustic integration

figure 1: final virtual result

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 1. 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 an optimized pavilion. 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/Thijs Koeleman

This workshop focuses on the integration of functions in an envelope component that can be manufactured additively. The specific functions can be stated as firstly, structural optimization based on structural simulation. The result is a more efficient use of material also reduces the amount of materials consumed. This principle is enhanced by integration of multiple functions in the same envelope component. Therefore, the second function relates to acoustic interior comfort. By researching acoustic and structural characteristics and simulating these in grasshopper scripts helps to optimize a simple envelope panel. Thereafter, the 3d model is then prepared to prototype an additive manufactured model on a scale limited by the printer's dimensions.

A. Relation with thesis

The starting principle in the first workshop of integrating functions is also the goal of the graduation research, linking this to material efficiency and circular principles. The functions in the workshop relate to structural and acoustical research, in the thesis this entails more facade performances. Firstly, the integration of thermal insulation through printing air cavities and structural optimization of these cellular pockets based on wind and gravity loads (see figure x). Secondly, the integration of adaptive technology in liquid circulation through the panel, resulting in fire resistance and solar energy harvesting performance. Based on a parametric approach in modeling a performative panel (and its constrained geometry) functions can be integrated into an innovative envelope. Thereafter, prototyping is needed in order to reflect and test the design.

B. Design to robotic production process

Research & Concept

Acoustics Research

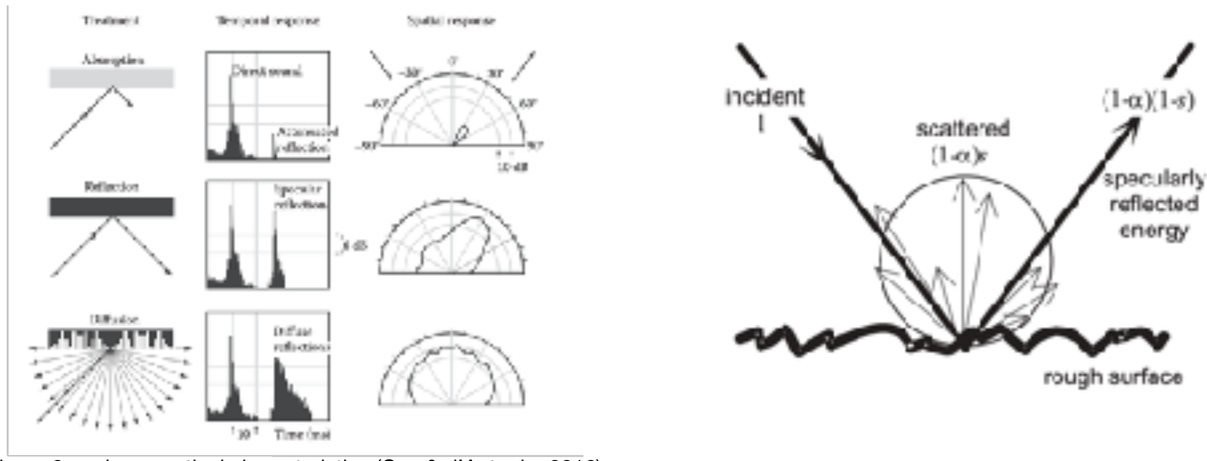

figure 2: main acoustical characteristics (Cox & d’Antonio, 2016)

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 characteristics, 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 2, 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 losing significant energy. Hence, researching diffusion as integrated function is interesting in order to determine the effects on different surfaces, while having optimized structural features.

Structure Research

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 new trend is mostly executed and visible in the optimization of different types of nodes as seen in the image below. 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.

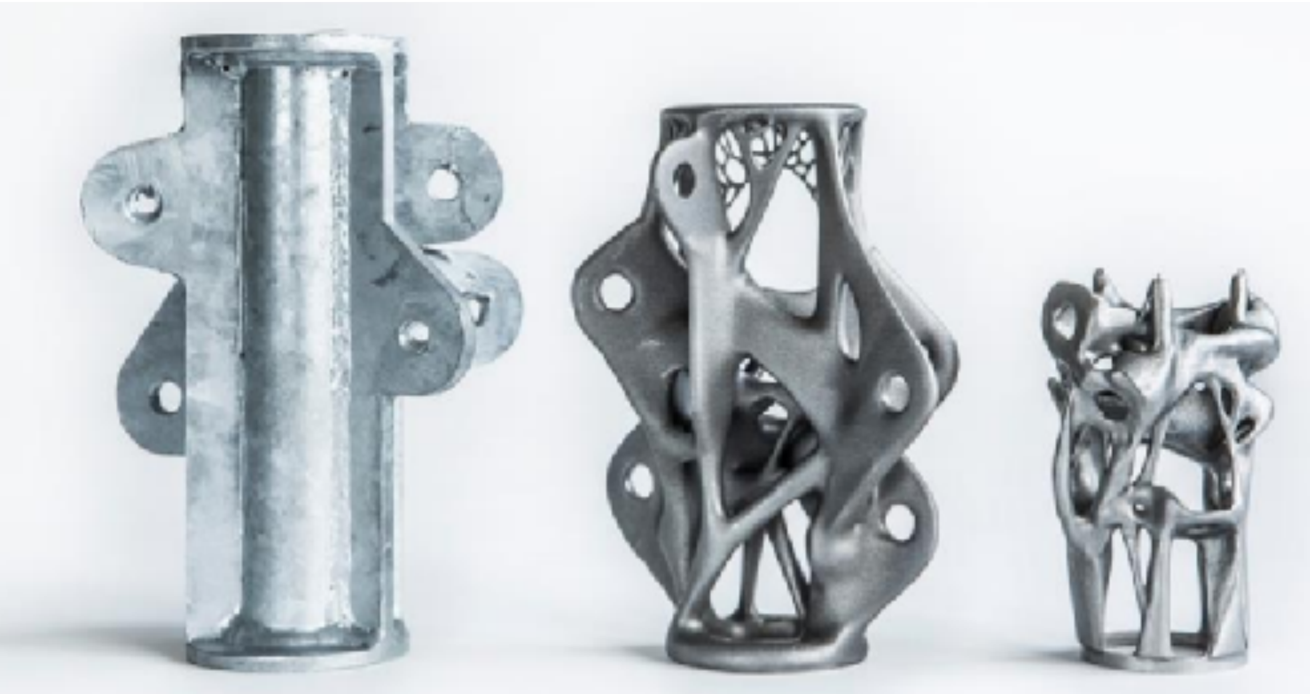

Figure 3: Optimization of structure in nodes (Galjaard et al., 2015)

Conceptual Design

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.

Figure 4: Conceptual Integration of Acoustics and Structure

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, which can be read as a section of the panel. 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.

Computational Design

Acoustic optimization

Figure 5: acoustic shoot analysis in scattered reflection

The above 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, a plug-in for Grasshopper in Rhino 6, 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 in fig. 4. The geometry acquainted from the structural optimization model is the basis for creating random scattering. The ray tracing component shows the results in spheres, 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 (fig. 3).

Structural optimization

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.

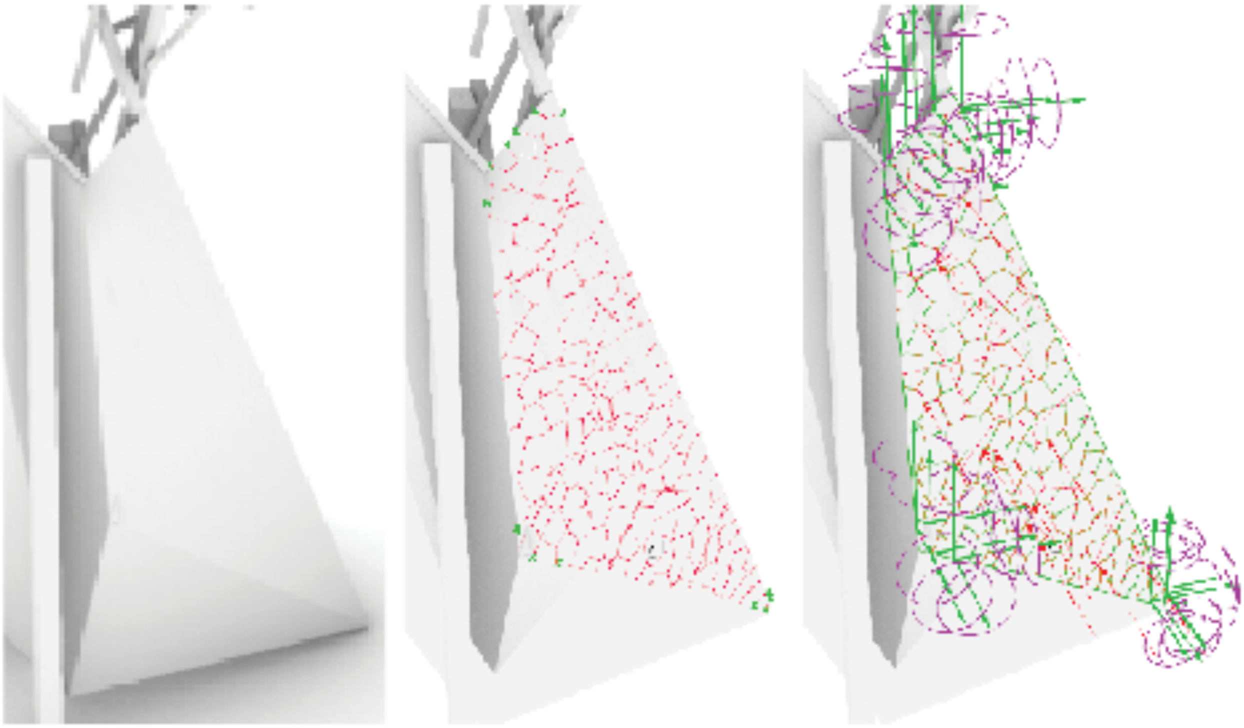

Figure 6: Panel placements, support points and loads

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.

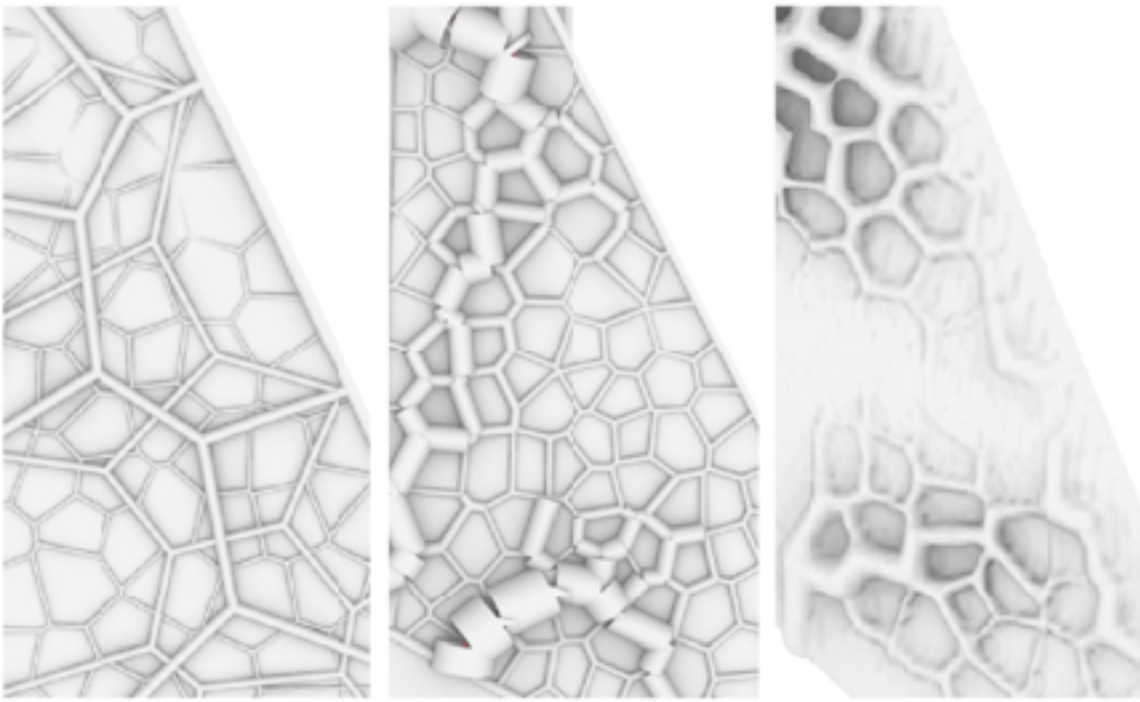

Figure 7: Evolution and optimization of panel structure

3D printed prototype

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.

C. Reflection

The research in computational design is a first obstacle in achieving the wanted performances. In the workshop the integration of one primary and secondary function showed already difficulties in achieving properly modeled geometry for additive manufacturing. The lessons learned are to start early with the first prototype in order to evaluate printability and secondly, develop a suitable concept for generating optimized geometry with the aid of computational (parametric) modeling and simulation. The structural optimization with karamba3d resulted in an optimized flow of force through a given voronoi, this research is extended by another approach. Through voxels or cellular geometry, the panel will be optimized in topology by given forces. Resulting in a panel consisting of cellular solids and voids, the dimensions of the void in relation to the solid could integrate thermal insulation and structural optimization.

References

Cox, T., & d'Antonio, P. (2016). Acoustic absorbers and diffusers: theory, design and application. Crc Press.

Galjaard, S., Hofman, S., Perry, N., & Ren, S. (2015). Optimizing Structural Building Elements in Metal by using Additive Manufacturing. Presented at the International Association for Shell and Spatial Structures (IASS), Amsterdam, The Netherlands. Retrieved from https://www.arup.com/projects/additive-manufacturing