Rapid Prototyping in Acoustics: Designing Sound Diffusive Panels with Rhino and Grasshopper for Robotic Fabrication

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Abstract

This paper examines whether parametric design and rapid prototyping can be used to design and test sound diffusive panels. Initially, the design and testing methods in Rhino and Grasshopper are presented, which were established during the Creative Tools course in Lunds Tekniska Högskola. Emphasis is given to the utilization of the Pachyderm plugin, which was used to simulate the panels' performance. Secondly, the acoustic measurements of the final products are explained, which are followed by the results of those measurements. Finally, the outcomes and observations of the experiments are discussed, with an emphasis on the collaboration between architects and acousticians, and options for alternative methods of fabrication and collaboration between designers and other specialists.

Keywords: Rhino, Grasshopper, Pachyderm, Architectural Acoustics, Sound Diffusing Panels.

1 Introduction

Acoustics are an essential part of architecture. Many studies have proven that quality acoustic performance within buildings can improve mental health, wellbeing, and productivity. A space that under-performs acoustically can, on the contrary, inhibit one's ability to concentrate, create frustration, impair healing and recovery of patients and even lead to health issues in the future. Additionally, the sound performance we expect within different spaces is specific to the activity and the people who are making use of the space.

The usage of rapid prototyping methods in architecture has been a much discussed and applied topic in recent years. These new technologies are altering the way we design and think of architecture. One notable example of additive manufacturing in architecture is 3D printed houses and the use of advanced CNC machine tooling for wooden buildings. Those techniques are increasingly contributing to shortening construction time and eliminating waste. [1] Another example would be using rapid prototyping in the design of furniture, which saves time and resources, and allows for more daring and innovative designs. [2]

This paper is an attempt to verify whether there is substance in these deemed advantages, and whether these methods could be applied to the design of acoustic panels, as well as explore and validate their impact.

2 Method

The aim of this course was to use parametric design and rapid prototyping methods to design, test and fabricate wall mounted diffusive panels. The focus was not only to create acceptable acoustic performance, but also to fabricate functioning diffusive panels as architectural elements.

The course was a collaboration between university and industry, where Saint-Gobain Ecophon brought the know-how in terms of acoustics while the students got to use their design abilities and their insights in robotic manufacturing technique to unite function with form.

A File-to-Factory approach was used to rapidly iterate and test the design of the diffusive panels, focusing on their performance in room acoustics.

The design of the diffusive panels was developed using 3D modeling software and parametric design tools (McNeel's Rhinoceros and Grasshopper). The acoustic performance of the diffusive panels was measured and simulated by utilizing Pachyderm, a free and source-available plugin for Grasshopper. Finally, fabrication of the diffusive panels was achieved through extruded polystyrene foam-carving using a ABB IRB 2400 robot arm outfitted with a custom-made foam wire cutting tool.

The process was divided into two parts. In the beginning of the course, the students worked individually, each designing and testing a single diffusive panel, familiarizing themselves with the software and its capabilities. The design procedure was introduced to the students via a series of video tutorials. A 200x600 mm box (the 'initial stock') was 'carved' in the desired shape using Grasshopper. [3]

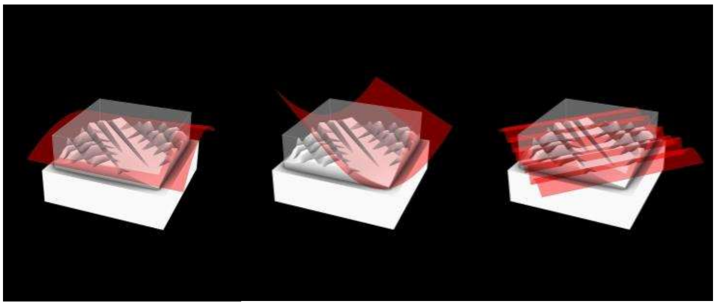

Figure 1 – 'Carving' of the panels in Grasshopper

Afterwards, the Robots plugin for Grasshopper was utilized to simulate and instruct the robot arm on how to move along the cutting surface.

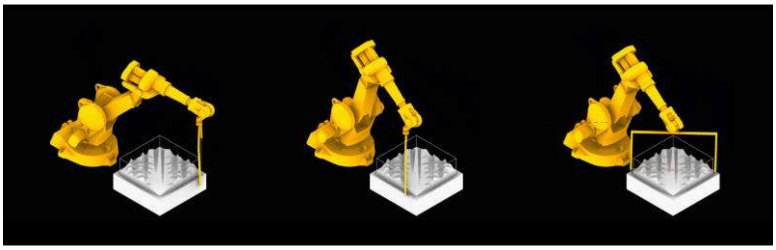

Figure 2 – The robot arm performing the cuts in the simulation.

Problem areas were identified and the direction and shape of the cuts was adjusted in order for them to be feasible without damaging the tool or the robot. [4]

The simulation for the acoustic performance of the diffusive panels in Pachyderm followed. The process of setting up a script for this simulation was also provided in video tutorials.

An 8 x 6 m room, with a height of 3 m, was used. The walls and floor were made of plywood, and the ceiling was fully sound absorbing. The absorption and scattering coefficients for these surfaces were set through Pachyderm.

The first simulation was a visual one. A source was set within the room, from which sound, represented as rays, was transmitted. The number of rays was determined using a Grasshopper component from the plugin ‘Pufferfish’. The number of bounces of the rays off the walls was determined using Pachyderm. Thus it was possible to visualize how the diffusive panels diffuse and direct sound. [5]

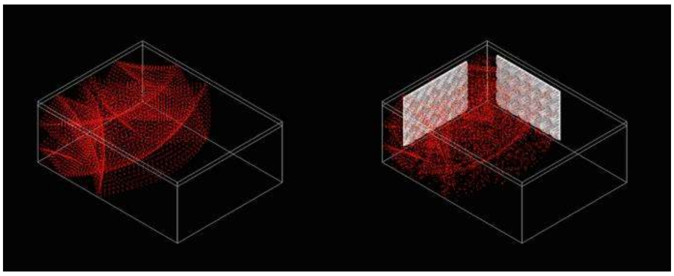

Figure 3 – Sound diffusion simulation. Left: room with absorbing ceiling and reflective walls. Right: room with absorbing ceiling and diffusive panels on two adjacent walls.

In the second simulation the reverberation time of the room was calculated, for 7 sound frequency ranges. A higher number of rays, or ‘samples’, was used this time: 5000. [6]

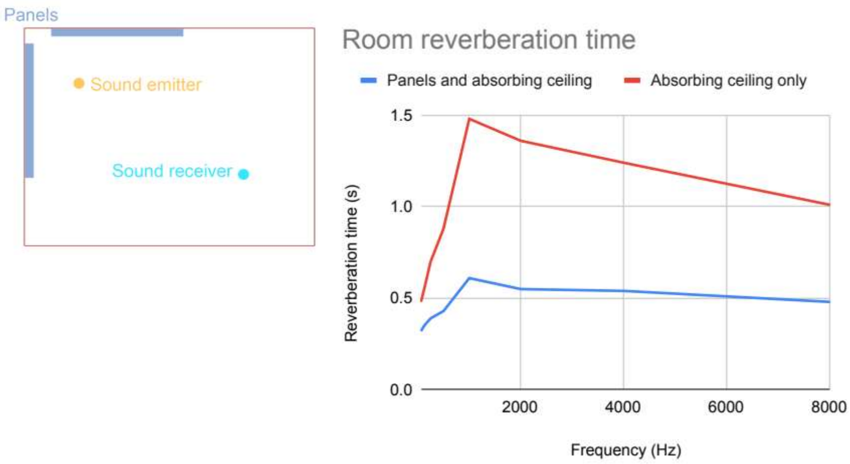

Figure 4 – Left: simulation testing setup. Right: room reverberation time of one of the final diffusive panel designs.

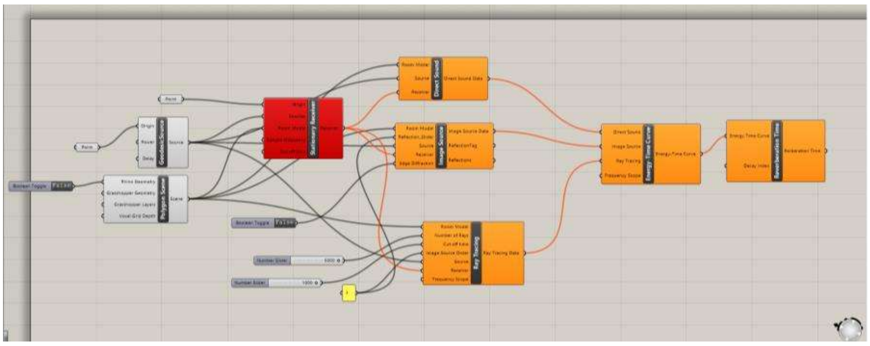

Figure 5 - Grasshopper canvas displaying components and relations for the calculation and simulation of room acoustics through the Pachyderm plugin.

In both cases, the simulation was run twice: once for an empty room, and a second time for a room where two adjacent walls were outfitted with diffusive panels. In all cases the rooms had a fully sound absorbing ceiling. This way, it was possible to evaluate the performance of the diffusive panels on many levels.

It was determined that the numbers for mid-to-high frequencies were accurate, but the accuracy in the lower frequencies left something to be desired.

The students had a few meetings to go over their individual design approaches. Initially, there were many similarities between designs. However, as the students became more comfortable they started pushing the capabilities of the design and wire cutting methods.

After individual feedback was provided by the course teachers and industry supervisors, and the individual designs were crystallized, the students formed teams of 3-4 people in order to prepare the final diffusive panels designs. The formation of the teams was a rapid process, guided by the teacher, although ultimately the decisions were taken by the students.

The outcome of this part of the course was three distinct diffusive panel libraries, one for each group. Those were the result of a very dynamic dialogue where students sculpted visually interesting forms, and SG Ecophon guided how to get the best acoustic performance from each design.

The first group worked on a diffusive panel concept inspired by Helmholz resonators. Their design ('Alpha') incorporated cavities where the sound waves would enter and become trapped, thus eliminating certain frequencies.

Figure 6 – Diffusive panel design Alpha. Left: object rendering. Middle: interior scene rendering. Right: finished product photo

The second group's diffusive panels would direct sound towards a sound absorbing ceiling. Their diffusive panel library ('Beta') consisted of three designs that could be arranged into various patterns. These designs incorporated horizontal 'hills' and grooves.

Figure 7 – Diffusive panel design Beta. Left: interior scene rendering. Right: finished product photo.

The third group focused on sound diffusion. Their diffusive panels ('Gamma') could be arranged into different seamless patterns with grooves that would diffuse and eliminate standing waves.

Figure 8 – Diffusive panel design Gamma. Left: interior scene rendering. Right: finished product photo.

At the end of the course, a single diffusive panel was produced from the individual designs in order to test the robotic wire cutting technique. The group designed diffusive panels were then produced en masse, resulting in 9 panels for each diffusive panel or diffusive panel library design. The robot arm was operated by the course teachers, due to Covid-19 restrictions.

When the cutting process started, some changes had to be made in order to avoid the robot from hitting itself. This was achieved quite easily through changes in placement of the initial stock in Grasshopper, and with adjusting tolerance.

Afterwards the groups covered the carved panels with concrete in order to provide them with a more refined surface and make them fully diffusive (whereas it is assumed that foam would have been at least partly absorbing). For the final presentations, the groups were asked to show the possibilities of the diffusive panels as design elements, experimenting with visualizations of scenes where the diffusive panels might be used.

Since the whole process took place during the coronavirus pandemic, meetings would take place online through Microsoft Teams, where students would show the designs and simulations directly from Rhino. This way, real time data was provided to the experts, who in turn gave instrumental advice on how to develop the designs further.

3 Measurements

Each group diffusive panel design was tested in real life in SG Ecophon's laboratories.
The diffusive panels were measured in a reverberant room with a suspended sound absorbing ceiling installed, see Figure 9.

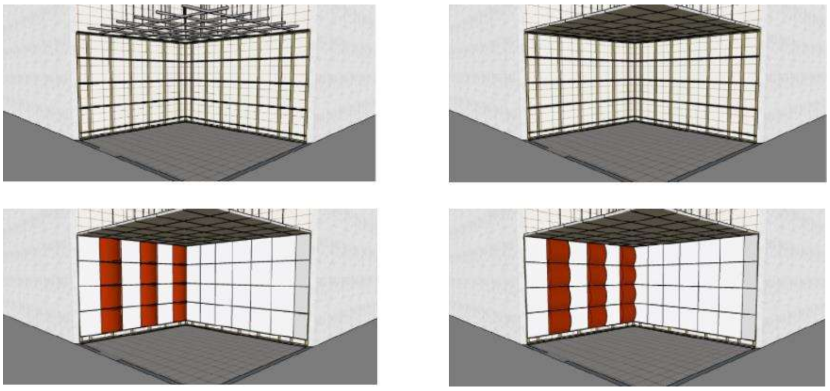

Figure 9 – Reverberant room. Upper left: without ceiling treatment (only grid system). Upper right: with sound absorbing ceiling. Bottom left: with vertically oriented diffusive panels. Bottom right: with horizontally oriented diffusive panels.

The diffusive panels were rotated 90 degrees to investigate directional effects of the diffusors, see Figure 9 bottom left and bottom right. Figure 10 below shows the reverberation chamber with the actual diffusive panels in vertical shaped orientation and horizontal shaped orientation, respectively.

Figure 10 – Diffusive panels 'Beta'. Left: vertical shaped orientation. Right: horizontal shaped orientation.

The room acoustic parameters reverberation time T20 and speech clarity C50 were measured for the diffusive panels in vertical and horizontal orientation. T20 and C50 are defined in the standards ISO 3382-2 and ISO 3382-1, respectively.

T20 is a derivative of the parameter T60, the amount of time required for the sound energy in a room to drop 60 dB. If T60 were to be visualized by a decay curve, T20 could be derived by evaluating the -5 to -25 dB part of it. [7] [8]

Speech clarity C50 is related to the time required for the sound reflections to reach the listener after the direct sound is created. It is the ratio between the sound energy reaching the listener in the first 50 ms after the direct sound was emitted, and the sound that arrives afterwards. [8]

Generally, lower values of T20 lead to increased damping in the room, and higher values of C50 to better speech intelligibility in the room.

The purpose of the measurements was to investigate how the different orientations of the diffusive panels relative to the sound absorbing ceiling affect the room acoustic parameters T20 and C50.

4 Results

Positions\Diffusive panel libraries	Diffusive Panels Alpha	Diffusive Panels Beta
Horizontal shaped orientation		
Vertical shaped orientation		

Table 1 – Orientations of the diffusors tested.

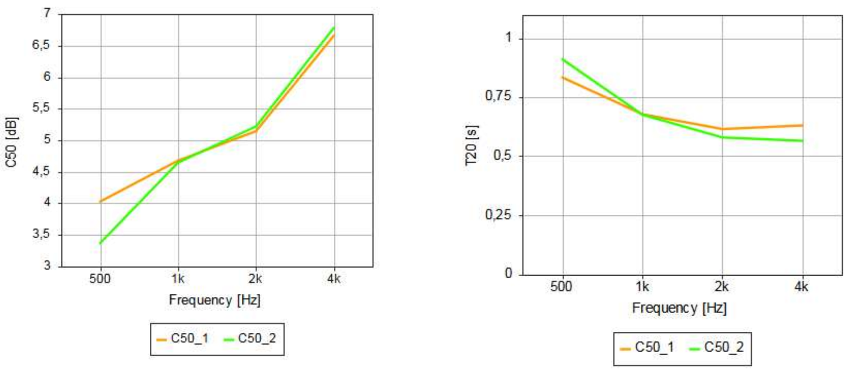

Figure 11 – Diffusive panels ‘Alpha’. Green – horizontal shaped orientation, red – vertical shaped orientation.

For the diffusive panels ‘Alpha’, one can observe low values of C50 and high T20 at lower frequencies, and higher values of C50 and low T20 at high frequencies. The difference of the effects between the two positions tested are not that pronounced. The irregularities in the ‘Alpha’ diffusive panels are small as well as the directional characteristics when rotated 90 degrees relative to the ceiling. Consequently, the two different orientations give more or less the same values of the room acoustics parameters as shown in Figure 11.

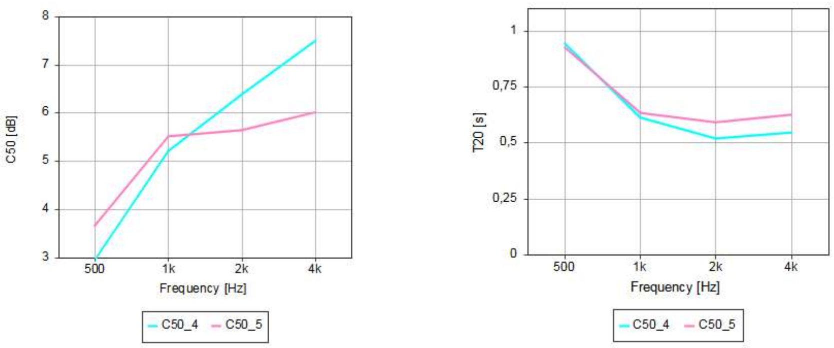

Figure 12 - Diffusive panels 'Beta'. Blue – horizontal shaped orientation. Pink – vertical shaped orientation

The 'Beta' diffusive panel, which was designed to direct sound waves towards an absorbent ceiling, behaves quite differently. When used as intended, in horizontal shaped orientation, the speech clarity is significantly higher for the frequencies 2kHz and 4 kHz compared to vertical orientation, see Figure 10. The differences are larger than JND (Just Noticeable Difference) according to ISO 3382-1. The frequency region above 1 kHz is important for the perception of speech. The difference is less pronounced for the reverberation times.

The 'Beta' diffusive panel was further tested, due to its design intention, to further understand how the sound is spread around it. The directional characteristics were measured in a semi-anechoic chamber. The reflected sound was measured in a quarter of a circle around the diffuser.

Figure 13 – Testing setup for diffusive panel 'Beta'.

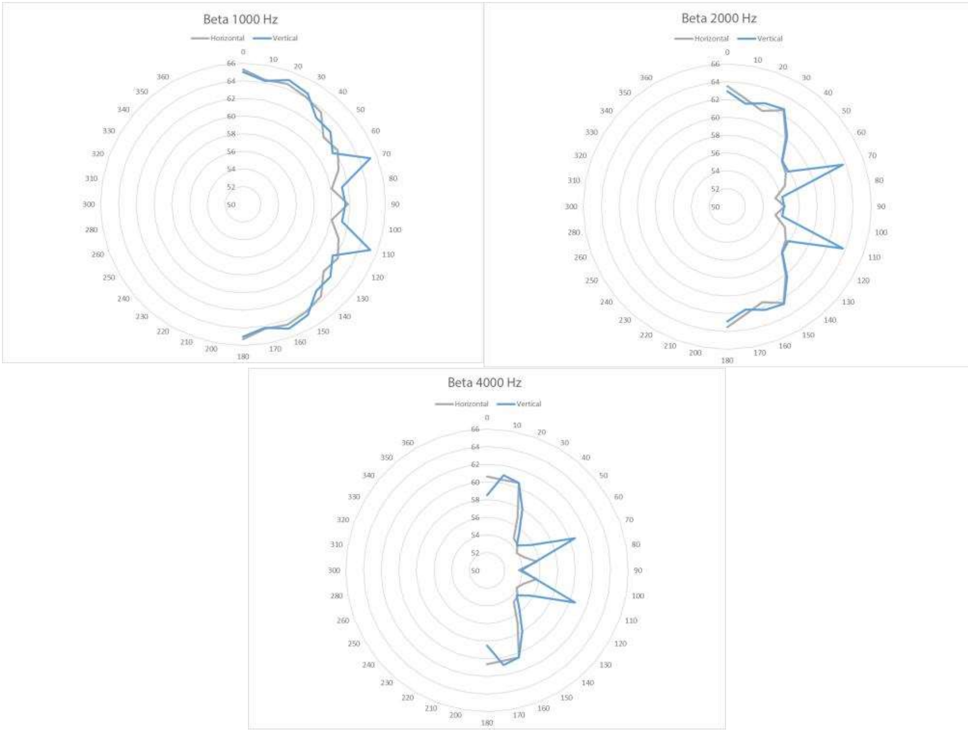

Figure 14 – Directional characteristic of 'Beta' diffusive panel measured in a semi-anechoic chamber. Both horizontal (grey) and vertical (blue) shaped orientation were measured.

When placed in horizontal shaped orientation, there is a somewhat even distribution of sound pressure around it, in all frequencies measured. Contrarily to that, when tested in vertical shaped orientation, there is a spike in sound pressure at a 70 and 110-degree angle, especially at 2000 - 4000 Hz. Thus, depending on the diffusive panel's orientation relative to the sound absorbing ceiling, more or less of the sound energy can be redirected towards the ceiling. This property of the diffusive panel makes it an efficient product to "fine tune" the room's acoustical parameters and in particular the speech clarity.

5 Discussion

There were numerous outcomes and observations derived from this initiative.

Firstly, through experimenting with form and function, a variety of distinctive panel shapes emerged. Many could also be considered decorative and useful as elements of interior design. It became apparent that there are many approaches that could lead to visually compelling outcomes and acceptable acoustic performance.

However, the design workflow used, as well as the method of wire cutting, has certain limitations that can influence the design direction. Incorporating sharp angles into a design is difficult, which leads mostly to organic shapes, curved edges and simplified cuts. Given other variables, tools and different sized panels, we could see further progression of the designs and tackle more of the limitations.

Another issue often encountered was the slight misalignments between the digital, 'perfect' design, and the one produced in reality. Also, technical difficulties with the robot would occasionally lead to 'flawed' panels being produced.

One solution to these problems could be using a combination of 3d-printers and CNC machines to provide alternative ways of manufacturing acoustic panels. That could bypass the restrictions mentioned above, and lead to even more daring and creative designs.

Secondly, there are multiple observations concerning the pedagogical setup of the course. The students enhanced their knowledge of acoustics and abilities within different software, as well as learning how to incorporate the feedback of experts into their designs. Also, having the experts present continually throughout the design process lead to a higher quality design experience. That may not have been so if feedback would have been provided only at the end of the course.

Thirdly, it was proven that this dialog between architects and acousticians, along with a file-to-factory method of design and production can lead to a great number of well-performing diffusive panel designs in a short amount of time, with designs catered for specific spaces.

These digital designs can easily be both mass-produced and mass-customized, as well as their performance simulated with software. This opens up the possibility to produce designs adapted to different contexts, but using the same foundation. Throughout the process, it became apparent that parametric design, with change just a click away, was enormously useful when responding to continuous feedback.

6 Conclusions

The iterative process of professionals providing expertise to the design students, using a file-to-factory approach and continual feedback proved to be an effective way of learning and producing prototypes fast and with high quality. This way of cooperation could be translated into other fields where expert knowledge is also of great importance and where there is a demand for fast results.

The method explored in this course could be a way to further strengthen the interaction between architects and designers on one side, and acousticians and other specialists on the other. As a matter of fact, our presence at Euronoise is one contribution to bridging the two fields.

This could even be a global process, since the course proved that great results could be achieved even if the only interactions between students and professionals are online. With that noted, the actual testing of acoustics is necessarily done in real life.

The aim of the course was to combine sufficient acoustics with pleasing and functioning aesthetics, and determine whether parametric design and rapid prototyping methods could be applied to the design of acoustic panels. While it would be difficult to answer this question definitively, we believe that this experiment is a significant attempt at exploring this new and promising field.

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