Parametric design of a modular acoustic volumetric unit for indoor recording spaces

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ABSTRACT

Increasingly sound recording studios are demanded to host projects of different acoustic needs. However, their sonic character, effect of their contents and bulky conventional treatment solutions, usually remains unchanged. This paper reports a modular volumetric unit's's early-stage design, aimed at providing usage flexibility to a group of representative recording rooms. The versatility refers to acoustical (absorption and reflection), practical (volume and weight), and aesthetic aspects. The geometry and materials of the panel were derived parametrically through computer modelling software, by implementing interdependent and adaptable elements to one unit. Existing recording spaces were recreated into computational acoustic models and tested in two states. Simulations of the rooms' acoustical behavior were run in turn, first with the original treatment, then with the panel replacing the treatment. The design goal was to have minimal differences in Reverberation Time, Early Decay Time, Clarity, Room Frequency Response for every room's two states. Results showed the panel performing better in rooms with larger volume. Overall, the panel matched the original acoustic response and character of the rooms, while providing versatility when compared to traditional acoustic treatment solutions. The development of such a product would allow future studio users to fine tune the room's performance according to their needs.

1. INTRODUCTION

The acoustical character of a recording space is mainly the result of its fixed characteristics such as shape, size, surface materials, contents, and structure. The problem with such a fixed acoustical character is the inability to cater specifically to different acoustical needs, which often come when various projects are being hosted in the same space. The objective of this work was to create a parametric design strategy for a modular unit that allows the alteration of a room's acoustical qualities, depending on the needs of the user.

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2. ADAPTABLE ROOMS

Variable acoustic solutions have been used to create transformable rooms. L' Espace de Projection in IRCAM which stands for Institute for Research and Coordination in Acoustics/Music (Peutz, 1978), and can change its volume using a movable ceiling system and its surface properties by having a modular unit build in all surfaces but the floor. The Resonant chamber (Thun, 2012) uses an origami inspired system with layered triangular surfaces of four composite panels (reflector, electronic, electroacoustic, and absorptive). That project, similar to its many predecessors (The adaptable room(Hunter, 2011), Variable Geometry acoustical domes(Serero, 2006)) use a "cloud" system, mounted on the space's ceiling. The VRAS variable room acoustic system (Poletti 2003) is a digital method for adding reverberation to a performance room without changing its actual physical properties.

Methods like this are important steps in making rooms adaptable. Lowering the ceiling and having large units (almost $1m^2$) with rotating components works in L' Espace de Projection but is difficult to apply to smaller spaces and was a space-specific solution. A cloud system gives a solution to changing the ceiling surface but not for the walls. And VRAS only digitally affects a space and does not alter its physical state.

Some of the weaknesses of the solutions are that they are limited in production and their design would have to be changed in order to fit different rooms (geometry, placement etc.), which would require time and increase the cost of the end product. Finding a simple, versatile solution that could be fitted into any room and alter its acoustical qualities while remaining easy to assemble, manufacture and change depending on the user's preferences would allow easy production and trustworthy results for a multitude of different occasions.

3. DESIGNING THE UNIT

In the case of this work, the early-stage design of a modular unit (Figure 1) is carried out. The aim was for the modular unit to not be room specific, be able to be fitted in front of walls to replace vertical surfaces. Finally, it was a volumetric solution to changing the acoustics of a space and not a digital modulation. The early-stage design is an exploration of the options that will be most impactful on final performance (Badino, 2020).

The modularity should allow for an optimal acoustical performance of a space even when one project is a single vocalist and the next is a five-piece loud rock band. This would enable the users to record the best possible sound at its source.

Due to this being the first step towards making the unit, a key tool which offers flexibility, control over dimensions, quick evaluation of the choices that are made was parametrization (Peters, 2009). That way there was control over percentages of surface area, number of specific elements that the unit could possibly need and more advanced aid tools such as code were implemented into the design process.

The unit had different properties on its surfaces that the user can choose which ones to face the interior of the room (absorption, reflection) to affect its qualities. Additionally, its shape and size allow for multiple units to be placed one after the other. That way the target surface areas of a room could be covered with the appropriate number of units so a modular surface is created which could affect a room's acoustic performance.

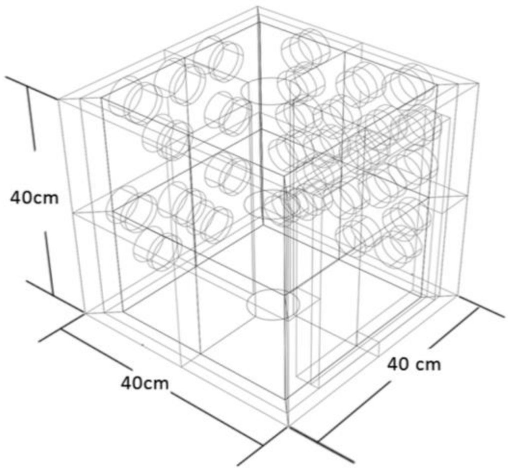

Figure 1. Panel wireframe view (left) and shaded view (right)

3.1. Geometry

The basic modular unit was made cubical so multiple units can be placed on top of each other vertically (Fig. 2) as well as next to each other horizontally (Fig. 3). The exterior was a shell of hard material (orange in Fig. 2), and the inside was a porous absorptive material (blue in Fig. 2). The depth of the unit had to be an amount that allowed for that absorptive material to be effective so for this stage of the design it was decided to be a 40x40x40 cm cube. In the center of each cube a cylindrical hole is left so that the panel can be rotated.

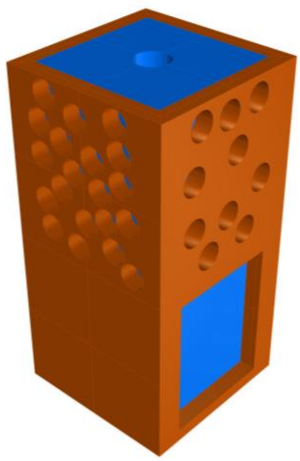

Figure 2. Two units stacked one on top of the other

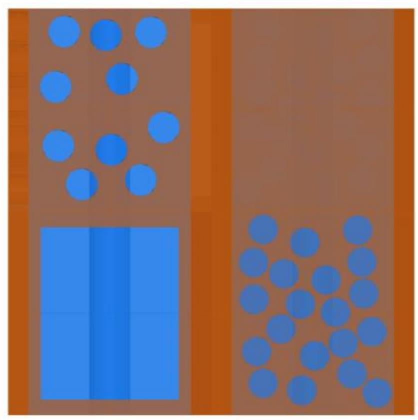

Figure 3. Four units stacked on top and next to each other. Various levels of perforation can be seen.

3.2 Materials

Two functions of the materials regarding acoustic performance are absorption and reflection (Gupta, 2019). Each of the four sides of the unit allow for different levels of absorption. That was achieved through increasing perforation levels on each side. The parametric approach allowed for control on the percentage area of the hard shell that was going to be perforated. So, one side was left with the absorptive material completely exposed which would count for 100% perforation and then the other surfaces were at 50% perforation and 25%. The last surface acts as a reflective surface so it was left at 0%.

3.2 Achieving the desired perforation

The number of holes on each side as well as the diameter of each hole were completely modular because of the algorithm used in grasshopper and the *C#* component. So, at each time if the evaluation did not produce the desired result, after revising the absorption coefficients of the materials the perforated surface area and diameter of the holes were changed until the panel performed as expected.

4. METHODOLOGY

To design the unit CAD software Rhinoceros (www.rhino3d.com) was used along the Grasshopper (www.grasshopper3d.com) plugin for parametric design and furthermore into grasshopper the plugin Pachyderm for evaluation of the room's acoustic performance. Echenagucia, 2014 designs an auditorium with the same means, by using acoustical parameter (Decay times, clarity, etc) optimization algorithms. Since the spaces are already designed in this study the same parameters will be used to evaluate the effectiveness of the unit. Here, C80, D50, RT and EDT were considered. Furthermore, a code component written in C# was integrated into one of the grasshopper components.

The use of grasshopper made the process quick to apply changes and easy to evaluate as well as to collect data because of the automatic export in the "panel" component of grasshopper.

This being an early stage in the unit's design the unit was assessed using geometrical models of rooms. Initially its ability to alter a space's acoustic performance was assessed by modelling a "simple" rectangular room with normal reflective materials and see how much the panel can alter the room's acoustics when applied to its surfaces.

After that three real life recording studios of increasing volumes were modelled in Rhino and their materials designed in pachyderm to represent accurate absorption coefficients based on tables with material properties. A large number of rays should be implemented in order for the simulated calculations to be trustworthy and efficient (Bors, 2011). This requires a significant amount of computational power which meant the more complex the model the longer the evaluations take to complete.

First the rooms were tested with their original materials and then their main acoustic treatment was changed with multiple units layered on top and next to each other and adjusted until similar values in RT, EDT, C80 and D50 were achieved. The evaluation was done with ray tracing (Saviola, 1999) and sources and receivers were placed digitally based on the BS EN ISO 3382-2:2008 Acoustics - Measurement of room acoustic parameters. Reverberation time in ordinary rooms.

4.1 The rooms

The largest room modelled after Sierra Studios (Fig 4) has a volume of 675 m^3 and complex geometry with angled walls a tilted roof with multiple height points. The materials on the walls are thick draperies in front of plastered walls, some glass in communication areas with the control room, plywood, brick and parquet, vinyl, and a carpet on the floor. The ceiling is absorptive to counteract a possible reflectiveness of the vinyl and parquet flooring.

The second room modelled after Antart Studios (Fig. 5) studios, a 300 $m3$ space has wooden and plaster walls and ceiling and carpeted floor. An intricate diffusing panel is on the ceiling and tilted wooden slabs in front of absorbing material act as a absorber on the side while providing some reflection as well.

The third room was modelled after Blackrock Studios which is 90 m^3 (Fig. 6) which is a small recording space in Santorini built in a Cycladic type house with painted white stone in the interior walls and an arched white stone roof. There were glass windows to allow communication with the control room and absorption panels fitted to the walls and ceiling as well as a panel with wooden slabs mounted on an absorptive surface covering the entire back wall.

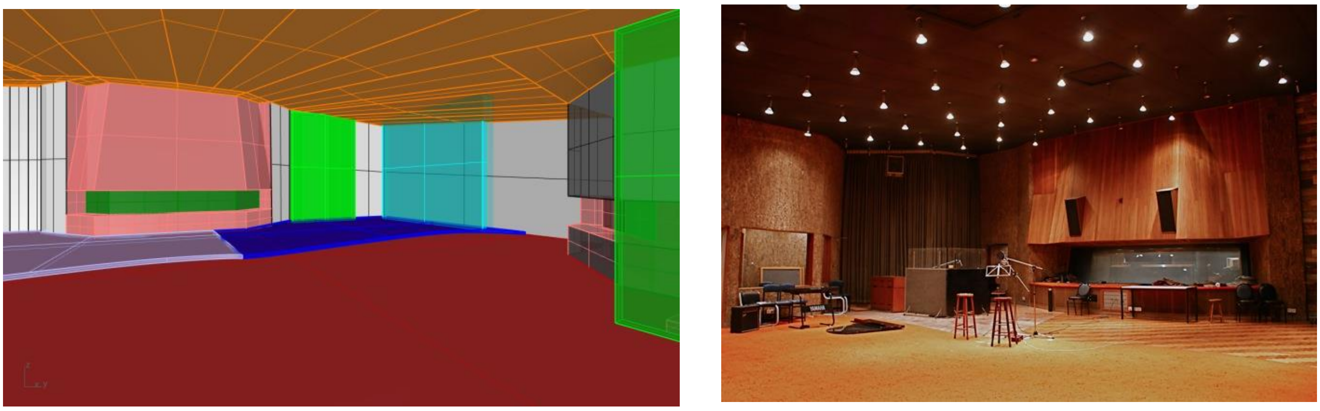

Figure 4. Sierra model (left) and Studio (right)

The roof surface materials were visually identified, and the closest description of the material found had its absorption coefficients in 1/1 Octave Bands assigned to the relevant one in each surface.

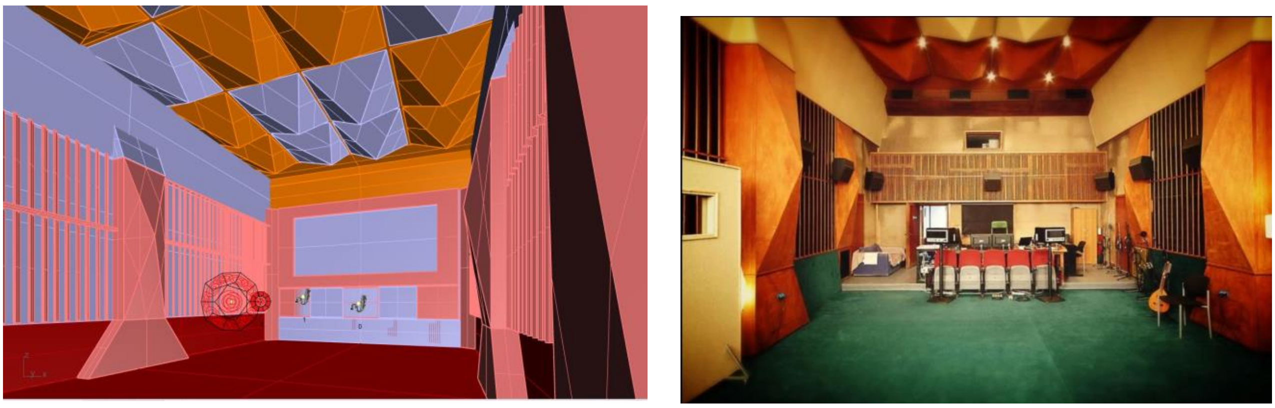

Figure 5. Antart model (left) and studio (right)

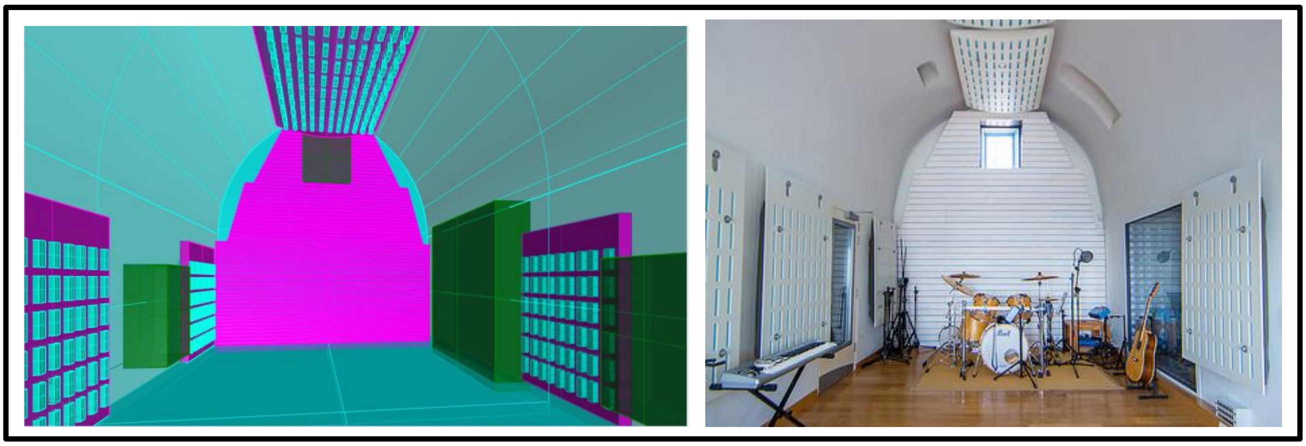

Figure 6. Blackrock model (left) and studio (right)

4.2 Algorithm

The workflow of the design algorithm was to construct the outer shell as four separate rectangles so each of them can have applied to it a different “hole” percentage area. Each rectangle was extruded into a box from its base points and the holes were modelled as cylinders that their shape was subtracted from the solid object. So, the *bRep* component (i.e., a part of the geometry grasshopper created, such as one of the cube’s surfaces) was deconstructed and one side of the box was chosen as the starting surface for the cylinders. The surface that was chosen was the inner one so that when the “hole” percentage would not overlap with the connection points with the other boxes at the corners.

First the cylindric gap was left in the center of the unit is so that the user can effectively rotate it and change which surface is on the front side. To construct it we set the rectangular base of the unit and place the cylinders center in the center of the rectangle. Then the Solid Difference component was used to separate the cylinder from the rest of the material (Fig. 7)

The outer surfaces of the panel (Fig. 8) were extruded as rectangle boxes from points on the XY axis.

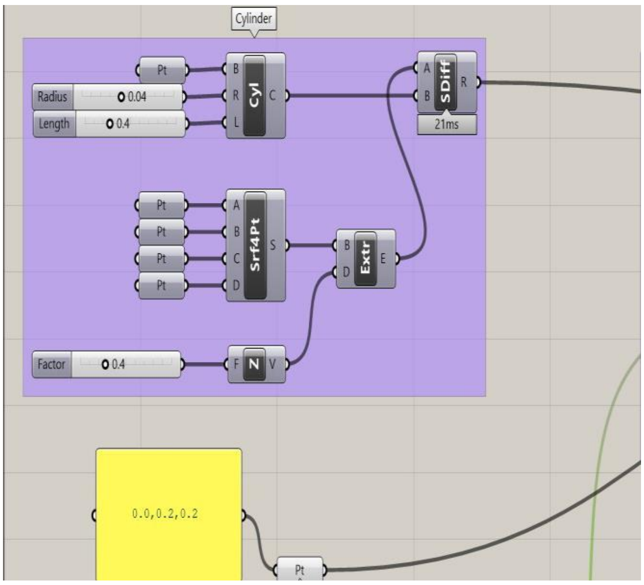

Figure 7. Algorithm for modular unit. Base and cylinder

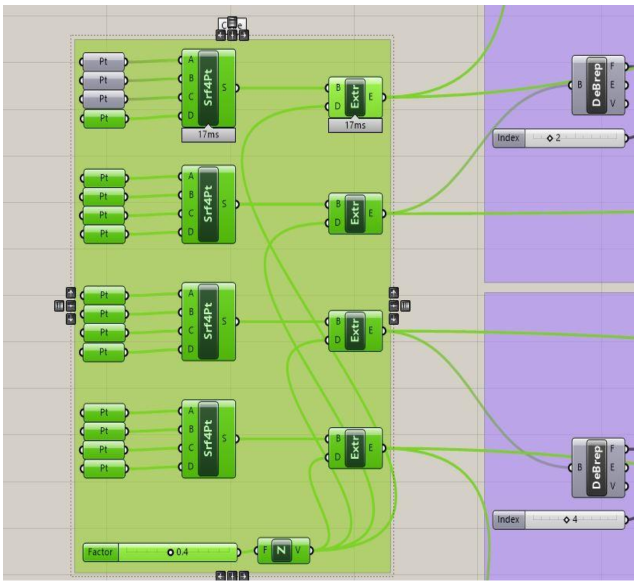

Figure 8. Algorithm for the outer surfaces of the unit.

The part of the algorithm controlling the perforation consist of two different sections. One is about choosing the surface and one about opening holes in it (Fig. 9).

The inner surface of the rectangles was chosen as the base of the perforation holes so that no holes overlap with the joint parts between the rectangle boxes of the outer shell (Fig. 9). Choosing each part of the geometry and deconstructing it to each component (from a total of four rectangular boxes, with the component “DeBrep”) and then specifying which of those surfaces we want with the component “Item” was next. The same pair of commands were used to deconstruct the surface into four points. Its length was measured and then connected with the cylinder’s radius so that their subtracted value is always greater than one. That way we ensure that the holes stay in the surface area that was chosen.

The part that controls the perforation (Fig. 9) works by selecting are coverage and hole count (seen as cylinders in the algorithm) first. Then the cylinder radius is specified and tied to the C# code implemented into the “populate 2d” component which randomly assigns cylinders on the selected surface. As all of these components are first designed on the XY axis they had to be oriented to the appropriate plane with “orient” component. This was particularly helpful as it is easy to change orientation and test different possible geometries if needed, instead of redesigning the cylinders from the beginning on a different plane.

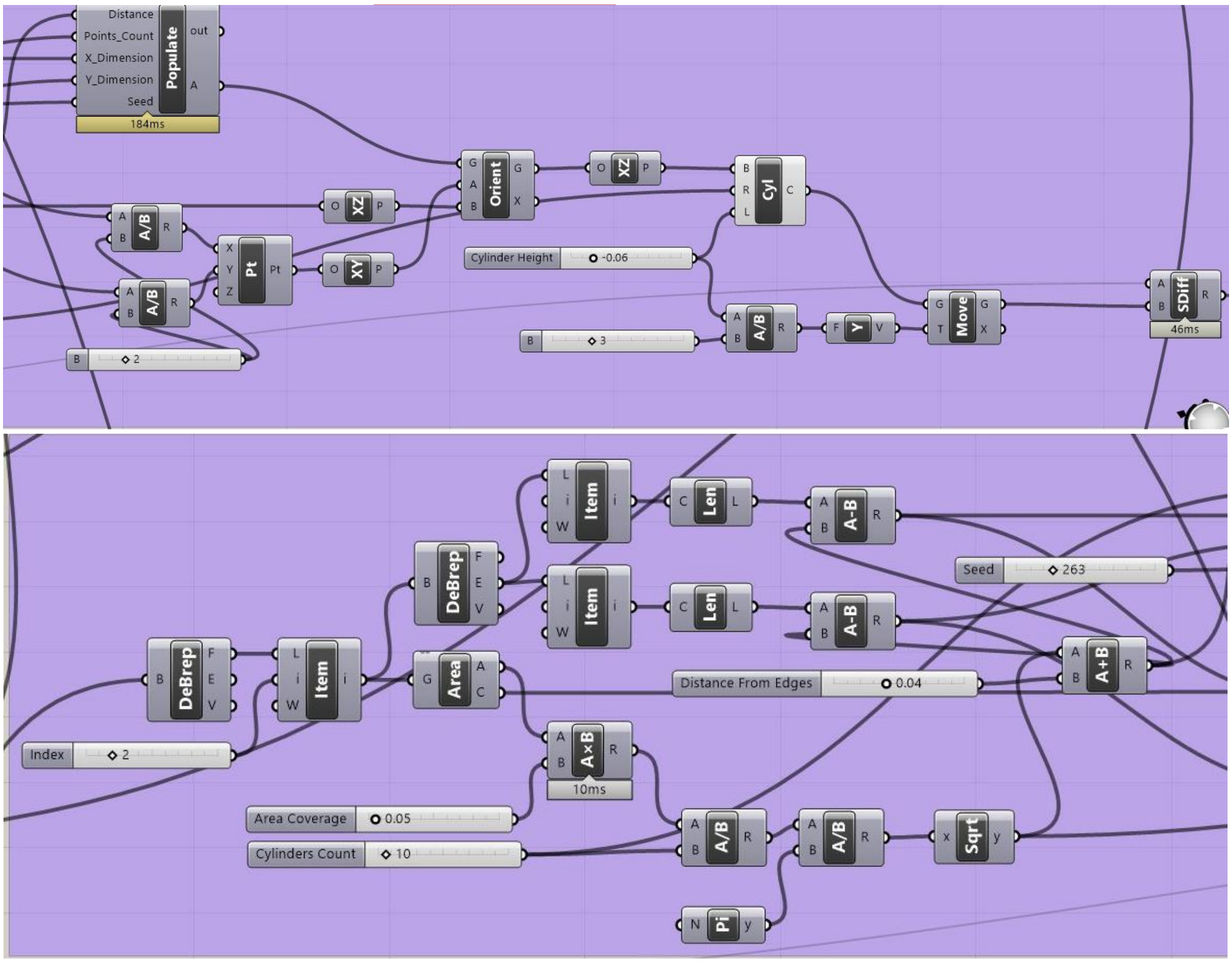

Figure 9. Algorithm for controling surfaces and perforation as well as orientation and final merging.

4. RESULTS

The first step was to see how the unit's various surfaces can affect a normal rectangular reflective room. Units were stacked on top of each other in front of specific surfaces in the models (surfaces originally treated in the studios). For the Test Room (i.e., Room in Fig. 10) the stacked units were placed front of half of the interior surfaces of the Test Room. Then a simulated measurement took place to test the model's acoustic parameters.

After each simulation, the surfaces were rotated and changed into a surface with more absorptive area. So, four different simulated measurements in total. One of the rooms itself without any additional units inside. And then three more, one with each surface of the units facing the interior. That means one with 25% perforation (Medium), one with 50% (Large) and one with 100% (Open) perforation on the surface.

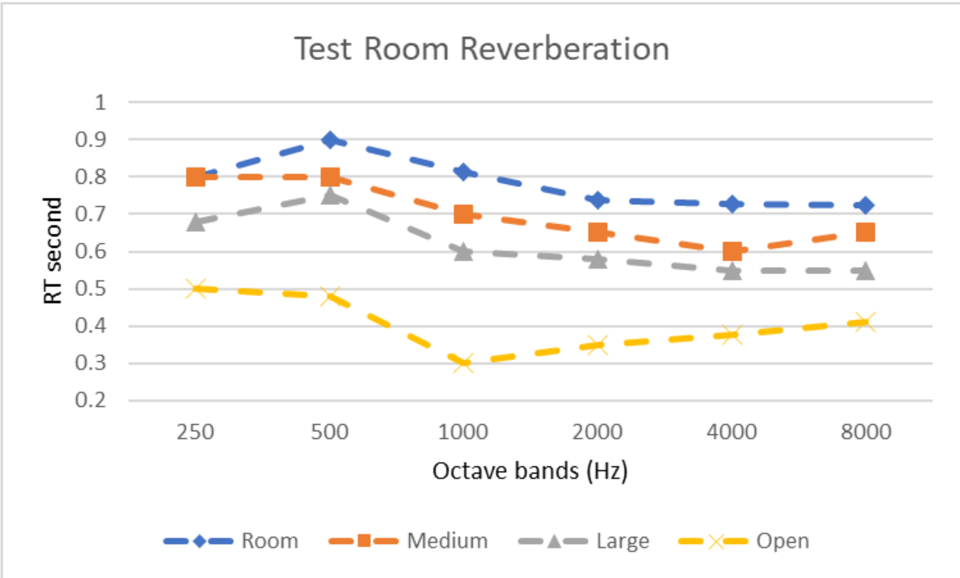

Figure 10. Test room Reverberation Time

The room, to which had been assigned reflective concrete surfaces and its dimensions are 3.75x4x3.35m has a reverberation time of 0.7-0.9s seconds in the different 1/1 Octave Bands (Fig. 10). By increasing the unit's surface absorption by 25% there was an almost uniform reduction of approximately 1 second on all octave bands, with the biggest difference in the 4kHz octave band of 1.2 seconds less. The same behavior was observed when we doubled the perforated area to 50%, with low frequencies not particularly affected, as much as higher ones.

The difference was more apparent when the 100% perforated surface of the unit was used. There was at least 1.5 second reduction in and in the 1kHz Octave band a significant 3 second reduction. This showed that there was a level of control achieved over the reflectiveness of the room by utilizing different functions of the panel.

Given the different combinations into which the unit's surfaces can be used it would normally be expected to be able to fine tune a Reverberation time up to 3 seconds lower (As seen in Fig. 10 in the 1000Hz band) if the unit is applied to enough surface area. In that particular octave band, the original RT in the Test Room was 0.8 seconds which means the Unit was able to achieve all the in-between values from 0.8 seconds down to 0.3seconds.

The next step was replacing all the originally acoustically treated surfaces of the real studios in the geometrical models of the same spaces with the unit (Fig. 12) and try to achieve similar results by using the appropriate amount of perforation and combinations of the unit (Fig. 13.). To see how close the values after the replacement could be, the data from the simulated measurements after the replacement were subtracted from the data from the simulated measurements of the original state of the rooms.

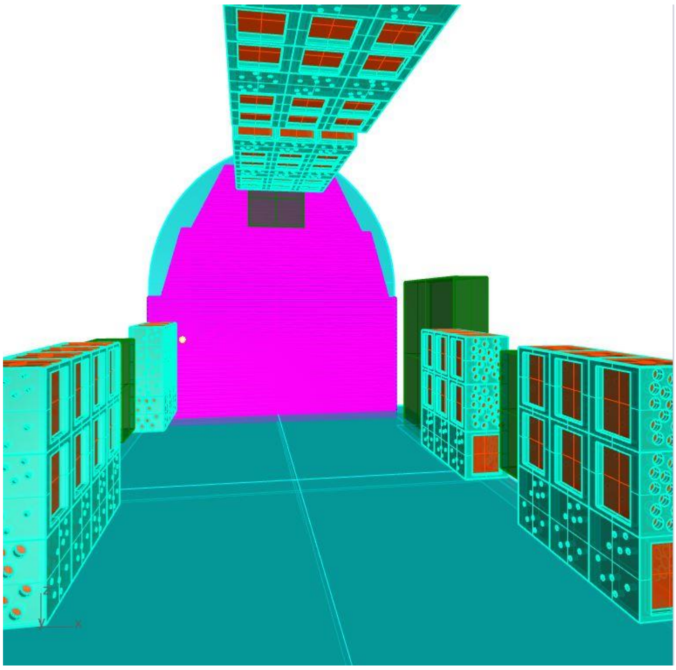

Figure 11. Blackrock model with units replacing the original panels

Frequency	Studio Name	Acoustic Parameters			
	Blackrock	RT	EDT	C	D
Hz	250	0.0	-0.1	0.1	-1.1
	500	0.1	0.0	-0.1	-1.8
	1000	0.1	0.0	-0.3	-2.8
	2000	0.1	0.0	-0.4	-3.2
	4000	0.1	0.0	-0.4	-3.2
	8000	0.0	0.0	0.0	0.0
	BIGFOOT	RT	EDT	C	D
Hz	250	0.3	0.3	-0.3	2.5
	500	0.3	0.3	-0.5	2.6
	1000	0.4	0.2	0.0	3.5
	2000	0.5	0.2	0.3	4.0
	4000	0.3	0.3	-1.8	-1.7
	8000	0.3	0.3	-1.8	-1.7
	Antart	RT	EDT	C	D
Hz	250	0.0	0.0	-1.0	-3.5
	500	0.1	0.0	-0.2	-0.1
	1000	0.0	-0.1	-0.4	0.2
	2000	0.0	0.0	-0.8	-1.8
	4000	0.1	0.0	-1.3	-3.6
	8000	0.0	0.0	-0.9	-2.8
	Sierra	RT	EDT	C	D
Hz	250	0.0	0.0	-0.3	-1.0
	500	-0.1	0.0	0.9	0.7
	1000	-0.1	0.0	0.7	0.0
	2000	-0.1	0.0	0.4	-0.3
	4000	-0.1	0.0	0.4	-0.2
	8000	-0.1	0.0	0.4	-0.2

Figure 12. Deviation from original acoustical parameters

When multiple units were stacked on top of one another in rows and columns (Fig. 11) performed as expected and enabled a level of control over various acoustic parameters such as RT, EDT, C80 and D50. The lower frequencies were more difficult to control, as could be seen (Fig. 12) on Sierra that the deviation on 125Hz is 3s, same as EDT while all the other Octave bands are either 0.1 or 0.0 when compared to the original values.

5. CONCLUSION

A modular volumetric unit was designed parametrically to allow alteration in room acoustic parameters of indoor recording spaces, by simultaneously having a simple shape to fit easily in many room types. An algorithm was used so easy changes could be applied immediately on the design stage until the results were satisfactory.

In the end the modular unit achieved a good level of control over the acoustic performance of the room depending on the needs of the user. Another important advantage was that during the trial process the algorithm made in grasshopper was easily changeable to design decision could be made quick and flaws could be corrected on the spot at the same time of the testing.

6. REFERENCES

1. Badino, E. Shtrepi, L. Astolfi, A. Acoustic performance-based design: A brief overview of the opportunities and limits in current practice. *Acoustics 2020, 2, 246-278, p. 264*
2. Bors V. Bors S. 2011, Computational design applied to small room acoustics: creating and evaluating custom solutions, Euronoise 2011, pp. 2-3
3. Serero D. 2006, Domes Acoustiques a geometrie variable. Journal de l'Academie de France a Rome, Villa Medicis, Rome
4. Echenagucia T.M., Astolfi A., Sassone M., Shtrepi L. ,2014. *EDT, C80 and G driven auditorium design*, p. 44
5. Gupta N., 2019, *An analysis of Acoustic Treatment on recording studio, International Research Journal of Engineering and Technology (IRJET),* Volume 06 Issue 10, p. 915
6. Peters B., 2009. *Parametric acoustic Surfaces*, pp. 175-177
7. Peutz V.M.A. and assicies, 1978. *The variable acoustic of the Espace de projection of IRCAM (Paris)*, pp 1-8
8. Savioja L., 1999. *Modeling Techniques for Virtual Acoustics*, pp. 17-21
9. Poletti M. A., 2003. Control of early and late energy in rooms with the variable room acoustics system, The journal of the Acoustical society of America-October 2003, pp. 215-216
10. Thun G. M , Sauve L. , 2012. Soundspheres: Resonant chamber, Leonardo august 2012, pp. 350-355
11. McNeel R. & Associates, 2022, Rhinoceros, 26/04/2022, www.rhino3d.com
12. Davidson S., 2022, Grasshopper algorithmic modelling for Rhino, www.grasshopper3d.com
13. BS EN ISO 3382-2:2008, 2008 *Acoustics – Measurement of room acoustic parameters, reverberation time in ordinary rooms*, pp.2-8