THE ACOUSTIC PAVILION

Prototyping Alternatives for Gypsum based Construction

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Abstract. Gypsum is one of the most commonly used building materials today and prevalent in architectural acoustics. However, despite its ubiquitous appropriation, few domains of research or practice seek to provide opportunistic approaches for its acoustical application. This paper outlines the computational design and fabrication processes for the development of a pavilion that explores alternative acoustic applications for gypsum. It demonstrates how sound performance can drive the conceptual agenda for a project by articulating the conditions of spatial experience through the design of architectural surface.

Keywords. Fabrication; computational design; acoustics; reflective surfaces; diffusive surfaces.

1. Introduction: Gypsum and Acoustics

Everyday architectural applications for sound quality often rely on quick material additions rather than acoustically designed solutions. Added layers of sound attenuated batt insulation help reduce sound leakage and additional layers of gypsum wallboard aid in mitigating transfer (Healey, 2014). Even the gypsum-based popcorn ceiling, which emerged in the 1930s, acts as a sound absorbing buffer by muffling noise with its increased surface area produced from the spray-on process. Gypsum is one of the most commonly used building materials today and prevalent in architectural acoustics. However, despite its ubiquitous appropriation few domains of research seek to provide opportunistic design approaches for its acoustical application.

Recognizing that designs are often constrained by preconceived ideas of building materials and their traditional applications, this research began by asking, how might methods for gypsum-based fabrication inform the design of sound based environments? This project avoids a purely building science or physics understanding of acoustics in favor of investigating sound qualities and their relationship to the perception of space. Surfaces, their materiality, density, and form, all affect the way sound propagates space. Considering these effects, the Acoustic Pavilion explores how sound performance can drive the conceptual agenda for a project by articulating the conditions of spatial experience through the design of acoustically informed surfaces, as seen in Figure 1.

PROJECTIONS, Proceedings of the 26th International Conference of the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA) 2021, Volume 1, 523-532. © 2021 and published by the Association for Computer-Aided Architectural Design Research in Asia (CAADRIA), Hong Kong.

Figure 1. Pavilion exploring alternative acoustical applications for gypsum.

2. Spatial Audio

The relationship between space and acoustics has a long history, with the vaulted ceilings of Gothic cathedrals and the domed interiors of the Baroque (Libera and Klein, 2012), designers have directed sound in buildings as means for expanding upon the auditory conditions of human experience. After the completion of the construction of the Salzburg cathedral in 1628, musicians playing wind instruments, percussionists, string orchestras, and a choir, strategically positioned themselves in and around the nave of the cathedral in order to enhance the audience's auditory experience (Klein, 2012). Later in 1881, Clement Ader experimented with spatial audio by setting up microphones in the front of the Paris Opera Hall, with their audio outputs running to a series of headphones in a room nearby (Davis, 2007). Ader's experiment demonstrated the ability to construct various audio configurations based on the listener's location in space.

Today, spatial audio technologies provide a similar multidimensional approach to sound. With the electroacoustical control of sound to various positions, headphones distribute digital soundtracks to left and right ears and surround sound systems disperse sound in a room by playing multichannel digital tracks to a set of speakers. The pavilion project outlined in this paper explores digital and material conditions of spatial audio with integrated speakers and surfaces directing and diffusing sound.

The project presents a design opportunity to articulate the unseen boundaries of space through subtle acoustical variations in the environment. It does so through collaborative efforts with a sound designer (name omitted for blind peer review) in order to compose various corresponding tracks played from different channeled speakers embedded in key geometrically altering sound panels, to generate a unique auditory experience based on the guests' proximity in and around the pavilion, as seen in Figures 2 and 3. The intent is not only to explore physical acoustical parameters, but also to develop material and fabrication strategies that expand the perception of auditory performance.

Figure 2. Speaker integrated in Acoustic Pavilion.

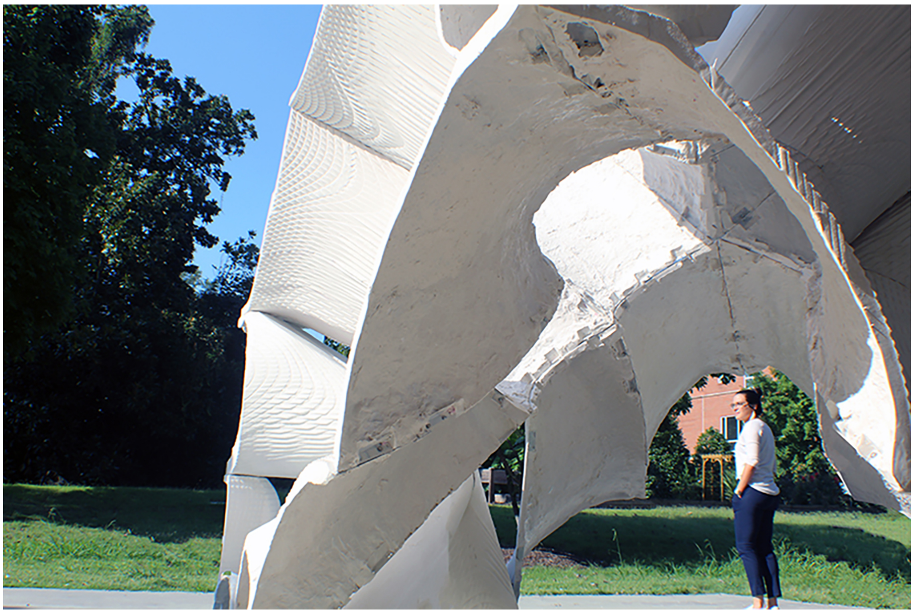

Figure 3. Pavilion visitor walking in and around pavilion discovering various acoustic conditions.

3. Diffusive Surfaces and Reflective Forms

Often the discussion of controlling sound in buildings refers to sound reduction (Cowan, 2007). However, in the case of the pavilion, the intent is to preserve and direct elements of sound from the speakers through reflection, while also reducing exterior noise through diffusion. These components provide a design opportunity to use acoustical tendencies as a means to articulate space through change in sound volume and quality.

The two acoustical tools that manipulate the conditions of spatial audio in the pavilion design include surface diffusion and form based reflection. Surface based diffusion aids in controlling harsh sound reflections, through variation in geometry, size and depth of surface patterns that correspond to sound waves (Ajlouni, 2017). The production of a series of ray tracing simulations, which describe the way sound scatters after contacting diffusive surfaces, aid in the design of the diffusing surface texture, as seen in Figure 4. The simulations characterize sound behavior with scattering coefficient measurements, which measure the amount of sound scattered away by comparing the ratio between non-mirrored and mirrored acoustic energy. In other words, a set of vectors projected toward the designed surface hit the surface and then the simulation provides a comparison between the vectors that directly bounce back as a mirrored condition with those that scatter based on the surface geometry.

These ray-tracing simulations aid in the design process and provide a way for the team to examine the reflection patterns from a variety of different surface conditions. These models help to produce an approximation of the scattering coefficient, which is well adapted for use in geometric room prediction methods (Cox, 2006). While the tests provided a basic understanding of the performance, a true scattering coefficient varies based on frequency and understanding of the wave nature of the sound (Cox, D'Antonio, and Embrechts, 2006), which is not accounted for in the design team's simulations. Instead, the predictions provide an approximation of the performance of the surface by comparing the behavior of rays that reflect secularly and diffusely. Also, the predictions show the smaller texture size with increased depth increases the degree of scattering. In order to accommodate a spectrum of sound wavelengths, the surface includes a range of scale in surface texture, depths, and angles to provide a range of diffusive qualities. Variation of these characteristics is optimal for diffusing a range of frequencies (Ajlouni, 2017). The parameters mapped in the model allow for flexibly based on size, depth and angle to accommodate a variety of surface inputs for testing. The method also provides a way to address specific design problems by adjusting input surface conditions to match acoustical preferences.

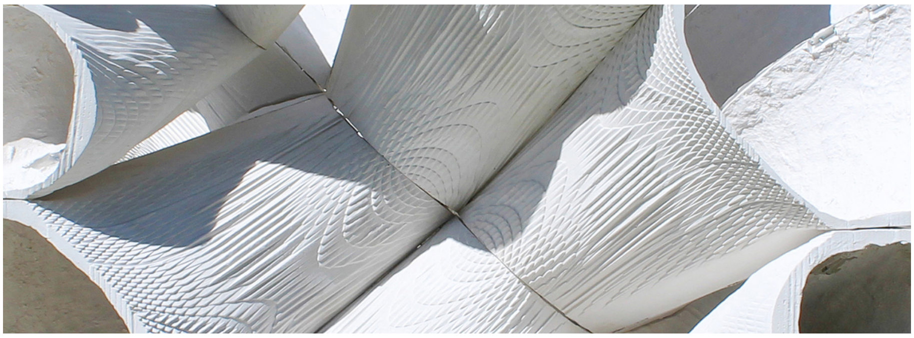

Figure 4. Diffusive sound surface texture.

The second acoustical component of study for the pavilion involves preservation and intensification of sound through form based reflection. Similar sound intensification projects include Anish Kapoor's Untitled, a stainless steel installation at the High Museum, Marirena Kladeftira's Whisper Dishes, and Zackery Belanger's Slumped Glass. The key to the pavilion's use of reflection is to avoid echoes and resonance, while also directing sound with curved surfaces. Specifically the project uses concave surfaces to focus sound energy from the speakers, while the convex sides of the panels with the surface texture diffuse sound from outside sources. The concave reflective surfaces create heightened auditory spaces with concentrated sound and lighter auditory spaces with less sound (Belanger, McGee, and Newell, 2008).

The configuration of individual panels into a larger system provides a means for aggregating the various sound conditions. Importantly, the design team avoided prototyping by adding the diffusing and directive panels to a typical wall or ceiling in order to generate auditory-based spaces delineated by a continuous surface. The panels vary in degrees of curvature and configuration in order to provide a range of results. The scale of the body informs the scale and aggregation logic of the panels. As seen in Figure 5, the location of directive panels varies based on human height for increased emphasis and at time face downward to cause additional directional emphasis toward the visitor. The central interior space provides the most even distribution of all the sound channels from the speakers, while the exterior focuses and reflects various tracks. The panels collectively send sound to spaces in and around the pavilion by enhancing sound through reflections, encouraging the visitor to experience, the composition in different ways based on their location. The shifting position of the visitor exposes the formalized acoustical environment with the different in qualities of the space and variations in sound composition.

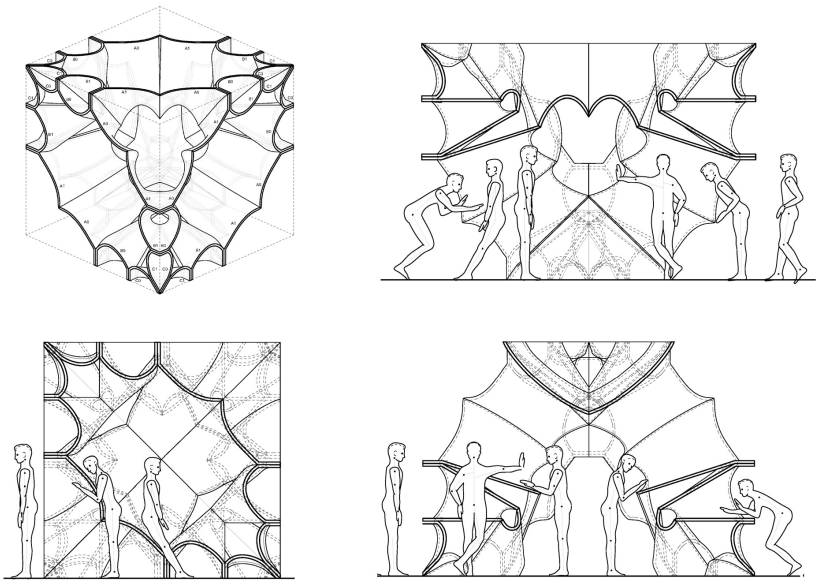

Figure 5. Scale drawings depicting scalar relationship of the configuration of panel to the body.

4. Design and Fabrication Methods

The project strives to strike a balance between material, form, fabrication, and acoustical performance. It does so by allowing material and fabrication procedures to inform and influence the design decisions along the way. The fabrication procedures for each panel involve the production of a CNC milled foam positives used to produce negative molds with a two-part silicon and fiberglass support shell. The silicon aids in capturing texture on the panel and allows for easy demolding, while the fiberglass shell supports the silicon and maps the overall panel form. A set of plywood ribs matching the sectional geometry of the panel support the fiberglass shells to avoid flexibility and ensure the molds maintain their form during the casting process. These rib supports negate deflection of mold during the casting process.

The diffusive surface design also takes into account the machine procedures of subtractive processes. It does so by optimizing the amount of time spent carving the foam positive, by accounting for the incremental carving procedure and using it as an expressive quality of the surface, which also acts as the sound diffusive surface texture of the resulting cast, as seen in Figure 6. Since the subtractive methods and step down texture directly relate to the form of the surface, the design team 3D modeled the incremental machine carved texture in order to compare optimized machine time with diffusive sound performance of the texture. The model parametrically adjusts to included variable depth of the texture to correspond to the cutting part of the milling bit and its plunge depth (i.e., how far the bit goes down into the material during the subtractive process). The other condition of the surface texture includes the scale, which directly relates to the curvature of the surface. (i.e., the tighter the curvature on the surface the smaller the texture). This direct relationship between surface geometry and texture also accommodates the relationship to the incremental carving process. The resulting step down surface design provides a balance between acoustical performance and optimization of fabrication processes to decrease overall machine time.

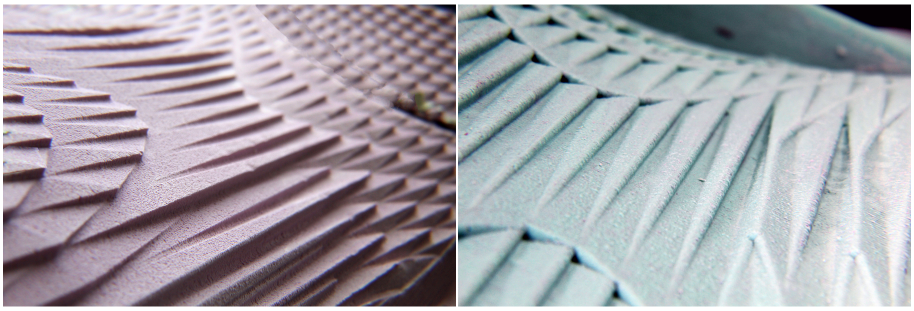

Figure 6. Image of positive foam texture (left) and silicon mold texture (right) based on step down procedures of the CNC mill.

The production of the pavilion integrates material and fabrication processes in the design evaluation by considering the optimization of machine time during subtractive processes and with the redundant use of molds. The fabrication procedures for redundant use of the molds, which are capable of producing three hundred casts, influence the design of the aggregation of panels by using a design assembly that involves aggregating similar panels in three-dimensional space with variable relationships between them, as illustrated in Figure 7.

This technique of aggregation differs from traditional parametric design approaches, which boast of variation from unique parts through mass customization. For instance, the production of the glass fiber reinforced concrete panels for the Heydar Aliyev Centre by Zaha Hadid uses a similar mold process; however, each mold was unique and therefore the fabricators only used the mold for a single cast before discarding. The approach for the pavilion achieves variation from repetition, which is similar to methods of combinatorial design.

Combinatorial methods study “discrete finite sets of units and their possible arrangement by an algorithmic or intuitive process” (Sanchez, 2016, p. 52). Combinatory design not only offers a means for exploring configurations, but also provides a fabrication strategy capable of producing multiple parts from a single mold. Such methods permit a similar approach to architecture as those used for advanced manufacturing strategies of automobiles, where complex geometry is efficient due to the quantity of parts produced from a single mold.

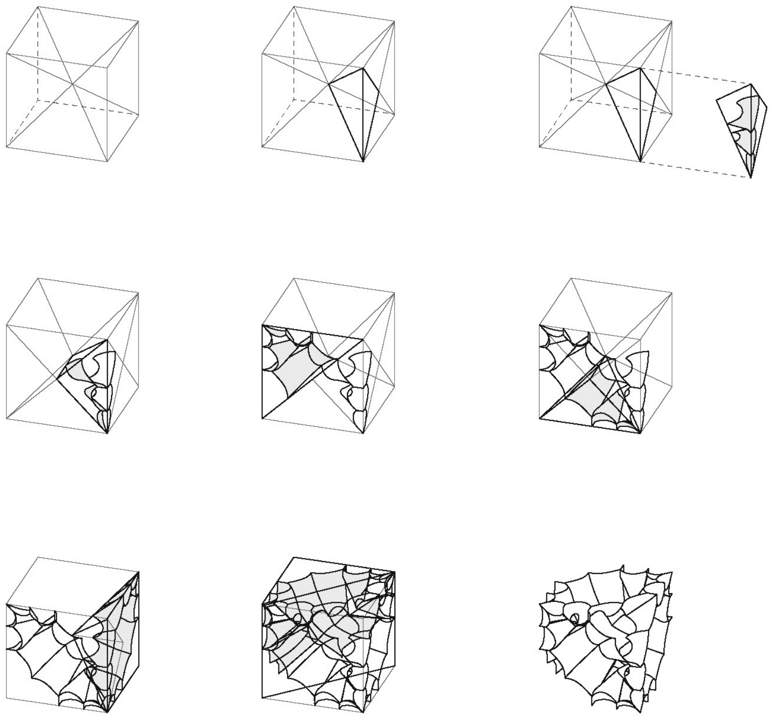

Figure 7. Diagram illustrating the design process for redundant panels that share variable relationships in three-dimensional space.

5. Conclusion

In order to render acoustical conditions as an architectural material, the investigation purposely generates a variety of inhabitable sound configurations for guests to perceive. The site and exhibition of the pavilion took place at (omitted for blind peer review) as demonstration of combined research and design activity between architecture and acoustics. The exhibition also involved two sound based performances. The first of which included the embedded speakers where the panels geometrically intensifies portions of sound tracks corresponding to different locations of the pavilion to generate a unique auditory experience related to space.

The second performance involved two members of (omitted for blind peer review), playing trumpet and trombone from within it the pavilion, strategically shifting their bodies and instruments to tune portions of their musical performance. Many of the pavilion visitors sensed the variations of the acoustical environment and called attention to the difference in sound qualities.

With industrialization, mass production of building materials, and stylistic concerns of the simple and sparse brought on by modernism, today there is a proliferation of large flat interior surfaces covering building frames and structures. Acoustician Trevor J. Cox writes, “There is a need for scattering surfaces that complement contemporary architecture in the way statuary coffered ceilings and relief ornamentation complemented classical architecture” (Cox and Peter D’Antonio, 2004, p.105-106). The uninterrupted oblique surfaces resulting from the abundance of banal architectural boxes that surround us are the source of the strong specular sound reflections and do little to diffuse unwanted noise in our everyday environments. A true consideration of sound performance in buildings, requires alternative fabrication and material approaches to contemporary architecture. Rather than layering on excess material or decorating the interior of our box buildings, perhaps we can design solutions that draw upon both the art and science of acoustics manifested from human perception of sound.

Acknowledgements

The Acoustic Pavilion was produced in collaboration with Alex Cabral, Drake Cecil, Hana Maleki, Margaret Martin, Jarrod Norris, Robby Sachs, and Hunter Sigmon.

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