HIVE: An Interactive Sculpture for Musical Expression

Şölen Kıratlı
Media Arts and Technology
University of California, Santa Barbara
Santa Barbara, California
solenk@gmail.com
solenk.net

Akshay Cadambi
Media Arts and Technology
University of California, Santa Barbara
Santa Barbara, California
akshay19.92@gmail.com

Yon Visell
Media Arts and Technology
Electrical and Computer Engineering
University of California, Santa Barbara
Santa Barbara, California
www.re-touch-lab.com

ABSTRACT

In this paper we present *HIVE* (2016), a parametrically designed interactive sound sculpture with embedded multi-channel digital audio which explores the intersection of sculptural form and musical instrument design. We examine sculpture as an integral part of music composition and performance, expanding the definition of musical instrument to include the gestalt of loudspeakers, architectural spaces, and material form. After examining some related works, we frame *HIVE* as an interactive sculpture for musical expression. We then describe our design and production process, which hinges on the relationship between sound, space, and sculptural form. Finally, we discuss the installation and its implications.

Author Keywords

Sound Sculpture, Spatial Sound, Parametric Design, Digital Fabrication, Embodied Interaction

ACM Classification

H.5.5 [Information Interfaces and Presentation] Sound and Music Computing, J.5 [Arts and Humanities] — Music, J.5 [Arts and Humanities] — Arts, fine and performing

1. INTRODUCTION

1.1 Background

Sound is intrinsically tied to the spaces it is disseminated in, unfolding in a constant interaction with the physical environment, colored and shaped by the material properties and physical geometry of architectural space. Along with dimensions such as pitch, rhythm, and timbre, spatialization is a crucial aesthetic consideration for musical composition [16].

Many composers have explored the aesthetics of spatial sound in their composition and mixing techniques [12][18][16]. Building on the ideas explored in these works, we developed a framework for spatial music composition based on the interaction of loudspeakers, architectural space, and physical form. This process led to the design of a custom sound object for spatialization which enables the exploration of the roles of space and form in sonic creations.

NIME'17, May 15-19, 2017, Aalborg University Copenhagen, Denmark.

1.2 Related Work

While loudspeakers are often designed to remain invisible and sonically transparent, they can be regarded as musical instruments in their own right [20]. This notion is reflected in the works of several composers, such as David Tudor's *Rainforest IV* (1973) [19], and researchers, such as Franz Zotter's *Icosahedral Loudspeaker (ICO)*. *ICO* is a loudspeaker array designed as an instrument for electronic chamber music which inverts the common 'surround sound' paradigm by having speakers project divergently from a point. [17]

In *ICO*, architectural space is also treated as an element of musical expression; the work uses space as an instrument equally important in shaping the musical performance and composition as the loudspeakers. Other artworks which integrate architecture into the compositional process include Bill Fontana's architectural sound installation, *Spiralling Echoes* (2009), which uses highly directional speakers to "inscribe space" [8] and Maryanne Amacher's *Maastunnel Sound Characters* (1995) [2] which integrates structure-born sounds into the artwork, rendering architecture as an instrumental body [10].

Composers and artists have also played with material means to shape the timbre and spatialization of sound. Inspirations to us are the sculptural musical instruments of Bernard and Francois Baschet [5] and Bernhard Leitner's *Parabolic Dishes Beaming* (2002) [11].

1.3 HIVE

Drawing from these threads we present *HIVE*, a parametrically designed interactive sound sculpture featuring an embedded multi-channel speaker array. Our approach fuses aspects of sculpture, sound reproduction, interactivity, and architecture. In *HIVE*, we explore the notion of spatiality in musical expression through a sculptural artifact that projects a field of sound outwardly, sonically articulating the surrounding environment. The timbre is influenced by the geometry of the sculptural form, as the speakers are mounted at the tapered ends of the horn-like inner structures which act as waveguides. The speakers and material geometry constitute both an instrument for timbral transformation and spatialization and an artifact for embodied interaction. The temporal nature of sound brings the otherwise inanimate sculpture to life, facilitating interaction and enactive engagement.

The remainder of this document describes the design strategies and methods used to realize this work, including considerations of the piece's design, fabrication, and audio system. This is followed by observations and documentation of an installation of this piece at a local venue. We conclude with a summary of the work and directions for further exploration.

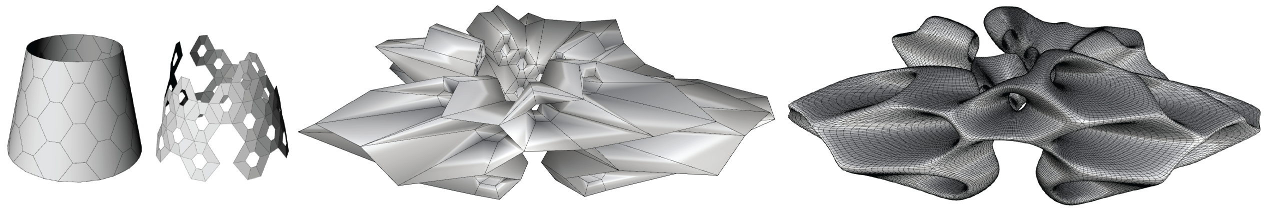

Figure 1: An illustration of the four stage process used to design the form. The resulting topology from the design procedure is an n-fold toroid, visually and structurally retaining the qualities of a honeycomb pattern while packing horn-like inner cells.

2. DESIGN STRATEGIES AND METHODS

In our design and production process, we followed a systems approach of taking sound and sculptural form -which causes spatial and timbral transformation- as a unified notion with unique affordances in composition, performance, and interaction. The physical composition of the sculptural form that produces the sound became a part of the musical composition process. In turn, design of the object is exclusively driven by this purpose and algorithmically generated.

The following three sections describe the design strategies and methods used. The first discusses the design of the sculptural form, the second the fabrication and the third discusses the challenges presented by the audio system.

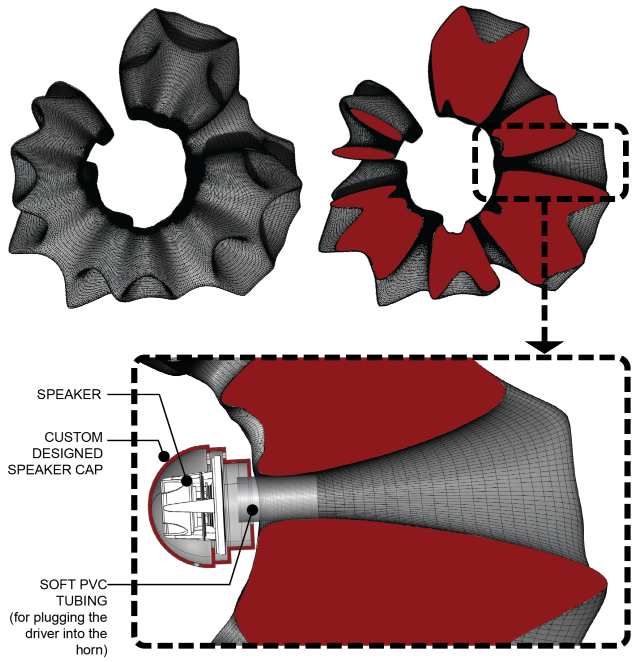

Figure 2: This figure shows a cross-sectional top view of the horn-like inner structure within the sculptural object.

2.1 Design

The sculptural form was designed with the intention of housing a dense array of speakers. With this design problem, we focused on creating a procedure that would be applicable to various base geometries, rather than a single object. We have two main inspirations for the physical design of the artifact. First is the horn loudspeaker design, in which the physical shape acts as an acoustical waveguide. This shape has been shown to have an impact on the spectrum, creating a presence effect [9]. The second is the use of honeycomb patterns as a means to achieve tight packing of these tubular inner cavities inside the sculpture. Honeycomb geometries, as often seen in nature, have been shown to present spatial advantages in this regard.

The design procedure followed a parametric approach and can be summarized in four essential steps, as depicted by Figure 1. The design was executed using several interrelated software tools [13][1], in the computer aided design software Rhinoceros [3]. The first step was to hexagonally tile an arbitrary curvilinear surface. The second step involved the exclusion of all peripheral cells that weren't complete hexagons. We also seeded random cells in order to create variations in density. In the third step, we used a mesh thickening algorithm [15] to create a non-linear extrusion [1] of this surface that uses the hypotenuse average based trigonometrical offset for computing a new mesh that is a closed solid. The final step employed Catmull-Clarke subdivision algorithm [15] to smoothen the mesh, resulting in a curvilinear cross section approximating an exponential horn-like inner structure. The resulting topology from the design procedure is an n-fold toroid, visually and structurally retaining the qualities of a honeycomb pattern while packing horn-like inner cells. This procedure can be applied to a variety of base geometries.

2.2 Fabrication

For the fabrication, we chose a truncated cone as a base geometry in order to allow for a centripetal projection of sound, creating a divergent soundscape around it. Given the complexity of the shape, we decided that additive manufacturing was the most appropriate method. However, since the overall size of the object was larger than the maximum printing area of most commercially available 3D printers, the model had to be printed in multiple segments. (Figure 3) The geometry processing software Netfabb [4] was used for segmentation of the model. After printing the pieces using ABS plastic, the interlocking parts were attached using two-part epoxy glue. Automotive body filler was used to cover the seams, which were then sanded down in order to prepare the structure for painting. The speaker caps which house the speaker drivers were fabricated using the same material. These were designed such that they inhibit the projection of sound from the driver in the backward direction and allow for coupling the driver to the horn throat.

2.3 Audio Design

This unique multichannel system presented several challenges from the perspective of spatial sound composition, or orchestration [12]. The speaker layout was fairly unconventional, pointing outward from the center creating a divergent projection (the opposite of most 'surround' layouts) emitted from multiple elevations. Furthermore, despite us-

[1]The documentation for the exact function used can be found at this URL: `http://rhino.github.io/components/weaverbird/meshThicken.html`

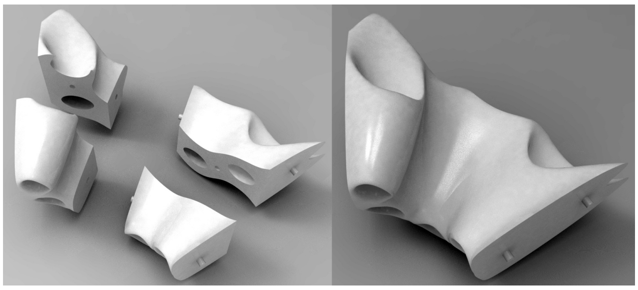

Figure 3: Since the overall size of the object was larger than the maximum printing area of most commercially available 3D printers, the model had to be printed in multiple interlocking segments.

ing identical speaker drivers each speaker is filtered with different responses due to the differences in horn size.

We empirically explored the aesthetics of this divergent sound projection configuration in several ways. Elementary tests involved circularly panning a wide-band source like white noise around the sculpture at a constant velocity. This gave rise to 'melodies' because the horn structures filtered each speaker's sound differently. There was also a rhythmic element due to the regular circular motion. Other experiments involved using generative up-mixing techniques: a small set of sound samples morphed using effects to create multiple copies that were played back simultaneously. Effects considered were simple tape-based effects like pitch-shifting, playback speed modulation, delays, reversal, and splicing. Another experiment used a cascaded delay line network such that each echo of a sound appeared from a different speaker. These echo channels were connected together in a network to create implied trajectories of movement.

These tests suggested the use of a zonal approach where different areas along the sculpture all had different effects processing (like reverberation), to create a heterogeneity in the timbral qualities of the soundscape in different directions. These tests also suggested the need for a manifold-based control and panning method like SpaceMaps [6] or Immlib [14] since it lends itself well to irregular physical geometries and speaker arrangements.

The C++ library Lithe [7], developed partly for this project, was used for sound synthesis and spatialization. Lithe is a library for object based audio-graphs as well as a generic workflow for trajectory processing via the use of manifolds. The framework's agnosticism toward underlying panning methods allowed for testing with different algorithms. This was used to create a modular synthesizer-like sound generation system where sound synthesis graphs of both sounds and their trajectories could be synthesized using a procedural workflow. Further, it also allowed for external input like microphones or sensors to trigger both sonic and spatial events like motions along a trajectory or modulation of velocity or position of sound objects. A more detailed description of the library can be found in [7].

3. INSTALLATION

HIVE was installed and exhibited to the public for several days at the Santa Barbara Center for Art, Science and Technology (SBCAST), Santa Barbara, CA. Figure 4 shows the top view of the installation. An additional quadraphonic speaker system was placed, external to the sculpture, in the four corners of the room with the intent of providing a foreground-background dichotomy in conjunction with the soundscape emitted by the sculpture. Additionally, piezoelectric sensors were placed under the carpets in the space around the sculpture whose output was fed into the audio system.

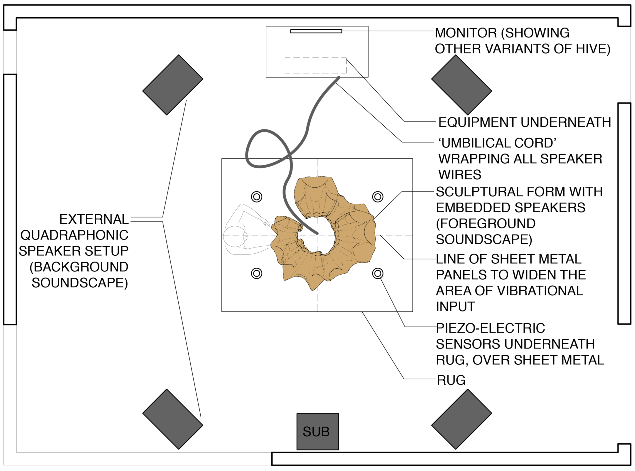

Figure 4: The top-view of the installation at SBCAST. An external quadraphonic system was used to create a foreground-background dichotomy with the sculpture. Piezoelectric sensors placed under the carpet on the floor around the sculpture picked up the movement of audience and used the input to react sonically.

HIVE used sixteen speaker drivers (model NE65W-04 2", Tymphany Inc., Sausalito, CA), driven by eight class-D stereo amplifiers (model DTA3116S, Dayton Audio, Springboro, OH) yielding 16 channels of audio. The audio signal was produced by a multichannel digital audio interface (model Ao24, MOTU, Cambridge, UK) connected to a computer running the custom synthesis software.

All the sounds used were taken from two field recordings. Play-rates were manipulated to conceal the source sound using a network of inter-modulated LFOs and AD envelopes; these sounds panned in circular paths around the sculpture at different rates and by experiment we found that this yielded the perception of rhythms. These panning rates were further modulated using another network of LFOs and AD envelopes, with some connected to those that modulated the play-rate. This patch[2] effectively created a swirling texture of sounds around the object with an irregular ebb and flow. In a similar manner, sounds were modulated to move back and forth from the sculpture to the external quadraphonic system. Since the external quadraphonic system was full range, and not affected by the speaker horns, it effectively distinguished the sculpture from the other sounds in its environment while bearing a resemblance in terms of continuity of rhythm and movement.

In addition, audio input was taken from piezoelectric sensors placed under the carpets in the room and processed by the audio-graph to trigger sonic and spatial events. Sonic events involved sharp or subtle rises and falls in the play rate, or the triggering of echoes. Spatial events involved modulations on the velocity of movement of the sound sources. Care was taken to make the effect of the piezoelectric input less obvious; the intention was to implore the audience to be more spatially and acoustically aware of the environment. This was achieved by means of introducing several seconds of delay, or obscuring the effect of the piezoelectric behind other sonic-spatial textures.

[2]A term commonly known to represent a set of interconnected modules in hardware modular synthesizers.

Figure 5: The installation at SBCAST, Santa Barbara. Photography by J. Armario.

3.1 Observations

Having a divergent speaker setup opened up new strategies for approaching sound design and interaction. Instead of looking at spatial orchestration alone, the object's geometry and filtering effects had to be strongly considered in the sound design. This led to the experimentation with strategies like circular panning, and zonal approaches. Due to these effects, the installation both articulated and was articulated by the acoustics of the room.

The primary means of interaction were through the footsteps of the audience around that sculpture that was picked up by sensors in the floor. However, during the exhibition of the installation, we observed that the audience had a strong and intuitive tendency to attempt to interact with the object gesturally: by moving their hands and bodies around the sculpture. The system however, only responded to the footsteps of the audience in indirect and subtle ways by triggering both sonic as well as spatial events like sudden changes in the velocity of moving sounds within the sculpture. This, therefore suggests considering a more gesture based means of input for interacting with the sculpture, for our future efforts.

4. CONCLUSION

In her book, Between Air and Electricity, Cathy Van Eck observes: "Whereas the musician is able to communicate visually with the audience, the microphone and loudspeaker on stage are just seemingly immovable devices, often painted black to remain as unnoticeable as possible" [20]. We expect performers and instruments to be expressive as a part of the musical performance. If loudspeakers and architectural space are considered instruments, what is the range of their expressive qualities and performative aspects?

The question for us then is: can sculptural form be considered as an instrument, an integral part of the composition process as well as musical performance? What would be the contribution of material artifacts to the expressiveness of musical pieces, both in musical means (timbre, spatialization, etc) and by means of performance? Although, many composers and sound artists[10] have addressed this notion through their work, a more formal study on the contribution of material and physical geometry to musical expression is yet to be made.

Through our installation work, we observed that the material geometry coupled with the speakers constituted not only an instrument for timbral transformation and spatial diffusion, but also an artifact for enactive engagement. The sculpture provokes a visceral experience —engaging by walking around, moving one's body and hands, impacting the sound field at times. If "the movement of sound reconnects us to the realm of kinesthetic experience" [16], the existence of sculptural form reconnects us to our bodies and space. Here, action and performance are guided by a material artifact, calling for unique affordances to be studied.

As we have mentioned, a more formal evaluation of the impact of performative aspects of sculptural objects on musical expression is yet to be made. Through the parametric workflow we introduced to the production process, we hope to do further studies with different artifacts and compositions.

5. ACKNOWLEDGMENTS

We would like to thank Re-Touch Lab, Interdisciplinary Humanities Center (University of California), Dr. Andrès Cabrera, and the entire SBCAST community for helping realize this installation.

6. REFERENCES

[1] Grasshopper, a graphical algorithm editor for rhinoceros. `http://www.grasshopper3d.com/`.

[2] M. Amacher. Sound characters (making the third ear) (audio cd). Tzadik Records, New York, 1998.

[3] R. M. . Associates. Rhinoceros. `https://www.rhino3d.com/`.

[4] Autodesk. Netfabb. `https://www.netfabb.com`.

[5] F. Baschet. *Les Sculptures Sonores: The Sound Sculptures of Bernard and Francois Baschet.* Soundworld Publishers, UK, 1999.

[6] E. Bates. Spacemaps, manifolds and a new interface paradigm for spatial music performance.

[7] A. Cadambi. Lithe: An object-based audio graph framework for spatial composition and sound design. `akshaycadambi.com/lithe`.

[8] S. F. A. Commission. Culture wire: Bill fontana's "spiraling echoes". `https://vimeo.com/3360330`.

[9] J. Dinsdale. Horn loudspeaker design. *Reprinted from Wireless World*, 1974.

[10] B. LaBelle. *Background Noise: Perspectives on Sound Art.* Bloomsbury Publishing, USA, 2015.

[11] B. Leitner. *Bernhard Leitner: P.U.L.S.E.* 2008.

[12] E. Lyon. Spatial orchestration. In *Proceedings of the 5th Sound and Music Computing Conference*, 2008.

[13] N. Miller. Lunchbox, a plug-in for grasshopper. `www.theprovingground.org`.

[14] M. C. Negrao. Immlib-a new library for immersive spatial composition. In *ICMC*, 2014.

[15] G. Piacentino. Weaverbird: A topological mesh editor (plug-in for grasshopper). `http://www.giuliopiacentino.com/weaverbird/`.

[16] C. Roads. *Composing Electronic Music: A New Aesthetic.* Oxford University Press, USA, 2015.

[17] G. K. Sharma, F. Zotter, and M. Frank. Orchestrating wall reflections in space by icosahedral loudspeaker: Findings from first artistic research exploration. In *ICMC*, 2014.

[18] K. Stockhausen. *Two Lectures.* T. Presser, 1961.

[19] D. Tudor. Rainforest 4. `http://www.getty.edu/research/tools/guides_bibliographies/david_tudor/av/rainforest.html`, 1973.

[20] C. van Eck. *Between Air and Electricity: Microphones and Loudspeakers as Musical Instruments.* Bloomsbury Academic, UK, 2017.