Soundspheres: Resonant Chamber

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ABSTRACT

This paper develops a brief historical account of the architectural development of auditory space and identifies the "soundsphere" as an acoustic project that connects the interrelationships between material, spatial form and sound. The instrumental design of the soundsphere has focused on three types of shells: hard, static, and inflexible; physically manipulable; and immaterial (or electroacoustic). This frames a disciplinary and historical context for Resonant Chamber, a prototype-based design research project that develops a kinetic and interactive interior envelope system aimed at transforming the acoustic environment through dynamic spatial, material, and electroacoustic technologies.

Introduction

> Auditory space, so critical to architectural problems today, is usually defined as "a field of simultaneous relations without center or periphery." That is, auditory space contains nothing and is contained in nothing.
> - Marshall McLuhan [1]

In his 1958 *Poème Electronique*, the architect Le Corbusier developed, in collaboration with composer Edgard Varèse, a total sensorial experience of light, sound, and image. The carefully curated imagery and colors presented in essence a cosmogony in seven sections. Meanwhile, Varèse's soundscape (although this term had not yet been invented) made use of 350 loudspeakers to create a spatial sonic experience, localizing sounds within the space and moving sounds through the space. Curiously, perhaps, Le Corbusier seems to have prioritized the spatial effects of sound and light production over his efforts on the design of the vessel the Philips Pavilion, which he seems to have left primarily in the hands of the project manager in his office, Iannis Xenakis [2]. Was it that Le Corbusier was more concerned with the fluid and dynamic auditory space (identified a few years later by McLuhan) than with its static container? In the ongoing project of defining the relationship between space and enclosure, center and periphery, material and void, transient and static, the electronic technology of the loudspeaker and artificial lighting had rendered the enclosure, the building, the architecture in a classic sense, superfluous. *Ceci tuera cela.*

Figure 1. (l-r) Solid shells: Danish Radio Concert House Auditorium, Copenhagen, 2009, Ateliers Jean Nouvel; manipulable shells: Danish Radio Concert House Recording Studio, 2009, Ateliers Jean Nouvel; immaterial shells: 40 Part Motet, Venice, 2010, Janet Cardiff. All photos by the authors.

  | Leonardo, Vol. 45, No. 4, pp. 348–357, 2012

Within the architectural traditions of auditory space, two distinct histories may be found: one of sound control in the physical realm of form and material, and the other in the electroacoustic realm of signal processing technologies. Resonant Chamber is a prototype for a responsive acoustic envelope system that aims to create a transformable acoustic environment that operates within the space of tension between these two realms. The work is developed through computational and material testing, as well as full-scale prototype installation, and it combines kinetic components with computationally driven sensing and actuation regimes that dynamically transform the acoustic environment relative to both sonic inputs and human interaction.

Background

Soundspheres

Within architecture, the acoustic project, or what might be termed the soundsphere, may be defined as a perceived volume of acoustic control or apprehension, variable according to spatial, material, physiological, psychological, social, and political contexts. The intentional shaping and control of aural space through the interaction of form and matter goes back to the original traditions of Western architectural practice and theory: ancient Greek amphitheaters, such as those at Miletus, Rhodes, Syracusa and Epidaurus, have all been found to deploy specific geometric and construction techniques to control and project the sounds of the performers [3]. Vitruvius famously and influentially describes the use of bronze sounding vessels to tune the acoustic properties of performance spaces, while reminding us of the need for architects to understand the harmonic properties of music [4]. In the context of the soundsphere, it has been argued that the building itself may become an instrument, coevolving with music, as has been proposed in the case of the evolution of medieval plainsong in the highly reverberant cathedrals to elaborate counterpoint in the less lively churches of the German reformation [5], or musical works designed for the highly specific acoustics of particular buildings [6]. Frances Yates has convincingly analyzed the Elizabethan theater as a carefully constructed and controlled soundsphere, with the actor placed strategically at the acoustic focus of the space [7]. Outside of spaces for music and performance, acoustic spaces within other listening contexts, such as Marin Mersenne's acoustic lenses, Athanasius Kircher's listening machines, and Christopher Wren's Whispering Gallery in St. Paul's Cathedral, all deliberately control, measure, understand, and make use of soundspheres as fundamentally borne of the synchronicity of material and geometric properties [8].

Shells: Material and Immaterial

The first major scientific breakthrough in control of the acoustic environment was Wallace Sabine's 1895 formulation of a mathematical model of reverberation time in relation to spatial volume and surface absorption [9]. For the first time, by linking formal, material and spatial variables to perception, the shape of the soundsphere could be opened to instrumental design. Design of spaces for acoustic performance became a science, but a maddening one: it soon became clear that a solution that works well for one listening need might not work for another. The shell – hard, heavy, and inflexible – offered control but also became a limit (Figure 1, left). Variable acoustic engineering developed highly sophisticated and often cumbersome mechanical and hydraulic systems for adjusting the parameters of concert halls, most notably in experimental facilities such as IRCAM in Paris, SARC in Belfast, or EMPAC in Troy, New York (Figure 1, center). Less flexible (and less costly) versions, offering a smaller range of variability but with more ease of operation, appeared in concert halls, especially those designed for contemporary music. Hung ceilings could be lowered or raised, wall panels rotated to absorptive or reflective surfaces, spaces expanded or contracted with the use of temporary enclosures. Outside the concert hall, the modern world became one of unprecedented noise and brute suppression, aided by the ubiquitous acoustic ceiling tile [10]. As composer R. Murray Schafer put it, in a world in which “the internal combustion engine provides the fundamental sound of contemporary civilization,” the design of the soundscape turned from productive to reactive ideals [11].

As Le Corbusier no doubt understood, technological developments in the electroacoustic production of sound – the invention of the multi-speaker array – made possible the shaping of a soundsphere without the introduction of a hard shell. By varying placement of sound sources, by “moving” sounds from one source to another, by varying volume and, in more sophisticated examples, wave phase, the perceived acoustics of a space could be rendered independent of physical form. The development of hard acoustic shells was accompanied by a contrary movement in which the acoustic envelope was dematerialized. This precisely paralleled the general fascination with the dematerialization of the building envelope in avant-garde architectural discourse in the 1960s and ’70s. The clear physical presence of audio equipment in Banham and Dallegret’s architecturally reductive Environment Bubble is telling (although the likely unpleasant acoustic conditions inside the bubble have not been considered). Sound artists as divergent in their practices as LaMonte Young, Janet Cardiff, George Bures Miller (Figure 1, right), and Bernhard Leitner are all engaged in the production of these immaterial shells and spheres. So is anyone who has ever worn a pair of headphones while walking down a noisy street, creating a personal, mobile soundsphere, immaterial, invisible, and transient.

Figure 2. Resonant Chamber prototype: (left) Surface detail. © RVTR. (right) Prototype installation of three operational acoustic clouds. © Peter Smith Photography. Photo by Peter Smith.

Resonant Chamber

Resonant Chamber is an exploration of the acoustic project through computational and prototype-based design research (Figure 2). The work emerges from an interest in the acoustic, spatial, and social possibilities of the acoustic shell as neither material-but-static nor flexible-but-immaterial; a soundsphere that is able to adjust its spatial, material, *and* electroacoustic properties in response to changing sonic conditions, to dynamically alter the sound of a performance space *during* performance, or to become itself an instrument inviting new forms of performance and play. Utilizing contemporary technologies for computational design, acoustic performance, material testing, digital fabrication, ubiquitous sensing, and real-time micro-actuation, we explore development of a system that might be robust enough, flexible enough, and adaptive enough to move out of the concert hall and make everyday spaces acoustically tunable to changing activities or needs. Through the use of interactive technologies, this flexible prosthetic shell could afford an almost seamless and perhaps even unconscious connection between listener and soundsphere, operating as a second-order cybernetic system.

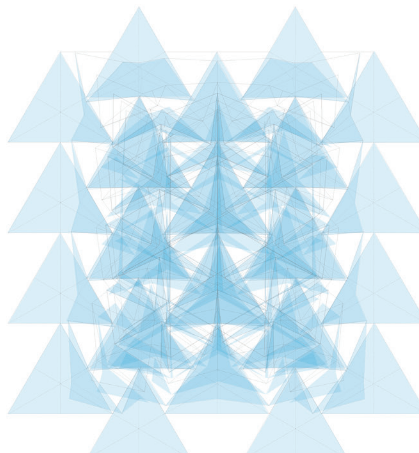

Figure 3. Rigid origami geometry and flat folding logic drawing. © 2012 RVTR.

Dynamic Surface Geometries

The first constructed prototype of Resonant Chamber is designed as an installation of a thick kinetic surface, transformable through the geometric properties of rigid origami. Rigid origami was explored as a flexible geometric system, as it makes it possible to achieve predictable spatial configurations through its surface properties of developability (folded from a single sheet), flat-foldability (ability to fold into a flat shape), and degrees of freedom (DOF) [12]. The origami-based geometry allows both for gross deformation of the surface to dynamically alter the aural volume's overall spatial form, as well as localized manipulation to vary the ratios of exposed surfaces with variable material (and therefore acoustic) properties and linkages.

Previous work by the authors in responsive envelopes has explored cable-strut tensegrity weaves as a lightweight, distributed structural framework that would be able to support kinetic deformation [13]. Rigid origami offers different advantages: as a result of the interconnected reactions between interior vertices and crease lines, which determine the DOF of the surface, physical actuation in one location has calculable effects on adjacent elements, thus reducing the number of points of actuation required to induce overall formal adjustments. The property of flat-foldability optimizes angles around a central vertex to allow the surface to tuck, enabling compact deployable structures within a limited space. Rhinoceros 4.0 software, and Grasshopper and Kangaroo plug-ins, were used to script and accurately simulate the relationship among geometries and gravitational and applied forces. This computational software will also allow us to develop different folding patterns that can be customized to suit a variety of spaces, potential aural volumes, and uses. The Resonant Chamber prototype uses a tessellated pattern first developed by Ron Resch [14], which deploys two sizes of triangular cells (Figure 3). This specific cell geometry, prototyped in bamboo plywood, was chosen as it proved to be most acoustically sensitive in a series of comparative tests evaluating performance of formal and material configurations, as well as integration with electroacoustics (Figure 4).

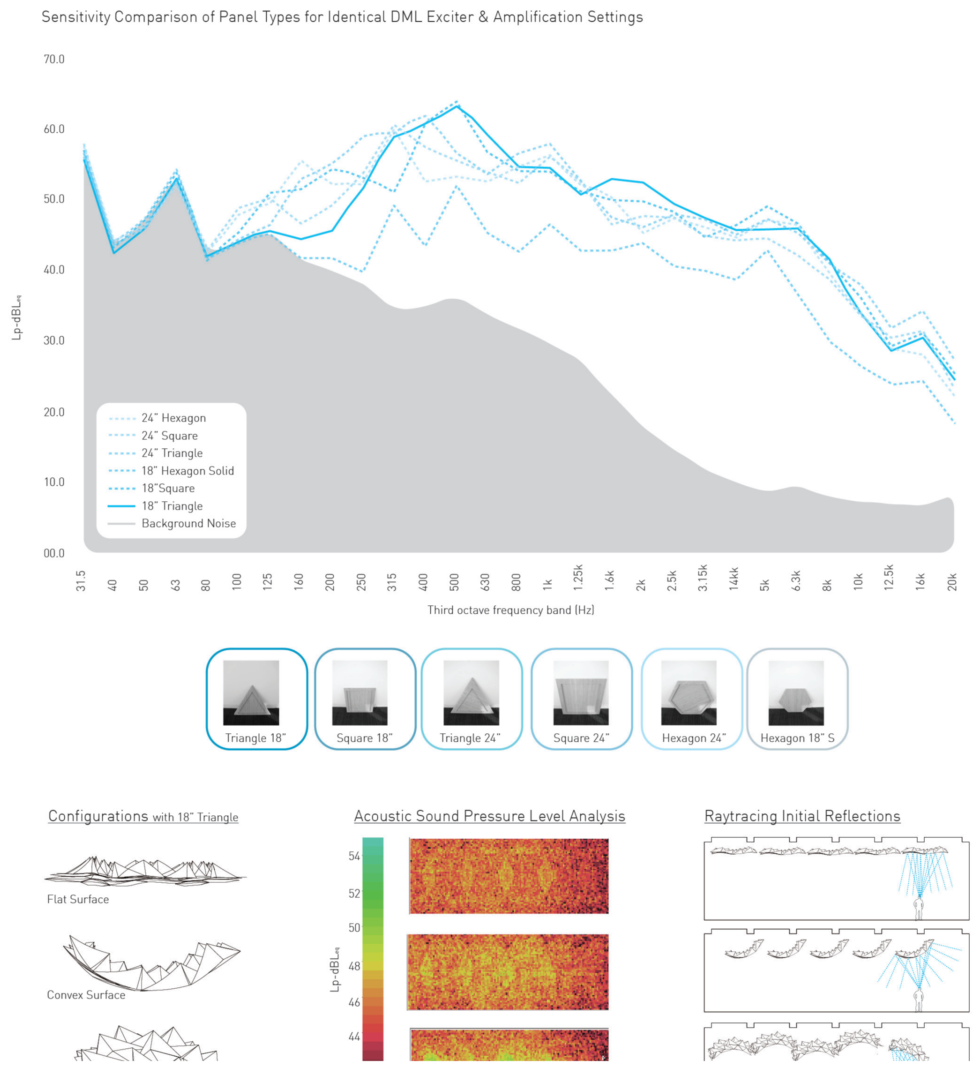

Figure 4. (above) Acoustic sensitivity comparison of panel shapes for identical DML exciter and amplification settings (chosen is the dashed line: 18" triangle); (below) Acoustic sound pressure analysis and acoustic reflections of surface configurations. © 2012 RVTR.

Performative Material Systems

Flat-foldability relies on the fundamental physical property of optimum zero thickness, as is the case with paper origami; to shape acoustic performance, however, materials with multiple thicknesses, three-dimensional profiles, and specific properties are necessary. Three parallel streams of development were necessary for this translation into a performative surface. First, joint details were developed that would allow for the flat-folding of thick surfaces [15]. This included material prototyping with laminated membrane hinge assemblies and development of panel profiles for folding. Second, three primary types of panel composites were developed to absorb, reflect, or elecroacoustically generate sound (Figure 5). Third, suspension and actuation technologies were prototyped that would allow the surface to be physically deployed within a space, and for its facets to move, either in response to sensor inputs or in pre-programmed modes (Figure 6).

The reflective, absorptive, and sound-generating panel types that comprise the material characteristics of the system were developed in collaboration with consultants at ARUP Acoustics. Digital acoustic simulations and physical panel prototype testing were undertaken to determine optimal geometry and material characteristics relative to acoustic performance

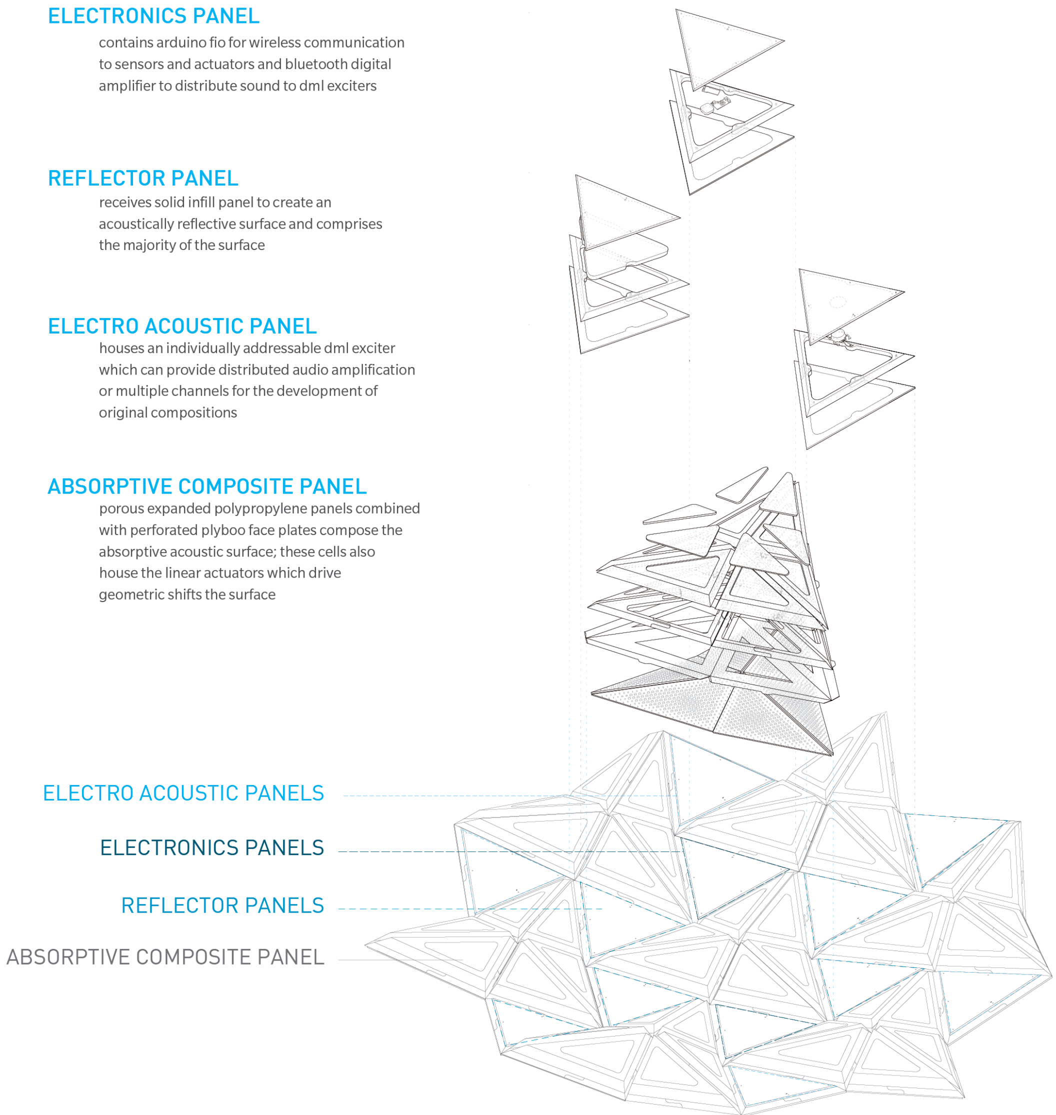

Figure 5. Composite panel assembly and materials. © 2012 RVTR.

when combined with the proposed geometric configurations and electroacoustic technology (Figure 7). The sound-generating panels have Distributed Mode Loudspeaker (DML) exciters embedded within their composition, effectively turning these panels into speakers. Although the integration of DMLs into a multichannel system has been realized successfully in the past [16], their integration into a kinetic surface has not been widely explored and opens up an array of possible applications. On one hand, the DMLs provide an augmented level of reverberation control and directional sound reinforcement, which can now be actively manipulated for greater acoustic control. On the other hand, they comprise an entirely different interactive interface from the spatial-material control approach of the physical system, opening up a variety of possibilities for interactive sound installations, immersive live performance spaces, or acoustically enhanced learning facilities. Resonant Chamber thus has the possibility to become a hybrid architecturally scaled instrument, a dynamic aural environment that not only facilitates performance, but also might perform itself.

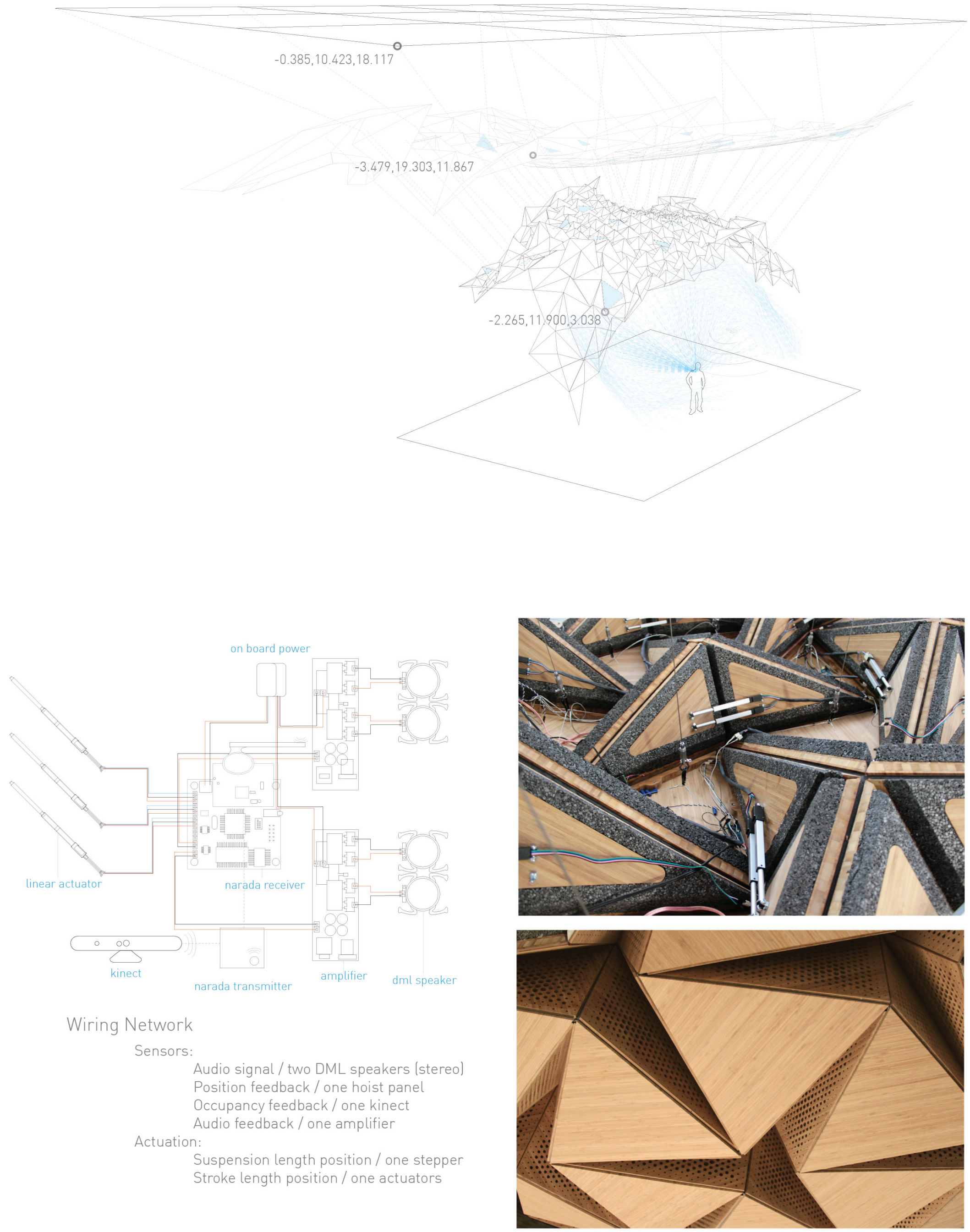

Figure 6. (above) Variable surface configuration through folding properties; (below left) circuit diagram and wiring network; (below right) wiring of prototype surface with actuators from above, and folded surface from below. © 2012 RVTR.

Variable Actuation and Response

A series of linear actuators mechanize the folding motion of the Resonant Chamber surface, locally varying material exposure for optimum acoustical tuning (Figure 8). A track system of stepper motors provides gross-motor positioning of the system within the space. Currently, Arduino micro-controllers are used to manipulate localized folding movements. Commands tied to the digital surface model communicate data via the Firefly software plug-in to calculate and coordinate desired movements. For the next prototype, we are collaborating with Jerome Lynch at the University of Michigan to incorporate into the assembly his Narada® system for wireless sensing, actuation, and on-board data processing.

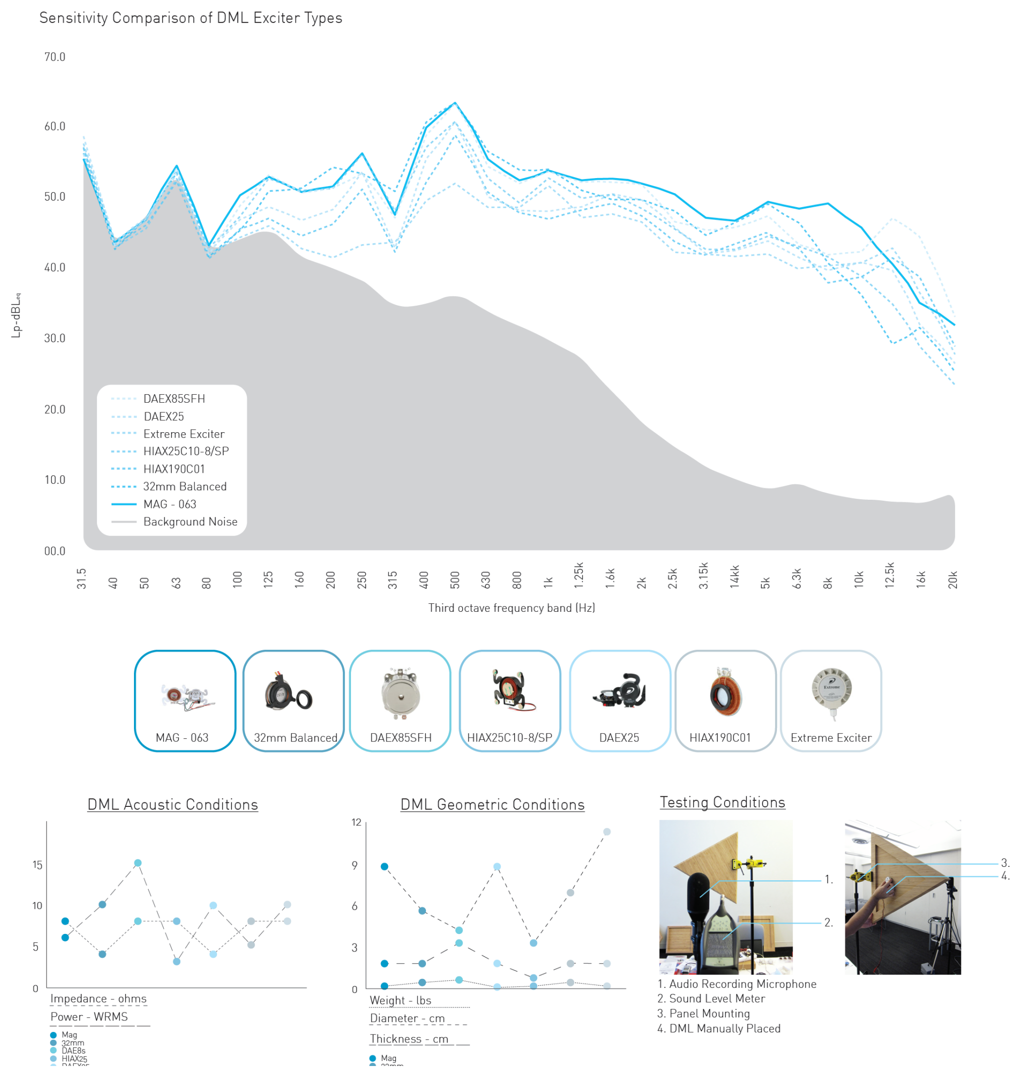

Figure 7. Physical sensitivity comparison and testing of DML exciter types with panel (chosen is the dashed line: MAG-063).
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The synchronized actuation systems will allow geometric optimization for early acoustic energy and alter surface material exposure for late acoustic energy. Early acoustic energy controls the acoustics occurring shortly after the direct sound at both a listener and performer location by adjusting the height, location, and curvature of the prototype. Late acoustic energy controls diffusion and reverberation by adjusting the absorption material exposure, size, and location of the prototype. Though there are precedents for control of late room response through the use of systems to manipulate height or orientation of a ceiling reflector [17], the use of a kinetic system to control wavefront curvature, level and time of arrival of early reflections constitutes a new advance in acoustic research.

In order to explore sensing and response, the installation space will be equipped with frequency, volume, and acoustic pressure sensors, which will process audio input in order to trigger physical and/or electroacoustic responses. Devices such as the Kinect sensor will locate the presence of people within the space and trigger transformations of the Resonant Chamber surface relative to location, number, and activity of occupants. Interaction modes will vary from tuning acoustics for specific performances to pattern languages that develop machine learning and cognitive responses relative to both actions and sounds of occupants.

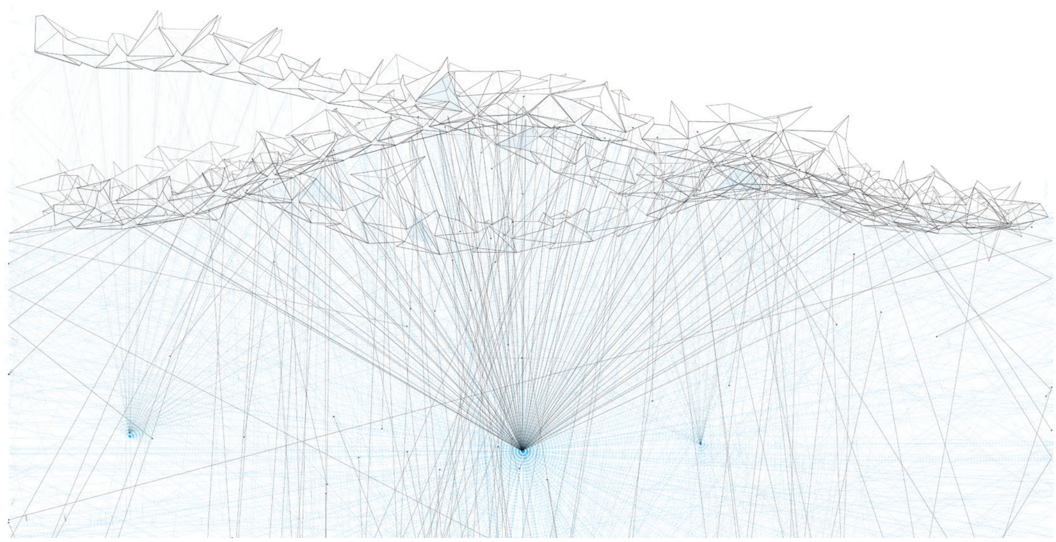

Figure 8. Resonant Chamber: ray-tracing of acoustic reflections due to variable spatial configurations delivered through gross displacement. © 2012 RVTR.

Projection

Resonant Chamber is currently in its second phase of research and prototyping, which will allow for refinement of material and technological components and performance, as well as for testing relative to human interaction and feedback. We will also be refining sensing and control regimes with regard to how the system might be deployed in a variety of spaces and uses – prioritizing, for example, particular aural qualities to enhance various configurations of live musical performance, blending aural and occupancy feedback to reconfigure the relationships between audience and performer, or developing individual need-based recognition systems that could dynamically recalibrate learning environments relative to inhabitant's aural ability – and assessing real-world manufacturing and installation issues. Resonant Chamber, in its aspirations to combine kinetic spatial reconfigurability, multiple surface material properties, electroacoustics, and interactivity, thereby produces a system of incredible complexity, both functionally and operationally. This is both its attractiveness and its limit. As an engineering problem to be solved, the adaptive system of such complexity is inherently difficult to predict and control, and its many moving parts are prone to failure and mechanical difficulties. However, the work makes a case for the territory within which the architectural project of the soundsphere may be located in our contemporary context – as a hybrid investigation of material, electronic, and human-interactive environments.

Acknowledgements

Project Team: Geoffrey Thün, Kathy Velikov, Lisa Sauvé, Wes McGee, Mary O'Malley, Colin Ripley, Adam Smith, Katie Wirtz, David Lieberman, Ian Ting, Lief Millar, Dr. Jerome Lynch, Devki Desai, Mike Kane. Acoustic Consulting Engineers: ARUP Acoustics - Raj Patel, Terence Caulkins, Dave Rife. Funding: University of Michigan Taubman College Research Through Making Grant, OVPR Small Projects Grant, and Center for Wireless Integrated MicroSystems; SSHRC Research Creation Grant.

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