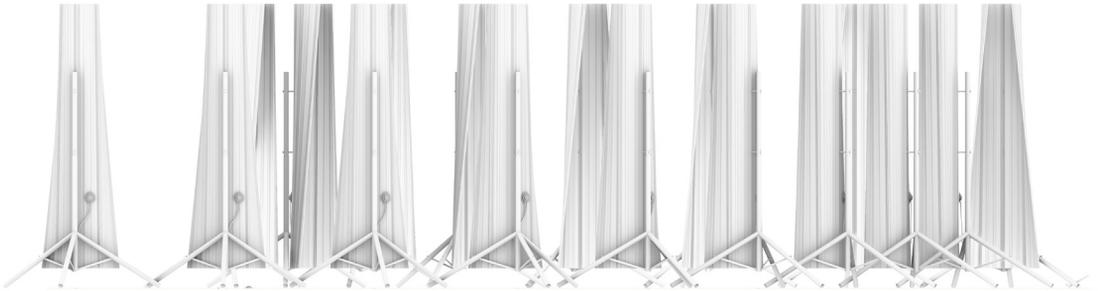


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Sounding Bodies:  
*Experiments in Sonically  
Active Surfaces*

Jonathan Tyrrell

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# Sounding Bodies: Experiments in Sonically Active Surfaces

Jonathan Tyrrell  
*University of Waterloo*

## i. SUMMARY

This research folio documents the technical and poetic development of an experimental architectural installation that points toward a new model of sonic materialism. 'Sounding Bodies', originally installed at Nuit Blanche Toronto 2019, used audio transducers to transform galvanized steel roofing material into inhabitable loudspeakers. Folio appendices include a systems diagram, bill of materials, and an illustrated selection of the bill of materials describing the 'Sounding Bodies' installation.

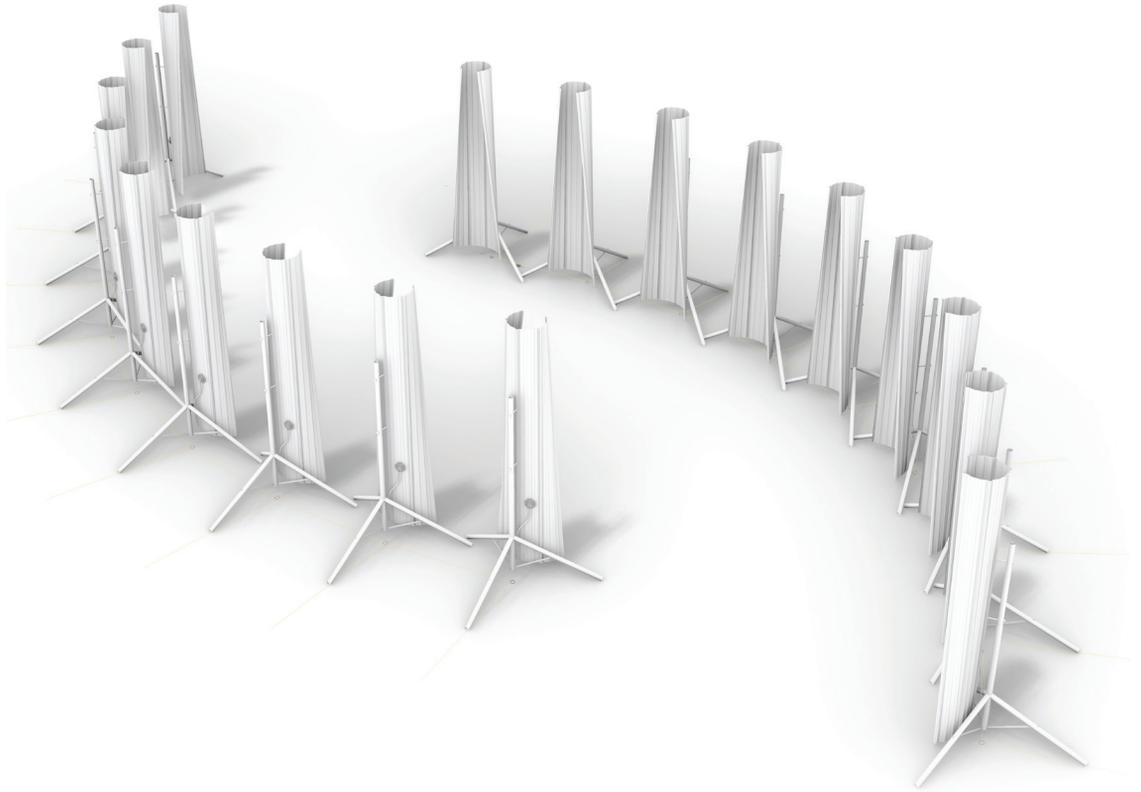
## 1. INTRODUCTION

There is no way of perceiving sound without also perceiving the space in which it propagates. The textures, densities, and geometries of an architectural volume alter soundwaves as they travel, building a tectonic signature of the enclosing space as they ricochet thousands of times in the span of a few seconds. In turn, space is highly altered by sound. Reverberation times can modulate our sense of scale, resonant frequencies can create loci of sound, absorption and diffusion can greatly influence the atmosphere of a space. Sound, being the most spatial of the senses, plays a special role in cultivating attunement: the complex fabric of connectivity between organisms and their environments.<sup>1</sup>

Whether by accident or by design, the ability for sound to enliven spaces and our connectivity to them has been understood for thousands of years.<sup>2</sup> As the Roman architect

<sup>1</sup> Pérez Gómez, Alberto. 2016. *Attunement: Architectural Meaning After the Crisis of Modern Science*. Cambridge, Massachusetts: MIT Press.

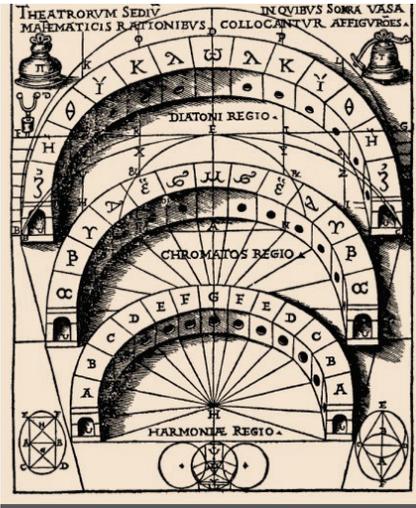
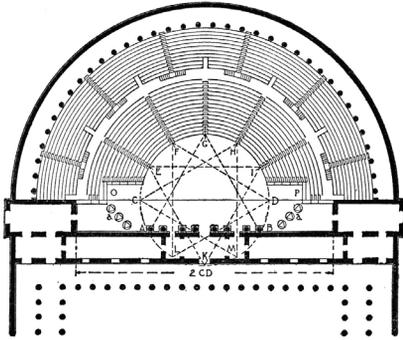
<sup>2</sup> Blesser, Barry and Linda-Ruth Salter. 2006. *Spaces Speak, are You Listening?: Experiencing Aural Architecture*. Cambridge, MA: MIT Press.



*Image 1 (top)* Aerial render of Sounding Bodies as installed at Nuit Blanche 2019

*Image 2 (facing top)* Plan of the Roman Theatre according to Vitruvius

*Image 3 (facing bottom)* The plan for large theatres from Vitruvius, *De Architectura*, Italian edition, from Thorp, John, "Vitruvius' Vases: Sound-amplification in ancient theatres" (2018). Philosophy Presentations. 15.



3.4 Godman, Rob. 2007. *The Enigma of Vitruvian Resonating Vases and the Relevance of the Concept for Today*. *The Journal of the Acoustical Society of America* 122 (5): 3054–. <https://doi.org/10.1121/1.2942890>. Press.

5 Vitruvius Pollio., M. H. Morgan, and John I. Rempel. 1960. *Vitruvius: the Ten Books on Architecture* New York: Dover.

Vitruvius describes in his Ten Books on Architecture, the craft of tuning space to sound is an ancient one, and critical to the education of the architect. The physics of sound propagation in Vitruvius' day was not fully understood, however his design guidelines for theatres demonstrate an empirical understanding of the wave-theory of sound, and a practical methodology for achieving good sonic distribution in an open-air semi-amphitheatre.<sup>3</sup>

What becomes clear in reading his treatise however is that proper attunement of sonic atmospheres in Roman theatres required more than a geometric understanding of acoustic ray tracing. He discusses at length the idea of incorporating 'echea', large bronze sounding vessels housed within niches in the seating 'cavea'. He provides instructions for their specific distribution, their mounting and orientation, and their frequency response (and thus size) based on the harmonic theory of the Greek philosopher Aristoxenus.<sup>4</sup> The vessels would resonate at specific frequencies tuned to the voice of the performer, which as a result would be "increased in clearness of sound, and will make an harmonious sound in unison with itself."<sup>5</sup>

This evocation of an architecture bedecked with sonic inclusions that come alive in response to the voice is a fascinating one. And yet, despite the important role of the echea in amplifying certain frequencies to achieve a heightened experience, the architectural space itself was predominantly a passive receptor of sound. It did not contribute actively to the sonic milieu.

Could this idea of sonically active inclusions be expanded? What new models of material agency might be achieved through sonic actuation? How might near-living qualities, sought after by architects and artists for millennia, be explored in the sonic realm using contemporary technologies and materials?

Sounding Bodies, an installation created for Nuit Blanche Toronto 2019 and Unsilent Night Cambridge, pursued just

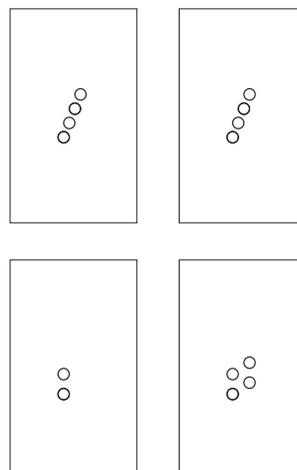
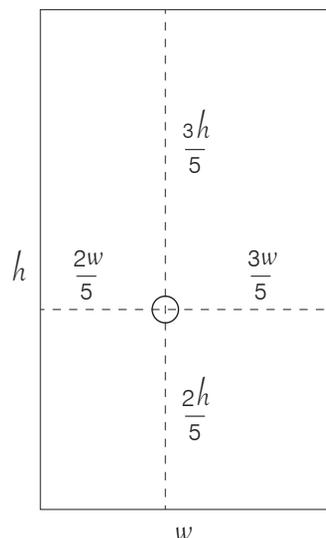
such a state of actively resonant architectural space. The ‘bodies’ themselves – galvanized steel roofing panels bent into cloak-like forms – operated like inverted, inhabitable versions of Vitruvius’ echea, emitting sound through the actuation of sonic transducers (exciters) and vibrating in sympathy with the human voice. This folio presents a technical and poetic account of its design and implementation, followed by a discussion of the central cultural themes of the work, and speculations about further experimentation along this line of research.

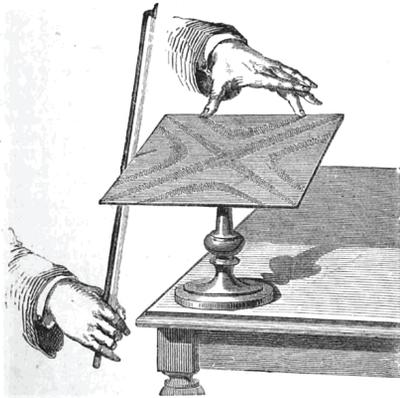
## 2. TECHNICAL DESCRIPTION

An audio exciter can be thought of as a loudspeaker without the cone or frame. Rather than pushing air with a traditional integrated paper diaphragm, the exciter produces sound when affixed to any rigid surface. The main components of the exciter are a rare-earth neodymium motor, a voice coil, and flexible attachment arms. Like conventional loudspeakers, exciters work by converting electrical energy into mechanical energy. When an electrical current is passed through the voice coil, it induces a magnetic field that interacts with the magnetic field of the permanent neodymium magnet. As an audio waveform is sent through the coil, like charges repel and opposite ones attract according to the frequency and amplitude of the sound. This motion, transferred to the material pushes air, creating longitudinal pressure waves that we perceive as sound.

The material properties of the excited surface play an important role in the acoustic performance of the assembly. Thickness, compressive strength, and bending strength all contribute to the specific frequency response, and thus fidelity to the source audio, while the weight of the material greatly affects broadband attenuation (overall volume).

Placement of the exciter on the panel also impacts performance. To avoid standing waves it is recommended that the panel’s width be less than  $4/5$  of its height. In other words an oblong rectangle is preferred to square. The placement of the





*Image 4 (top)* This 1879 illustration of a Chladni plate, named for the German physicist Ernst Chladni, demonstrates how standing waves can build up at certain frequencies on a square panel.

*Image 5 (facing top)* Dayton Audio Exciter, 32mm 40W model DAEX32QMB-4.

*Image 6 (facing middle)* Optimal placement of the exciter on a flat panel.

*Image 7 (facing bottom)* Guidelines for placing multiple exciters on the same panel. These diagrams have been adapted from technical information found at: [www.daytonaudio.com](http://www.daytonaudio.com)

exciter should be at a 2/5 to 3/5 relationship in both width and height. Additional detailing like the rounding of corners can also prevent the buildup of standing waves.

### 3. DEVELOPMENT

This description of material choice and placement of transducers assumes a paradigm of optimization. The maximum amount of energy is transferred to the air by the chosen surface, and the reduction of standing waves ensures the flattest possible frequency response, and thus the most fidelity to the source audio. In short, sonic transparency.

The Sounding Bodies project approached this question in the opposite way. How can sound be actively shaped by the material that voices it? In turn, how is sound composition affected when dealing with a non-neutral playback system?

Initial testing was conducted using 18-gauge corrugated steel window wells. This form was chosen for two reasons 1) its ability to connect easily at the flanges and quickly array into larger tessellations, and for its semi-enclosed profile that could produce pockets of localized sound. Providing it was isolated from contact with other surfaces, the steel produced a strong response to low frequency square waves with a particularly acute response to pulses generated at 13Hz. In the end it was felt that this particular steel was too thick, absorbing too much of the kinetic energy of the exciter and requiring it to be driven beyond safe limits.

Other lightweight rigid materials were tested including 6mm plywood, 50mm expanded polystyrene foam boards, and 3mm corrugated cardboard. Each provided some colouration to the sound but generally tended toward a more acoustically transparent effect. Experiments using 28-gauge galvanized steel roofing panels provided the most interesting colouration to the sound, resulting in their selection for the installation. The corrugated profile allowed for large panel sizes (914mm x 2438mm) with thin material, providing for an optimal balance between low frequency response and weight.



*Image 8 (top left)* Exciters installed on steel roofing material during testing.

*Image 9 (top right)* Double window wells used for testing.

*Image 10 (left)* Possible configurations of window well material in plan.

*Image 11 (facing top)* Visitors engaging with a cluster of Bodies at Nuit Blanche Toronto 2019. (Image credit: Meghan T. Won)

*Image 12 (facing bottom)* Individual engagement with a single Body. (Image credit: Meghan T. Won)

*Image 13 (following page)* Sounding Bodies Nuit Blanche with Toronto Skyline in the background (Photo credit: Max Schramp)



A tension member was added to the panel's top corners, changing it from a two-dimensional panel to a 3-dimensional shell-like structure. This design decision had several advantages: 1) sculpturally the form related more to the human body 2) as a three-dimensional object it allowed for inhabitation and more localized sound 3) it produced a gradient of frequency response and sonic effects across the panel.

Typical design of loudspeakers is driven almost exclusively by optimization and the aforementioned audio transparency paradigm. Rarely is much consideration given to the sculptural qualities of sound-emitting devices for audio playback. Musical instruments on the other hand must balance sonic performance with accommodation to the human form. The wooden body of a Cello, for instance, must not only perform as a resonating chamber but must also consider the embrace and motion of the cellist. Because of this need to accommodate the body, musical instruments often bare anthropomorphic traces in their curves and profiles. In *Sounding Bodies* this embrace is reversed as the visitors inhabit the interior volume



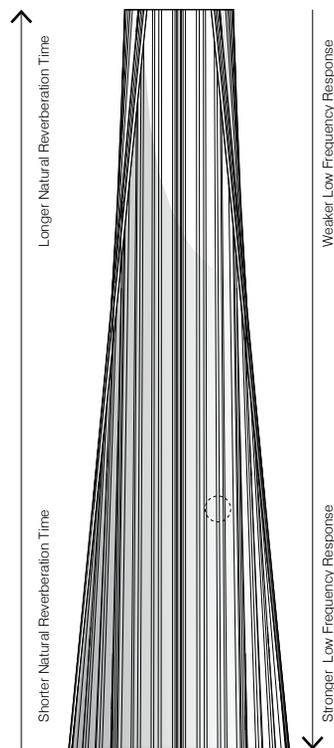


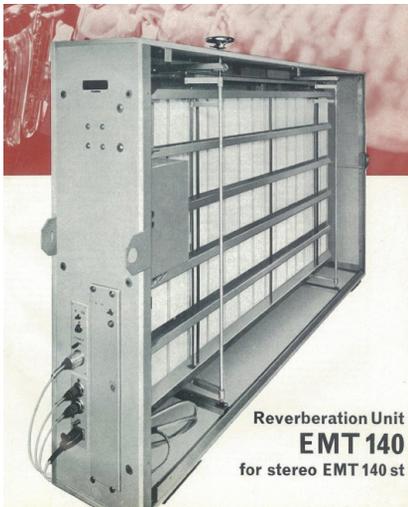
of the instrument. The sculptural resonance with the human body is then two-fold: on the one hand it presents itself as a columnar element, picking up on the deep associations of the column with the human body throughout architectural history, while also presenting itself as an empty shell, or cloak; a void that invites inhabitation.

The enveloping sculptural nature of the individual 'body' also creates a mini-internal soundscape with varying frequency responses and sonic effects throughout. Near the bottom of the element (which is also close to where the exciter was placed) the low frequency response was very strong. Tones in the 100-150Hz range were very rich and 'warm', especially when listening at close range. Moving up the panel the frequency curve was less biased to the low end but other effects began to take over. Owing to the natural properties of steel, and the way in which the panel was mounted, the element showed an overall natural reverberation. This functioned much the same way as a plate reverb unit. However, the gradual curvature of the upper portion meant that natural reverberation times were increased. In addition, internal reflections were increased in the upper portions owing to their elliptical shape and reduced lower down as it approached a more gentle arc. This also resulted in a 'fidelity' gradient, where sounds that required signal transmission (speech) were less legible when perceived in the upper section of the panel.

#### Additional Elements

Experiments were also carried out with affixing additional resonating elements to the panels including washers mounted to straightened steel wire, and steel strings used for musical instruments. The washers and wire were conceived as percussive resonators in the same fashion as the 'snare' on a snare drum, or the 'zills' on a tambourine. Not only would they vibrate at particular frequencies, they would also visually amplify the mechanical motion of sound propagation within the assembly as a whole. Commercially available brass-wound bass guitar strings were also mounted to the panel (piano wire





*Image 14 (top)* Illustration of a plate reverb unit from 1957. A suspended thin steel plate outfitted with pick ups added artificial 'space' to a recording. A secondary damping plate allowed for adjustable reverberation time.

*Image 15 (facing top)* Diagram showing the inverse gradients of frequency response to reverberation time.

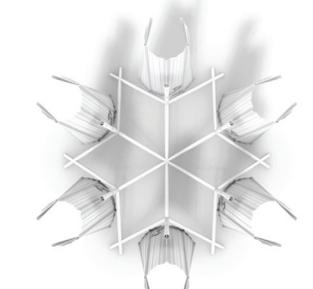
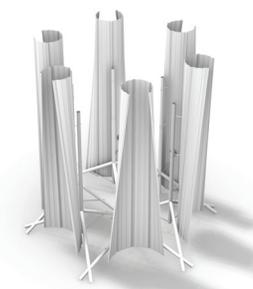
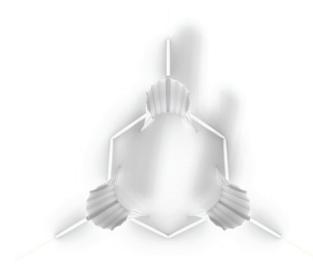
*Image 16 (facing bottom)* Tuning up the instrument strings on one of the Bodies during installation at Nuit Blanche 2019. (Photo credit: Max Schramp)

was also used but the tension force required to tune them to an appropriate frequency was too great). The strings were then amplified through a contact microphone mounted to the back of the panel.

#### Experiments with Feedback Loops

An additional exploration used contact microphones, and commercial dynamic microphones to set up feedback loops between the exciter and material. The goal was to balance the amplitude of the emitted sound wave, and the gain of the contact microphone, such that the material could be struck gently and vibrate freely or autonomously, 'coming to life' so to speak. The specific frequency of audio feedback in a PA system arises from the interaction of the microphone, sound emitter, and the room that houses the system. In this case the feedback is generally undesirable, resulting in loud hi-frequency tones. Audio feedback between guitar amplifiers (generally thought of as more desirable) is less direct in that the sound waves must create sympathetic vibrations within the instrument which are then picked up by the magnetic coils in the electric guitar itself.

The exciter assembly functions more like a conventional loudspeaker. Therefore in order to achieve complex feedback, a chain of consumer-grade effects pedals including distortion and delay, were introduced. The results of these experiments were mixed. With the help of the effects chain the contact microphones and dynamic microphones produced some interesting feedback textures, but the real-time balance between inputs and outputs was not achievable without the introduction of further signal processing.



*Image 17 (top)* Octagonal cluster installed at NAISA (New Adventures in Sound Art), 2021.

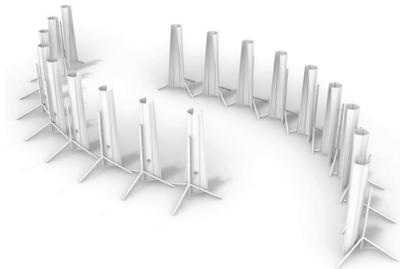
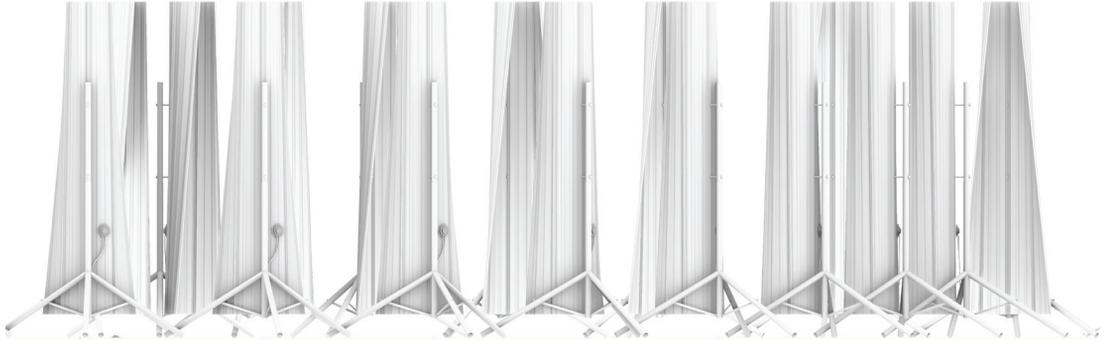
*Image 18 (bottom left)* Studies of various cluster configurations: 3-way (inward facing), and 6-way (outward facing).

*Image 19 (facing top)* Elevation of Nuit Blanche configuration showing parallax effect.

*Image 20 (facing side top)* Aerial view of opposing arcs.

*Image 21 (facing side middle)* Janet Cardiff, *The Forty-Part Motet*, installed at the BALTIC Centre for Contemporary Art, 2012.

*Image 22 (facing side bottom)* Bernhard Leitner, *Le Cylindre Sonore*, Paris 1987. Both this project and Cardiff's *Forty-Part Motet* served as important references for Sounding Bodies.



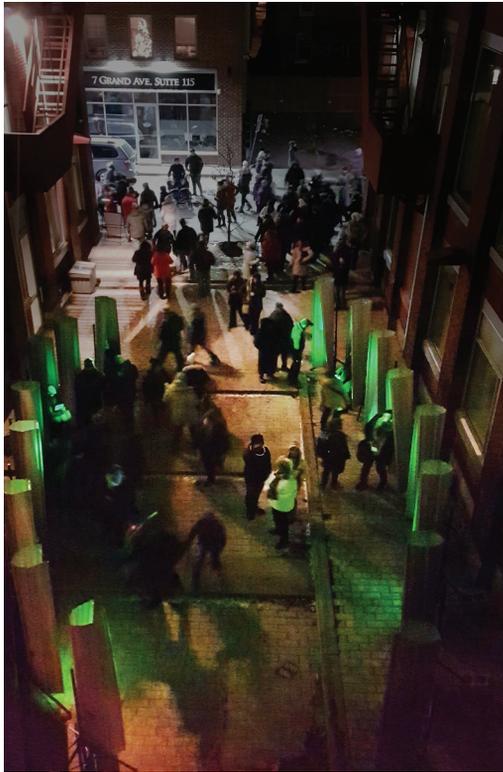
#### Site Implementation

Several spatial configurations were tested during the development of the final installation. Smaller clusters made for more intimate settings. Outward facing arrangements prioritized individual relationships to the surrounding context. The final form, two interior-facing offset arcs, combined these approaches, creating a semi-permeable sound-space.



Particular consideration was given to how the 'bodies' created overlapping acoustic arenas that structured individual and collective relationships within the piece. Because of the localized sonic effects outlined above, the experience of an individual 'body' was very different than the polyphonic experience of the whole. Enveloped by the partially enclosed steel diaphragm, an individual listener would perceive monophonic tones, punctuated by intimate whispers. Moving around the whole installation was a constant play between the individual and the chorus. Tones would blend into a contingent polyphony that would continually form and re-form. There was no singular, privileged point from which the sound resolved itself, even the theoretical point of convergence of each arc was obstructed by the opposing arc.





#### 4. AUDIO AND VIDEO CONTENT

Artistically, the project draws inspiration from a generation of Canadian sound artists including Glenn Gould, R. Murray Schafer, and Hildegard Westerkamp, and from the origins of sound recording itself. Particular inspiration is found in Gould's *The Idea of North* from his *Solitudes Trilogy*. This experimental sound composition from 1967 featured five different narrators describing contrary views of the Canadian North, their voices woven in and out of each other in a form that Gould described as 'contrapuntal radio'. *Sounding Bodies* sampled micro fragments of human speech from *The Idea of North* which were repeated at high enough frequency to be perceived as textured tones (a method akin to 'granular synthesis'). The 'bodies' were each assigned different synthetic 'voices' (tones) which were then played against one another to form a shifting

*Image 23 (top)* Installation of the piece at *Unsilent Night* Cambridge, 2019.

*Image 24 (facing top)* Photograph of Glenn Gould. He believed that solitude was essential to human creativity and happiness, and he saw an analogue for this in the emptiness of the Northern landscape.

*Image 25 (facing middle)* Lawren Harris, *North Shore Lake Superior*, 1926. Harris' iconic landscapes fit well with Gould's vision of the North but both have been criticized for their colonial stance.

*Image 26 (facing bottom)* Thomas Edison with his second phonograph, 1878



polyphony. Interlaced with these tones were more legible fragments of speech from the original Gould documentary, and from an oral account of the installation site's history as the birth place of colonial Toronto.



Contemporary with Gould's experimental documentary was the birth of the World Soundscape Project at Simon Fraser University in the late 60s and early 70s. Led by R. Murray Schafer, this group first articulated the idea of the Soundscape as a field of intellectual and creative exploration, and Acoustic Ecology as the broader methodological framework for engaging it, using techniques such as field recording and sound walks. The relationship between sound and the vast Canadian landscape - embodied in Gould and articulated by Schafer - changed the way we think about not only the sounds, but the environments that envelop us, support us, and shape us; and by extension the myths that sustain our national identity.



Sounding Bodies attempts to harmonize Gould's intimate multiplicity from *The Idea of North* with the acoustic ecology of the World Soundscape Project. Gould's pioneering work not only served as a source for audio content, it also prompted a critical reflection on how attitudes to the country's north have shifted in the face of climate change and the nation's relationship to First Nations people. *Sounding Bodies* creates a critical pairing of Gould's late-colonial vision of the North as a place of heroic solitude with projected imagery of it burning due to severe wildfires and human activity. In this way it alludes to some of the goals of the World Soundscape Project - namely the use of sonic analysis to reveal relationships between humans, non-humans, and their shared environments, and to highlight the consequences of those relationships.

A third source of inspiration reaches back to the origins of modern sound reproduction: Thomas Edison's invention of the phonograph in the late 19th century. For Edison the promise of the Phonograph was mostly in its mnemonic capacity, as a vessel for preserving the disembodied voice after death.

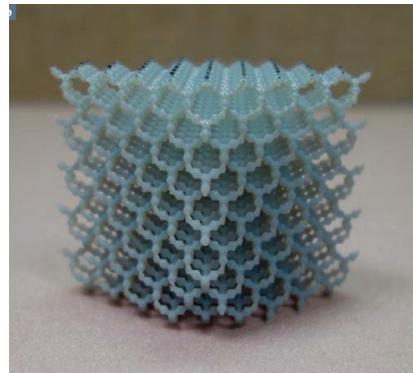
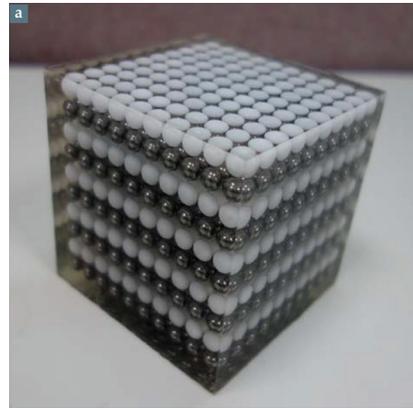
He writes:

"Your words are preserved in tin foil and will come back upon the application of the instrument years after you are dead in exactly the same tone of voice you spoke in then ... This tongueless, toothless instrument, without larynx or pharynx, dumb voiceless matter, nevertheless mimics your tones, speaks with your voice, speaks with your words, and centuries after you have crumbled into dust will repeat again and again, to a generation that could never know you, every idle thought, every fond fancy, every vain word that you chose to whisper against this thin iron diaphragm."<sup>6</sup>

This passage evokes a clear phenomenological relationship between matter and the recorded voice. Having a 'voice' is synonymous with agency, thus the preservation of the voice, on a delicate membrane of metallic foil was a profound idea in the Victorian imagination. This link between sound and matter, and matter and the voice, is far less clear in the contemporary context where the mechanics of sound recording and reproduction are becoming less and less manifest. Aside from the artistic inspirations of Gould and Schafer outlined above, *Sounding Bodies* attempts to recapture an aspect of the reverence and mystery of early sound reproduction by celebrating the physical apparatus that makes it possible, and by spatializing this mechanized sounding in a way that can be experienced by the body in motion.

## 5. CONCLUSION – TOWARD A SONIC MATERIALISM

The pursuit of acoustically tuned architectures that come alive through their sounding is an ancient one, the explicit design criteria for which had been codified as early as Vitruvius. But while the Greek and Roman theatres used a combination of geometry and sounding vessels to achieve a rich sonic atmosphere, the spaces were ultimately passive, awakening only when struck by the human voice. Rather than simply receiving sound energy, could material surfaces become sites of sonic exchange? In doing so could they contribute to further reciprocity between the animate and inanimate worlds?



*Image 27 Real-World Acoustic Metamaterials.* The figure on top shows the periodic arrangement of elastic spheres in a polymer matrix. The bottom image is a 'pentamode structure' which supports stress in only 1 of 6 possible modes. From: Haberman, Michael R, and Matthew D Guild. 2016. *Acoustic Metamaterials*. *Physics Today* 69 (6): 42–48.

<sup>6</sup> As quoted in: Kim-Cohen, Seth. 2009. *In the Blink of an Ear: Toward a Non-Cochlear Sonic Art* New York: Continuum.

Might this be considered a kind of ‘sonic agency’?

Recent research into acoustic metamaterials (AMMs) has offered tangible possibilities for further pursuit of these questions. Through their geometry and structure, these engineered composites are able to manipulate sound waves at deep sub-wavelengths, decoupling the traditional relationship between sound absorption and mass. Other effects such as acoustic cloaking and negative refraction suggest powerful new ways to shape the sonic field in which architecture participates. Even more pertinent to the work outlined in this research folio are experiments with tunable AMMs which use electromagnets to dynamically adjust the absorption frequency of the material, allowing it to respond to specific sonic stimuli in the environment.<sup>7</sup>

7 Kumar, Sanjay, and Heow Lee. 2019. *The Present and Future Role of Acoustic Metamaterials for Architectural and Urban Noise Mitigations*. Acoustics (Basel, Switzerland) 1 (3): 590–607.

The Sounding Bodies installation offers a speculative reflection on the above questions. The elements of the installation bear some resemblance to Vitruvius’ sounding vessels, formally and materially, and in their responsiveness to sympathetic frequencies from occupants and adjacent ‘bodies’. They also invert this notion, becoming active generators and participants in the local soundscape to which they are simultaneously responding. While the installation makes use of traditional natural materials (sheet steel), more complexity could be achieved through the incorporation of AMMs.

This folio, and the speculative questions asked therein, point toward living qualities in next-generation architecture that might be achieved through sound. It considers listening and sounding as reciprocal operations that could be integrated into architectural environments, allowing much greater agency for architecture in shaping the expanded sonic field in which it participates.

APPENDIX A: GLOBAL SYSTEMS DIAGRAM

**UB:** Unactuated Body

**STB:** Strung Body

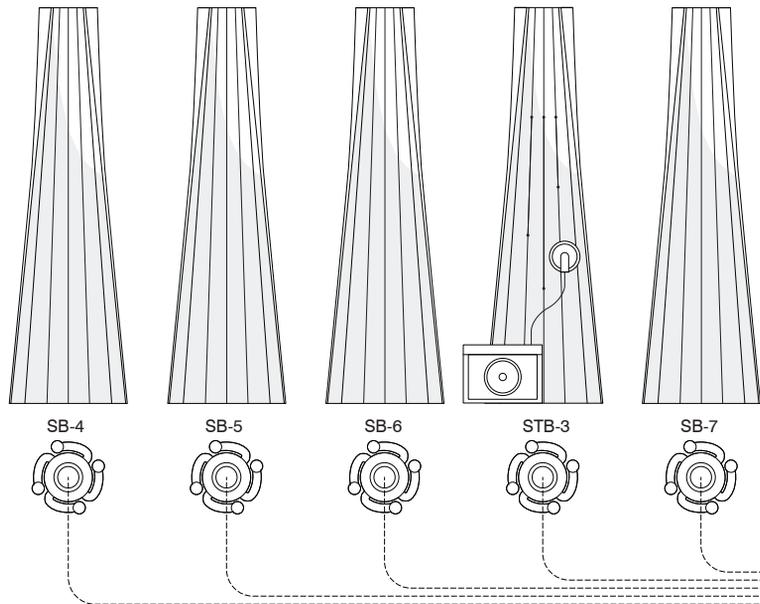
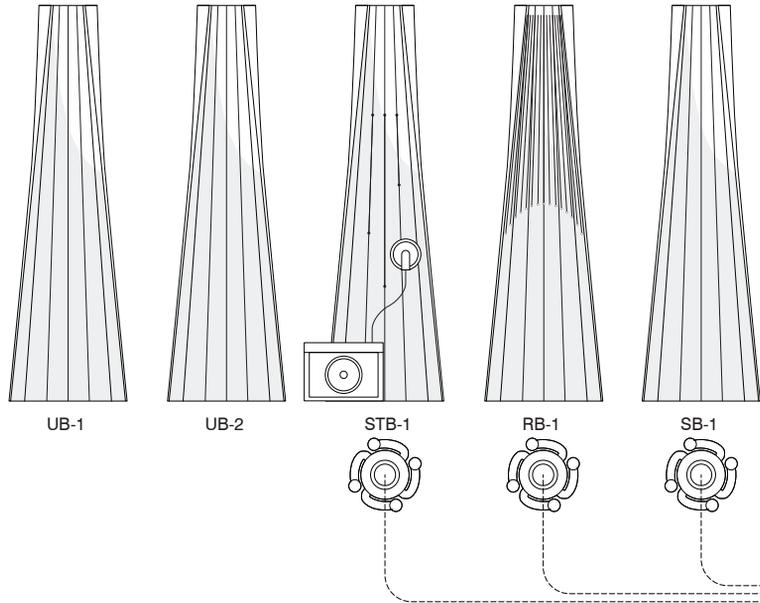
10W 4-feet 25mm Exciter  
 1-3 Steel Wound Instrument Strings  
 Piezoelectric Contact Microphone  
 Local Amplification

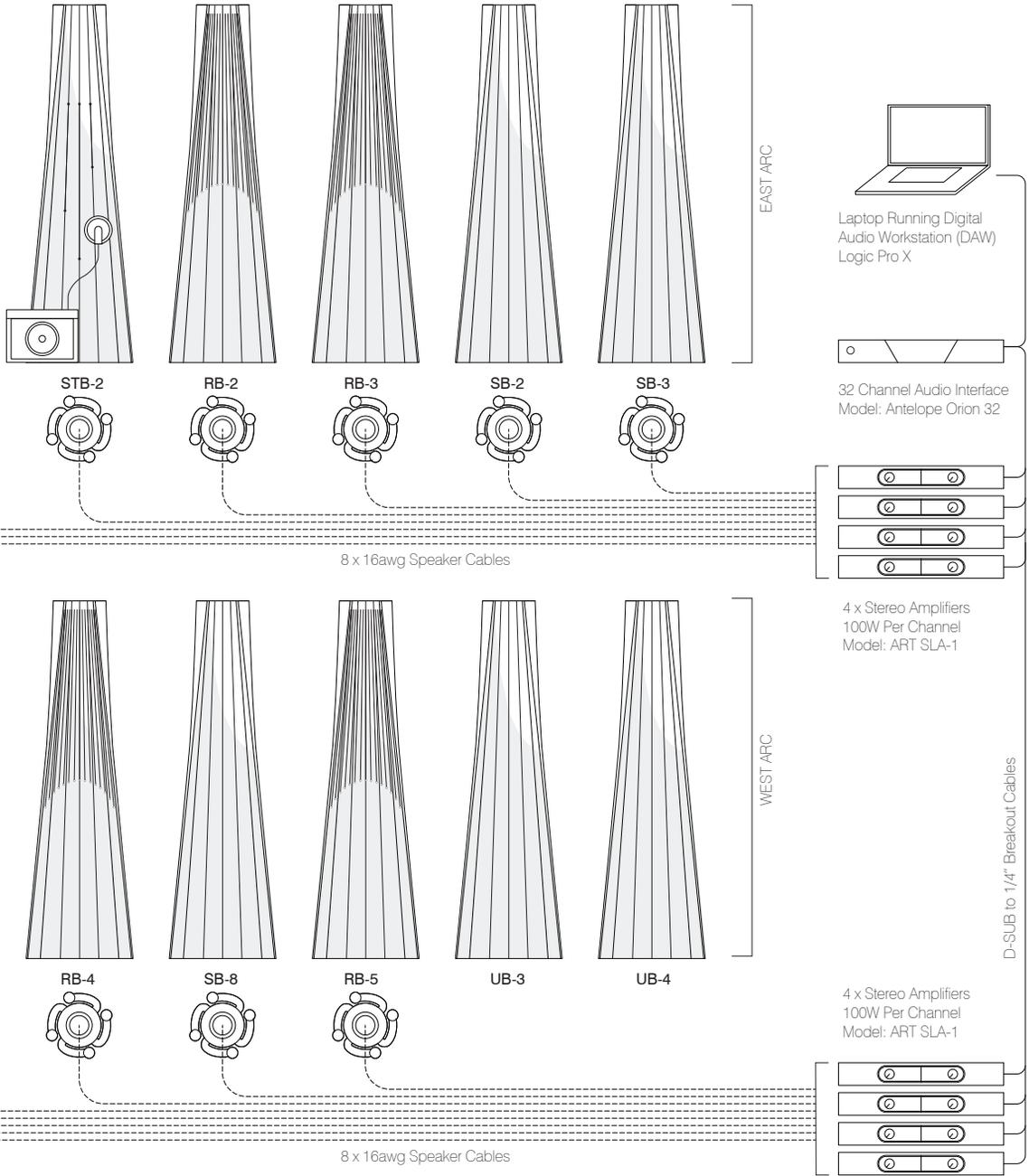
**RB:** Resonating Body

10W 4-feet 25mm Exciter  
 19mm Saddle Washers  
 Mounted on 10ga Steel Wire

**SB:** Sounding Body

10W 4-feet 25mm Exciter





APPENDIX B: BILL OF MATERIALS

| Description                                                       | /sheet | Qty. | Cost ea. | Extended | Source                  |               |
|-------------------------------------------------------------------|--------|------|----------|----------|-------------------------|---------------|
| <b>1.0 Speakers and Transducers</b>                               |        |      |          |          |                         |               |
| 1.1 DAEX25 Sound Exciter Pair                                     |        | 6    | \$24.75  | \$148.50 | Solen.ca                |               |
| 1.2 DAEX32QMB-4 Quad Feet Mega Bass 32mm Exciter 40W 4 Ohm        |        | 12   | \$23.89  | \$286.68 | Solen.ca                |               |
| 1.3 Piezo Contact Microphone                                      |        | 3    | \$14.99  | \$44.97  | Amazon.ca               |               |
| <b>2.0 Audio Playback and Amplification</b>                       |        |      |          |          |                         |               |
| 2.1 Macbook Pro (Late 2015, 2.5 GHz Core i7, 16 GB RAM)           |        | 1    | -        | -        |                         |               |
| 2.2 Antelope Orion 32 Channel Audio Interface                     |        | 1    | \$183.00 | \$183.00 | Long & McQuade (rental) |               |
| 2.3 D-Sub to 8 x 1/4" Mono Breakout Cable                         |        | 2    | \$11.00  | \$22.00  | Long & McQuade (rental) |               |
| 2.4 ART SLA1 100W 2-Channel Amplifiers                            |        | 8    | \$13.00  | \$104.00 | Long & McQuade (rental) |               |
| 2.5 Yorkville Parasource 1800 Watt Peak 1x12 Active Subwoofer     |        | 1    | \$23.00  | \$23.00  | Long & McQuade (rental) |               |
| 2.6 Vox AC15C1 Guitar Amplifier                                   |        | 3    | \$26.00  | \$78.00  | Long & McQuade (rental) |               |
| <b>3.0 Video Projection</b>                                       |        |      |          |          |                         |               |
| 3.1 Optoma Technology EH412 4500-Lumen Full HD DLP Projector      |        | 2    | \$120.00 | \$240.00 | Vistek (rental)         |               |
| 3.2 Manfrotto 087NW Double Wind with T Bar                        |        | 2    | \$37.50  | \$75.00  | Westbury (rental)       |               |
| 3.3 Projector Spider Mount                                        |        | 2    | -        | -        | Westbury (rental)       |               |
| 3.4 16" x 24" 1/2" Plywood                                        |        | 2    | \$20.00  | \$40.00  | Home Depot              |               |
| 3.5 U bolts for mounting to T Bar                                 |        | 4    | \$16.00  | \$64.00  | Home Depot              |               |
| <b>4.0 Cabling</b>                                                |        |      |          |          |                         |               |
| 4.1 16-Gauge Speaker Wire (100' roll)                             |        | 5    | \$16.99  | \$84.95  | Amazon.ca               |               |
| 4.2 XLR Cable (100')                                              |        | 3    | \$3.00   | \$9.00   | Long & McQuade (rental) |               |
| 4.3 Power Extension Cables (50')                                  |        | 2    | \$45.00  | \$90.00  | Home Depot              |               |
| 4.4 IEC C13 to NEMA 5-15P Power Cables                            |        | 6    | \$6.99   | \$41.94  | canadacomputers.com     |               |
| 4.5 50' HDMI Cable                                                |        | 2    | \$54.99  | \$109.98 | canadacomputers.com     |               |
| 4.6 HDMI Coupler                                                  |        | 1    | \$5.99   | \$5.99   | canadacomputers.com     |               |
| 4.7 1/4" Mono Patch Cord                                          |        | 3    | \$1.00   | \$3.00   | Long & McQuade (rental) |               |
| <b>5.0 Physical Materials</b>                                     |        |      |          |          |                         |               |
| 5.1 Vicwest UltraVic Metal Roofing - AZ 150 Galvalume Plus Finish | 1      | 20   | \$39.99  | \$542    | Rona                    |               |
| 5.2 Yorkville Heavy Steel Speaker Stand                           | 1      | 20   | \$3.00   | \$60.00  | Long & McQuade (rental) |               |
| 5.3 Mounting Hardware:                                            |        |      |          |          |                         |               |
| a. Steel Hex Head Screw, 5/16"-18 Thread Size, 4"                 |        | 2    | 40       | \$2.50   | \$100.00                | McMaster-Carr |
| b. 5/16" Acorn Nut                                                |        | 2    | 40       | \$0.75   | \$30.00                 | Lowe's        |
| c. Steel Hex Nut, Grade 2, Zinc-Plated, 5/16"-18 Thread Size      |        | 3    | 60       | \$0.75   | \$45.00                 | McMaster-Carr |

| Description                                           | /sheet | Qty. | Cost ea. | Extended | Source                 |
|-------------------------------------------------------|--------|------|----------|----------|------------------------|
| d. Rubber Washer                                      | 2      | 40   | \$0.05   | \$2.00   | Lowe's                 |
| e. Steel Washer                                       | 4      | 80   | \$0.40   | \$32.00  | McMaster-Carr          |
| 5.4 Acoustic Enhancements                             |        |      |          |          |                        |
| a. Eye Nut-Style Hangers, 1/4"-20 Thread, 1-1/2" Long | 12     | 192  | \$0.52   | \$99.84  | McMaster-Carr          |
| b. Steel Triple-Wave Washer for 5/8" Screw Size       | 12     | 192  | \$0.12   | \$23.04  | McMaster-Carr          |
| c. 18-8 Stainless Steel Washer for 5/16" Screw Size   | 12     | 192  | \$0.05   | \$9.60   | McMaster-Carr          |
| d. 20-Ga. 30-Lb Max Stainless Steel Wire (25ft)       | 1      | 12   | \$4.64   | \$55.68  | Home Depot             |
| 5.5 Tuned Instrument Strings                          |        |      |          |          |                        |
| a. Steel Piano Strings                                |        | 3    | \$23.00  | \$67.00  | JD Grandt Piano Supply |
| b. Piano Tuning Pins                                  |        | 3    | \$3.00   | \$67.00  | JD Grandt Piano Supply |
| c. Guitar Machine Head (pk of 6)                      |        | 4    | \$40.00  | \$160.00 | Long and McQuade       |
| d. Acoustic Guitar Strings                            |        | 6    | \$6.50   | \$39.00  | Long and McQuade       |
| e. SBR Rubber Grommet for 3/16" Hole Diameter         |        | 27   | \$0.05   | \$1.35   | McMaster-Carr          |
| f. Hardwood Mounting Block for Tuning Pin             |        | 3    | -        | -        |                        |
| <b>6.0 Additional Rigging and Staging</b>             |        |      |          |          |                        |
| 6.1 2" aluminum pipe (6 ft lengths)                   |        | 20   | \$2.50   | \$50.00  | Westbury (rental)      |
| 6.2 Swivel Cheesborough Clamps                        |        | 40   | \$2.00   | \$80.00  | Westbury (rental)      |
| 6.3 Sandbags                                          |        | 40   | \$3.50   | \$140.00 | Westbury (rental)      |

**Total Materials and Equipment Cost (Rental + Purchase):**

**\$3,257.52**

## APPENDIX C: ILLUSTRATED BILL OF MATERIALS (SELECTION)



### 5.3 Mounting Hardware

Fender Washers (4), Rubber Washers (2), 3/8" Hex Nut (3), 3/8" Acorn Nut (1), 3" x 3/8" Bolt (1), Plastic Tubing

The bolt is slotted through the holes in the speaker stand and secured with a nut and washer on either side. The metal panel is then sandwiched between steel washers and rubber washers to dampen vibration. A short piece of plastic tubing slides over the bolt to further reduce vibrations through contact with the metal panel. An acorn nut is used to finish the end of the bolt on the visible side

SOURCE: Most hardware stores



### 1.3 Piezo Contact Microphone

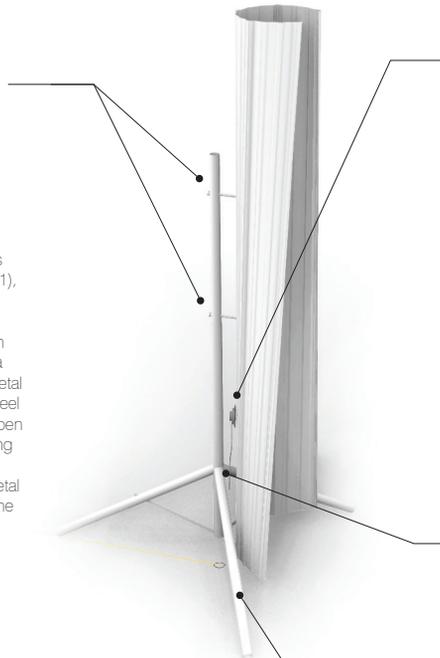
This is an affordable and widely available type of contact microphone. Its low-frequency response is not very strong however. An option would be to use a rubber adapter with a hydrophone (underwater microphone). See [www.aquarianaudio.com](http://www.aquarianaudio.com) for more information.



### 5.5(d) Acoustic Guitar Strings

Various gauges of acoustic guitar strings were tried. Brass-wound strings provided the best results in our experiments.

SOURCE: Long & McQuade



### 1.2 Dayton Audio DAEX32QMB-4 Quad Feet Mega Bass 32mm Exciter 40W 4 Ohm, front and back.

These were preferred over the DAEX-25 for their higher power output and better low-frequency response. They can be mounted using the 3M VHB tape pads provided, but we found it more useful to adhere them with hot glue. This bonds well to the metal for short term applications and can easily be removed with no residue.

SOURCE: [www.solen.ca](http://www.solen.ca)

This is a far cheaper source than Amazon and they have numerous other speciality components for building speakers.



### 4.1 Speaker Wire - 16 Gauge.

Smaller gauges can be used for shorter cable runs but 16 gauge is a good overall size. It's flexible and easy to work with. Any stranded wire will do however and searching for 'lamp wire' offers some interesting options with different visual qualities. The wire can be looped through the terminals on the Exciters for prototyping but for the installations it's better to use crimp-on spade connectors for a more secure connection.

SOURCE: Speaker wire is available at most hardware stores but the best prices are on Amazon.



### 5.5 (b) Piano Tuning Pin

We tried using custom made steel piano strings to achieve very low notes (G1 - 49Hz) in some of the Bodies. Tuning pins were mounted through the metal sheet into a hardwood block affixed to the back. The tension required was too great for this setup however. In future iterations we plan to install a metal angle as a structural spine on the back of the sheet.

SOURCE: J.D. Grandt Piano Supply

### 5.5 (c) Guitar Machine Head

An easier approach was to use guitar machine heads. A 1/2" wood block was needed on the back of the sheet to achieve the necessary depth for the ferrule.

SOURCE: Long & McQuade



### 5.2 Yorkville Heavy Steel Speaker Stands

The advantage of these stands is that they have pre-drilled holes which can be used for the mounting bolt. They also allow fine height adjustment to account for uneven ground.

SOURCE: Long & McQuade



### 2.1 Macbook Pro Running Logic Pro X

We used Logic Pro X to run the installation, mostly because of existing familiarity with the program. While Logic is a fairly affordable DAW (Digital Audio Workstation), it is only available for Apple computers and may be out of price range for some. An excellent alternative would be Reaper by Cockos (\$60 USD). The company has a mission statement of providing high-quality software at very affordable prices to create the widest benefit. Reaper is fully functioning at that price and includes many more features than light versions of more popular DAWs like Cubase or ProTools. It also runs very well on Windows-based computers offering much more affordable laptop options.



### 2.2 Antelope Orion 32 Audio Interface

Not many audio interfaces have more than 8 output channels. It is possible to chain together two interfaces to get 16 but some stability issues might arise. This was the main reason for renting the Orion 32 even though we only needed half the channels. Additional benefits include the D-Sub outputs which, although requiring specialty cabling, offer a much neater cable setup than using typical 1/4" patch cables.

SOURCE: Long & McQuade (rental)



### 2.3 D-Sub to 1/4" Breakout Cable

This cable is much cleaner than using 16 individual patch cables, or even a 8 x 1/4" snake. That said their drawback is that it isn't easy to swap out a simple cable for debugging purposes. During the setup we found that one of the channels was not working properly which turned out to be an issue with the cable.

SOURCE: Long & McQuade (rental)



### 2.4 ART SLA1 100W 2-Channel Amplifier

These amplifiers provided much more power than necessary to drive the Exciters but they offered several advantages. They have a screw terminal outputs on the back which allowed us to use speaker wire, which is cheap and can be cut exactly to length. The amplifiers are also a 'half-rack' form factor which meant they are stackable and have the same basic dimensions as the Antelope 32.



### 6.0 Additional Rigging Elements

The galvanized steel sheets ('bodies') put an eccentric load on the Yorkville speaker stands. To address this we added lateral bracing between the stands using swivel pipe clamps and lengths of aluminum pipe. Additional counterweighting was achieved by adding 2x 25lb saddle-style sandbags on the rear foot of each stand.

SOURCE: Westbury National (rental)



### 3.3 Projector Spider Mount

This is a useful tool for working with projectors on stands. For Sounding Bodies we fastened it to a small plywood plate which was attached with U-bolts to a standard T-Bar projector mount. This allowed for quick adjustment of rotation and tilt.

SOURCE: Westbury National (rental)



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# Sounding Bodies: *Experiments in Sonically Active Surfaces*

This research folio documents the technical and poetic development of an experimental architectural installation that points toward a new model of sonic materialism. 'Sounding Bodies', originally installed at Nuit Blanche Toronto 2019, used audio transducers to transform galvanized steel roofing material into inhabitable loudspeakers. Rather than considering sonic emitters as point sources whose physical nature is often conceptually absent from their environments, this work embraces the material and spatial possibilities latent in active sound generation.

The publication begins with a discussion of ancient Roman architect Vitruvius' use of bronze sounding vessels in theatre design. It then presents a technical explanation of the transducers used in the Sounding Bodies installation, followed by an account of experiments undertaken in its development and documentation of the built project. A concluding section discusses how the poetic content of the project, which builds on pioneering work by Glenn Gould and The World Soundscape Project, connects back to the cultural origins of sound reproduction and offers a reflection on how sonically active surfaces might contribute to next-generation living architecture.

Jonathan Tyrrell studied architecture at the University of Waterloo where he also teaches as an adjunct professor. He will be pursuing a PhD at The Bartlett School of Architecture in fall 2021 where his research will focus on the relationship between sound, matter, and space. He has worked as an associate at Dereck Revington Studio in Toronto, leading the design and implementation of award-winning public art projects and memorials. Prior to this he worked extensively with Philip Beesley on the Hylozoic Series, developing specialized experience in interactive system design, digital fabrication, and component design.

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