SONIC FACADE, CREATING A SOUNDING ARCHITECTURE

by

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ABSTRACT

While architecture inherently makes sound when people and the environment interact with it, architects seldom orchestrate a building to produce sound. This thesis proposes a sonic facade that turns an existing building into a sound producing instrument. Sonic facade is a wind powered sound producing device that can be integrated into a wall structure. The facade is produced out of a series tubes, or more technically, a series of air column vibrators. While all the tubes may be the same length, the combination of three different types of tubes produces different sounds. This thesis proposes a seven rule shape grammar for users to determine the placement and implementation of the sonic facade on an existing building and site. The shape grammar allows for a range of simple to complex possibilities that could be applied to a variety of buildings. The sonic facade not only has an aural quality, but it is also an indicator and transmitter of the outside world. When the tubes pass from the outside to the inside of a building, the wind, the rain, and passersby bring sound inside the building.
ACKNOWLEDGEMENTS

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TERRY KNIGHT & RIZAL MUSLIMIN

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AND MY ARCHITECTURE FAMILY
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1. INTRODUCTION

MOTIVATION
OBJECTIVES AND SCOPE
MOTIVATION

Architects primarily deal with sight and the visual quality of our work, while the other senses seem to fall to the wayside. One of those senses, hearing, is often overlooked in architecture. While architects may design auditoriums, concert halls, and anechoic sound chambers, architects seldom think about architecture producing sound.

Sound is all around us and should be taken into consideration when designing any project. Floors make sound as you walk across them. The wind makes sounds as it blows across the frame of the window. Every material has some effect on sound, where sound can be either amplified and reflected or dampened and absorbed. The form of a building can carry sound from one part of a building to another, creating an auditory experience.

As a woodwind player I am interested in sound production, which inspired me to analyze the way in which wind creates sound in a pipe. Wind has been used by sound art artists to capture the intangible, ephemeral, and temporal nature of the environment. By using wind, sound artists are able to scale traditional instruments into instruments playable by nature. Instead of using a blown stream of air, they use the wind. Instead of a bellows, they can use water to change the air pressure in a space. Drums don’t need to be played by sticks and mallets, but can be played by rain and other falling debris. The sound produced is an active response to the environment. For example certain sounds could be made if it is raining, if there is a tornado, or if it is hot or cold.

Originally the concert hall and auditorium were developed to separate the outside world from the sonic world according to Murray Schafer, a researcher into soundscapes. He has traced the evolution of the concert hall as “a substitute for outdoor life.” Composers would then use nature to shape their work, such as Vivaldi’s Four Seasons, Handel’s Water Music, or Olivier Messiaen’s transcriptions of bird calls. But I believe that there is no need for the separation of the sonic world from architecture, and want to question how architecture and a sonic experience can coexist.

This thesis deals with producing sound using wind, and I have been motivated by my own background and the need for investigation into a sound producing architecture. Sound artist interested in sound installations, Bernhard Leitner, criticizes modern architecture for having little to no relationship between “sound, space, and the body.” This thesis explores sound and architecture and how a new sonic space can be created through a sonic facade. The thesis finally asks readers to keep their ears open, as our ear is always open and always receiving information.

OBJECTIVES AND SCOPE

The overall goal of this thesis is to explore the interaction between architecture and sound by creating a sonic facade. One avenue to explore this was to create a grammar that could be applied to any number of buildings. A great deal of research was also conducted to understand how sound was produced with a tube, and how this sound could be controlled. Only a limited number of examples and uses of such a facade are offered at the end of this thesis, but the grammar can be implemented on any building. One example features the sonic facade placed on a real building, MIT’s Green Building. Another goal is to speculate and generate a hypothesis of what the installation would sound like.
2. PRECEDENTS
INSTRUMENTS

The Hornbostel-Sachs method divides instruments into membranophones (vibrating stretched membrane), idiophones (vibrating body of instrument), chodophones (vibrating string) aerophones (vibrating column of air), and electrophones (sound through electronics). While any of these methods are valid ways of producing sound, this thesis focuses aerophones.

Aerophones produce sound by causing the body of air inside the instrument to vibrate. While the air column inside the instrument is vibrating, the body of the instrument does not vibrate considerably, therefore the materiality and thickness of the walls have little impact on the sound.

The precedents shown are a pan flute, xylophone, clarinet, and a trombone. The pan flute is the most simple, an air column vibrator with both ends open. The xylophone’s air column is activated through the hitting of a mallet on a wooden bar above the tube. The clarinet features an air column with a tapered bore with one open end and one closed end. The trombone features bends in the section of the instrument.
SINGING, RINGING, TREE : TONKIN LIU

Singing, Ringing, Tree is a sculpture composed of galvanized steel in Lancashire, England. It is produced with tubes that feature two open ends and tubes that have one open end, one closed end, and one long transverse slot.

LISTEN TO SINGING, RINGING, TREE : TRACK 1
AEOLUS : LUKE JERRAM

Aeolus is a project that uses the concept of an Aeolian harp to produce sound. As wind blows over the strings, they vibrate, creating sound in the same way as a harp string is plucked. Many of these strings are attached to the end of tubes which form a circular structure. The tubes themselves resonate as well as sound and wind travels through them.

LISTEN TO AEOLUS : TRACK 2
SONG_LINES : JOE SNELL

Songlines is a 10 meter high cylinder outside the Sydney Conservatorium of Music. It contains three aeolian harps so that as the wind blows, the harps produce sound. An aeolian harp produces sound from wind blowing across a string that causes it to vibrate, and the sound is amplified from the use of a sounding board and resonating chamber behind the strings. Low-energy LEDs glow and change color as the harps play.

LISTEN TO AN AEOLIAN HARP : TRACK 3
CHIMECCO : MARK NIKKON

Chimecco is an installation beneath a bridge in a forest in Denmark. Metal pipes were hung from the bottom of the bridge so that they make noise as they collide. This happens not only when people walk a cross, but it also works like a wind chime.

LISTEN TO CHIMECCO : TRACK 4
SONAMBIENT : HARRY BERTORIA

Sonambient is a series of sound sculptures that creates a spatial and tonal environment. The structures have individual stalks that wave and knock into each other as they are touched or as the environment interacts with the sculpture, creating mysterious, organic sounds.

LISTEN TO SONAMBIENT : TRACK 5
ORGAN OF CORTI : LIMINAL

The Organ of Corti by Liminal is an arrangement of tubes based on a sonic crystal that modulates sound as it passes through. The cylinders cancel out all other noises except those that enter the array of tubes in the installation, which it amplifies. As a result, each section of the crystal array tunes sounds from the environment differently, giving the listener a unique auditory experience.

LISTEN TO ORGAN OF CORTI : TRACK 6
3. WIND STUDIES

WIND RELATIONSHIP TO STRUCTURE
POSSIBLE PLACEMENTS OF TUBE
WIND RELATIONSHIP TO TUBE
WIND RELATIONSHIP TO STRUCTURE

Wind tries to find the shortest path around an object in its way. When wind runs into an object such as a building, it speeds up it goes around. This causes concentrations of wind flowing in a narrow region around the contour of the building as air accelerates over edges. This makes the area around openings in a building an ideal place for placing a facade.

To study the wind relationship to the structure I not only researched discourse, but also used an IPad application called Wind Tunnel Pro HD. With the application it is possible to see fluid flow around any objects you draw on the screen. It also provides other types of visualizations such as pressure, speed, and vector fields.
SONIC FACADE, CREATING A SOUNDING ARCHITECTURE
ALINA GRANVILLE
UNDERGRADUATE THESIS: ADVISOR JOHN FERNANDEZ

ABSTRACT
SONIC FACADE is a wind powered sound producing device that can be integrated into a wall structure. While architecture seldom intentionally produces sound, SONIC FACADE turns a building into a sound producing instrument. The facade is produced out of tubes, more technically a series of air column vibrators. While all the tubes may be the same length, the combination of different types of tubes produces different sounds. The facade's design is determined through a seven rule shape grammar. The instrument not only has an aural quality, but it is also an indicator and transmitter of the outside world. When the tubes pass from the outside to the inside of a building, the wind, the rain, and passersby bring sound inside the building.

INSTRUMENTS

LARGE WIND POWERED INSTRUMENTS
LARGE SCALE INSTRUMENTS
SINGING, RINGING, TREE: TONKIN LIU
SONGLINES: JOE SNELL
AEOLUS: LUKE JERRAM

CHIMECCO: MARK NIKKON
SONAMBIENT: HARRY BERTORIA
ORGAN OF CORTI: LIMINAL

PRECEDENTS
WALL AND TUBE RELATIONSHIP STUDIES
WIND STUDIES
SECTIONAL WIND AND TUBE STUDIES

PLAN: AIRFLOW AROUND A SQUARE BUILDING
PLAN: AIRFLOW OVER A TALL BUILDING
POSSIBLE PLACEMENTS OF TUBE

The effect of wind primarily flowing around edges makes any openings in a building an ideal place for placing a facade. Tubes can be placed on the outside of the wall to pick up on the air that travels around the building. Tubes could also be placed such that they intersect the building. This would create a connection between the inside and the outside of the building, and could isolate different sounds based on the pipes used. The relationship provides a sensory experience to the outside world that can alter people on the inside of the building to the weather or other events occurring outside.
SONIC FACADE, CREATING A SOUNDING ARCHITECTURE

ALINA GRANVILLE

UNDERGRADUATE THESIS: ADVISOR JOHN FERNANDEZ

ABSTRACT


INSTRUMENTS

LARGE WIND POWERED INSTRUMENTS

LARGE SCALE INSTRUMENTS

SINGING, RINGING, TREE: TONKIN LIU

SONGLINES: JOE SNELL

AEOLUS: LUKE JERRAM

CHIMECCO: MARK NIKKON

SONAMBIENT: HARRY BERTORIA

ORGAN OF CORTI: LIMINAL

PRECEDENTS

WALL AND TUBE RELATIONSHIP STUDIES

WIND STUDIES

SECTIONAL WIND AND TUBE STUDIES

SECTION PLAN

PARALLEL TO WALL

PARALLEL TO WALL TOUCHING GROUND

SLANTED

SLANTED TOUCHING GROUND

SLANTED INTERSECTING WALL

SLANTED TOUCHING GROUND INTERSECTING WALL

REVERSE SLANTED

REVERSE SLANTED TOUCHING GROUND

REVERSE SLANTED INTERSECTING WALL

REVERSE SLANTED TOUCHING GROUND INTERSECTING WALL

PERPENDICULAR

PERPENDICULAR INTERSECTING WALL

WIND STUDIES | 25
WIND RELATIONSHIP TO TUBE

Only certain placements of tubes can be applicable for making sound. Not all possibilities are applicable. For example, the pipe shouldn’t be supported by or placed in the ground because air will not be able to enter the pipe, resulting in no sound being made.

To complete these studies, I also explored them in iPad application Wind Tunnel Pro HD to study the relationship between the wind and the tube.
SONIC FACADE, CREATING A SOUNDING ARCHITECTURE

ALINA GRANVILLE

UNDERGRADUATE THESIS : ADVISOR JOHN FERNANDEZ

ABSTRACT


INSTRUMENTS

LARGE WIND POWERED INSTRUMENTS

LARGE SCALE INSTRUMENTS

SINGING, RINGING, TREE : TONKIN LIU
SONGLINES : JOE SNELL
AEOLUS : LUKE JERRAM

CHIMECCO : MARK NIKKON
SONAMBIENT : HARRY BERTORIA
ORGAN OF CORTI : LIMINAL

PRECEDENTS

WALL AND TUBE RELATIONSHIP STUDIES

WIND STUDIES

SECTION : TUBE INTERSECTS WALL

SECTION : TUBE PERPENDICULAR INTERSECTION
4. SOUND STUDIES

RESEARCH
TESTING
SELECTED TUBES
RESEARCH

Sound waves are longitudinal waves that can travel in solid, liquid, or gas. Sound waves are affected by many environmental factors like temperature, gas makeup, density, pressure, and altitude. The speed of sound \([c]\) is said to be 340 m/s in an ideal setting, and this value will be used during this thesis for all calculations. A simple equation to determine the speed of sound more accurately is \(c = 331.3 + 0.6t\).

I focused the bulk of my research on tubes producing sounds, because I predetermined I wanted to use these structures. Sound waves behave differently in two categories of tubes. The two types of tubes are tubes with two open ends and tubes with one open and one closed end. It isn’t possible to have a tube with two closed ends since in theory the sound would never be able to be released from the tube.

The two types of tubes produce different pitches. The pitch that is produced is identified by its frequency. The tubes produce different sounds due to the movement of a sound wave in the tube. In the case of the tube with two open ends, the sound wave is reflected once. On the other hand, in the case of the tube with one closed end, the sound wave is reflected three times. This causes the length of the wave in the tube with one open end to be twice the length of the tube with the two open ends. The longer the sound wave, the lower the frequency, and the lower the sound. Therefore, at their fundamental frequencies, the tube with one open end produces a lower sound than the tube with two open ends. This can be seen in the following graphs. If the wind speed is high enough, it is possible to excite the air column into having more nodes, and produce a higher pitch that is a harmonic of the fundamental frequency.

Humans have a huge range of hearing. We can hear sounds from 20 Hz to 20,000 Hz. To put this range into context, the notes on a piano range from 27.5 Hz to 4186.01 Hz. I feel studying frequencies over the range of the piano are appropriate, because a piano covers several octaves of frequencies, without the notes becoming too low or too high. I decided that I wanted to use tubes with a 6” diameter in my sonic facade, because if the tubes were too small or too large it was hard for the air column to begin to vibrate. For a tube with two open ends a 27.5 Hz frequency corresponds to a 19.8816’ tube and the highest frequency the tube will be possible to play is 1318.51 Hz with a tube length of .02301’. For a tube with one open end and one closed end a 27.5 Hz frequency corresponds to a 9.94078’ tube and the highest frequency the tube will be possible to play is 1318.51 Hz with a tube length of .0115. As it can be seen, high frequencies correspond to very short lengths of tube. It was later determined that the shorter the tube, the faster wind speed needed to force the air column to vibrate, therefore a minimum length of 2’ was placed on the lengths of tubes in the sonic facade.

SOUND STUDIES | 29
TUBE WITH TWO OPEN ENDS

- n = 1 (FUNDAMENTAL FREQUENCY)
- n = 2
- n = 3
- n = 4

LENGTH OF TUBE VS PITCH

- L [feet]
- f [Hz]

- "1"
- "3"
- "6"
- "9"
- "12"

WAVELENGTH [λ], SPEED OF SOUND [c] = 340 m/s, NODES [n], LENGTH [L], FREQUENCY [f]

- λ = 2*L [FOR FUNDAMENTAL FREQUENCY]
- f = c/λ
- L = (n*λ)/2 -.8d [WITH END CORRECTION]

- λ = 4*L [FOR FUNDAMENTAL FREQUENCY]
- f = c/λ
- L = (n*λ)/4 -.4d [WITH END CORRECTION]
TUBE WITH ONE OPEN END, ONE CLOSED END

LENGTH OF TUBE VS PITCH

WAVELENGTH \( \lambda \), SPEED OF SOUND \( c \) = 340 m/s, NODES \( n \), LENGTH \( L \), FREQUENCY \( f \)

\[
\lambda = 2L \quad \text{[FOR FUNDAMENTAL FREQUENCY]}
\]

\[
f = \frac{c}{\lambda}
\]

\[
L = \left( \frac{n\lambda}{2} \right) - 0.8d \quad \text{[WITH END CORRECTION]}
\]

\[
\lambda = 4L \quad \text{[FOR FUNDAMENTAL FREQUENCY]}
\]

\[
f = \frac{c}{\lambda}
\]

\[
L = \left( \frac{n\lambda}{4} \right) - 0.4d \quad \text{[WITH END CORRECTION]}
\]
TESTING

The tubes were tested by blowing air across the openings in a variety of ways. Devices used were a desk fan, an air conditioning unit, a blow dryer, and the wind outside. I also tried blowing across each tube with my mouth. The speed of the air produced by each method was recorded with a wind speed measurement instrument. The desk fan produced an airspeed of 9 mph, the air conditioner produced 7.5 mph, and the blow dryer could produce a speed of 5 mph on “low” and 12.5 mph on “high.” Human blowing, however, was found to produce a greatly different effect. It produced a much higher pressure concentration of airflow at high speed, which turned out to be an unrealistic representation of wind since it averaged 23 mph. The different fans could be used to represent different wind conditions, as constant wind speed generally ranges between 5 and 10 mphs.

When I began testing tubes, I thought a good starting point was tubes similar to that of a piccolo. I began testing tubes with a diameter of 1/4” to 1”, but I struggled to have these tubes produce a clear audible sound. I began to explore bottles, with the hope that the childhood instrument of blowing over a coke bottle could be implemented into the sonic facade. I found that bottles did not work well when implemented in the wind, as they were very hard to have enough air enter their mouth. At one point I was suggested to look into organ style pipes and pipes with a smaller opening. I found that the organ pipes and the tapered section tubes faced the same problems that the bottle did. The Helmholtz resonator shape did not allow for enough air to easily enter causing the air column to vibrate. Unlike an organ whose bellows supports and adds pressure to the air forcing it through the tube, the wind was not able to produce this same effect. I finally began experimenting with tubes again, but this time increasing in scale with 2” diameter tubes and found great success.
1 : CIRCULAR SECTION WITH TWO OPEN ENDS [BASIC HUMMING SOUND]

2 : CIRCULAR SECTION WITH ONE OPEN END AND ONE CLOSED END [LOWER THAN TUBE 1]

3 : CIRCULAR SECTION WITH BLOCK ABOVE OPENING [TUBE MUST BE PERPENDICULAR TO BLOCK, SAME PITCH AS TUBE 1 BUT LOUDER]
**SOUND TUBE RESEARCH AND TESTING**

- **Tube Sound Waves**

  - \( n = 1 \): Fundamental Frequency
  - \( n = 2 \), \( n = 3 \), \( n = 4 \), etc.

- **Tested Tubes**
  - Wavelength \( \lambda \), Speed of Sound \( c \) = 340 m/s, Nodes \( n \), Length \( L \), Frequency \( f \)
  - \( \lambda = 2L \) [FOR FUNDAMENTAL FREQUENCY]
  - \( f = \frac{c}{\lambda} \)
  - \( L = \frac{(n \lambda)}{2} - .8d \) [WITH END CORRECTION]

- **Length of Tube vs Pitch**

  - **Straight Tubes**
  - **Bent Tubes**
  - **Split Tube**
  - **Transverse Opening Tubes**
  - **Interior Partition Tubes**

  - **Selected Tubes**
    - **4:** Circular section with small bend
      - [Basic humming sound]
    - **5:** Circular section with 180° bend
      - [Basic humming sound]
    - **6:** Circular section with 180° bend and one closed end
      - [Basic humming sound]
    - **7:** Circular section with 180° bend with different lengths
      - [Basic humming sound]
TRANVERSE OPENING TUBES

8 : CIRCULAR SECTION WITH ONE OPEN END AND TRANSVERSE LONG SLOT [BASIC HUMMING SOUND, MAKES WHISTLING SOUND WHEN AIR ENTERS INTO THE TOP OF TUBE]

9 : CIRCULAR SECTION WITH ONE OPEN END AND MULTIPLE LONG TRANSVERSE SLOTS [NO SIGNIFICANT SOUND]

10 : CIRCULAR SECTION WITH ONE OPEN END AND TRANSVERSE WIDE SLOT [SLOT HAD NO EFFECT ON SOUND, SAME SOUND AS TUBE 2]

11 : CIRCULAR SECTION WITH ONE OPEN END AND MULTIPLE LONG LINEAR TRANSVERSE SLOTS [FREQUENCY OF SOUND CORRESPONDED TO LENGTH BETWEEN ENTRY POINT AND FIRST SLOT]
12: **BOTTLE** [WORKS WITH HUMAN BLOWING ACROSS OPENING, BUT ONLY WORKS WITH WIND WHEN AIR ENTERS DIRECTLY INTO OPENING]

13: CIRCULAR SECTION WITH TAPERED END [BASIC HUMMING SOUND, ONLY WORKS WHEN AIR DIRECTLY ENTERS TAPERED END]

14: CIRCULAR SECTION TAPERED [BASIC HUMMING SOUND, ONLY WORKS WHEN AIR DIRECTLY ENTERS TAPERED END]
15 : CIRCULAR SECTION SPLIT INTO TWO TUBES [BASIC HUMMING SOUND]

16 : CIRCULAR SECTION WITH INTERIOR CROSS WALL [SAME SOUND AS TUBE 1, PARTITION HAD NO EFFECT]

17 : CIRCULAR SECTION WITH INTERIOR WALL [SAME SOUND AS TUBE 1, PARTITION HAD NO EFFECT]
SOUND TUBE RESEARCH AND TESTING

**Tube Sound Waves**

- **Fundamental Frequency**
  - $n = 1$
  - $n = 2$
  - $n = 3$
  - $n = 4$

**Pressure and Air Motion**

- Two Open Ends
- One Open End, One Closed End

**Wavelength ($\lambda$)**

- $\lambda = 2L$ [For Fundamental Frequency]
- $\lambda = 4L$ [For Fundamental Frequency]

**Speed of Sound ($c$)**

- $c = \lambda/2f$

**Length ($L$), Frequency ($f$)**

- $L = (n*\lambda)/2 - .8d$ [With End Correction]
- $L = (n*\lambda)/4 - .4d$ [With End Correction]

**Tested Tubes**

- **Straight Tubes**
- **Bent Tubes**
- **Split Tube Transverse Opening Tubes**
- **Interior Partition Tubes**

**Length of Tube vs Pitch**

<table>
<thead>
<tr>
<th>Length of Tube (feet)</th>
<th>Frequency (Hz)</th>
</tr>
</thead>
<tbody>
<tr>
<td>18</td>
<td>19</td>
</tr>
</tbody>
</table>

**18: Square Section Aeolian Harp**

[Instrument proven to work when wind blows over strings but did not in experiment]

**19: Circular Section Aeolian Harp**

[Instrument proven to work when wind blows over strings but did not in experiment]

**20: Circular Section with One Closed End and Harp String Attached**

[Produced no sound with wind, but made sound when plucked, proven to work in Aeolus project]
ORGAN PIPE INSPIRED TUBES

21 : SQUARE SECTION [BASIC HUMMING SOUND]

22 : CIRCULAR SECTION WITH TRANSVERSE FLAP [SAME SOUND AS NO TRANSVERSE OPENING]

23 : CIRCULAR SECTION WITH TRANSVERSE FLAP [SAME SOUND AS NO TRANSVERSE OPENING]

24 : CIRCULAR SECTION WITH END FLAP [SAME SOUND AS NO TRANSVERSE OPENING]

25 : SQUARE SECTION WITH TRANSVERSE FLAP [SAME SOUND AS NO TRANSVERSE OPENING]

26 : SMALL CIRCULAR SECTION CONNECTED TO LARGE CIRCULAR SECTION [NO SOUND PRODUCED, OPENING TOO SMALL FOR AIR TO ENTER]
WAVELENGTH [λ], SPEED OF SOUND [c] = 340 m/s, NODES [n], LENGTH [L], FREQUENCY [f]

\[ \lambda = 2L \] [FOR FUNDAMENTAL FREQUENCY]
\[ f = \frac{c}{\lambda} \]
\[ L = \frac{n\lambda}{2} - 0.8d \] [WITH END CORRECTION]

\[ \lambda = 4L \] [FOR FUNDAMENTAL FREQUENCY]
\[ f = \frac{c}{\lambda} \]
\[ L = \frac{n\lambda}{4} - 0.4d \] [WITH END CORRECTION]

HARRY BERTORIA TUBES

27 : CIRCULAR SECTION WITH INTERIOR RODS
[PRODUCES SOUND AS RODS HIT EACH OTHER, DIFFICULT TO ACTIVATE]

28 : NO TUBE WITH ARRAY OF RODS
[PRODUCES METALLIC SOUND AS RODS HIT EACH OTHER]
EXAMPLE OF SOME TESTED TUBES
SELECTED TUBES

For the sonic facade I picked three tubes, all with circular sections. One had two open ends, one had both and open and closed end, and the other was with one open end and one closed end with a long transverse slot. I picked them because they are simple, but produce different tones even though they have the same external shape and length. The most basic tube with both open ends produces a traditional, medium pitch humming sound. The tube with one open and one closed end produces a lower pitched sounds. The tube with the transverse slot produces a higher pitched sound with a whistling noise.

The next step was to record the sounds produced by the different pipes. Audacity, a sound editing program, was used for this. First, a microphone was clipped on the sound producing opening of the pipe in a not obstructing way. Background noise was recorded first, including the crackle of air blowing over the microphone. Then, air was blown into the tubes so that the tubes produced their sound. The background noise was used for noise canceling in order to isolate the sound produced by the tube. The sound was finally then amplified so that it would be audible.
1: CIRCULAR SECTION WITH TWO OPEN ENDS

L = (n*λ)/2 -.8d [WITH END CORRECTION]
f = c/λ
λ = 2*L [FOR FUNDAMENTAL FREQUENCY]

WAVELENGTH [λ], SPEED OF SOUND [c] = 340 m/s, NODES [n], LENGTH [L], FREQUENCY [f]

LISTEN TO CIRCULAR SECTION WITH TWO OPEN ENDS: TRACK 8

2: CIRCULAR SECTION WITH ONE OPEN END AND ONE CLOSED END

L = (n*λ)/2 -.8d [WITH END CORRECTION]
f = c/λ
λ = 2*L [FOR FUNDAMENTAL FREQUENCY]

WAVELENGTH [λ], SPEED OF SOUND [c] = 340 m/s, NODES [n], LENGTH [L], FREQUENCY [f]

LISTEN TO CIRCULAR SECTION WITH ONE OPEN END AND ONE CLOSED END: TRACK 9

8: CIRCULAR SECTION WITH ONE OPEN END AND TRANSVERSE LONG SLOT

L = (n*λ)/2 -.8d [WITH END CORRECTION]
f = c/λ
λ = 2*L [FOR FUNDAMENTAL FREQUENCY]

WAVELENGTH [λ], SPEED OF SOUND [c] = 340 m/s, NODES [n], LENGTH [L], FREQUENCY [f]

LISTEN TO CIRCULAR SECTION WITH ONE OPEN END AND TRANSVERSE LONG SLOT: FUNDAMENTAL FREQUENCY: TRACK 10
LISTEN TO CIRCULAR SECTION WITH ONE OPEN END AND TRANSVERSE LONG SLOT: FIRST HARMONIC: TRACK 11
LISTEN TO CIRCULAR SECTION WITH TWO OPEN ENDS RAW : TRACK 7
LISTEN TO CIRCULAR SECTION WITH TWO OPEN ENDS : TRACK 8
5. SPATIAL RELATION

SPATIAL RELATION AND BASIC GRAMMARS
BASIC GRAMMARS [2 RULES]
BASIC GRAMMARS [3 RULES]
SPATIAL RELATION AND BASIC GRAMMARS

By using a simple spatial relation of two pillars placed next to each other rotated by 15°, it is possible to create a variety of different designs. The basic pillar has a symmetry of 16, meaning there are 16 possible transformations [reflection, rotation] that can be applied to the pillar to make itself. Because it has symmetry of 16, there are 16 possible labeling conditions, and the different labeling conditions produce 16 possible basic grammar designs.

The basic designs produced by the basic label rules have a variety of results. There are tight and loose spirals, linear designs, and designs that became an identity of the spatial relation. Overall the designs are very predictable and simple due to the same spatial rule being repeated.

The basic label grammars are said to produce 16 possible designs using one rule, 256 possible designs using a combination of two rules, and 4096 possible designs using a combination of three rules.
SPATIAL RELATION AND BASIC GRAMMARS

BASIC SHAPE

LABEL RULE 1

LABEL RULE 2

LABEL RULE 3

LABEL RULE 4

LABEL RULE 5

LABEL RULE 6

SPATIAL RELATION
50 | SONIC FACADE, CREATING A SOUNDING ARCHITECTURE
SPATIAL RELATION AND BASIC GRAMMARS

BASIC RULES [1]: 16
BASIC RULES [2]: 256
BASIC RULES [1]: 4096

LABEL RULE 1
LABEL RULE 2
LABEL RULE 3
LABEL RULE 4
LABEL RULE 5
LABEL RULE 6
LABEL RULE 7
LABEL RULE 8
LABEL RULE 9
LABEL RULE 10
LABEL RULE 11
LABEL RULE 12
LABEL RULE 13
LABEL RULE 14
LABEL RULE 15
LABEL RULE 16
**BASIC GRAMMARS [2 RULES]**

Based on basic grammars, this exploration only used basic label rules that did not induce a turn into the design [label rule 1, 2, 5, 6, 9, 10, 13, 14]. This series of explorations combined two of the basic rules together in a repeating pattern A – B – A – B. It was found that the designs that used the identity rules [label rule 2, 5, 10, 13] from the basic label rules did not aggregate in a linear pattern and would not be suitable for a facade. The designs produced from using two basic grammars are more interesting than the basic grammar designs, but were still very predictable.
54 | SONIC FACADE, CREATING A SOUNDING ARCHITECTURE
58 | SONIC FACADE, CREATING A SOUNDING ARCHITECTURE
LABEL RULE 14, LABEL RULE 6

LABEL RULE 14, LABEL RULE 9

LABEL RULE 14, LABEL RULE 10

LABEL RULE 14, LABEL RULE 13

INFINITE LINEAR

INFINITE LINEAR

FINITE

FINITE FLAT CIRCLE
BASIC GRAMMARS [3 RULES]

Based on the basic grammars and basic grammars with two rules study, this exploration only used basic label rules that did not turn or created an identity [label rules 1, 6, 9, 14]. This series of explorations combined three of the basic rules together in a repeating pattern A – B – C – A – B – C. All designs in this exploration are usable for a facade as they all continue to aggregate linearly. The designs produced using three basic grammars are complicated and do not appear to be very predictable due to the longer time before repetition in the pattern.
LABEL RULE 1, LABEL RULE 14, LABEL RULE 6

LABEL RULE 1, LABEL RULE 14, LABEL RULE 9

LABEL RULE 6, LABEL RULE 1, LABEL RULE 9

LABEL RULE 6, LABEL RULE 1, LABEL RULE 14

INFINITE LINEAR

INFINITE LINEAR

INFINITE LINEAR

INFINITE SPIRAL

SPATIAL RELATION
LABEL RULE 9, LABEL RULE 1, LABEL RULE 6

LABEL RULE 9, LABEL RULE 1, LABEL RULE 14

LABEL RULE 9, LABEL RULE 6, LABEL RULE 1

LABEL RULE 9, LABEL RULE 6, LABEL RULE 14

INFINITE LINEAR

INFINITE LINEAR

INFINITE SPIRAL

INFINITE SPIRAL
LABEL RULE 9, LABEL RULE 14, LABEL RULE 1

LABEL RULE 9, LABEL RULE 14, LABEL RULE 6

LABEL RULE 14, LABEL RULE 1, LABEL RULE 6

LABEL RULE 14, LABEL RULE 1, LABEL RULE 9
LABEL RULE 14, LABEL RULE 6, LABEL RULE 1

LABEL RULE 14, LABEL RULE 6, LABEL RULE 9

LABEL RULE 14, LABEL RULE 9, LABEL RULE 1

LABEL RULE 14, LABEL RULE 9, LABEL RULE 6
6. SONIC FACADE GRAMMAR
This grammar creates a sonic facade. It constructs the sonic facade through seven rules, but allows for user variations in the appearance. The grammar starts by determining the area to place the facade in plan, and then the user decides how long each sound tube will be. The tubes are represented as pillars throughout the grammar, but in the final step the pillars are later substituted with three different sound tubes.

I chose to work with a grammar, because it allowed for a set of parametric rules to be created. The grammar can be applied to different scenarios and applied in different ways to create different possibilities. The grammar allows for non-determinism and user choice. While many of the rules are mathematically described some of this rules are informal and mainly use verbose to convey their direction.

On the following pages I have chosen to contrast the rules of the sonic facade grammar on the left side of the page with an example on the right side of the page. This example later becomes example building 1 [complicated with awning].
RULE 1 [DECIDE LOCATION OF FACADE]

DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT. MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

START [X1,Y1]  END [X2,Y2]
RULE 1 [DETERMINE LOCATION OF FACADE]
DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT. MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

RULE 2 [DETERMINE HEIGHT OF TUBE]

RULE 3 [CALCULATE NUMBER OF TUBES]
DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE.
FOR FACADE SEGMENT \( F \) WITH A DISTANCE \( D \), \( D/6" = \) NUMBER OF TUBES \( N \).

RULE 4 [PLACE STARTING PILLAR]
PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. AND LABELINGS FOR TUBE NUMBER \( Z \) AND TUBE TYPE \( T \). NOTE THE TWO STARTING LABEL POSITIONS.

RULE 5 [AGGREGATE PILLARS]
ADD PILLARS WHILE \( Z \leq N \) USING STRAIGHT RULE. IF \( Z = N \) AND \( C > 0 \) USE TURN RULE ONCE.

RULE 6 [ADD COLORING]
ADD COLORING TO PILLAR. THE COLORING MARKS THE LOCATION FOR THE CONNECTION DETAIL BETWEEN THE TUBE AND THE WALL.

RULE 7 [SUBSTITUTE PILLAR WITH TUBE]
TWO OPEN ENDS ONE OPEN END AND SLOT ONE OPEN END

RULE 8 [LABEL RULE]
LABEL RULE 1 LABEL RULE 6 LABEL RULE 9 LABEL RULE 14 LABEL RULE 3 LABEL RULE 7 LABEL RULE 12 LABEL RULE 16
RULE 2 [DETERMINE HEIGHT OF TUBE]


GROUND TO TUBE [G] ≥ 3”
2’ ≤ LENGTH OF TUBE [L] ≤ 19.88’
SOUNDING FACADE GRAMMAR

RULE 1 [DETERMINE LOCATION OF FACADE]
Determine start and end points on building to place tubular facade attachment. Moving from start to end should progress in a counterclockwise manner.

RULE 2 [DETERMINE HEIGHT OF TUBE]
Determine the height of the tube. The tube should be placed at least 3 inches off of the ground, and can reach the same height of the building, higher than the building, or lower than the building.

\[ G = 3" \]
\[ 2' \leq L \leq 19.88' \]

RULE 2A

RULE 2B

RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]
Determine number of tubes to be located on each segment of the facade.
For facade segment [F] with a distance [D], \( \frac{D}{6"} = N \).

Determine number of corners [C].

RULE 4 [PLACE STARTING PILLAR]
Place first pillar at starting point at least 3 inches away from wall. Labelings for tube number [Z] and tube type [T]. Note the two starting label positions.

RULE 5 [AGGREGATE PILLARS]
Add pillars while \( Z \leq N \) using straight rule. If \( Z = N \) and \( C > 0 \) use turn rule once.

STATE LABELING PATTERN FOR TUBE TYPE [T]:
If \( L > 9.94' \): 1 - 2 - 1 - 2 - 1 - 2 - ...
If \( L \leq 9.94' \): 1 - 2 - 3 - 1 - 2 - 3 - ...

RULE 6 [ADD COLORING]
Add coloring to pillar. The coloring marks the location for the connection detail between the tube and the wall.

RULE 7 [SUBSTITUTE PILLAR WITH TUBE]
Substitute pillar for tube based on labeling.
Substitute connection detail based on parametric color grammar.

ELEVATION

H = 8'
L = 7.75'
G = 3"

SONIC FACADE GRAMMAR
RULE 3 [CALCULATE NUMBER OF TUBES]

DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE. FOR FACADE SEGMENT [F] WITH A DISTANCE [D], D/6" = NUMBER OF TUBES [N]. THEN DETERMINE NUMBER OF CORNERS [C].

\[
\begin{align*}
N_1 &= D_1/6" \\
N_2 &= D_2/6" \\
C &= 1
\end{align*}
\]
SOUNDING FACADE GRAMMAR

RULE 1 [DETERMINE LOCATION OF FACADE]
Determine start and end points on building to place tubular facade attachment. Moving from start to end should progress in a counterclockwise manner.

RULE 2 [DETERMINE HEIGHT OF TUBE]
Determine the height of the tube. The tube should be placed at least 3 inches off of the ground, and can reach the same height of the building, higher than the building, or lower than the building.

RULE 2A

RULE 2B

RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]
Determine number of tubes to be located on each segment of the facade. For facade segment \( F \) with a distance \( D \), \( D/6" = \text{number of tubes} \ [N] \).

RULE 4 [PLACE STARTING PILLAR]
Place first pillar at starting point at least 3 inches away from wall and labelings for tube number \( Z \) and tube type \( T \).

RULE 5 [AGGREGATE PILLARS]
Add pillars while \( Z \leq N \) using straight rule. If \( Z = N \) and \( C > 0 \) use turn rule once.

RULE 6 [ADD COLORING]
Add coloring to pillar. The coloring marks the location for the connection detail between the tube and the wall.

RULE 7 [SUBSTITUTE PILLAR WITH TUBE]
Substitute tube for pillar based on labeling. Substitute connection detail based on parametric color grammar.
RULE 4 [PLACE STARTING PILLAR]

PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. ADD LABELINGS FOR TUBE NUMBER [Z] AND TUBE TYPE [T]. NOTE THE TWO POSSIBLE STARTING LABEL POSITIONS.

WALL TO TUBE DISTANCE [W] ≥ 3"

STATE LABELS:
TUBE NUMBER [Z] = 1
TUBE TYPE [T] = 1
SOUNDING FACADE GRAMMAR

PLAN

RULE 1 [DECIDE LOCATION OF FACADE]
DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT.
MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

START
END

PLAN

WINDROSE N

\[ \begin{align*}
\text{[X1,Y1]} & \quad \text{[X2,Y2]} \\
\text{[0',9']} & \quad \text{[18',0']} \\
\end{align*} \]

THIS GRAMMAR PLACES CREATES A SOUND FACADE. IT CONSTRUCT THE SOUND FACADE, BUT ALLOWS FOR USER VARIATIONS IN THE APPEARANCE. THE GRAMMAR STARTS BY DETERMINING THE AREA TO PLACE THE FACADE IN PLAN, AND THEN THE USER DECIDES HOW LONG EACH SOUND TUBE WILL BE.

THE TUBES ARE REPRESENTED AS PILLARS AT FIRST BUT THESE ARE LATER SUBSTITUTED WITH THREE DIFFERENT SOUND TUBES.

RULE 2 [DETERMINE HEIGHT OF TUBE]

\[ \text{GROUND TO TUBE } [G] \geq 3'' \]
\[ 2' \leq \text{LENGTH OF TUBE } [L] \leq 19.88' \]

\[ H = 8' \]
\[ L = 7.75' \]
\[ G = 3'' \]

ELEVATION

RULE 2A
RULE 2B
RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]
DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE.

FOR FACADE SEGMENT \([F]\) WITH A DISTANCE \([D]\), \[D/6'' = \text{NUMBER OF TUBES } [N]\].

DETERMINE NUMBER OF CORNERS \([C]\).

\[ N_1 = 18 \]
\[ N_2 = 36 \]
\[ C = 1 \]

F1
F2

N1 = D1/6''
N2 = D2/6''
C = 1

RULE 4 [PLACE STARTING PILLAR]
PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. AND LABELINGS FOR TUBE NUMBER \([Z]\) AND TUBE TYPE \([T]\). NOTE THE TWO STARTING LABEL POSITIONS.

WALL TO TUBE DISTANCE \([W]\) \[\geq 3'' \]

STATE LABELS:
TUBE NUMBER \([Z] = 1\)
TUBE TYPE \([T] = 1\)

\[ Z = 1 \]
\[ T = 1 \]

\[ W = 3'' \]

RULE 5 [AGGREGATE PILLARS]
ADD PILLARS WHILE \([Z] \leq [N]\) USING STRAIGHT RULE. IF \([Z] = [N]\) AND \([C] > 0\) USE TURN RULE ONCE.

STATE LABELING PATTERN FOR TUBE TYPE \([T]\):
IF \([L] > 9.94'\) : \(1 - 2 - 1 - 2 - 1 - 2 - ...\)
IF \([L] \leq 9.94'\) : \(1 - 2 - 3 - 1 - 2 - 3 - ...\)

STRAIGHT RULES

Z Z + 1 Z Z + 1

WIDTH OF PILLAR \([W]\) IS DETERMAINED BY SIZE OF NECESSARY TUBE TO COMPLETE TURN AND MAINTAIN TUBES PLACED 3 INCHES FROM THE WALL.

\[ L \]
\[ W \]

Z = N
C
Z = 1
C - 1
L
W
Z = N
C
Z = 1
C - 1
L
W
Z = N
C
Z = 1
C - 1
L
W

TURN RULES

Z Z + 1 Z Z + 1

LABEL RULE 1 LABEL RULE 6 LABEL RULE 9 LABEL RULE 14 LABEL RULE 3 LABEL RULE 7 LABEL RULE 12 LABEL RULE 16

SOUNDING FACADE GRAMMAR
RULE 5 [AGGREGATE PILLARS]

ADD PILLARS WHILE $Z \leq N$ USING STRAIGHT RULE. IF $Z = N$ AND $C > 0$ USE TURN RULE ONCE. WIDTH OF PILLAR [W] IS DETERMINED BY SIZE OF NECESSARY TUBE TO COMPLETE TURN AND MAINTAIN 3 INCH DISTANCE FROM WALL.

STATE LABELING PATTERN FOR TUBE TYPE [T]:
- IF $L > 9.94'$: 1 - 2 - 1 - 2 - 1 - 2 - ...
- IF $L \leq 9.94'$: 1 - 2 - 3 - 1 - 2 - 3 - ...

STRAIGHT RULES

<table>
<thead>
<tr>
<th>RULE 1</th>
<th>RULE 6</th>
<th>RULE 9</th>
<th>RULE 14</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>$L$</td>
<td>$L$</td>
<td>$L$</td>
</tr>
<tr>
<td>$Z$</td>
<td>$Z$</td>
<td>$Z$</td>
<td>$Z$</td>
</tr>
<tr>
<td>$Z + 1$</td>
<td>$Z + 1$</td>
<td>$Z + 1$</td>
<td>$Z + 1$</td>
</tr>
</tbody>
</table>

TURN RULES

<table>
<thead>
<tr>
<th>RULE 3</th>
<th>RULE 7</th>
<th>RULE 12</th>
<th>RULE 16</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L$</td>
<td>$L$</td>
<td>$L$</td>
<td>$L$</td>
</tr>
<tr>
<td>$Z = N$</td>
<td>$Z = 1$</td>
<td>$Z = N$</td>
<td>$Z = 1$</td>
</tr>
<tr>
<td>$C$</td>
<td>$C - 1$</td>
<td>$C$</td>
<td>$C - 1$</td>
</tr>
</tbody>
</table>

76 | SONIC FACADE, CREATING A SOUNING ARCHITECTURE
RULE 1 [DETERMINE LOCATION OF FACADE]

DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT. MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

RULE 2 [DETERMINE HEIGHT OF TUBE]


\[ \text{GROUND TO TUBE (G) } \geq 3" \]
\[ 2' \leq \text{LENGTH OF TUBE (L)} \leq 19.88' \]

ELEVATION:

\[ H = 8' \]
\[ L = 7.75' \]
\[ G = 3" \]

RULE 2A

RULE 2B

RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]

DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE.

FOR FACADE SEGMENT \([F]\) WITH A DISTANCE \([D]\), \(D/6" = \text{NUMBER OF TUBES (N)}\).

DETERMINE NUMBER OF CORNERS \([C]\).

\[ N_1 = 18 \]
\[ N_2 = 36 \]
\[ C = 1 \]

RULE 4 [PLACE STARTING PILLAR]

PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. AND LABELINGS FOR TUBE NUMBER \([Z]\) AND TUBE TYPE \([T]\). NOTE THE TWO STARTING LABEL POSITIONS.

\[ \text{WALL TO TUBE DISTANCE (W) } \geq 3" \]

STATE LABELS:

\[ \text{TUBE NUMBER (Z)} = 1 \]
\[ \text{TUBE TYPE (T)} = 1 \]

\[ Z = 1 \]
\[ T = 1 \]
\[ W = 3" \]

RULE 5 [AGGREGATE PILLARS]

ADD PILLARS WHILE \(Z \leq N\) USING STRAIGHT RULE. IF \(Z = N\) AND \(C > 0\) USE TURN RULE ONCE.

STATE LABELING PATTERN FOR TUBE TYPE \([T]\):

IF \(L > 9.94'\) : 1 - 2 - 1 - 2 - 1 - 2 - ...

IF \(L \leq 9.94'\) : 1 - 2 - 3 - 1 - 2 - 3 - ...

RULE 6 [ADD COLORING]

ADD COLORING TO PILLAR. THE COLORING MARKS THE LOCATION FOR THE CONNECTION DETAIL BETWEEN THE TUBE AND THE WALL.

RULE 7 [SUBSTITUTE PILLAR WITH TUBE]

TWO OPEN ENDS ONE OPEN END AND SLOT ONE OPEN END

\[ T = 1 \]
\[ T = 1 \]

\[ Z = 1 \]
\[ Z = 36 \]
\[ T = 1 \]
\[ T = 1 \]
\[ C = 0 \]

SUBSTITUTE TUBE FOR PILLAR BASED ON LABELING.

SUBSTITUTE CONNECTION DETAIL BASED ON PARAMETRIC COLOR GRAMMAR.
RULE 6 [ADD COLORING]

ADD COLORING TO PILLAR. THE COLORING MARKS THE LOCATION FOR THE CONNECTION DETAIL BETWEEN THE TUBE AND THE WALL. THERE ARE FOUR POSSIBLE WAYS TO ORIENT THE COLORING ON THE PILLAR AS SHOWN BELOW.
RULE 1 [DECIDE LOCATION OF FACADE]
DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT. MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

RULE 2 [DETERMINE HEIGHT OF TUBE]

RULE 2A
RULE 2B
RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]
DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE. FOR FACADE SEGMENT [F] WITH A DISTANCE [D], D/6" = NUMBER OF TUBES [N].

RULE 4 [PLACE STARTING PILLAR]
PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. AND LABELINGS FOR TUBE NUMBER [Z] AND TUBE TYPE [T].

RULE 5 [AGGREGATE PILLARS]
ADD PILLARS WHILE Z ≤ N USING STRAIGHT RULE. IF Z = N AND C > 0 USE TURN RULE ONCE.

RULE 6 [ADD COLORING]
ADD COLORING TO PILLAR. THE COLORING MARKS THE LOCATION FOR THE CONNECTION DETAIL BETWEEN THE TUBE AND THE WALL.

RULE 7 [SUBSTITUTE PILLAR WITH TUBE]
TWO OPEN ENDS
ONE OPEN END
AND SLOT
ONE OPEN END

T = 1
T = 2
T = 3

SOUNDING FACADE GRAMMAR
PLAN
WINDROSE N
[X1,Y1]
[X2,Y2]
[0',9']
[18',0']

THIS GRAMMAR PLACES CREATES A SOUND FACADE. IT CONSTRUCT THE SOUND FACADE, BUT ALLOWS FOR USER VARIATIONS IN THE APPEARANCE. THE GRAMMAR STARTS BY DETERMINING THE AREA TO PLACE THE FACADE IN PLAN, AND THEN THE USER DECIDES HOW LONG EACH SOUND TUBE WILL BE. THE TUBES ARE REPRESENTED AS PILLARS AT FIRST BUT THESE ARE LATER SUBSTITUTED WITH THREE DIFFERENT SOUND TUBES.
RULE 1 [DECIDE LOCATION OF FACADE]

DETERMINE START AND END POINTS ON BUILDING TO PLACE TUBULAR FACADE ATTACHMENT. MOVING FROM START TO END SHOULD PROGRESS IN A COUNTER CLOCKWISE MANNER.

RULE 2 [DETERMINE HEIGHT OF TUBE]


RULE 2A

RULE 2B

RULE 2C

RULE 3 [CALCULATE NUMBER OF TUBES]

DETERMINE NUMBER OF TUBES TO BE LOCATED ON EACH SEGMENT OF THE FACADE. FOR FACADE SEGMENT [F] WITH A DISTANCE [D], D/6" = NUMBER OF TUBES [N].

RULE 4 [PLACE STARTING PILLAR]

PLACE FIRST PILLAR AT STARTING POINT AT LEAST 3 INCHES AWAY FROM WALL. AND LABELINGS FOR TUBE NUMBER [Z] AND TUBE TYPE [T].

RULE 5 [AGGREGATE PILLARS]

ADD PILLARS WHILE Z ≤ N USING STRAIGHT RULE. IF Z = N AND C > 0 USE TURN RULE ONCE.

RULE 6 [ADD COLORING]

ADD COLORING TO PILLAR. THE COLORING MARKS THE LOCATION FOR THE CONNECTION DETAIL BETWEEN THE TUBE AND THE WALL.

RULE 7 [SUBSTITUE PILLAR WITH TUBE]

SUBSTITUE TUBE FOR PILLAR BASED ON LABELING. SUBSTITUE CONNECTION DETAIL BASED ON PARAMETRIC COLOR GRAMMAR.

T = 1  TWO OPEN ENDS  T = 2  SLOT  T = 3  ONE CLOSED END
SOUND FAÇADE GRAMMAR

Plan

Rule 1 [Decide Location of Façade]
Determine start and end points on building to place tubular façade attachment. Moving from start to end should progress in a counter-clockwise manner.

Plan

Windrose N

This grammar places creates a sound façade. It constructs the sound façade, but allows for user variations in the appearance. The grammar starts by determining the area to place the façade in plan, and then the user decides how long each sound tube will be.

Rule 2 [Determine Height of Tube]
Determine the height of the tube. The tube should be placed at least 3 inches off of the ground, and can reach the same height of the building, higher than the building, or lower than the building.

\[ \text{Ground to Tube} \quad G \quad \geq 3" \]
\[ 2' \leq \text{Length of Tube} \quad L \quad \leq 19.88' \]

\[ H = 8' \]
\[ L = 7.75' \]
\[ G = 3" \]

Elevation

Rule 2A

Rule 2B

Rule 2C

Rule 3 [Calculate Number of Tubes]
Determine number of tubes to be located on each segment of the façade.

For façade segment \( F \) with a distance \( D \), \( D/6" = \text{Number of Tubes} \quad N \).

\[ N_1 = 18 \]
\[ N_2 = 36 \]
\[ C = 1 \]

Plan

Plan

Rule 4 [Place Starting Pillar]
Place first pillar at starting point at least 3 inches away from wall. Labelings for tube number \( Z \) and tube type \( T \).

\[ W \quad \geq 3" \]

\[ \text{State labelings:} \]
\[ Z = 1 \]
\[ T = 1 \]
\[ W = 3" \]

Rule 5 [Aggregate Pillars]
Add pillars while \( Z \leq N \) using straight rule. If \( Z = N \) and \( C > 0 \) use turn rule once.

\[ \text{State labeling pattern for tube type} \quad T \quad : \]
\[ \text{If} \quad L \quad > \quad 9.94' \quad : \quad 1 - 2 - 1 - 2 - 1 - 2 - ... \]
\[ \text{If} \quad L \quad \leq 9.94' \quad : \quad 1 - 2 - 3 - 1 - 2 - 3 - ... \]

Straight rules

\[ Z \quad Z + 1 \quad Z \quad Z + 1 \]

Width of pillar \( W \) is determined by size of necessary tube to complete turn and maintain tubes placed 3 inches from the wall.

\[ L \]
\[ W \]

Turn rules

\[ L \quad 6" \]

\[ Z \quad Z + 1 \quad Z \quad Z + 1 \]

Label rules

1 Label rule
6 Label rule
9 Label rule
14 Label rule
3 Label rule
7 Label rule
12 Label rule
16 Label rule

Substitute tube for pillar based on labeling. Substitute connection detail based on parametric color grammar.

Sonic Façade Grammar
7. CONCLUSION

CREATING THE FINAL SOUNDS
EXAMPLE BUILDING 1 [COMPlicated WITH AWNING]
EXAMPLE BUILDING 2 [SIMPLE WITH OPENINGS]
EXAMPLE BUILDING 3 [GREEN BUILDING]
DISCUSSION
CREATING THE FINAL SOUNDS

From the beginning I wanted to hypothesize what my facade would sound like. I listened carefully to two of my most similar precedents, Aeolus and Singing, Ringing, Tree. They all had their sounds layered on top of one another, and I wanted to replicate this in my own sound clips. To do this, I turned back to Audacity. I took my three original sound clips and added each clip several times into my file. I was then able to edit each track separately using the change speed, change pitch, amplify, and reverse functions.

While these constructed clips are not accurate to the sound of the facade, I believe that they are a good representation of what the sonic facades will sound like in relation to each other. I was able to shift the pitch of the sound clips to match the relative lengths of the tubes, giving some walls overall higher or lower composite sounds. I was also able to layer in as many sounds to match the different types of pipes in the design.
EXAMPLE BUILDING 1 [COMPLICATED WITH AWNING]

This design is based on the hypothetical case proposed in section 6 [Sonic Facade Grammar]. In this design all tubes are of the same 8' length, but the tubes are arranged in different ways on the different walls. First a pattern of label rule 1, 9, 14 is repeated on the shorter length wall, and a pattern of label rule 1, 6, 9 is repeated on the longer wall. This design features one turn. This design has a complicated appearance, because the facade undulates and spirals. These undulations and spiral allow for interesting moments such as an awning and small private partitions. Only three different sounds are produced by the tubes along this facade, due to all tubes being the same length.

LISTEN TO EXAMPLE BUILDING 1 : TRACK 12
EXAMPLE BUILDING 2 [SIMPLE WITH OPENINGS]

This design is also based on the hypothetical case proposed in section 6 [Sonic Facade Grammar]. In this design there are three different lengths of tubes – 2’, 3.25’, and 9’. Only label rule 6 is used to generate the design, but variation is introduced to the design through different starting label positions from the sonic facade grammar rule 4. Because the design is simple, the facade isn’t very distracting and only functions as a facade. This design features no corner tubes, but is shaped around openings in the facade. Nine different sounds are produced by this facade due to the multiple lengths of tubes. Due to the shorter tube lengths, this design features higher pitches than the previous design.

LISTEN TO EXAMPLE BUILDING 2 : TRACK 13
EXAMPLE BUILDING 3 [GREEN BUILDING]

This design is implemented on MIT’s Green Building, otherwise known as Building 54. After researching the site and obtaining a wind rose from an MIT feasibility study called Project Full Breeze, I was able to determine where to locate the sonic facade. Since there is a prevailing Northwest wind I decided to place the sonic facade on the northwest facade, or the facade closest to Building 56. The design uses the longest tube length possible 19.88’, and therefore only the tubes with two open ends and one open end and one long transverse slot can be used. The aggregated design frames the entry way to the Green Building and creates a place that students can come hang out and listen to the facade during the day. Only two different sounds are produced by this design, and it is considerably lower in pitch than previous designs.

LISTEN TO EXAMPLE BUILDING 3 : TRACK 14
DISCUSSION

The results of this thesis explore the creation of sound in a tube in relation to architecture. The sonic facade is likely to only be applied to certain typologies of buildings, such as buildings in the public realm, educational institutions, and museums. Currently it would not feasible to attach this structure onto a house and an office building as the users will likely be annoyed by not being able to control the sound, until a tube cap is developed that would be able to be attached onto the tubes to turn their sounds off.

The sonic facade grammar is capable of generating a wide range of possibilities. Throughout this thesis, I have tried to let the grammar speak for itself, embracing the possibilities that it allowed. The grammar is flexible enough to allow for openings and different designs based on user preference. The visual appearance of the facade is very unrestricted and is free to be as complicated or simple, or as ugly or as beautiful as the user choses it to be. I chose to limit the grammar to only have two or three types of tubes depending on the set length, to control the amount of variation in the design. I felt the grammar would be more powerful if not every aspect of it was parameterized; therefore, there would be a way to control the sounds produced by the facade.

However, the grammar does have some faults. It currently does not allow for the facade to be applied to a curved surface. Nor does it allow for controlled variations in the lengths of the tubes which would further increase the number of possible pitches. The system for creating openings could also be written more powerfully into the rules.

While one of my goals was to produce sound throughout this thesis, it should be questioned if the grammar should try to control the frequency and sound of the tubes. While many have criticized that the sounds produced should be the driving factor to my grammar, I felt that the grammar was best written not to control the frequency of the tube. The sound is abstract enough that the sound is not seen as a particular pitch or turned musical note. Controlling the frequency through the grammar, indicates that sound is a fixed feature of a tube, but this is not true. Sound quality and pitch fluctuates with the environment.

While the sounds produced in this thesis are computed edited, a real mock up would produce a real example of what the sonic facade would sound like. The edited compositions are based on real recordings from tested tubes, so while the clips do not flawlessly replicate the sonic facade, the results are within reason. Furthermore, comparing the edited compositions with known examples of tubular sound producing sculptures like Singing, Ringing, Tree and Aeolus, the edited compositions sound similar.

Looking to the future, it would be best to further work though the grammar and further refine it and begin building these facades at full scale to understand what they really sound like. The grammar can be applied to other possibilities, not only facades. The grammar could become structural, define space, and make buildings. It can also be scaled to produce furniture. I believe the relationship between the exterior and the interior should be further explored as it has only been touched upon in this thesis.
7. REFERENCES

**IMAGE CREDITS** [ALL IMAGES ARE PRODUCED BY THE AUTHOR OTHER THAN THOSE LISTED BELOW.]

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**SOUND CREDITS** [ALL SOUNDS ARE PRODUCED BY THE AUTHOR OTHER THAN THOSE LISTED BELOW.]

TRACK 1 | http://www.youtube.com/watch?v=4B0hGyKV9qs
TRACK 2 | http://www.youtube.com/watch?v=XbT2Q1meF4E
TRACK 3 | http://www.youtube.com/watch?v=p7Vx16uhuo&feature=related
TRACK 4 | http://www.youtube.com/watch?v=m6gyfORWvWw&feature=related
TRACK 5 | http://www.youtube.com/watch?v=TtZqmGBWEM