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I, Kurt S Lehecka, hereby submit this original work as part of the requirements for the degree of Master of Architecture in Architecture.

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aural design: merging of sound and space

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aural design: *merging of sound and space*

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abstract

The human experience is not purely based on visual relationships. In today’s built environment, sound has become a secondary concern to visual perception. We experience noise in various environments that may or may not be enjoyable to the sense. Health and productivity can be affected negatively if noise is not addressed during the design process. This thesis will explore architectural environments through a sonic experience. As well as studying the effect that sound has on the health and well-being of humans.

This document will begin with research that introduces the terminology and ideas related to acoustics. Additional studies will be done to examine how sounds react to architectural forms and materials. Lastly, this thesis will introduce a design for a sonic pavilion that aims to create an environment that will heighten visitors’ awareness of sound.
I lived in New York City during the summer of 2016 and my experiences there serve as my inspiration in writing this paper. Whether I was walking along the Hudson River or enjoying nightlife in Chelsea, the sounds of the city were unavoidable. For three months I lived in Harlem, a large and dynamic neighborhood in northern Manhattan. Every weekday I commuted twenty minutes on the subway to Bryant Park, 42nd St and 5th Ave. To distract myself during the journey I would listen to music on my phone. As I rode the subway and walked to work, I was disoriented as I never heard the screeching of the subway wheels coming to a halt or the sounds of traffic. My music needed to be turned up to mask the noise of subway, street, and occasionally the office place. I felt the effects of louder music in my stress level as well as my health.
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1.0 introduction

This thesis started with the intent of creating healthier spaces through acoustics in architecture. Constant developments in the building industry have created additional acoustical problems that are not addressed during design. Advancements in technology have increased a building’s dependence on machines adding to the noise within the interior of a building and its exterior.¹ There is the opportunity to create a positive experience that can effect the well-being of a building’s occupants by designing with sound. Men and women interact with numerous environments on their daily commutes to and from work each day. There is the potential to design these interior and exterior environments in a way that creates an enjoyable aural experience rather than a loud unpleasant space that magnifies stress.

Architecture is a multi-sensory field, however the visual aspect is regarded the highest. Sound offers a lot of information the brain uses to understand and relate the body to; bringing about strong emotions in people. As a result, acoustic design should be on the architect rather than an engineer. This thesis will investigate sound as the primary driver of architectural design combining it with materiality and a unique program. It is intended to be a tool for designers to consider acoustics in all project types.

The resulting project is a pavilion structure that raises the awareness of visitors to their sonic environment. Through visual aesthetics and aural perception, visitors will be able to understand the sounds around them. The design will allow visitors to experience loud and quiet spaces. As well as experience spaces with low and high frequencies. The spaces will highlight the importance of designing to sound.
2.0 sound

2.1 understanding sound

“(1) physically speaking, it is a fluctuation in pressure, a particle displacement in an elastic medium, like air. This is objective sound. (2) Physiologically it is the auditory sensation evoked by the physical fluctuation described above. This is subjective sound.”

Sound is the product of vibrations of an object. The vibrations of an object, such as a guitar being strummed, passes through the ears of the listeners. As sound is created, it spreads out in all directions while decreasing in intensity. This effect can be visualized by a stone being dropped into water. Ripples are created by the stone that spread out from where the stone initially hit the surface. As the waves spread out, the magnitude of their size also diminishes. As sound energy travels further away from its source, it decreases in intensity.

2.2 sound behavior

Reflection, absorption, diffusion, diffraction, and reverberation make up the components of sound within this document. The application of light and reflection is similar to the study of sound reflection. As shown in Figure 2-1a, the angle between the sound ray and the

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2 Doelle, Leslie L. Environmental Acoustics, p. 12
3 Doelle, Leslie L. Environmental Acoustics, p. 14
surface’s perpendicular plane is the angle of incidence. The reflected ray is the product of the sound ray reflected by the surface. Hard surfaces will reflect most of the energy from an incident ray. Surfaces made of concrete, brick, stone, plaster, or glass do not absorb sound and will create louder spaces. Soft and porous materials make for better materials of sound absorption as it allows sound energy to change form to heat energy while passing through the surface (Figure 2-1b).

**Sound diffusion** (Figure 2-1c) is the dispersion of sound evenly throughout a space. Different than sound reflection, sound diffusion reflects sound in many directions evenly distributing sound in a space. The built environment is made up of walls, columns, and corners that can impede the travel of sound. **Sound diffraction** is when sound waves bend around these obstacles (Figure 2-1d). High frequency sound waves, high pitch, do not diffract as well around objects as low frequency due to their short wavelengths.

Lastly, **reverberation** is known as the prolonged sound in spaces created from sound energy repeatedly reflecting off surfaces and not being absorbed.

### 2.3 ear/space/body

Humans are able to spatially locate themselves in space through sound. Three components make up spatial hearing. **Interaural intensity difference** is shown in

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4 Doelle, Leslie L. *Environmental Acoustics*, p. 23
5 Doelle, Leslie L. *Environmental Acoustics*, p. 23
6 Doelle, Leslie L. *Environmental Acoustics*, p. 25
7 Doelle, Leslie L. *Environmental Acoustics*, p. 26
The sound source is on the left side of the person. The sound emitted from the source will appear louder in the left ear than it does in the right ear. Next, there is **interaural time delay**. In Figure 2-2a, the sound will appear sooner to the person’s left ear than it will in the right ear. Using interaural intensity difference and interaural time delay, the listener is able to infer that the source is located to their left. Figure 2-2b illustrates the last spatial component, **spectral differences**. The shape of the human ear allows humans to determine if the location of the sound source is in front or behind the body. Humans have a harder time placing themselves in spaces where a sound source is covered up.

When the source is covered up, the sound is reflected and makes the brain believe it is coming from somewhere else. In Figure 2-2c, the source is reflected off the wall and arrives at the person’s left ear first. This situation makes the person aware that either the source or a reflected surface is to the left. The sound from the source will appear altered to the person. High frequencies do not diffract as well around the wall as low frequency. The person’s right ear will hear less high frequency waves than his left and will be able to spatially locate himself through interaural time delay and interaural intensity difference.

**Figure 2-2**: (a) interaural intensity difference & interaural time delay (b) spectral differences (c) spatial perception

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9 Blauert, *Spatial Hearing*, p. 72
10 Blauert, *Spatial Hearing*, p. 138
11 Doelle, Leslie L. *Environmental Acoustics*, p. 18
The world is a visual place in which the human eye gathers most of the information to process. During times of limited visibility, the ear is able to gather information. Reflection of sound gives information about the volume of a space allowing humans to speculate the height, width, and depth.

2.4 sound-space

Analyzing an everyday listening situation at the park will provide a better understanding of the relationship between sound and the human body. As shown in Figure 2-3, a man is sitting on a bench conversing with a woman. The man’s attention is focused on the conversation he is having with the woman. This makes up the inner radius of the man’s sound-space.

The man’s intermediate radius of his sound-space is what extends past his immediate hearing. It contains speech by other visitors of the park, music, and laughter of children playing. The level of attention towards this sound-space is low. However, it can divert the man’s attention away from

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13 Leitner, Bernhard Leitner: Sound, Space, p. 213
14 Leitner, Bernhard Leitner: Sound, Space, p. 213
his own conversation.

Lastly, there is the outer radius of the sound space. Commotion from the street as well from noise from airplanes and construction in the distance make up this zone. The noise is not high in intensity and is not distracting. Background noise gives spaces a sense of place. Background noise is lower in tone as it is sound energy with a low frequency. Without noise, spaces would feel uninviting and empty.

2.5 *urban*

Various human activities and actions produce sounds that fill the urban environment. The city soundscape is comprised of natural, man-made, vehicular, construction, and machine sounds.\(^{16}\) As city populations increase, the noise levels will also increase resulting in an evolving

\(^{16}\) Doelle, Leslie L. *Environmental Acoustics*, p. 137

![Figure 2-3: sound-space](image-url)
soundscape. As noise levels increase, the radius of individual soundscapes decrease. Therefore diminishing the aural awareness of the population. Schafer addresses the world’s changing soundscape as,

“Is the soundscape of the world an indeterminate composition over which we have no control or are we its composers and performers, responsible for giving it form and beauty.”

In the urban environment, the relationship between man and sounds need to be determined. There is potential in design to compose a soundscape that is pleasing. Sounds of the soundscape need to be identified to control which to eliminate and which sounds to preserve, encourage, or multiply.

Urban environments are filled with undesirable sounds. Within an urban environment, the range of a sound-space is limited due to the presence of traffic and construction. Urban noise diminishes the range in which people can hear compared to that of a rural environment. The urban environment thrives on activity. With a vibrant landscape comes various types of sound.

2.6 experience

Sounds are identified as undesirable or desirable.
Undesirable sounds, or noise, can be the product of vehicular traffic, airplanes, people, and construction. Noise is regarded as a sound that is unpleasant to the ear. The perception of noise can change from person to person as a sound that seems irritating to one person can be enjoyable to another. The addition of noise into a space can diminish and hinder the human experience within a sound-space.\textsuperscript{21}

Aural architecture is described as the experience of human listening within a space. It differs from acoustics in architecture as aural architecture primarily addresses the listener’s emotions.\textsuperscript{22} With sound, emotions can be aroused and cause fear, delight, and enjoyment. Aural architecture is the creation of a virtual experience in the listener’s head in which a physical space does not exist. Listening to music is similar to this. Whether through headphones or a stereo, the music is not being performed live or in the same vicinity of the listener. However, the music allows the listener to put themselves in a space through their own illusion.\textsuperscript{23}

2.7 space

Bernhard Leitner, a sound architect, states that his sound art should possess an aesthetic appeal as visual quality and aesthetics cannot be ignored for the human experience.\textsuperscript{24} The color of a material can influence the sound perception of a space. Spaces can appear wide

\textsuperscript{21} Schafer, R. M. \textit{The Music of the Environment}, p. 17
\textsuperscript{22} Blesser, \textit{Spaces speak, are you listening?}, p. 5
\textsuperscript{23} Blesser, \textit{Spaces speak, are you listening?}, p. 6
\textsuperscript{24} Leitner, Bernhard Leitner: Sound, Space, p. 90
or narrow based off of characteristics of a material used in a space: intensity, color, and frequency. In Leitner’s “Sound Cube” installation, he arranged sixty-four loudspeakers in a grid on all six surfaces of a cube. With an individual inside the cube, sounds were played through the loudspeakers to create virtual geometry in the listener’s head. Sounds that are light and dancing created a high arch. That same arch can appear to flatten out with the sound of dullness or heaviness.

“Sound is measurable, it draws lines, builds walls and permeates according to architectural rules.”

2.8 health

Prolonged exposure to high intensities of sound, more than 80dB, can lead to health effects. Interaction with different types of sound is inevitable in day to day tasks. In New York City, there is constant exposure to noise on a daily commute. As Figure 2-4 shows, there is sound from the moment of waking up in the morning to sitting at a desk at work. The intensity of sound varies throughout the everyday environment. A subway’s noise intensity is far greater compared to a walk down the street. The subway station is a small enclosed space with very reflective materials on all surfaces. A spectrum reading from a subway station, Figure 2-6, shows the decibel level

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25 Leitner, Bernhard Leitner: Sound, Space, p. 90
26 Leitner, Bernhard Leitner: Sound, Space, p. 90
27 Leitner, Bernhard Leitner: Sound, Space, p. 147
Figure 2-5: equal-loudness contours
reaching 91.5dB at 280Hz. Referring to Figure 2-5, this level is near the threshold of pain. Normal conversations occur at about 60dB.\textsuperscript{29}

Individuals avoid the city soundscape by escaping to their own virtual experience through the use of headphones. The volume of personal stereos is constantly fluctuating to compete against the noise of the urban environment and to keep listeners in their own self-oriented experience.\textsuperscript{30}

A commuter on the London tube system explains his strategy while commuting:

“I need to have it loud because of all the noise and all that. It’s the loudest on the tube. More often than not it’s on so loud I can’t hear anything.”\textsuperscript{31}

Individuals can experience hearing damage and an increase in stress from the noise pollution in cities.\textsuperscript{32} The presence of undesirable sounds can create psychological and social stress. Sounds that are normally quiet to an individual can come across as irritating when the individual is under stress.\textsuperscript{33}

Listeners can feel discomfort as sounds become louder.\textsuperscript{34} Figure 2-5 shows the range of sound from threshold of audibility to the threshold of pain. The graph shows that humans cannot hear low frequencies at low intensities.

\begin{itemize}
\item \textsuperscript{29} Doelle, Leslie L. \textit{Environmental Acoustics}, p. 16
\item \textsuperscript{30} Bull, Michael. \textit{Sounding out the city: personal stereos and the management of everyday life}, Berg, Oxford; New York, 2000, p. 21
\item \textsuperscript{31} Bull, \textit{Sounding out the city}, p. 21
\item \textsuperscript{32} Rylander, “Noise, Stress and Annoyance.”, p. 36
\item \textsuperscript{33} Rylander, “Noise, Stress and Annoyance.”, p. 33
\item \textsuperscript{34} Doelle, Leslie L. \textit{Environmental Acoustics}, p. 17
\end{itemize}
For example, a sound of 50 Hz within the threshold of audibility for humans, would have to be at an intensity of about 45 dB. In contrast, human ears are can detect higher frequencies at lower intensities. A 2,000 Hz tone can be heard at 8 dB.

Additionally, the contours on Figure 2-5 illustrate how humans respond to various sound frequencies. A sound of 40 Hz with an intensity level of 60 dB sounds equally as loud as 200 Hz at 25 dB, 2,000 Hz at 18 dB, and 9,000 Hz at 32 dB. A change of intensity level in low frequencies has a higher effect on the human ear. The threshold of audibility of a 20 Hz tone is about 75 dB. An increase of 30 dB changes the tone to 105 dB or near the threshold of pain. While a tone of 4,000 Hz can be heard at 4 dB. Changing the sound pressure by 30 dB would result in the intensity equaling 34 dB, well within the threshold of audibility.

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35 Doelle, Leslie L. Environmental Acoustics, p. 17
3.0 methodology

Spaces with varying levels of sound can be created with architecture. Architectural elements impact the human soundscape experience by either blocking sound or allowing sound to reach the ear. Traffic and construction noise are widely regarded as a nuisance and the built environment is utilized to decrease the noise through absorption or reflection.¹

Architectural walls can be utilized to decrease or increase sound levels. As Figure 3-1 illustrates, a wall reflects sound energy, increasing the intensity of the space. The wall also blocks energy from the opposite side, decreasing the intensity. Sound levels can also be decreased by adjusting the ground plane. Lowering the plane allows the space to avoid the sound emitted from a source (Figure 3-2). The use of an absorbent material will also minimize the reflection of sound and decrease the intensity of sound and reverberation in a space.²

Sound can be manipulated by form to increase the intensity within a space. Sound energy striking a concave form, Figure 3-3, will focus the sound. The surfaces opposite the concave form reflect the sound back toward the curve. Sound is unable to escape and only diminishes through decay. This space will have a high amount of reverberation. Raising the ground plane will increase the

¹ Doelle, Leslie L. Environmental Acoustics, p. 150
² Doelle, Leslie L. Environmental Acoustics, p. 156
sound intensity of the space (Figure 3-4). As a result of sound reflection and sound diffraction the area will be exposed to more sound rays.\textsuperscript{3} The raised plane exposes occupants to more direct sound as well as reflecting energy from the ground surface.

Masking sound in a space is another option to control its acoustics. Introducing new sound to mask the existing noise can make a space appear quiet. The addition of a waterfall in a space adds positive noise and masks the existing noise. In New York City, sound intensity of a street is consistently above 60dB, Figure 3-5. Many New York City park’s have waterfalls that create white noise and mask the street noise. The waterfall’s sound cancels out all other sound, but establishes a consistent background sound. Making for a more relaxing environment even though the strength of the sound does not diminish (Figure 3-6).\textsuperscript{4}

Frequency and pitches of sound can also be influenced through architecture. Sounds with high frequency do not diffract as well as sounds with low frequency. Walls or other barriers can alter the balance of frequencies in sound waves altering a visitor’s experience and spatial perception within a space.\textsuperscript{5} As shown in Figure 2-5, low intensities of high frequencies can sound as loud as high as high intensities of low frequencies.

\textsuperscript{3} Doelle, Leslie L. \textit{Environmental Acoustics}, p. 149
\textsuperscript{4} Doelle, Leslie L. \textit{Environmental Acoustics}, p. 158
Variable acoustics change the composition of a space and in effect change the acoustics of the space.\(^6\) In Figure 3-7, a large room is adjusted to sound smaller by lowering the ceiling and drawing curtains along the walls. The surfaces reflect the sound at an earlier point in time increasing the intensity of the room’s acoustics. Figure 3-8 demonstrates how a small room can be made to sound much larger than it appears. Openings in the small room envelope allows sound energy to escape through diffraction into the larger enclosure. The sound reflects off of the surfaces of the larger enclosure and are heard by the occupants. The amount of time it takes the sound to reflect back to the listeners gives them the spatial awareness that the volume is much larger than it visually appears.

Several computer simulations were conducted to understand the characteristics of sound. Figure 3-9 shows as series of forms containing sound. The more enclosed a space becomes, the sound within makes the space echo. A higher reverberation time also occurs as the sound energy has nowhere to escape. Concave and convex forms were tested in Figure 3-10. Concave forms focus the sound energy towards the center while convex forms disperse the energy. Figure 3-10a features two concave forms oriented towards one another. This simulation features minimal voids for sound to escape. Sound energy is continuously reflected off the surfaces until the sound energy is converted into heat energy. As the image shows

Figure 3-9: square forms (a), (b), (c)

Figure 3-10: curve forms (a), (b), (c)

Figure 3-11: forms (a), (b), (c)
Figure 3-12: wall transformation (a), (b), (c), (d)

Figure 3-13: wall transformation (a), (b), (c)

Figure 3-14: wall transformation (a), (b), (c), (d)
Figure 3-15: passage transformation (a), (b), (c), (d), (e), (f)
there is a large amount of echo and reverberation in the space. Figure 3-12 illustrates the transformation of a wall and how it impacts the acoustics of a space. Sound energy is being diffused in Figure 3-12 and spreads the sound over a larger area. However, the form reflects sound creating dead spaces in which sound does not reach. Figure 3-12c and Figure 3-12d are tighter forms that also diffuse sound, but do not do it as effectively. The angles are too extreme that cause sound to get pinned within the wall through reflection. This situation creates a greater sound intensity close to the wall. Figure 3-15 shows the progression of how a path can influence a space’s acoustics. As more angles are introduced into the forms, it causes sound to reflect more. As more reflections are integrated, less sound is able to travel to the end of the path.
4.0 sonic pavilion

4.1 site selection

It was established early in the project that the site would be adjacent to a busy and populated street in Midtown Manhattan (Figure 4-1). Due to the nature of the project Midtown Manhattan is a logical choice as it is loud which contributes to overall stress of its residents. People living and working in Midtown do not have a lot of access to parks where they can relax and enjoy some quiet. Parks offer solitude from the urban noise. The goal of the project is to offer a place within walking distance of work or home to block out the city’s construction and traffic noise. The pavilion will not emit noise from the presence of vehicles, pedestrians, and construction, but make the pleasure of people watching more enjoyable. The plaza in front of the News Corp Building on 47th St. and 6th Ave. in New York City will serve as the site for the sonic pavilion (Figure 4-2). The site offers a variety of sounds with a high level of pedestrian and vehicular traffic. The News Corp Building has heavy traffic from both New Yorkers and tourists due to its location near the Rockefeller Center and Times Square. The diversity of sounds on site create multiple opportunities for the design of the sonic pavilion.

People exit and enter the site for access to the News Corp building as well as the 47-50 Streets, Rockefeller Center Subway Station. The station accommodates
Figure 4-1: Manhattan parks
Figure 4-2: site context
Figure 4-3:
(a) construction noise
(b) human noise
(c) music noise
(d) nature noise
(e) transportation noise
(f) circulation

Figure 4-4: News Corp plaza looking south
Figure 4-5: News Corp plaza looking west
both southbound and northbound B, D, F, and M trains.

The site is exposed to both desired and undesired sounds. In the foreground, conversations and human activity can be heard. The sounds from traffic, construction, and airplanes can be heard in the background (Figure 4-3). A majority of vehicular traffic flows past the site on 6th Avenue traveling from south to north. The heavy density of traffic produces a high intensity of low frequency noise (Figure 4-4). There is also a large population of pedestrians that travel along 6th Avenue coming from both the south and north directions. Pedestrians contribute to the intensity of low frequency sound entering the site. There is a minor flow of both vehicular and pedestrian traffic along the north border of the site on 48th Street (Figure 4-5). The human activity along 48th Street creates low frequency sounds that enters the site. Also, high frequency sounds, produced from nature, can be heard along the north side of the site at a higher elevation.

Sound intensity levels were taken at four locations on the site (Figure 4-6e). The first location was adjacent to 6th Avenue along the side of the building (Figure 4-6a). The building adjacent to the reading is constructed of a glass

<table>
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<tr>
<th>Description</th>
<th>125</th>
<th>250</th>
<th>500</th>
<th>1000</th>
<th>2000</th>
<th>4000</th>
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</thead>
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<td>0.015</td>
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</tr>
<tr>
<td>Glass</td>
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<td>0.04</td>
<td>0.03</td>
<td>0.02</td>
<td>0.02</td>
</tr>
<tr>
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<td>0.35</td>
<td>0.15</td>
<td>0.05</td>
<td>0.05</td>
<td>0</td>
</tr>
<tr>
<td>Acoustic felt</td>
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<td>0.45</td>
<td>0.7</td>
<td>0.85</td>
<td>0.95</td>
<td>0.85</td>
</tr>
</tbody>
</table>

Table 4-1: sound absorption coefficients of materials
curtain wall. Table 4-1 shows that a glass curtain wall has its highest sound absorption coefficient of .18 at 125 Hz. Meaning the surface absorbs eighteen percent of the sound energy that hits its surface. With higher sound frequencies, glass absorbs even less energy. The ground surface of point A is a rough concrete. Concrete absorbs even less sound energy at 125 Hz. Its sound absorption coefficient is .01. At point A, the highest decibel reading was 65.3 dB at the frequency of 65 Hz. Humans can hear sound wavelengths from 20 Hz to 20,000 Hz. Additionally, human conversation happens at 60 dB, and sounds above 85 dB are harmful. 65 Hz is at the lower end of the human audible scale while still within a safe exposure.

The next reading was taking near the entrance of the News Corp building. Point B in Figure 4-6e, is in the corner of the site with the building located to both the west and south. The building surfaces are glass and the ground remains concrete. The reading should be expected to be higher than at point A, as point B now has two vertical surfaces reflecting sound. Figure 4-6b shows that point B was loudest at 65 Hz with a reading of 68 dB. The loudest frequency remained the same between point A and B as the heavy vehicular traffic along 6th Avenue produces a low frequency sound.

Point C is located in the middle of the plaza between both

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Figure 4-6:
(a) sound spectrum at point A
(b) sound spectrum at point B
(c) sound spectrum at point C
(d) sound spectrum at point D
(e) point locations on site

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1 Doelle, Leslie L. Environmental Acoustics, p. 227
2 Doelle, Leslie L. Environmental Acoustics, p. 12
48th Street and 6th Avenue. The faces of the building are oriented away from the area, so sound will be reflected away from the point. The ground surface is concrete and the building surfaces remain a glass curtain wall. In Figure 4-6c, the highest sound intensity was at 43 Hz. The sound level at 43 Hz was 67.8 dB. Point C has a lower frequency level than both point A and B as well as a higher intensity than point A. This could be due to point C’s exposure to both 48th Street and 6th Avenue. An explanation to why point C was loudest at 43 Hz is that low frequency wavelengths travel farther and around obstacles more efficiently than high frequencies.

Lastly, point D is located at the far west end of the site. It is located in the corner of the News Corp building with a glass facade making up two sides around it. It is to be expected that the reading for point D is less in intensity than the other three points. 48th Street has a minor traffic flow in comparison to 6th Avenue. The building will block a majority of sound created from 6th Avenue. A majority of sound measured at point D should be a result of pedestrians and reflections of sound from other buildings. The highest intensity of sound was measured at 65 Hz at point D (Figure 4-6d). The decibel reading was 63.1 dB.

Figure 4-7 illustrates how sound is reflected off of nearby buildings and reacts with the site. These site simulations confirm the results from the site readings done in Figure 4-6. Along 6th Avenue is the loudest part of the plaza.
Figure 4.7:
(a), (b), (c), (d), (e)
4.2 program elements and considerations

The sonic pavilion will be a structure to encourage visitors to wander the plaza and discover sound by listening and looking at the design. Since the site is located near a major office building, people that come across the site everyday will constantly be able to realize something new about sound and how it relates to the design. The soundscape of the city is constantly evolving with construction and changing traffic. Therefore the design will be evolving along with the soundscape. The sonic pavilion will include the following program elements:

- Loud Area
- Quiet Area
- Café
- Kitchen
- Restrooms
- Storage
- Subway Entrance
- Exterior Seating
- Performance Space

The loud program piece is to be a area that is clearly louder than its surrounding environments. It is to be designed this way to create curiosity among people that walk through the space. The area devoted to be loud will be mostly standing room. There will be some sitting areas with seating facing each other to encourage conversations.
The addition of conversation will add to the intensity of the area.

The quiet space is to be a space to sit and relax in quiet amidst the loud urban sonic environment. Seating throughout the areas will be oriented away from each other to encourage silence.

The cafe is a space for people to grab a quick coffee or to enjoy a meal within this unique sonic environment. The conditioned space will allow patrons to enjoy their meals in an enjoyable setting. Within the café, the design of the space should also allow patrons to control the sonic environment.

A subway entrance for the 47-50 Streets, Rockefeller Center Subway Station is located on the site. The subway is one of the loudest sonic experiences in New York. Incorporating the subway entrance into the café can create a unique New York experience.

The performance space is to be a space where musicians can showcase their talents. Many street performers play in unsuitable environments that do not allow passersby to fully appreciate the music they are playing. The space can also be utilized for events.

The site can be accessed from both 6th Avenue and 48th Street. At both locations a cue from the design will introduce a passerby to the site and make them aware
of their surrounding sonic environment. The addition of nature in the site will increase the absorption of sound. There will be a clear sonic difference throughout the seasons as vegetation alters during the winter.

4.3 construction

A modular system was chosen as the construction of the sonic pavilion. The program on the site has different types of acoustics. A modular system allows the design to be cohesive while changing appropriately for each program piece’s required sound restrictions. Additionally, keeping in mind the goal of the project to allow visitors to understand their sonic environment; this system visually reveals how the sound around the site is interacting with the design.

A series of seven different bi-truncated cubic polyhedron modules were developed to assist with the acoustical needs of the site design. A tessellation of these modules over the site allows for a natural diffusion of sound (Figure 4-34). The combination of these shapes reflects sound energy in many different directions.

The modules will feature differing hole sizes, which are influenced by the program’s sound requirements. As the openings within the surfaces become larger, the more sound energy is able to pass through into the space. Also, the materiality among the modules will vary as some surfaces will need to be constructed of hard materials and others will need to be made of soft materials. Modules
Figure 4-9: solid, hard module
Figure 4-10: semi-solid, hard module
Figure 4-11: structural module

Figure 4-12: solid, soft module
Figure 4-13: semi-solid, soft module
Figure 4-14: glazing module
required to reflect sound energy will be fabricated out of metal. Referring back to Table 4-1, metal has a sound absorption coefficient of .5 at 125 Hz and .05 at 2000 Hz. Metal reflects high frequency sound wavelengths better than low frequency wavelengths. Acoustic felt will make up absorbent modules. The sound absorption coefficient of acoustic felt at 2000 Hz is .95 and .45 at 250 Hz. Acoustic felt absorbs high frequency sound wavelengths better than low frequency.

The first module is fabricated completely out of metal with no apertures in its surfaces, Figure 4-9. This module reflects sounds as well as diffuse it. Sound from outside the site is reflected. It also reflects sound that is emitted within the space increasing the sound intensity. With a series of these modules, it is expected to hear more high frequency tones rather than low frequency.

The second module is also out of metal but has apertures in its surfaces, Figure 4-10. The surface reflects sound and is part of a larger whole to diffuse sound. The apertures allow for sound into the space through diffraction. Apertures within the surfaces can vary in size from module to module. More low frequency sounds will be heard as low frequency bends around obstacles better than high frequency. Overall, this semi-solid module will allow outside sound into a space while also reflecting sound within the space.

The next module type is fabricated with a metal structural
frame overlapped by acoustic felt, Figure 4-12. In addition to diffusing sound, the module absorbs sound. A space is quieter with a combination of this module as it absorbs sound from both outside the site and sound created within the site. Due to the sound absorption coefficient of acoustic felt, this module absorbs high frequency sound more efficiently. In result, low frequency sounds will be heard more.

Another module is designed to absorb sound but also to allow some sound through its apertures, Figure 4-13. The semi-solid module is structurally made with metal but the surfaces are composed of acoustic felt. Acoustic felt absorbs high frequency tones more efficiently, resulting in more low frequency tones to be heard with the use of this module. The use of this module will absorb sound from outside and inside the site.

Fully enclosed, conditioned spaces require insulated modules. This module is made with structural metal and filled with insulation. This module can be altered for reflective or absorbent properties. It will not have any apertures in any of the surfaces, as it will enclose spaces.

To allow natural light into conditioned spaces, a module was designed that incorporates glazing (Figure 4-14). The module will reflect sound and will not allow any sound to pass through it. The size of the glazing in the module can vary from one to another to allow different amounts of daylight into the space. This will result in the interior space
being activated by various sizes of shadows that evolve throughout the day.

Lastly, there is a module that is completely structural (Figure 4-11). It is fashioned out of only metal. The module will allow all sound from outside the site to pass through it as well as letting sound from the site to flow out.

4.4 site design

From the analysis of the site, it was discovered that the site has a natural decrescendo of sound, Figure 4-15. The southern most area of the plaza near 6th Avenue being the loudest. The quietest part of the site is the most west area along 48th Street. The site was designed using common circulation paths across the site, Figure 4-16. The majority of foot traffic on the site is to access the subway stop and the News Corp Building. With the subway entrance located in the middle of the site, the design should accommodate these circulation paths to not cause too much of a disturbance on the site.

The program was arranged on the site using the existing acoustic conditions. Figure 4-17 diagrams the sound conditions of each program piece. The loud area is the loudest piece, followed by the cafe, exterior seating, performance, and then the quiet area. The program was positioned in a linear fashion on the site as the site’s sound decreases in a linear way, Figure 4-18. The loud
program piece is located next to the entrance of the News Corp Building along 6th Avenue. At the intersection of 6th Avenue and 48th Street is the placement of the cafe. Next, the performance space and the quiet area are located along the narrow strip of the site along 48th Street.

4.5 program requirements

The loud area is constructed in a way to allow sound from outside of the area to flow into the area increasing the intensity of sound. Through architectural form, sound will also be redirected. As a majority of sound that enters the site is low frequency, the loud area will have a high decibel level of low frequencies. High frequency sounds will also be utilized within this space as high frequency tones with low intensities can sound just as loud as shown in Figure 2-5. As the space requires sound to be reflected, the material used will need to have a hard surface and not be porous.

Throughout the quiet area street noise will be blocked and absorbed so that the low frequency sounds will be at a low intensity that they are not audible to the human ear. This will allow the higher frequency sounds of nature to be heard in the quiet zones. As the space requires street noise to be omitted a mixture of hard and soft materials will be used to reflect sound away from the site and absorb sound. Adding noise to the space through a waterfall creates white noise that is peaceful to the space.
The sound requirements within the cafe are more complicated than the other spaces. Sound should always be present that allows patrons to converse in a way that allows private conversations to remain private. However, the space shall not be too loud that it discourages social interaction. The materials used within the café will influence the sound character of the space (Figure 4-20). Hard materials on the walls, tables, and ceiling will help reflect sound around the space to fill the interior with activity. The addition of people act as sound absorbers. Sound absorbing material placed occasionally on the walls will help with the acoustics within the space. The option of having an open kitchen will increase the sound intensity within the space. The use of variable acoustics can create a dynamic space through sound during all times of the day. The café enclosure is enclosed by another shell that allows the space to have various acoustic properties. It is expected that the café will be less occupied after lunch and after the work day (Figure 4-19). The busiest times of the day for the café will be during lunch hours as well as after the work day. When the space is unoccupied during slow hours of the day, the inner enclosure is closed to allow sound energy to reflect off the walls sooner, making the space sound louder. During busy hours of the day when there are more visitors, the inner enclosure is opened to allow the sound energy to exit into the second enclosure. Even with the increase of people in the space, it does not sound any louder. A kitchen, restroom, and storage room will be integrated into the café.
A lower ground level creates a quieter environment by blocking sound. Utilizing this technique, the performance space will be lower than street level. The performance space will be highlighted by sounds from within the space rather than from street activity. Architectural form will not only block unwanted sounds from entering the space, but also enhance the sounds produced. This natural form of amplification is done by the use of hard materials. The activity from within the performance space will be able to pass into outside areas to cause intrigue among pedestrians. Sounds from outside of the space will be either reflected away or absorbed to highlight the performance activity sounds.

4.6 final design

The final design was first created by placing walls across the site (Figure 4-21). In Figure 4-21a, a large curved form is created to capture noise coming from 6th Avenue. Since the vehicular traffic on 6th Avenue travels from south to north, the sound sources are oriented north. The form controls the noise and utilizes it to raise the sound intensity of the loud area. The form also blocks any unwanted noise coming along 48th Street from entering the site at the performance and quiet spaces. This form interacts with people just passing by the site and has the potential to intrigue pedestrians to enter the site.

Next, a series of layers were created to produce a decline of sound through the site (Figure 4-21b). An additional
layer was created to mark the entrance to the cafe and to buffer the entrance from any street noise. The two other layers divide the site based on the circulation routes and create two separate sonic environments. One arc creates separation between the circulation path established by the subway and the performance space.

Figure 4-21c shows the development of the cafe between two layers. The cafe is located adjacent to the subway entrance allowing commuters to stop and enjoy the establishment during their commute. The two layers encompassing the cafe form an entryway from both the sidewalk and the building entrance that leads to the entry of the cafe and subway.

Lastly, openings were created within the form to allow for better circulation (Figure 4-21d). The openings also provide an acoustic property for sound diffraction. The placement of the openings allow pedestrians to access the entrance of the cafe while preserving the ability of the form to block street sound from the entrance. Sonic environments are created by interlacing walls, floors, and roofs within the structure to form a single entity. The architecture shows a continuation of space and movement as the spaces flow together and form the environments to fulfill the sound requirements of each program element.

The modules were then distributed across the forms regarding each program’s sound requirements. To create a space that is louder than its surrounding environments, the
use of the solid hard (Figure 4-9), semi-solid hard (Figure 4-10), and structural (Figure 4-11) modules were used. Mixing these units together around the loud area, Figure 4-22, allows noise from street activity to flow into the space as well as reflecting any sound from within the site into the area. A mixture of both low and high frequencies will be heard through the modules.

Both insulated modules and the glazing module (Figure 4-14) are used to create the outer shell of the cafe, Figure 4-23. These modules will allow the interior of the cafe to be conditioned as well as block exterior sound from being heard from within. The solidity of the exterior shell provides the cafe with various acoustic properties. When the interior shell is open, the sound will be able to reflect off of the exterior shell making the cafe sound larger than the space appears. The interior shell, Figure 4-24, of the cafe is fabricated with both semi-solid modules (Figure 4-10, Figure 4-13) and some solid hard modules (Figure 4-9). Exterior views are preserved with the use of these modules. As well, the mixture of soft and hard modules creates a balanced sound environment with sound being reflected and absorbed.

Glazing modules (Figure 4-14), solid soft (Figure 4-12), and both semi-solid modules (Figure 4-10, Figure 4-13) are arranged around the exterior seating area to preserve views, Figure 4-25. The glazing units allow daylight and views to the street for the enjoyment of people watching, but also do not allow street noise into the space. A
mixture of both high and low frequencies are able to be heard within this space.

To create a quiet environment conducive to performances, the solid hard (Figure 4-9), solid soft (Figure 4-12), and semi-solid hard (Figure 4-10) modules were chosen, Figure 4-26. The units reflect sound within the space producing a natural amplification sound. Outside noise is also blocked from entering by absorption. Noise composed within the space will be able to flow through the semi-solid units and be heard outside the space.

The quiet area, Figure 4-27, is formed by both solid modules (Figure 4-9, Figure 4-12) and the semi-solid soft module (Figure 4-13). The hard module is used to reflect the waterfall noise across the area. Both soft modules are to absorb sound within the space and block out any additional noise.
Figure 4-28: west/east section

Figure 4-29: south/north section

Figure 4-30: cafe interior
Figure 4-32: loud area detail

Figure 4-33: performance area detail
Figure 4-34: loud area

Figure 4-35: site approach
5.0 evaluation

The building creates numerous sonic environments that provoke visitors to pay attention to the soundscape around them. The design is effective in doing that and does so without breaking the site up into disconnected pieces. Circulation flows fluently through the site and creates paths for pedestrians to come in contact with multiple sound environments.

The cafe is the most difficult aspect of the program. It is unknown if the variable acoustic system would be used appropriately. The system requires additional construction so it costs more, but is advantageous in that it provides a more enjoyable interior environment. If the system is not used, the cafe would be very loud during high occupancy times and in return be a waste of money.

The different modules work nicely to meet the needs of each program’s acoustic requirements. However, the system may not be practical for a large site such as the News Corp plaza. The system works better for a smaller installation rather than a building. Constructing the pavilion with modules works well in that it can be constructed off site and assembled on site. This causes less interruption to the circulation of the plaza and the road traffic. For the amount of modules that are needed for this design, this system may not be the most cost efficient. Additionally, the modules create a task of waterproofing that can create
a technical difficulty.

Visitors have the potential to have a greater understanding of sound. With the various modules, there are visual cues that allow people to form relationships between the architecture and what they are actually hearing. With a consistent construction type, the materiality and aperture sizes differ from space to space allowing visitors to form relationships between them.
6.0 conclusion

Every project should consider sound in some regard, as it can have implications on the standard of living. Not every design needs to go into the depth of this document when considering sound. Having a generic knowledge of the field will improve designs and the impact architecture has upon the soundscape. There are possibilities to create architecture that is enjoyable to listen to that are not in reference to a concert hall.

Aural architecture has its difficulties too. It may be hard to convince clients to pay for a design that is aurally pleasing when the program is not sound driven.

There are many ways this research could continue. Additional research could include the relationship between sound frequencies and form and what the resulting spaces sound like. This research could better control the frequencies that are heard in each program piece of the sonic pavilion. Further research on the effects of temperature on sound would prove useful for exterior spaces.

Designing for sound should happen for any type of project. Types of spaces are anticipated to sound a certain way. It is expected that a subway station will be loud and ear shattering and visitors do not think what could be of the space if it sounded like a different sonic environment.
Designing for sound within a space could provide alternatives to a common perception. Acoustics is thought of by architects when they are designing a concert hall, but everyday spaces can be designed for sound without the need for an acoustician.
bibliography


appendix

The following projects address strategies in controlling noise. By limiting or increasing noise to enhance the visitor experience.

Greenacre Park

Built in 1975, the project is located on E 51st St in New York City. The 6,000 square foot pocket park provides ample seating on three tiered surfaces. Located closest to the street is the main sitting area with a grid of honey locust trees. The lower-level sitting area steps down from the main sitting area providing a more intimate experience with the waterfall. Along one wall is a trellis covered terrace with seating.

Sound control throughout the space is done with sound absorption, sound diffusion, sound diffraction, and sound masking. Along the terrace seating is an ivy wall absorbing any sound. A granite relief sculpture on the opposite wall of the ivy wall diffuses sound. The space contains a lot of hard materials that reflect sound. Sound is evenly distributed throughout the space by a sculpture wall. From the sculpture wall, sound is primarily reflected towards the ivy wall. The three tiers of seating areas create unique hearing experiences. Each tier sounds different as a result of sound diffraction. Street noise carries into the space.
and bends around the elevation changes decreasing the intensity as high frequency sounds are lost. Lastly, the lower seating tier is overwhelmed with the noise of the waterfall as it masks the street noise.

**Responsive Acoustic Surfaces**

The project, completed by a team at Smartgeometry in Copenhagen, studies the relationship between geometry and sound diffusion.\(^2\) By analyzing Gaudi’s Sagrada Familia, the hyperbolic surfaces of the ceiling distributes the sound in a way that other spaces of equal volume does not. The interior of the church does not have a long reverberating echo even though its interior is made of reflective stone.

Sound absorption was not studied in this project because of the use of reflective stone. Scale models of a curved smooth wall and a curved wall made of hyperboloids were constructed of plaster.\(^3\) With a sound source aimed at the smooth wall, a noticeable echo was generated. This was expected because the cylindrical geometry concentrates and reflects the sound back at its origin. However, the curved wall made of hyperboloids does not produce an echo as a result of the hyperboloid geometries. The hyperboloids reflect the sound in many directions lessening the intensity of the acoustics within the space.

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\(^3\) Burry, “Modeling Hyperboloid Sound Scattering,” p. 96
Bing Concert Hall

Stanford University’s concert hall can host an array of performances including orchestras, theater, dance, solos, as well as amplified performances.\textsuperscript{4} The theater of eight hundred forty-two seats is encased by a twelve inch thick concrete enclosure. With each seat no farther than seventy-five feet from the stage, it creates an intimate and impressive experience. Describing the theater, the lead designer, Richard Olcott explained, “We looked at the science of sound and likened it to textures and curves, looking at imagery of water and rippling landscape, sand dunes, clouds—there are not straight lines, just organic shapes.”

The design contains variable acoustics to be able to suite various performance styles. Between the sails on the walls are curtains that can be adjusted to better suite the space. When the curtains are adjusted, sound escapes into the cavity behind the sails and minimizes reverberation through the space.

Malta’s Hypogeum Hal Saflieni

The series of chambers are a natural form of amplification.\textsuperscript{5}

Sound within the domed vaults is magnified and can be


heard throughout the underground labyrinth. Sound within is resonated at 110 Hz due to the dimensions and the characteristics of the stone.

**Baptistry of St. John**

The Baptistry consists of two sets of outer walls that reflect sound as well as a dome above. Sound is reflected off the inner circle while sound is traveling to the outer circle creating various echoes. Meanwhile, sound is also traveling to the top of the Baptistry where sound is reflected off the dome. The use of absorbent material is minimal in the Baptistry.

**Resonant Form**

Sound frequencies were examined through vibration in which they create various designs that are called cymatic formations. The formations show a relationship between the frequency of sound and formal complexity.

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