BINAURAL ARCHITECTURE

[sonic compositions of everyday spaces]

by Emily R. Brett

A thesis submitted to the Faculty of Graduate and Postdoctoral Affairs in partial fulfillment of the requirements for the degree of

Master of Architecture [M.Arch]

Carleton University
Ottawa, Ontario

B I N A U R A L

[sonic compositions of everyday spaces]

ARCHITECTURE

Emily R. Brett 2014/2015

Thank you to my thesis advisor, Federica Goffi, for her encouragement and guidance. Thanks Matt Edwards, for the initial inspiration in the topic of aural architecture, and the final clarity. And to my parents, the dream house I owe you keeps getting bigger and bigger, thanks for everything.

bin·au·ral

1 - of, relating to, or used with both ears "human hearing is binaural" [1]

2 - sound recorded using two microphones and usually transmitted separately to the two ears of the listener [1]

3 - Binaural is the 6th album by the band Pearl Jam, released in May 2000 [2]

[1] "Definition of Binaural." *Oxford Dictionaries*. (Oxford University Press). www.oxforddictionaries.com.

[1] "Binaural" *Pearl Jam.* (Pearl Jam. Monkeywrench). www.pearljam.com.

ABSTRACT

Sound has the ability to affect people in a positive or negative manner: physiologically, psychologically, cognitively and behaviourally, at all times and in all places.[1] Architecture plays a key role in shaping sound, and in defining a soundscape. Architectural discourse is often dominated by visual design while the aural architecture becomes a result of the visual decisions, despite that all five senses are important to the experience of a space. Designing our soundscapes, both inside and out, is essential to creating environments which are conducive to their intended function, and not negatively effecting inhabitants. This thesis will investigate the often neglected aural qualities of architecture in order to conceptualize design solutions which engage the auditory sensory system in a positive manner. A tuned soundscape can then be proposed, exploring material and design manipulations, which help to create a more beneficial and enriching environment.

How does sound, as shaped by architecture, affect inhabitants and the experience of a space?

1 Julian Treasure, "Why Architects Need to Use Their Ears." *TED Conferences LLC.* www.ted.com.

CONTENTS

"Now I will do nothing but listen…

I hear all sounds running together, combined,

fused or following,

Sounds of the city and sounds out of the city, sounds

of the day and night…

Walt Whitman, Song of Myself [1]

INTRODUCTION

Our world, and especially in the way we design it, tends to be visually oriented. Spaces react to our presence, as Pallasmaa wrote in The Eyes of the Skin: "*buildings do not react to our gaze, but they do return our sound back to our ears*;"[2] yet we rarely consider the significance that acoustics will have on inhabitants in a space. The impacts of sound on our health, productivity, learning and information retention and general well-being are surprisingly significant. Sound defines space as much as space shapes the sound:

> "*...hearing structures and articulates the experience and understanding of space. We are not normally aware of the significance of hearing in spatial experience, although sound often provides the temporal continuum in which visual impressions are embedded.*"[3]

Sound is a sensory stimulus which can, among many things, contribute to making a room feel warm or cold independent of the actual temperature, intensify an exulted feeling in a grand cathedral, or invoke a sense of intimacy and contemplation in a small chapel.[4] Acoustic design can be greatly improved from current standards and have a more positive influence on an inhabitant's well-being, by not only diminishing noise, but creating a positive soundscape to help enhance our environments.

introduction

Every surface, geometry and different material in a space has unique sonic properties, which combined with perception and the human experience of sound, contribute to creating the aural architecture of a space. Acoustics define a basic perceptual understanding of physical spatial properties, giving a sense of the scale and materiality of the room. The study of aural architecture "*looks at sound as design: how sound defines space, creates realms of privacy or society, and produces a sense of place*."[5]

Sound is intrinsically related to its container; it radiates from a source and is influenced by every object and material it encounters. The layers of all sounds in a given place result in a soundscape, an immersive environment, which includes both natural and human made sounds.

While visual design is communicated through conventional drawings, renderings and language, clearly conveying aural architecture is more difficult through these traditional means. Sounds are impul-

Aural: "parallels visual, refers exclusively to the human experience of a sonic process".[A]

Aural architecture: "properties of a space that can be experienced by listening; an aural architect, acting as both an artist and a social engineer, is therefore someone who selects specific aural attributes of a space based on what is desirable in a particular cultural framework." [B]

sive events and are created or affected by the occupants of a space, which makes them difficult to predict and document. Museums and archives have a wealth of visual artifacts from past cultures, however sound and acoustic spaces could not be preserved until the invention of recording devices. The acoustics of musical spaces is well recognized as a significant design factor with a wealth of knowledge and written work from past centuries and contemporary times, although it is still difficult to understand how these spaces sound without actually hearing them.

The common approach to architectural design is to specialize acoustics mainly for spaces which are preeminently concerned with sound as performance, while acoustics are treated as an afterthought in what is presently seen as a pragmatic program such as offices, schools, etc. However, soundscapes are central to our everyday experiences, and these environments can be tuned to elicit more positive outcomes amongst occupants. Sound can also have a significant impact in many ways, as it "*drives some of our most important*

subconscious and conscious processes,"[6] and is "*one of the most important and fastest-acting triggers for emotion*."[7] While the individual psychological aspects of sound are more difficult to define, the impacts of sound on our health, productivity, learning and information retention and general well-being are significant. These are issues that we have essentially created for ourselves due to a lack of attention towards acoustic design, and preference for modern visual aesthetics. The prominence of hard materials and clean lines in our designs both inside and out, as well as ever-growing urban environments, has lead to an increase in the noise levels of our cities. There are many aural issues present in our everyday environments, such as high noise levels correlated to responses such as an increase in blood pressure and heart rate, sleep disturbances, a lack of privacy, increased stress, etc. Visual and aural meanings can also be contradictory which defeats the purpose of the visual design intent, for example a space with warm colours to evoke a comfortable feeling yet is comprised of hard materials that make the room sound sterile and cold.

introduction

The methodological approach adopted for this thesis includes the study of written work, site visits, precedent projects and aural analyses. This establishes an integration of history, theory, previous research and experiential knowledge to understand aural architecture topics. It includes both objective sound measurements and preceding research, as well as subjective assessments and ideas from users of the spaces which were evaluated. This research endeavours to identify and understand the many components and effects of aural architecture and the ways in which our designs shape sound, in order to propose an educated design solution. The design project portion of this thesis will consider how designers can better incorporate soundscape and acoustic considerations into everyday architecture, through the design of an aurally motivated building.

[1] Walt Whitman. "Song of Myself." *Leaves of Grass.* (New York: Pocket, 2006) 51.
[2] Juhani Pallasmaa. *The Eyes of the Skin: Architecture and the Senses.* (Chichester: Wiley-Academy, 2005) 49.
[3] Pallasmaa, *The Eyes of the Skin,* 49.
[4] Barry Blesser and Linda-Ruth Salter. *Spaces Speak, Are You Listening?: Experiencing Aural Architecture.* (Cambridge, MA: MIT, 2007) 2.
[5] William L. Hamilton "The World of Sound." *Dwell,* http://www.dwell.com/essay/article/world-sound.
[6] Seth S. Horowitz. *The Universal Sense: How Hearing Shapes the Mind.* (New York: Bloomsbury, 2012) 102.
[7] Horowitz, *The Universal Sense,* 113.

[A] Blesser and Salter, *Spaces Speak,* 5.
[B] Blesser and Salter, *Spaces Speak,* 5.

AURAL ARCHITECTURE

"The echo of steps on a paved street has an emotional charge because the sound reverberating from surrounding walls puts us in direction interaction with space, the sound measures space and makes its scale comprehensible…every city has its echo which depends on the pattern and scale of its streets and the prevailing architectural styles and materials. The echo of a Renaissance city differs from that of a Baroque city. But our cities have lost their echo altogether. The wide, open spaces of contemporary streets do not return sound, and in the interiors of today's buildings echoes are absorbed and censored… our ears have been blinded." [1] *- Juhani Pallasmaa*

Aural refers to the sense of hearing. Aural architecture encompasses the "*composite of numerous surfaces, objects, and geometries in a complicated environment*"[2] which are experienced by listening. It considers the emotional, behavioural and sometimes physical response to sounds in a space, whereas the terminology of acoustic architecture is used to refer to the physical properties of sound in an architectural space. A soundscape is the aural or auditory landscape, the transient composition of layers of sonic information, which are present in an environment. Aural architecture and soundscapes exist regardless of whether they are intentionally designed, which is why it is an important consideration in the design

process. For example, while open plan classrooms may seem like a good idea visually and organizationally, a $50 million school built recently in the U.K. was designed with a large central atrium and classrooms leading off it with no back walls. The children couldn't hear the teachers, and so they had to go back and spend an additional $1 million on adding walls.[3] In contemporary architecture, acoustic design is often disregarded in ordinary spaces. As sound can have such significant effects on a listener's mind and body, there is an opportunity to encourage beneficial sounds and control noise strategically for creating more immersive experiences and environments through design.

We are dependent on our combined senses to understand and interpret spaces, and the sounds of a place can carry social meaning and cultural values. As a social and cultural signifier, aural characteristics can define a space as public or private, grand or intimate, relaxing or stressful, etc. The experience of the sounds of a space can be equated to that of a film soundtrack, as the matching of aural and visual can

Hearing: "the detection of sound." [A]

Listening: "active attention or reaction to the meaning, emotions, and symbolism contained within sound." [B]

greatly impact the perception of a scene. A lobby with hard marble floors reflects the sound of footsteps throughout the room, as if to announce the visitor publicly. However if the floor was to be covered with a carpet, it would instead dampen the sound making the arrival unnoticed and more private. Similar acoustics in a different setting can convey a different feeling; such as in an apartment, hard surfaces can make the room seem cold and uninviting, whereas soft materials and furniture add warmth and intimacy. Visual and aural meanings are often complementary, such as the design of religious spaces. A cathedral is visually expansive with resounding acoustics that amplify the speaker or music, together creating a sense of transcendence appropriate to an architecture dedicated to spirituality. In smaller chapels or niches in a cathedral, the acoustics reinforce the need for intimacy with a more quiet, less reverberant space. While the sounds of a cathedral are due to the unaltered, cavernous form of the building, grand concert halls are designed precisely to shape and control sound for optimal clarity during performances. Just as the tiered seating layout allows for viewers to see the performance from

all positions, well designed acoustics control the sound to be heard properly throughout. When visual and aural cues are contradictory, the response can conflict with the intentions of use. Restaurants often include visual elements, which should invoke a relaxed atmosphere to socialize and enjoy your meal, however they are typically very loud, making it difficult to understand conversation and shrinking the distance of social interaction. This experience of isolation conflicts with the intent of a restaurant as a social gathering space.[4]

An acoustic horizon is most often delineated architecturally by physical boundaries such as walls, or by increasing the distance between the sound and listener. In French villages in the 19th century, the maximum distance from which a town's bells could be heard determined the boundaries of the community. If you were not within the acoustic horizon of the bells, you were not considered a citizen of that town.[5] An acoustic horizon can also be altered by the proportion of target sound to unwanted noise. For example, in a loud restaurant where conversation is difficult, an ideal solution would be to

Acoustic horizon - "maximum distance between a listener and source of sound where the sonic event can still be heard... the acoustic horizon is thus the experiential boundary and delineates which sonic events are included and which are excluded."[C]

attenuate background noise, such as music and other conversations, instead of increasing your own voice to converse. Sounds usually have a much larger acoustic horizon than the distance the eyes can see, and are able to travel through architecture whereas visual obstructions completely block sight. Additionally, architectural boundaries may be visual, aural, or both. A glass facade is an auditory partition but not visual, whereas a light curtain is a visual boundary but allows sound through.

Animals very effectively use sound signals and adapt to their acoustic environments. While walking through a jungle in Costa Rica, the sound of howler monkeys resonated through the dense forest even though we were unable to actually see the monkeys.

A soundscape is the voice of a society and an environment. Our everyday activities animate the soundscape, but how and what we build is what amplifies or controls the sound. Derived from the word landscape, a soundscape is the acoustic manifestation of a place comprised of sonic events and objects, which are heard, not seen. Soundscapes can be conceived as a system of communication, like an urban composition with multiple layers of contributors, unique locally and culturally. Sound can help add to an understanding of a place, which may not otherwise be visually identifiable. The dis-

Soundscape: the auditory equivalent of landscape, a sound or combination of sounds in an environment. (The term was first used by Canadian composer, environmentalist and writer R. Murray Schafer.)

tinguishable features of a soundscape are keynotes, sound signals and sound marks.[6] Keynotes are the background tonality of a place, such as sounds created by the geography and climate of a region. A signal is a sound directing attention, and a soundmark is analogous to a landmark. When Frank Lloyd Wright designed Fallingwater in the mid 1930s, he made an important aural design decision to place the house over the falls rather than viewing them from across. The unique keynote sound of the falls is always heard rather than seen, as the water can constantly be heard throughout the house.

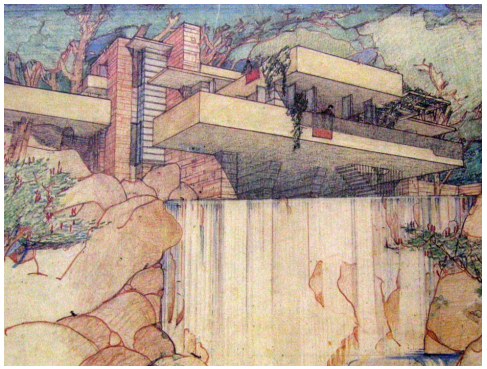


Figure 1: Fallingwater sketch by Frank Lloyd Wright.

Much of our modern soundscape is less than desirable, with noise abatement becoming increasingly necessary, and as R. Murray Schafer contends: "*it would seem the world soundscape has reached an apex of vulgarity in our time*."[7] Schafer considers a favourable soundscape to be a hi-fi (fidelity) system, in which discrete sounds are discernible with lower ambient noise levels and perspective created by background and foreground sounds. However, the Industrial Revolution introduced soundscapes to low-fi, with sound congestion

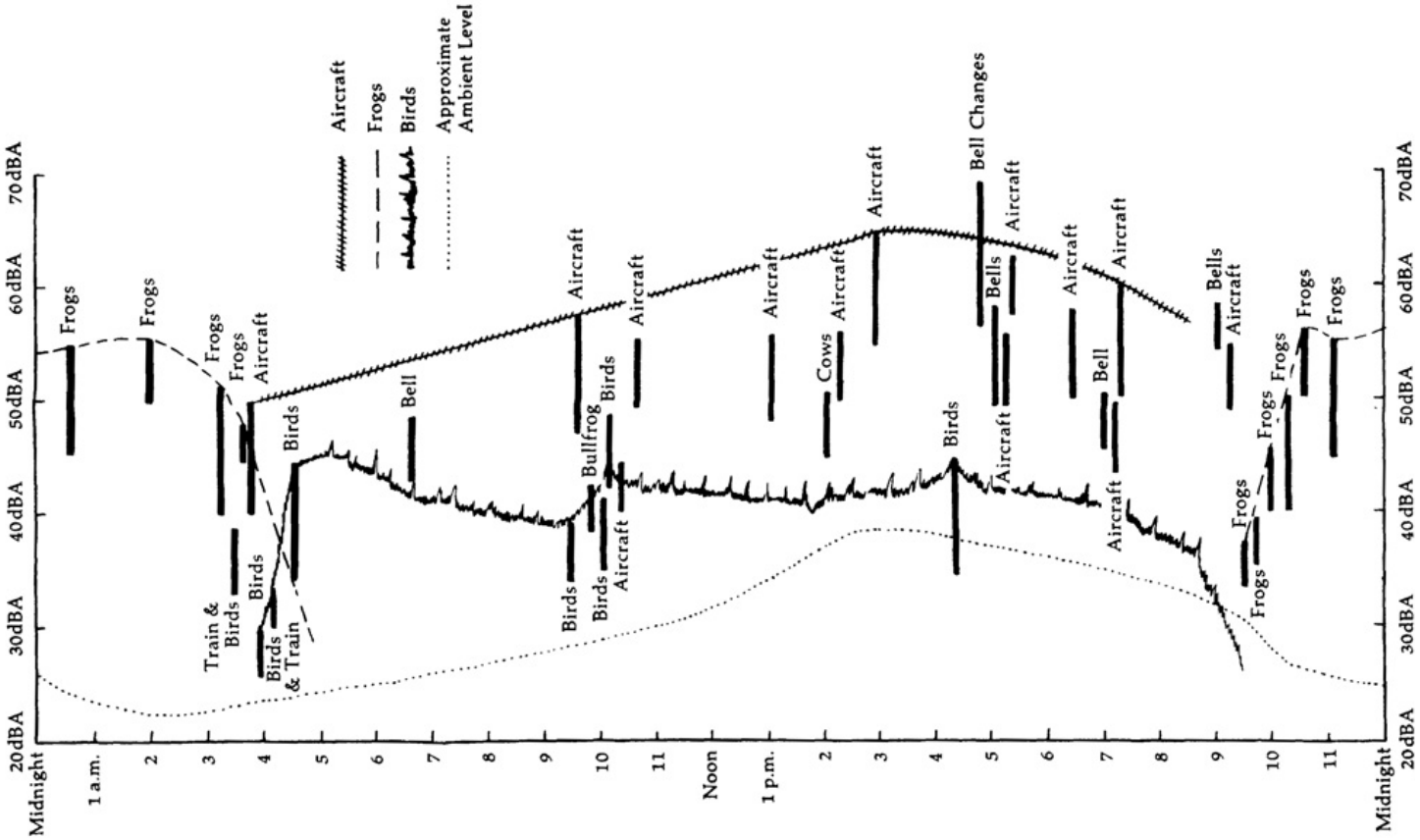


Figure 2: R. Murray Schafer's log of sound events in the countryside of British Columbia, during a 24 hours period.

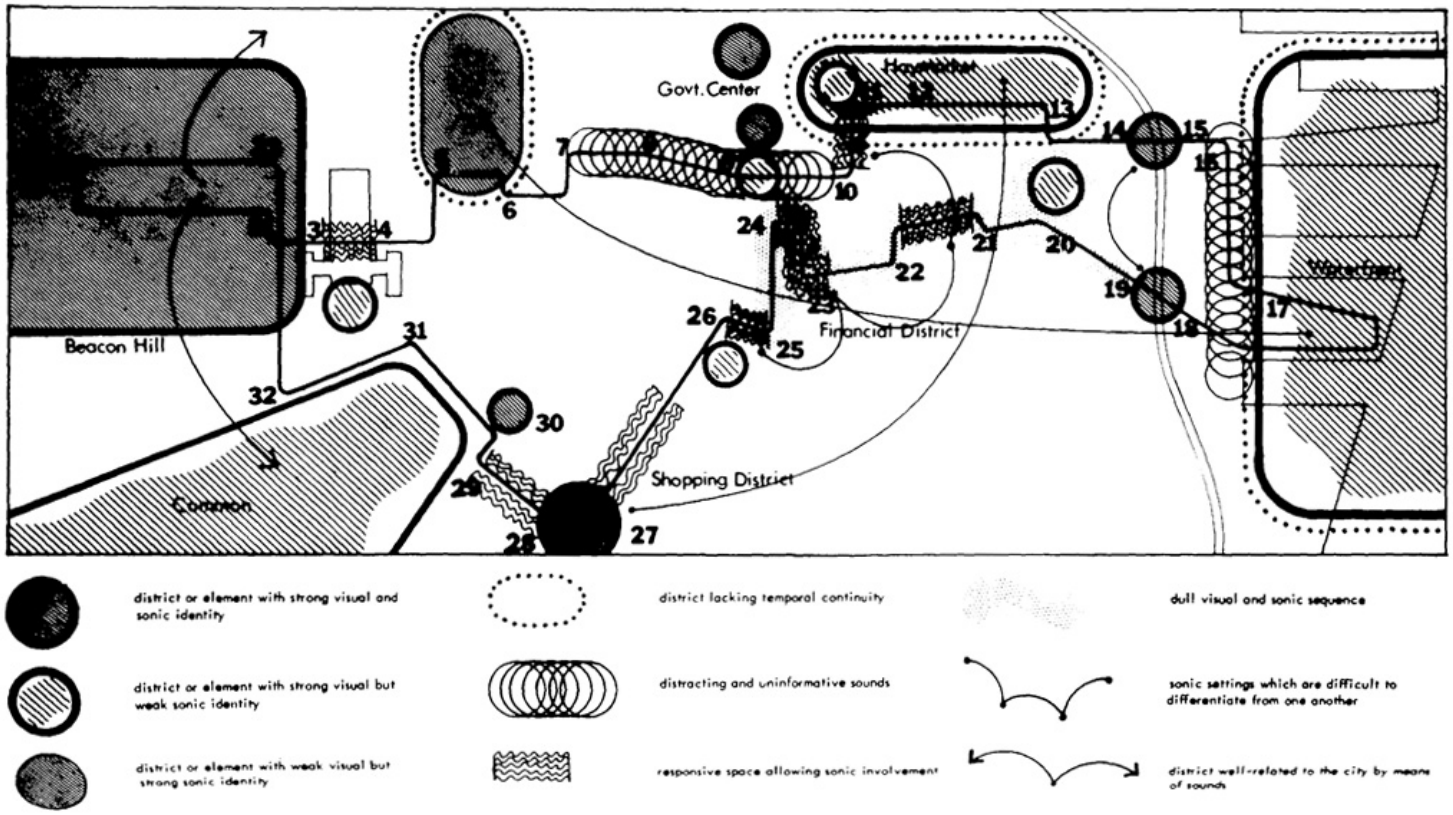


Figure 3: A sound event map by Michael Southworth, downtown Boston, showing areas with similar and contrasting sonic environments.

and louder noises. The World Soundscape Project (WSP) was established by Schafer in the late 1960s in order to research, document and educate on the changing soundscape at the time.[8] The group initiated a study called The Vancouver Soundscape, which included recordings of the city, as Schafer was concerned that the Vancouver soundscape was degrading and that important soundmarks were being lost as the city developed. The WSP is significant as it was a relatively new idea that sound education and preserving soundmarks and sound environments is important.

While much of history is conserved through drawings or photographs, sound recordings are not as prevalent and only began when the technology became available. The physical degradation of a building is easily visible, and recognized heritage buildings are protected in Canada with strict rehabilitation and restoration guidelines. However, the same attention is not given to the conservation of soundscapes or soundmarks, which can also have cultural character defining elements just as a heritage building does. For example,

the completely manual fifty-three bell Peace Tower Carillon in Ottawa can be heard blocks away and sounds to mark important occasions. This is a unique sound mark to Ottawa, which Prime Minister Mackenzie King called, "*the voice of the nation*."[9] Ottawa has strict building height control regulations in the downtown which protect the integrity of views towards the Parliament Building Peace Tower, however there are no similar acts of preservation towards soundmarks. When the Carillon was first inaugurated, it was likely heard from a much greater distance than it is today due to the growth and traffic of the current downtown area. Unfortunately, the bells will continue to fade into the background of the downtown soundscape if the area becomes even more full of noise in the future.

Figure 4: Carleton University's music department offers a "Certificate in Carillon Studies" as a performance-studies option for music students, which recognizes the cultural and historical importance of Ottawa's carillon.[D]

While noise abatement is a negative approach towards sound, aural architecture and soundscapes can be designed in such a way that instead encourages and preserves desired sounds. For example, in health care facilities, certain sounds are important alerts to nurses, speech intelligibility is crucial for physician communication and

music can relax patients. Although high noise levels can lead to health related issues (as will be discussed in the succeeding chapter), erasing or minimizing all noise would eliminate sounds that are important signals. Rather than reducing all sounds, "*the ultimate endeavour is to learn how sounds may be rearranged so that all possible types may be heard to advantage - an art called orchestration*"[10]

aural history

Performance spaces and places of worship are the most prevalent buildings analyzed within the history of aural architecture, as their programmatic success is more dependent on carefully articulated acoustics. Societies have evolved from adapting caves as ritual spaces for their resounding reverberation, to building highly detailed cathedrals and concert halls, to the use of technology to reproduce sound in a controlled environment. Early societies believed sounds to come from powerful spirits, such as those from thunder, wind and resonant caves. Cave wall pictures are often deliberately acoustically related, where images of animals seem to come alive in highly reverberant spaces as people's movements create sound. Aristotle first introduced the concept that sound was a physical phenomena as opposed to spiritual around 350 BC.[11] In ancient times and through the Medieval period and Renaissance, sound and music were thought to be inherently connected to architecture by the fundamental harmony of the universe. Architects worked to re-create the divine order through the use of numeric ratios that represented the harmonies of music and order of the cosmos.

During the 19th century, theatre and music became more commercialized, meaning that larger theatres had to be built and paying audiences had to be able to hear the performance. The British Architect George Saunders proposed an oval theatre shape based on his investigations of audibility, determined by encircling a person speaking and marking out the most distant point at which he could hear the speaker. Joseph Henry, a mid 19th century physicist, used a vibrating tuning fork to determine the absorptive effects of materials on sound energy. In 1890, Dankmar Adler and Louis Sullivan completed Auditorium Theatre in Chicago, which was considered a great success acoustically. Adler was the acoustic expert behind the theatre, however he was unable to describe why his design was a success beyond basic geometry, aside from Sullivan's declaration that Adler's sense of acoustics was simply "intuitive". A more technical acoustic breakthrough in 1900 came in the design for Symphony Hall, when Wallace Sabine was able to create a mathematical equation, calculating the reverberation time by the volume of the room and surface area of each individual sound-absorbing material within.

Figure 5: Auditorium Theatre, Chicago, view from the stage.

Figure 6: Auditorium Theatre, Chicago, view from the audience.

Figure 7: Boston Symphony Hall

An ideal reverberation time for the theatre could then be controlled in the design using his formula, and elements could be adjusted with mathematical precision, although Sabine's formula relied on the limitations of the human ear as a measuring device. Sabine measured a sound source using a stopwatch and his ears, timing the delay between the source until when he was no longer able to hear the sound.

Figure 8: Notre Dame Cathedral, Paris, a highly reverberant stone cathedral.

Connecting musical styles and acoustics through history demonstrates that musical genres are inherently connected to the context they are played in; a social response to auditory awareness. For example, in stone-walled Gothic cathedrals of the Middle Ages the reverberation time is very long, which influenced music to be comprised of long notes in a modal structure as this is what sounded the best. Mozart later played in smaller, less reverberant rooms often with heavy carpets and curtains, allowing his music to be very intricate with clarity. Mozart's music would have become blended and incomprehensible in a Gothic cathedral, making the venue a key element to his music.[12]

aural history

The relationship between sound and space changed significantly in the 20th century, as new technology began to gradually disassociate the relationship of space from sound. By the 1920s, the building materials industry offered a range of sound-absorbing materials, with new electroacoustic measuring instruments now available to research and advance these materials. New inventions in sound reproduction and reception through microphones and speakers resulted in a shift towards conceiving sound as electric signals, rather than as an acoustic phenomena. These new technologies provided the capabilities to construct the sound of a space, rather than relying on the acoustics of the architecture. The reverberation of a room:

> *"had always been a direct result of the architecture that created it, a function of both the size of a room and the materials that constituted its surfaces. As such, it sounded the acoustic signature of each particular place, representing the unique character (for better or worse) of the space in which it was heard. With the rise of the modern soundscape this would no longer be the case. Reverberation now became just another*

kind of noise, unnecessary and best eliminated."[13]

The new standard for acoustics was efficient, clear, controllable electronic sound, disassociated from the aural architecture of the room and lacking the distinctive qualities that came along with a room's individual sound.

Figure 9: John Cage's 4'33", where the performer sat without playing a note, but still flipped through each page of sheet music.

In 1952, the American experimental composer John Cage performed a piece called 4'33" (4 minutes, 33 seconds). The score simply instructed the piano player to not play a thing during the entire length, which instead made listener's aware of sounds in their immediate surrounding. Cage hoped to attune his listeners to the importance of silence in musical structure. This gives the audience a focused attention to the aural architecture of the space which they would not normally have, revealing the ambient sounds of the space.

It was also not until the 20th century that the understanding of experiential qualities of spatial acoustics emerged, connecting topics such as perception, psychology and neurophysiology to sound. Most

designs today consider acoustics as secondary to visuals, in favour of aesthetically pleasing architecture. While aural architecture is not traditionally associated with most building designs, establishing and advancing the connection can present this missing sensorial design element and eliminate the negative effects of poor acoustics, creating a more aurally conscious society.

[1] Pallasmaa, *The Eyes of the Skin,* 51.
[2] Blesser and Salter, *Spaces Speak,* 2.
[3] Treasure, "Why Architects Need to Use Their Ears." (TED talk)
[4] Blesser and Salter, *Spaces Speak,* 3.
[5] Barry Blesser and Linda-Ruth Salter, "Questions and Answers about: Spaces Speak, Are You Listening? Experiencing Aural Architecture." www.blesser.net
[6] Murray R. Schafer. *The Soundscape: Our Sonic Environment and the Tuning of the World.* (Rochester, Destiny Books, 1994), 9.
[7] Schafer, *The Soundscape*, 3.
[8] "The World Soundscape Project." *Simon Fraser University*. www.sfu.ca.
[9] Michael Morreale, "The Peace Tower Carillon: Canada's Most Iconic Instrument." *CBC Radio-Canada*. www.music.cbc.ca.
[10] Schafer, *The Soundscape*, 238.
[11] Blesser and Salter, *Spaces Speak,* 80.
[12] David Byrne. *How Music Works.* (San Francisco, CA: McSweeney's, 2012), 20.
[13] Emily Ann Thompson, *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933.* (Cambridge, MA: MIT, 2002), 3.

[A] Blesser and Salter, *Spaces Speak,* 5.
[B] Blesser and Salter, *Spaces Speak,* 5.
[C] Blesser and Salter, *Spaces Speak,* 22.
[D] "Certificate in Carillon Studies." *Carleton University*. www.carleton.ca/music/carillon

THE BODY + SOUND

"We shape our dwellings, and afterwards our dwellings shape us."
- Winston Churchill, 1943 [1]

Hearing and listening are not only complementary to vision and the other senses in comprehending a space, but can also evoke responses such as physiological reactions, feelings, emotions and memory associations. Some aural environments have an obvious impact on a listener, such as a restaurant where a high ambient noise level makes it difficult to carry a conversation. This type of atmosphere is generally considered irritating and not enjoyable, as "*aural architecture can influence our moods and associations. Although we may not be consciously aware that aural architecture is itself a sensory stimulus, we react to it*."[2] Noise pollution is now a recognized and wide spread issue as high levels of noise can cause various negative effects on the body, and these levels of sound are found in hospitals, classrooms, offices and streets.

Inhabitants of a space react to the sound source as well as the spatial acoustics, as each is an aural stimulus and can therefore trigger anxiety, tranquility, socialization, isolation, frustration, fear, boredom, pleasure, etc.[3] The recognition of an auditory event can be effective

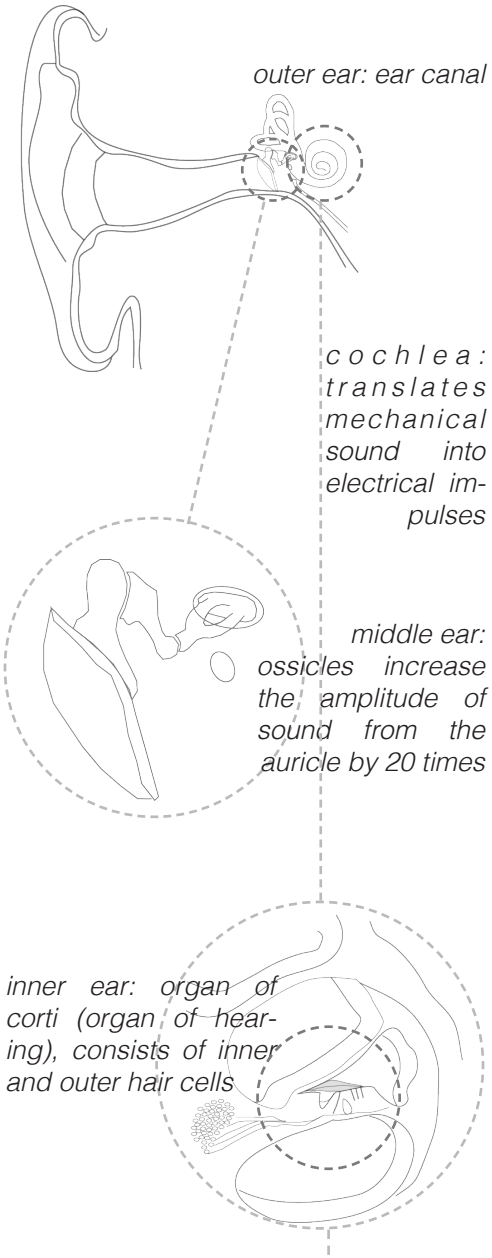
at three basic levels; categorized as sensation, perception and affect. Raw sensation is simply the detection of a sound without meaning, resulting in little reaction. The following stage is perception, which is a recognition through cognitive processing that gives significance to the sound. For example, comprehending speech requires knowledge of the language, otherwise the words would be insignificant tones. Affect is the impact response to a meaningful sound, which can produce an emotional or visceral response, attentiveness, etc. Such responses can be overt or subtle, and conscious or unconscious.

Auditory spacial awareness: "more than just the ability to detect that space has changed sounds; it includes as well the emotional and behavioural experience of space...listeners reach both to sound sources and to spatial acoustics because each is an aural stimulus with social, cultural and personal meanings."[A]

Decoding sound and spatial perception are directly related to various brain functions, "*sound and silence have profound effects on the nervous system, on our emotional responses to the world around us, and on the nerve chemicals and hormones flowing from those emotion centres, which ultimately affect the immune system and how we heal*."[4] The Academy of Neuroscience for Architecture (ANFA) was founded in 2003 to advance research ties between the two fields, studying the relationship between neuroscience and the human re-

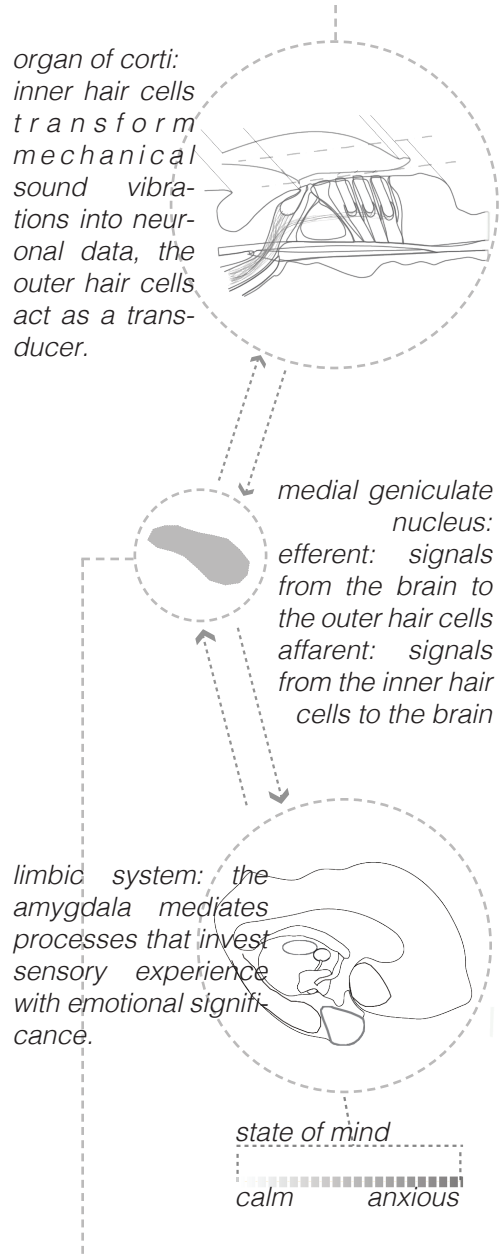
sponse to the built environment. The five areas in brain systems, which are categories of study, are sensation and perception, learning and memory, decision making, emotion and effect and movement.[5] The areas which pertain most to aural design are sensation and perception (which studies how we see, hear, smell, etc,) and emotion and affect (how we become afraid, excited, happy or sad). Different areas in the brain are specialized in the detection of speech or musical features and different sounds are directed to various emotional centers in the brain, therefore triggering an emotional response.

Marco Frascari wrote of the importance of designing spaces for emotional experiences in "*De Beata Architectura: Places for Thinking*". He described how the details of architectural forms and surfaces have been shown to emotionally engage people with their environment, and that this connection can enrich our experience, as well as our of well-being. Empirical evidence and recent research has connected that "*our neurological mechanism reacts to the emotional field, while inducing a physical reaction. Some of the highest*



levels of sensory connection to the built environment have been evidenced in the great buildings and urban spaces of the past."[6] Modern architects create buildings which are functionally well suited to their programmatic activity, yet the emotional component is often absent. Frascari contends that only places which allow for 'thinking' can result in a vita beata (a good life).[7] Sound, and the combination of all five senses, act as a direct stimuli and are therefore the catalyst for this emotional component.

The contrast between silence and sound creates a noticeable response, as nerve cells react to an impulse more than an unchanging repeated stimuli. The brain's fear centre, the amygdala, responds to the startle reflex from a loud noise. The basic human primal response to loud noises is that danger is nearby, known as the "fight or flight" instinct. Loud noises hinder the healing process due to the effects of stress on the immune system, such as "*prolonging wound healing, reducing the body's ability to make antibodies, and impairing the immune system's ability to fight infection in many other ways*."[8] The



brain's amygdala region relays the fear state from any concerning sound to various systems, such as loud noises, which can result in an increased heart rate (sound levels above 60dB), increase in blood pressure (above 50dB), heart attack incidence, permanent hearing loss (above 70dB), higher cholesterol levels, frozen body movement, slowed digestion, and many other issues.[9] High levels of noise creates stress, which increases cortisol levels, and can impair memory. This can be a significant issue in an open plan office for example, as noises from around the office are not only disruptive, but stress can also impede productivity and cause co-workers to be less amiable when working together. In contrast, natural sounds such as birds have an ingrained positive response biologically and evolutionary, as our caveman ancestors knew that there were no predators nearby with the presence of bird sounds. Similarly, we are dependent on our binaural hearing to localize sounds, such as prey and predators. At a concert, musical instruments are transformed by spatial reverberation, which can create enveloping reverberation, a feeling that the audience is surrounded by sounds with no clear source location.

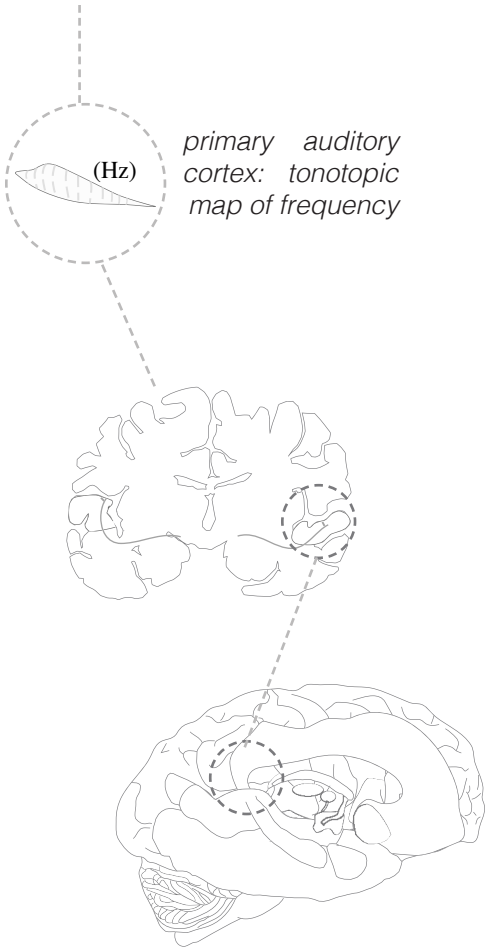
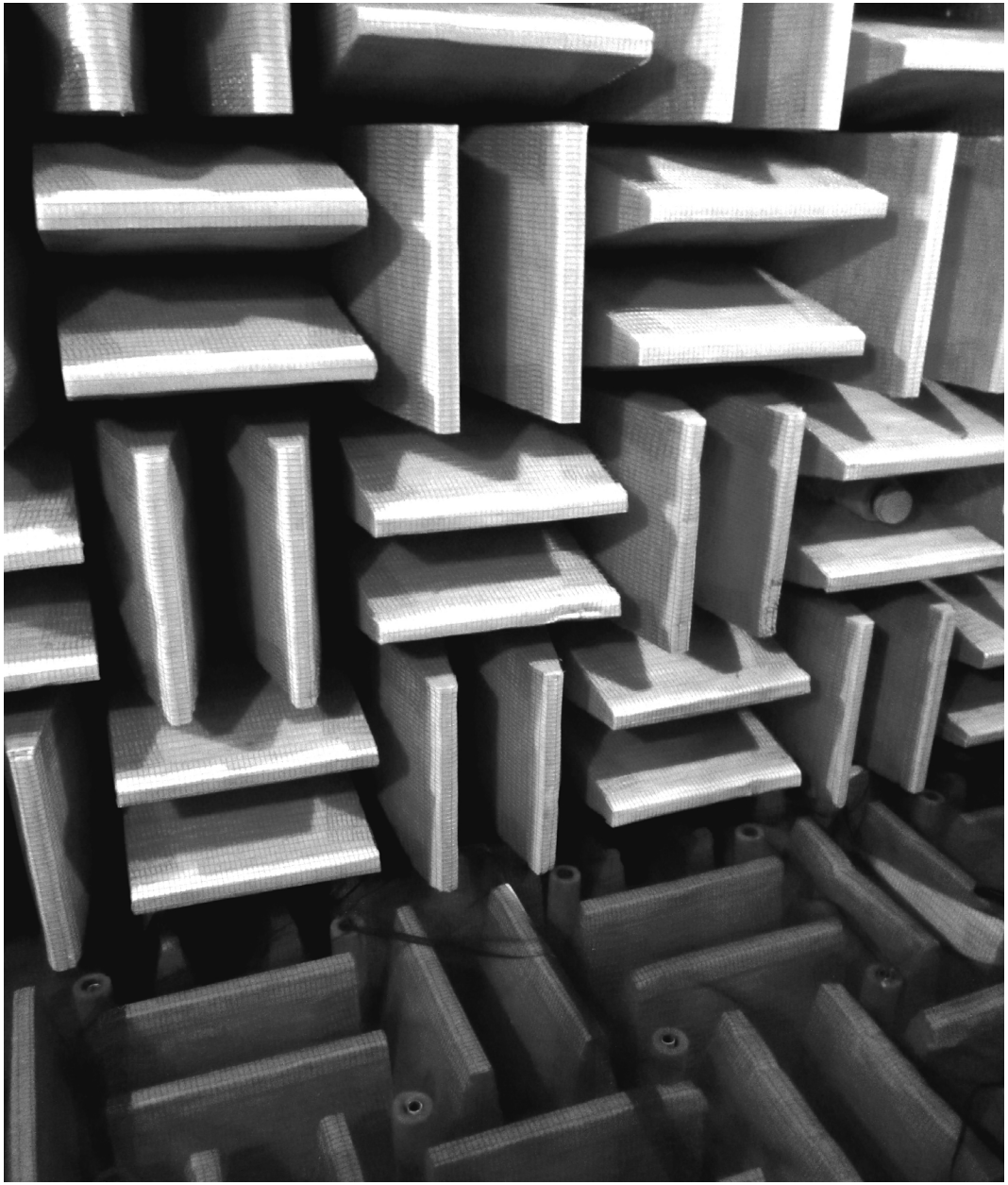


Figure 10: Illustrations of the auditory system.

This inability to localize a sound can result in anxiety, awareness and/or excitement, and enveloping reverberation acts as an aural stimulant.[10] In contrast, monotonous repeated sounds can cause less of a response over time due to habituation and even become relaxing, such as rain, waves, wind and low level HVAC, known as pink noise. Music has been shown to cause a shift in nervous system activity, from the sympathetic (stress) to parasympathetic (relaxation). Listening to classical music, called the "Mozart Effect" has even been shown to increase test scores, learning and memory retention.[11] Both sound and silence affect the body profoundly, from the "*nervous system, emotional responses to the world around us, and on the nerve chemicals and hormones flowing from these emotion centres, which ultimately affect the immune system and how we heal*."[12] In these ways, aural environments are constantly affecting our well-being, and can therefore be conceived to produce beneficial responses when designed to do so.

Contrary to environments that are too loud, sensory deprivation dis-

connects us from the physical and social environment. An anechoic chamber demonstrates that the absence of sensory input can also be detrimental. Such a space is a highly engineered acoustic room, which almost completely absorbs all sound reflections (over 99%), mostly used for research and recording. In an anechoic chamber the ears can become sensitive two new sounds, one high and one low as described from John Cage's experience: "*the high one was my nervous system in operation, the low one my blood circulation*."[13] Speaking to a person directly beside you instead feels like they are far away as your words seems to drop off in front of you, and your own presence in the room is not reflected by an acoustic response. The brain struggles with the missing sense of sound, and such a disconcerting experience can cause some people to feel dizzy or even hallucinate as spacial orientation is difficult to comprehend.[14] Though anechoic chambers are an extreme situation of sound control and not an everyday occurrence, they exemplify how much we rely on sound as a component of the sensory perception of a space.



The anechoic chamber at The National Research Council (NRC) in Ottawa, showing a wall and the floor platform. (Image taken by Emily Brett)

the body + sound

Each individual perceives and reacts to specific sounds differently, as sounds can hold different meanings or memory associations for everyone. In outdoor soundscape studies considering how people perceive different sounds, most natural sounds are considered enjoyable, such as birds, insects, frogs, wind, water, waves, etc. Cultural sounds are also favourable, such as sound marks like church bells, festivals or fireworks. However, many daily life sounds such as traffic, garbage collection and noise from neighbours' are heard negatively.[15] Ambient background sounds, such as traffic noise or sounds from other classrooms, has even been shown to impede reading skills in children (and add to the difficulties of poor acoustics).[16] Sounds can also alter our behaviour in a space to some extent, such as a space where voices carry and echo, causing people to lower their voices. This is often noticeable in larger art galleries or museums, where a visitor's own footsteps reverberate throughout the space, making them more aware of the level of their own sounds.

Music is one type of sound which most clearly exemplifies how

effects of sound

[+]

natural sounds
birds, insects, frogs, wind, water, waves

music

cultural sounds
church bells, clock chime, festivals, fireworks

sleep quieter spaces result in better sleep

performance the "Mozart Effect" shows that classical instrumental music can increase test scores, learning and memory retention

relaxation monotonous sounds can be relaxing (ex. rain, waves, wind, etc.)

stress cortisol (stress hormone) decreased with calming music

the body + sound

sound can have significant effects on listeners, similar to the reactions we have to regular sounds. A performance with loud music makes the listener feel excitement, as loudness represents intense activity and enhances neurological attentiveness.[18] This is why playing faster music loudly can help with exercise intensity and motivation, such as running, while the listener may not even perceive a change in effort. Just as loud sounds effect the body, music can also result in an increased heart rate, blood flow, stress on the immune system, etc. Depending on the genre of music we listen to, a change in emotion is usually noticeable, such as the relaxing feeling of listening to classical music or the tranquility of natural sounds. Sound installations are a simple example of how sound can be used to beneficially affect behaviour and can have a significant impact in urban environments. In England, sound systems that played classical music were installed in the London Underground at a station where crime was so prevalent that train drivers refused to stop there. Eighteen months later, robberies had decreased by 33%, assaults on staff by 25% and vandalism by 37%. A similar installation in California used music

effects of sound

[-]

daily noise
traffic, HVAC, garbage collection, neighbours

loud sounds
excessive noise /reverberation, airplanes, trains, crowds, horns

↓

sleep decreased sleep, more awakenings

heart rate increases (60dB+), blood pressure increases (50dB+)

hearing loss (70dB+)

performance lack of ability to concentrate, less speech intelligibility

stress link between stress and release of cortisol, cortisol can impair memory

and bird sounds along one of the city's main roads, resulting in a 15% crime reduction in the first year.[18]

Although many of the consequences of sound are subtle, personal, or often not well known, considering how the aural setting of a place could effect inhabitant's is an important design detail. When designers are not mindful of the aural qualities associated with the architecture, negative sound effects can make the spaces not enjoyable and unsuccessful. An office environment should not cause unnecessary stress or distraction from work, and a classroom should always allow for each student to clearly hear their teacher. Understanding how sound can affect us, and connecting this to the built environment can lead to designs which are fully supportive and beneficial to their use.

[1] Blesser and Salter, *Spaces Speak,* 1.
[2] Blesser and Salter, *Spaces Speak,* 2.
[3] Blesser and Salter, *Spaces Speak,* 11.
[4] Esther M. Sternberg, *Healing Spaces: The Science of Place and Well-being*. (MA: Belknap of Harvard UP, 2009), 74.
[5] John P. Eberhard, "Applying Neuroscience to Architecture." *Neuron*, Vol. 62 Issue 6 (2009), 755.
[6] Marco Frascari. "De Beata Architectura: Places for Thinking." *The Cultural Role of Architecture: Contemporary and Historical Perspectives.* (Milton Park, Abingdon, Oxon: Routledge, 2012), 91.
[7] Frascari, *De Beata Architectura*, 83.
[8] Sternberg, *Healing Spaces*, 73.
[9] John P. Eberhard, *Brain Landscape: The Coexistence of Neuroscience and Architecture.* (Oxford: Oxford UP, 2009), 123.
[10] Barry Blesser and Linda-Ruth Salter, "Aural Architecture: The Missing Link." www.blesser.net
[11] Donna Lerch and Dr. Thomas Anderson, "The Mozart Effect: A Closer Look." (2000) www.lrs.ed.uiuc.edu.
[12] Sternberg, *Healing Spaces*, 74
[13] Schafer, *The Soundscape*, 256.
[14] "Quietest Place on Earth' Causes Hallucinations." *SmartPlanet*. www.smartplanet.com.
[15] A.L. Brown, "Acoustic Objectives for Designed or Managed Soundscapes." *Soundscape Volume 4 Number 2* (2003), 19
[16] Eberhard, *Brain Landscape,* 62.
[17] Barry Blesser and Linda-Ruth Salter, "The Other Half of the Soundscape: Aural Architecture." www.blesser.net
[18] Julian Treasure. "Building in Sound" *BIAMP Systems*, 9.

[A] Blesser and Salter, *Spaces Speak,* 11.

ARCHITECTURAL ACOUSTICS

"Listen! Interiors are like large instruments, collecting sound, amplifying it, transmitting it elsewhere…" - Peter Zumthor [1]

While the role of an aural architect is not an existing profession, the idea is that an aural designer can discover what aural properties are functional and desirable for the inhabitants of a space or soundscape. Acoustic engineers focus on the specific measurable physical acoustics, but it is important to first understand how to best aurally design spaces to meet the needs of inhabitants.[2] As early as the first century BC, Vitruvius wrote of Greek and Roman theatre design in Ten Books on Architecture, including the importance of acoustic design. Vitruvius' ideas are based on fundamental principles of how sound waves travel due to geometry, proportion and layout. The human voice is crucial to theatre performance, and before amplification it was solely shaped by the surrounding space. Vitruvius wrote of harmonics as a musical science, resonating vessels, acoustics of the theatre site, etc.[3] While current acoustic design has become more advanced and is often considered the role of an engineer, Vitruvius' principles exemplify the importance of the architect in shaping the aural environment and how this was previously thought to be part of the architect's understanding.

architectural acoustics

The focus of this thesis is on composing spaces for the desired experiential qualities and how architectural decisions define the acoustic outcome of spaces and soundscapes, rather than quantifying sound as an acoustic engineer does. In order to do so, a basic understanding of acoustic principles is required to link the contents of previous chapters to ways in which physical design shapes the sounds of spaces. Sound sources are modified by spatial acoustics through reflection, transmission, diffraction, absorption, reverberation, etc, which are dependent on form and materiality. For example, a piano sounds very different in a concert hall compared to a living room due to the different shape and materials of the spaces. Concrete, glass, steel and other hard, smooth materials are prominent in many designs today because of their aesthetic appeal, however they reflect rather than absorb sound waves and can create very noisy, homogenous environments. In contrast, the city of Venice has a lot of traditional limestone buildings, making a quieter city because limestone is a more porous and less reflective material than our typical glass and concrete buildings.

materiality

Sound absorption and reflection are a result of material properties, as well as how these materials are assembled and detailed. Softer, more porous and dense materials are more absorbent, such as carpet, heavy fabrics and batt insulation. In contrast, brick, concrete, glass, gypsum board, plywood, tiles and steel are usually more reflective depending on how they are constructed. Concrete can be aerated to increase the porosity, which helps it to be more absorptive. As gypsum board resonates when given an airspaces, it can absorb low frequencies, but still reflects higher frequencies. Plywood is similar in its ability to resonate, and specially detailed resonant absorbers can be used to "tune" a room.[4] Sounds can also be transmitted through thin walls and materials like partition walls or light fabrics, or attenuated through thicker materials such as concrete and brick exterior walls.

Materials can also be described in terms of timbre, a psychoacoustic quality of how we perceive the tone color. In comparison to visual, we often associate colors such as red and orange to warmth and blue

and green as cold. It is easier to understand this quality of sound when listening to instruments, but aural architecture can also be perceived in terms of timbre. A church with wood panels and pews will sound warmer than a lobby with steel columns and tile floors, as wood and fabrics are generally associated with warmth (lower pitch), while aluminum and steel are considered cold (higher pitch). For example, the Swiss Soundbox by Peter Zumthor is described as sonically warm due to the majority of wood throughout, "*the structure is an enormous cabinet of larch and pine, warm to both the hand and the ear…The structure breathes and sings with beautiful timber lungs*." [5]

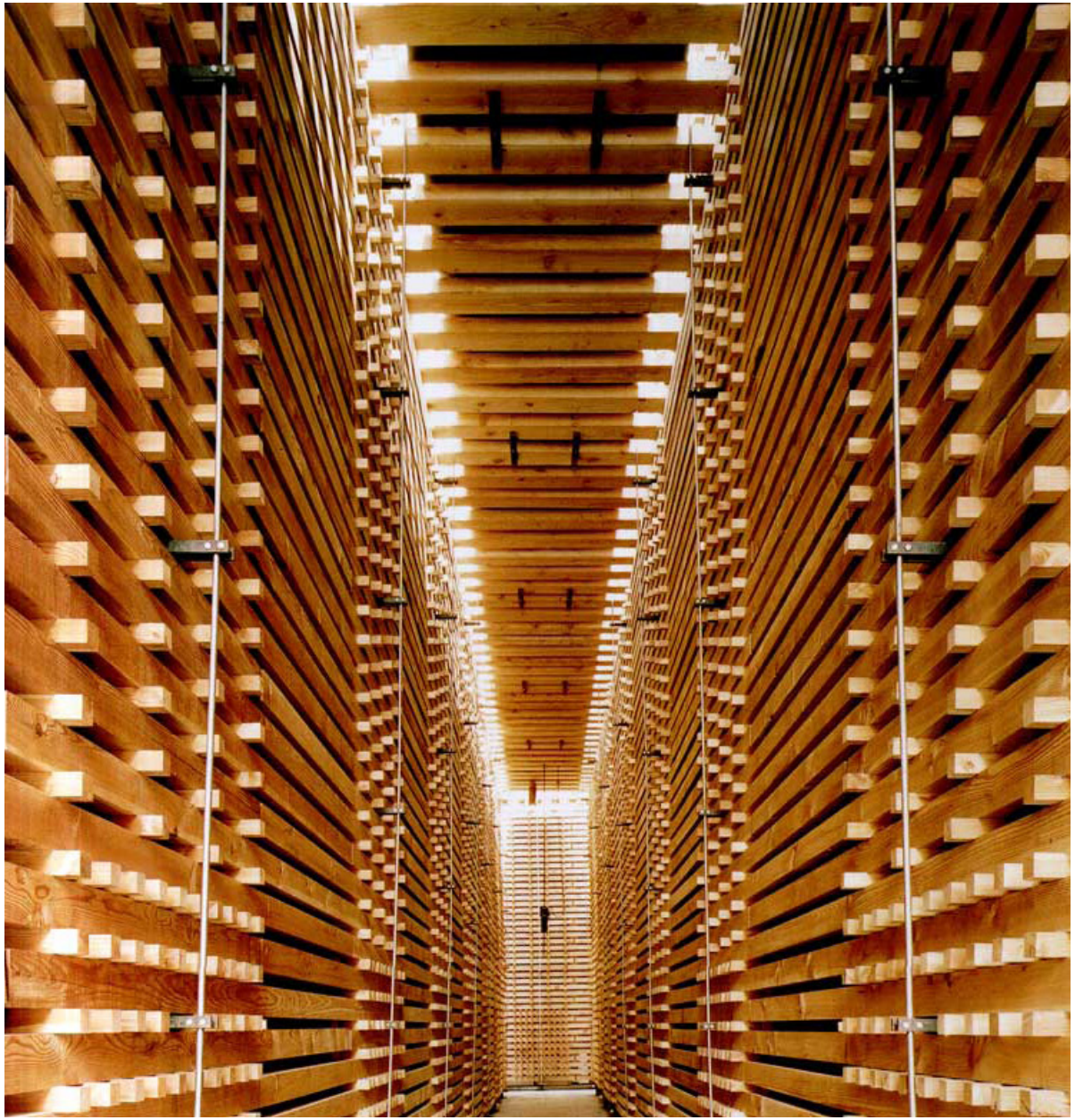
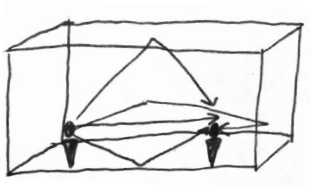


Figure 11: the Swiss Soundbox by Peter Zumthor.

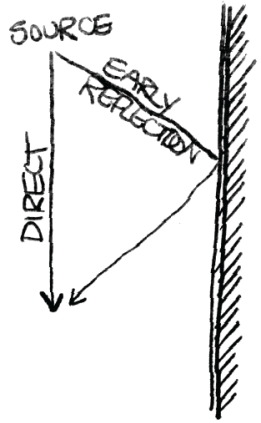
sound properties + behaviour

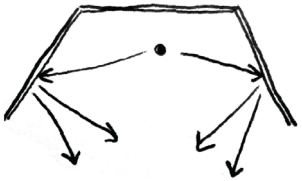
Sound is created by vibrations or pressure changes through an elastic medium, which the ear then detects and passes along to the brain to decode.[6] What we hear is essentially wave vibrations altered by our environments. Sound radiates from a source as a wave; when it comes in contact with a surface, it behaves in a similar way to light.



Direct sound and early reflections off the walls, floor and ceiling.

Reflection: Sound waves are reflected from all surfaces in a room, and the angle of reflection of the ray will be equal to the angle of incidence to the surface.[7] A concave shape can focus sound, and a convex form will disperse the sound. For example, The Integratron by George Van Tassel is a dome structure with unique sonic properties due to its unusual form. An article headline reads, "Welcome to the Integratron, a place of spiritual healing and musical sound baths in the Mojave desert. It was designed by an alien."[8] Van Tassel was an Aviation Engineer when he claimed that his weekly meditation led to a UFO encounter, in which he was given "a formula for a proprietary frequency for rejuvenating living cell tissues."[9] However he may have imagined this structure, Van Tassel began building The

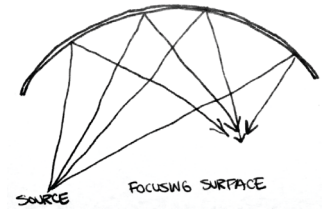


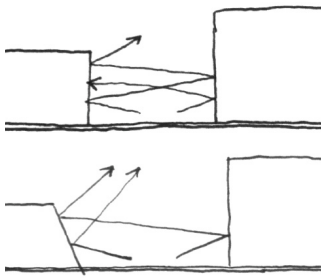


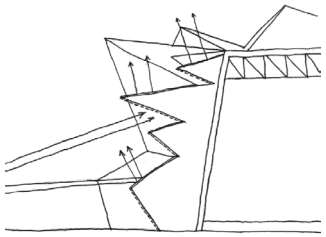
Integratron in Landers California in the late 1950s. The structure is a 38-foot high, 55-foot diameter wood dome, which he intended to use for rejuvenation and time travel. The dome is an incredibly reverberant and unique acoustic structure due to the curved dome shape, like natural surround sound. It is currently used by musicians, scientists, sound therapists, yoga and meditation groups, etc. At the focal point of the dome, even a whisper resonates throughout the room, creating an aural experience of relaxation, rejuvenation, peace, and heightened awareness.[10]

Diffraction: If a surface is not large enough in relation to the wavelength of sound, the wave will bend around smaller obstacles and spread out by diffraction. The effects of diffraction and reflection are the reasons that we are able to hear sounds around corners or barriers.

Dispersion: An uneven or textured surface will break up and scatter sound into smaller, weaker waves, rather than reflecting them as a







Pavilion 21 Mini Opera Space by Coop-Himmerlblau, Munich. The facade reflects sound upwards and absorbs on the angles facing downwards to reduce exterior noise.[A]

smooth surface would. Dispersion will reduce the intensity of the reflected sound, which can help to minimize echoes, diffuse reverberation and prevent standing waves between parallel surfaces.[11]

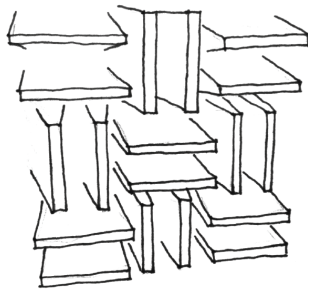
Transmission: Sound can be carried through a building in a number of ways by the transmission of vibrations. Airborne transmission is caused by air pressure waves, which then vibrate another element. The Sound Transmission Class (STC) of a partition is the rating of how well the assembly reduces airborne sound, including ratings of interior walls, ceilings, floors, doors, windows, etc. Impact transmission is caused by the direct impact of an object, such as footsteps heard from a room above. The building itself can also transmit sound through flanking, where vibrations travel through materials such as structural steel. David Byrne's sound installation "Playing the Building" uses the physical building as a giant musical instrument through transmission. Mechanisms attached to the building's metal beams, columns, heating and water pipes are used to make these things create sound through wind, vibration and striking.

Figure 12: Playing the Building, David Byrne.

sound properties + behaviour

"*The devices do not produce sound themselves, but they cause the building elements to vibrate, resonate and oscillate so that the building itself becomes a very large musical instrument*."[12]

Absorption: When sound comes in contact with a surface, some amount of absorption occurs, where sound energy is lost and transferred to heat energy. Absorption is dependent on materiality, as rough and porous materials absorb more sound than those, which are smooth, dense and rigid.[13] Materials also absorb different amounts of sound at different frequencies. An anechoic chamber is both an acoustically and visually strange experience, because the ceiling is comprised of deep, absorbent wedges on every side. The form and depth help to trap the sound, which looses energy as there are no reflective surfaces.



Absorbent wedges of an anechoic chamber, which absorbs 99.99% of sounds.[B]

Reverberation: A sound is first heard directly from the source, then as early reflections off surfaces, followed by reverberation depending on the materiality. Reverberation is the continuation of sound in a

space, after the initial source has ended. In a classroom, the reverberation time should be about 3/4 of a second for good speech intelligibility, whereas a concert hall sounds best between 1.5 to 2.25 seconds depending on the type of music being played.[14] "Forty-Part Motet" by Janet Cardiff is a sound exhibit at the Rideau Chapel in the National Gallery in Ottawa. It is comprised of 40 speakers, each with a different recorded choir voice, positioned around the chapel to illuminate the highly reverberant space as it would have been during church services. The piece is an experience of complete aural envelopment. The voices reverberate throughout the old wooden chapel, and change as one walks around the room, creating a relaxing, warm and transcendent feeling.

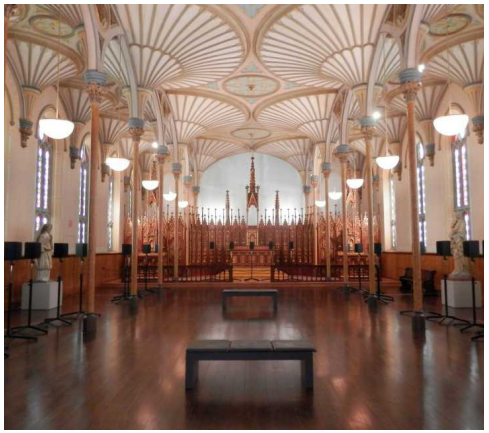
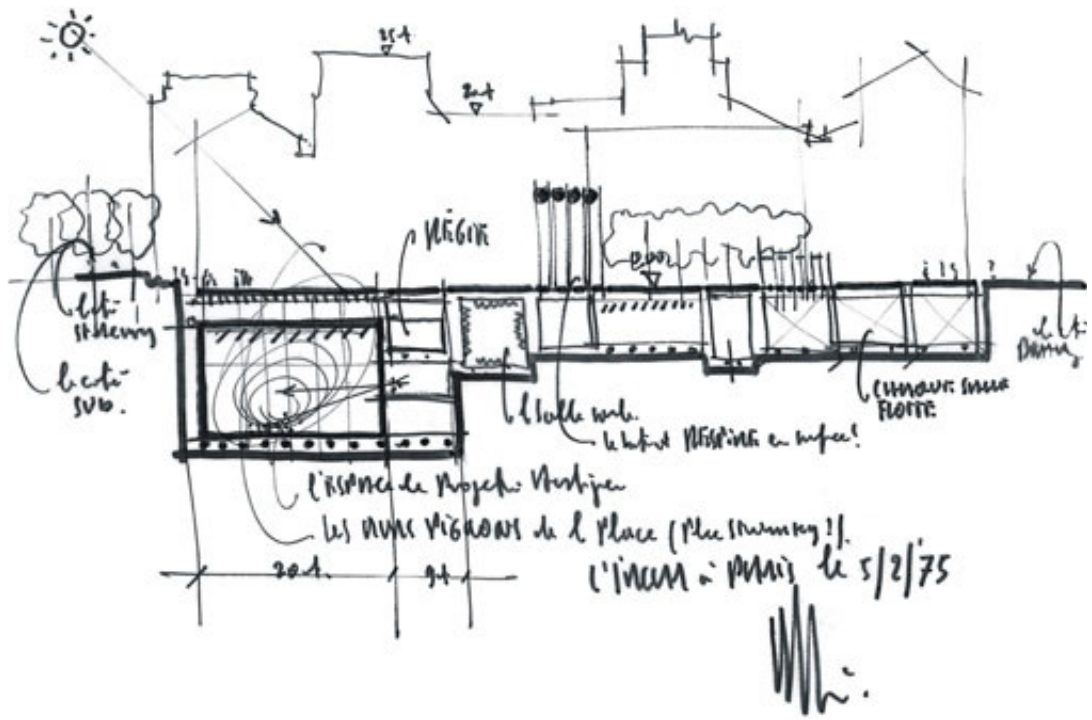


Figure 13: Forty-Part Motet at the Rideau Chapel by Janet Cardiff.

When designing The Institut de Recherche et Coordination Acoustique/Musique (IRCAM), Renzo Piano created specific spaces where the acoustic properties could be changed. IRCAM was built in the late 1970s as part of the Centre Pompidou development, acting as a collaborative building for scientists and musicians. The original por-

tion of IRCAM was built completely underground, with an above ground tower added in 1990. The three underground levels are made to be completely adaptable in order to allow for sound research and experiments. These rooms include ceilings, floors and walls, which can be moved to change the volume and acoustics for different performances or research.[15]

Figure 14: Sketch of the below grade portion of IRCAM by Renzo Piano Building Workshop.



aural connectivity

The aural experience of a space can be altered through the difference in thresholds and aural connection of spaces. Aural connectivity is the overall pattern of where users can hear and respond to different key sounds, such as being able to hear a conversation from across the room in an office. A threshold occurs when two spaces or areas differ aurally; this usually aligns with a visual or physical threshold.

The article "Mapping sound-space: the Japanese garden as auditory model" analyzes sound and space of the Japanese garden. Fowler suggests that through soundscape mapping and analysis, connections and disconnections between the auditory and visual can act as a framework for design. The analysis considered each element in Japanese gardens and auditory zones. For example, features such as water elements are natural aural components, gravel paths make a person more conscious of their presence and others around them, and control of the path widths or shape can slow movement to allow for more time to notice a certain element. Lines of trees, hedges or stone walls can help to block out exterior sounds of the city, making

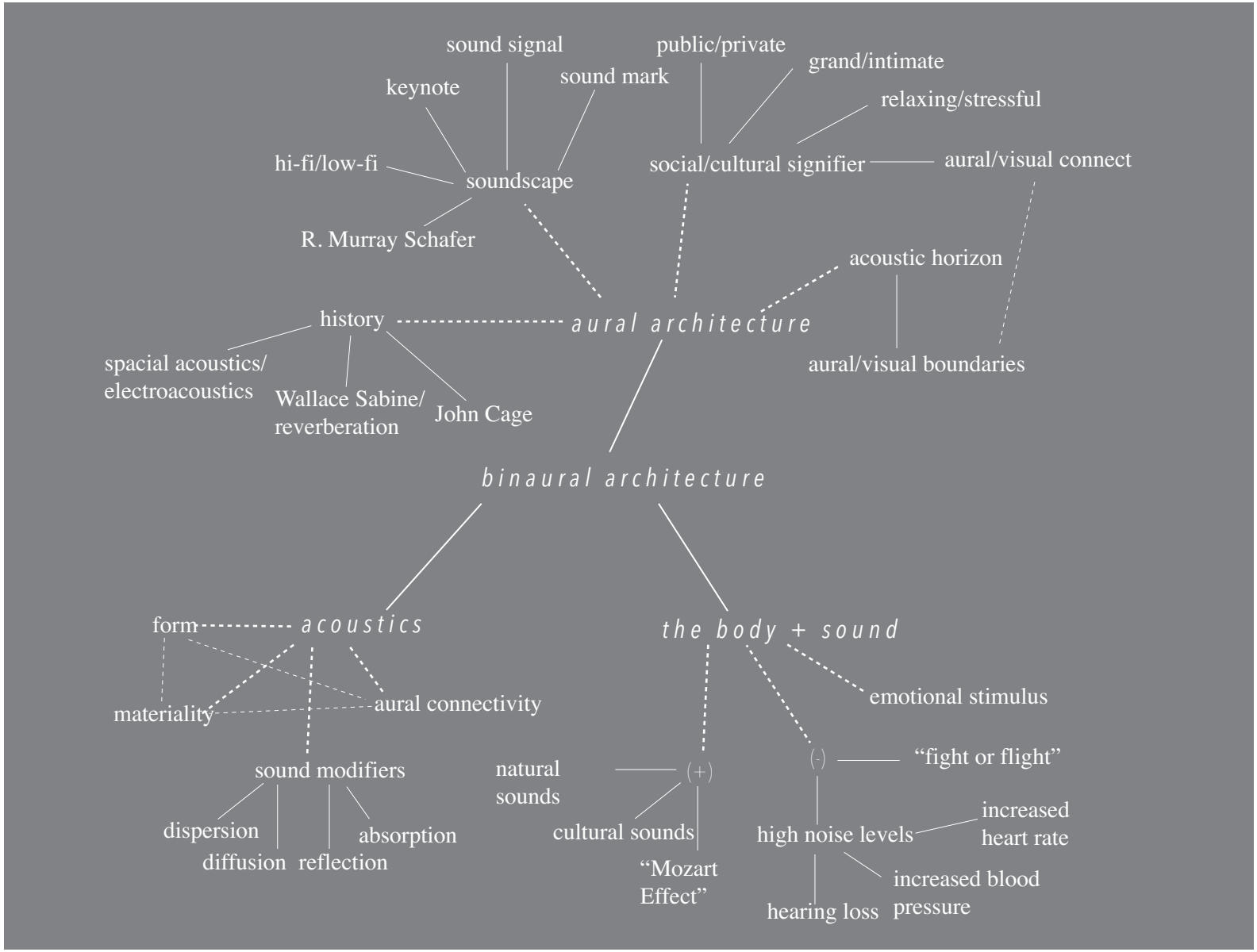
the aural threshold between the garden and city clearly divided. In the Japanese garden, each segment is carefully arranged to achieve the desired and connected aural and visual experience.[16]

As the Japanese garden example demonstrates, each element throughout an environment or building can affect the overall experience, based on how these pieces are arranged and connected. An understanding of the basic acoustic design principles addressed can help to better design for this intended arrangement and connection of spaces, and how each contributes to the overall aural perception of architecture.

1 Peter Zumthor. *Atmospheres: Architectural Environments.* (Birkhauser Architecture, 2006), 9.
2 Blesser and Salter. "Aural Architecture: The Missing Link."
3 Vitruvius, *The Ten Books on Architecture, Book V. Cambridge: Harvard University Press, 2006).*
4 William J. Cavanaugh and Joseph A. Wilkes. *Architectural Acoustics: Principles and Practice.* (New York: Wiley, 1999), 63.
5 Lance Hosey. *The Shape of Green: Aesthetics, Ecology, and Design.* (Island Press, 2012), 70.
6 John Edwin Moore. *Design for Good Acoustics and Noise Control.* London: Macmillan, 1978), 3.
7 Moore. *Design for Good Acoustics and Noise Control,* 24.
8 Jody Rosen, "Welcome to the Integratron." *The New York Times.* www.nytimes.com.
9 "History of the Integratron." *Integratron.* www.integratron.com.
10 "About." *Integratron.* www.integratron.com.
11 Moore. *Design for Good Acoustics and Noise Control,* 29
12 David Byrne. "Playing the Building." www.davidbyrne.com
13 Moore. *Design for Good Acoustics and Noise Control,* 34
14 Moore. *Design for Good Acoustics and Noise Control,* 181-183.
15 "Ircam." *Renzo Piano Building Workshop.* www.rpbw.com/project/12/ircam.
16 Fowler, Michael. "Mapping Sound-space: The Japanese Garden as Auditory Model." *Architectural Research Quarterly 14.1* (2010): 63-70.

A *"Pavilion 21 MINI Opera Space." Coop Himmelb(l)au. www.coop-himmelblau.at*
B "Quietest Place on Earth' *SmartPlanet.*

research summary



INTERLUDE

"Now I will do nothing but listen,
To accrue what I hear into this song, to let sounds contribute toward it.

I hear bravuras of birds, bustle of growing wheat, gossip of flames,
clack of sticks cooking my meals,
I hear the sound I love, the sound of the human voice,
I hear all sounds running together, combined, fused or following,
Sounds of the city and sounds out of the city, sounds of the day and night,
Talkative young ones to those that like them, the loud laugh of work-people at their meals,
The angry base of disjointed friendship, the faint tones of the sick,
The judge with hands tight to the desk, his pallid lips pronouncing a death-sentence,
The heave'e'yo of stevedores unlading ships by the wharves, the refrain of the anchor-lifters,
The ring of alarm-bells, the cry of fire, the whirr of swift-streaking engines and
hose-carts with premonitory tinkles and color'd lights,
The steam whistle, the solid roll of the train of approaching cars,
The slow march play'd at the head of the association marching two and two,
(They go to guard some corpse, the flag-tops are draped with black muslin.)

I hear the violoncello, ('tis the young man's heart's complaint,)
I hear the key'd cornet, it glides quickly in through my ears,
It shakes mad-sweet pangs through my belly and breast.

I hear the chorus, it is a grand opera,
Ah this indeed is music—this suits me." [1]

[1] Walt Whitman. "Song of Myself." *Leaves of Grass.* (New York: Pocket, 2006) 51.

LISTEN *[mini thesis]*

Listening was previously defined as the active attention to sound, something that we often do not do enough. As part of my mini thesis submission in January, I included an 'audio-book' of various sections of text. Each was recorded in a different location with different aural qualities, in order to have the reader listen, rather than just looking at visual images. This gave a better idea of how sounds can be altered by our everday spaces. The interesting aspect of these recordings was that not all sections were easily intelligible, which emphasizes the importance of properly designed acoustics. The recording locations were as follows:

1 - Quiet apartment: sitting at a desk, with the recording device held at an arm length away, the words were clear with a slight reflection off the desk surface.

2 - Master's studio, Architecture Building: sitting at a desk with the recording device again held at an arm length away, my voice was raised due to the HVAC noise in the background. The studio almost has a masking effect due to the HVAC noise, which makes it difficult to talk between different tables.

3 - Carleton Library Starbucks: the new renovation is very well designed visually, however I have attempted to read there many times and always find it too difficult to concentrate with all the noise. The recording device was held at the distance to a friend sitting across the table, and I had to raise my voice due to the background noise.

4 - The Pit, Architecture Building: this recording took place where many architecture lectures and presentations are held. A friend sat about 3m away, where the audience is usually positioned. My voice was a normal level, but the recording is difficult to hear. This can be the case for some pit lectures when the speaker does not use a microphone, especially if sounds from the adjoining spaces can be heard.

5 - Room 209, Architecture Building: a friend sat at the back of the classroom holding the recording device, and I spoke from the front of the class as a professor would during lectures. Even though my voice was raised slightly, it is still difficult to hear the words clearly.

6 - Underground tunnels, Carleton University: the recording device was held at the distance between two people having a conversation. It is difficult to hear the conversation due to the many other voices, footsteps and occasional carts. However, the tunnels are an interesting aural space, with a high reverberance from the concrete surfaces, where your footsteps echo loudly around you. You are also able to hear other people approaching, often before you can see them around a corner, which gives some sense of safety when walking alone.

7 - Minto Park, Elgin/Cartier Street: situated in the middle of the park with the recording device held as usual, sounds of traffic from the street and people in the area can be heard. My voice is clearly intelligible (you can hear how cold I was). As the recording was done in January, natural sounds such as birds and rustling leaves are not heard, but would be in other seasons.

The recordings can be found at:

https://www.youtube.com/watch?v=6rYALHV4tEc

[BIN]AURAL DESIGN

This thesis initially began by questioning how the aural qualities of our architectural spaces can affect people and their experience of that space. The succeeding chapters then described ways in which sound can define spaces and stimulate reactions. Historical examples, precedent studies and the basic acoustic principles addressed then gave insight into how we design (or neglect) our aural spaces and soundscapes. Finally, the current chapter will explore a design idea in which aural architecture can be 'tuned' to manifest a more noticeable and beneficial role in our everyday spatial experiences.

'Binaural' design refers to the desire to fully engage our sense of sound, in listening with both ears, rather than regarding sound as background noise. Thus, the Ottawa Sonic Centre serves as a place of retreat from the consequences of noisy, unhealthy and uninspiring aural environments within our cities, where visitor's can appreciate the varying aural spaces throughout.

[bin]aural design

While teaching at Harvard, Peter Zumthor tasked his students with designing "the house without a form". They were to present the site with no plans, sections or models. The objective was to inspire a new sort of space, described by sounds, smells and verbal description:

> *"When I look at this kind of house without a form, what interests me the most is emotional space. If a space doesn't get to me, then I am not interested...I want to create emotional spaces which get to you."*[1]

In addition, as previously mentioned Marco Frascari's writing on 'places for thinking' asserts that architects are well versed in programming buildings for our daily activities, yet few places focus on the experiential qualities. The Sonic Centre design will take a similar approach to Zumthor's 'formless house' project and Frascari's 'places for thinking', in creating a program-less building which instead asserts the importance of the aural effects. The centre defines a use by the aural characteristics, with some ability to be tuned to the aural needs of specific users as desired. For example, "the Pit" area of the Azrieli School of Architecture and Urbanism at Carleton

functions so well for the school because of its lack of programmatic script, yet ability to adapt as needed. Students and professors insert their own programs into the space, based on the built characteristics of the pit that work for their desired use. The pit has hosted a variety of activities including guest lectures, student presentations, event receptions, music practise or performance nights, etc. (although the acoustics are not always ideal for different uses).

The process of tuning, in any context, is done to adjust something to a specific and best function. A tuned aural architecture is then an environment which has been designed to meet the needs of its intended use, for a particular space, time and context, one which does not elicit unintentional or unwanted aural effects. These should be preconceived design intentions of what acoustic experience the designer proposes for the space, rather than reactive solutions to fix issues after the building is in use. When aural characteristics are not considered in design, we end up with buildings that not only sound monotonous and uninspiring, but also spaces which can have a nega-

tive effect on inhabitants or not work for their purpose (such as the examples of the open plan school and a noisy restaurant).

There are two different ways to define the idea of tuning a building to the desired aural characteristics, using musical instruments as an analogy. First, a piano is tuned very precisely to the exact set of pitches, which can be compared architecturally to a room designed specifically to its use. The second type of tuning is that of a guitar, where each string is tuned to a specific pitch, however there are alternatives to the standard tuning that changes the pitch of different strings, which changes the way the guitar can be played or the sound of chords. For example, "drop D" tuning is common in classical guitar, and "open tuning" is often used in blues or folk. This second idea of tuning is used for the adaptable spaces of this project, as multipurpose rooms can often accommodate different uses, which should then include a change in the aural characteristics.

[bin]aural design

The Ottawa Sonic Centre will include the required pragmatic supporting programs in addition to the adaptable spaces, and each contributes to the overall aural experience of the building. This project will explore how to aurally infuse these everyday spaces in order to enhance our environments through sound. In doing so, visitors will become more aware of their sonic surroundings and how these qualities impact their activities, which can help to encourage a desire and understanding for better designed aural environments. The design will investigate how sound defines spaces and how the many aural characteristics contribute to the experience of a space. The project addresses basic architectural acoustic principles, but would require the "fine tuning" of an engineer to work as intended.

[bin]aural design: design process

Zumthor's method of formless design was an initial model of how to begin to describe and create a building focusing on the sounds. The challenge in initially designing the aural architecture of this project was to put aside instinctual visual ideas and focus on aural characteristics. Designers often start with a vision of how a space should look, or how the building's form is generated. In this case, it was important to describe and design for sound first and foremost, then align the aural and visual elements. The following steps explain the design process which was taken, established through the project and based on the research topics:

1 - Site analysis:

In addition to typical site analysis items, such as circulation and development proposals, a soundscape analysis considers the existing sounds including keynotes, sound marks, sound signals, etc. and consider which sounds should be preserved, minimized, or amplified through the design. This included a larger soundscape map of Ottawa, as well as the site itself.

2 - Program

While listing what programs will take place in the building, sounds that will be introduced by the program and people using the spaces were considered.

3 - Connectivity

An aural connectivity map connects and plans the acoustic horizon and boundaries, at what distance should sounds be heard from and at what levels, between which areas, etc.

4 - Characteristics

Each space can be described in terms of social and cultural purposes for the intended use, such as public or private, grand or intimate, warm or cold, relaxing or stressful, etc.

[bin]aural design: representation

As previously mentioned, conventional design drawings and images traditionally represent the visual aspects of a design, while the other senses are more difficult to describe as a drawing. The physical properties of sound can be described by complex sound reflection and reverberation diagrams, the loudness in decibels, or varying levels as a sound wave. However, these types of drawings can be difficult to interpret and comprehend, and still leave out the experiential qualities. Visuals were used in a traditional sense in this thesis to explain the plans, sections and elevations. This gives an idea of the form, materiality and connectivity of spaces. The design renderings show a conceptual idea of how the space is intended to react to sound, however this is not calculated, but rather the intended outcome of the design. In addition, a 'sound rendering' video walkthrough of the spaces will accompany the drawings to substitute this missing piece of information. This can help to give a more clear idea of the aural intentions of the design, and is easily understandable.

site location

The site is located in the Lebreton Flats area of Ottawa, an area currently under development. The National War Museum is North of the site and will soon be surrounded by mixed used and residential buildings, as well as the new Pimisi station on the Ottawa Light Rail Transit (LRT) system. The nearby Ottawa River provides a place for recreation, including the running and bike path and beaches further West. This site was chosen as the expanding population in the area could benefit from a Sonic Centre, and it will be well connected to the rest of the city once the LRT system is in place. It also demonstrates an exterior soundscape where the natural environment of the nearby Ottawa River and green space has been washed out by man-made noise. The Sir John A. Macdonald Parkway and Transitway on either side of the site overpower these natural sounds, as is often the case in our cities. As the area continues to develop, noise levels will rise if the soundscape is not taken into consideration.

Ottawa Sound Map

Some of the many interesting and unique sounds, acoustics or soundscapes in Ottawa:

1. *Peace Tower Carillon, est. 1927*
2. *Rideau Street underpass (jazz music playing)*
3. *Plaza Bridge (reverberant underpass)*
4. *Canal Locks, est. 1832*
5. *Whispering Wall (Robert Baldwin & Sir Louis-Hippolyte LaFontaine memorial)*
6. *Janet Cardiff installation at the Rideau Chapel*
7. *National Arts Centre*
8. *Oscar Peterson Statue (playing music)*
9. *Social soundscapes (high activity & night life)*
10. *Business soundscape (higher buildings, glass, concrete)*
11. *Dominion Arboretum (natural soundscape)*
12. *Experimental Farm (natural soundscape)*
13. *Church bells (many more not noted)*
14. *Rideau Canal (skating or summer activities)*
15. *O-train Stations (train chime, rails)*
16. *Hogsback Falls*
17. *Carleton University tunnels*
18. *The Byward Market Courtyards*

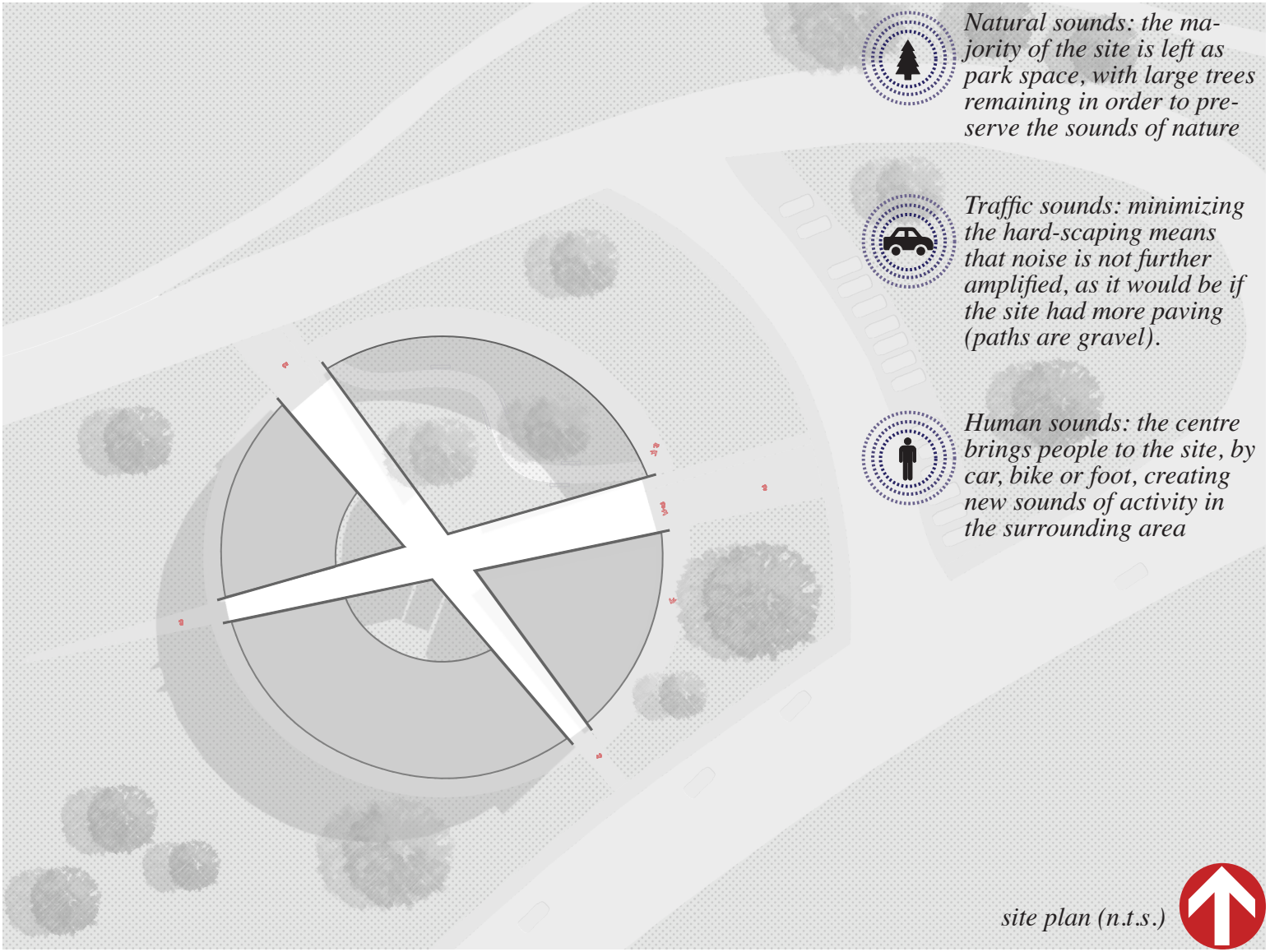
site location

site location

Lebreton Flats future development, land use from the Ottawa Official Plan.[A]

site location

Ottawa Sonic Centre: site plan



program map

Entrance: distinct transition between interior and exterior sounds, height-en awareness of sound
Sounds: exterior traffic, nature, voices, footsteps

Admin: private, quiet, connected work spaces
Sounds: staff, sounds from hallway, office equipment , coffee machine, phone calls

Cafe: semi-private, relaxing, supports social interaction or privacy
Sounds: self, other conversations, soft music, cafe equipment

Lobby/Reception: personal, welcoming, warm, animates sounds within
Sounds: conversations (public and private), footsteps, reception (phone)

Multi-purpose
program examples

Yoga: calming, support music, maximize voice of instructor, mini-mize sounds of class, semi-private
Sounds: instruc-tor, music, people in class, eliminate exterior traffic

Classes: maximize speech intelligibility of speaker, mini-mize backround noise
Sounds: speaker, class members

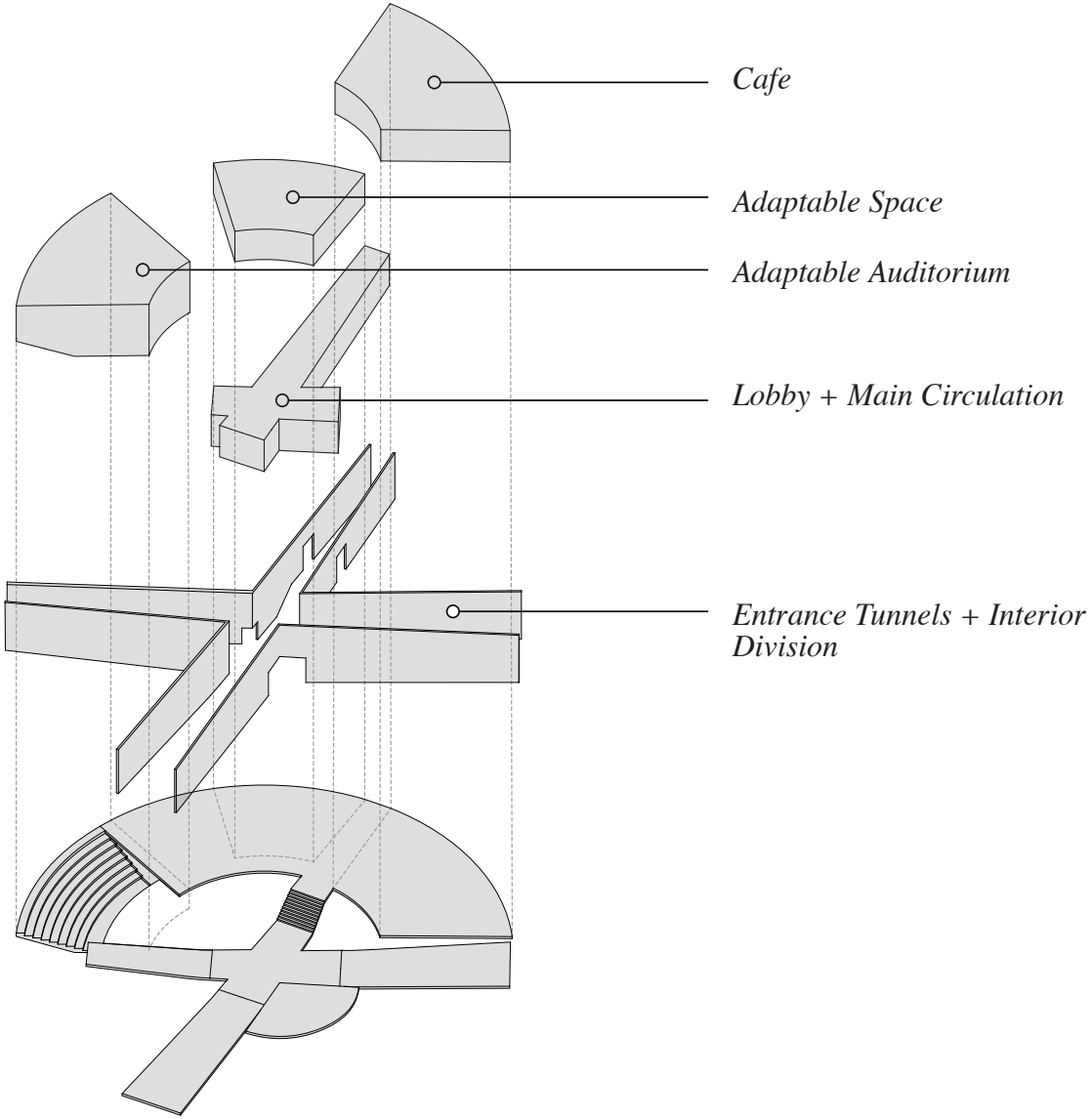
Music lessons: mini-mize backround noise, enhance specific type of music, clarity of sounds
Sounds: instructor, class/individual, instrument/vocals

Auditorium
program examples

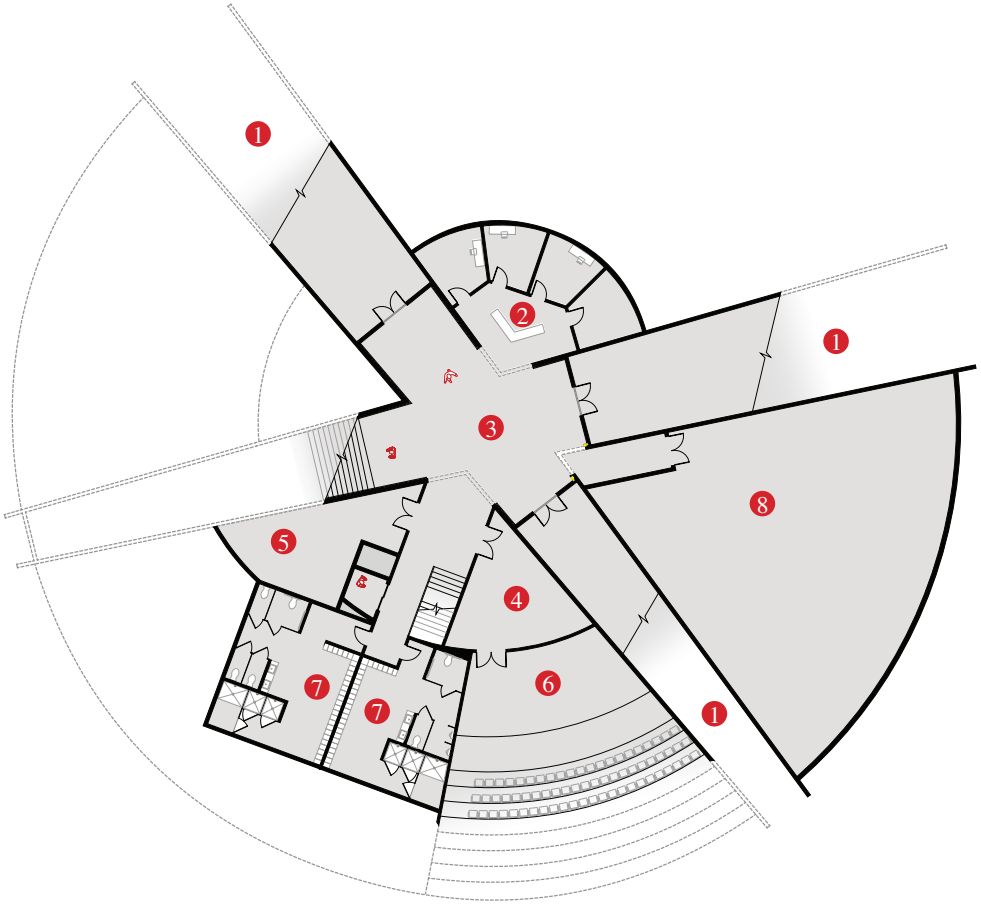
Music/ Theatre: adapt to different types of music or perfor-mance, minimize audience noise
Sounds: music, speaker, audience

Lecture: maxi-mize speech intelli-gibility of speaker throughout, mini-mize backround noise of audience
Sounds: speaker, audience, presenta-tion media

Ottawa Sonic Centre



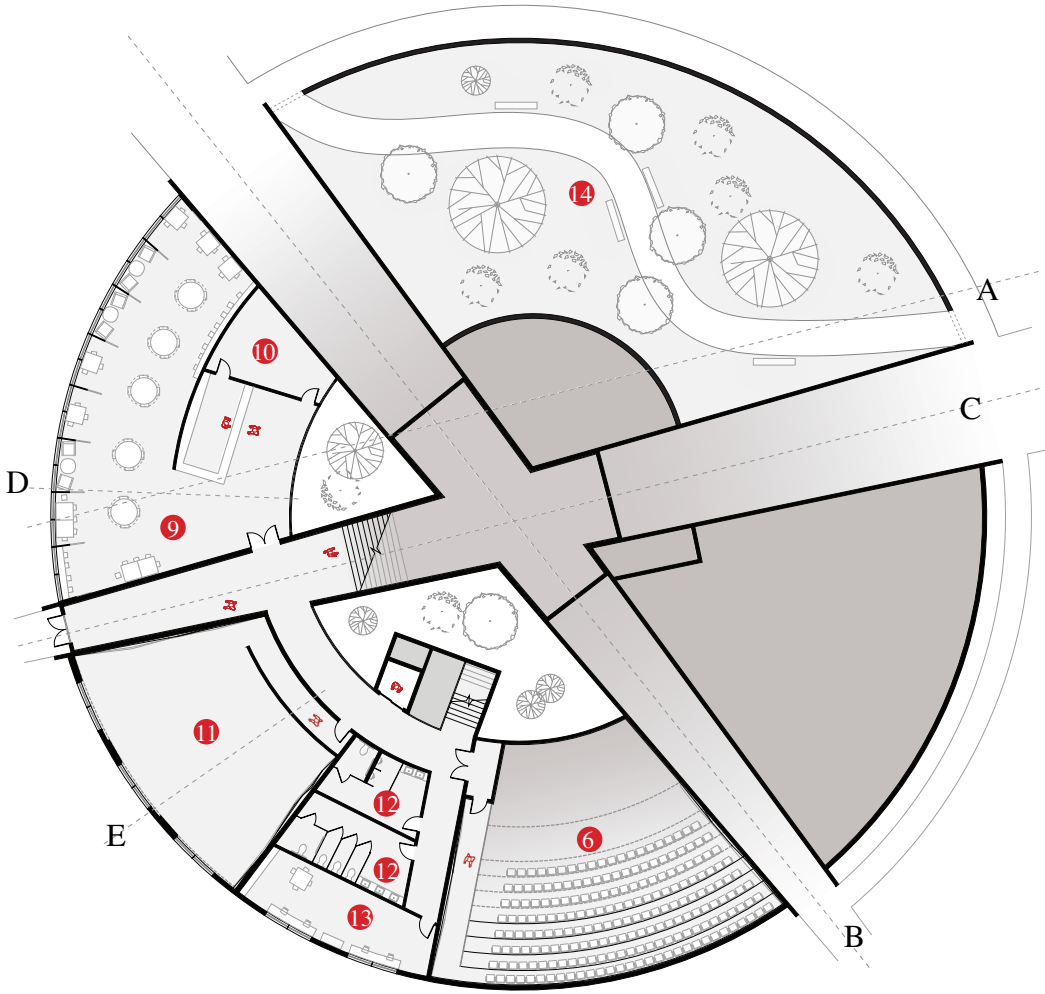
Ottawa Sonic Centre: below grade



1. *entrance tunnels*
2. *reception*
3. *lobby*
4. *auditorium storage*
5. *storage*
6. *auditorium (level 1)*
7. *change rooms & washrooms*
8. *large multi-purpose room*

below grade (n.t.s.)

Ottawa Sonic Centre: main level



9 *cafe*

10 *cafe kitchen*

11 *small multi-purpose room*

12 *washrooms*

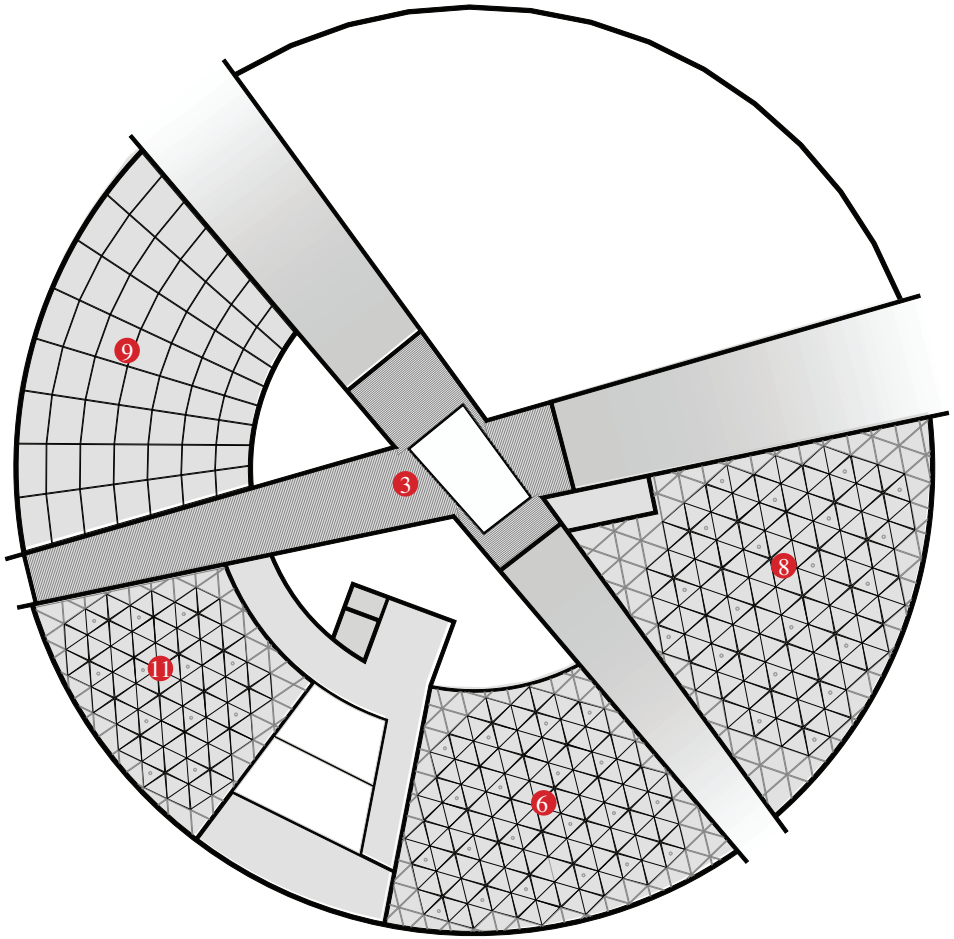
13 *office*

6 *auditorium (level 2)*

14 *garden*

main level (n.t.s.)

Ottawa Sonic Centre: RCP



9 *cafe*

3 *lobby/main hallway*

11 *small multi-purpose room*

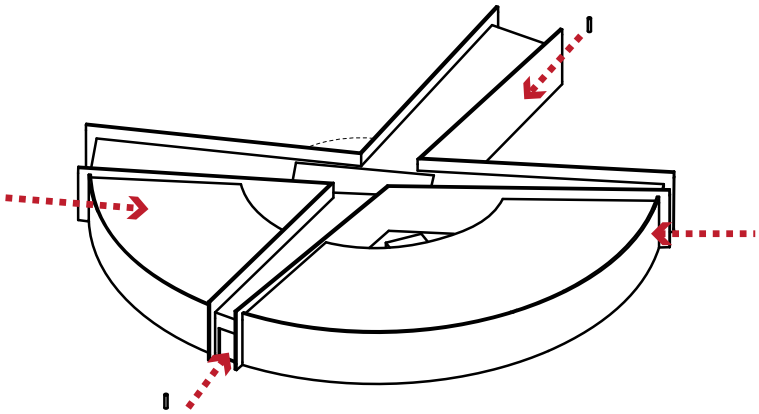
6 *auditorium*

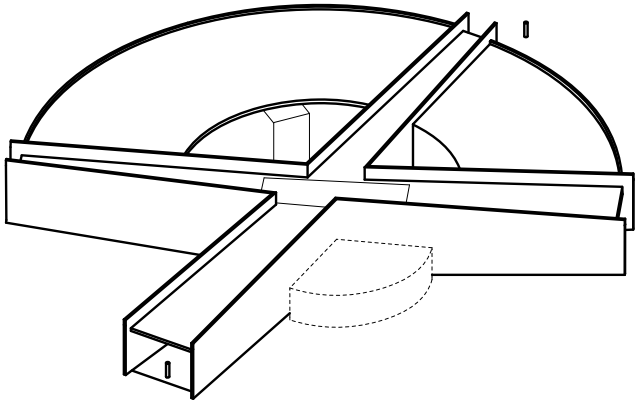
8 *large multi-purpose room*

main level RCP (n.t.s.)

Ottawa Sonic Centre: entrances

Entrances: The three main paths leading to the building begin the aural approach, each made of gravel to initially invite the visitor to listen (a paved path accompanies these paths for visitor's with accessibility issues). The building's entrances descend to the main lobby. Each is tunnel-like with hard, concrete surfaces, so that the reverberant entrance makes visitor's become more aware of sounds. The tunnels are also dimly lit, heightening the sense of sound.

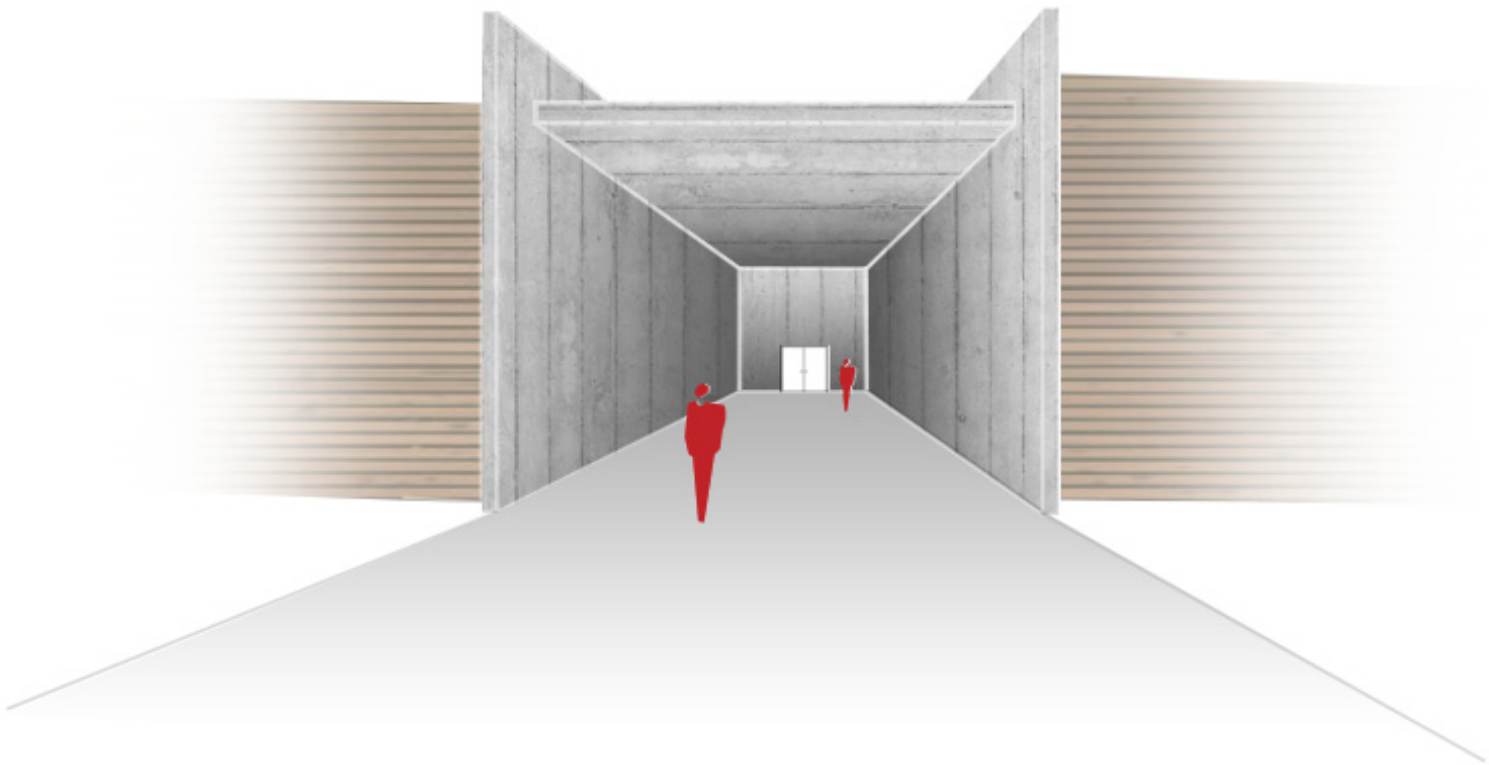




Ottawa Sonic Centre

East entrance elevation

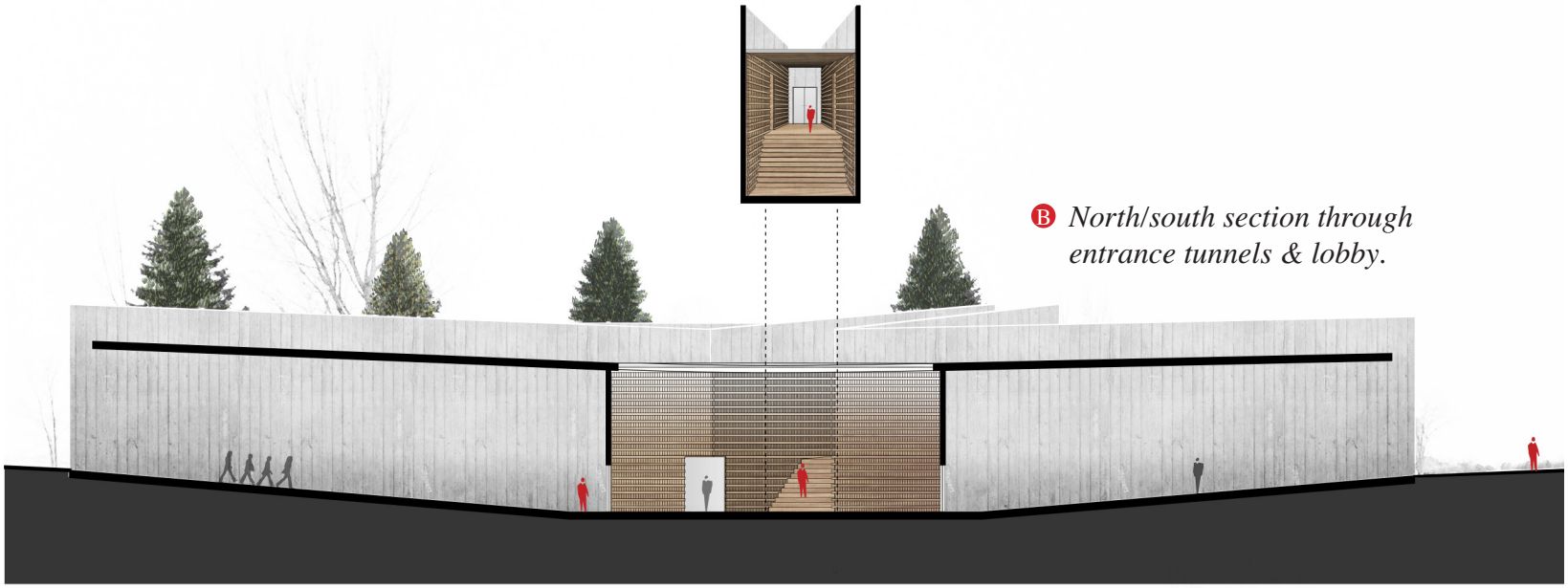
Ⓐ *East/west section, entrance, lobby, reception & garden*



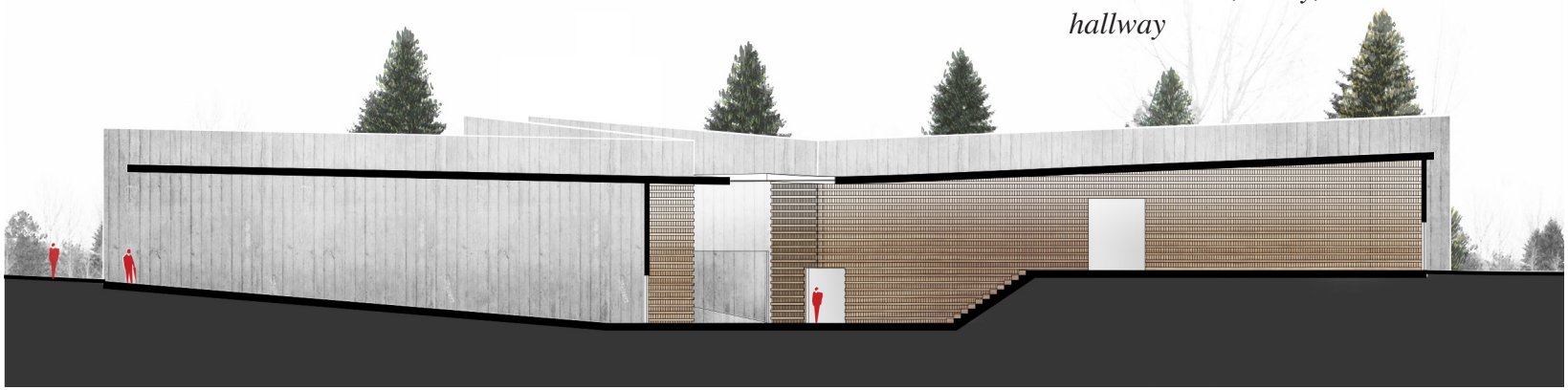
East entrance perspective view

Ottawa Sonic Centre: lobby

Lobby: The threshold between the entrance and lobby differentiates the noisy exterior environment and the intentional interior aural spaces. At the centre of the building, the lobby connects circulation and programs, with a reception area to one side. The use of wood throughout the lobby and adjoining hallway animates the sounds within, with a warm tone to contrast the hardness of the exterior tunnels. This is meant to evoke a welcoming feeling, whereas a corporate lobby with hard surfaces can often feel intimidating and cold. A skylight in the roof allows for natural light, without exterior windows to distract from the internal environment.



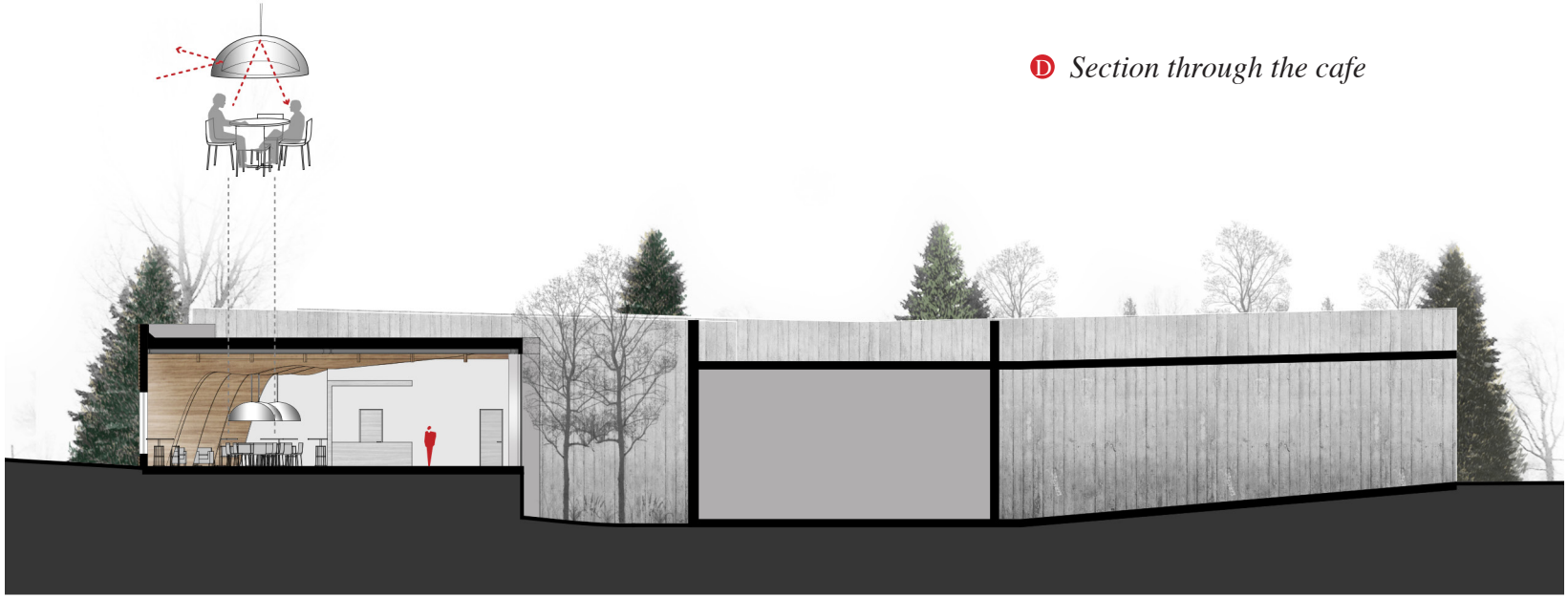
B North/south section through entrance tunnels & lobby.



C East/west section through entrance tunnel, lobby, and main hallway

Ottawa Sonic Centre: cafe

Cafe: The cafe is meant to support a social setting or a quiet place to read. As opposed to most open plan cafes, the design is meant to break up the space into smaller, more intimate pockets without visually confining the room. The cafe serving area is turned away from the seating, with a back wall and ceiling to minimize noises such as the coffee machines, blenders, sales, etc. Tables by the windows are separated with floor to ceiling wood divisions, which would help to eliminate some of the noise from carrying between tables. The tables in the centre have umbrella-like forms above to concentrate the sounds to that table, while deflecting some of the sounds from other tables.



D *Section through the cafe*

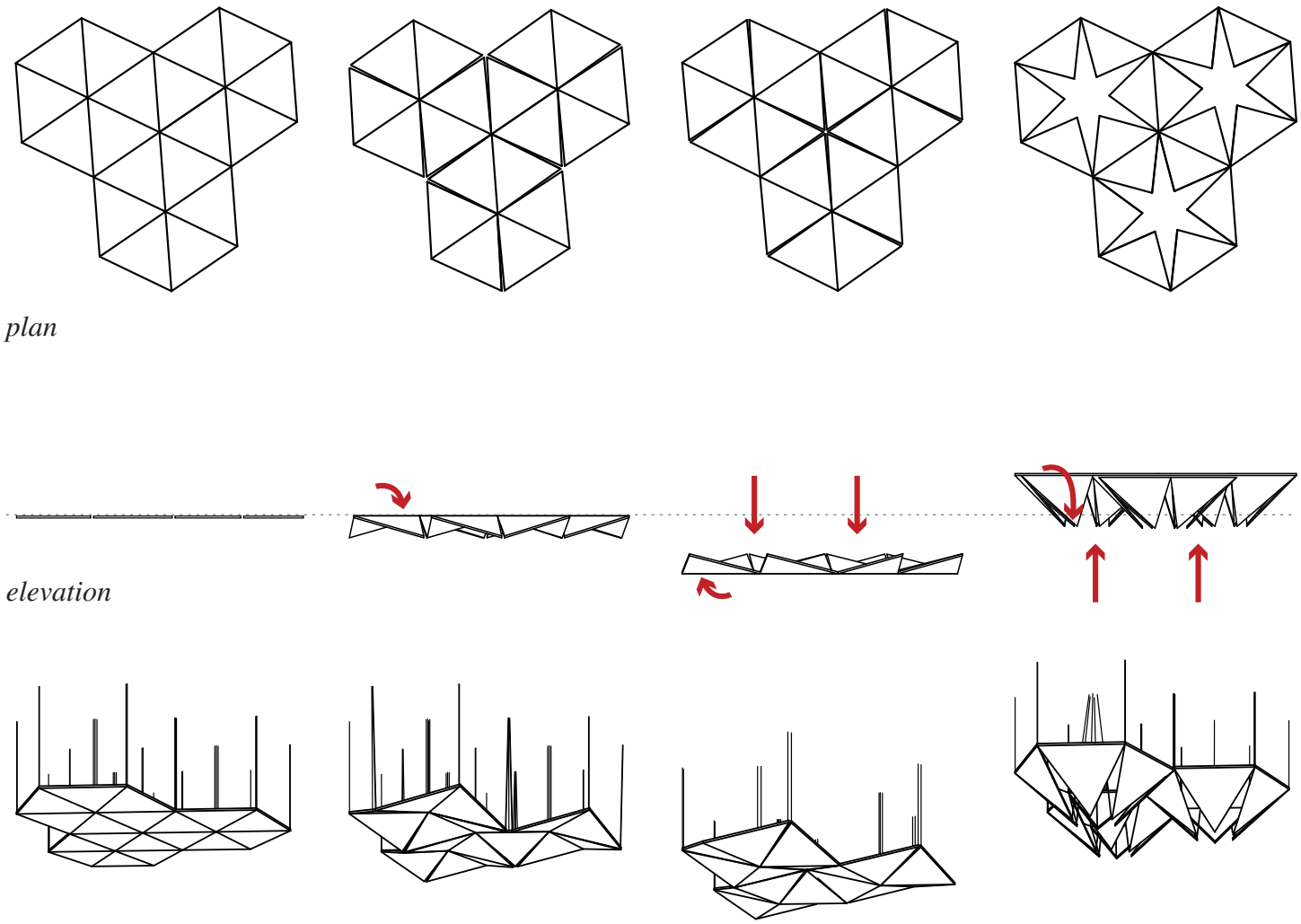
Cafe rendering with conceptual sounds.

West entrance night rendering, looking into the cafe.

Ottawa Sonic Centre: adaptable

Adaptable Multi-Purpose Room: The entrance to this room has an additional hallway from the door, with absorbent panels covering the walls to minimize sounds that would leak in from the main hallway when the door is opened. Within the room, a convex wall at the front can be used to help amplify a speaker. The windows opposite this have sliding panels to change the lighting, or eliminate the high sound reflectivity of the glass. Speakers are built in to the ceiling panels throughout so that music or sound can be played an even level. The ceiling is comprised of adjustable absorbing panels which can be moved up and down as a whole or individually, and open to reveal the reverberant wood shell above. This allows for the height of the room and materiality to be changed, increasing or decreasing the reverberation. Moving the panels individually can change the ceiling angles, which alter the directions in which sounds are directed.

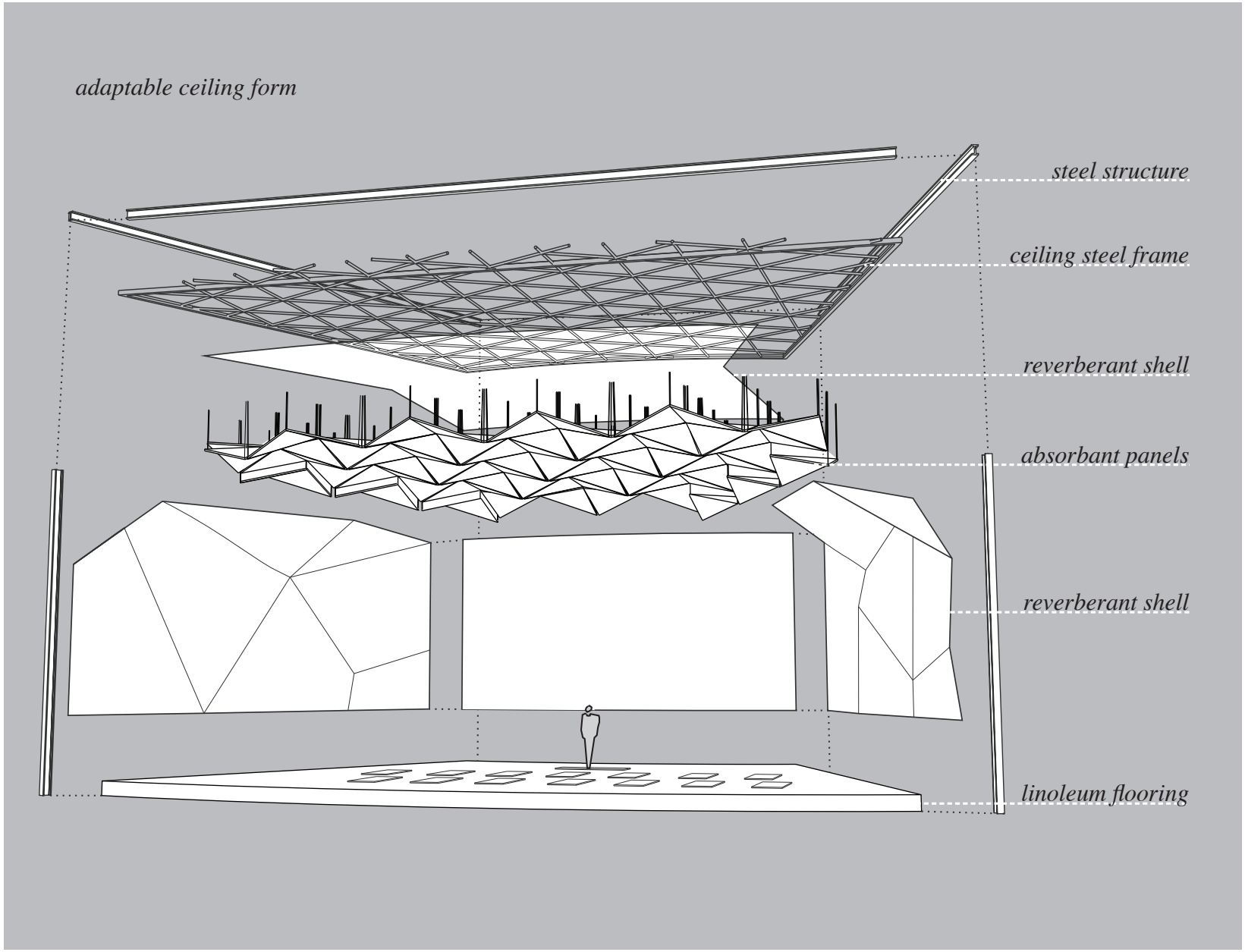
adaptable ceiling form



plan

elevation

perspective


adaptable ceiling form
steel structure
ceiling steel frame
reverberant shell
absorbant panels
reverberant shell
linoleum flooring

Because the multi-purpose room can be adjusted acoustically, it can suit a variety of community programs:

Yoga

There are many different types of yoga, but they generally all focus on relaxation through yoga poses. The environment is a key aspect in being able to fully relax, particularly sound as many people close their eyes during various poses. Sounds such as somebody else talking, the door clicking open and closed, or the music being too loud or too quiet, can defeat attempts at relaxing. An ideal yoga space would sound calming, quiet and intimate, with the music heard at an even level throughout the class. The instructor's voice also needs to be heard above all, without having to raise their voice. The adaptable room can accommodate yoga with a low reverberation level for a quiet, calming, intimate space. The double entrance hallway helps to eliminate noise from visitor's arriving late to class or activity in the hall. The instructor can situate themselves at the front of the class where the convex wall will reflect their voice outwards to the

class. The speakers throughout allow for the music to be played at a low level, but still heard by everyone at that same level. In addition to the surfaces of the room itself, yoga mats taking up the floor space would add to the sound absorption, as well as the visitors in the class.

Music Practise & Lessons

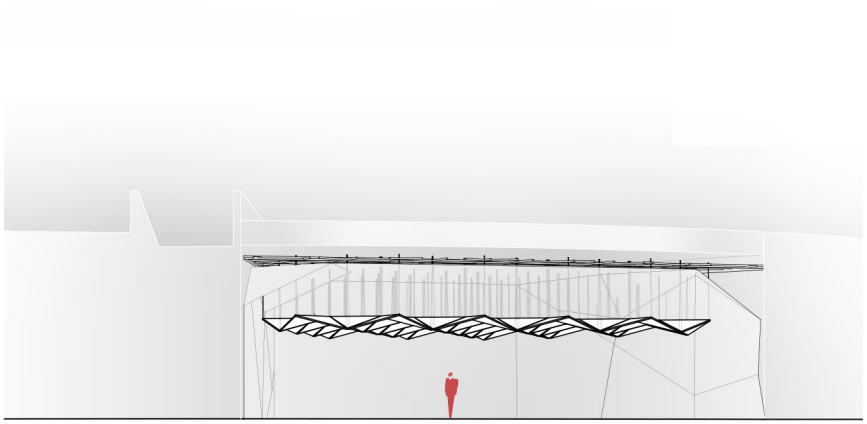
An instrument is like a miniature acoustic space in itself, as the body of the instrument resonates to produce the sounds we hear. Those notes can then sound very different, depending on the room in which the instrument is played. This is key to different genres of music, as some require minimal reverberation to allow for intricate details to be heard, or well blended notes such as choir vocals. Depending on the type of instrument or vocals being practised, the ceiling may be opened to allow for a higher reverberation level, or lowered less reverberation. This can also change how intimate or grand the space feels acoustically. For example, with the adaptable room set to a lower reverberation, the space would work well for private or small

group guitar lessons. The instructor and students would be able to clearly hear the notes being played, in order to correct students and teach listening exercises. The space would also feel more intimate, as learning a new instrument can be intimidating and students may feel self conscious if their mistaken notes were to reverberate loudly throughout the room.

Choir practise

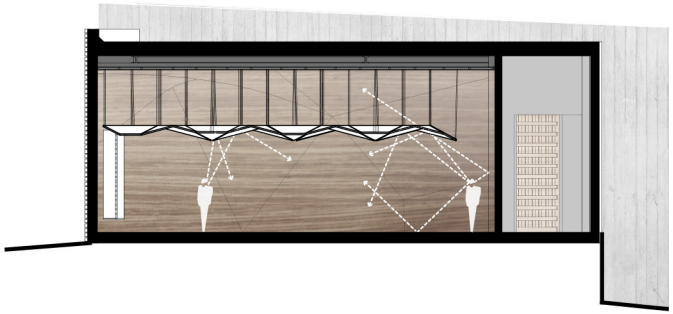
To tune the same space to a choir practise, a higher reverberation time would allow for the vocals to blend smoothly together so that the individual voices sound in unison, similar to a church space (though the size of this room could not emulate the resonance of a large church or cathedral). As the shape of the room does not consist of any parallel walls, this helps to eliminate flutter echoes. By changing the angles of the ceiling panels, this can also help to better disperse the sounds. With the ability to adapt to different types of music and practise uses, this space allows for a greater diversity in users and musical genres.

Ottawa Sonic Centre

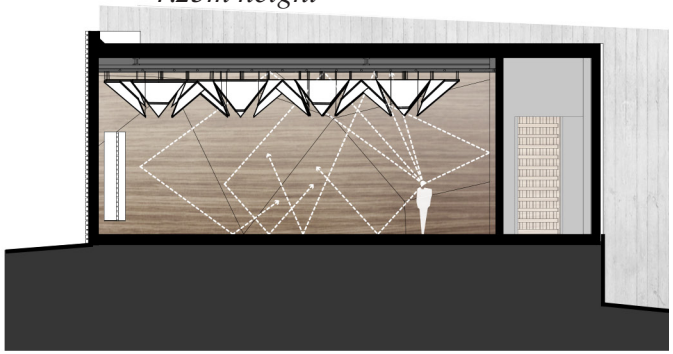


Ⓔ *Flat ceiling at 3m height*

Ⓔ *Angled panels at 3m height*



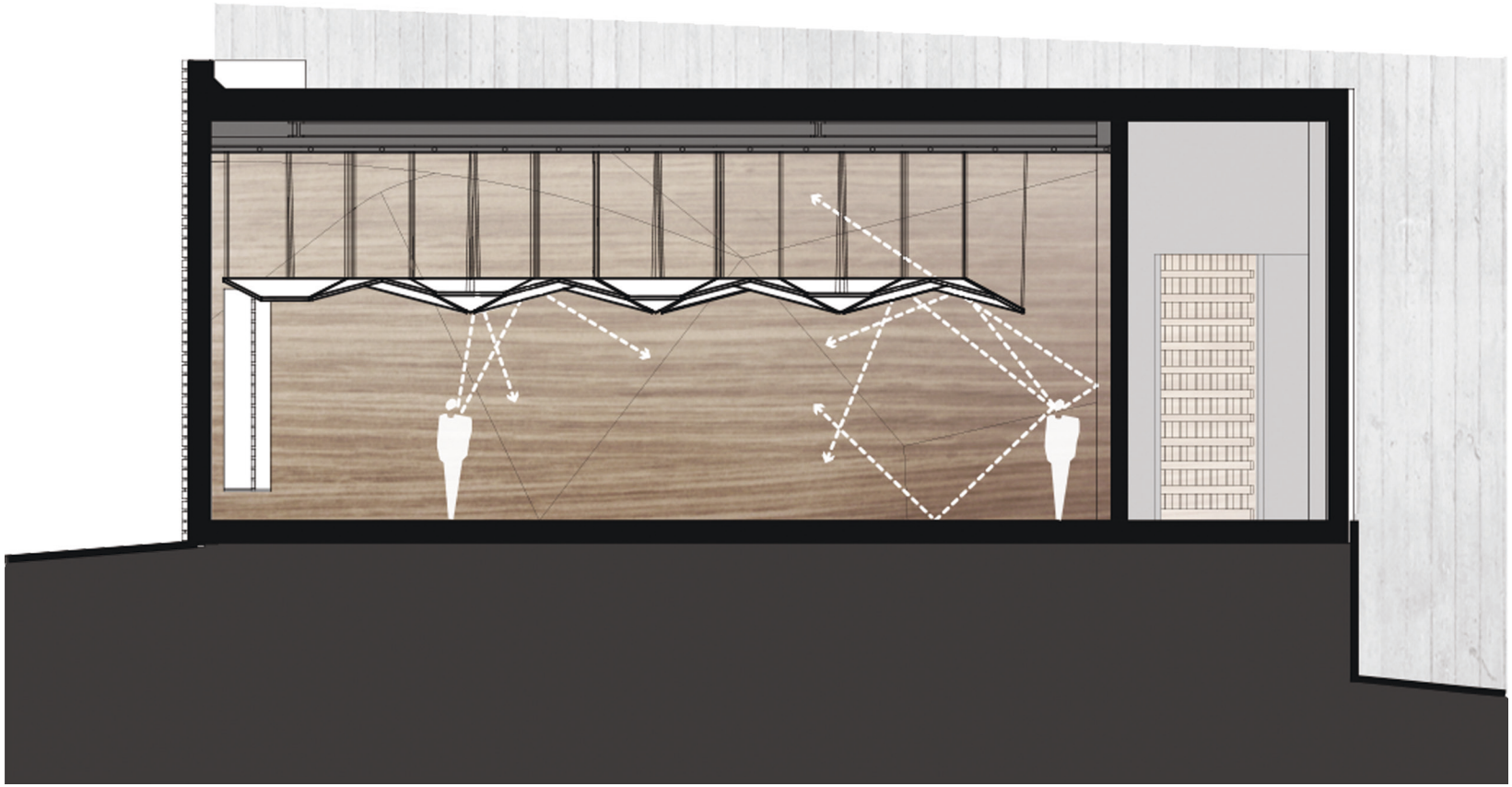
Ⓔ *Angled and opened panels at 4.25m height*



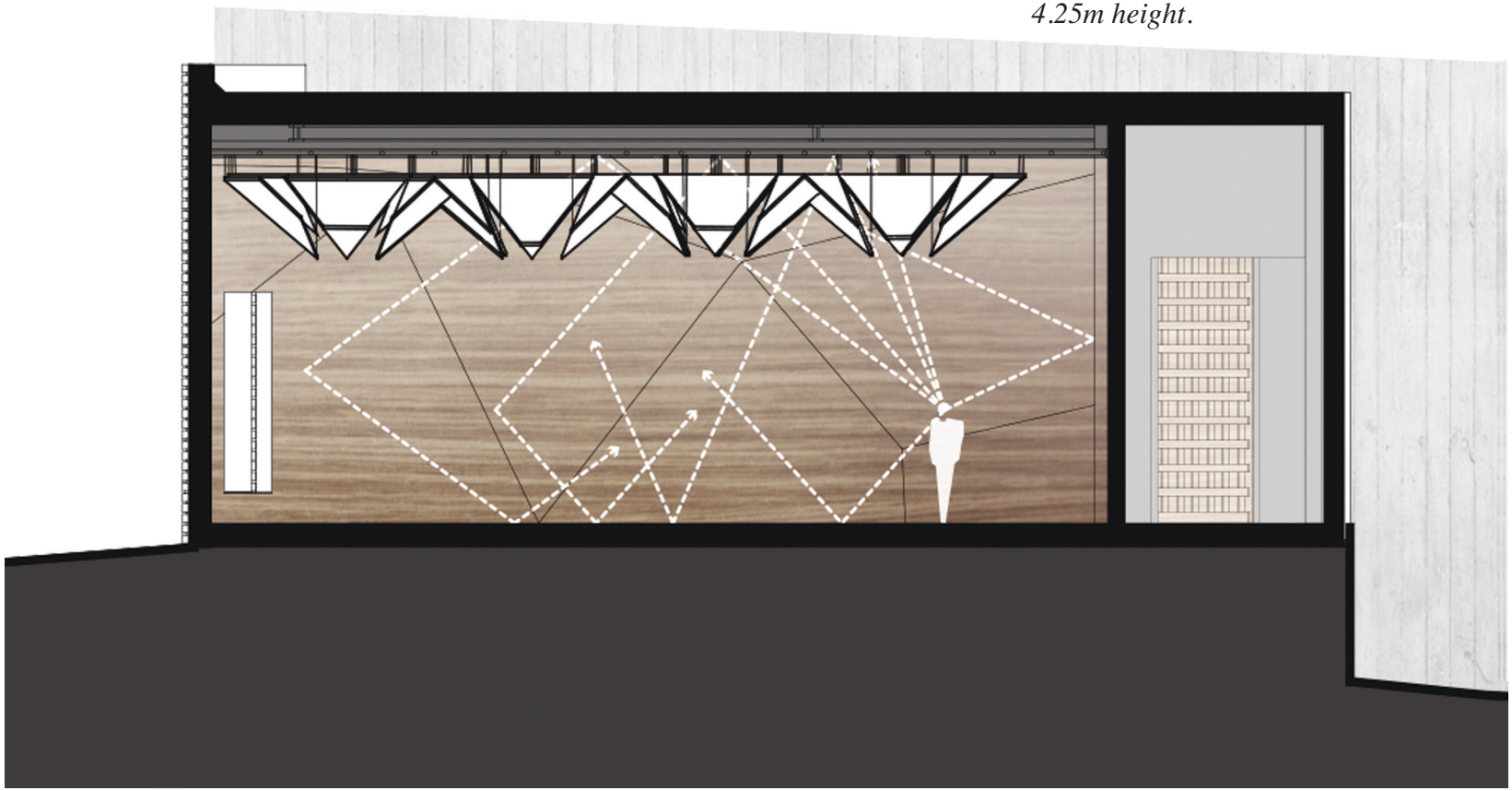
Flat ceiling at 3m height

Multi-purpose space used for yoga, with conceptual sounds shown.

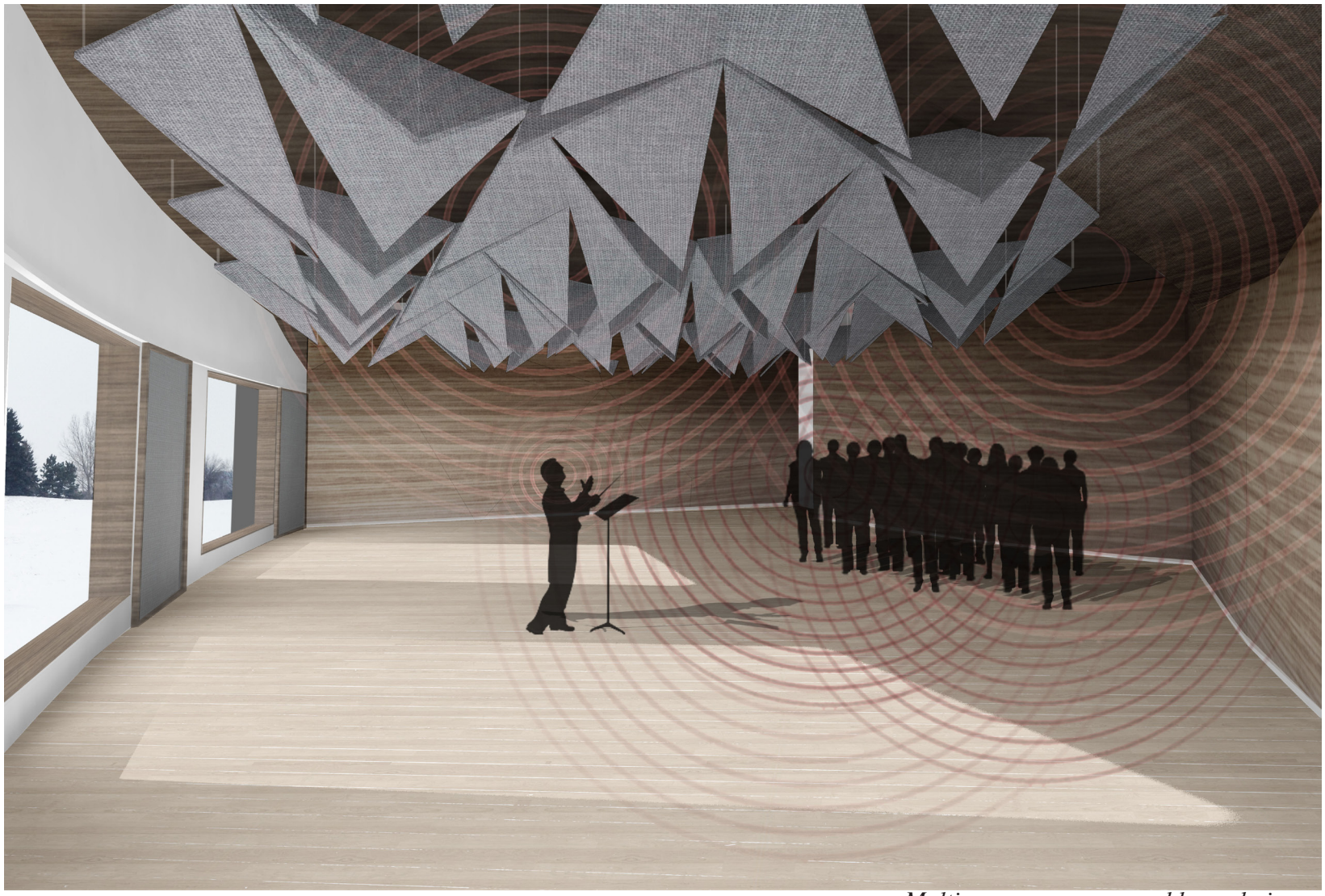
Angled panels at 3m height.



Multi-purpose space used for music practise, with conceptual sounds shown.



Angled and opened panels at 4.25m height.



Multi-purpose space used by a choir, with conceptual sounds shown.

Ottawa Sonic Centre: auditorium

Adjustable Auditorium: The auditorium functions acoustically in the same was as the multi-purpose room, but can accommodate programs that require seating of just over 200 people. This space could be tuned to events such as lectures, classes, plays or small concerts, and allow for all members of the audience to hear voices and sounds clearly. It could also allow for spatial acoustics to define the sounds, or accommodate amplification through the built in ceiling speakers. Just as the multi-purpose room allows, the auditorium acoustics could feel intimate (less reverberant) or more grand (more reverberant).

The building as a whole is meant to respond to the use through program specific acoustics and aural qualities, as well as create an interesting and dynamic sonic environment throughout. These are design ideas which are often not considered in everyday buildings, but can help to create a more immersive sensory experience and avoid the negative effects that poorly designed acoustics can create. Architecture which sounds monotonous and banal can be compared to the

visual equivalent of white walls and floors, but much like painting or adding visual elements, we can significantly alter the feeling and affects of a space.

A 'sound rendering' video walkthrough was created for this project in order to give an approximation of how the space would sound, and show how sound can add to the understanding of a space. Sounds were recorded by the author (or found from sources noted on page 104), altered to the desired qualities and added to the video walkthrough. This is not something that is commonly done in architectural design presentations as we focus so much on visuals, and animations are instead often accompanied by music. The video can be found at:

https://vimeo.com/125947082

[Bin]aural Architecture by Emily Brett on vimeo.com

[1] "Peter Zumthor: Seven Personal Observations on Presence In Architecture." *ArchDaily*. December 3, 2013. www.archdaily.com/452513/peter-zumthor-seven-personal-observations-on-presence-in-architecture

[A] "Ottawa Official Plan: Schedule Q-Plan Q." *City of Ottawa*. www.documents.ottawa.ca/sites/documents.ottawa.ca/files/documents/schedule_q_en.pdf.

CONCLUSION

This thesis has investigated the significance of sound in architectural design, and how the role of the aural architect can become beneficial in detailing our surroundings. Every space has aural qualities, regardless of whether or not they were conceived in the design, which is why it is necessary to consider acoustics in all facets of design. This can change the feeling of a space, regardless of the intention of visual elements. Additionally, sound can have an effect on the body and cause unintentional negative reactions. The research lead to a project which aims to align the desired effects of a space with basic acoustic principles, in order to create a design which is ideally tuned to its use and encourages inhabitant's to listen to the spaces, in order to provide a more complete sensory experience. Rather than hearing sound as noise, which is often the case when spaces are too noisy or the acoustics are not suited to the program, this method of 'binaural' design attempts to entice people to fully listen to their environments with both ears. Through aural design that is unique, interesting and tuned accordingly, architecture can become better engaged with our sense of sound and positively effect our experiences in spaces.

IMAGES

figure 1: “Edgar J. Kaufmann Jr. Residence - Fallingwater ” Wright on the Web. www.wrighton-theweb.net/flw8-8.htm.
figure 2: Schafer, R. Murray. The Soundscape: Our Sonic Environment and the Tuning of the World. (Rochester, Destiny Books, 1994), Appendix I.
figure 3: Schafer, R. Murray. The Soundscape: Our Sonic Environment and the Tuning of the World. (Rochester, Destiny Books, 1994), Appendix I.
figure 4: “Certificate in Carillon Studies.” Carleton University. www.carleton.ca/music/carillon
figure 5: “25 Facts about the Auditorium Theatre in Chicago, celebrating its 125th anniversary.” Mom Factually. http://momfactually.com/facts-auditorium-theatre-chicago/
figure 6: “Adler, Dankmar: Auditorium Theatre.” Encyclopaedia Britannica. http://kids.britannica.com/comptons/art-122202/The-Auditorium-Theatre-in-Chicago-built-in-1889-displays-the.
figure 7: “Sound Architecture: The Spaces That Speak.” BBC Radio 4. http://www.bbc.co.uk/programmes/b00j3w8k.
figure 8: Metcalfe, John. “Notre Dame Cathedral Just Got An LED Makeover.” City Lab. March 11, 2014. http://www.citylab.com/tech/2014/03/notre-dame-cathedral-just-got-led-makeover/8606
figure 9: “John cage 4’33”.(1952). ” Vimeo. https://vimeo.com/49738079.
figure 10: Crow, Frances and Prior, David. “Final Report: Tranquility is a State of Mind.” Liminal. June 2010. www.liminal.org.uk.
figure 11: “The Swiss Sound Box.” Ghana+Europe. August 22, 2011. www.carolinaverdial.wordpress.com/2011/08/22/hello-world.
figure 12: “Playing the Building.” DavidByrne.com. www.davidbyrne.com/archive/art/art_projects/playing_the_building/
figure 13: “Winter Trip to Ottawa: January 22-25, 2014.” SIM Publishing. www.sim-publishing.com/ottawa.htm.
figure 14: “Ircam.” Renzo Piano Building Workshop. www.rpbw.com/project/12/ircam.

BIBLIOGRAPHY

Anderson, Dr. Thomas, and Lerch, Donna. "The Mozart Effect: A Closer Look." (2000) www.lrs.ed.uiuc.edu.

Augoyard, Jean François, Andra McCartney, Henry Torgue, and David Paquette. *Sonic Experience: A Guide to Everyday Sounds*. Montreal: McGill-Queen's University Press, 2005.

Blesser, Barry, and Linda-Ruth Salter. *Spaces Speak, Are You Listening?: Experiencing Aural Architecture*. Cambridge, MA: MIT, 2007.

Blesser, Barry, and Linda-Ruth Salter. "Aural Architecture: The Missing Link." www.blesser.net

Blesser, Barry, and Linda-Ruth Salter. "Questions and Answers about: Spaces Speak, Are You Listening? Experiencing Aural Architecture." www.blesser.net

Blesser, Barry, and Linda-Ruth Salter. "The Other Half of the Soundscape: Aural Architecture." www.blesser.net

Brown, A.L. "Acoustic Objectives for Designed or Managed Soundscapes." *Soundscape Volume 4 Number 2* (2003). (Accessed online: http://wfae.proscenia.net/journal/scape_7.pdf)

Byrne, David. *How Music Works*. San Francisco, California: McSweeney's, 2012.

Byrne, David. "Playing the Building." www.davidbyrne.com/archive/art/art_projects/playing_the_building

Cavanaugh, William J., and Joseph A. Wilkes. *Architectural Acoustics: Principles and Practice*. New York: Wiley, 1999.

"Certificate in Carillon Studies." *Carleton University*. www.carleton.ca/music/carillon

Cox, Trevor. "Sound Architecture: The Spaces That Speak." *BBC News*. BBC, http://www.bbc.co.uk/programmes/b00j3w8k

Cox, Trevor. "TEDxSalford - Trevor Cox - Become a Sound Explorer." www.youtube.com

Eberhard, John P. "Applying Neuroscience to Architecture." *Neuron, Vol. 62 Issue 6* (2009).

Eberhard, John P. *Brain Landscape: The Coexistance of Neuroscience and Architecture*. Oxford: Oxford UP, 2009.

Emmons, Paul, John Hendrix, and Jane Lomholt. "De Beata Architectura: Places for Thinking, by Marco Frascari." *The Cultural Role of Architecture: Contemporary and Historical Perspectives*. Milton Park, Abingdon, Oxon: Routledge, 2012.

Fowler, Michael. "Mapping Sound-space: The Japanese Garden as Auditory Model." *Architectural Research Quarterly vol. 14 number 1* (2010): 63-70.

"Guidelines for Community Noise" *World Health Organization*. http://who.int/docstore/peh/noise/guidelines2.html

Hamilton, William L. "The World of Sound." *Dwell*. http://www.dwell.com/essay/article/world-sound.

Horowitz, Seth S. *The Universal Sense: How Hearing Shapes the Mind*. New York: Bloomsbury, 2012.

Hosey, Lance. *The Shape of Green: Aesthetics, Ecology, and Design*. Island Press, 2012.

Hsu, Timothy Yuan-Ting. *Relating Acoustics and Human Outcome Measures in Hospitals. 2012*. https://smartech.gatech.edu/bitstream/handle/1853/47620/hsu_timothy_y_201205_phd.pdf?sequence=1

"Integratron: Landers, California." *Integratron*. www.integratron.com.

"Ircam." *Renzo Piano Building Workshop*. www.rpbw.com/project/12/ircam.

Moore, John Edwin. *Design for Good Acoustics and Noise Control*. London: Macmillan, 1978)

Morreale, Michael. "The Peace Tower Carillon: Canada's Most Iconic Instrument." *CBC Radio-Canada*. www.music.cbc.ca.

"Ottawa Official Plan: Schedule Q-Plan Q." City of Ottawa. www.documents.ottawa.ca/sites/documents.ottawa.ca/files/documents/schedule_q_en.pdf.

Pallasmaa, Juhani. *The Eyes of the Skin: Architecture and the Senses*. Chichester: Wiley-Academy, 2005.

"Pavilion 21 MINI Opera Space." *Coop Himmelb(l)au*. www.coop-himmelblau.at/architecture/projects/pavilion-21-mini-opera-space.

"Peter Zumthor: Seven Personal Observations on Presence In Architecture." *ArchDaily*. December 3, 2013. http://www.archdaily.com/452513/peter-zumthor-seven-personal-observations-on-presence-in-architecture/

Prince-Ramus, Joshua. "Joshua Prince-Ramus: Building a Theater That Remakes Itself." *TEDTalk*. http://www.ted.com/talks joshua_prince_ramus_building_a_theater_that_remakes _itself.html

"Quietest Place on Earth' Causes Hallucinations." *SmartPlanet*. www.smartplanet.com.

Rosen, Jody. "Welcome to the Integratron." *The New York Times*. (The New York Times: 19 Aug. 2014), www.nytimes.com

Ryherd, Erica. "Too Noisy to Heal." *Healthcare Design Magazine*. http://www.healthcare-

designmagazine.com/article/too-noisy-heal.

Schafer, R. Murray. *The Soundscape: Our Sonic Environment and the Tuning of the World*. Rochester, Destiny Books, 1994.

Sternberg, Esther M. *Healing Spaces: The Science of Place and Well-being*. Cambridge, MA: Belknap of Harvard UP, 2009.

"The World Soundscape Project." *Simon Fraser University*. www.sfu.ca.

Thompson, Emily Ann. *The Soundscape of Modernity: Architectural Acoustics and the Culture of Listening in America, 1900-1933*. Cambridge, MA: MIT, 2002.

Treasure, Julian. "Julian Treasure: Why Architects Need to Use Their Ears." *TED Conferences LLC*.http://www.ted.com/talks/julian_treasure_why_architects_need_to_use_their_ears.html

Treasure, Julian. "Building in Sound." *Biamp Systems*. (Accessed from www.juliantreasure.com)

Ulrich, Roger S. "Essay: Evidence-based Health-care Architecture." *The Lancet 368* (2006): S38-39.

Vitruvius. *The Ten Books on Architecture, Book V. Cambridge: Harvard University Press*, 2006). (accessed from www.gutenberg.org).

Whitman, Walt. "Song of Myself." *Leaves of Grass*. New York: Pocket, 2006.

Zumthor, Peter. *Atmospheres: Architectural Environments*. Birkhauser Architecture, 2006. (Accessed from: http://ebookbrowsee.net/zumthor-peter-atmospheres-pdf-d321765560).

SOUND CLIP SOURCES

[Bin]aural Architecture by Emily Brett (https://vimeo.com/125947082)

"The Gaslight Anthem interview - Brian (part 1)." https://www.youtube.com/watch?v=vhmXMfp LfIQ&spfreload=10.

"Kids Playing Sound Effect." https://www.youtube.com/watch?v=EBNDGtJ_Rs4&spfreload=10 "Bird Sound Effect." https://www.youtube.com/watch?v=mknJ5znyt1c&spfreload=10

"The String Quartet Tribute to Nirvana - Polly." https://www.youtube.com/watch?v=1Zb1-cBw3Ks&spfreload=10

"Door Open and Close Sound Effect." https://www.youtube.com/watch?v=k3v37Ac_CvI&spfreload=10

"FootstepsonConcrete."https://www.youtube.com/watch?v=5v3FY_HrC2I&spfreload=10 "Lululemon | Yoga - The Shangri-La Hotel, Toronto ." https://www.youtube.com/watch?v=oKRo UdeWudQ&spfreload=10

"People Talking in Background Ambience." https://www.youtube.com/watch?v=YsiaBSHGenE& spfreload=10

"Jazz Street Musicians." freesound.org. https://www.freesound.org/people/reinsamba/sounds/54066/