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SOUND CREATED FORM

By

Benjamin N. Gaum

Bachelor of Environmental Design, Halifax, 2006

A design thesis / project

Presented to Ryerson University

In partial fulfillment of the

Requirements for the degree of

Masters of Architecture

Toronto, Ontario, Canada, 2009

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Benjamin M. Gaum

Abstract

Sound Created Form

Benjamin N. Gaum Masters of Architecture Ryerson University, Toronto, 2009

Exploring the influence of sound on architectural form and the aural quality of spaces it can create.

Although people have been trying to understand the connection between music, sound and architecture for thousands of years, the role of acoustics continues to play a fairly secondary role in the process of design of architectural projects. It has been mostly relegated to a band-aid condition that is applied after the building has already been designed, or worse, left to chance. This research and design thesis will examine potential relationships between sound and architecture and explores the ways sound can be a source for the generation of spatial forms and the aural quality of spaces they can create. The approach to this thesis will be to see how sound influences architecture in three basic conditions. They are: Environmental acoustic design, program/experiential consideration and formal exploration.

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I also would also like to acknowledge and thank my fellow student and good friend Mark Friesner for all his help, expertise and espresso's.

Dedication

I dedicate this thesis project to my loving and supporting parents, family and friends who showed great patience and understanding during my 6 year journey to “go back to school”, and who essentially paid for all my beer while I was a poor student. And to my loving finance who was crazy enough to start dating a man who was just about to enter into a masters of architecture program at the age of 34.

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Introduction / Background

It is no secret, nor any wonder for that matter that the relationship between music or sound and architecture dates back as far as Vitruvius, and possibly further. In his book "The Ten Books of Architecture", Vitruvius devotes as much text to "sound, music and acoustics as he did to site design, materials and color; a level of attention unheard of in current architectural writing" (Sheridan, p.3). Although they have always displayed strikingly similar attributes in terms of balance, structure and emotional interpretations, architecture and music have come so close, but have never fully been able to bridge the gap that lay between them. It was always a question of sensory differences that found it impossible for architecture to be "heard" and for music to be "drawn" (Ripley, 3).

Sound offers a rich medium for exploration: it is an essential element of how we understand and relate to space, and its properties and behavior are intimately linked to the physical experience of an environment (Bryant, 2008).

In more recent years it has been the trend in movements such as *Acoustic Ecology* and *Soundscape Study* to try and understand the effects of sound and music in our built environment. Based on more subjective qualities, these areas of study have proved to be more interpretational or conceptual ways of thinking of sound to shape the experience of space rather than results based in a more scientific, engineering reality that could actually be proven or shown in a physical architectural model.

This first half of this thesis will attempt to return to more scientific and engineering practices to apply quantitative and numeric data to the analysis of both architectural form and the interpretations of the people who use them in hopes of finding a connection between the two. The second half of this thesis will apply the knowledge gained from acoustical analysis into an architectural design. The intent of this thesis is to understand the reasoning of how **form affects sound** and address the main problem statement of the research by asking how **sound affects form**.

Research Question(s)

In order to focus the research in this topic, it is necessary to ask specific questions that will help come to some sort of a conclusion regarding the affect of form on sound and the affect of sound on form. The majority of this research study will focus on different temporary structures that act as main venues for various jazz festivals across Canada. The interest in temporary structures as opposed to permanent structures will address the issue of flexibility within a structure to respond to specific environmental, acoustical and architectural impacts and how might these impacts affect the overall form.

What are these paradoxical affects on architectural forms? It would be interesting to investigate a form of architecture that although, has rarely been examined in terms of its acoustical properties, holds such acoustical importance for countless music festivals around the world. The temporary form allows for a much greater ease of formal exploration both before the erection of the structure but possibly during a performance as well, posing the question, "can a building be **tuned**"? Can the acoustical study of several temporary structures be compared and contrasted to analyze optimal characteristics, or **quantifiers**, as well as deficient ones that might affect the formal outcome as well as the acoustical outcome of design? Can the input of the musicians, technicians and engineers who use the structures be collected in order to offer data in the form of **qualifiers** to help analyze these temporary structures? Can a connection be made between these **quantifiers** and **quantifiers**? Again, it isn't the "temporary structure" itself that is of particular interest to this study but rather the possibility of a dynamic, flexible nature of structural form that might be able to change or adapt to certain acoustical conditions and thus potential be applied to the design portion of this thesis.

Literature review

History

From the numerous whispering galleries found in ancient architecture, to the perfect clarity of the Greek amphitheatres, it is clear that the importance of sound and music has played an important role in architecture from the beginning. In *The Ten Books on Architecture*, Vitruvius devotes as much text to “sound, music and acoustics as he did to site design, materials and color. His focus was both quantitative and qualitative as he explored the mathematical and rhythmic characteristics of music as well as the sensory and ephemeral ones.

Vitruvius deals with sound in both “proportional” and “actual” modes. The “proportional” mode “relates the spatio-visual experience of width, height, and depth to the tonal experience of harmonic musical notes,” which provides a “basis for linking the two types of experience and a practical guide for sizing the various parts of building.” (Sheridan, p.3)

This would effectively trigger an interest in the connection of these two artistic and technical disciplines for centuries to come.

Interpretations

In June of 2006, Ryerson University in Toronto held a conference called *Architecture/Music/Acoustics*. It was an in depth, cross disciplinary look into the effects and connections of music, sound and architecture. The conference produced a multitude of papers by a number of expert contributors that were subsequently published in a book called “In the Place of Sound”. The papers presented offer a diverse look into the discussion of the “sound/space nexus” (Ripley) but often fail to connect to the scientific and quantitative approach to form exploration that is going to be used in this thesis research. This was also found to be true in the two other landmark publications on the subject, namely “*Resonance, Essays on the Intersection of Music and Architecture*” and “*Architecture as a Translation of Music*”. Although the majority of the papers presented were based on the purely sensory and philosophical aspects of sound and the *interpretations* of sound to shape the experience of space, they reinforce the importance and interest in the continued discussion in the field and show the complexity in the relationship and representation of music and architecture. The creative ideas of inspiration and interpretation might be able to be re analyzed during the design phase of this thesis project

Intersections

"In the Place of Sound" however, presents three papers that are able to cross over and make more of a scientific, quantitative approach with regards to connecting music and acoustics to architectural form. The "Mix House", "The Architecture of Pianos", and "Multiple Scales: Sounding Forms from Instruments to Skylines" offer interesting examples of the flexibility of forms that are able to react to specific acoustical characteristics and represent these reactions in intriguing design projects.

In the papers taken directly from the Toronto Conference itself, the studies relating to the "Spaces for Performances" were found to be very practical in nature and asked very practical questions relating to actual built forms.

What is and what should be 'space' for performance? What recent examples re-define the 'space' for performance? How do intersection between Architecture | Music | Acoustics inform building design from the formal level to the detail level? What normative/traditional associations should be challenged in future performance spaces? (Ripley, 5)

Although not all of these questions are answered in full, in any of the texts, just the formation of the questions themselves begins to help focus and formulate the research being looked at in this thesis.

Connections

Leo Beranek's book *Concert Halls and Opera Houses*, along with *Soundscape, Architecture for Sound and Vision* by Peter Grueneisen begin to show promise of an approach to the connection of music, sound and architecture that wasn't based solely on interpretation or subjective qualities. Backed by a scientific approach in the attempt to understand these subjective reasoning's behind music, sound and acoustics, Leo Beranek combines the quantifiable data gathered from various acoustical studies of concert halls and opera houses and plots them against the qualitative data acquired by questionnaire surveys that compare these same structures on a more subjective level. The surveys were sent to musicians, conductors and engineers who have had intimate, musical experiences with the buildings in question. By combining the quantitative with the subjective information collected, he hoped to possibly formulate a more generalized, global understanding of what desirable acoustics could be both in specific venues and structures as well as for specific types of performances.

Research Methodology

Although the basic elements of this research will be setup mostly like a scientific experiment, an attempt will be made to use Beranek's approach and combine the collection of acoustical data on both the scientific engineering and subjective levels in order to find a connection between architectural form and the subjective interpretation of music.

The first phase of research will be based on the basic understanding of acoustics both in a general sense and in an architectural sense. It will probably be close to impossible to understand the quantitative data acquired, or the method in which to acquire them during this experiment without this introductory knowledge of sound and acoustics that will be outlined in Chapter 1 of this paper. Although Chapter 1 will not provide an exhaustive study of any one particular aspect of *Architectural Acoustics*, it will provide a solid background and general overview of the historical, technical, physical and perceptual aspects that will be a key in understanding the main issues dealt with in this thesis.

The second and main phase of the research will consist of a **simulation study** and a **survey data** collection and analysis. The experiment being set up will focus on looking at 3 different temporary structures that have been erected for the purpose of musical performances for various jazz festivals across Canada and will include: *The Atlantic Jazz Festival*, *The Montreal Jazz Festival* and the *Toronto Jazz Festival*. Upon gathering structural and layout information about the structures themselves, a 3D model will be constructed and analyzed using acoustical engineering software called *CATT Acoustic*. As an additional element of the simulation study, an acoustics survey will be conducted to gather subjective data from the various venues themselves. In order to maintain a level of consistency for all the surveys, a single song from a single band that has been played in all three venues will be used as a base for the survey analysis. The survey will be given to individual musicians, technicians and engineers that were directly linked to and involved with the venues in order to give an accurate account of what the sound quality and acoustics were like in that specific venue when that specific song was played.

Chapter 1: A Basic Understanding of Acoustics

1.1 A Brief History of Music and Sound in Architecture

"Everything in the world was created by sound and analyzed by vision. God spoke first, and saw that it was good second" (Shafer, 163). The connection between sound and architecture is one that can be traced back to the whispering galleries as well as the amphitheatres of ancient times where "the perfect clarity of the Greek amphitheatre and a speaker, standing at a focal point created by the surrounding walls, is heard distinctly by all members of the audience" (Sheridan, 3). Surprisingly, the levels of knowledge of the basic principles of acoustics in architecture have been known for thousands of years. The importance it plays in Vitruvius's *10 Books of Architecture* is a clear demonstration of its primary role in the creation of architectural spaces. He speaks of a clear understanding of reflection,

reverberation and resonance of sounds through a space and makes suggestions for several ingenious devices to help with the acoustics of a building such as the built in resonant vessel.

By the gothic period, much of the basic understanding of the science of acoustics that we know of today had already been defined to a fairly high degree. Through Gregorian chanting, came the invention of a body of music that was the first to be notated in a system ancestral to modern musical notation. It was the performances of these chants, in their grand gothic cathedrals that opened the door for the exploration of the effect architecture could have on music and sound. This would eventually influence the medieval and renaissance music and architecture to follow. The world would witness a development of bigger and taller cathedrals and temples that would effectively create larger, broader, more resonant displays of both religious and political importance. This would include the Taj Mahal in India, with a later recorded reverberation time of 28 seconds.

Fig 1.1 Timeline of Sound and Architecture

ACOUSTIC SCIENCE	
6 th CENTURY BC	
Music and mathematics, vibrating strings (Pythagoras)	
3 rd CENTURY BC	
Acoustic principles, sound propagation (Aristotle)	
1 st CENTURY AD	
<i>De Architectura Libri Decem</i> (Ten Books on Architecture) (Marcus Vitruvius Pollio)	
16 th CENTURY	
Music for specific buildings (Adrian Willaert)	
17 th CENTURY	
Room acoustic principles (Athanasius Kircher)	
Sound requires a medium (Robert Boyle)	
<i>New Sciences</i> (Galileo Galilei)	
18 th CENTURY	
Term "acoustics" introduced (Joseph Savour)	
Speed of sound (Pierre Simon Laplace)	1816
Limits of hearing (Felix Savart)	1830
Isoacoustic curve (John Scott Russell)	1839
Precedence effect discovered (Joseph Henry)	1850
Heinrich Hertz	1857
<i>On the Sensations of Tones</i> (Hermann Ludwig Ferdinand von Helmholtz)	1863
<i>The Theory of Sound</i> (J.W. Strutt - Lord Rayleigh)	1877
Fogg Museum Lecture Hall (Wallace Clement Sabine)	1895
Boston Symphony Hall (Wallace Clement Sabine)	1900
<i>Acoustics of Buildings</i> (Floyd Watson)	1923
Sound transmission loss calculations (Edgar Buckingham)	1925
Anechoic chamber (Floyd Watson)	1927
Sound level meter (Paul Sabine)	1930
<i>Reverberation in Dead Rooms</i> (Carl Eyring)	1930
Auralization with scale models (Spandöck)	1933
<i>The Effects of Noise on Man</i> (Karl Kryter)	1950
Acoustic computer modeling	1965
PC programs for reverberation time in simple rooms	1981
Full graphic MacIntosh modeling CAD program (BOSE)	1986
EASE modeling program (Wolfgang Ahnert)	1990
CATT Acoustics (Beng-Inge Dalenback)	1990
<i>Concert and Opera Halls</i> (Leo Beranek)	1996

FIG 1.2 Timeline of Acoustic Science

The baroque and classical periods would bring on the major influence of music as non religious spectacle. This would push for the development of small theatres, ballrooms and eventually concert halls and opera houses that were being built specifically for musical performances of some kind. Composers like Mozart, Beethoven and Haydn would continue to push the limits of musical exploration thus forcing the architecture to try to keep up.

Built in the late 19th century, the *Musikverein* in Vienna would go on to become considered one of, if not the finest concert halls in the world. It was being studied very carefully at the time by a young American physicist named Wallace Clement Sabine in order to understand what its physical acoustical properties were that made it such a successful concert hall. His story in short is the story of the birth of the field of modern architectural acoustics. By analyzing the *Musikverein* he developed his Sabine equation which established a relationship between the reverberation time of a room, its volume and its total absorption (in sabins). This equation would prove to be

instrumental in the future development of architectural acoustics. Sabine would in fact use his equation for his role as acoustical architect of Boston's Symphony Hall in 1900 which also became known as one of the world's three best concert halls for its acoustics.

The turn of the 20th century would bring on the invention of recorded music and speech, making way for further advancements in acoustic sciences. Recording studios, along with modern concert halls, would become the new focus of acoustical analysis and help push the computers role in assisting in the study of acoustic architecture. Studies were also being done to improve the acoustics in classrooms, board rooms, office spaces and even environmental acoustic conditions.

This would bring us up to modern day where computer technology is helping us build 3D acoustic models of spaces to both analyze and predict the acoustic outcome of a given design.

1.2 Fundamentals of Sound

Basic Physics

Acoustics	The science of sound
Amplitude	The height or magnitude of a pressure wave at a given time
Atmospheric pressure	Basic air pressure, depending on altitude and weather
Compression	Increase in pressure through the crowding together of particles
Decibel (dB)	User friendly unit for sound pressure level
Frequency (f)	Number of cycles per second, in the hertz (Hz), kilohertz (kHz).
Harmonic	A sound component of a multiple of the fundamental frequency
Interference	Interaction between different sound waves
Loudness	Subjective perception of a sound pressure level
Medium	Environment through which sound is transmitted
Noise	Sound with no periodic frequency
Octave	Interval between two sounds with double or half the frequency
Receiver	Human listener, microphone, etc.
Sound Pressure	Acoustic force per unit area, in pascals (Pa) $1\text{Pa} = 1\text{ Newton/m}^2$
Source	The originator of a sound vibration
Tone	Pure sound, sine wave

Sound is defined as the sensation produced by stimulation of the organs of hearing by vibrations transmitted through the air or other medium (dictionary.com). It is a pressure wave in a medium that, when unrestricted, spreads from its source outwards in all directions at a speed of 1130 feet per second (in air). When a sound wave finally hits a surface, part of the energy is reflected, part transmitted and

FIG 1.3 Transmission of Sound

the rest of it is absorbed. The percentages of these occurrences depend greatly on the density and makeup of the surface itself which is reflected in the following substances sound absorption coefficient chart.

FREQUENCY (Hz)	125	250	500	1000	2000	4000	NRC
FLOORS							
Concrete floor, smooth	0.01	0.01	0.02	0.02	0.03	0.03	0.02
Floor covering: linoleum, cork, rubber, vinyl	0.02	0.03	0.03	0.03	0.03	0.02	0.03
Polished stone, glazed tile	0.01	0.01	0.01	0.01	0.02	0.02	0.01
Wood parquet, glued down	0.04	0.04	0.07	0.06	0.06	0.07	0.06
Wood floor	0.15	0.11	0.10	0.07	0.06	0.07	0.09
Carpet on concrete	0.02	0.06	0.14	0.37	0.60	0.65	0.29
Carpet on soft pad	0.08	0.24	0.57	0.69	0.71	0.73	0.55
WALLS, CEILINGS							
Concrete block raw	0.36	0.44	0.31	0.29	0.39	0.25	0.36
Concrete block painted	0.10	0.05	0.06	0.07	0.09	0.08	0.07
Acoustical concrete block (RPG DiffuserBlock)	0.78	0.90	0.93	0.78	0.80	0.77	0.85
Acoustical concrete block painted (Proudfoot Soundblock)	0.57	0.76	1.09	0.94	0.54	0.59	0.83
Brick raw	0.02	0.03	0.03	0.04	0.05	0.07	0.04
Gypsum board over wood framing, filled with fiberglass	0.55	0.14	0.08	0.04	0.12	0.11	0.10
Plaster on lath	0.14	0.10	0.06	0.05	0.04	0.03	0.06
Plywood panels 3/8"	0.28	0.22	0.17	0.09	0.10	0.11	0.15
Plywood panels 1" over airspace	0.19	0.14	0.09	0.06	0.06	0.05	0.09
Fabric over 1" fiberglass over airspace	0.29	0.82	1.02	1.00	1.03	1.06	0.97
Fabric over 2" fiberglass	0.38	0.60	0.78	0.80	0.78	0.70	0.74
Cotton fiber duct liner 1"	0.07	0.33	0.72	0.99	0.93	0.96	0.74
Cotton fiber insulation 3.5"	0.95	1.30	1.19	1.08	1.02	1.00	1.15
Cotton fiber insulation 5.5"	0.97	1.37	1.23	1.05	1.00	1.01	1.16
Sintered aluminum panels 3mm (Almute) over 2" fiberglass	0.36	0.86	1.13	1.06	0.90	0.71	0.99
Foamed aluminum panels 1" (Alusion)	0.13	0.14	0.55	0.53	0.70	0.85	0.48
Open-cell foam, 1" wedge-shape	0.07	0.11	0.20	0.32	0.60	0.85	0.31
Open-cell foam, 2" wedge-shape	0.08	0.25	0.61	0.92	0.95	0.92	0.68
Wood shredded fiberboard 1" over 1" fiberglass	0.16	0.43	1.00	1.05	0.79	0.98	0.82
Acoustic tile on concrete	0.14	0.20	0.76	0.79	0.58	0.37	0.58
Acoustic tile ceiling 1" suspended	0.76	0.93	0.83	0.99	0.99	0.94	0.94
Glass 1/4" regular window	0.35	0.25	0.18	0.12	0.07	0.04	0.16
Glass heavy laminated	0.18	0.06	0.04	0.03	0.02	0.02	0.04
Drapes light, over flat wall	0.03	0.04	0.11	0.17	0.24	0.35	0.14
Drapes heavy, draped together	0.14	0.35	0.55	0.72	0.70	0.65	0.58
LOW-FREQUENCY ABSORBERS (EXAMPLES)							
Resonant panel absorber 10mm	0.38	0.22	0.17	0.09	0.10	0.11	
Volume absorber 4mm panel, 100mm air with 50mm fiberglass, 1.4% opening	0.25	0.96	0.66	0.26	0.16	0.10	
SOUND ABSORPTION BY AUDIENCE							
Occupied seats	0.60	0.74	0.88	0.96	0.93	0.85	0.88
Unoccupied leather seats	0.44	0.54	0.60	0.62	0.58	0.50	0.59

FIG 1.4 Sound Absorption Coefficients

1.3 Environmental Acoustics

The human perception of sound occurs within the acoustic environment. This consists of the sound source that causes the vibration, the path of transmission through a medium, and the receiver. The quality of sound at the receiver is a function of each of the three parts (Grueneisen, 45). Sound sources are typically considered either a desirable sound (e.g. music, speech, chirping birds); or an undesirable noise (e.g. traffic, machinery) (Grueneisen, 45).

“Desirable” sound is the result of *periodic* sound waves: regularly repeated patterns of oscillations, the most simple of which is a sine wave representing a pure tone. In contrast, undesirable noise is the result of *aperiodic* sound waves that have no periodic frequency or oscillation (Bryant, 8). Undesirable sounds are typically understood as *environment acoustics*. From a typical design standpoint, *environmental acoustics* typically attempt to diminish and control unwanted noise such as traffic noises, construction noises, man made noises as well as natural sounds, in hopes of improving desirable sound levels. For the purposes of this thesis, undesirable sounds had to be understood and taken into consideration as *background noise* for the venues studied. As these were semi-enclosed buildings in outdoor venues, there were many environmental acoustical sources that were affecting the performance and acoustical qualities of the venues. They will continue to play an important role in future stages of this thesis study as entire urban areas for jazz festivals will be looked at instead of just the single venues themselves.

FIG 1.5 Environmental Acoustics

1.4 Perceptions of Sound

What are good acoustics? This is a question that cannot be answered simply. While measurements of the physical aspects of sound are repeatable and allow an accurate prediction of its variables, human perceptual responses are largely less predictable (Grueneisen, p. 53). These human perceptions of sound are what give us subjective, sensory insight into sound, acoustics and ultimately the architecture that encompasses it. Although a lot harder to purely define, a glossary of subjective terms has been developed in recent years out of the dialogue between musicians and acousticians to generally describe sound, especially in music. Leo Beranek, in his book *Concert Halls and Opera Houses*, helps define these terms and uses them in conjunction with detailed acoustical analysis of 100 halls that essentially acts as a methodology model for the experiments laid out in this thesis project.

"I cannot agree with those who would call acoustics a mere matter of taste, denying the existence of "good" and "bad" sound. Were that the case, acoustics would stand alone as the one thing in the world possessed of different degrees of quality," (Beranek, 38).

His hope is to try and find a connection between the objective and subjective data that describes the physical properties of these spaces. In general, it can be agreed upon by almost all music professionals and music lovers alike, that a space for listening to music should be quiet enough to be able to hear any very soft (pp) passages as well as have a reverberation time long enough to carry crescendos to dramatic very loud (ff) climaxes. It should posses a high level of clarity and a spacious sound, making the music full and rich and apparently much "larger" than the instrument from which it emanates, (Beranek, 2).

Physics

- Frequency (Hz)
- Sound Pressure level (dB)
- Spectrum

Perception

- Pitch (mels)
- Loudness (phons, sones)
- Timbre, or tone color, quality

Fig 1.6 Relationship between Frequency, Wavelength and Rang of Sound

1.5 Acoustic Design

Although acoustical design characteristics are taken into serious consideration for all types of rooms and venues for listening, the subject of spaces for live music performances has filled volumes, and is

considered the epitome of room acoustics (Grueneisen, 63). The main cause for acoustical difficulties in rooms is the relatively low speed of sound in air. For better or worse, this relatively slow speed of sound allows us to easily perceive the differences in the arrival times of both direct and reflected sounds (Grueneisen, 62). When summing up his works on interviews and surveys of over 100 conductors around the world, Beranek states:

“An analysis of the subjective responses made it apparent that of all acoustical elements, **reverberation time** comes to a conductor’s mind first, because it directly affects his ability to achieve the clarity, fullness of tone, and phrasing consistent with his interpretation of the composer’s intention” (Beranek, 2).

FIG 1.7 Reflection Patterns and Modal Distributions

FIG 1.8 Outdoor and Indoor Acoustic Properties

Reverberation Time

Reverberation is defined as the continuation of a sound in an enclosed space after the source that has created the sound has ceased. The sound, after it is created, then radiates outward from all directions and encounters the surrounding surfaces that include walls, balcony fronts, ceiling and the audience area (Beranek, 20).

"Reverberation is in itself neither desirable nor undesirable; it is one of the components available to the composer (and performer) for producing a musical effect. Because the reverberant sound fills the spaces between new notes as they are played, it provides the "fullness of tone" that musicians may employ or restrain, as their needs demand," (Beranek, 22).

The *reverberation time* (RT), introduced by Sabine in the late 18th century, refers to the amount of time it takes for that sound to become completely inaudible after it is stopped. There is still a wide range of acceptable levels for reverberation times depending on the type of music been played in a specific venue? Where as a longer reverberation time for example would tend to be more appropriate for a performance of *Gregorian* chanting, a shorter reverberation time would force musicians and performers to play much more precisely because no lingering reverberation smoothes over slight imperfections (Beranek, 2). Even though there is no objective result to exactly define a singular idea of the perfect reverberation time for a musical venue, there are ideas of general desirable reverberation times to try and achieve.

FIG 1.9 Illustrations of Reflections

FIG 1.10 Desirable Reverberation Times

Chapter 2: Acoustical Analysis

2.1Experiment Setup / Objective

As mentioned in the research methodology, the experiment will consist of two sections. The first will be a simulation study and collection of *quantitative data*, involving the acoustical analysis of three temporary structures used for music festivals across Canada. The structural and specifications of each venue will be acquired and used to build a 3D computer model that will then be analyzed for its acoustical and physical properties using software called CATT Acoustics.

The second will be the collection of *qualitative data* by means of a survey that will be sent out to various musicians, technicians and engineers across Canada. To ensure an even, level and consistent approach to the survey data collection, a single song from a single band that has been played in the three separate venues will be used. It will be a requirement that all the people surveyed would have been present at the playing of this one song in at least one of the venues in question. Three venues from three separate jazz festivals across Canada have been chosen and include:

The Toronto Jazz Festival	Main performance tent	Nathan Phillips Square
Montreal Jazz Festival	Main performance stage	Place des Arts
Atlantic Jazz Festival (Halifax)	Main performance tent	Dalhousie Tuns Campus

The band chosen for this experiment is *The New Deal*. A Toronto based band that has had much success playing all over North America, including many high profile jazz festivals. They are a three piece instrumental ensemble that describes their style as *live progressive house*. They are comprised of:

Jamie Shields	Keyboards / Synthesizer / Piano
Darren Shearer	Drummer / Percussion / Vocals
Dan Kurtz	Upright Bass / Electric Bass

FIG 2.0 The New Deal

The song that has been chosen for the audio source of this experiment is a song called *VL Tone* and can be found on the bands website at: <http://www.myspace.com/tndmusic>.

“At the vanguard of a new progressive style, the New Deal has become a live touring phenomenon. They have appeared at Bonnaroo, Langerado, Jazz Fest New Orleans, the Coachella Festival, Street Scene in San Diego, Berkfest, Gathering of the Vibes, Camp Bisco, and the Detroit Electronic Music Festival to name just a few. They have headlined over 400 shows in the past 4 years. The New Deal inspires audiences of all kinds, from packed dance clubs across North America, to spellbound receptions during opening tours with Herbie Hancock and Page McConnell from Phish”
(<http://www.myspace.com/tndmusic>).

2.2 Section 1 – Simulation Study (Quantitative Data Collection)

FIG 2.1 CATT Acoustics Software

The process for the simulation study started with the contacting of the directors of each of the various jazz festivals. The jazz festivals had to be carefully chosen and matched up with venues that *The New Deal* had not only played in, but had played the one specific song being used for the basis of the survey questionnaire. In order to start building any simulation models it was important to gather as much information about the specific venues as possible with regards to overall dimensions, layouts, materials and

surrounding site conditions. After all the important information was acquired, 3D models were built that included material attributes for each face that would be able to be read and analyzed in CATT Acoustics. Proper locations for sources and receivers of sound had to be properly placed in the model as well as sound absorbing coefficients for each material used.

Upon completion of the model building for each venue, the models were then analyzed for various acoustic properties. Although there are a large number of acoustic properties that can be analyzed using this software, it was decided for this simulation study to focus on the *quantitative* properties that would most accurately match the *qualitative* properties that would be looked at in the section 2, the survey study. The quantitative properties that were looked at in the simulation study were:

C-80 (Clarity)

Clarity is defined as the degree to which a listener is able to distinguish between specific sounds and details in a musical performance. For C-80, the sound that reaches the listener within 80 milliseconds of the arrival of the direct sound is integrated with the direct sound. Generally an average of C-80 values at 500, 1000 and 2000 Hz is considered. For the venues analyzed in this simulation study, it would be expected that a C-80 average between +1db to -4db would be considered acceptable (Metha, 266).

SPL (Sound Pressure Level)

Sound Pressure Level can be defined as a measure of sound pressure of a sound relative to a reference value measured in decibels (dB) above a standard reference level. The commonly used reference sound pressure in air is usually considered the *threshold of human hearing* (Metha, 270). For this study, an acceptable SPL level would simply have to show a level of uniformity across the expanse of the venue itself.

G (Total Sound Level or Loudness)

The loudness of music is obviously an important attribute. Inadequate loudness is frustrating and excessive loudness can be overpowering. A large venue may suffer from lack of loudness, particularly in seats away from the sound source, while in a smaller venue the seats closer to the source might be too loud. In the case of this study, all three venues are roughly the same overall size. The total sound level in all seats should be in the range of 4 to 5.5dB, using an average of both the 500 and 1000 Hz octave bands (Metha, 276).

RT Reverberation time (as was defined at the end of Chapter 1)

In the case of this study, we will be looking for a reverberation time of 1.5s to 1.8s at the 500 Hz octave band.

2.2a Gable End (Clear span) Tent Structure / Toronto Jazz Festival

FIG 2.2 Main Tent, Nathan Phillips Square, Toronto

Specifications:

Dimensions:	L=30m x W=45m overall layout		
	3m side wall height		
	H=8.5m overall height		
Proportion Ratio:	L: 1	W: 1.5	H: 0.3
Seating Capacity:	1200 people		
Materials:	Aluminum and Steel Frames		
	21 ounce vinyl fabric sides and roof		
Manufacturer:	Regal Tents, Toronto

FIG 2.3 Gable End Tent Specs

FIG 2.4 Gable End Structural Layout

FIG 2.5 Site Study and Environmental Acoustic Analysis

Acoustical Analysis:

FIG 2.6 Gabel Tent Interior

C-80 After analyzing the C-80 results of each C-80 values at 500, 1000 and 2000 Hz, it was concluded that the average of the three was 0dB. This is within Metha's guideline of +1db to -4db and thus should be considered acceptable. In general, the level of clarity for this venue is well within an acceptable range. Please refer to *Appendix A1* for graphic results of the CATT Acoustics analysis.

SPL A sample for SPL levels was taken at 500, 1000 and 2000 Hz to acquire a general overview of SPL levels in the venue. It was found that for each band frequency, the SPL levels remained constant and uniform throughout the venue from 0.0 ms to 200ms and beyond determining they were well within they're acceptable range. Please refer to *Appendix A2*

G The results found for G at 500 Hz was roughly 9dB and 11dB at 1000Hz. The average therefore would be around 10dB for the venue which would exceed the acceptable levels for this venue. This number is slightly higher than results that would be normally attained during an actual performance. This is probably due to the fact that on occasion, the walls of the venue are opened up and would allow for more sound to escape in effect reducing the level of Loudness being experienced in the venue. It does however speak to the lack of proper absorbent materials being used in the walls and especially the lack of covering over the concrete floor. Please refer to *Appendix A3*

RT The reverberation times calculated for this venue were much higher than the acceptable levels mentioned above. We were looking for an RT of around 1.5s to 1.8s at the 500 Hz octave band and the analysis shows a time of closer to 3.5s. This again can be attributed to the lack of proper absorbent materials being used in both the walls and especially the floors. Please refer to *Appendix A4*

2.2b Mass Tent Structure / Atlantic Jazz Festival (Halifax)

FIG 2.7 Atlantic Jazz Festival

Specifications:

Dimensions:	L=60 ft. x W=130 ft. overall layout		
	10 ft. side wall height		
	H=27 ft. overall height		
Proportion Ratio:	L: 1	W: 2.2	H: 0.45
Seating Capacity:	1200 people		
Materials:	Aluminum and Steel Frames		
	21 ounce vinyl fabric sides and roof		
Manufacturer:	Commercial Tents, New Brunswick

FIG 2.8 Site Mast Tent Specs

FIG 2.9 Site Mast Tent Structural Layout

FIG 2.10 Site Study and Environmental Acoustic Analysis

Acoustical Analysis:

FIG 2.11 Mast Tent

C-80 The average of the three frequency levels was roughly +5dB. This is above the acceptable average for proper clarity levels in a venue this size. This is possibly due to a restriction in the reverberation time or perhaps the speed in which the music was played. A large part of *The New Deal's* repertoire is played at mostly high speeds. Please refer to *Appendix B1*

SPL For the most part, the SPL levels recorded for this venue are relatively uniform. We do start to see a decrease in this uniformity as we approach the 80-200ms timeframe. We also see pockets of non uniform SPL around the sides and towards the rear of the stage. This is probably because no *monitor* system (speakers that play back performed sounds to the performers) was put in place in order to simplify the analysis. Please refer to *Appendix B2*

G The average for the 500Hz and 1000Hz frequencies was roughly 3, between 0dB and 5.5dB. This is within the acceptable range for Loudness levels in a venue of this size. Please refer to *Appendix B3*

RT The reverberation time calculated for the 500Hz frequency was around 0.8ms – 1.2ms. This is slightly lower than the preferred RT's for a venue of this size but would still be considered fairly acceptable for a band like *The New Deal* and the style of music they play. Please refer to *Appendix B4*

2.2c Open Air – Covered Stage / Montreal Jazz Festival

FIG 2.12 Main Stage, Montreal Jazz Festival

Specifications:

Dimensions:	L=42 ft. x W= 44 ft. Overall layout		
	10 ft. side wall height		
	H=29 ft. overall height		
Proportion Ratio:	L: 1	W: 1.05	H: 0.7
Seating Capacity:	NA		
Materials:	Steel and Wood Frame		
	Wood paneling

FIG 2.13 Open Air / Covered Stage Specs

FIG 2.14 Open Air / Covered Stage Structural Layout

FIG 2.15 Site Study and Environmental Acoustic Analysis

Acoustical Analysis:

FIG 2.16 Main Stage, Montreal Jazz Festival

C80 The average of the three frequency levels was roughly 0dB which is within the acceptable range of +1dB and -4dB. In general, the clarity levels of this venue are good. Please refer to Appendix C1.

SPL The sound pressure levels for this venue appear to be more spread out in groupings or pockets. This is due to the open air nature of the venue compared to the other two venues. Although spread out, the readings do tend to be fairly uniform within their grouping. On a whole, the *SPL* of this venue look to be pretty good. Please refer to Appendix C2.

G The average for the 500Hz and 1000Hz frequencies was roughly 0. This is lower the acceptable range for Loudness levels in a venue of this size due to the open nature of the venue. Please refer to Appendix C3

RT The reverberation time calculated for the 500Hz frequency was around 0.0ms – 0.8ms. This is lower the acceptable range for Loudness levels in a venue of this size due to the open nature of the venue. Please refer to Appendix C4

LEAK This is the calculation of how much sound is leaking or escaping out away from the venue. This is an important factor in an open air venue. Although there is no specific acceptable number for *LEAK* calculation, the results can be compared against other, slightly modified models of venue to try and reduce the actual number of leaks that occur. In this case, the three sources analyzed accounted for 2876 total leaks [$source (A0 = 463) + (B0 = 1282) + (B1 = 1131) = 2876$]. Please refer to Appendix C5.

2.3 Section 2 - Acoustical Survey (Qualitative Data Collection)

For his experiment of attempting to quantifiably rate the top 100 concert and opera halls, Leo Beranek devised a survey questionnaire that would help him understand the more subjective characteristics of the acoustic qualities of spaces. In order to conduct this survey properly, a list of subjective terms and definitions describing acoustical properties needed to be compiled. Although these properties are defined in subjective terms, some of the definitions are the same as the ones used in the simulation study in section 1. The definitions are repeated here for continuity purposes.

The survey being used in this thesis research is largely based on the survey questionnaire that was used by Beranek for his study. The survey focuses again on the three members of *The New Deal*, as well as other musicians who have played in the venues, technicians and engineers who have worked the venues and manufacturers of the structures themselves. The analysis of these surveys will attempt to compare, contrast and connect the results found with similar attributes of the quantifiable data found in section 1.

Clarity (similar to C-80)

Clarity is defined as the degree to which a listener is able to distinguish between specific sounds and details in a musical performance. It is discernable in both horizontal and vertical forms. Horizontal forms are related to tones played in succession while vertical forms are related to tones played simultaneously (Beranek, 30).

Reverberance (similar to RT)

Reverberance is a reference to the degree of a perceived reverberation in a temporal sense; the degree to which sounds are heard relative to the background of preceding events. Having the character of a loud deep sound; the quality of being resonant (dictionary.com)

Envelopment

While listening to a musical performance, the listener will have a certain sense of being surrounded or “enveloped” by the reverberant sound. It is the sense that the sound is actually coming from all sides rather than from limited directions. Essentially it is an observation as to whether the sound waves have the freedom to travel around the overhead surfaces at the front, sides, and rear of the venue (Beranek, 30).

Intimacy

This refers to one's degree of identification with the performance, whether one feels acoustically involved with or detached from it. Just as a small room can have a visual intimacy, it can possess an acoustic intimacy as well based on how soon after the direct sound the first reflection reaches the listener's ears (Beranek, 27).

Loudness (similar to G)

Loudness is a subjective perception or force of the volume of a direct sound at one's ears. It is related to sound pressure levels and can be formulated with a high level of precision by measuring it with microphones and calibrated sound-level meters (Beranek, 30).

FIG 2.17 Interrelations between Audible Factors and Venues

ACOUSTICAL ANALYSIS SURVEY

QUESTIONNAIRE USED FOR ASSESSMENT OF TEMPORARY MUSIC VENUES IN
CANADIAN JAZZ FESTIVALS

NAME

OCCUPATION

FESTIVAL NAME

TORONTO JAZZ FEST

STRUCTURE TYPE

GABLE TENT

CLARITY

refers to the ability to perceive musical detail

1 2 3 4 5 6 7 8 9 10

MUDDY ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ CLEAR

REVERBERANCE

refers to the degree of perceived reverberation in a temporal sense; the degree to which sounds are heard relative to the background of preceding events.

1 2 3 4 5 6 7 8 9 10

DEAD ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ LIVE

ENVELOPMENT

refers to the spatial aspect of the perceived sound; the degree to which one feels acoustically involved with or detached from it.

1 2 3 4 5 6 7 8 9 10

CONSTRICTED ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ EXPANSIVE

INTIMACY

refers to one's degree of identification with the performance, whether one feels acoustically involved with or detached from it.

1 2 3 4 5 6 7 8 9 10

REMOTE ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ INTIMATE

LOUDNESS

Should be assessed relative to what one considers acceptable for the orchestral forces involved.

1 2 3 4 5 6 7 8 9 10

QUIET ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ ☐ LOUD

BALANCE-1

Treble re. Mid Frequencies

	1	2	3	4	5	6	7	8	9	10	
WEAK	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	LOUD

BALANCE-2

Bass re. Mid Frequencies

	1	2	3	4	5	6	7	8	9	10	
WEAK	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	LOUD

BALANCE-3

Singers / Soloists

	1	2	3	4	5	6	7	8	9	10	
WEAK	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	LOUD

BACKGROUND NOISE

	1	2	3	4	5	6	7	8	9	10	
INTOLERABLE	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	INAUDIBLE

OVERALL IMPRESSION

	1	2	3	4	5	6	7	8	9	10	
VERY POOR	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	EXCELLENT

FIG 2.18 Survey Questionnaire

The results of the survey were gathered and organized into an easy to read, quantitative format for analysis. In total, 30 surveys were filled out with 10 surveys per venue. The final numbers that were charted were a result of the overall averages taken from each survey.

2.3a Toronto Jazz Festival

FIG 2.19 Toronto Jazz Festival Survey

The main stage at the TJF was overall a very well received venue. The numbers from the survey demonstrate very well balanced acoustic properties. The relatively low number for the *reverberance* is directly related to the low number also given to *background noise*. This is perhaps due to the fact that it is an “outdoor” venue located in the middle of the downtown core on a very wide open site. In Toronto, the site that the venue is located really has no help of environmental acoustic barriers like close buildings or much vegetation. During the festival, the vast, open area of Nathan Phillips Square allows for a very large number of people surrounding the structure to create a great deal of uncontested, unwanted background noise. We do however see a high level of *clarity* that is most likely due to the large, clear span of the interior of the structure that allows for a higher level of continued direct sound energy without an excessive amount of reflections. This also relates directly to the acceptable clarity levels found in the simulation study in section 1. The vinyl material that covers both the walls and the ceiling also does a good job of absorbing just enough of the sound energy to cut down on unwanted reflections that would impair the level of clarity in the space. We also see a direct relation to the high level of *loudness* found here and back in the simulation study of the same space.

2.3b Atlantic Jazz Festival

FIG 2.20 Atlantic Jazz Festival Survey

Although just slightly lower in *overall impression*, the mast tent of the AJF holds very similar acoustic qualities to the TJF tent. This isn't too surprising seeing as they have very similar shapes, material qualities and somewhat similar sizes. The *reverberance* remains relatively low and somewhat related to the low score for *background noise*. It also relates directly to the lower than acceptable result for *RT* in the simulation study. The *background noise* here has a slightly higher value than that of the TJF. Even though at the AJF, more of the sides of the tent are usually left open to the public, both the smaller size of the crowd surrounding the tent and the surrounding environmental acoustic barriers could help attenuate propagated sound and help block out overbearing background noise. The open sides on the structure also allow for less reflection of sound waves that in turn, might allow for a higher level of clarity and precision when listening to the music performed, again which relate directly to the acceptable *clarity* result in the simulation study. The smaller size of venue and smaller crowd size are what give the mast tent a higher score when it comes to *intimacy* and *loudness* which also corresponds directly with the *loudness (G)* result in the simulation study.

2.3c Montreal Jazz Festival

FIG 2.21 Montreal Jazz Festival Survey

The main stage at the MJF is the only one of the three venues that is, for the most part, open to the elements. It is essentially a large covered stage that is almost perfectly square. This accounts for many of the very different results we find from the first two examples. Although totally open on one side, the close quarters of the three other closed sides causes many unwanted, extended reflections of sound on stage that could potentially explain the low score for *clarity* from the musicians in the survey. This is probably the same factor that would also account for the high score for *loudness* on stage. The covered stage is located at the intersection of two major streets on the site and is flanked by two large buildings on either side. This could also account for a number of extra undesired reflections of sound causing the low levels of *clarity*. The low score for *background noise* could come from the fact that the stage is open to the crowd or receiver positions, as well as the actual large number of people in the crowd during most performances. It is also this large number of audience members that probably accounts for such a low score for *intimacy*.

2.3d Collective Analysis

FIG 2.22 Collective Survey Analysis

This final graph shows a direct comparison of the scoring of all three venues. It shows very clearly the similarities between the TJF and the AJF and the obvious differences those both have from the MJF. Other than the characteristics described above regarding the intimacy levels of the AFJ, the two tent structures are almost identical in average outcomes. The major differences between them and the covered stage of the MJF can be found in *clarity*, *reverberance* and *intimacy* which is largely in part due to the fact that although the MJF venue is the smallest in size, it ends up accommodating for the largest crowds during its performances. It is also more likely for musicians to associate *intimacy* with an enclosed or indoor space rather than a covered stage.

It is also interesting to note that the score for *balance-1*, or the treble to mid frequencies, scored low in all three cases relative to *balance-2* and *balance-3*. This might have something to do with the proportions of each of the spaces examined. According to Grueneisen, as well as several other acousticians, the room proportions strongly affect the acoustical performance, especially in smaller spaces (Grueneisen, 57). Improper room proportions can be highly problematic and reinforce standing waves that color and distort lower frequency bass sounds. According to the chart below, all three of the

structures examined had proportions that were not in highly desirable ranges for optimal acoustics. The higher amounts of bass frequencies being heard by the subjects surveyed are related to the standing waves or room modes that are a result of the build-up of low-frequency sound waves in these unproportioned spaces. This higher buildup of bass frequencies probably masked out the treble frequencies and made them a lot harder to distinguish.

Upon meeting with the musical director of the TJF, Patrick Taylor, he produced several well documented, positive reviews of both the festival and the venue itself. He mentioned how most musicians who play in the venue do seem to like the acoustics and the overall warmth but wasn't sure if that was due to the physical, structural qualities of the venue or because of the really high end PA and sound system that was being used to project the sound. The sound systems being used for the musical performances in these types of venues is something that, although was not a primary focus of this study, undoubtedly should be looked at in any future analysis of the acoustic properties of these structures. There is no doubt that they can have extreme effects on the overall sound quality of a space for better or for worse.

FIG 2.23 Desirable Room Proportions

2.4 Research Conclusions

The intent of this research chapter was to understand the reasoning of how **form affects sound** and then address the main problem statement in the design portion of chapter 3 by asking how **sound affects form**. The early research done in chapter 2 was able to provide a solid background in the fundamentals of acoustics to help setup and understand the two main studies that were performed later on in the chapter. Although a more scientific, quantitative approach to the acoustical analysis was originally intended, it became very clear that when dealing with perceptions of sound and acoustics, the subjective analysis was just as important. By comparing and contrasting the strong connections made from the quantitative and qualitative data, both studies proved *instrumental* in understanding the acoustic properties of different venue types. This new understanding will help in the decision of venue type to propose, test and ultimately design in chapter 3 of this thesis. It is very evident that by producing an architectural form first, it will inevitably have an effect on sound. This is what ultimately leads to acoustical design of a building as a secondary or band-aid solution to be added after design is complete. Chapter 3 will attempt to look at acoustical design as part of the early, overall design process. A venue type can be proposed and then tested for its acoustic properties and ultimately changed to suit the desired requirements and specifications.

Chapter 3: Design – Research Implementation

3.1 Design Goals / Introduction

The Montreal Jazz Festival is currently the largest and arguably one of the most important jazz festivals in the world. For 30 years this festival has been drawing massive crowds and continuously attracting the biggest names in the music world despite never really having a proper central location for operations. This thesis design project will explore the influence of sound on architectural form and the aural quality of spaces it can create, by designing a new “Maison du Festival” that will act as the main welcome center, archive/museum and operations center for the Montreal Jazz Festival of the future.

According to the director of the festival, the growth of the festival over the last five or so years has been seen as a true double edged sword. Although the increase in festival goers and popularity has been great for the festival in general, it has also caused them many technical problems with regards to proper outdoor venue locations and sizes as well as surrounding acoustic conditions.

The approach to the design element of this thesis project would be to see how sound influences architecture in three basic conditions. They are: Environmental acoustic design, formal exploration and program/experiential consideration

The environmental acoustic design will look at the design of the building on a larger urban scale and ultimately how the building can be used and integrated into both the overall festival site and the city as a whole. The program for the building is based on the idea of sound vs. noise. Sound is an audible experience to be embraced and enjoyed such as music and natural sounds whereas noise can be described as unwanted or undesirable sounds such as traffic or construction. The placement of the program takes into consideration the proper controlling of both sound and noise in the buildings plan as well as the buildings orientation on the site. Sound was also used in the formal exploration of the building. Various sound wav samples running along the length of the surrounding streets of the proposed site were taken at various times of the day, both during and after the festival. They were then converted into a three dimensionally generated form that was then used to create the overall form of the building.

3.2 Program Elements and Considerations

The program of the design project, or "*Maison du Festival*", will be a 54000 sq. ft., 3 storey building that will act as the main welcome center, archive/museum and operations center for the Montreal Jazz Festival of the future. It will include:

- 20000 sq. ft. of gallery space for museum and festival display

- 3500 sq. ft. café

- 4500 sq. ft. festival operations office space

- 5000 sq. ft. recording studio and rehearsal space

- 2500 sq. ft. multipurpose spaces

3.3 Site Selection

The site chosen for this project will be a site just west of the existing festival site at *Place des Arts* in the central downtown core of Montreal (Fig 3.6). Currently, the site is an open park site with no existing buildings on it. Focus will be placed on designing a building form that will allow for as much green space to remain to be used during the festival as well as year round.

3.4 Environmental Acoustic Conditions

Before the design of the building itself can begin, an analysis of all the surrounding environmental acoustic and site conditions had to be considered as was done previously in the case studies section of the research portion of this thesis. Conditions that have to be addressed include:

- Proposed site in relation to the existing site at Place des Arts
- Building types, sizes and orientations on the Place des Arts site
- Building types, sizes and orientations surrounding proposed site
- Green spaces surrounding proposed site.
- Vehicular traffic surrounding proposed site
- Existing subway conditions surrounding site.
- Existing and proposed festival stage locations and the size of spectators they service

The existing *Place des Arts* site is a full city block that consists of 2 large indoor performance spaces and a large art gallery, all of which are roughly 40-50 feet in height. By putting a new building on the proposed site to the west, it would solidify this entire area as a strong cultural hub of the city of Montreal as a whole. The buildings surrounding the proposed site are quite different and have to be addressed with regards to their acoustic properties. On the west side of the proposed site there are 2 residential brick buildings of 7 and 14 storey's high. These will have to be protected against any unwanted sounds or noise being produced during the festival. On the south side of the site, there are commercial properties that include a 20 storey hotel on the south east corner. This will also have to be considered in terms of protection of unwanted noise as well as sound reflections off the hotel back onto the outdoor performance areas. To the north of the site there are two open green spaces with enough vegetation to somewhat protect the residential buildings beyond them of unwanted noise from the festival. The vehicular traffic, although fairly heavy at times both to the north (Rue Demaisonneuve) and south (Rue St. Catherine) of the site are blocked off from vehicular traffic during the festival. The subway that runs below Rue Demaisonneuve to the north shouldn't pose any serious acoustic problems as long as no part of the proposed building is put below grade at the north end of the site.

An analysis of the current location, crowd capacity and sound projection directions of the existing outdoor venues shows that at present, an intricate choreography of different show times must be used in order for the performances to go on and not to cancel out or interfere with each other acoustically (Fig 3.8). By redirecting the two large main venue positions and creating two amphitheater sections of the proposed building by projecting sound onto the new *Maison du Festival*, it would allow for more flexibility of the other outdoor venues around the festival site being used (Fig 3.9). This design approach uses the new building as a backdrop for the festival itself by engaging the entire festival site as well as the surrounding city. It gives organizers much more flexibility over visual considerations and circulation throughout the site as well as far more control and containment of the sound being projected from the two main event stages themselves for optimal acoustical conditions.

Conceptual Design

As the strongest element in the conceptual design, the two outdoor amphitheater sections will allow for performances from two outdoor stages to be projected onto the building itself. Initial sketches show how the introduction of the amphitheatre sections aim to accommodate and replace the existing performances stages being used by the festival (Fig 3.0). The north amphitheater section will replace the festival's largest performance area by allowing approx. 50 000 spectators and the south amphitheater will allow for performances with close to 25 000 spectators. Early diagrams show the curved form of the design taking shape as theoretical sound sources from the north and south performance stages are projected onto a flat plane (Fig 3.4). Although the outdoor amphitheater sections will be mainly seasonal, the indoor program of the building will be useable all year long.

FIG 3.0 Concept Sketch

MASTERS THESIS
CONCEPTUAL DESIGN.
JUNE 2/09.

Fig 3.1 Early Concept Sketch

MASTERS THESIS
CONCEPTUAL DESIGN
JUNE 1/007.

RESIDENCES

- ARTIST LIVE SPACE.
- HOTEL / RESIDENCE FOR FESTIVAL MUSICIANS.

Fig 3.2 Early Concept Sketch

FIG 3.3 Early Concept Sketch

- sections 2-6 are pair of diag. that break apart and become performance struts 2-6 on right side.
- remaining spaces become outdoor performance location for struts (1)
- outdoor portion of indoor performance hall becomes stage location for struts (7)

Fig 3.4 Formal Exploration

Fig 3.5 Formal Exploration

FIG 3.6 Site Plan – Environmental Acoustics

FIG 3.7 Aerial Views of Proposed Site

FIG 3.8 Existing Festival Venue Locations

FIG 3.9 Proposed Festival Venue Locations

3.5 Formal Exploration

In order to explore and examine the possibilities that could inspire the formal outcome of the building, an interpretational approach to a scientifically acoustic process was taken to generate the buildings organic form. Audio recordings were taken along the length of the three streets that directly border the proposed site. Rue De Maisonneuve to the north (Fig 3.11), Rue Jeanne-Mance to the east (Fig 3.12) and Rue Balmoral to the west (Fig 3.13). The recordings were taken at three different times of day both while the festival was in full swing as well as when the festival was over. A multitude of interesting sounds and noises were recorded, from people walking, car traffic, truck traffic, children yelling, crowds cheering and music playing. The recordings of each street were then compiled together in bands to create an entire grouping of the possible sounds that could be heard along that street. These recordings, in wav file, were then plugged into a 3D generation program called *SoundPlot* that was developed by Michael B Pliam of PliaTech Software. The program serves one very basic purpose. That is, it converts sound waves into 2 and 3 dimensional surfaces which can subsequently be edited using standard engineering design tools (Soundplot). The desired sound bite is then generated and exported into a *Rhino* file that can be altered and manipulated to suit (Fig 3.10).

For this project, close to 200 different 3D wav file forms were generated. From this large number of series of wav files generated, a select few were chosen that would most accurately match the desired program, form and orientation of the building required. In this case, the major forms that were trying to be matched were the amphitheater areas of both the north and south sections of the building.

Fig 3.10 Generated Wav Forms

FIG 3.11 Recorded Sound Wav along Rue De Maisonneuve

FIG 3.12 Recorded Sound Wav along Rue Jeanne Mance

FIG 3.12 Recorded Sound Wave along Rue Balmoral

The early forms of these amphitheater sections can be clearly seen in the 3D generated wav files (Fig 3.14, 3.15). After selecting 'strips' that would best fit the desired form from each group, the 'strips' were put together to form a uniform building envelope (Fig 3.16). A great deal of tweaking and altering of the forms had to be done in order to mould them into their desired shape. Over 20 different renditions were generated before the final building envelope took its final form.

FIG 3.14 Rough Building Form – North East View

FIG 3.15 Rough Building Form – North West View

FIG 3.1b 3D Printed Sketch Model

3.6 Acoustical Analysis of Building Form

After a final general form was worked out, it had to be analyzed acoustically to determine its effectiveness on the surrounding site. Again, the two main areas that were to be analyzed were the north and south amphitheater sections. Each section was analyzed separately using CATT Acoustics, the same acoustics analysis software that was used in the research portion of this thesis. To perform the CATT Acoustics analysis, an acoustic 3D model of each section would have to be built that would include a detailed geometry file, a material's file and sound source and receiving files. The geometry file would consist of a computer generated 3D model and its general massing. The materials file would identify the proper material that would be used on the final design along with its properly calculated absorption coefficient. The sound files would locate the source and receiver locations in relation to each amphitheatre section. By using the CATT Acoustics software as well as information gathered from previous studies of outdoor performance spaces, it was determined that the form of the original building had to be altered in order to satisfy desired acoustical parameters that were required for the musical performances. The results from the CATT Acoustics LEAK analysis showed that the north amphitheater section ended up being too small and was not able to contain or control enough of the projected sound to satisfy the festivals requirements. Fig. 3.17 shows that 7104 LEAKS were recorded during the analysis. A solution would require that the width of the section be enlarged drastically as well as an increase in height. The analysis of this revised version (Fig. 3.19) shows a drastic decrease in the number of LEAKS recorded at 1436 which is a much more acceptable level. The overall width of the section was increased to allow for a full 15 degrees on either side of the performances center stage. The south amphitheater section although smaller in overall size, proved to satisfy its requirements due to its slightly curved roof section that had been generated in the original 3D wav form (Fig 3.21). This slightly curved roof section essentially helped project the sound back down onto the spectators watching the performance. It was also determined that the original steel material being suggested for the outer skin layer of the building in the conceptual design proved to be too highly reflective in nature and was therefore causing a large amount of unwanted reflected noise. Another solution would have to be found (see materials sections 3.9). The CATT Acoustics software proved instrumental in providing the acoustical analysis information that would help accurately transform the buildings form and materiality to properly satisfy the acoustical requirements of the festival organizers. It should be noted also that the proper design of the two sections proved instrumental in providing enough environmental acoustic protection to the two residential structures to the west of the proposed building site.

FIG 3.17 North Amphitheatre LEAK Analysis

FIG 3.18 North Amphitheatre Acoustic Analysis

FIG 3.19 Revised North Amphitheatre LEAK Analysis

FIG 3.20 Revised North Amphitheatre Acoustic Analysis

FIG 3.21 South Amphitheatre LEAK Analysis

FIG 3.22 South Amphitheatre Acoustic Analysis

3.7 Resulting Building Design / Layout

The overall layout of the building was divided into three main sections. The north section would house all of the festival offices, the central section would house the galleries and the south section would house the sound recording, rehearsal rooms and archive space. This grouping of program was done for obvious cohesive layout as well as acoustical considerations. The overall organic form of the design provides a multitude of interesting visual as well as acoustic changes as you walk through the building. A constant changing, opening and closing, widening and narrowing of the overall form gives a living, breathing feel to the architectural experience.

Starting on the first floor (Fig 3.24), there are three entrances to the building. Both the north and south ends of the building are entrances for the offices and studio spaces respectively. They are specifically acoustically separated and placed at either end of the building. They are less public entrances and are intentionally more unassuming in nature. During the festival these entrances would not be as directly connected to the action and large crowds entering through the eastern, main public festival entrance that is located off of Rue Jeanne Mance. This entrance is set 5 feet below grade, located at the bottom of a ramp that is gently sloped down from the street level (Fig 3.35). Acoustically, this allows visitors to gently be pulled out of the everyday sounds of the surrounding city and directly into the 3 storey entrance hall atrium and main display gallery spaces. These gallery spaces will house current exhibits that would highlight the current jazz festival musicians, participants and characters. The info/reception booth, an oval outer shell surrounding an inner rectilinear shape, sets a formal tone of “form within a form” that we will see throughout the building. Primarily, this can be seen in the two large egg shaped masses that hang above the south end first floor listening gallery and north end café. These work to compliment the non linear, overall organic form of the building but were also designed specifically for acoustic purposes. In the first floor listening gallery, the resulting convex form of the ceiling helps to diffuse sounds in order to make for a more enjoyable listening experience. Individual listening pods are provided for visitors as well to help isolate and control the listening experience visitors will have in the gallery. In the north café, the convex form of the ceiling provides the same diffusion of sound for a quieter, less intrusive dining experience. Performance nooks are available for individual, random performances from musicians to come and play for patrons of the café further enhancing the musical, friendly, openly expressive nature of the jazz festival. In one nook performers might be strumming some bluegrass, while at the same time; in another nook separate performers might be offering acoustic blues. Exterior festival viewing or seating is also provided at both amphitheater sections. The festival

viewing areas are designed in much the same way the seating was designed in traditional amphitheatres but also provide a continuity between the building form and the ground plane.

Each large egg shaped mass is offset by a central, solid rectilinear circulation core that rises up through the form and includes: elevators, emergency stairs and washrooms. As well, visitors are offered a more introspective audible ascent into the masses themselves as you leave the openness of the first floor up into the vertical tube like effect of the circular formal staircase provided in each of the two masses.

On the second floor plan (Fig 3.25) we begin to fully experience the “form within a form” design. The south end mass houses the irregular, polygon shaped recording studio and lounge that are consistent with proper conventional, contemporary studio design. The offset or difference between the egg shape and the polygon interior produces a *pochet* effect that creates essentially an outer and inner shell, allowing for an inhabitable space between the two shells for acoustic separation as well as placement of services. The north end egg shaped mass houses the main festival offices that overlook the entire north side of the festival site. Both the rehearsal rooms and common festival offices double as festival viewing rooms that overlook each of the south and north amphitheatre sections respectively. Here, VIP festival onlookers can have optimal, “luxury box” like seating in which to enjoy the festival with specially designed balconies that are incorporated into the structural design of the building.

site plan

FIG 3.23 Site Plan

FIG 3.24 First Floor Plan

FIG 3.25 Second Floor Plan

FIG 3.26 Third Floor Plan

FIG 3.27 Section Cut through Structural Bay

FIG 3.28 Section Showing Extent of Building Envelope

FIG 3.29 Section Showing Balcony System

FIG 3.30 Interior View

FIG 3.31 Interior View

FIG 3.32 Exterior View of West Side of Building

FIG 3.33 Exterior View of West Side of Building

Fig 3.34 Section A-A

Fig 3.35 Section B-B

Fig 3.36 Section C-C

Fig 3.37 Section D-D

Fig 3.38 Section E-E

Fig 3.39 Perspective View looking South

Fig 3.40 Perspective View looking South along Rue Jeanne Mance

Fig 3.41 Perspective View of Main Festival Entrance on Rue Jeanne Mance

Fig 3.42 Perspective View of South Amphitheatre Section

Fig 3.43 Perspective View of North Amphitheatre Section

3.8 Structural System

The inspiration for the structural system design came from the Strong Museum design in Rochester New York by Chaintreuil Jensen Stark architects. It provides proper structural support but allows for similar form generation as in this thesis project (Fig 3.40). The structural frame of the building is a triangulated steel truss system that flares out to create an inner and outer truss section at the second and third floors. This flare creates a space between the two sections of truss that can again be inhabited and is used to create the festival viewing balconies (Fig 3.29). Where as in traditional design, the balconies are an added appendage that cantilever out from the main wall of the building exterior, in this design the overall flow and form of the building are never compromised or interrupted in order to accommodate the balconies. The triangulation of the truss allows for added structural strength while also allowing for maximum flexibility to achieve the desired form.

FIG 3.44 Strong Museum Case Study

3.9 Materiality

The materiality for this design had to be seriously considered with regards to the acoustic nature and effect the materials would have on this project. As was shown in the research portion of this thesis, the acoustic nature of a material is largely based on their absorption coefficients. Materials for this project had to be aesthetically pleasing as well as satisfy all required acoustic parameters. The envelope of the building is a double glazed insulated glass panel wall system. On the south/west side of the building, this double glazing allows for the incorporation of a passive heating system that can then be distributed to the rest of the building. On the north/east side of the building, primarily on the non-amphitheatre sections of the entire façade, the outer layer of the double glazed system will be perforated with 2" diameter perforations. This will help with the absorption and diffusion of unwanted environmental noise into the cavity provided. To replace the original outer steel skin proposed in the conceptual design of the building, a green wall or living wall system will be incorporated onto the amphitheatre sections to help with the proper absorption of projected sounds from performances much the same way diffuser and absorption panels are used to line the interior walls of recording studios.

3.10 Summary / Conclusion

My reasoning for choosing this topic to do an architectural thesis project on came from my wanting to marry my two passions of music and architecture into a comprehensive 1 year intensive study. My concerns, upon comparing previous thesis projects of the same general topic, were the highly conceptual and mostly interpretational nature of these projects. Understanding how inherently subjective the topic of sound or music could be (with respect to architecture in this case) my initial goal was to see how much of a scientific approach I could take to both the research and design portions of this project. My first step would include choosing Professor Ramani Ramakrishnan as my thesis advisor, who is an acoustical engineer and not an architect. He was instrumental in helping me formulate and generate the scientific parameters from which to begin doing my experiments for the research in chapter 2 and somewhat in chapter 3. Even in the early stages it was proving difficult to completely remove or at least filter out the subjective aspects of acoustical analysis, as was proven by the Beranek readings. Beranek's attempt at solving this problem was to attach qualifying attributes to subjective terms used by conductors and other acoustical professionals to describe certain spaces used for music and sound. In my case, instead of my continuing to try to find a way to eliminate the subjective factor, Beranek's method allowed me to incorporate them into my analysis by comparing and plotting them against the quantitative data gathered.

The intent for the design section chapter 3 would be to include as many of the same analysis principles that were used in chapter 2 when designing my building. It wasn't easy to choose a building type to design, that would demonstrate my research findings. Initially my intention was to design a building that was not directly related to music or the music industry at all. However, having had such a wonderful experience in dealing with the director of the Montreal Jazz Festival Vince Robillard during my research of his festival, I decided that this would make a perfect site condition for my design exploration. I decided to design a building that would encompass as many different aspects of acoustical design, both musical and non, and still maintain realistic program requirements for the Montreal Jazz Festival.

Again, it became more and more evident over time how present the subjective nature of this study was becoming. The formal exploration of the building, although derived from 3D generations of recorded wav files, really held no scientific acoustic reasoning at all. They were in fact simply an interpretational form generator to help inspire and push the formal design of the building. My original ideas that these

forms could potentially help cancel out standing waves of environmental sounds along the length of each respective street, although interesting in theory, were never able to be fully proven.

The goal of this thesis was to explore and understand the connection and relationships between sound and architecture. Through the analysis of environmental acoustic design, formal exploration and experiential consideration, it was shown that sound can be both a starting off point as well as main driving force in the design process.

Appendix A – Toronto Jazz Festival CATT Results

A1 – C80 Results

A2 – SPL Results

A3 – G Results

Appendix B – Atlantic Jazz Festival CATT Results

B1 – C80 Results

B2 – SPL Results

B3 – G Results

B4 – RT Results

Appendix C – Montreal Jazz Festival CATT Results

C1 – C80 Results

C2 – SPL Results

C3 – G Results

C5 – Leak Results

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Goolemaps <http://maps.google.com/>

Programs:

CATT Acoustics	v8.0g (build 2.02)	Copyright CATT 1988-2007
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Soundplot	Michael B. Pliam	Copyright PliaTech Software 2000-2008
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