Visualizing Sound:
A Musical Composition of Aural Architecture

by

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We depend on our collective senses in order to rationalize and negotiate space. Unfortunately, sound and acoustics has become a secondary concern to that of the visual perception in architecture. The initial design intent for many modern performance spaces and music education space, for about the past one-hundred years, has not been driven by sound or acoustics, as a consequence the visual perception has become the major influence.

Prior to modern acoustical applications, performance spaces have been designed for the essence of sound and the form and function had no divisible lines, but with amplification of sound and the technology to reproduce and manipulate sound, form over took acoustics as a design based idea.

This thesis is a direct reaction to the way acoustics and sound, in performance spaces, has evolved over the past hundred years with the advent of modern acoustical technology. This thesis will ask the question of how can sound and acoustics be the main inspiration for the design intent and a formal determinate of space. By using sound and acoustics as a design based method of space making, architecture can achieve a visualization of space through the aural perception of sound.

Reexamining how sound reacts to the geometric shapes and forms in architecture can unveil a solution to poor acoustics in many performance spaces, and result in a method of visualizing sound and acoustics in space and not merely a visual experience of the built form.

This document will analyze the principals and the application of acoustical design in performance and musical education spaces and re-establish the connection of music, acoustics and architecture. The outcome for this thesis will result in the holistic approach to an acoustically designed performance center inter-connected with scholastic spaces for musical education.
"We experience spaces not only by seeing but also by listening. We can navigate a room in the dark, and "hear" the emptiness of a house without furniture. Social relationships are strongly influenced by the way that space changes sound. Spaces Speak, Are You Listening?"  Barry Blesser and Linda-Ruth Salter
Thesis Project Description

The built environment in which we dwell is interpreted through our inherent senses. We as human beings depend upon our sensorial perceptions in order to rationalize and negotiate space. Without a visual or audible connection to the built environment the perception of architecture would not be so amazing. Aural perceptions of music and tonal effects augment every aspect of life. Through the phenomenon of music and sound our relationships with each other as well as the natural elements coalesce to create a holistic entity of dwelling within the world of architecture.

Music, acoustics and sound plays a quintessential role in our everyday life and yet the facilities that teach these arts do not receive the same respect as others. The architecture for these programmatic issues is generic and lacks the educational sources to produce the final product, music, that is intertwined in every aspect of our lives. By examining the ways that sound reacts to space and how sound can create space is going to be the first step in the direction to create a new type of aural architecture suited for an educational purpose. By using the natural elements and the built environment one can perceive the wind, water, light and tactile qualities of space without the use of typical barriers. The typical space for musical education is a simple square room with an additive aspect for sound response. The original idea for the space was not sound or music, it is only a container for the program. Space for this purpose must be considered in the initial design and structure as a whole entity.

Sound can not be physically seen, even though sound is matter and occupies space, the perception of sight cannot detect audible sound waves. One must envision the connection of the senses, vision has connections to taste, smell and tactile qualities, if one sees and object one can perceive the essence of that object such as smell, taste, and touch while the audible sense activates only a visual perception, an audible perception responds to the “minds eye”. We as human beings have been programmed to link sounds with a certain image of an object, therefore sound can be seen through a psychological aspect.

This thesis began to develop from an exploration of the aural perception of space
in architecture. Space is perceived through an accumulation of all the senses and yet the modern day architecture is mainly concerned with the iconic visual representation of the architecture.

Today’s modern architecture has a strong influence to the visual component of perception and the audible component has diminished from the importance of the design phase in its infancy. This thesis consists of three main goals as well as the intent to improve the quality of the aural architectural environment in which we dwell:

1) To analyze and explore the possibilities of sound as a design inspiration and generator of space in performance spaces.  
2) To increase awareness and improve the quality of acoustics in the space utilized by performance halls and the musical education.  
3) To unite music and architecture in such a way that the design influences and inspires creativity and encourages an exploration of sound and music by the students and performers.

The intent is to heighten ones awareness of the essential role that sound plays in the built environment and to revitalize the aspect of aural design in architecture. This thesis looks to provide a framework for inhabitable spaces that consist of the perception of sound through the built environment.

Rethinking how sound can evolve into inhabitable space and employing the principals of sound in space this thesis will attempt to redefine how people occupy the built environment through sound and not only the typical visual aspect. This thesis will prove that aural architecture can and will be a sustainable characteristic of modern architecture.

The conceptual and schematic phase of design will have to incorporate the ideas of sound as divisions of space and not solely rely on walls and barriers to define said space. Applying aural and acoustical systems to create a sensorial relationship with the built form will only enhance the architecture and hopefully start to reveal that the reality of sound as a generator of space is a facet that is missing in architectural design today.
“As opposed to acoustics in architecture, which focuses on the ways that space affects the physical properties of sound waves (spatial acoustics), aural architecture focuses on the way that listeners experience the space”. (Blesser, p.5). Acoustics manipulate the actual sound waves to enhance or diminish the perception of sound in itself, but aural architecture has a psychological impact on the perception of space through the way sound is understood as a medium of space.

A visual connection of space is inhibited by barriers such as walls, structure and obstacles yet an aural connection is uninhibited by such physical obstructions. A space is therefore combined into one entity through the aural perception of space. The human body responds to space instinctively and directly through the receptors of vision, hearing, smell and touch, but through the passing of time technology has somehow overshadowed this connection of perception to emphasis the dominant sense of vision.

Ancient architects could not afford to isolate the senses into separate entities and had to design using the holistic realm of perception. Examining the ancient amphitheaters and the architecture prior to the introduction of modern technology one can find that the acoustics of space were designed from the initial inking of the pen. Acoustics and sound has played a major role in the formation and spatial configuration of architectural spaces of the past. (Bryant, p.9)

This is evident in the ruins of ancient buildings especially the “perfect clarity of the Greek amphitheaters where a speaker, standing at a focal point created by the surrounding walls, is heard distinctly by all members of the audience.” (Bill Viola in Sheridan, p.3). The essence of sound and acoustics were the main focus and they achieved some of the purest quality of sound that still exists today. (Bomgardner, p.231)
Some of the top rated performance centers today have extremely well designed acoustics. The problem is just that, engineered sound and not the pure quality of sound that is the being perceived.

Architecture has given birth to quite a few specialized fields such as the acousticians and sound engineers. The element of sound has been written out of the architect’s equation as a design inspiration.

This document will compare the modern and ancient performance venues and analyze the characteristics which improve or diminish the acoustical qualities of the space. Music is an expression of an idea and an idea is a generator of space. The historical technique of designing amphitheaters or acoustical space, especially without the modern technology, is quite amazing. These spaces consist of the pure essence of sound. The space resonates through natural qualities and is not muddied with additive aspects to enhance the acoustics of the space. The importance of looking back to what has been done can only improve what will be done. A series of acoustical studies will prove that acoustics can be a visual connection to an educational experience of space.

Our senses are combined into one entity, the human body. Not all of our senses are equal though, vision seems to be the dominate overall factor as well as in architecture and the others senses seem passive to that of vision.

The way that architecture has evolved the audible aspect of perception has diminished into the overlaying of materials and not the architecture in itself, therefore rethinking how sound is perceived and the psychological and physiological effects on the human psyche in relation to architecture will begin to evolve into a new method of visualizing sound in performance space.

This Document will employ the following methods research:
- Case Studies and Combined Strategies -
  > Modern day theaters
  > Modern music schools
  > Performance halls
- Interpretive Research -
  > Greek and Roman amphitheaters
  > Origins of acoustical planning
History of Music / Acoustics

The evolution of technology for acoustics and music was basically unchanged for nearly 1800 years. Dating back to the era of the Greeks in 350 B.C. up until the 1500s performance settings were open air forums. The advent of performance halls required a selection of distinct materials to control the reverberation time of the sound. Prior to this, the material that were used had a major effect on acoustics. Dorian chants were created to either shorten or extend the reverberation time of sound and therefore a pioneer of acoustics in space.

The same principal applies to instruments as well. The harp, piano and violin could project their sound for quite a distance, but with invention of electric amplifiers the need for self-sustaining instruments diminished and this brought about a new era in sound and spaces for sound.

In modern day writings about architecture there seems to be very little about acoustics and sound in the overall planning of design, but Sheridan states that Vitruvius, in The Ten Books on Architecture, emphasized an equal amount of 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) The aspect of sound in Vitruvius’ writings re-late to “proportional” and “actual” modes. (Bryant, p.15) The “proportional” mode “relates the spatio-visual experience of width, height, and depth to the tonal experience of harmonic musical notes,” this 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 concept is arguably the foundation for the concept of architecture as frozen music”. (Bryant, p.15)

The “actual” mode of Vitruvian theory “relays specific advice, derived from experience and experimentation, on how sound behaves under certain physical conditions”, including the topics of propagation, reflection and sympathetic resonance: a clear forerunner for today’s modern acoustic engineering practices”. (Sheridan, p.8)

The evolution of modern acoustics dates to the late 1800’s. Sabines are a measurement of acoustical values. The name was derived by its inventor Wallace Sabine, 1868-1919. The first application of his research was Fogg Hall at Harvard University. “Sabine’s career is the story of the birth of the field of modern architectural acoustics.
Sabine’s Equation

In 1895, acoustically improving the Fogg Lecture Hall, part of the recently constructed Fogg Art Museum, was considered an impossible task by the senior staff of the physics department at Harvard. The assignment was passed down until it landed on the shoulders of a young physics professor, Sabine”. (AE)

“Sabine was able to determine, through these late night forays, that a definitive relationship exists between the quality of the acoustics, the size of the chamber, and the amount of absorption surfaces present. He formally defined the reverberation time, which is still the most important characteristic currently in use for gauging the acoustical quality of a room, as number of seconds required for the intensity of the sound to drop from the starting level, by an amount of 60 dB (decibels).” (AE)

“The formula is RT60 = 0.049V \Sa Where RT60 is the reverberation time, V is the volume of the room in cubic meters, and \Sa is the total absorption, a is the average absorption coefficient of room surfaces and S is the surface area”. (Sabine) “Note that the reverberation equation formula is just that, a formula, not an actual equation. By studying various rooms judged acoustically good for their intended uses, Sabine determined that good concert halls had reverberation times of 2-2.15 seconds (“with shorter reverberation times, a music hall seems too “dry” to the listener”) (AE), the average known “good” reverberation time for this space was slightly under 1 second.

Looking at Fogg Museum’s lecture room, Sabine figured out “that a spoken word remained audible for about 5.5 seconds, or about an additional 12-15 words if the speaker continued talking”. (Sabine) This would result with very high values and ranges of echo and resonance.

Utilizing his discoveries used for the Fogg Hall, “Sabine deployed sound absorbing materials throughout the Fogg Lecture Hall to cut its reverberation time down and reduce the “echo effect.” This accomplishment cemented Wallace Sabine’s career, and led to his hiring as the acoustical consultant for Boston’s Symphony Hall, the first concert hall to be designed using quantitative acoustics. His acoustic design was a great success and Symphony Hall is generally considered one
of the best symphony halls in the world.” (Thompos-

The way sound defines space has a direct cor-
relation to the spatial qualities of the space. Soci-
ety and culture are key formal determinates of how
space is defined and how people inhabit the built
environment. Blesser refers to space making as”
incidental consequences of sociocultural forces.”
(Blesser, p. 5) which is to say that a certain culture
will form space through the beliefs of their culture
and the sounds that envelope their surroundings.

"Listeners react both to sound source and to
spatial acoustics because each is an aural stimulus
with social, cultural, and personal meaning depend-
ing on the physical design and the cultural context,
aural architecture can stimulate anxiety, tranquil-
ity, socialization, isolation, frustration, fear, bore-
dom, aesthetic please, and so on”.
(Blesser, p. 11)

This thesis exploration will attempt to de-
fine space as an aural perception. While occupying
space there are psychological and physiological as-
pacts to inhabitation. The audible sense is the main
focus of this exploration being used to determining

the spatial qualities. Sound is essential to the
rationalization of our world and the realm of
architecture.

Through the built form this thesis will
employ 3d modeling and simulation as well
as the use of case studies and interpretive
research methods employed in the present
and past. The first step in beginning the ar-
duous task of reinterpreting how sound, as
a determinate factor of space, is a plausible
application that needs to, and must be, rein-
troduced to the world of architecture.
Fig. 3 Sound Wave
Physical Acoustics

“Sound is a travelling wave which is an oscillation of pressure transmitted through a solid, liquid, or gas, composed of frequencies within the range of hearing and of a level sufficiently strong to be heard, or the sensation stimulated in organs of hearing by such vibrations.”

“Acoustics is the interdisciplinary science that deals with the study of sound, ultrasound and infrasound (all mechanical waves in gases, liquids, and solids). A scientist who works in the field of acoustics is an acoustician. The application of acoustics in technology is called acoustical engineering. There is often much overlap and interaction between the interests of acousticians and acoustical engineers.”
Perception

The perception of sound has a wide range of effects on the psychological and physiological state of the perceiver. These images show how the different types of music influence different receptors in the brain shown by intensity of red.

The fundamental building block of music is a vibrating object and sound waves, and the harmonic series — a physical constant that when a string vibrates, it’s first in half, then in thirds... etc. etc. So you hear a pitch, and then a series of overtones in the background. Sound is simple geometry. Just take a look at these simple musical sounds vibrating in water, and the shapes created by these vibrations. (Author)

These studies were conducted in a controlled environment with random sounds of music. Patterns that form are from acoustics in water. Water has a very strong acoustical quality and water has the ability to carry sound waves for quite a distance. Ultrasonic sound waves have been used to map the 3-d form of many different surfac-
Psychoacoustics

Psychoacoustics is the precise scientific study of the perception of sound. This field includes psychological and physiological effects upon the nervous system. Sound is perceived through the auditory system collected by the outer ear and processed through the middle and inner ear to the auditory nerve which produces a physical response.

"An important distinction is the difference between a psychological and a neurological perception. A song or melody associated with childhood, a teenage romance, or some peak emotional experience creates a memory-based psychological reaction. There is also a physiological response to sounds, however. Slightly detuned tones can cause brain waves to speed up or slow down, for instance. Additionally, soundtracks that are filtered and gated (this is a sophisticated engineering process) create a random sonic event. It triggers an active listening response and thus tonifies the auditory mechanism, including the tiny muscles of the middle ear." (Leeds)

Psychoacoustics is comprised of subcategories such as ear physiology, ear sensitivity and binaural hearing. The attributes of these are pitch, loudness and timbre (sound quality). Pitch is the psychological perception of frequency. Loudness is a subjective perception of the intensity of a sound, in terms of which sounds may be ordered on a scale extending from quiet to loud. Timbre is that attribute of auditory sensation in terms of which a listener can distinguish two similar sounds that have the same pitch and loudness. (Music-Miami)
Room Acoustics

Room acoustics is the workings of sound in an enclosed or covered space and has a direct effect on the sound perception of the space. Such considerations that have to be dealt with is size, volume, shape and materials of the space as well as many other indirect characteristics of sound.

The properties of acoustics can be analyzed by their inherent attributes, such as reverberation time, reflection, refraction, diffusion, this is only a few of the main principals of sound, but these play a huge role in the understanding how sound reacts to space. Acoustics can enhance or diminish the sound quality of space and turn a well designed space into a undesirable experience of music and space.

The way that sound reacts to a room can be divided into four mainly unique frequency zones: “The first zone is below the frequency that has a wavelength of twice the longest length of the room. In this zone sound behaves very much like changes in static air pressure. Above that zone, until the frequency is approximately 11,250(RT60/V)1/2, wavelengths are comparable to the dimensions of the room, and so room resonances dominate. The third region which extends approximately 2 octaves is a direct level transition to the fourth zone. In the fourth zone, sounds behave like rays of light bouncing around the room.” (Leeds)

The zones and regions that are created by sound waves also create problems within enclosed space. Sound waves have reflections from floors, ceilings and walls. Source waves and reflected waves come into contact with each other and create standing waves or high pressure zones. In response to this Oscar Bonello, in 1981, utilized a modal density concept solution called “Bonello Criteria” which uses concepts from psychoacoustics. “The method analyzes the first 48 room modes and plots the number of modes in each one-third of an octave. The curve increases monotonically (each one-third of an octave must have more modes than the preceding one)”. (Bryant p.54)
Sound Mapping

Sound mapping has become a very useful tool in the realm of architecture. The urban sounds that occupy the exterior of buildings and the canyons of the city dictate the layout of many public and private spaces. Noise is defined as “In common use, the word noise means unwanted sound or noise pollution.” (Websters) As seen in Fig. 19 the massing of urban sound is directly related to population. The sound is a collection of all sounds and noises. The idea of mapping sound came about when residential areas started to sprawl away from the downtown zones. The ability to understand the way sound can influence the habitation of space can achieve a sense of collaboration of the built form and sound. Sound has mass and depth but is unable to be seen by the human eye, but by using computer technology one can visualize the form of sound and how sound can indeed be seen. Sound can be broken down into a mathematical equation of pressure / time and wavelength / amplitude. Frequency is the number of occurrences of a repeating event per unit time. The basic building blocks of sound are a combination of all of these bundled into one unit of sound. The measurement of these characteristics enable the mapping of sound waves and sound occurrences along planes.

Fig. 18 Sound Map through population

Fig. 19 3-D Map of Sound
Sound in space is very distinctive to the principals of acoustics. The form of a given space can either enhance or diminish the quality of perception. Examining fig. 26 one can see how sound waves react to a non-conforming space of flat planes. Sound reflects off of a given surface and impedes the following transmission of the next wave. By utilizing acoustics sound can be tuned to the specific space, but by doing this the essence of the sound is compromised. The Space must represent the sound and not the sound representing the space. Sound is an explosion of energy spreading out in all directions. See fig. 22.

Reflection, absorption and diffusion are major considerations of sound design because of the way that sound reacts to a solid object. Diffusers will “soften” the sound and absorption will “nullify” the wave through the use of juxtaposition of the surface. The sound wave has a rise (compression) and a fall (rarefraction) that comprises the amplitude and wavelength. This breaks down to a height and distance of sound, therefore acoustics can not only be measured in terms of mass, but can also demonstrate mass through volume which is a definer of space.
Theatre at Epidaurus

Country: Greece (Ellás)
City: Epidaurus
Location: South-East of the Sanctuary of Asklepios Ancient Greek theatre, built ca. 350-300 BC by Polykleitos the Younger. Originally 6210 seats. Later extended by 21 rows (then ca. 14000 seats). Famous for its unparalleled acoustics. Still used for theatre performances.

The ancient Greeks and Romans were not concerned with the enclosure of their amphitheaters but with the acoustics that were produced within the space. The structure was utilized for the resonance and reverberation of sound and the perception of the receiver and not the iconic representation of the built environment. (Chase, p.25)

The Greeks used specific materials and the physics of sound to ensure that the perceivers in the amphitheater, no matter where seated, could hear even a whisper from the lower level of the skene. (Bomgardner, p.28) The acoustic qualities that were incorporated into the Epidaurus theatre were not utilized into other Greek amphitheaters. The materials were changed and the layout as well. The Epidaurus was the only space built in this manner of using limestone for the seats and with the slope of the rows.

"Now, researchers at the Georgia Institute of Technology have discovered that the limestone material of the seats provide a filtering effect, suppressing low frequencies of voices, thus minimizing background crowd noise. Further, the rows of limestone seats reflect high-frequencies back towards
The use of aural architecture is the subject matter of relevance to this thesis. The Greeks utilized the sense of audible perception and did not rely on the visual aspect alone in the construction of this space. With the emphasis on the audible, the space transmits sound throughout the entire area through elements of architecture and nature. Sound is the main generator of space in this instance therefore the inhabitation of sound through a spatial composition is achieved.

The Greeks used scups in the front of the seats to direct and channel sound and diffuse the frequencies that had undesirable results. Fig. 30

The theatre was recessed in the ground to utilize the prevailing winds that helped transmit the sound waves. Fig. 28 Limestone used in the seating area was the secret to the perfection of the ancient acoustics. Fig. 29

The overall analysis was conducted through an exploratory and descriptive research. Interpretive research was employed in the case study of the theatre at Epidaurus, Greece. While looking at the main form of the performance halls one thing runs consistent with all of the cases is that they were all designed with acoustics in mind, but the only one that was designed for pure essence was Epidaurus. The materials were the secret to the phenomenon. The limestone took the low frequencies out of the mix and intensified the middle and high frequencies.
“The objectives of Adrienne Arsht Center for the Performing Arts of Miami-Dade County are to:

- Offer state-of-the-art accommodations for artists, cultural organizations and their audiences;
- Operate in an efficient and cost-effective manner and attract governmental and foundation fund raising;
- Provide a range of performing arts experiences beyond what is available regionally;
- Act as a catalyst for area revitalization and enhance regional economic opportunities through the Center’s appeal to tourism.”

The Adrienne Arsht Center, formally known as the Carnival center, was built to facilitate the growing need for acoustical environments that acted as an “educational and cultural resource” for the urban fabric of Miami-Dade County and the surrounding areas. The acoustics were designed by Russell Johnson, master acoustician and theatre planner. While Pelli designed the space the actual acoustics “make” the space, for without the utilization of acoustical interventions the space would not function as a performance venue. Acoustics in the ballet performing area are intertwined with the architecture and allow the sound to infiltrate the whole existence of the space.” (Hall, p.18)

The surrounding walls of the theater were designed not only to isolate the interior but to insulate the acoustics. Fig. ## The dampering doors are built so that they may be adjusted to the particular type of performance. Johnson spent his entire professional life mastering the acoustical values of space and how to achieve the optimal level of excellence in acoustics.

The center has two main performance (acoustical) spaces as well as a black box theatre that functions on acoustical qualities. The building is constructed so that the per-
formance spaces are encapsulated inside the envelope in order to isolate the possible opportunities of the acoustics. The ceiling panels are adjustable in such a way as to maximize the refraction and reflection of the sound waves. The center is not only for performances they provide an educational realm as well. The center encompasses the entire realm of the performing arts from ballet to musical composition, theater and education while utilizing the principals and theories of acoustics to create their spaces.
Tempe Center for the Arts

Designed by Tempe-based Architekton and Barton Myers Associates of Los Angeles, houses a state-of-the-art, 600-seat proscenium theater, a 200-seat studio theater and a 3,500 square-foot gallery.

The main characteristics of the room are:
Volume: 18 900 m³, Seats number: 600, Volume / seat: 6.9 m³/st, Max width: 29 m - average width 21 m, Mean ceiling height: 15.9 m, Distance to the second balcony most distant seat: 39 m, Distance to the stage for the most distant VIP seats: 25 m, Distance to the stage for the stalls seat: 29 m (low), 33 m (upper).

The Tempe center of the arts was tuned to accommodate a wider range of performances. The hall is more adaptive to a varying range of genres. The architect designed the center with other functions as well. The educational program included in the design focuses on the journey from learning to showcasing ones talent in the hall. The diversity of the hall is part of its success. The universal space is an asset to the Tempe community.

Tempe Center for the Arts stages innovative programming that enriches, enlightens, inspires and expands the artistic horizons of the Tempe community.
community. The TCA is a unique visual and performing arts experience built by the community for the community. It is a professional level venue in which local groups are expected to provide more than 75 percent of the overall programming. The center offers a unique blending of arts and culture at a distinctive destination that features what few cities can boast – Town Lake’s endless outdoor activities, the dining and nightlife of a vibrant downtown, a dynamic shopping venue and one of the nation’s top universities.

The Facility: The 88,000 square-foot facility features a theater, studio, gallery, banquet/meeting room, donor lounge, an on-site, full-service box office, theatrical and administrative support areas, two dedicated catering areas, arts retail space, a lounge and a 17-acre art park.

Theater - At the heart of the TCA is a 600-seat performance hall able to accommodate dance, drama, small scale opera, musical theater, orchestral performances and solo recitals. The auditorium incorporates four seating levels - an orchestra level, parterre and two balconies. To the sides of the auditorium, boxes extend and nearly connect to the stage. Above the forestage, an overhead grid allows suspension of scenery, lighting and sound equipment. A state-of-the-art computerized control system offers maximum flexibility for theatrical lighting and the latest in audio-video and communication systems technology.
Shanghai Oriental Arts Center

Location: Century Avenue, Shanghai
Total surface area: 39,694 sqm
Auditorium capacities:
Philharmonic Orchestra Hall: 1,979 seats
Lyric Theatre: 1,054 seats
Chamber Music Hall: 330 seats

The main characteristics of the room are:
Volume: 28 450 m3, Seats number: 1979, Volume / seat: 6.9 m3/st, Max width: 37 m - average width 38 m, Mean ceiling height: 28.9 m, Distance to the second balcony most distant seat: 46 m, Distance to the stage for the most distant VIP seats: 36 m, Distance to the stage for the stalls seat: 28 m (low), 39 m (upper)

Project description: The Oriental Arts Centre project is a first rank public cultural building, encompassing mainly three venues: a 1,979 seats Philharmonic Orchestra Hall, a 1,054 seats lyric Theatre, a 330 seats chamber Music Hall. With a 39,694 sq.m construction site area, the project will be built on 7 main levels.

The project architectural intend is based on the following basic principles:
- The building has a base on which the public spaces will develop.
- The halls will emerge from the base as trees from the earth.
- The building should be covered and enclosed by one unique cantilevered roof, linked by curved glass walls to the base.
- Spaces inside the building are distributed around and from a central circulation and meeting point. This should apply to the public as well as to the performers and the VIP’s.
- The public space should be open and adaptable in order to increase the potential of use of the building.
- The performers should be provided with an efficient and agreeable working space.
- The three performance halls should be different in form and use different materials.
- The outside walls of the three halls will use enamel ceramic as their main common mate-
Viewed from above, Shanghai Oriental Art Center is just like five blossoming petals, which constitute respectively the entrance hall, Oriental Performance Hall, Oriental Concert Hall, Exhibition Hall and Oriental Opera Hall, forming a beautiful butterfly orchid in full bloom.

- The material of the façades will be a glass incorporating a perforated metal sheet of variable density.
- The façades design itself will express innovation, modernity and enhance the public areas.
- Although secondary in their functional importance, the public spaces will define the character of the building and its fitting with the spirit of the time.

Located in the administrative and cultural center of Pudong New Area, Shanghai Oriental Art Center is the east starting point of Shanghai cultural axis in the new round of cultural layout. With an investment of 1 billion RMB by Shanghai Municipal Government and Pudong New Area Administration, Shanghai Oriental Art Center is one of the most important symbolic cultural projects. It occupies a total area of nearly 40,000 square meters and is designed by Paul Andreu, the famous French architect.

The construction started on 26th March 2002 and was finished with the grand New Year Concert as its Opening Ceremony on 31st December 2004, which marked the beginning of its trial operation. And its official operation is dated on 1st July 2005.

Fig. 42 Plan of Context
Walt Disney Concert Hall Los Angeles, California, USA, Metro Area: Los Angeles, World Region: North America.
Project Type: Special Use
Land Use(s): Performing Arts Facility, Open Space, Structured Parking
Site Size: 3.6 acres/1.5 hectares
Site Statistics - Date Completed 2003
Project Street Address: 111 South Grand Avenue
Los Angeles, California, USA

The main characteristics of the room are: Volume: 35,762 m³, Seats number: 2000, Volume / seat: 8.3 m³/st, Max width: 37 m - average width 35 m
Mean ceiling height: 21.6 m, Distance to the second balcony most distant seat: 46 m, Distance to the stage for the most distant VIP seats: 35 m, Distance to the stage for the stalls seat: 34 m (low), 38 m (upper).

The hall met with lauded approval from nearly all of its listeners, including its performers. In an interview with PBS, Esa-Pekka Salonen, Music Director of the Los Angeles Philharmonic, said, “The sound, of course, was my greatest concern, but now I am totally happy, and so is the orchestra,” (PBS) and later said, “Everyone can now hear what the L.A. Phil is supposed to sound like.” (Scher) This remains to be one of the most successful grand openings of a concert hall in American history.

The walls and ceiling of the hall are finished with Douglas-fir while the floor is finished with oak. The Hall’s reverberation time is approximately 2.2 seconds unoccupied and 2.0 seconds occupied. (Nagata)

The building mass was designed by Frank Gehry and the acoustics were designed by Yoshira Toyota. The interior of the hall is was tuned in such a way that the acoustics are considered some of the best in the world.

Fig. # The disadvantage for Frank Gehry is
that the main design intent was that of the acoustician and not the architect. The diminishing role of the architect is contributing to the diminishing aspect of sound as a design inspiration. This leads to a solely visual aspect for design intent.
The overall analysis was conducted through an exploratory and descriptive research. Interpretive research was employed in the case study of the theatre at Epidaurus, Greece. While looking at the main form of the performance halls one thing runs consistent with all of the cases is that they were all designed with acoustics in mind, but the only one that was designed for pure essence was Epidaurus. The materials were the secret to the phenomenon. The limestone took the low frequencies out of the mix and intensified the mids and highs.

The performance halls of The Tempe center, Oriental arts center and Walt Disney concert hall were all designed by an acoustician and the architect designed the “shell” in which it rest.

<table>
<thead>
<tr>
<th>Performance Hall # of seats</th>
<th>TCA</th>
<th>SOAC</th>
<th>WDCH</th>
</tr>
</thead>
<tbody>
<tr>
<td>600</td>
<td>1979</td>
<td>2250</td>
<td></td>
</tr>
<tr>
<td>Reverberation time -</td>
<td>2.7 sec</td>
<td>2.4 sec</td>
<td>2.2 sec</td>
</tr>
<tr>
<td>Distance Stage to furthest seat -</td>
<td>21 m</td>
<td>46m</td>
<td>44 m</td>
</tr>
<tr>
<td>Materials - Mahogany/Cherry, Oak-Acoustical Panel, Douglas Fir / Oak</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Form- Semi-Circle, Semi - In Round, Semi - In Round</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Direct sound perception -</td>
<td>195’</td>
<td>360’</td>
<td>360’</td>
</tr>
<tr>
<td>Sound Absorption - Diffusers</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

The analysis not only focused on the space as an inhabitable form, but mainly focused on the relation of space to acoustics and sound within the space. The Walt Disney concert hall, designed by Frank Gehry has unparalleled acoustics designed by Yoshiuro Toyota. The hall was tuned for an orchestra setting to achieve the optimal aural perception anywhere in the room. The hall is embedded in the overall plan of the complex and yet it is the main hub of the building.

The Tempe center of the arts was tuned to accommodate a wider range of performances. The hall is more adaptive to a varying range of genres. The architect designed the center with other functions as well. The educational program included in the design focuses on the journey from learning to showcasing ones talent in the hall.

The Shanghai Oriental arts center, designed by French architect Paul Adreau in collaboration with Marko Vian (acoustician), was intended to unite all genres of music and performance arts.
Program Elements
The intent of the program is to integrate the aspect of musical education and the experience of musical performance. The main design intent is to improve the acoustical qualities of the performance space and explore the “lost” aspect of sound as a design driver. The main concept is the performance hall’s acoustics, but the aspect of learning is equally important. By using the actual sound of music as a generator for space the spaces will not evolve as a typical arts center, but will transform from a space that sound is engineered for into a space that is tuned for the sound.

The evolution of technology has put limitations on the way performance hall are designed either by form or budget. The sound has some major considerations that must be incorporated in the design for a successful space to come to fruition and poses the qualities that the space deserves.

The space for musical education is where the program must consider the effect of the student in the space. The typical room for practice is a small space that is not even treated for acoustics. The student perfects their skill in a space that is totally substandard for the role music plays in our lives. From this space the student is placed in a hall that totally changes the acoustics and effect of the sound in such a large room. The transitions from learning to performing has to be seamless. A space intended for a certain function should portray the intent through the experience of space in which one is about to inhabit.
Program Exploration

The main focus of this project is to integrate the education of music and performance into a holistic entity through the built form of architecture. The goals for the design are to:

- Establish a path/journey from musical education to the performance stage while allowing the architecture to “breathe” by not utilizing overlaying materials to try and compliment the original acoustical intent of the design.
- Allow the exterior of the structure to be fully involved within the space.
- Use environmental sounds to mold the journey from learn to perform.
- Establish a connection with the qualities of sound and acoustics with the built structure.
- Examine the possibility of a transformable space that could work for many different venues.
- Acoustical parameters must “feel” comfortable, form must compliment the acoustics, i.e. avoid echoes, standing waves and focusing.

The spaces researched for this type of building usually require the incorporation of such spaces as well as the use of many special spaces unique to the design.
3-D Program Layout

Fig. 51 Program Analysis
Program Square Footage

Spaces for performance hall program
- Entrance / exterior space - ..........................................................2,000 sq. ft.
- Lobby - ..........................................................................................2,000 sq. ft.
- Large performance hall - ...........................................................40 – 45,000 sq. ft.
- Stage - left / right, back stage - .......................................................750 sq. ft.
- Dressing rooms - .................................................................10 @ 100 sq. ft. ea.
- Green room - ..............................................................................750 sq. ft.
- Production office - ..................................................................4 @ 200 sq. ft. ea.
- Planners room - .................................................................2 @ 100 sq. ft. ea.
- Box offices - ..............................................................................500 sq. ft.
- Restrooms and vending - ..............................................................10,000 sq. ft.
- Restaurant / Café - .............................................................2,000 sq. ft.
- Gift Shop - ...............................................................................300 sq. ft.
- Loading dock - ...........................................................................500 sq. ft.
- Stage equipment room - ..........................................................500 sq. ft.
- Mechanical (tare spaces) / services - ..............................................10,000 sq. ft.
- Studios / class - ........................................................................10 @ 1,500 sq. ft. ea.
- Class rooms - ...........................................................................8 @ 1,000 sq. ft. ea.
- Practice rooms - ......................................................................150 sq. ft. ea.
- Practice hall - ..........................................................................10,000 sq. ft.
- Admin. Offices - ........................................................................10 @ 250 sq. ft. ea.
- Gallery - ..................................................................................1,000 sq. ft.
- Multi-purpose room - .....................................................................750 sq. ft.
- Restrooms / mechanical (tare spaces) - ...........................................500 sq. ft.
- Storage - .................................................................500 sq. ft.

Total sq. ft. 90,000 sq. ft.
Site Selection
The sites were chosen for the surrounding context of Sarasota. The array of different types of urban, green space and residential areas is quite astonishing. The three sites all have their own characteristics and attributes, but the final choice of site is one that has three very distinct areas that will compliment the program as well as the building. The Gulf coast has very calming properties that will be emphasized in the design.
Proposed Site

Location: Televast Rd. between 18th St. East and U.S. 301. The site stretches from Televast Rd. and University Parkway. The size of the site is .5 miles x .4 miles. The space is heavily spotted by trees and natural bush lines. The large lot of land would be sufficient for this type of use but looking at the pros and cons of the site the choice would have to meet the main list of criteria. (See program analysis list).

Advantages of site: Large site, non-residential zone, centrally located between Bradenton and Sarasota. The land is mainly unpopulated and the surrounding space is isolated by the interstate U.S. 301. The site is closely linked to many other minor destinations and some major transportation hubs.

Disadvantages of site: The site is set back off of the bay and has no link to the south side of the city. The site is isolated by the airport and U.S. 301. The residual noise from the airport is the main reason...
Location: N. Tuttle Ave. between Myrtle St. and Dr. Martin Luther King Jr. Blvd. Sarasota Florida. The size of the lot is .25 miles x .21 miles. Advantages of site: The site is located north of the downtown districts and south-east of site number one. The site has adequate space for the program and usage for the building. Tuttle Ave. is the set of an isolation area that leaves the site to sit by itself. The space has quite a lot of natural elements as far as trees and shrubs that outline the space. Disadvantages of site: The main disadvantage of the site is that there are too many residential areas that sit right outside of the boundaries. The east, west and south sides of the site are neighborhoods and are growing. Just north of the site is a golf course that would cause problems for the noise / sound level of a residential zoned area.
Location: Van Wezel Way and 10th St. bordered by U.S. 41 and Sarasota Bay. Size of lot is .15 miles x .11 miles. The site has a direct link to the downtown districts as well as the natural elements. Advantages of site: The site has three different zones of acoustics that infiltrate the space. On the east side U.S. 41 runs north to south and creates a boundary that separates the residential towers from the site. The west side has Sarasota Bay a natural inlet that incorporates the natural elements such as wind, water and beautiful vistas. The south view is that of the Van Wezel Performing Arts Center which will compliment the program. The north edge has an inlet for boats and watercraft which serves as a natural boundary for the site. Disadvantages of site: The cons of site number three are few and far between. The site has limited parking space and access to the site, but realignment of the major axis will correct this problem. The site is set in a downtown district zone and satisfies all site criteria.
Selected Site

The site is positioned on Sarasota Bay just north of the John Ringling Blvd., that leads to St. Armonds Circle, Lido Key and Longboat Key. The site peers out over the bay while being nestled on the edge of the urban fabric.

The downtown district sits to the south-east of the site on a grid layout that intersects with the coastline.

The Bridge crossing the bay has recently been replaced with an architectural arched bridge, adding to the beauty of the site and coastline.

The Coastline is adorned by marinas and tourist activities up to 10th St. then the residential zone comes into play.
Site Analysis
Environmental

~Florida receives some of the most intense sunlight in the southern regions therefore shading is a must in the design phase.

~Humidity is quite high in this region so the design must consider this aspect of construction.

~The wind speed on the coast has a constant flow over the site and the inland areas.

~The average temp. of the region is the high 70s to low 80s but with the humidity it “feels” hotter.

~The amount of rainfall is very high in the summer and moderate throughout the rest of the year.

The population in Florida is somewhat sparse when one looks at Fig. #. The coast seems to be the popular areas and in the central zone around Orlando. The Tampa Bay area has quite a high population that stretches down to Sarasota and through to Naples.
The site is situated in such a way that it is in close proximity to many other points of interest such as the Modern Life Museum, Van Wezel performing Arts Center, The Arts Center of Sarasota and The Sarasota Opera to mention only a few. The major transportation hubs are only a few miles away at the most. The bus transit passes 1 block to the east and the airport is 2 miles to the north. The downtown district is a 10 min. walk to some of the areas great restaurants and attractions. The marinas and boat dock scatter the coast so the site offers many ways of access. Sarasota is a city known for the arts and entertainment. The arts is something that is imbedded in the culture of Sarasota. The most recent additions and renovations to this area are the Sarasota Opera which underwent a $20 million dollar restoration and next door is the Golden Apple theater. Just to the south of downtown sits Marie Selby Gardens established in 1973 which only adds to the ambiance of the area. Having a direct link to the natural elements and the urban districts this site will enhance the building and lend a hand in the molding of the design for having the attributes and characteristics of art and music inherent to itself. The possibilities of interaction and connectivity with the site’s context can be almost seamless due to
The downtown area of Sarasota has some very nice green spaces but there could definitely be more. Fortunately the west coast of Sarasota has some lush open green spaces and parks that dot the shoreline of the bay. The site has a thin line of green at the shore but there will be a full restoration of the site due to the parking lot on the space at the present.
The major vehicular movement through downtown Sarasota is Tamiami Trail (US 41) which was named for the connection from Tampa to Miami. US 41 is a heavily traveled road. Sarasota is a direct link to many of the surrounding cities as well as being a major tourist attraction for people all over the world.
The transition of sound through the site has a three fold effect. The first is one of nature as the site evolves from the bay and gradually steps into the second zone. The second zone is comprised of “mid sound noises”, The perception of natural sound fading as urban cityscape sounds slowly start to evolve into the space. From the combination of these two zones the third starts to take over as the urban edge begins at US 41. A site that has these attributes can be very influential to the way the design of acoustical space evolves.
Project Concepts
Project Concepts

The main concept for this thesis is acoustics so the first conceptual analysis was for the sound of the site and how the transitions create zones and regions. Looking at how sounds move through the site leads to positioning points and points of spacial placement. All of the sound analysis had concentrations of sound mixes in the mid zone. Utilizing the site lead to important issues such as thresholds and connections of program that are essential to the design.

Fig. 88 Site Diagram

Fig. 89 Natural Sound at Site

Fig. 90 Man Made Sound at Site

Fig. 91 Spatial Transition
Every piece of music has a distinct footprint or signature that expresses the essence of that music or instrument. By examining the structure of all of these elements and overlaying the sound map a certain pattern arose. Fig. # Music is comprised of single notes combined to create a holistic composition, and the same goes for architecture. A collection of structure overlaid by the skin. Here the underlying framework is the scale and the skin is the notes. A chord is made up of the 1st, 3rd and 5th note of a scale all played together, looking at fig. 95 one can see how the interlocking triangles of the 1,3,5 pattern emerges. This not only emphasis’ the structure but the rhythm, melody and overall concept of the piece plays through.
This concept model examines how sound as a formal determinate of space can express movement through pitch and frequency at concentration points on site. The movement of a sine wave tells of the amplitude and wavelength and at the same time expresses structure and form. The movement from the bay to the street edge is a composition all its own waiting to take shape.
Placement / Organization

The first Scheme focused on the connection of the bay and the urban districts. The exploration was to focus the performance hall to the community face and shoulder the bay. The education aspect was to be the connecting stitch of the fabric and the experience.

The second scheme was intended to be a stage for the community focusing on the face of the performance and to be the center of attention on the site. The layout set in the lower center of the site and looks at the urban set as a performer.

The third composition was a combination of the visual aesthetic of the bay interconnected with the aural perception of the performance while the interplay with the community and the urban aspect. The educational concept is to evolve from the idea to the expression of the idea.

Fig. 103 Scheme Concepts
Parti Exploration
Parti Exploration

The parti exploration was based on the concept of including the community in the function of the center. The education of music is a universal language that all of mankind speaks. The coastline enhances the appeal of the site and allows the design to include all of the aspects of sound from nature to urban sounds.

The center of all the connection is the performance hall and to follow is the musical education school. The parti allows for the encompassing of the whole concept of music, from the aspect of inspiration to the delivery of performance. The journey of knowledge is one of ups and downs just like the compositions of music.
The second exploration takes on the attributes of the composition in a whole. The sweeping sound of tone intertwined with the structure of music and a path that roams through it all. The approach is one of anticipation and intrigue. With the bay as the backdrop and the downtown district as the front playground this parti plays with the idea of integration and connection. The story line plays out from the front entrance to the center allowing the journey and path to tell a story of acoustics and music from one origin and the evolutionary path upon which they travel.
Conceptual Design
Conceptual Design

The concept of music is one of motion, therefore the overlaying ideas of acoustics in motion and music in time directs the evolution of the design through movement of structure and form that follow the function. The idea of time and space allow flexibility in the overall scheme. With the incorporation of education the intensity of rise and fall will come into play and partner with sound as a formal determinate of space.
The conceptual designs for this project started with the exploration of movement and expression of sound. Through these drawings a pattern started to emerge of a conical presence. The overlapping of sound and acoustics creates low, mid and high regions as does music.
Sound explodes in three different phases. The first phase is the direct perception, the second is a reflected perception and finally the third is the echo phase. Many designers attempt to isolate or delete most of echo and yet sometimes the echo is needed to enhance the sound in itself. The time it takes sound to propagate is extremely quick. Sound travels at 1130 ft. per second and if the room is only 100’ in length the time it would take for a perception is going to be measured in hundredths of a second. Therefore the layout of the design must compliment this occurrence. By designing in concentric rings the sound is allowed to respond by using its own attributes. The sound is not corrected to the space but the space is designed for the sound. The site was allowing for the building to respond to the environment as well as the function for which it is intended, once the sound is manipulated the design is obscured and sound engineering takes over.
Design Phase

The actual design grew from the influence of sound as a design element and a formal determinant of space making. The design includes the three distinct spaces for performance. The main performance hall, a mid size hall and the practice assembly space in the school are all focused on the journey that a musician must travel throughout their path to the large hall. The floorplans encompass the overall idea of sound propagation moments after the explosion. Sound travels in concentric rings as well as 360 degrees sphere. The idea of inhabiting the fringes of that explosion is where the inner space evolved from. If one is centered in the path then the three phases of sound will brighten the perception at that moment in time.

The distance of the performance space is 87' therefore the time to design space is only seven hundredths of a second. By utilizing the vertical aspect of design the design was able to elevate the tiers and provide a direct line of sight and a direct line of audible perception. The connection of the ellipsoid to the outer shell is one of no connection. The outer dome is intended to encompass the entire aspect of the function of the space. The conditioned space is all captured
The building is comprised of 3 distinct floorplans with an intermediate plane that is set for the lower seating just above the stage. The school extends down from the medium performance hall and greets the street on the east side of the site. All of the production offices and administration spaces are integrated just northeast of the main performance space.

The domes are positioned in just a way as to grab the shore line for aesthetics and the sound waves for the audible connection back to nature. As the building approaches the east the sounds start to evolve into a mix of urban and natural sounds creating a distinct zone inside of the complex.

The shoreline has been preserved as it is due to the fact that Sarasota is known for the beautiful bay and shoreline. The area in which the building sits is the arts district for Sarasota and all of the other buildings respect the same rules that were applied to this design.
Sections

Fig. 127 Sections
The section perspective expresses the interior qualities of the performance hall and the connection of the floor plates and the interior ellipsoid. The coverage of the outer dome forms the circulation throughout the building.
Elevations

South Elevation

West Elevation
East Elevation

North Elevation
Details

Fig. 131 Details
Anechoic Concept

The anechoic concept was incorporated into the inner lining of the shells to cancel and absorb the unwanted sound waves and limit the reflection and echo.
Acoustical Testing - Ray Tracing

Wallace Sabine Harvard 1895 - Fogg Hall

Sabine Formula -

\[
RT_{60} = \frac{c \cdot V}{S_1 + S_2 + S_3}
\]

where \(RT\) = the reverberation time
\(c\) = the room time, speed of sound in defined space
\(V\) is equal to the volume of 3 dimensional space meters cubed
\(a\) = average coefficient of absorption for material
\(S\) is equal to the surface of the room meters squared

Reverberation time

Sabine's Formula applied to performance hall
\(c\) (Room Time) = \(Rd / 1130\) ft per second = 5\(s\)
\(c\) = \(0.075243\) ft per sec.
\(V\) = volume of area = \(833340\) cubed ft.
\(S\) = \(A = 13965\) ft sq.
\(a\) = 8.9 @ 750-1000 hz

\[
RT_{60} = \frac{c \cdot V}{S_1 + S_2 + S_3}
\]

\(
(0.075)(833340)
\)

\(
(13965 + 9783(2) + 14724)(8.9)
\)

\(= 1.4459\) sec. (full room cloth seats chamber slots closed)

\(= 1.8452\) sec. (empty room cloth seats chamber slots open)

Fig. 133 Acoustical Testing
Acoustical design is quite difficult due to there being so many unknowns. The frequencies can cause trouble with a design. In order to solve for the unknown exacting dimensions and configurations should be used to organize and prioritize placement and position of design elements that will enhance the sound and not merely the visual aesthetic that so many other buildings employ in their design. Ray tracing was the major tool used in this design. Going back to basics and utilizing the old technique of designing acoustics performed perfectly in this space.
Renderings

The renderings (see right) express the interior qualities of the hall and vertical circulation. The material chosen were for their acoustical attributes and properties. Douglas fir and oak were the wood finishes applied to the interior and dyed concrete (smooth finish) for the circulation and main floor plates. A polystyrene resign makes up the transparent glazing, mainly for the strength and UV properties.

The section/floorplan (see below) show how the building works. The inner circulation wraps the shell and allows panoramic views out to Sarasota Bay.
View of main performance hall from water.
View of main performance hall at night from water.

Fig. 138 Renderings
Interior performance hall view out to the bay.
Main entrance view from listening sphere.
Fig. 141 Renderings

View of student hall from second floor of main hall.
Draft Model

The initial draft model took form and allowed the design to reveal its faults. Through the exploration of study models the design evolved into a holistic approach at acoustics in architecture. Acoustics, as a design influence, has long been abandoned by the architecture profession. This is possibly one way to reintroduce the acoustical aspect of design back into the design phase as an element or an inspiration for the overall approach to the initial lining of the paper.

Fig. 142 Draft Model
An anechoic chamber concept has been incorporated into the ceiling panels that can be opened or closed depending on the performance in the space at any given time. These baffles consist of triangle shaped wedges lining the shell’s inner core. The wedges disperse the energy in the wave once it enters the chamber. This results in a lessening of unwanted waves in the actual performance area and thus increases the quality of sound in the hall.
Final Model
Conclusion

In conclusion; throughout all of the research and analysis the main idea of using sound and music as the main influence for the design remained constant through the design phase and ultimately answered the thesis question of how sound can be a design inspiration as well as a formal determinate in the design phase. The popular trend for today’s modern architecture is one of convenience. The architect has bypassed the obligation and the duty to design all aspects of inhabitable space. Over the passage of time the profession of architecture has spawned many other professions and led the way to the demise of the “Master Builder” depiction that the architect once possessed.

This thesis reinforces the fact that all aspects of sound in space is able to be designed by the architect and does not have to be leased out to a consultant to do “our” job. Sound is something that should not be designed. The space for the sound is the design in itself that compliments the music and therefore the music is free to play upon the structure of the architecture, both of these elements coalescing to create a holistic entity called musical architecture.

Fig. 149 Final Model
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