Acoustics as an Inspiration in Architecture

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ABSTRACT

Material is a common denominator between acoustics and architecture. The most basic building blocks of material are the elements: Earth, Water, Air (and Fire). Water is explored as an acoustic reflector, air as an escape path for sound, and earth as diffusor/absorber/reflector. This exploration of work dives into how acoustics can inspire architecture from the start. The thesis used two design projects to test the ideas: *The San Francisco House of Music* and *The Boston Elemental Theater*. Through this work I found the two interrelated fields can work together, and find a process and direction of design that raises the level of both disciplines.

This hard work is dedicated to my mother, Donna Kanapesky

Special Thanks to:

My Father Ray for unconditional love and support
Michael, Heiner, and Scott for their patience, knowledge, and guidance
Andrew Hulva for being an incredible mentor
Randall Rehfus, Jeff Rynes, and Abram Diaz for selfless assistance
& all who have molded me to where I am today

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Acoustics as an Inspiration in Architecture

Fig. 1 - San Francisco House of Music - concert hall

I. San Francisco House of Music

Fig. 2

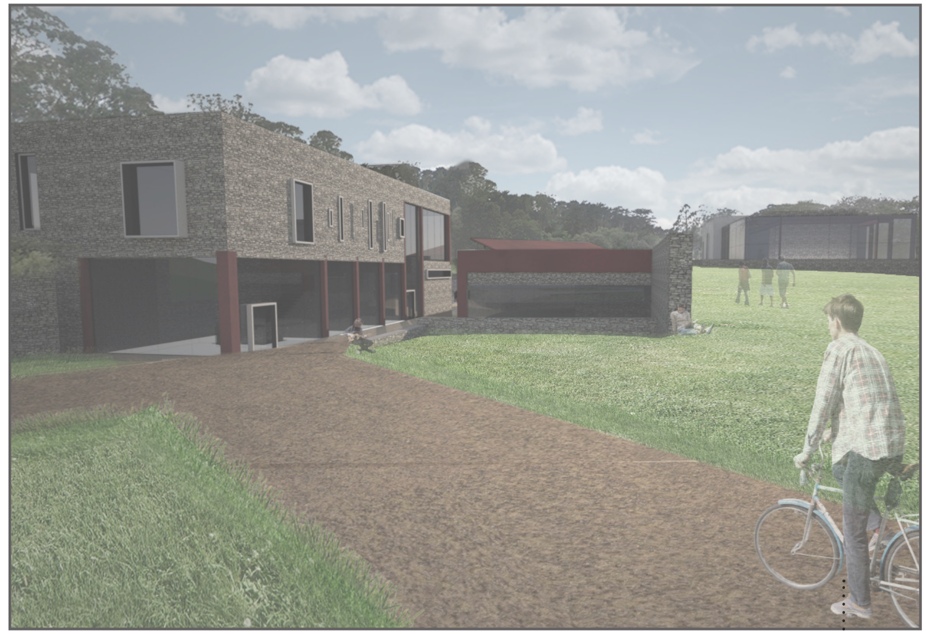


Fig. 4

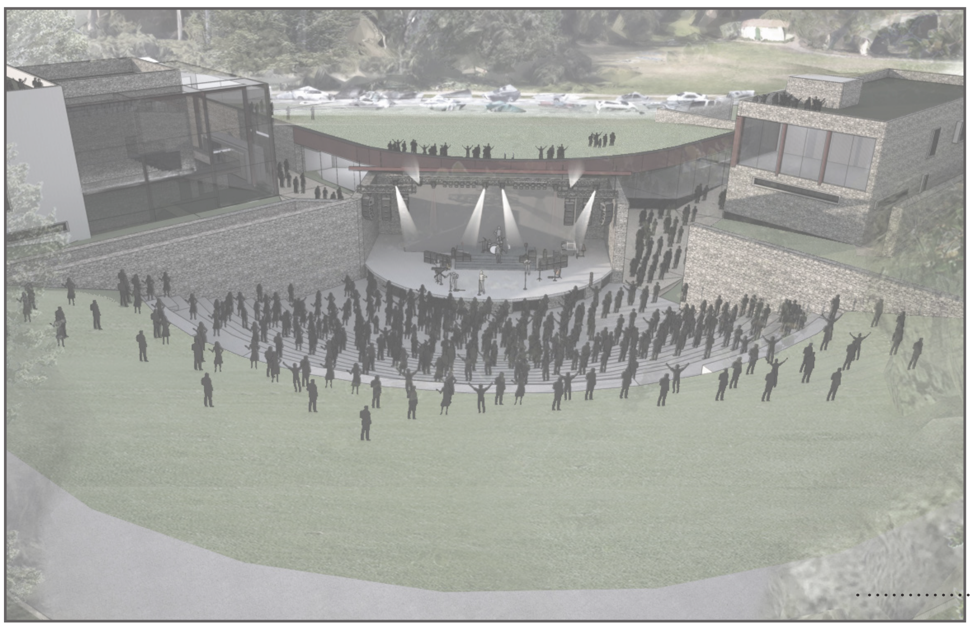


Fig. 3

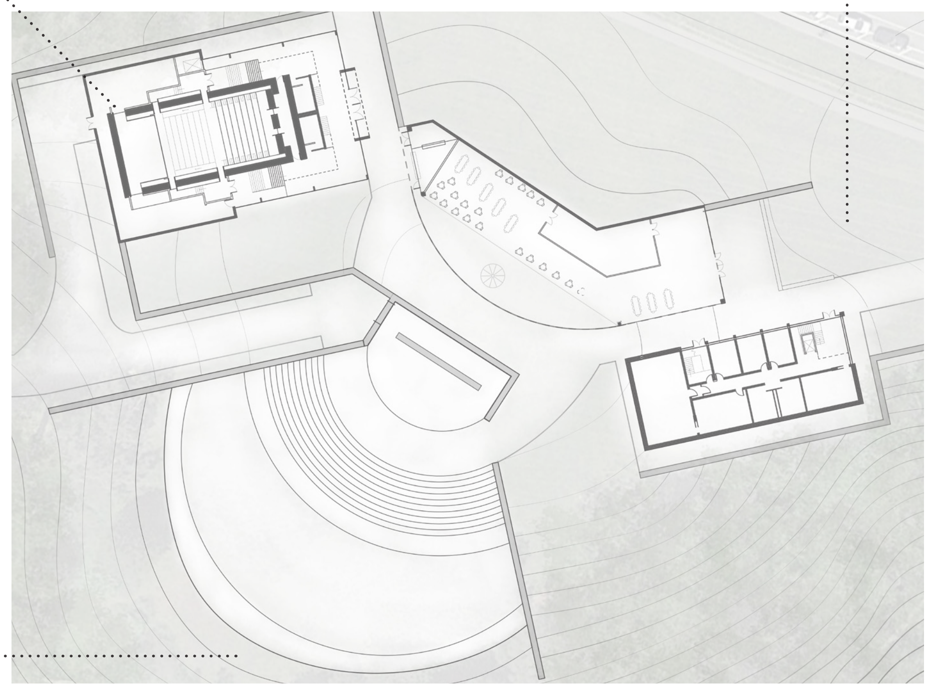


Fig. 5

Fig. 6 - Boston Elemental Theater

II. Boston Elemental Theater

Fig. 7


Fig. 8

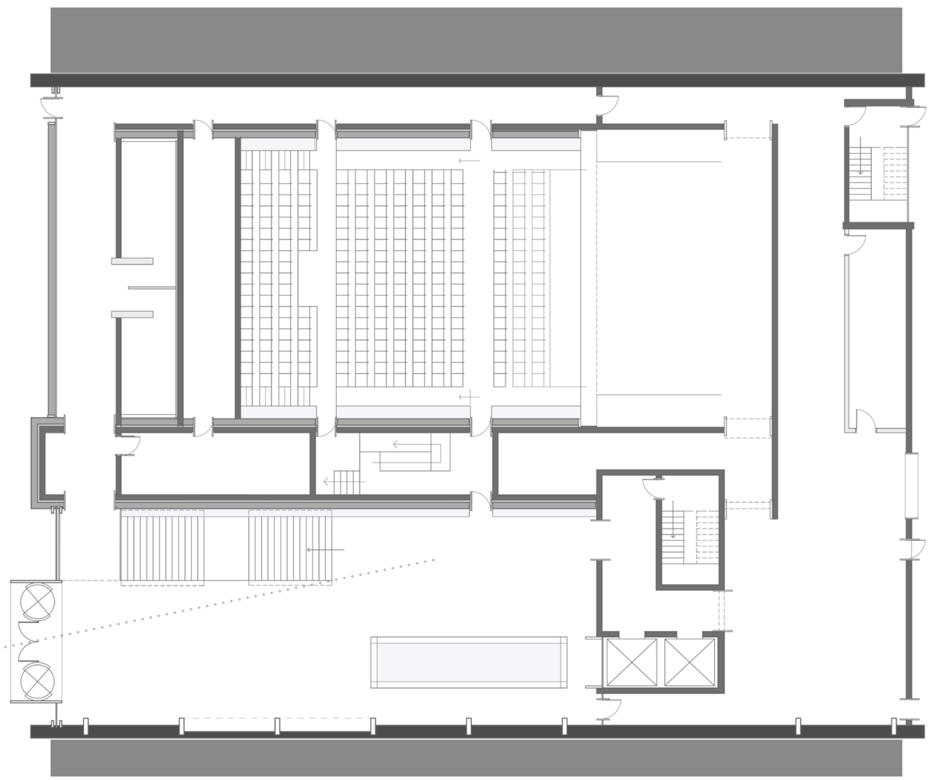


Fig. 9

Fig. 10 - MIT Chapel

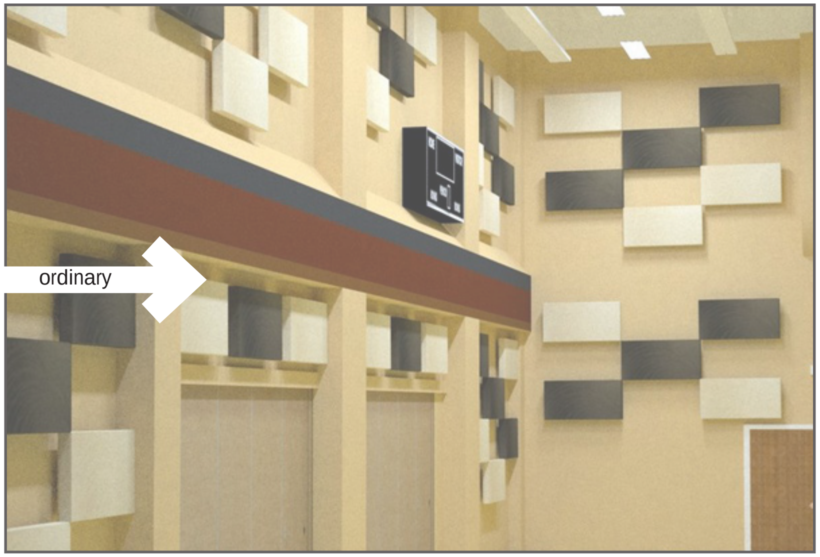


Fig. 11 - Normative Acoustic Treatment (fair use)

Consideration of Acoustics

What is the difference between these two spaces? Both spaces share a need for acoustic treatment. Both examples execute the treatment in very different ways. Eero Saarinen pulls the brick apart in the MIT Chapel (fig.10), allowing sound to travel through in order to be absorbed via fiberglass. The generic space (fig.11) represents what happens more commonly. The existing architectural language is altered by an additive (the acoustic panel) without consideration of the original architectural idea. Imagine the MIT chapel with acoustic panels instead of brick voids. Architecture can be inspired by something technical like acoustics, rather than simply being altered.

Earth

Four classical elementary building blocks of material are the elements: Earth, Air, Water, (and Fire).

From the point of acoustics, the "performance" of earth ranges from the absorptive nature of loose dirt, to the highly reflective nature of smooth concrete. There may be situations that call for absorption, and some for reflection. Earth is versatile enough in form to range from one condition to the other.

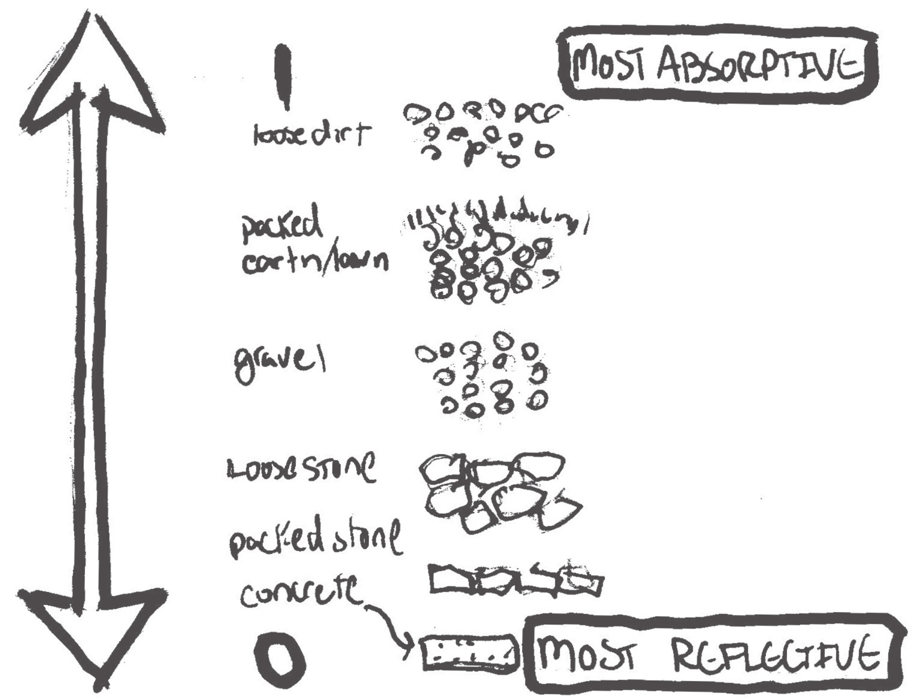


Fig. 14

Fig. 12 *Absorption vs Reflection*

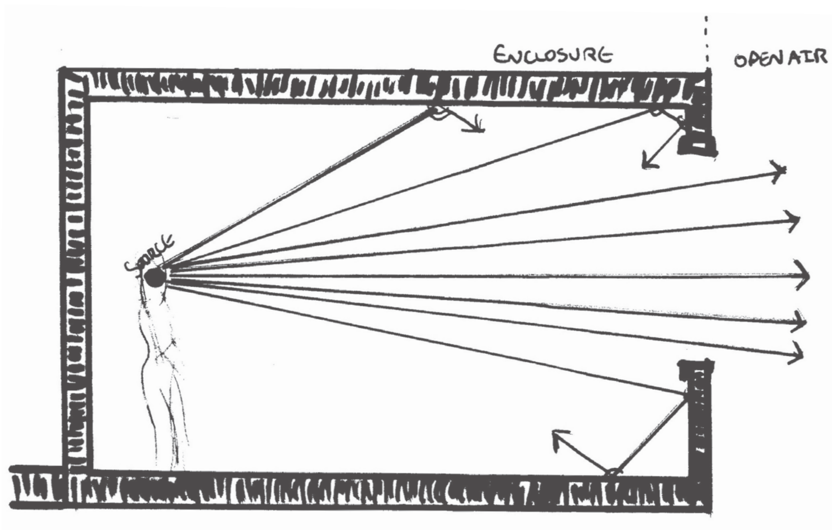


Fig. 15

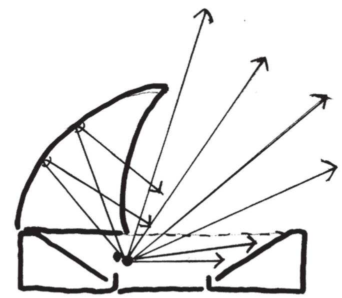


Fig. 16.1 - Roof Open

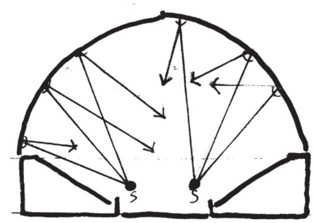


Figure 16.2 - Roof Closed

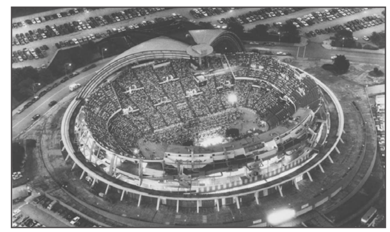


Fig. 17.1 - Civic Arena 1961 (fair use)

Fig. 17.2 - Civic Arena 2009 (fair use)

Air

Air is considered a perfect acoustic *absorber* when observed in the context of an open aperture. Air in the context of this thesis refers to sound spreading and transmission. The former Civic Arena (1961-2010) in Pittsburgh, Pennsylvania, was the first retractable roof of a major sports-venue. It was the idea of Edgar J. Kaufmann to build a home for the Pittsburgh Civic Light Opera (CLO), and the design of firm Mitchell and Ritchey[1]. An operable roof allowed changes to the space for events typically held indoors. When amplified events took place such as a rock or pop concert, the roof would be retracted and over 70% of the ceiling was open to the air. This allows the excess sound of an amplified performance to escape through the open roof, resulting in a clearer sound for the audience. A closed roof typically muddies the sound due to the large volume of arenas. Depending on the event, one condition is preferred over the other. For example: a hockey atmosphere with the roof closed is much more energetic than with the roof open, or even an outdoor crowd. When an arena is too “dead,” or acoustically absorbent, the atmosphere is often described as lifeless.

1. The Civic Arena (Mellon Arena) History 1961 - Present. N.p., n.d. Web. 07 Sep. 2016.

Water

Water is considered a *reflector* when viewed as a surface of a body. When looking at sound, the surface stood out as the controlling factor. Sound energy has difficulty transferring from air to water and has no choice but to reflect. In essence, the water surface acts as an acoustic reflector.

In the context of this thesis, each element emerged with an acoustic role. The water surface is the reflector, and the open air is the absborber. Earth is able to bridge the gap with its acoustic versatility.

Fig. 19 - Fountain at Belvedere Gardens in Salem, Virginia

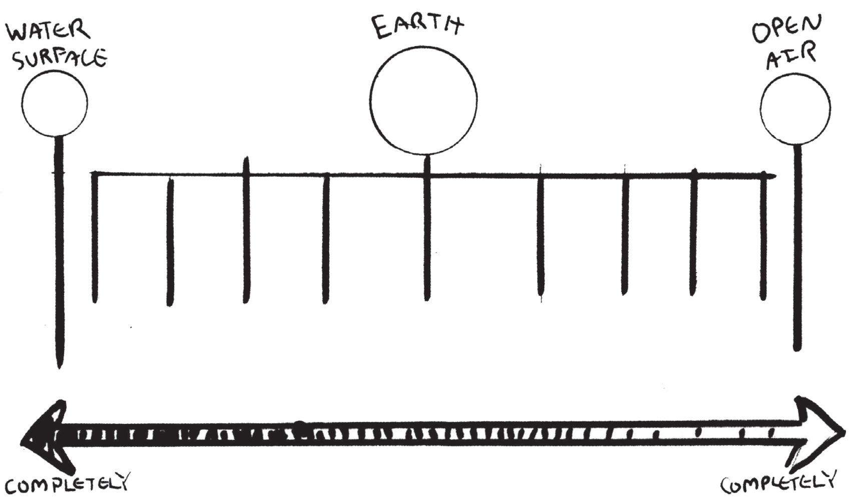


Fig. 18

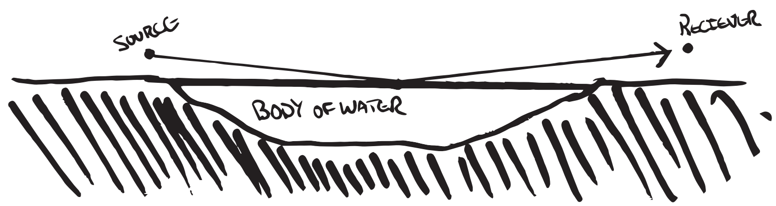
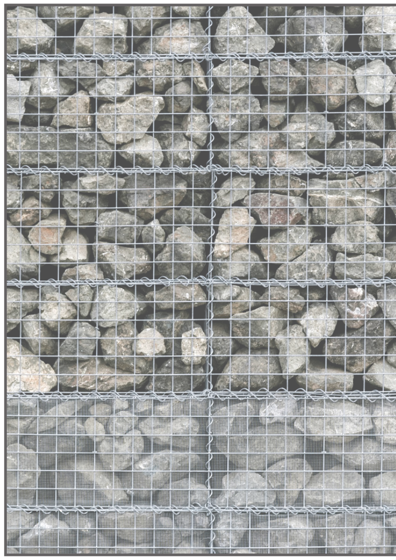


Fig. 20

IV. Materiality & Room Acoustics



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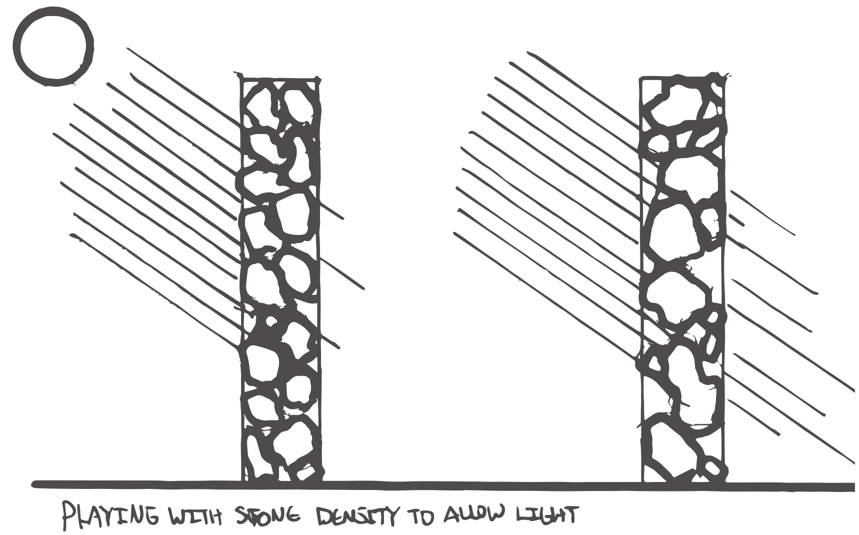

Fig. 23

Gabion Systems

Typically used in a utilitarian manner, the gabion wall is simply a steel basket of stones, or randomized reflective surfaces. The more random and concentrated the reflective surface, the more diffusion occurs. The Dominus Winery by Herzog & De Meuron was one of the first projects to use gabion wall systems as a controlling element in a building. In some instances the gabion is dense, tightly packed with a variety of stone sizes to prevent any daylight from getting through. In other instances, larger stone that are similar in size fit together but leave air space in between. As light is able to be manipulated through this assembly, sound can as well. The diffusive nature of the natural randomization of stone faces and variation of porosity enable sound to pass through the gabion. Depending on the context, this can work for outdoor venues or there can be additional acoustic absorption such as fiberglass behind the gabion wall. Rather than an add-on square acoustic panel, the absorption becomes architecturally integrated into a system.

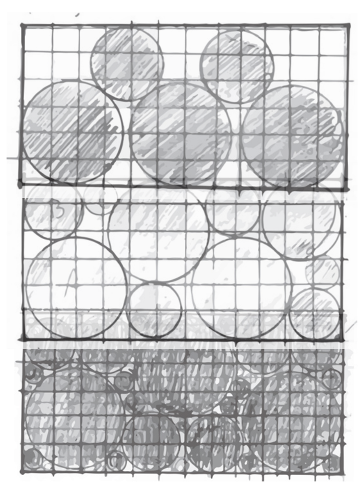

Fig. 24

Legibility

Architectural form derived from acoustic discovery requires rules. The Danish Radio Concert Hall (fig.27) is an example of the "performance-driven" design model which overtly displays it's acoustic measures resulting in an architectural busyness. Even more busy is the Esplanade Concert Hall (fig.26). With program that requires focus on the relationship between audience and performer, perhaps the architecture should strive for legibility and simplicity. If the space is legible and has clarity, it can be less demanding and promote a focus on the event. In the Amangiri Resort (fig.28), the framed landscape is the obvious focus on the event.

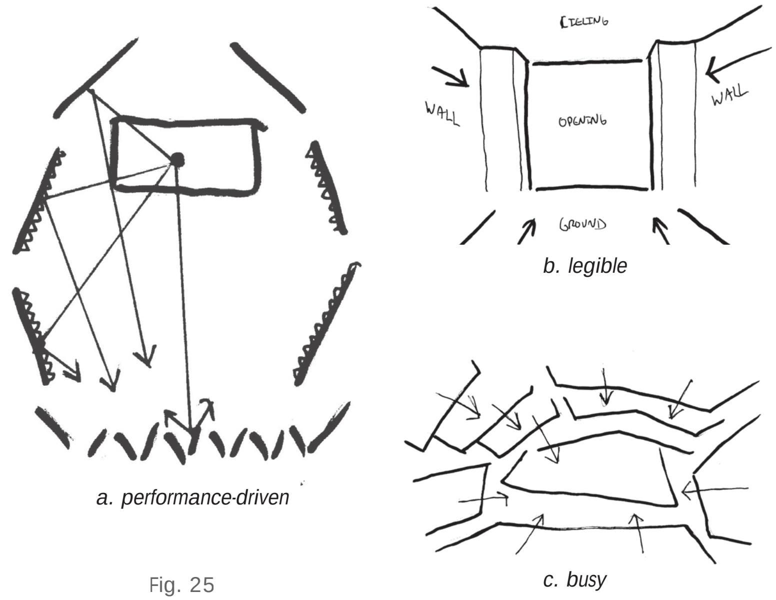

Fig. 25

Esplanade Concert Hall - DP Architects & Michael Wilford

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Danish Radio Concert Hall - Jean Nouvel & Nagata Acoustics

Fig. 27 (fair use)

Amangiri Resort de Lujo - Rick Joy

Fig. 28 (fair use)

Concert Hall

The randomized stone faces of the gabion strategy act as acoustic reflectors in all directions, thus becoming diffusers. Density of stone determines how much air passes through and can be absorbed by a fiberglass backing. The shoebox approach supports not only architectural clarity, but also preferable acoustics. The top concert halls in the world are shoebox design for acoustic, visual, and perceptual reasons. Adopting the shoebox as a point of departure, the wall system and it's properties of the material become the means of acoustic control. In this case, an ideal volume was chosen for a target reverberation time of 1.6 - 1.8 seconds. This range is tuned for performance music over speech or musicals. The absence of a fly tower allowed the performance stage to reside within the same volume as the spectators. Not only does this improve first-order sound reflections, but it helps the sound "surround" the spectator and fill the space. Seen below is a CATT acoustics model visualization of sound energy with performers in the same volume as the audience. CATT enabled iterations of the gabion types, from dense gabion cage to an empty cage with fiberglass.

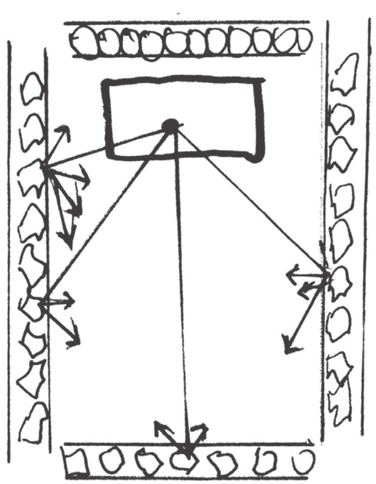


Fig. 29 *form-driven*

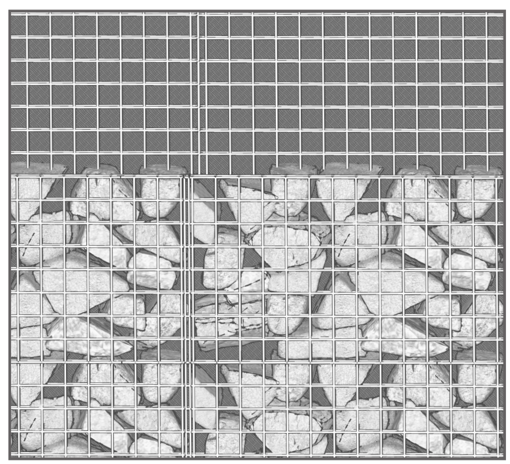


Fig. 30 *back wall condition*

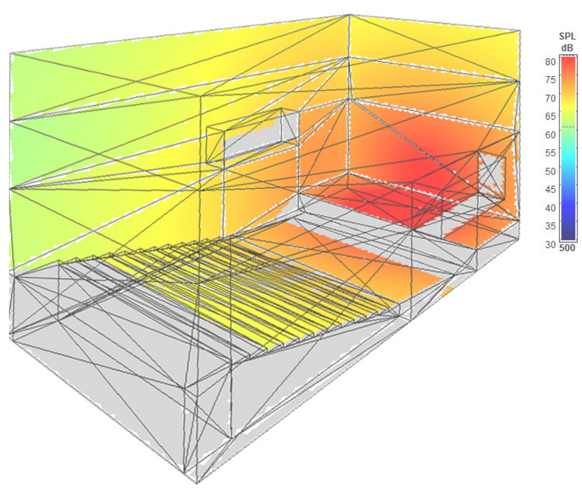


Fig. 31 *CATT energy mapping*

Fig. 1

Design Decisions

While simulating diffusion, reflection, and absorption through density of stone, multiple acoustic needs were addressed. In order to preserve the architectural clarity of a massive shoebox, the overhead balcony was removed in this iteration. The gabion wall terminates at a profile, towering like a mass protecting the hall from the outside. The concert space is a box within a box, sitting inside of a glass lobby and the back-of-house spaces. In order to pass through this massive, 1m thick genuine gabion wall, steel boxes denote sharp frames and selected punched openings. These steel passages accommodate circulation, and penetrate the room above. Rather than a traditional balcony, the steel boxes give unique views of the stage, and provide a sense of privacy away from the main crowd. The tradeoff is a space that has a lower reverberance and less spatial awareness. The front of house is solid earth, in this case concrete, which supports the projection of direct sound. The side walls diffuse direct sound while the back wall allows sound to pass through the gaps into fiberglass absorption. Finally, the seating is designed to fit as many people in the space as possible, promoting people as a source for absorption.

V. Water Wall Study

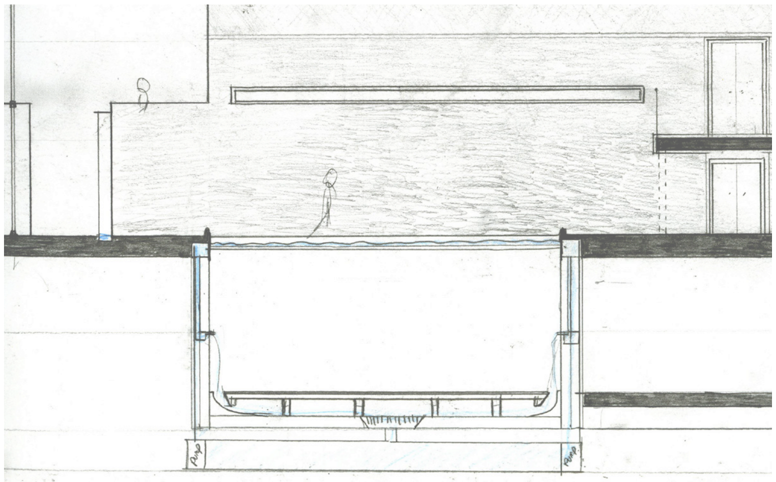


Fig. 32

Surface as an Acoustic Reflector

When overflowing uniformly, water falls in a laminar sheet. Assuming it behaves as a reflector, the water sheet can became a part of the architecture. Typically this is seen in the form of a fountain, with the water falling completely normal to it's landing surface. In this experiment, there were three underlying goals:

1.) design and fabricate a water wall able to be tested
2.) discover ways to quiet the impact noise of the water
3.) develop and execute testing method to confirm reflection

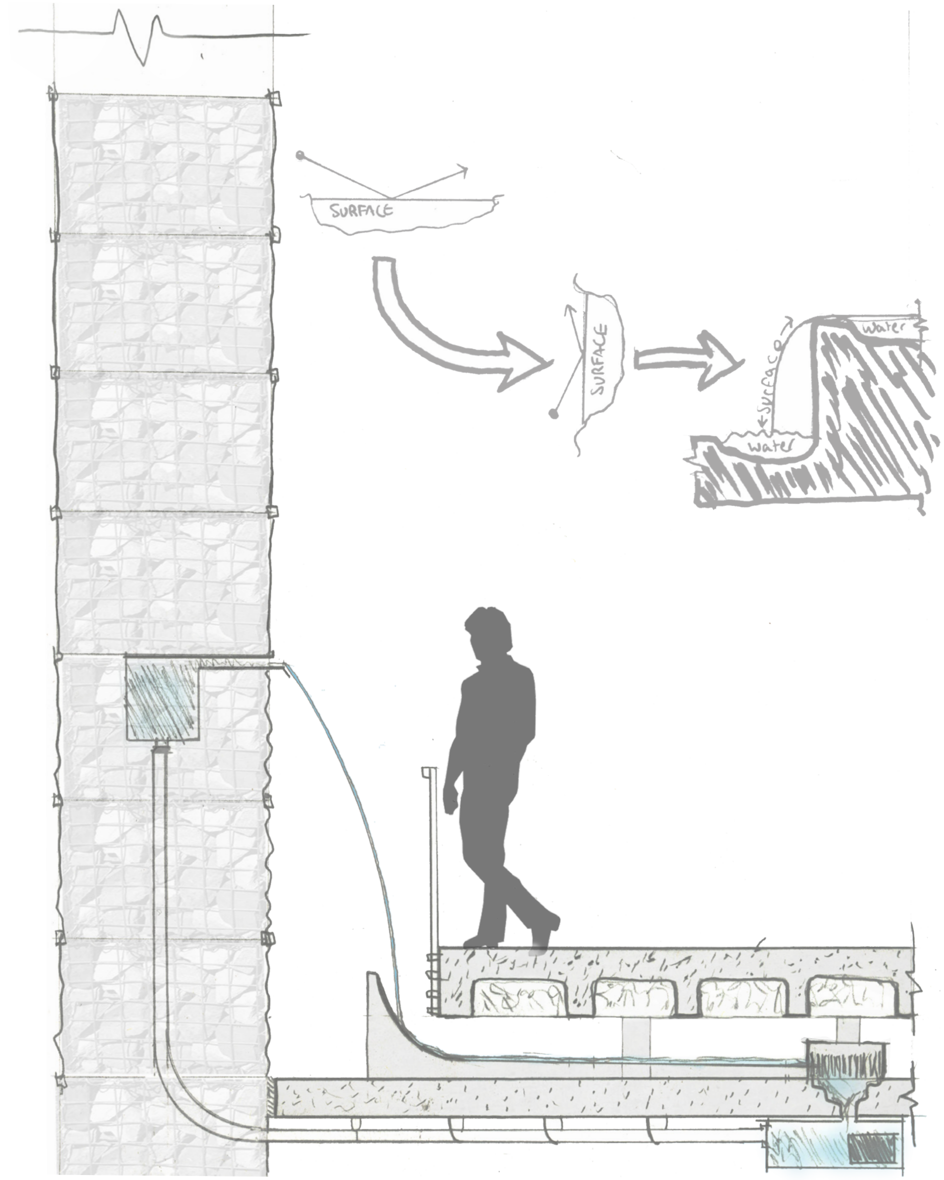


Fig. 33

Fabrication and Iteration

Designing the experiment to be portable and temporary was key. The rig also needed to be clean and efficient enough to test inside of an anechoic chamber. This limited the size of the setup as well as the pump strength. These constraints led to three prototypes; from discovering the proper lip to finding just the right amount of pan volume for water pressure. An in-situ water wall 12+ ft. wide at nearby Belvedere Gardens in Salem, Virginia, was measured at over 90 dB of noise from a 4-foot distance. This was due to the high quantity of water falling directly normal onto it's collecting pool, maximizing impact noise. Here, the testing rig is designed to catch the water on a curved surface somewhere between 30-80 degrees normal of the falling water. This inclined surface dampened the impact, which was further dampened by adding diffusion with, for example, an air filter as seen in fig. 35.

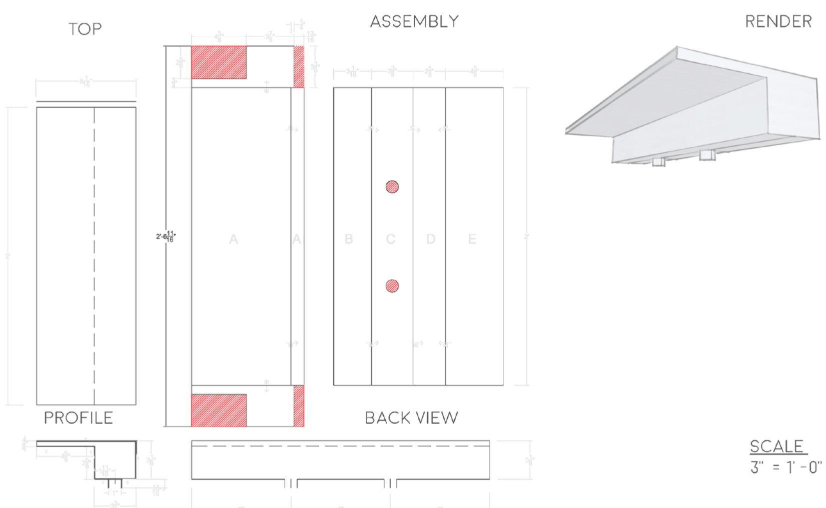
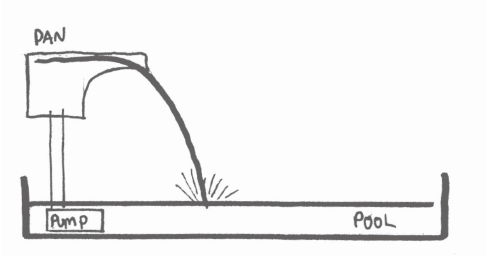


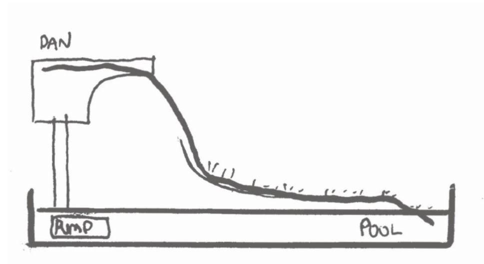
Fig. 34 *assembly drawing*

Fig. 35 *water wall rig*

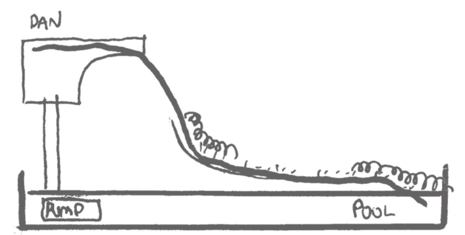
Fig. 36



A. water landing normal



B. water caught at angle



C. water caught at angle with diffusion

Testing Dampening

As expected, catching the water at an angle decreased the impact noise. The difference is about 10 dB from condition A (water landing normal) to condition B (water received at an angle). The initial assumption to reduce noise was to catch the water as close to 90 degrees as possible, but the testing revealed that any angle from about 30 degrees to just under 90 performs relatively similar. The results suggested that as long as the water is not colliding completely normal to the surface landing, the impact noise decreases. After diffusion is added, the noise drops about another 10 dB! Inferred from the experiment, a room with a background noise of 35 dB would hide the sound of the water falling under the noise floor (level of background noise in a room). The diffusion / dampening was generated with a simple air filter, but more creative solutions are available.

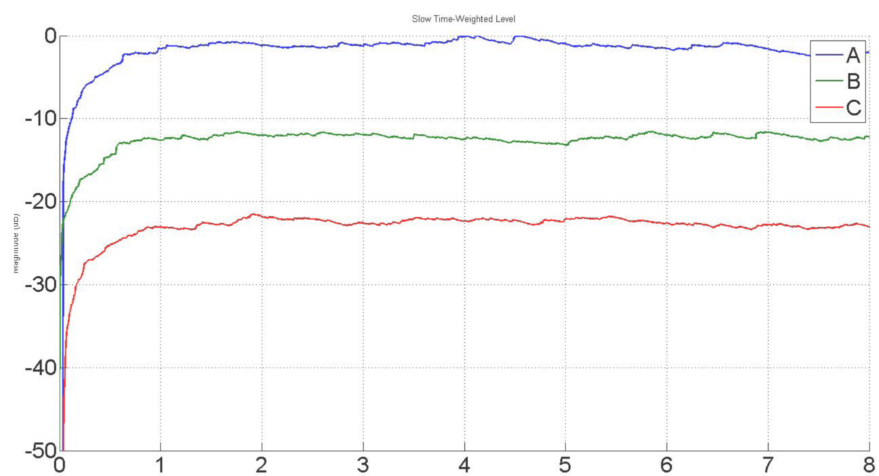


Fig. 37

Testing Reflection

It was determined the most efficient testing strategy was to take an impulse response and visually check for a reflection. This response is how the room reacts, or responds to a sudden noise. These signals when mapped can be read. The blue data is the setup seen below tested with the water off. The green data is with the water on. The first peak is the direct noise from the speaker,and the rest is what is bouncing in the room. The only variable is when the water is turned on. The difference is the mic picks up a distinct, obvious reflection seen in green near .5 ms. This proves that the sheet of falling water does reflect incident sound well.

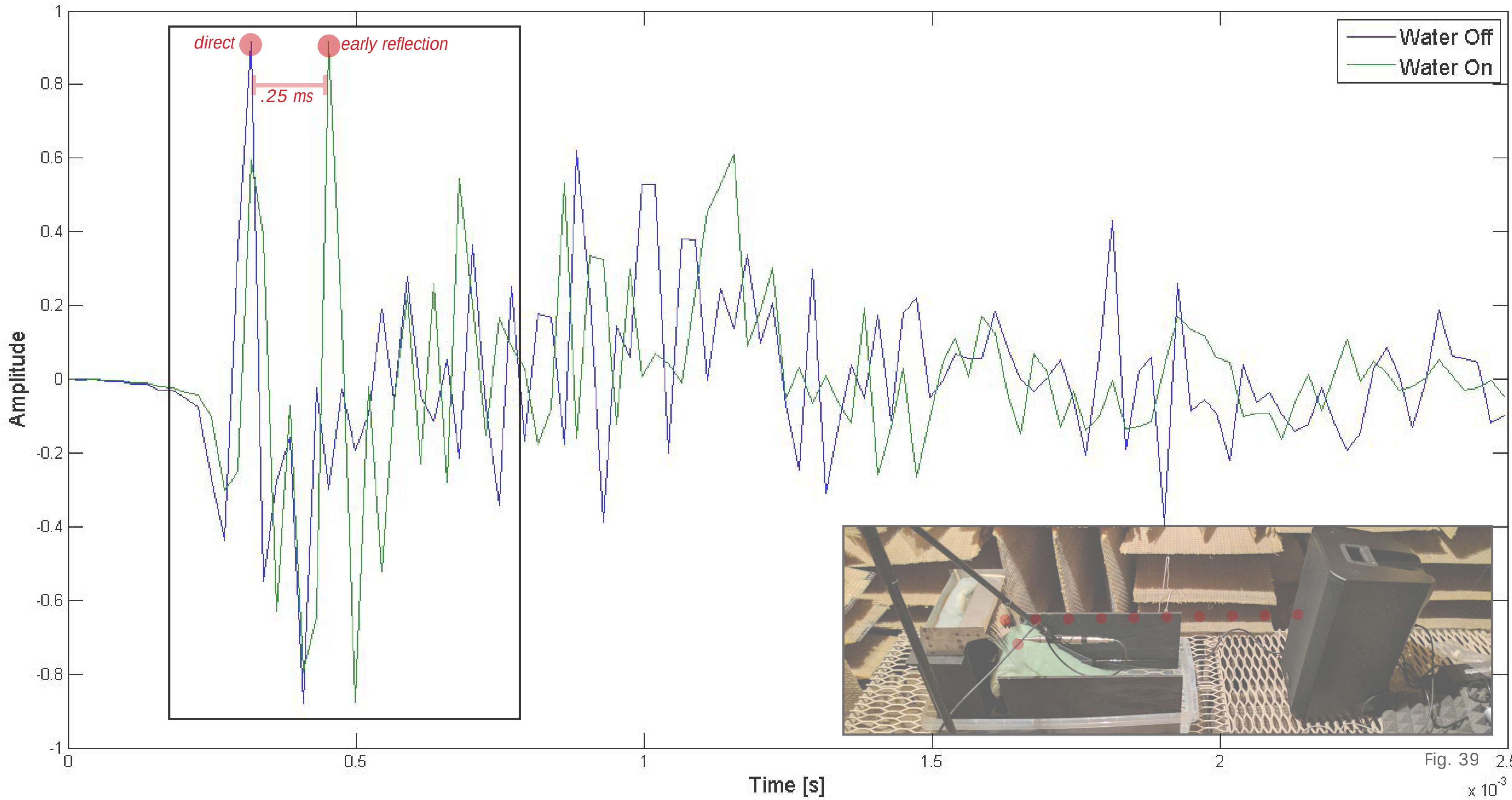


Fig. 39

Fig. 38 *impulse response comparison*

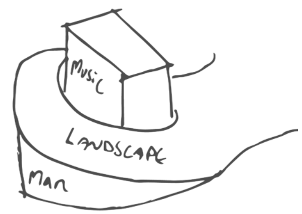
VI. Comparing Context

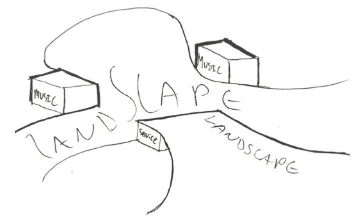
Green Field Condition

The San Francisco House of Music competition was chosen as a vehicle to test the ideas of the thesis. The program required, but was not limited to:

1.) 300 person concert hall for music
2.) practice & rehearsal classrooms
3.) outdoor amphitheater

The initial strategy focused on designing the concert hall, and placing everything else in support of it. This resulted in an acoustically competent concert hall, but an underdeveloped overall architecture. Located in Golden Gate Park, not far from the De Young Museum, the site had primarily an english garden character with no built context in close range. The park, inspired by Olmsted, in the spirit of the *picturesque* features winding roads, vistas, and open lawn space. The original idea for the music complex was a single house within the landscape, which evolved into an ensemble of three parts collaborating with the in-between spaces and the landscape.





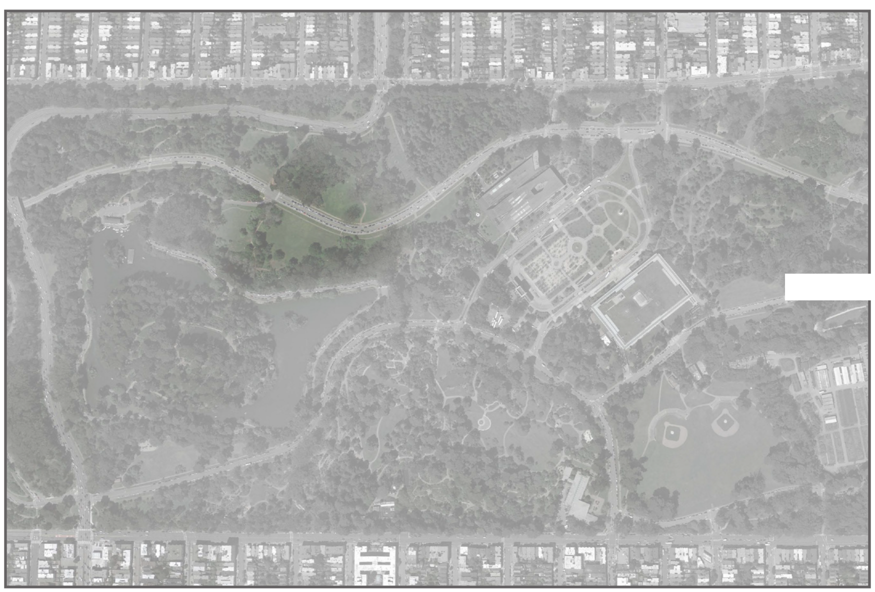


Fig. 40 *Golden Gate Park*

Fig. 41 *Immediate Site*

Fig. 42

Fig. 43

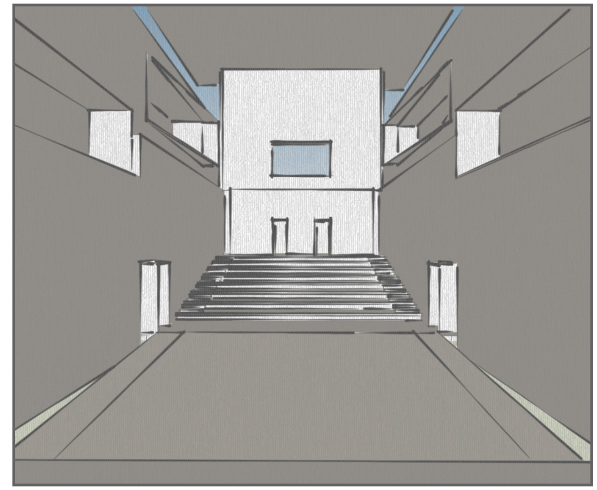


Fig. 44

Process

The performance space, although not constrained by any major requirements, went through several iterations. A floating balcony and retracting roof in the end emerged as a box-within-a-box in essence. The concert hall focused on quality acoustics for unamplified music, while the outdoor amphitheater catered to amplified performances.

Fig. 45

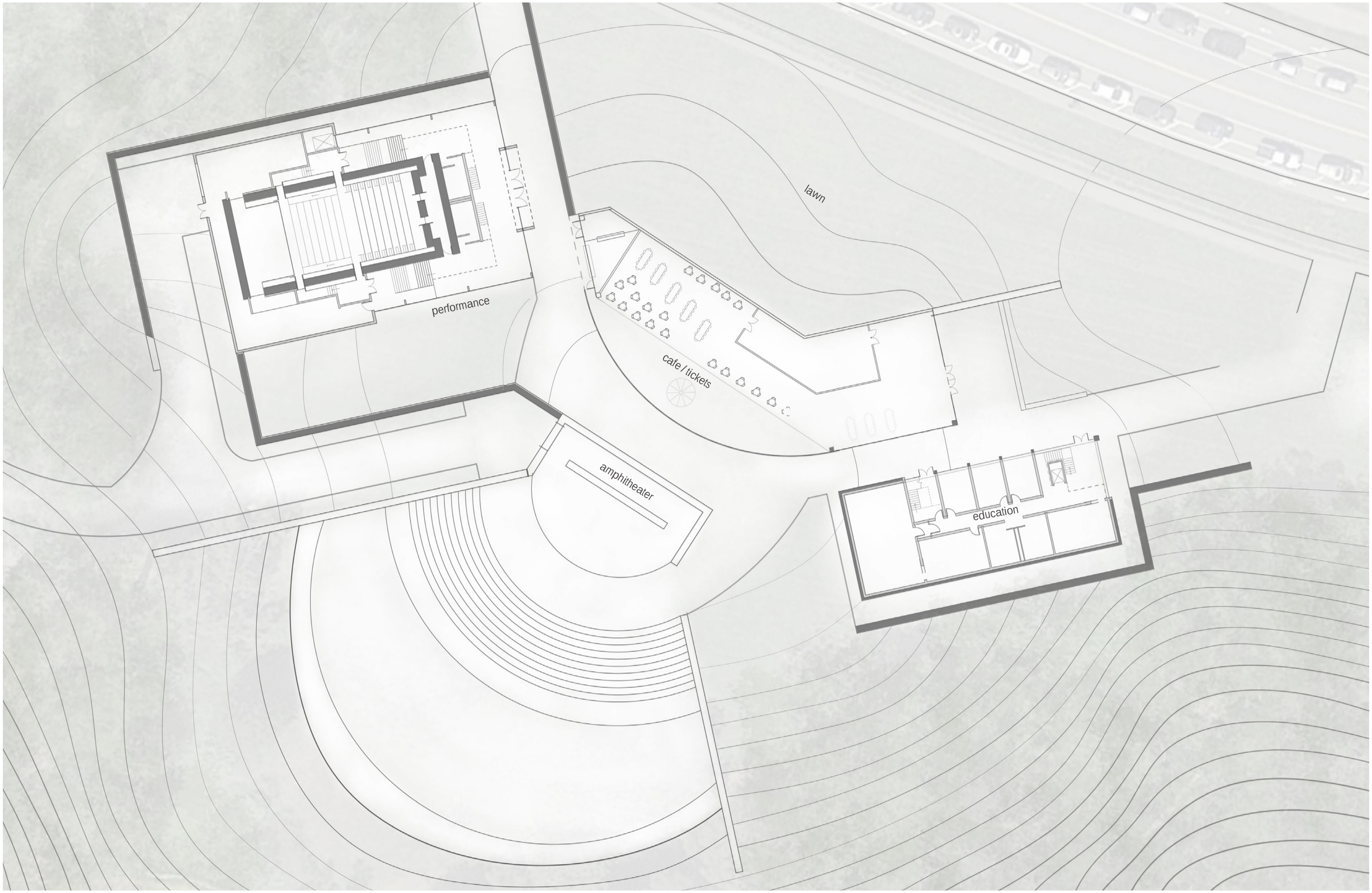


Fig. 5 - San Francisco House of Music - Site Plan

Fig. 2 · San Francisco House of Music · performance block

Urban Infill

The second vehicle for this thesis focused on a multi-purpose university theater in Boston located at a generic 130’ x 100’ infill site. With almost identical programs between the two projects, the biggest difference is the response to context. The major pieces of the Boston program are:

1.) 600 person multi-purpose theater
2.) 3,000 SF rehearsal room
3.) variety of service and back-of-house requirements

The Boston proposal employs the same acoustic and architectural ideas as the San Francisco project, but adapted to the new site. As a primary difference, the box-within-a-box was physically limited to the infill site despite the performance space needing to become larger. The shoebox was elongated and slighty widened. Paying more attention to circulation and acoustic isolation also challenged keeping the space legible. The lobby was modified from a very function-driven approach toward a balance between formal considerations and pragmatic needs. The performance space as an isolated and legible volume was the goal in the tight lobby.

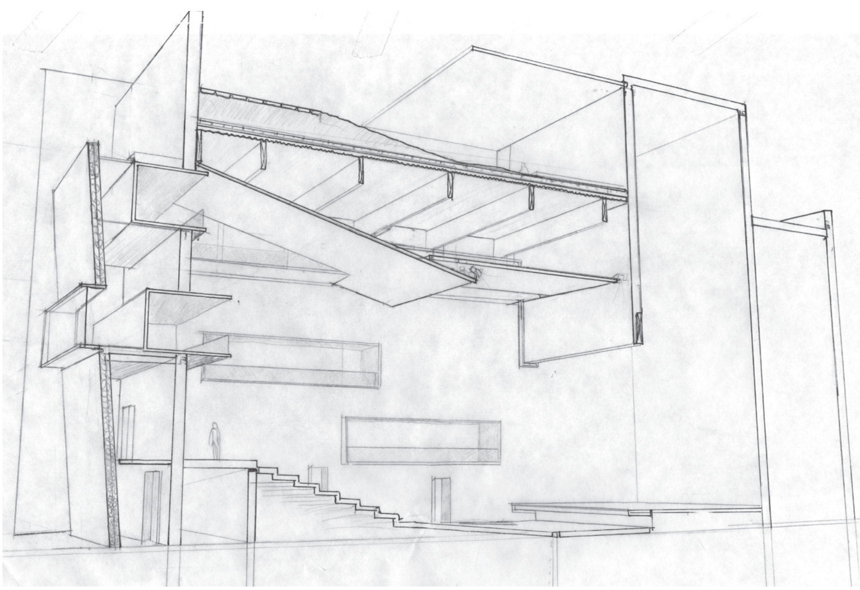


Fig. 46 - Boston Elemental Theater - section perspective

Fig. 47 - lobby iteration

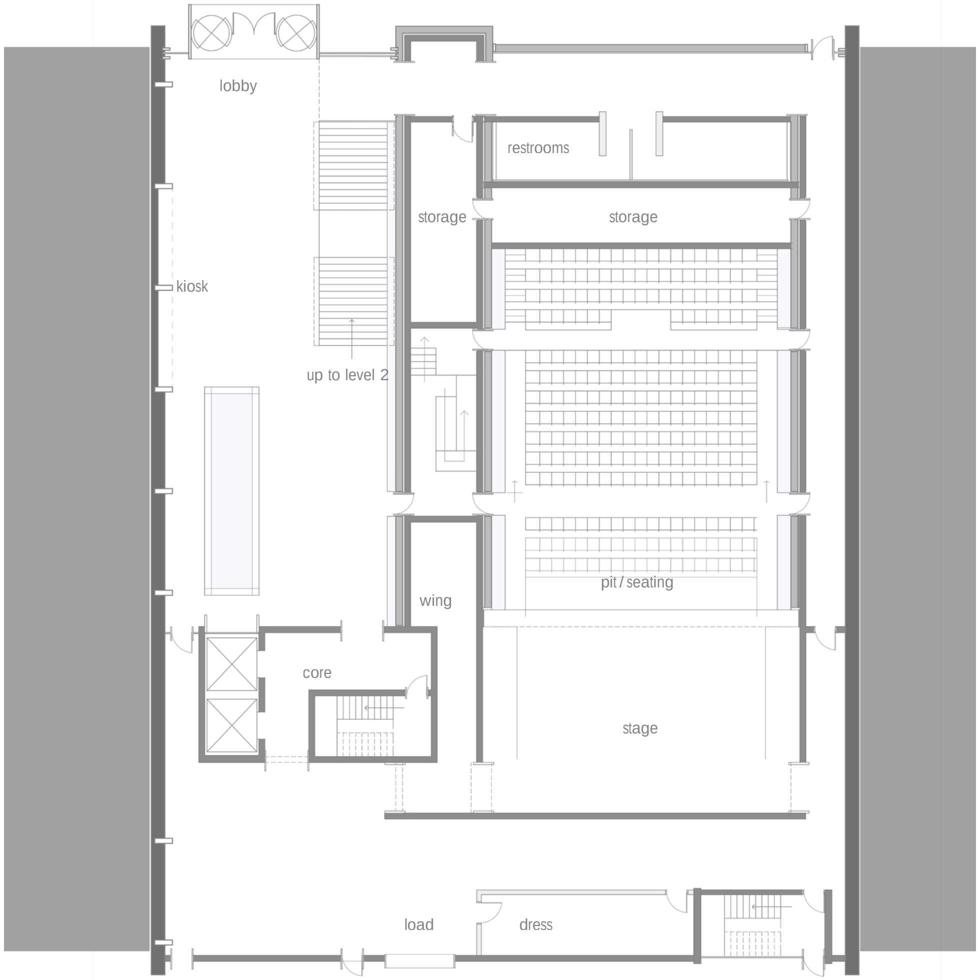
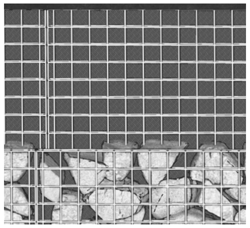


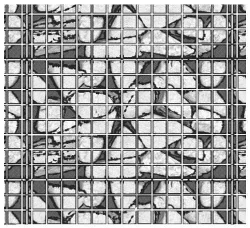
Fig. 9 · ground floor plan · oriented to correspond to fig. 7

The plan shows how tight the lobby space became with such a large program. Several layers buffer and isolate unwanted noise in the concert hall. Toward the neighboring buildings, a thick party wall physically and visually isolates the interior. The performance space is designed as an isolated volume between the party walls. It’s boundary consists of the circulation corridors and a massive gabion wall as the buffer between the lobby and the concert hall.

Fig. 7 · lobby

Fig. 6 - Boston Elemental Theater - concert hall





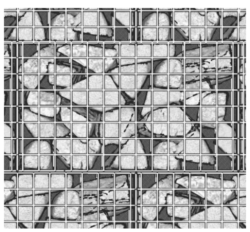


Fig. 48

The roof venue seemed possible when considering a green roof. Similar to a rooftop bar, but with impact noise isolation via intensive green roof.

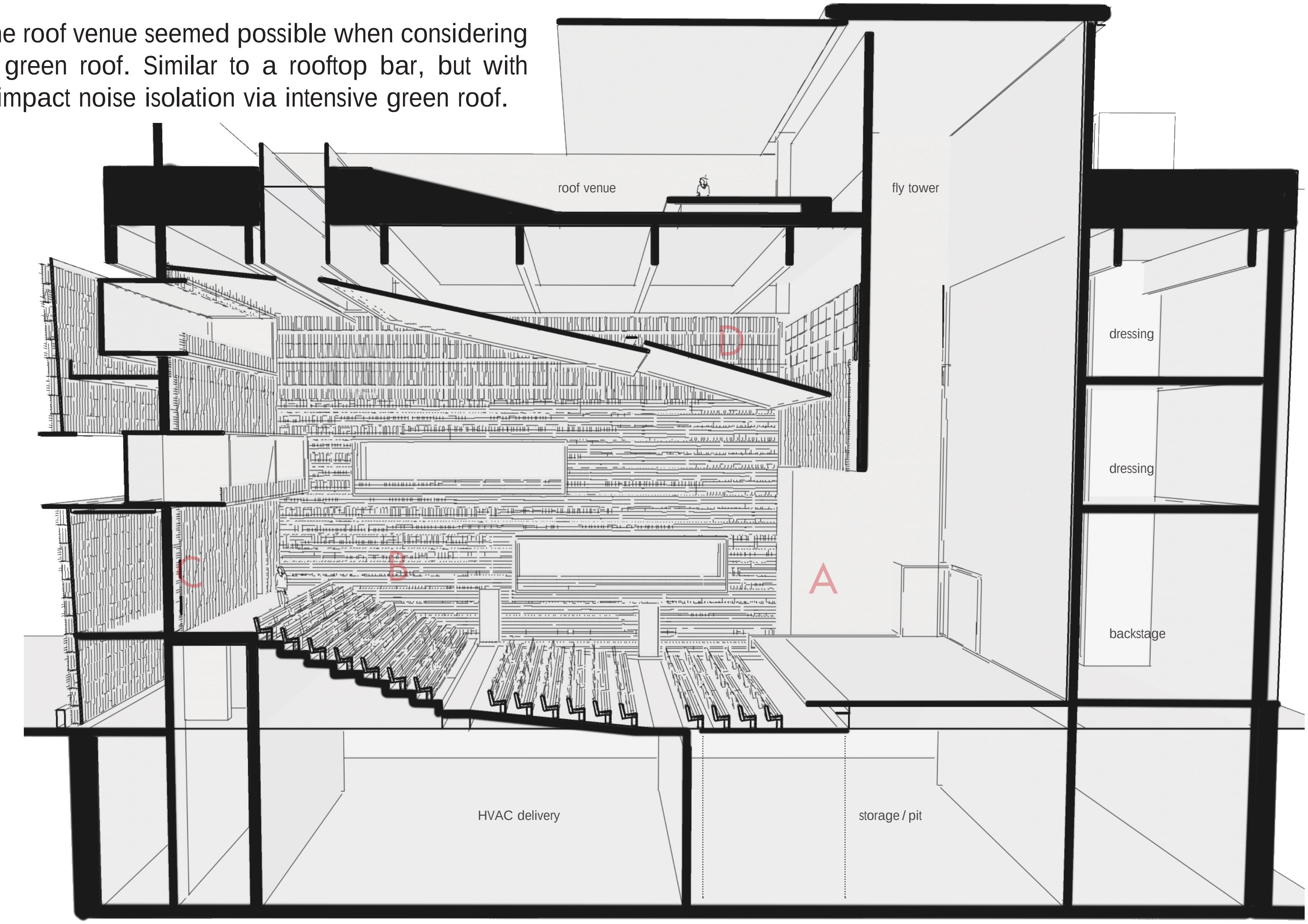
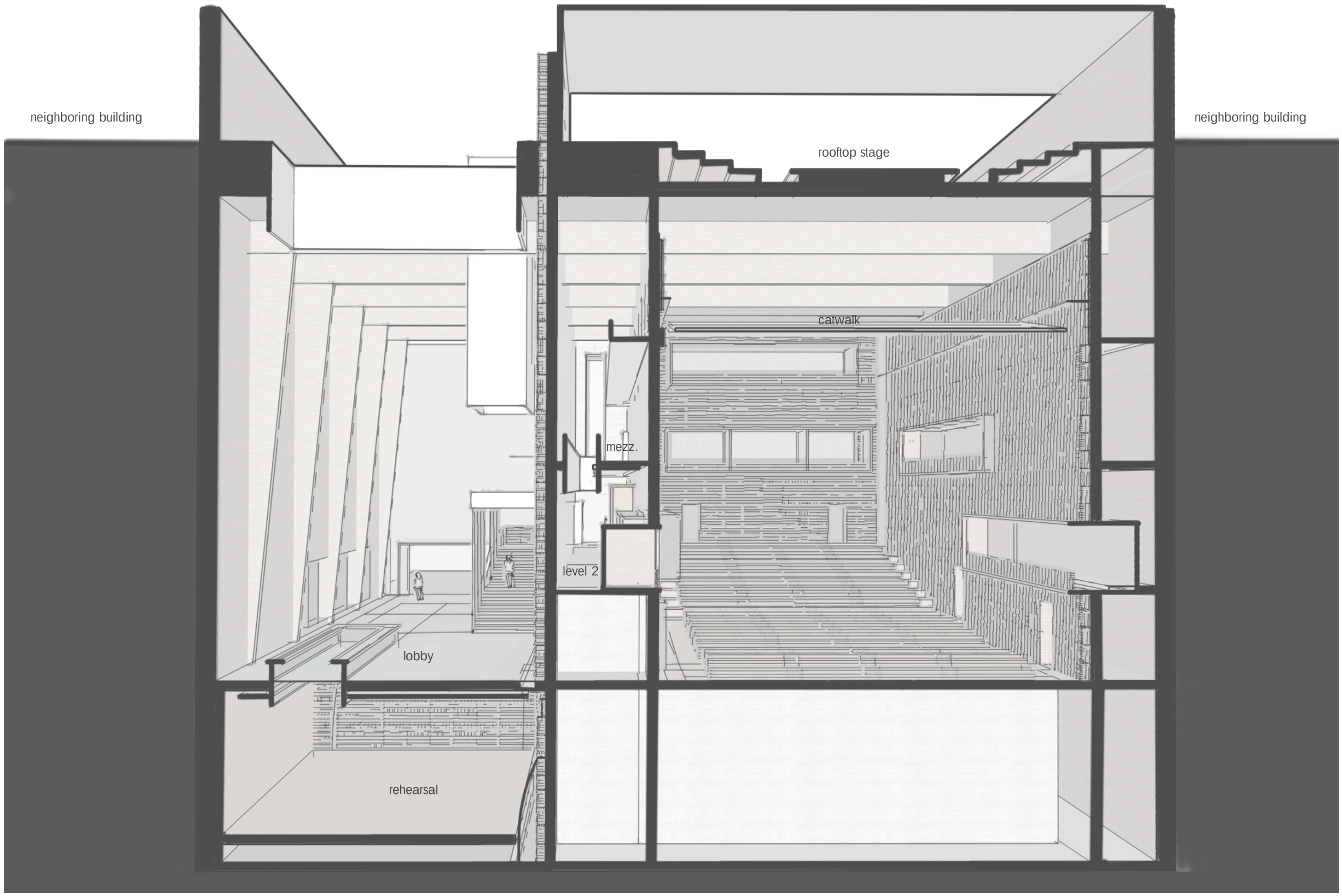


Fig. 49 · section perspective through performance space


Fig. 8 - rehearsal room featuring water walls with variable acoustic capabilities

This section shows the layers of isolation, from the building envelope to the balcony / hallway scale. Providing natural light was possible through the roof and from only one building facade due to the infill condition. Another result of the proportion of the lobby is the expression of the structure. The thick glu-lam beams that support the roof are supported themselves by tapered columns embedded into the party wall. The beams create a visual rythym within the large volume, yet hide above the wood ceiling of the performance space to avoid creating unwanted reflections.

Fig. 50 - section perspective through lobby



Comparing Context

Using The Fly Tower

The fly tower itself was an opportunity to create a backdrop for a rooftop stage. This is a space to enjoy the skyline and music at the same time. A semi-enclosure ensures that the crowd sitting in the lawn receives a first-order reflection from the source, and a sense of place both acoustically and visually. In an outdoor setting, getting the direct sound to the audience is key. The stage is set up to either be used facing a side for a smaller crowds, or front facing to have a medium-large events. The surrounding gabion walls create relative isolation to the street side and enclosure on a rooftop scale.

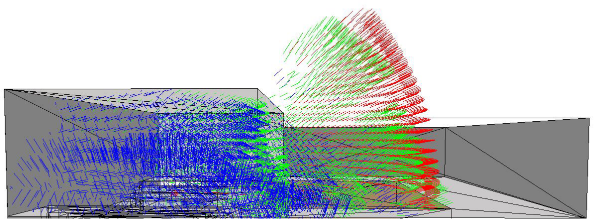


Fig. 51 - CATT ray trace

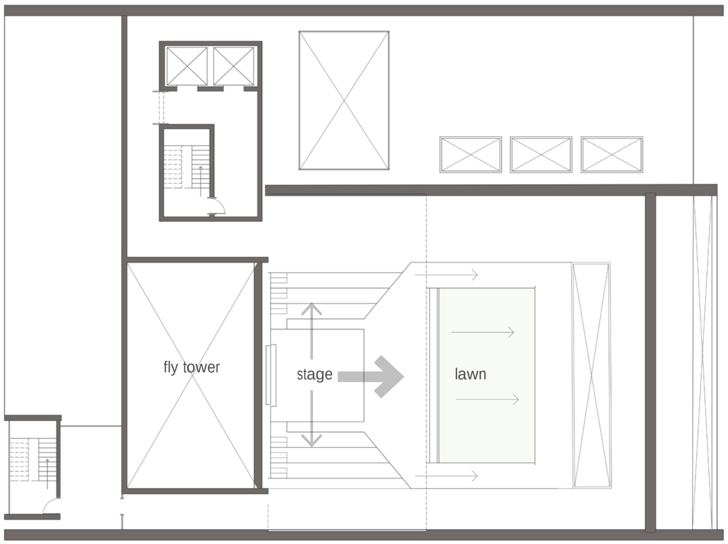


Fig. 52 - roof plan

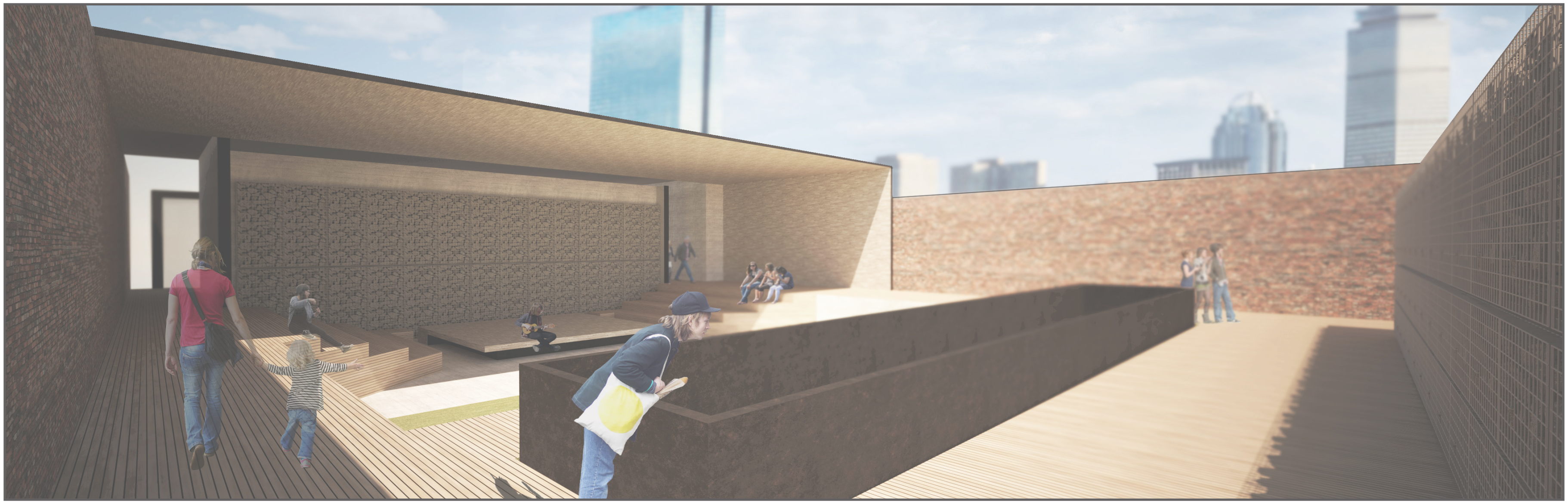


Fig. 53 - rooftop venue

Facade Composition

Acoustics delegated the gabion wall, which is usually an exterior building technique, to the interior to diffuse sound. The lobby needed as much light as possible, thus resulting in a transparent curtain wall on the street facade. The circulation is carved as a cavity into the gabion mass, which expresses itself on the exterior as well. The largest portion of the front facade is a glass enclosure, with a gabion rainscreen as the outer face. Instead of acoustics, this gabion wall is playing with light. The base is packed solid, hiding the ground floor circulation from the outside. The language of the interior steel penetrations appear in the front facade as well. The two party walls form a strong sound barrier toward the neighboring buildings.

Fig. 54 · front facade

VII. Conclusion

Expanding the Thesis

Often acoustics is not the initial catalyst of an architectural approach, and more often appear as an add-on. The technical requirements do not need to be at odds with the architectural language. The *Elbphilharmonie*[2] in Hamburg for example uses panels uniquely produced to respond directly to the predicted acoustics of the space. Despite the high priority of acoustics, there are cases where the architecture trumped technical performance. While each panel is specifically designed for the acoustic conditions of a certain location, panels within the range of human touch change from rough, performance-driven grooves to smooth, touch-friendly grooves. This is an example of a wider architectural consideration.

The water wall exploration produced unexpectedly positive results, but has not reached potential as a design idea. Reflecting sound with a moving sheet of water that is quiet can be the preface to acoustic and other spatial aspects. The gabion wall as a versatile acoustic material can develop as well. Typically gabion is 1m thick and used for highway barriers or retaining walls. Employing a gabion system as an acoustic diffusor, reflector, or absorber can create a unique exterior, or interior performance space. A 1-ft thick gabion "skin" could potentially produce the same diffusive / reflective effect as the 1m block, but in an efficient way for potential interior use.

Air, in the form of an aperture, can also be used intentionally. As amplified sources are more common, being able to open or close a "plane" for absorption can be an advantage. Using open air as an acoustic design element may be ignorant of noise control at this stage, and assumes acceptance of the escaping sound. An example is the Civic Arena, where concerts with the roof open also meant a free concert for people in the parking lot.

Viewing the elements through an acoustics lens was beneficial to launching other architectural ideas. Returning to the basics of material provided avenues for exploration. These concepts were tested through the design vehicles, yet suggested to have much broader implications than originally anticipated.

2. Stinson, Elizabeth. "The Stunning Elbphilharmonie Is What Happens When Algorithms Design a Concert Hall." Wired. Conde Nast, 12 Jan 2017. Web. 06 March 2017