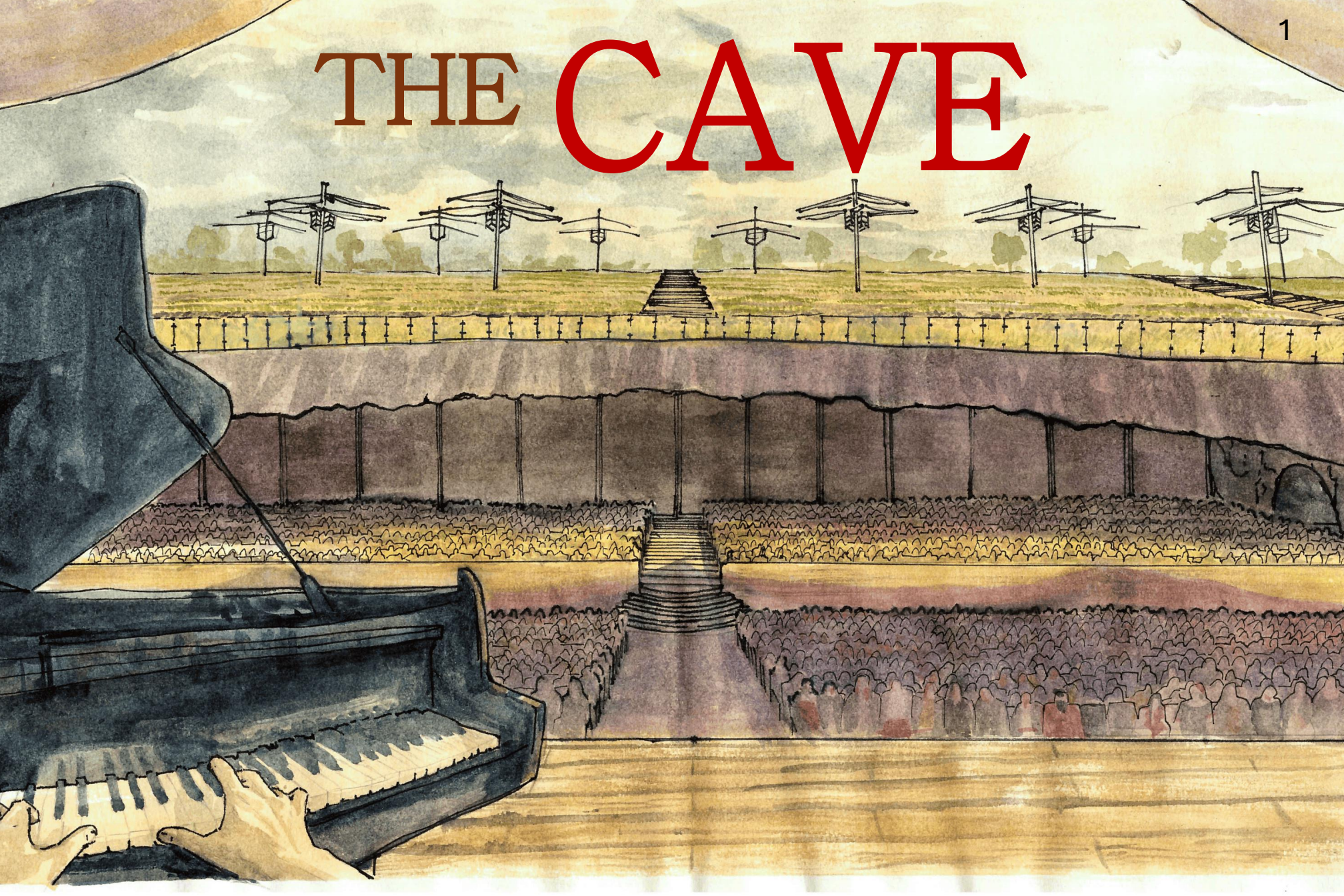

Between Cave and Landscape – Architectural Mimicry of Nature and its Acoustic Qualities.

Rebecca Baker, 05/23/2026.
Bachelor's thesis/ Kandidatarbete Arkitektur och teknik.
In collaboration with Sanna Hallqvist, Edwin Blomqvist & Albin Wessman.

Designing an outdoor concert pavilion for 13,000 visitors involves more than accommodating performance and audience. The project investigates how architecture can shape a collective acoustic experience at the scale of landscape.

Developed as part of an architectural competition, the proposal explores the relationship between sound, structure, natural mimicry, and topography. Room acoustic performance became a primary generator of form, creating both the spatial organization and the geometry of the cave and stage.

This article documents the development of the project, from early site analysis and acoustic studies to conceptual iterations and the final proposal. It reflects an approach in which technical performance and architectural expression took precedence.

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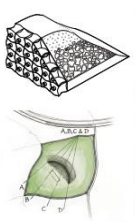
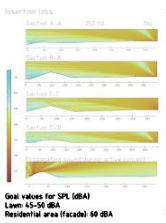
The concept of the cave was born from a simple question: do different types of seating need to have different quality, or can they be equally good? Can one venue create different experiences? We place the seated audience in a cave, and make the lawn a grassy hill right on top of said cave. This creates two completely different experiences, although with the same closeness to the stage, and high sound quality in all seats. Electro-acoustics supply the lawn audience with music, while analog acoustics are applied in the cave.

THE SITE

WILL YOUR EXPERIENCE BE OVER OR UNDER GROUND?





Goal values for SPL (dBA)
Lawn: 45-50 dBA
Residential area (facade): 60 dBA

SITE PLAN, 1:2500

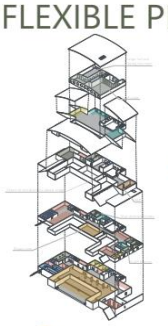
The site has been planned with acoustics in mind. The placement of the parking house helps blocking noise from the corner of the lot that is the most exposed from road noise. The hill which the lawn is placed on helps reducing noise from the surrounding roads from reaching the audience, and keeps the produced noice from reaching the residential area.

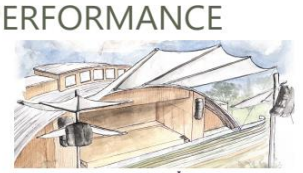
In the surrounding park and on the backside of the hill, native plants will be planted to provide ecosystemic services in the form of natural habitat for native insects, birds and amphibians. The wildlife will also help improve the sound environment, where pleasant sounds help cover unpleasant sounds, such as noise from the surrounding roads.

The area is protected from traffic noise by a sound barrier constructed using modular Helmholtz resonators. The system is tuned to 250 Hz, to maximize attenuation at a frequency that propagates efficiently over long distances and constitutes a significant portion of traffic noise. The insertion loss scale illustrates the reduction in sound level from the road.

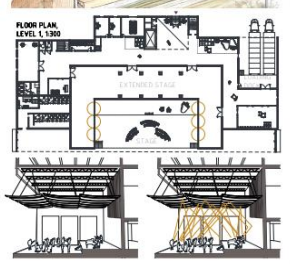
The wall is supported from the back with a thick dirt wall, that further helps reduce low frequencies. Advantages with the modular system is that singular modules can be exchanged. They can also be glazed in different colors, creating a beautiful mosaic-like wall.

FLEXIBLE PERFORMANCE





FLOOR PLAN, LEVEL 1, 1:300



To ensure adequate communication for the musicians on the relatively large stage, the acoustic design prioritizes the reflection of sound back to the performers. This is achieved through switching the standard cone shape for a rectangle, and the use of turnable reflective wall panels. These can reflect sound backwards but also open up into an extended stage, increasing the volume to enlongate the reverberation time. These back side of the panels can also be clad with sound absorbing materials, to shorten the reverberation time. In addition, the ceiling is designed to allow vertical adjustment depending on the intended use of the space and the orchestra. Ray tracings of the stage show good early reflections, and overall good hearing on-stage.

Practice rooms are following the international standard for acoustic quality criteria for music rehearsal rooms and spaces. They are spread out through the building. Lockers for orchestra members are spread out between dressing rooms and rehearsal rooms. The loading dock and machinery are placed separately from acoustically sensitive areas. The entire building is raised to the height of the stage, so that heavy equipment does not need to be lifted. This is also a good fit for a raised loading dock.

A pertruding roof combats glare and rain, protecting the musicians and their instruments. It also covers part of the seated audience, helps guide music towards the lawn and connects the volumes.

Reverberation time and clarity at 500 Hz

Stage	T60 [s]	C80 [dB]
Open panels (absorbtion)	0.6	2.6
Open panels (reverb)	1.6	2.6
Closed panels	1.2	3

...OR HEAVY AND ENCLOSED?

CAVE AND LAWN SECTION, 1:200

According to Plato, what we see in an enclosed space such as a cave might not be the reality, but maybe we can use that to our advantage, and create a surreal experience, if only for a few hours?

Speakers by the cave opening provide music, but in the cave, analog acoustics take over.

Reverberation chamber
Panels at the rear of the cavecan be opened to increase the total volume of the space. This results in a longer reverberation time, enhancing the perception of spatial depth and cavernous character. In this configuration, the acoustics are well suited for chamber music, where a richer and more immersive reverberant field is desirable. When the panels are closed, the reverberation time is reduced, creating conditions more appropriate for contemporary music.

Closing the panels also improves speech intelligibility, making the space more suitable for theatrical performances. Rotating panels enable the space to be acoustically tuned by adjusting the degree to which they are opened, allowing the room to exhibit different acoustic properties depending on their position.

Diffusers in the cave
The irregularities of the walls and ceiling acts as diffusers for a fuller and enhanced sound quality, while architecturally imitating the inside of a natural cave. The soundwaves scatter and spreads evenly across the hall, creating a sense of spaciousness.

Reverberation time and clarity, open panels

Freq[Hz]	T30 [s]	C80 [dB]
125	2.2	1.8
250	2.2	3.1
500	2.4	3.9
1000	2.1	4.1
2000	2.0	4.6

LIGHT AND AIRY...

Lawn seating plan, 1:2000

The lawn is a greasy, terraced hillside that slopes toward the stage, ensuring that every guest has a clear view of the performance. It offers an experience distinctly different from that of the cave, while still providing equally excellent sightlines and acoustics. The butterfly-inspired pillars support speakers that distribute sound evenly across the entire lawn.

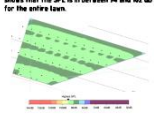
Lawn terraces, 1:20

The sails, or wings, of the butterflies help guide the sound while also providing a measure of shade for guests. The lawn area is covered by five rows of evenly distributed line array positions, each mounted at an approximate height of 10 meters above ground. This elevated placement ensures extended throw while maintaining consistent coverage across the audience area.

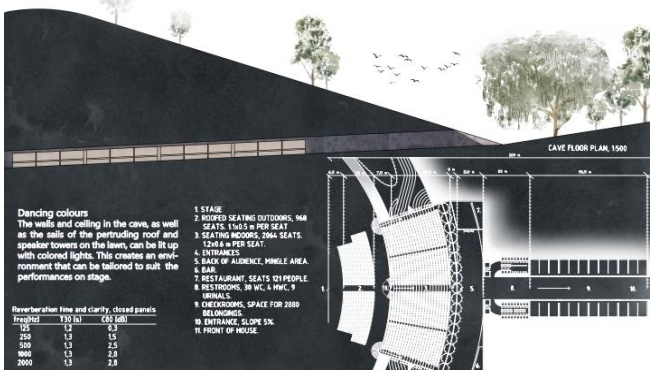
Each position consists of three cardioid line array loudspeakers. The use of cardioid technology minimizes rearward radiation and easily controls the sound distribution, thereby improving clarity and maintaining a strong directional perception toward the stage. To further optimize coverage, each array is configured with an 80° horizontal dispersion.

The vertical coverage is controlled using splay angles of 10° between the top and middle enclosure, and 14° between the middle and bottom enclosure. This creates a progressive curvature that allows the system to effectively cover both near and far audience areas, which is essential due to our inclined lawn seating system. In the terraces, there are built in gabions that absorb sound, reducing reflections from behind the audience.

The figure illustrates the Sound Pressure Level (SPL) distribution at listener height, and shows that the SPL is in between 94 and 102 dB for the entire lawn.



Speaker tower, 1:100



Dancing colours
The walls and ceiling in the cave, as well as the sails of the pertruding roof and speaker towers on the lawn, can be lit up with colored lights. This creates an environment that can be tailored to suit the performances on stage.

1. STAGE
2. ROOFED SEATING OUTDOORS, 968 SEATS. 1.1x0.5 m PER SEAT
3. SEATING INDOORS, 2964 SEATS. 1.2x0.6 m PER SEAT.
4. ENTRANCES
5. BACK OF AUDIENCE, MINGLE AREA.
6. BAR.
7. RESTAURANT, SEATS 121 PEOPLE.
8. RESTROOMS, 30 WC, 4 HWC, 9 URINALS.
9. CHECKROOMS, SPACE FOR 2000 BELONGINGS.
10. ENTRANCE, SLOPE 5%.
11. FRONT OF HOUSE.

Reverberation time and clarity, closed panels

Freq[Hz]	T30 [s]	C80 [dB]
125	1.2	0.3
250	1.3	1.5
500	1.3	2.5
1000	1.3	2.8
2000	1.3	2.8

COMPETITION SUBMISSION

BRIEF

' A city orchestra wishes to construct a new 13,000-seat music pavilion with covered and lawn audience seating to serve as its summer home. The music pavilion will have a variety of programing acts, with the orchestra as a resident company during the summer season. Additionally, the pavilion will host touring acts, like pop and rock shows to balance out revenue stream in support of the orchestral program.

The pavilion should be sized to accommodate 3,000 seated audience members under a roof and 10,000 audience members in an open lawn. The anticipated number of audience members is 7,500 people for orchestra performances and 13,000 people for touring acts. The orchestra desires a stage environment that supports natural, unamplified ensemble hearing among musicians.

Amplification via an electro-acoustic sound reinforcement system will be used to provide coverage for both seated and lawn audiences. The project site has a natural slope and provides several different locations and orientation options. Location and orientation should be considered for the impact of event sound on the surrounding communities.

The site is surrounded by a river to the north, a state highway to the south and state roads to the east and west. There is a major 6-lane interstate located 200 feet to the east of the site. Sound levels measured from the interstate have been provided and must be taken into consideration. Please see attached site plan.

Back of house (BOH) support space will be required; some spaces will be acoustically sensitive. Solo dressing rooms will also serve as practice rooms. Mechanical, Electrical, Plumbing (MEP) services will be required to serve BOH and stage spaces. Considerations should be made on the impact of noise and vibration generated from building systems and equipment for on-stage hearing, microphone pickup, and environmental impact to nearby residential zones.'

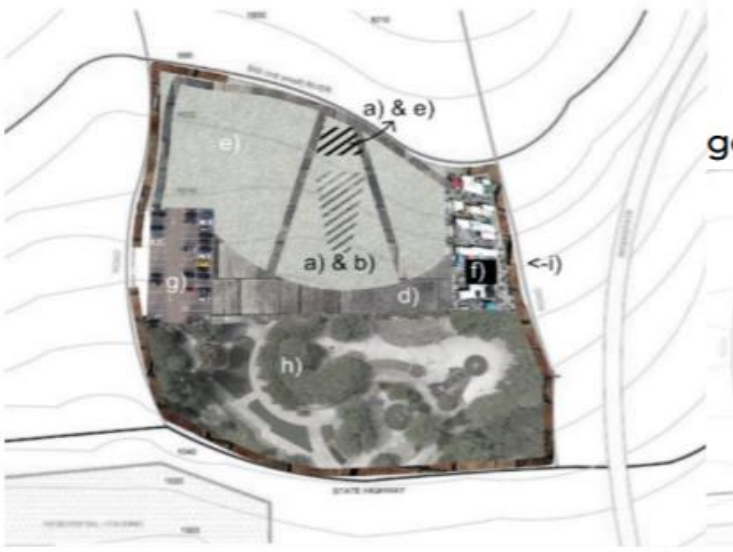
CREATIVE PROCESS

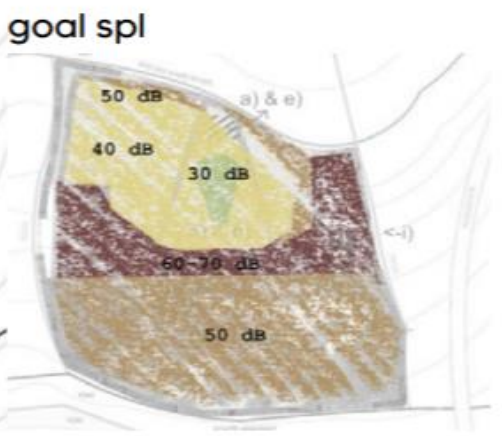
ASSIGNMENT 1

In the first assignment of the bachelor project, the task was to create three distinct concepts. These concepts were to be communicated through three sections of the entire length of 500-meter site in the scale 1:100, creating three five-meter-long sections.

In all proposals we placed the stage close to the river in the north, and so we decided to paint the proposals on top of each other to display their differences and similarities.

Our last concept, “the egg”, is what will later be developed into the cave. This early concept is never compromised other than for function.





a) Stage & BOH
b) Roofed seating and balcony seating
c) Lawn seating
d) Major walkways
e) Lawn/Park
f) Market area/ toilets/ square
g) Parking
h) Forest/park with art-/ sound instillations
i) Acoustic barrier/wall.

the stage is placed close to the river to the north. This creates a large distance between the stage/audience, and the road to the south. The position also creates nice areas to dwell by the water and gives freedom in placing entrances. Later in the project, we come to realize that the road to the east is more critical, which makes us rethink our site plan. All concepts include an “art park”, where local artists can contribute installations, preferably surrounding music and the sounds of nature. The concepts also include a market area, where food trucks and other supporting businesses can be placed during larger events.

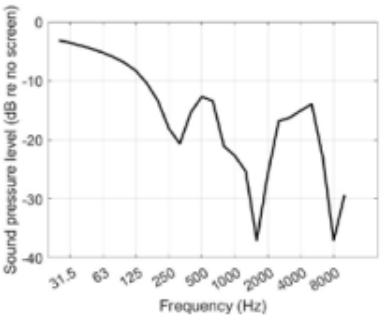
We planned to let the back and sides of the hill be a bit noisier and more connected to the city life, while the part of the lawn closest to the stage would be a true musical experience, disconnected from the surrounding area.

ASSIGNMENT 2

For assignment two, the task was to create acoustical models of the different parts - the stage, the seated area and the lawn. This process was a way of visualizing how sound moves, which materials it meets and where and how it reflects. The models were also where we first started forming an understanding of where speakers will need to be placed, and how speaker towers could be designed to fit the ambience of the lawn. At this point, we realized the size of the cave necessary to fit such a large audience, and the extensive care needed to make it accessible and open. We then added openings on all sides to be used as paths, as well as a possibility to change the acoustics inside.

The second clay model was created by cutting the top of the first one, displaying the inside of the cave. At this point, we realized the length of the cave was an issue, since a room length over 50 meters can create unwanted echoes. We split the volume with a wall, giving us the possibility to integrate facilities such as bathrooms, bars and wardrobes inside the hill. We also had the idea to make the wall possible to open, which results in a different reverberation time. We can also use dissimilar materials to our advantage.

The first acoustic solution we found before meeting our acoustic counterparts were the Helmholtz bricks designed by Joe Makes for his architecture thesis. These are resonators that can be stacked and mass produced using slipforms. In addition, they can also be glazed creating a simple and aesthetic acoustic element. We decided we wanted to use it as a part of the colorful identity of the project as an absorber for the highway and interstate. This later became the protective wall that follows the entire circumference creating curious and representative visual introduction saloon the surrounding roads. This later proved to be necessary as the geometry of the wall and distance from the interstate made certain frequencies hard to block and even amplified some. Using the Helmholtz resonator these frequencies could be targeted and effectively absorbed.



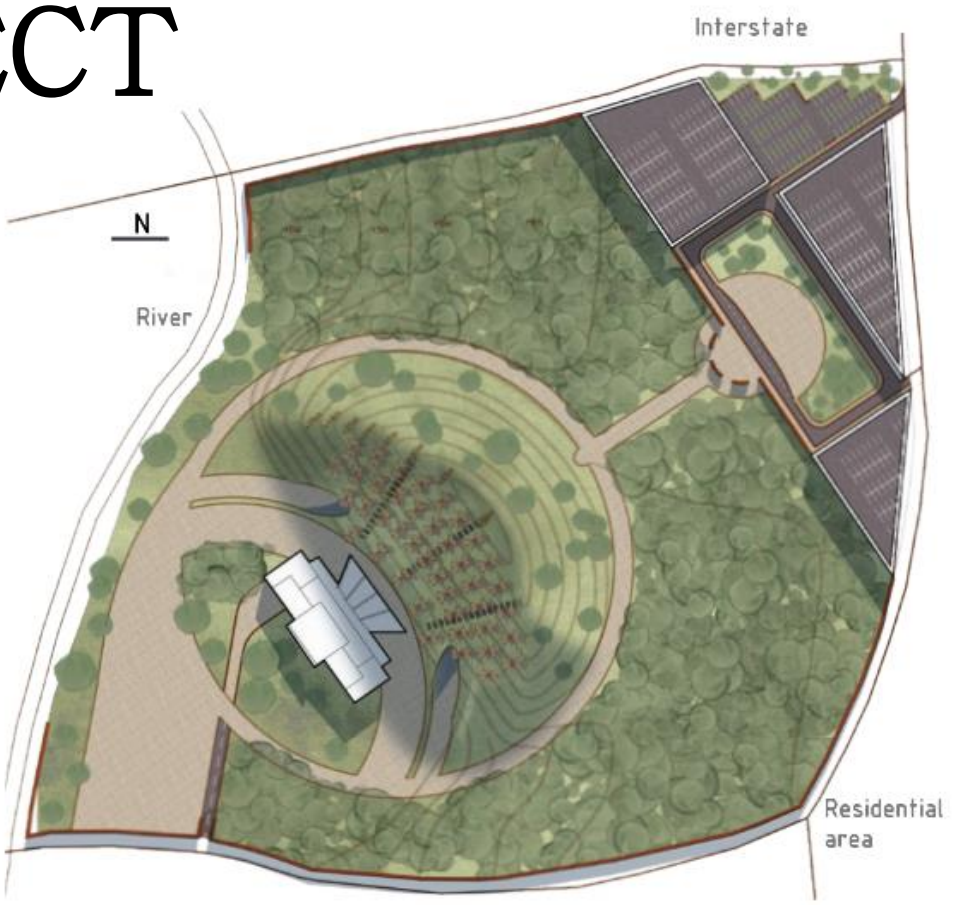
FINISHED PROJECT

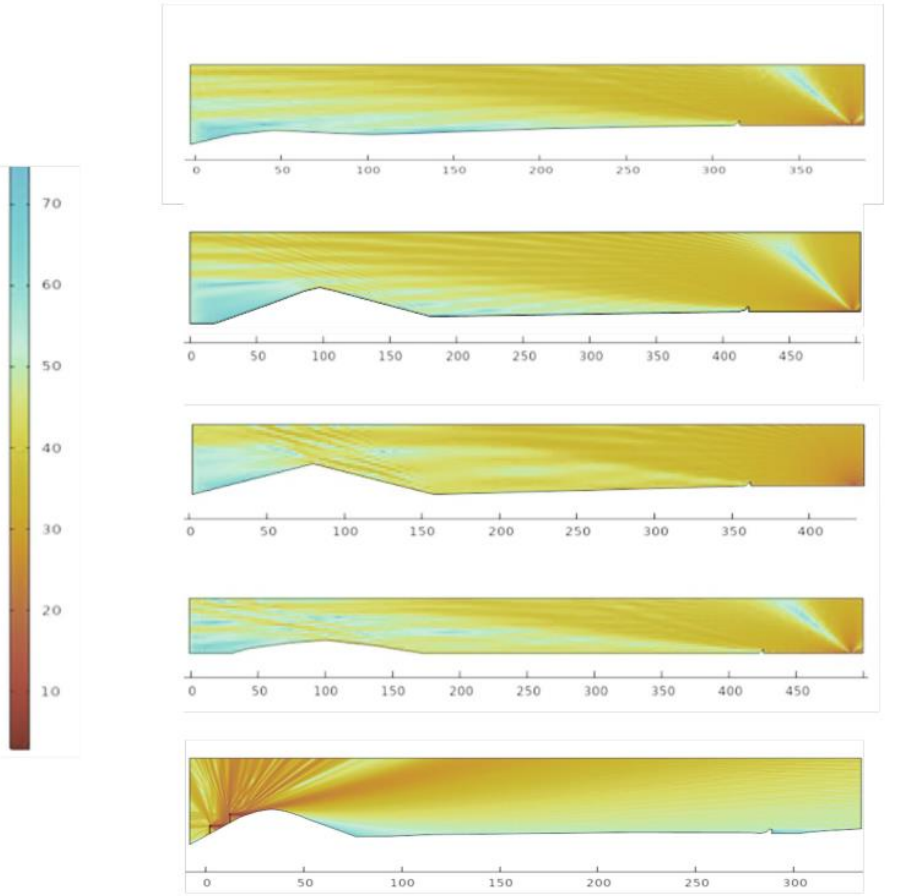
THE SITE

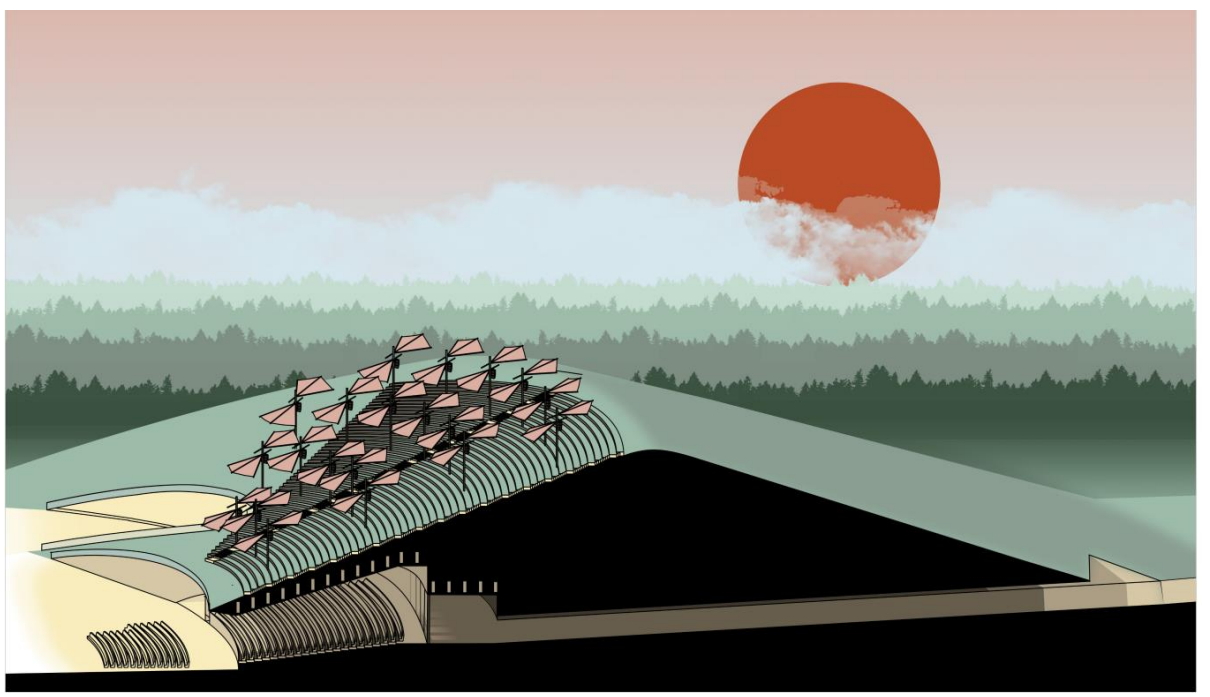
The site has been planned with great acoustics in mind. The placement of the parking house helps blocking noise from the corner of the lot that is the most exposed from road noise. The hill which the lawn is placed on helps reducing noise from the surrounding roads from reaching the audience and keeps the produced noise from reaching the residential area.

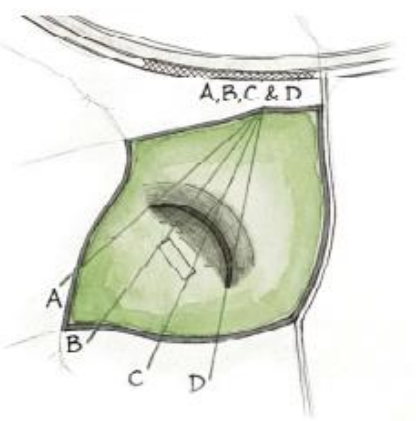
In the surrounding park and on the backside of the hill, native plants will be planted to provide ecosystemic services in the form of natural habitat for native insects, birds and amphibians. The wildlife will also help improve the sound environment, where pleasant sounds help cover unpleasant sounds, such as noise from the surrounding roads.

When approaching the site, you follow the mosaic like wall of Helmholtz resonators that are built along the site borders. Going through the entrance, the parking houses create a square-like opening, giving direction towards
the cave and the lot. From there, guests can freely climb the hill, go through the tunnel to the cave or take the scenic routes past the forest or the river to find their seats.



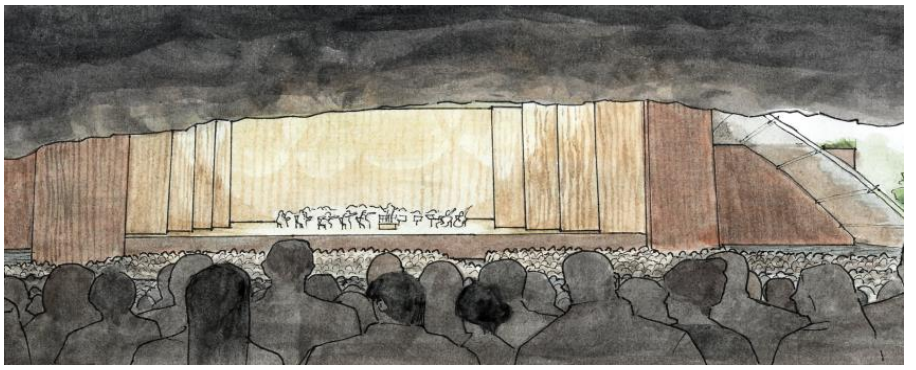


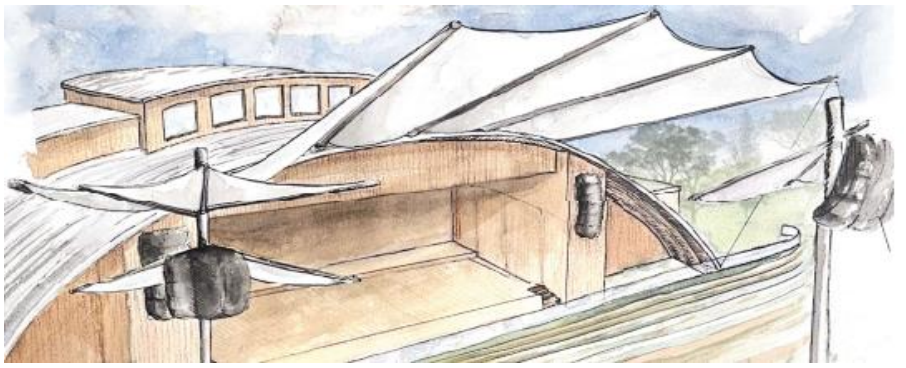


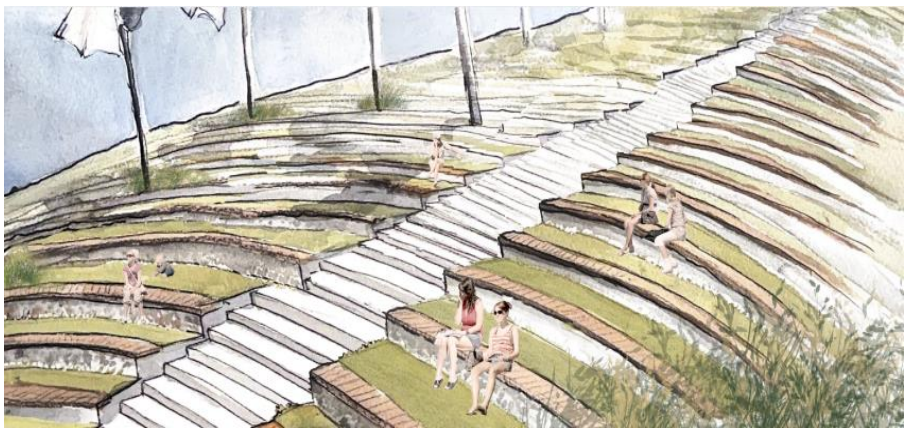


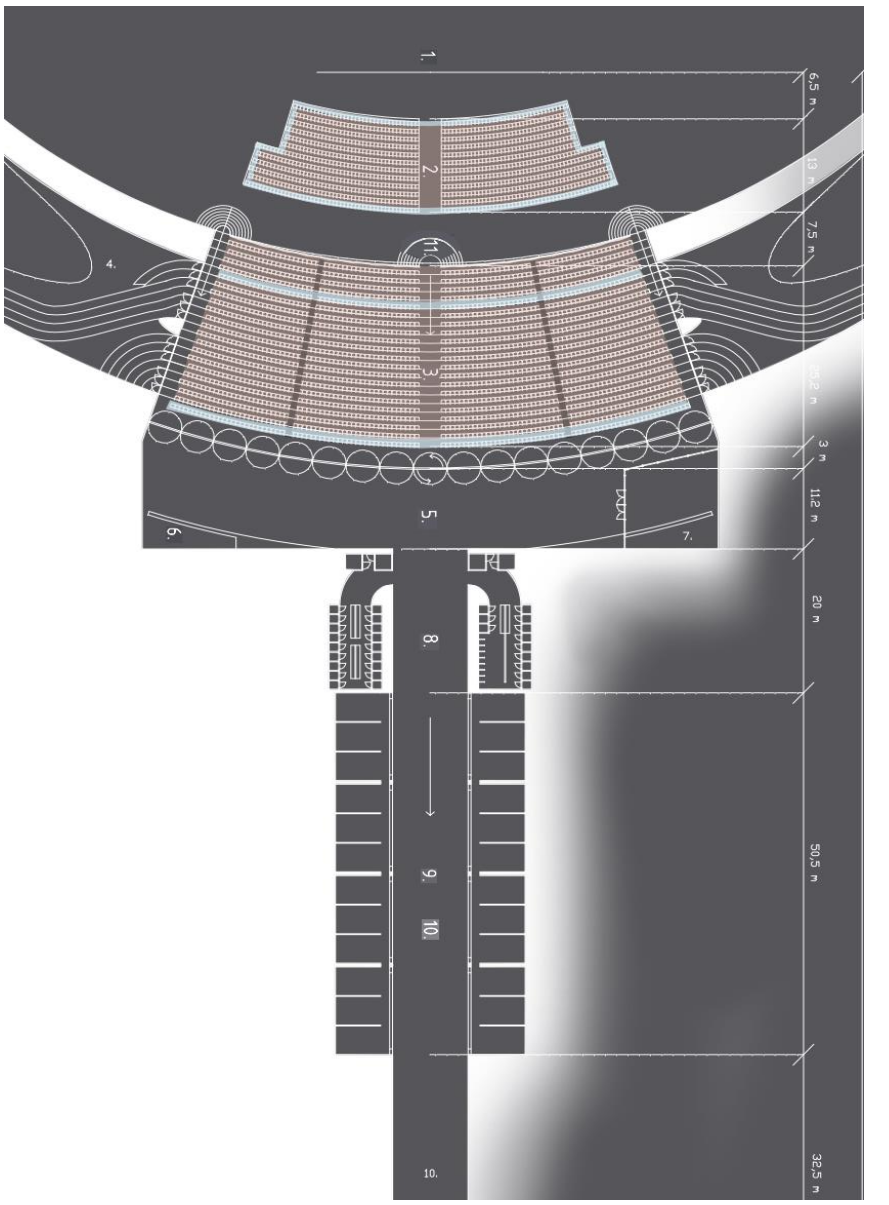
Goal values for SPL (dBA)
Lawn: 45-50 dBA
Residential area (facade): 60 dBA

ARCHITECTURAL DESIGN





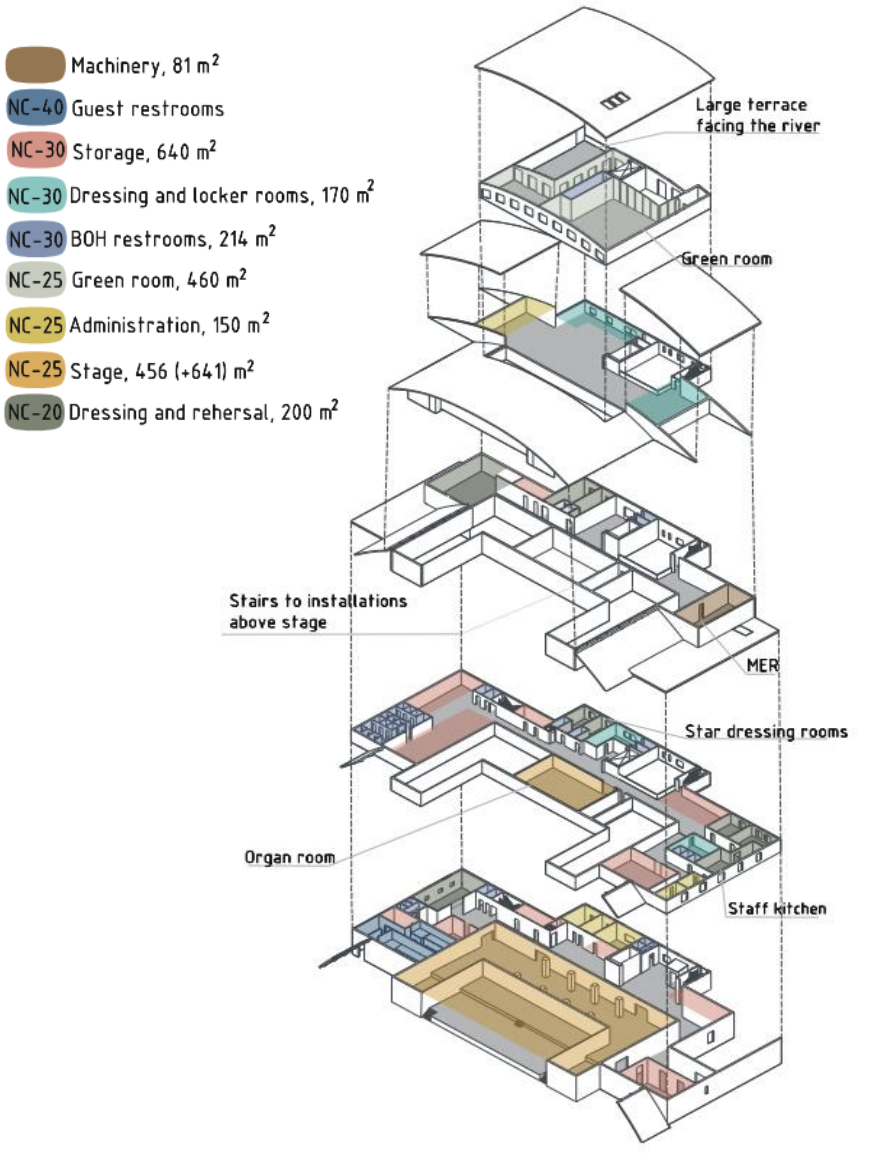




The lawn is a grassy, terraced hillside that slopes toward the stage, ensuring that every guest has a clear view of the performance. It offers an experience distinctly different from that of the cave, while still providing equally excellent sightlines and acoustics.

The cave seats most of the covered audience and offers a dramatic heavy experience suited for classical music. The cave has a main entrance through a tunnel from the back. When entering through here, you pass by bathrooms, wardrobes, a bar and a restaurant before reaching your seat. These areas can be covered in art and mosaics, to make the space more interesting and to reference the colorful Helmholtz wall around the site. The cave also has entrances to the sides, to keep some connection to the outdoors. There are rotatable panels between the seats and back of audience area. When open, the panels resemble pillars.

The stage is entirely made of wood for a natural heavy design mirroring the cave. The roof protruding from it connects the three areas, the stage building and the hill. It is made from a thick weather-proof textile. We imagine colored LED-spot lights, that can be controlled from the front-of house area and change with the performance.



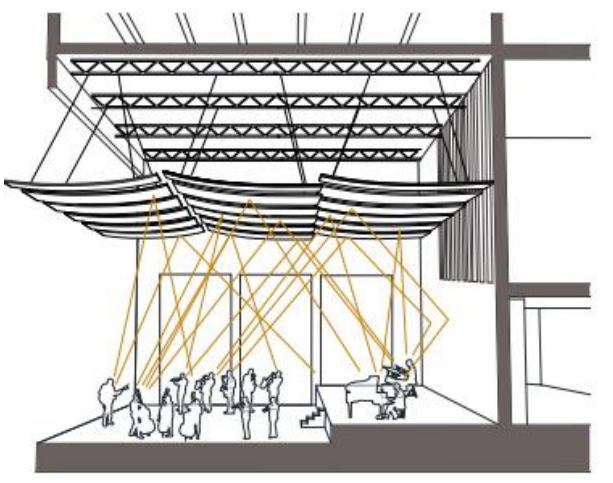
ROOM ACOUSTICS

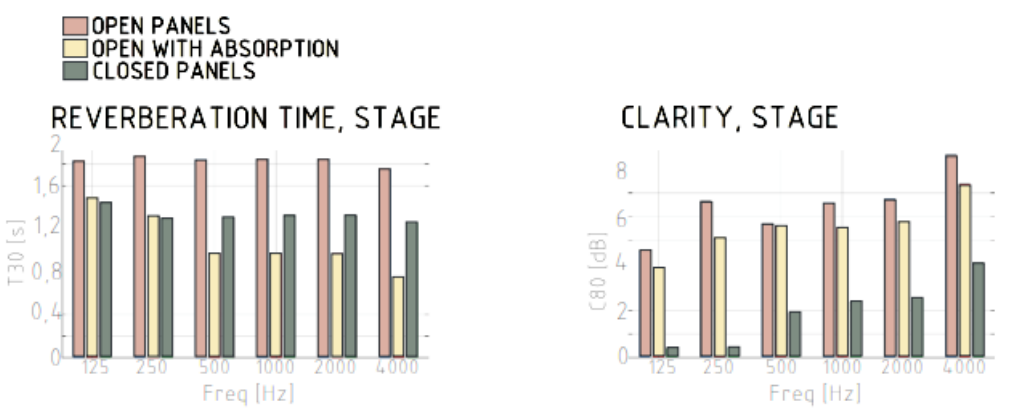
THE STAGE

To ensure adequate communication for the musicians on the large stage, the acoustic design prioritizes the reflection of sound back to the performers. This is achieved through switching the standard widening stage walls for perpendicular turntable reflective wall panels. These can reflect sound backwards but also open into an extended stage, increasing the volume to increase the reverberation time. These back side of the panels can also be clad with sound absorbing materials, to shorten the reverberation time. In addition, the ceiling is designed to allow vertical adjustment depending on the intended use of the space and the orchestra. Ray tracings of the stage show good early reflections, and overall good hearing on-stage.

Red: open panels.
Blue: closed panels
and curtains.

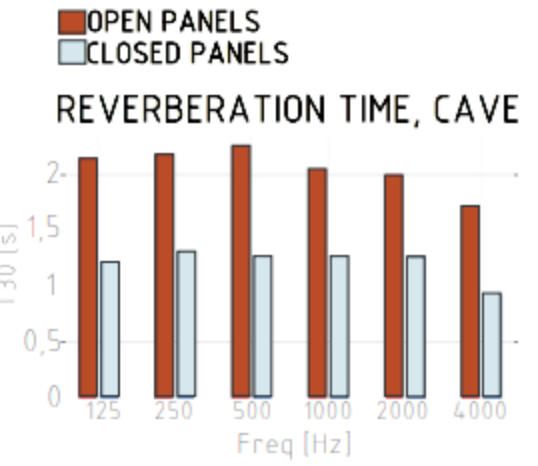
THE STAGE, RAY TRACING



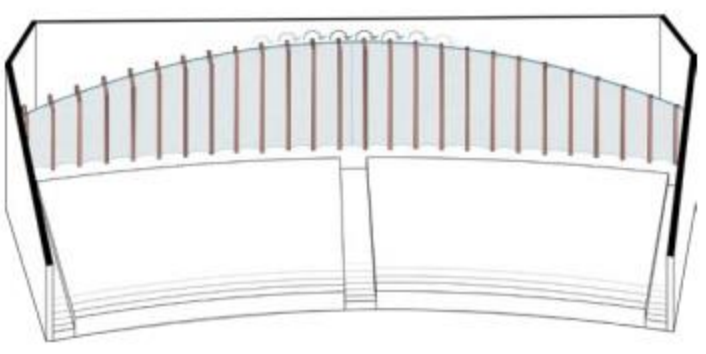


THE CAVE

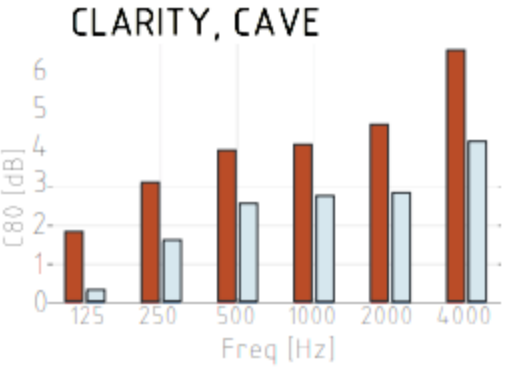
Panels at the rear of the cave can be opened to increase the total volume of the space. This results in a longer reverberation time, enhancing the perception of spatial depth and cavernous character. In this configuration, the acoustics are well suited for chamber music, where a richer and more immersive reverberant fi eld is desirable. When the panels are closed, the reverberation time is reduced, creating conditions more proper for contemporary music. Closing the panels also improves speech intelligibility, making the space more suitable for theatrical performances. Rotating panels enable the space to be acoustically tuned by adjusting the degree to which they are opened, allowing the room to show different acoustic properties depending on their position.



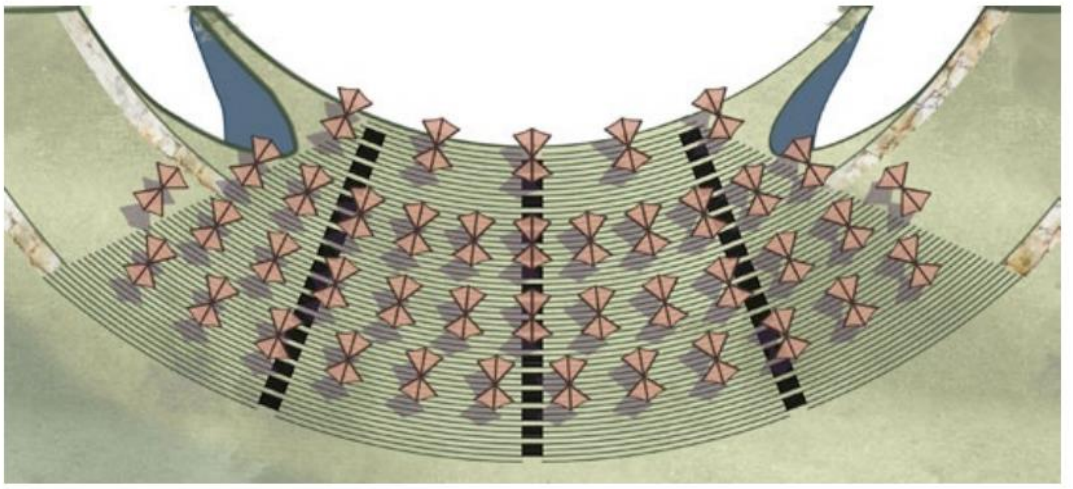
THE CAVE, REVOLVING PANELS

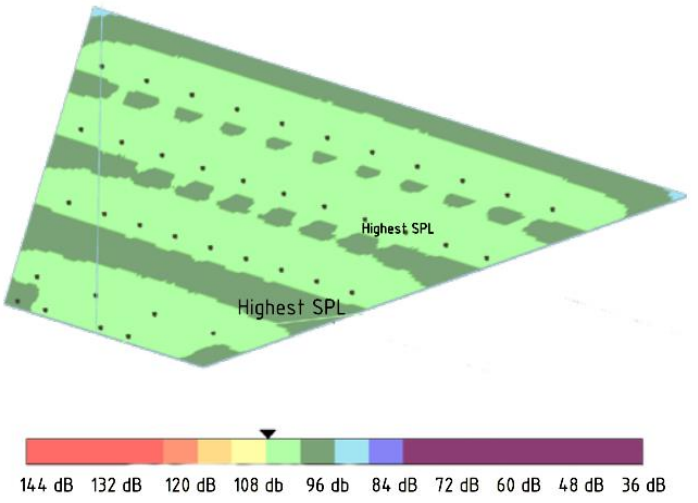


Red: open panels.
Blue: closed panels
and curtains.



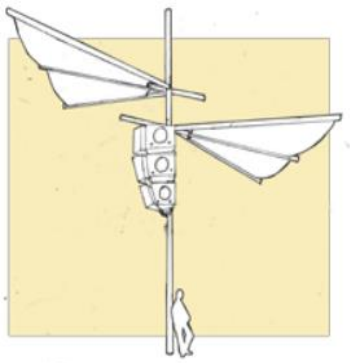
ELECTRO ACOUSTICS & BIODIVERSITY



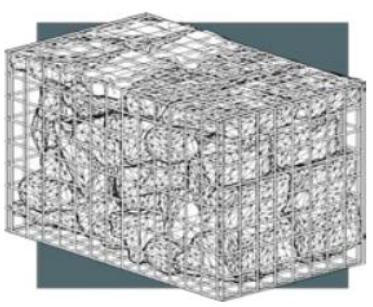


The figure illustrates the Sound Pressure Level (SPL) distribution at listener height for 1000 Hz, and shows that the SPL is in between 94 and 102 dB for the entire lawn.

Higher vegetation is placed behind the speakers where sightlines are impaired. In addition to improving biodiversity, the higher vegetation and soft ground absorbs some sound, combating reflections on the lawn.



The sails, or wings, of the butterflies help guide the sound while also providing a measure of shade for guests.



In the terraces on the lawn, there are built in gabions that absorb sound, reducing reflections from behind the listeners and preserving a sense of direction.

Oak trees: Supports over 500 species of caterpillar, supplying bird food.
Willows: Produces nectar early in the season to provide bees and other pollinators.
Black cherry: Supports massive biodiversity through trunk, flowers and berries.
Serviceberry: Provides birds with berries.
Milk weed: Essential for Monarch butterfly breeding.
Goldenrod: A powerhouse for bees, wasps and butterflies.
Coneflower: Attracts bees and supplies birds with seeds.
Asters: Crucial late-season nectar and pollen source.
Sunflowers: High seed-production for birds.
Switchgrass: Great for erosion-control and nesting habitat.
Broom sedge: Provides winter coverage for wildlife.
Bearberry: Evergreen ground coverage, that sustain animals even in winter.

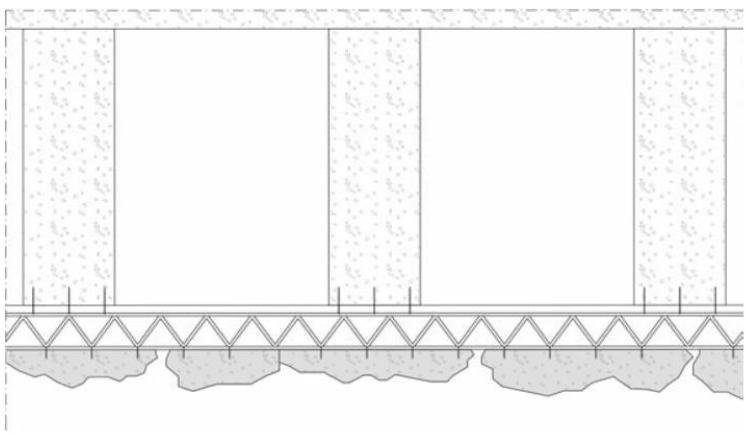
Freq [Hz]	Std dev [dB]
63	1,35
125	1,34
250	1,36
500	2,27
1000	2,41
2000	3,16
4000	4,08

The table presents the calculated standard deviation (dB) from the mean sound pressure level across the lawn, where the sound sources are the evenly distributed line arrays.

Evenly distributed on the lawn there are butterfly-inspired pillars. They support speakers that distribute sound evenly across the entire lawn. The lawn area is covered by five-line array positions, each mounted at approximately 10 meters height to ensure long throw and consistent audience coverage. Each position consists of three cardioid line array loudspeakers. The cardioid design minimizes rearward radiation, improving clarity and supporting a strong directional focus toward the stage.

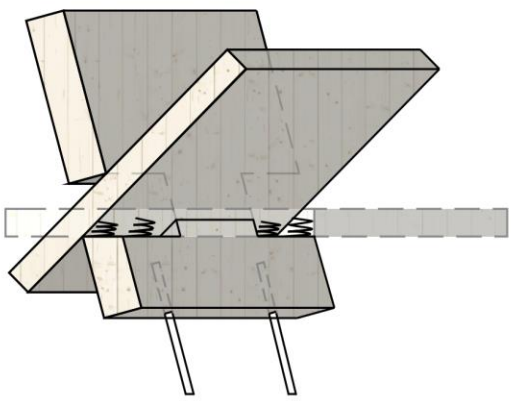
In addition, natural sounds help cancel out noise from the interstate, since 50 dB of road noise is far more aggravating than 50 dB of bird song. High vegetation requires soft soil, which in combination helps absorb low frequencies. Having this type of ground in large parts of the site will stop some sound from escaping and reaching the events. We are also planning to incorporate some patches of higher vegetation on the lawn, in spots where sightlines are impaired or speakers are too close for comfort. This brings some biodiversity close to the audience and makes the spot more connected to nature. On the hill you would be among the treetops, sitting in between patches of wildflowers, viewing the river, and listening to the bird song, while enjoying classical music with friends and family.

CONSTRUCTION & SUSTAINABILITY



1:50 detail
Up to down:

1. Waterresistant film
2. Concrete layer 150 mm
3. Post stressed concrete beam 60x1800 mm, 2000mm apart
4. 20 mm repurposed sheet material (block resonation between the beams)
5. 150 mm flat steel truss, 1000mm apart
6. repurposed rubble 100-500 mm



The project relies on large-scale proportions and a layered system, with the lawn audience positioned above the cave audience. This arrangement is constrained by sightlines and structural demands; we could not add pillars in the cave without creating seats with blocked views, and the lawn required a steep slope for clear visibility. These factors led to a compact design where post-tensioned concrete vaults became the only practical way to reduce the distance between the cave roof and the lawn while supporting the load above. This approach results in a significant carbon footprint, both from materials and construction. To address this, we have explored alternative options for materials that are still undecided in the design.

Wood and Metals: Our material choices consist of concrete, stone, wood, and metals such as aluminum and steel. While concrete is impossible to recycle without adding more cement, metals are highly recyclable, and wooden panels can easily be reused since studs have standard dimensions. This approach can be applied to the stage and back-of-house areas, using primarily metal and wood aside from smaller components and the elevator shaft. The result would be a structure made from recycled or reused steel, surfaces in reused or locally sourced wood, and roofing in recycled aluminum. This also reinforces the grounded, natural character of the design, with aged wood panels and intentionally imperfect details.

Concrete: The cave walls and roof were originally lined with cast concrete shaped to resemble a cave. This helps address the concave geometry and slanted roof, which can create acoustic issues such as sound hotspots and dead zones. Instead, the textured form diffuses sound, producing a more even and balanced soundscape.

An alternative is to use reclaimed concrete from rubble. Its natural fractured surfaces are well suited to this purpose, as concrete often breaks with one flat side. These pieces can be mounted as panels with the flat face against the roof and the rough face exposed, mimicking a cave-like surface. Remaining rubble can be crushed into smaller stones to fill out the surrounding hill or further processed into gravel.

Chairs: In total, around 3,000+ chairs are needed for the project. This stands for a significant material demand, accompanied by emissions from long-distance transportation. The issue is worsened by the fact that furniture in the cave and in front of the stage will be exposed to weather, reducing its lifespan. A solution lies in using materials already available on site. Wood, and leftover rebar from construction can be repurposed to produce chairs locally. With a simple, repeatable design, they can be efficiently mass-produced while minimizing waste. Chairs are particularly suited for this approach, as their components are relatively small and adaptable. By also making the chairs removable, they can be stored during the winter season when the orchestra is not in use, protecting them from the elements. Storage space is available both behind the stage and in wardrobe areas in the cave.

REFLECTION

We are happy with the way we met challenges in this project. For example, we needed to enlarge the volume of the cave to create a longer reverberation time, while keeping the same distance to the back wall, since pushing it further back would create other acoustical issues we decided to tilt the ceiling, while keeping the sight lines on the lawn. These sight lines in both the cave and on the lawn were another issue that needed precise design to ensure all seats are of excellent quality about both sound and view.

As we went on, we realized that the concept was a great solution to several issues. The terraces on the lawn, necessary for safe seating, help with erosion and drainage, and gives room to place higher vegetation that absorb sound. The entire hill helps to block noise from the interstate from reaching the audience and stage, while also shielding the residential areas from noise from the event. We had many acoustical solutions on hand, such as reverberation chambers, Helmholtz resonators, absorbing materials, embankments and soft ground and vegetation, and we had loads of room to incorporate such solutions when needed. This made the design process easy, and no issue felt impossible to combat.

For the visualizations we decided to create watercolor paintings by hand, to capture the storybook fairytale ambience that we tried to hold on to throughout the project.

A few of our main concepts are contrasts and flexibility. The goal was to create two entirely separate experiences for the lawn audience and the seated audience in the cave, and great adaptability for the acoustics in the cave and on stage. This enables many architectural and acoustical qualities at once. All seats are close to the stage, and all 13 000 visitors have a clear view and hearing of the performance. The cave also enabled us to hide supporting facilities behind the audience that are necessary for the large crowd. Our concept fits safety, necessities, and communications in a natural way, imbedded in the cave-like atmosphere.

The stage and back of house has a shape that communicates with the hill and contrasting materiality that amplifies the airy atmosphere of the outdoor areas. Inside, we have designed a functional workspace that prioritizes the well-being of the staff through easy access to bathrooms, spacious dressing rooms, lounge areas, and efficient communication spaces without need for heavy lifting.

After our project was completed, we received a critique on the Friday before submission to the competition. This entailed several points that both resonated with us but also created situations where sacrifices would be needed to remedy the issues brought up. The largest critique concerned the slant of the cave roof. As previously mentioned, this was a result of a need for a higher reverberation time that was directly tied to volume. A too broad volume would result in an echo feedback audibly noticeable to audiences, so the only solution lay in raising the roof. This directly affected the slant of the hill and lawn, dictated by sightlines, which led us to a slanted design loosely following the slant of the hill to generate a reasonable acoustic environment while simultaneously constraining the hill to a reasonable height. The problem presented itself as a feeling of a cut off view for audiences as if something was descending upon them. While this strengthened the visual connections to a cave it could also be viewed as disruptive. A solution to this would be to dig down the stage, audience and cave further down allowing for a steeper hill but lower overall height, this would however create water drainage constraints. Another possibility would be to draw back the roof to create an entirely horizontal vaulted roof. This would however decrease the number of seats in the cave and push the lawn audience further away from the stage which worked against two core components of our project. In the end we saw both the slanted roof as a quality of the cave like appearance and could neither find a viable solution in time which led to us to discard any changes for the final product. With more time or a complete workaround, we could find a solution.

Another critique we received at a later stage regarded the design of the back of house. This had been an earlier discussion within the group where we were split between a grounded post-modernist volume, a traditional design, or a natural hill-like design. In the end no real conclusion was drawn and because of time constraints we continued with a certain design and tried to tie it to the site using speaker towers. Given the uniqueness of this design the project communicated in three languages, the natural, the traditional and the colorful. This created a messy result that could have been better integrated or changed given more time.