



The possibilities of clay in
architecture and acoustics

PORTFOLIO
CANDIDATE THESIS
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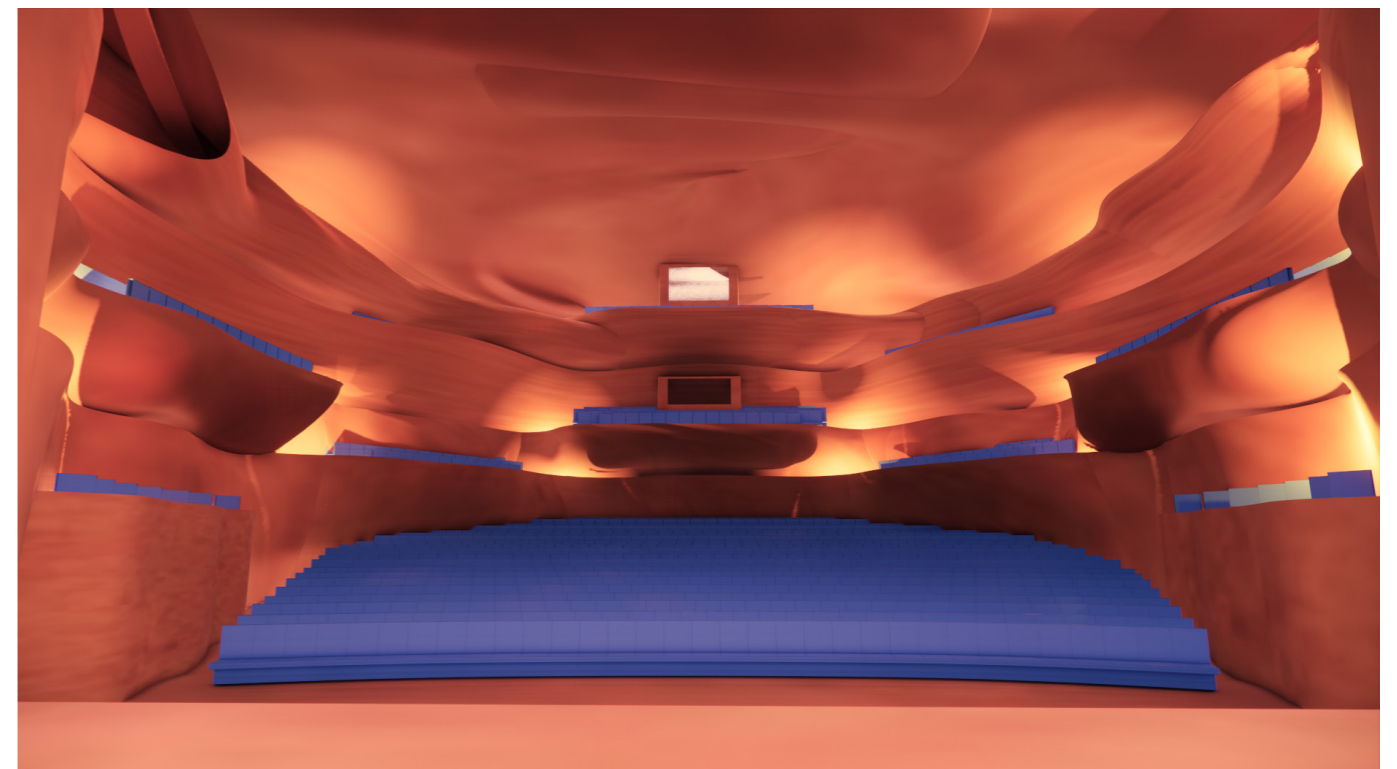
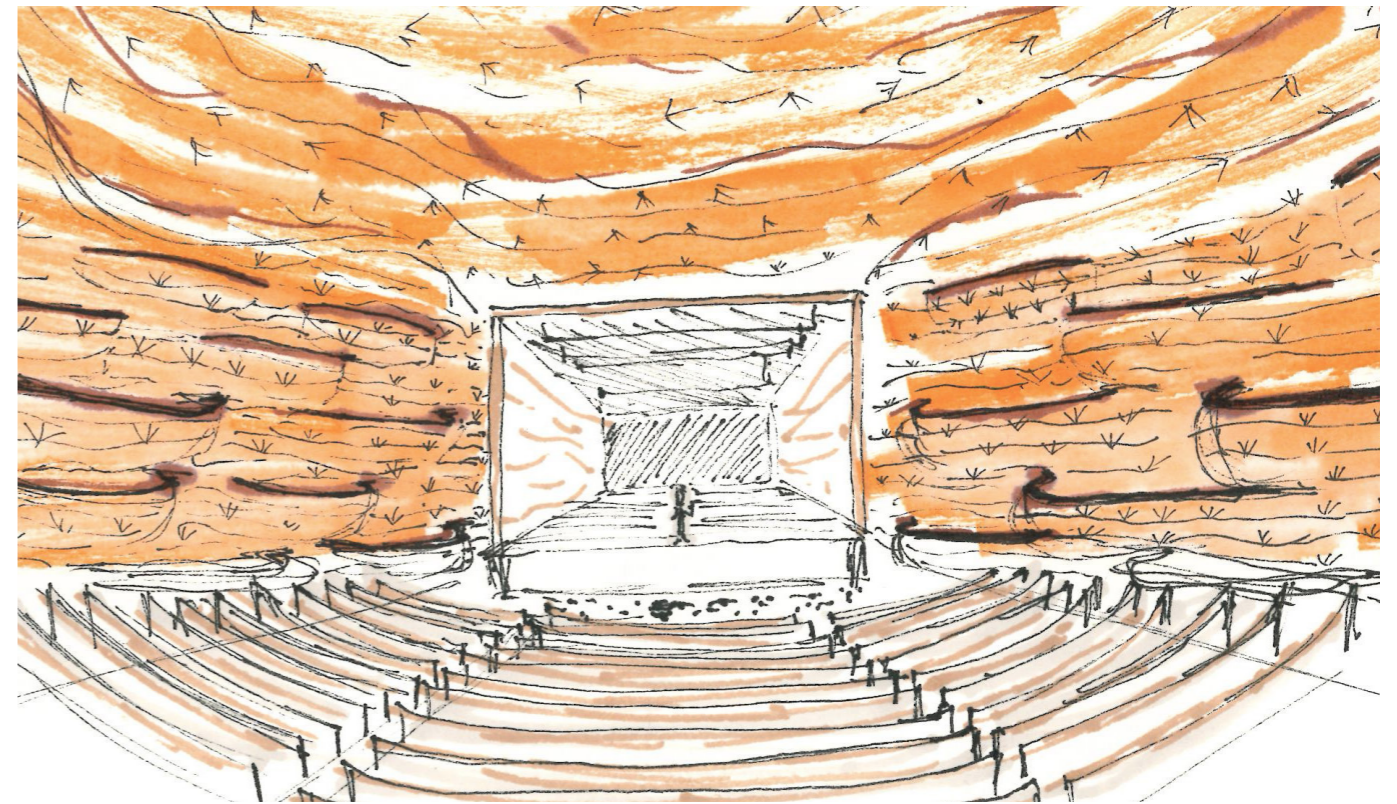
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Brief

My bachelor thesis project was based on a competition in architecture and acoustics where we were to design an opera hall on a university campus in an innovative way or with new solutions to room acoustics and structure. Me and my team member decided early on that we wanted our focus to be on materiality, sustainability and craft. I have been inspired for a long time by ancient building techniques and we decided to work with clay.

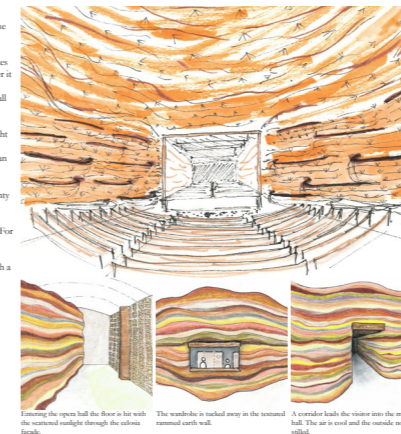
Clay offered some very interesting acoustical properties and benefits: noise insulation, space for Helmholtz resonators and other absorption, moisture control and diffusive capabilities by shaping the clay.



OPERA HALL

The interior is engineered for acoustical excellence. The unique properties of clay, combined with strategically placed fiber, a sound-absorbing element, create an immersive auditory experience that transports audiences into a world of deep, soft and vibrant sounds. Whether it is the melody of a grand opera or the declamated speeches of guests and school presidents, the opera hall envelops performers and audiences alike.

The opera hall and stage tower require significant height and the opera hall also has a large span. This presents several challenges when working with clay. The German building codes for rammed earth give the maximum height as ca 5 meters. However in hot climates people have been using rammed earth to build as high as twenty meters. To achieve our heights of 30 meters we will employ both wooden pillars and rammed earth with a combined width of ca 2.5 meters at the ground floor. For overhangs and panels we will use a combination of weaving and wooden structures. These rammed earth walls also support the inner ceiling and roof along with a concrete ring that supports the inner gridshell.



STUDENTS

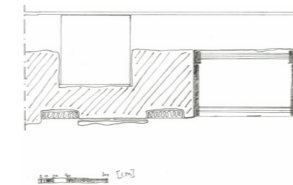
Our design incorporates several key features tailored to its educational purpose. Firstly, we have included several practice rooms for the students to use. Secondly there are designated separate areas with quieter study spaces at the front and back of the house.

Using colored glass bottles as a light source embedded in some of the walls in the building, the interior will build an ambience that can have a positive impact on the students' creativity. Students can also be involved in the building process due to several hand-made elements.

REHEARSAL ROOM

The rehearsal room is accessible by the public for intimate performances and by the musicians and actors for practice. Since the main hall is not flexible in terms of size this is a multi-purpose room and is larger than a rehearsal room solely for practices. The windows utilize the thickness of the walls and double layers of glass to be large enough to let in daylight through the colosa.

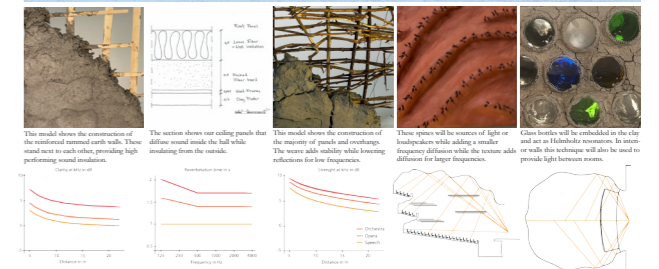
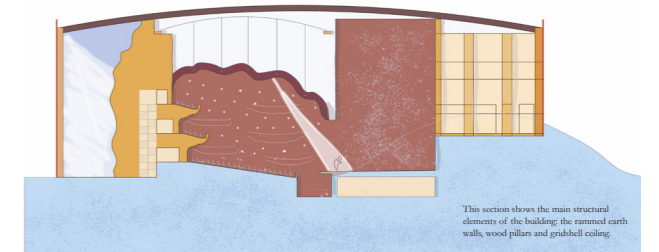
The volume of the rehearsal room is 2000 m³ and the reverberation time is adjusted to 1.5 second. The absorption in the rehearsal room is accomplished through bottle Helmholtz resonators, fixed broad band absorptive panels and the same flexible panels as are used in the main hall. This gives an expected clarity of 5 dB and a strength around 6 dB in the diffuse field.



ACCESSIBILITY

As the building is grounded and sturdy, it offers sufficient space inside for a comfortable journey for all ability levels. The crossover corridor is designed to be used by disabled with ramps/elevators.

Since several key rooms, such as practice rooms, green room and offices, are above the ground floor, they are accessible by both elevator and stairs.



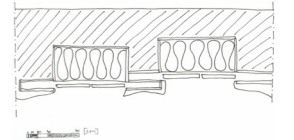
ACOUSTICS

The room volume is dimensioned for opera to minimize the use of additional absorption. By opening sliding doors covering deep broad band absorbers it is possible to fine-tune the reverberation time. If you open all available absorbers the reverberation time can be lowered to 1 second suitable for speech. Closing all doors and adding an orchestra shell increases the reverberation time to around 1.8 seconds for orchestra music. By dimensioning for opera the strength and clarity are high as well.

The walls are made of three massive walls of rammed earth each with a thickness of more than 0.6 m which easily supply the needed air-borne sound insulation to the hall. The roof of the hall is designed as double wall construction. The outer roof uses a gridshell construction and is made primarily of wood. The inner roof is elastically suspended which at the same time is the ceiling of the hall. The ceiling and the walls of the scene house directed towards the hall are made of wood with clay plaster.

EARLY REFLECTIONS

Early reflections are supplied by the ceiling and the sidewalls. The ITDG is for most places between 15 and 35 ms. However, there are positions close to the walls where the ITDG is substantially smaller and in the front rows of the auditorium where the ITDG exceeds

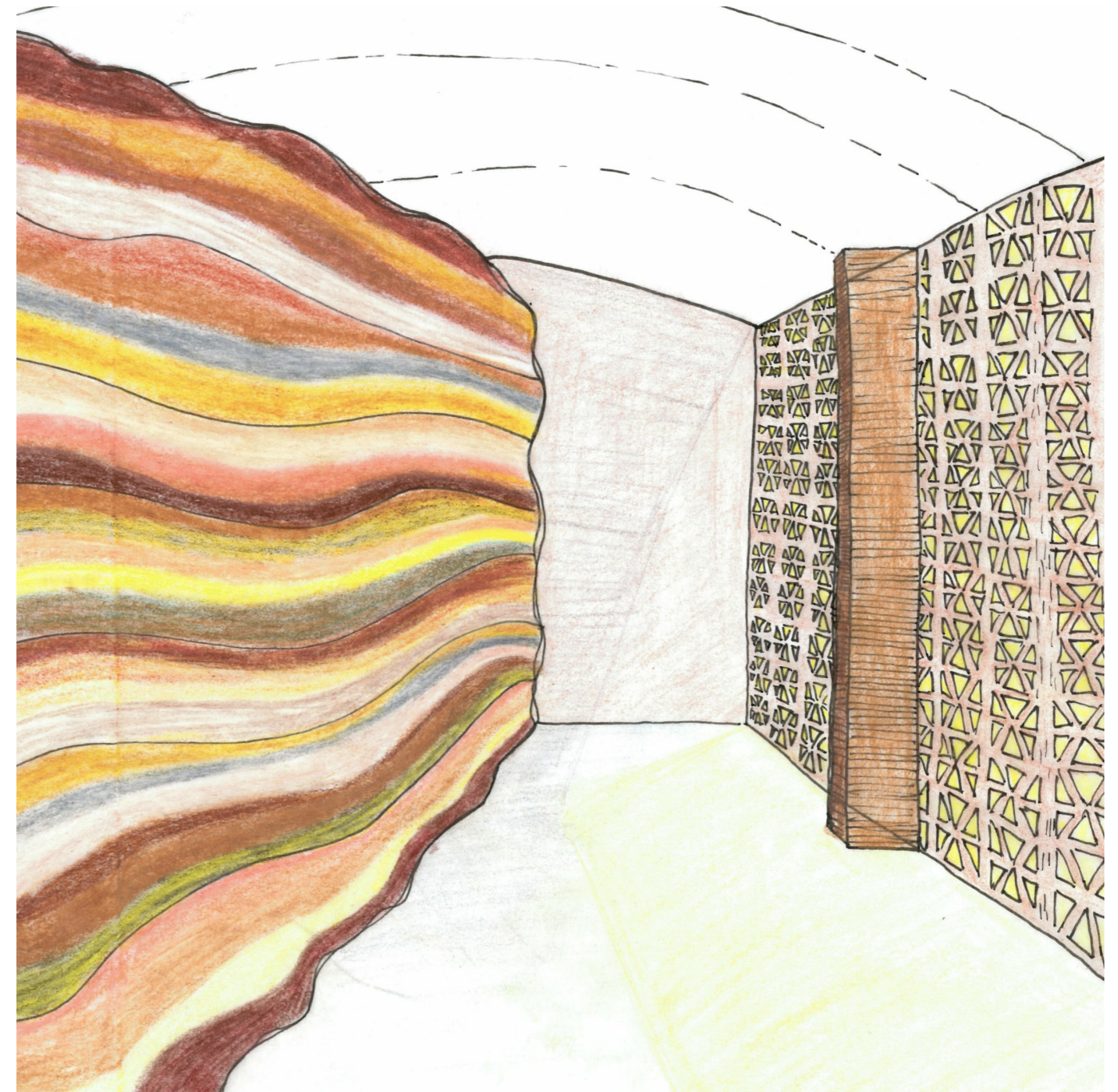


The politics of building techniques used by the poor

With this project we were interested in exploring a material that has fallen by the wayside in western culture and which is slowly resurging.

Clay has been widely used in all climates but has been most prominent in hot areas because of its availability, ease of construction and temperature regulating capabilities. Though used in tall, complex structures in for example Sana'a in Yemen clay is often seen by the average westerner as dirty and uncultured as a building material. It is a grave misunderstanding of the material.

The artisans, architects and engineers who design clay palaces, mosques and churches should be equally respected as those creating from wood or concrete. It is in the same way that anyone can draw on paper while some are masters of the craft. We need to stop undervaluing knowledge based on who holds it. In the face of the challenges of the future maybe we should embrace the ways of those who have been building sustainably for the longest.



Entering the opera hall the floor is hit with the scattered sunlight through the facade.

Reparation and love of a building

Most buildings made of rammed earth and clay can stand for centuries, but it will always be nearly impossible to date these structures since they are repaired and remade throughout their life. Maybe our most loved structures can be like the ship of Theseus, ever changing and remaining. That would be the greatest symbol of love from a people to architecture.

Certain materials are better suited for this than others but what most have in common is a level of truth of material; the material is applied to its fullest capacity and techniques conform to it rather than the material conforming to the aesthetic of another. Composite materials are often only repairable in the long term if thought of it was included in the design. Examples include mass timber, light timber, clay, stone, masonry, solid concrete blocks, bamboo and weaved structures.

These principles also make it easier to reuse the material in other projects, prolonging its life span. As discussed in Upscaling Earth, clay and earth buildings can be recycled infinitely when not mixed with chemical additives. This means that it may be the only fully cradle-to-cradle material.



The facade made of celosia, a type of brick, lets the light shine out at night. The curves of the inside can be hinted at through the strict facade. The contrast between the outside

and inside was a key architectural quality in our design. We wanted the building to mirror the acoustical contrast between the noisy outside and still main hall.

The hand made

Since the techniques used in the project are able to be made by hand it is a perfect way to involve the local community and student population in the creation of the building. This will provide local jobs and give the community a sense of ownership over the building.

Rammed Earth

Rammed earth is one of the oldest techniques used and can be done both by hand and using machines. It is created by slowly adding layers onto a wall and then using force to compress a stiffer clay into it. These layers can have different colored clay and this creates a beautiful effect which is what I illustrated with colored pencil in the storyboard. In our project these are used in several combined layers surrounding the main hall and throughout the rest of the building. Openings are created with beams embedded into the walls and we chose to use wooden beams.

Clay plaster

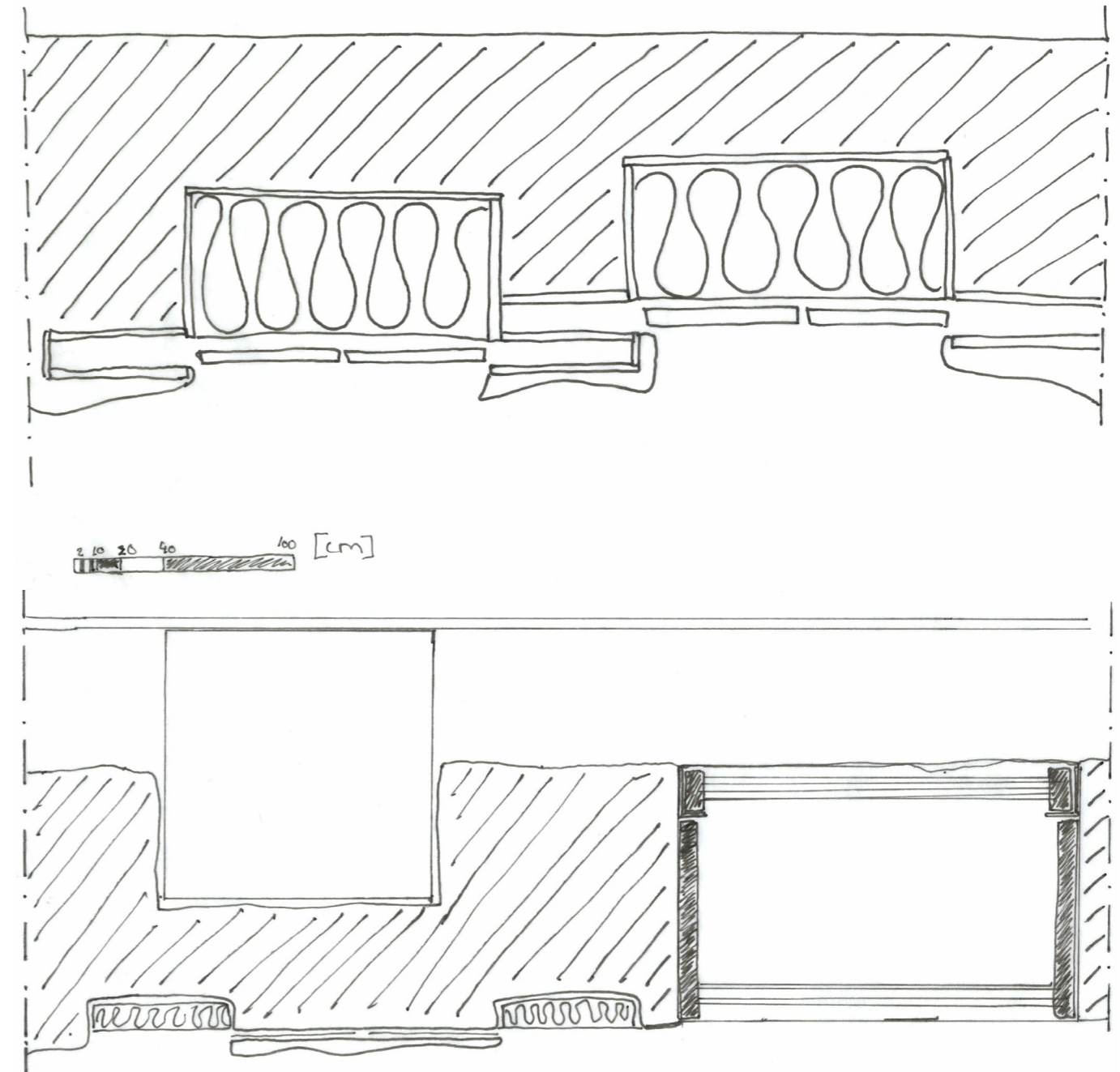
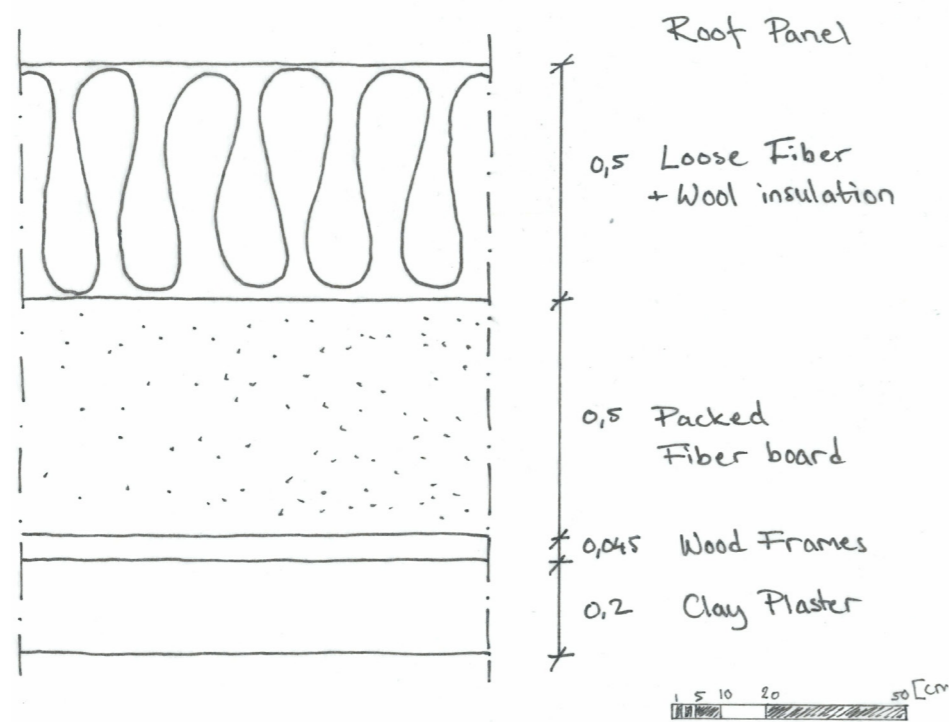
Since rammed earth is not suitable in areas that cantilever such as balconies and ceilings we chose to use clay plaster in these areas. This is created by making a wooden support structure, weaving smaller sticks, bamboo or thick fiber and then packing layers of a fiber-clay mixture onto the weave or grid. The outer layers can be made to be smooth or textured depending on the need for diffusion or as decoration.



Fiber insulation and sound absorption

There are several ways of using fibers as insulation and sound absorptions. Loose fiber insulation is most commonly made of wool, cotton, flax or hemp or a combination of these. In our project it was used in the space above the hanging ceiling in the main hall to shield the room from outside noise and noise generated from inside the building.

Fiber with clay coating uses similar materials but the fibers are coated with a loose clay and dried into an effective sound absorber. The ratios of clay and fiber and the thicknesses can be used to target different frequencies.



The section above is of the adjustable paneling in the opera hall. By opening sliding doors covering deep broad-band absorbers it is possible to fine-tune the reverberation time. The absorption is from fiber insulation and the diffusive outer elements are made of clay plaster.

The section below is of a rehearsal room wall. The windows utilize the thickness of the walls and double layers of glass to be large enough to let in daylight through the celosia while providing sound insulation. The room uses bottle Helmholtz resonators, fixed absorptive panels and flexible panels.

Iteration one

Since there is not wide-spread use of clay as a structural building material in modern Europe we needed to do a lot of research before starting our work for the competition. We read several books that were key to understanding the material.

We also had conversations with three people who work with clay, one of whom is from Mexico and these conversations were incredibly informative and positive. Their names are Lena Falkheden, David Escobar and Shea Hagy.

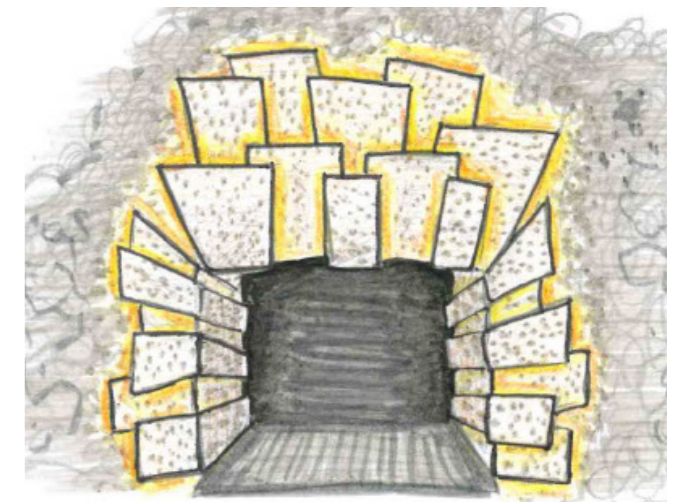
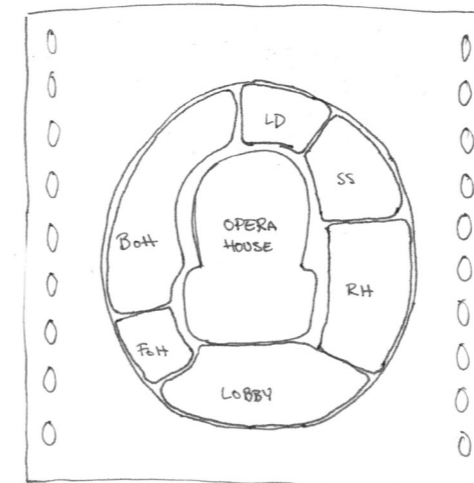
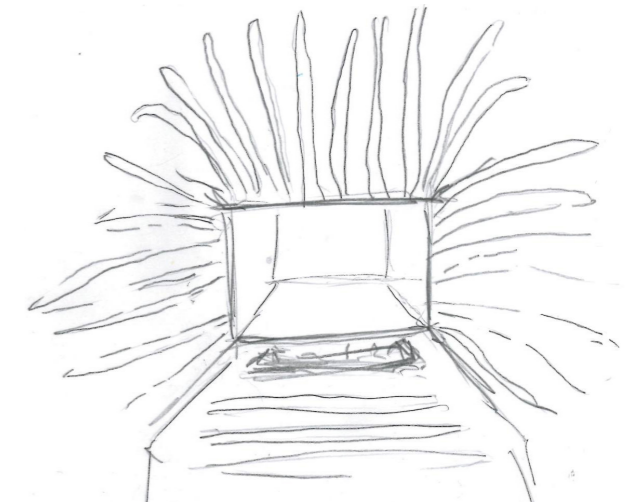
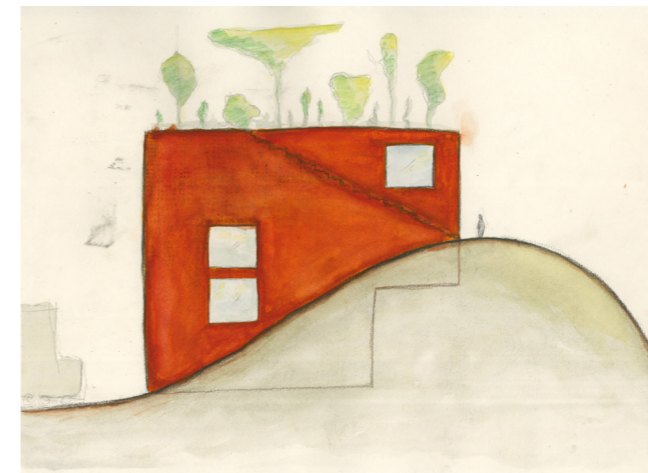
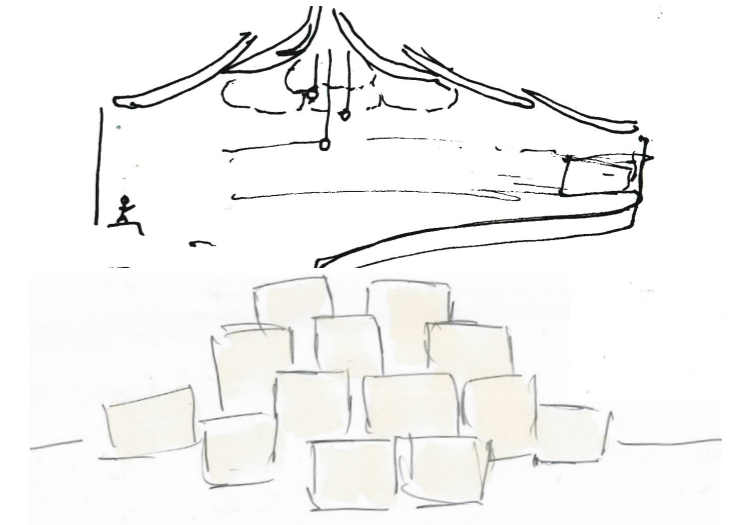
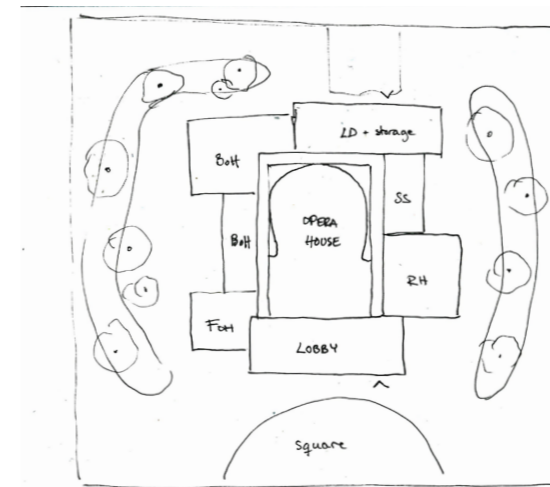
We were able to pick the location of our project and because of the climate and a heritage of working with clay and adobe structures we chose Mexico. After speaking with the expert from Mexico we felt confident in that decision and placed the building in Monterrey since the risk of earthquakes is much lower there. It was also in that conversation we made the final decision to also use a rammed earth technique with supporting embedded pillars as the structural material of the building. This was a critical decision since the height and span needed was around thirty meters. Before speaking with David we were unsure if rammed earth would be strong enough to support such heights but with his council we made the structure with several walls supporting the ceiling.

These walls have and a combined width of ca three meters at the lowest level and reducing in width at the top.

As reference buildings we looked at the clay cities in Yemen, the Fujian Tulou in China, traditional clay and timber houses in Sweden and adobe structures in Mexico.

When we had chosen Mexico and our structural elements we started working on our design ideas and came up with three versions that we showed to the acoustics students.

The three design proposals were inspired by Mexican architectural styles, themes and imagery. One resembled a village structure, another a strict cube with a flower-inspired inside and the third was a cactus with a flowing inside. We chose with our acoustics student to move forward with a combination of the outer form of the second option and the inside of the third.



Iteration two

During the second iteration we created acoustic prototypes for the building. The goal was to create innovative acoustic solutions within our chosen topic, so we created several drawings and models. We made models for both structural and acoustic elements. Our acoustics student was absent for the second iteration of the project so we continued by ourselves.

We wanted to use as little new material for our models as possible so materials included:

- sticks from outside,
- bottles from a party,
- blue clay that was donated to us from a local construction site,
- leftover air-dry modeling clay,
- sawdust from the workshop,
- pieces of leftover wood
- Sewing thread
- Some wire we found.

Iteration three

The third iteration involved making preliminary posters where we created a composition, wrote texts, selected images and sketched thumbnails. The preliminary posters were then presented in a gallery critique where students and teachers wrote suggestions on the posters for edits and improvements. This gallery critique marked the halfway point of the project.



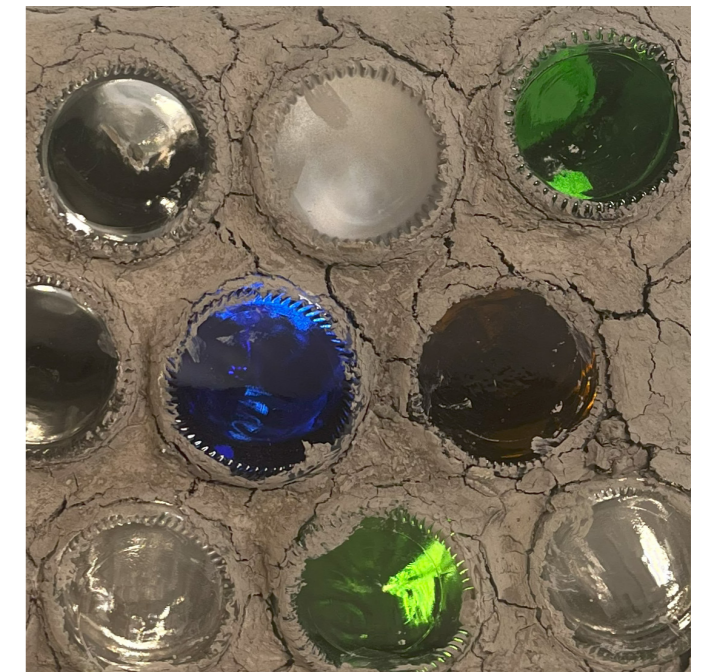
This model shows the construction of the reinforced rammed earth walls. These stand next to each other, providing high performing sound insulation.



This model shows the construction of the majority of panels and overhangs. The weave adds stability while lowering reflections for low frequencies.



These spines will be sources of light or loudspeakers while adding a smaller frequency diffusion while the texture adds diffusion for larger frequencies.



Glass bottles will be embedded in the clay and act as Helmholtz resonators. In interior walls this technique will also be used to provide light between rooms.

Methodology

The structure of the course: iterations followed by critique and feedback really helped with consolidating ideas and moving forward. I wish we had the time for our preliminary study before the project instead of during the first iteration since it could have led to a more complete building. However I would absolutely not have traded away that time since we learned so much interesting and valuable information.

I really enjoyed making physical models. I had never worked with clay before and our models cracked several times. After being advised to incorporate sawdust the cracked became much smaller and there were obvious textural differences. The weaved model was interesting because I had to experiment with different types of sticks and methods of soaking and binding to make sure they did not break. I would love to continue working with this but on a larger scale, perhaps making 1:1 models or a smaller real project like a gazebo, doghouse or fire pit.

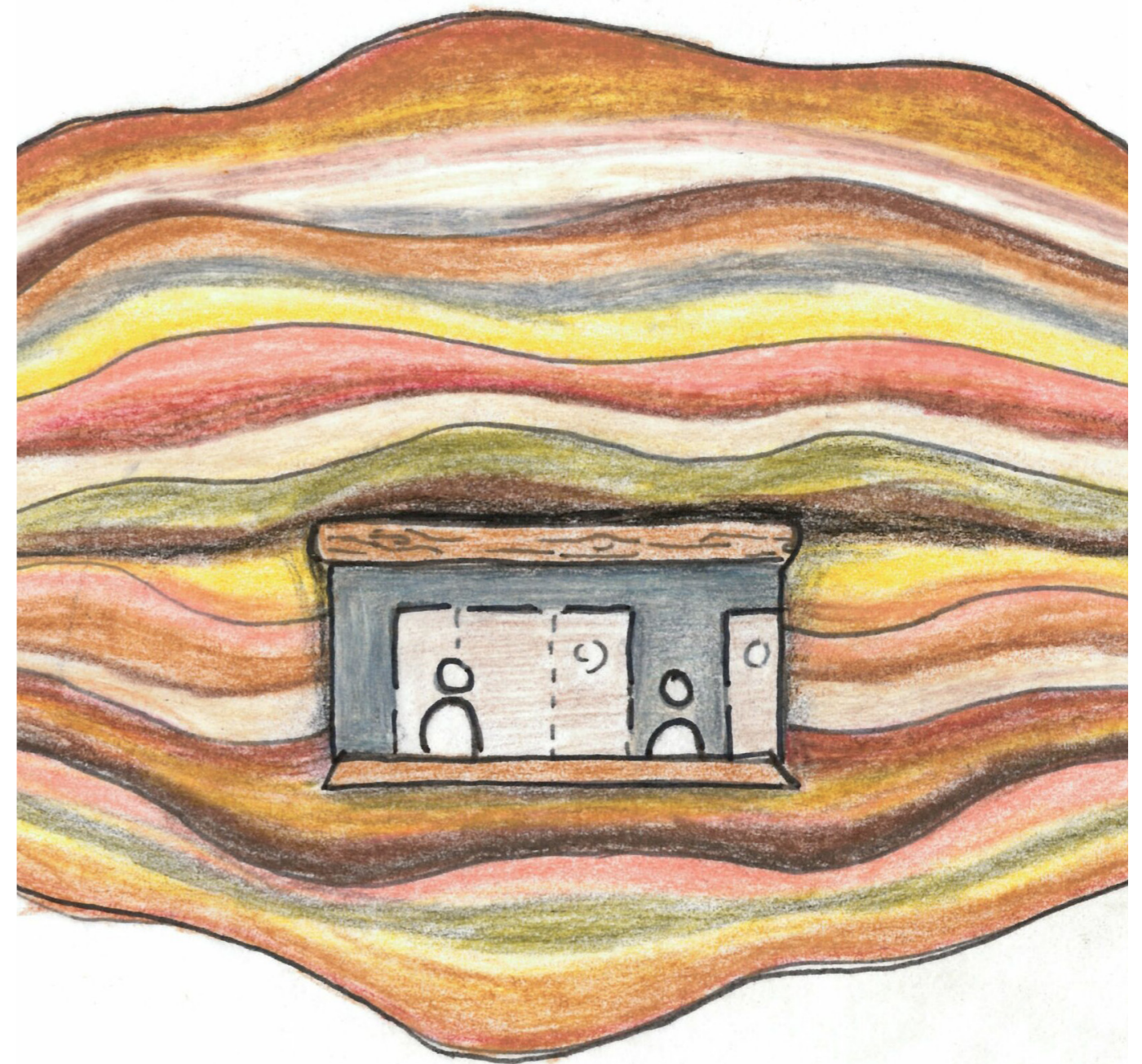
We used a mixture of digital and hand drawn as well as rendered images which was effective in conveying the warmth of the clay and communicating a more rustic image to the viewer. We tried making renderings of different scenes but decided that it portrayed an image of completeness and finality that the hand made pictures did not. There needed to be a clear distinction between our proposal and the possible final product that lets you imagine the beauty. Our digital model was very helpful in producing our plans and sections and we used a script in Grasshopper to make sure we had sufficient seating.



Collaboration

Collaboration was a huge aspect of the project and I feel incredibly fortunate for my partner Isabell Norrby as well as our instructors. Unfortunately our acoustics student was often absent and after several attempts at working together our instructors recommended to continue without him. This impacted our progress in the beginning and middle of the project but by the end we had great conversations with and help from our acoustics teacher, who had previously worked with clay plaster and was very enthusiastic about the project.

Me and Isabell worked very well together, encouraging each other and fueling the others' curiosity. Our ideas built on the others' and we communicated openly about our needs and priorities. I feel very strongly that the whole project belongs to us both, regardless of whose brush laid the final stroke.



The wardrobe is tucked away in the textured rammed earth wall. You can see the wooden beam. This was based on a sketch by my partner and is illustrated by me.

Quality of the design

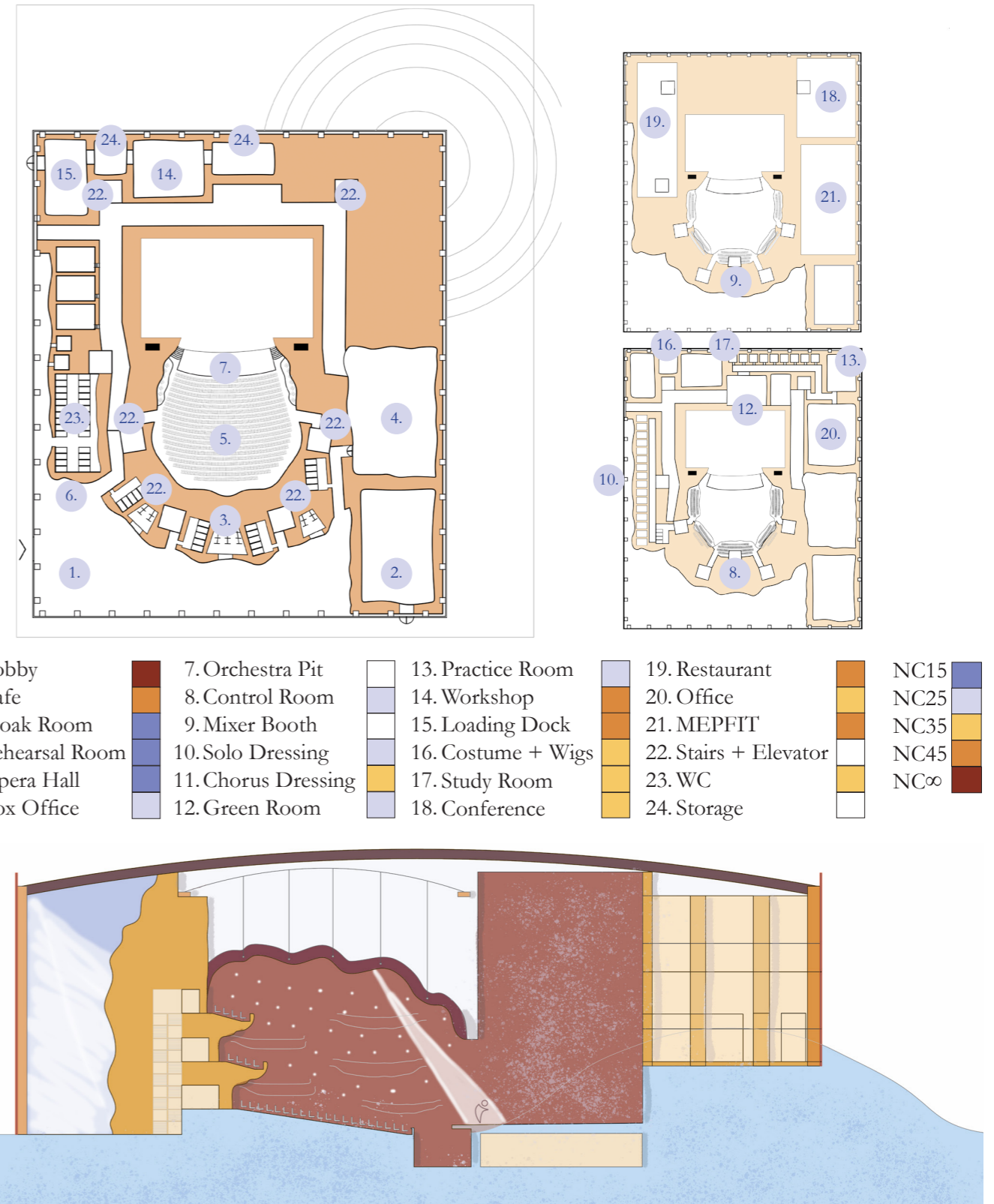
This was a very rewarding project and I feel like I have learned so much. I am satisfied with our competition proposal, though I feel that there are improvements to be made to the plans and section. Since it was a competition with a limited time frame we prioritized innovation, structure and material and used a quite conventional layout. To me the strongest parts were our acoustic and structural prototypes and solutions as well as the concept and vision.

My future:

The project inspired me to continue working with earthen structures and involve other types of sustainability in my projects. It definitely cemented my love of materiality, texture and truth of construction in architecture. I feel like I have not learned nearly enough about building techniques using less common materials and it will probably be a life long learning process.

I would also like to work on similar interdisciplinary teams and attempt to design holistically and not only aesthetically. I really loved working on physical models and have thought about taking up sculpture or ceramics as another artistic avenue. I hope that I can be a part of building smaller full-scale projects in the future.

Overall I had so much fun working on this project and am looking forward to what my future holds.



Literature used:

Architectural Acoustics, Marshall Long, 2006,
Elsevier Academic Press

Building With Earth - Design and Technology of
a Sustainable Architecture, Gernot Minke, 2nd
edition 2009, Birkhäuser

Earth Architecture, Ronald Rael, 2009, Princeton
Architectural Press

Lehmbau handbuch - Der Baustoff Lehm und
seine Anwendung, Gernot Minke, 1995,
Ökobuch

The Art of Earth Architecture - Past, Present,
Future, Jean Dethier, 2020, Thames and Hudson

Upscaling Earth, Material Process Catalyst,
Anna Herlinger, Lindsay Blair Howe, Martin
Rauch, 2019, gta Verlag ETH Zürich