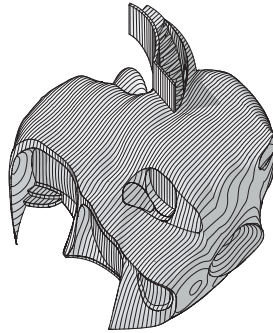


Immersive Architecture

A Study of the Possibilities with Virtual Reality in Architecture

Gustav Nyman
Chalmers School of Architecture
Examiner: Daniel Norell
Tutor: Jonas Lundberg & Karin Hedlund

"This is only the beginning."
-Christopher Nichols



Immersive Architecture

A Study of the Possibilities with Virtual Reality in Architecture



CHALMERS
UNIVERSITY OF TECHNOLOGY

Gustav Nyman
Chalmers School of Architecture
Master's Thesis in Architecture & Urban Design
Examiner: Daniel Norell
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Preface

In the initial quote by Nichols, he refers to that even though resolution, latency, and field of view is getting better we still don't know how to use Virtual Reality. How do we move safely, how do we shape experiences? This is very much connected to this thesis, in which I explore some of the unknowns.

The image on the previous page is the resulting design of this thesis, more on this can be found in part 3.6.

A general interest in technology and a belief in VR as a future medium in architecture helped me choose this subject. The journey has been long and hard, but also educational. A year spent from beginning to end, although not all spent working. No previous knowledge of VR and its workings, VR being a somewhat new technology with limited use cases, and a bit of uncertainty of the direction of the thesis provided some of the challenges faced during this year. But the most difficult part might have been how to convey something that is very experience-based into images and illustra-

tions. On the other hand I learned a lot, not only about VR, but also about myself.

Before the start of the thesis I tried a few demos and games in VR, which gave me the conviction about VR's potential future. During the course of the thesis I also had the opportunity to test a demo from an architectural office. It had two parts, one in which you could move about in a small apartment, and the other in a large city scale - where you also could be either large or normal sized. The combination of these gave a bit of inspiration for some of the experiments along the way, as well as ideas for the demos that I made.

Finally, I would like to thank everyone that provided much needed support at various stages during this year.

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Abstract

What is the potential of Virtual Reality pertaining to architecture, and can it change the way we design? The purpose of this Master's Thesis is to explore and investigate what Virtual Reality might do for the architect and architecture. One aspect is how the design can be influenced by the experience when drawing in a first-person view in a one to one scale. Another aspect is how design decisions might be more informed when being able to set the experience to the perspective of others.

Virtual Reality, shortened VR, refers to a technology that simulates a near reality-like experience. This is done mainly by feeding your eyes separate images through the VR-headset to provide a perception of depth. VR is not a new technology, however, due to low graphics and insufficient computing power, up until recently it hasn't been able to provide the immersive experience needed to truly be applicable in the field of architecture. With more and more players entering the market and driving the develop-

ment forward, it lowers the cost and makes the technology more accessible. Even so, at this point, VR is still considered to be in its infancy.

By researching VR and using it as the main tool in a design process, this thesis aims to illustrate some of its potentials and how immersion can affect design.

The result of the investigations is a small villa, designed directly and entirely in a VR environment. Also displaying some of the particulars of sketching in VR, e.g. how the body affects the design with its limitations in movement.

Virtual Reality has a lot of potential, and will come to be greatly used for design by architects in the near future. However, the software has some catching up to do before it can be incorporated as one of the standard tools. The design itself will inevitably contain individual "fingerprints" from the designer when using the method in this thesis, depending on the reach and agility of said designer.

Student Background

Bachelor studies

BSc of Architecture and Engineering
Chalmers University of Technology

Master studies

Master's Program: Architecture and Urban Design
Sustainable Development and the Design Professions
Material and Detail
Design & Communication Tools
Housing Inventions
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1. Introduction

1.1 Purpose

The purpose of this Master's Thesis is to explore and investigate some of the potentials of Virtual Reality in regards to architecture. Primarily how it can be used as a tool for the architect in his or her work:

- If and how it might help with the design process.
- Any benefits there are of immersion and direct feedback when designing in full scale and/or different scales.
- Any possible affects on the design itself due to the characteristics of the tool.

1.2 Questions

With Virtual Reality being a relatively new phenomenon, it has countless unanswered questions that merit being answered. However this thesis is mainly aiming to answer these two questions:

- Are there things you can do with Virtual Reality that you cannot do without, and what does this do for architecture?
- How is the design influenced by the experience?

1.3 Background

Virtual Reality, shortened VR, is a technology used to simulate either the real world or a fictional world. It then lets you experience these worlds in a spatially realistic way. This can be of great use in many fields, architecture being one of them.

In this field, the use of Virtual Reality is currently used mainly for visual representations of designs and to examine the feasibility of designs at different stages. The number of architecture firms using VR is quickly rising (O'Connell, 2016) and with the increasing number of users, the way VR is being used will change and evolve. However, today there is not much done in terms of designing directly in VR. This is something that needs to be developed more, not only regarding work flow, but also the tools and software.

1.4 Method

Through various experiments the potentials and disadvantages of VR was examined, in the process exploring the tools and simultaneously gaining a deeper understanding of the subject. Using VR as a design tool, both as a complement to conventional tools as well as the main creative tool, provided insight on possible future use.

1.5 Theory

The theory behind the thesis is provided by a variety of different texts on the subject of VR — history, practical, and theoretical — but also videos of presentations and conferences. These have provided valuable knowledge about the subject and will be referred to when relevant.

1.6 Delimitations

Even though Augmented Reality, AR, is related to Virtual Reality to some degree, I have not included it in this thesis. AR uses different hardware, have other interesting qualities than VR, and deserves a thorough analysis on its own.

I have chosen not to include some of the existing software used for quickly getting your 3D-model into VR, since they often are expensive, limiting in what modelling software you can use, and limited in how to steer the experience.

Possible methods of building the proposed Villa have not been investigated, mainly because it is not directly connected to the subject of this thesis.

1.7 Reading Instructions

After a brief introduction to the subject, some of the most important tools used are presented and explained.

The experiments that follow are to be viewed as separate case studies. Each experiment provides with conclusions or questions that in some cases leads to the next experiment. The design of the Villa is in itself a case study and should not be evaluated on its level of details.

It concludes with an overview of the demos, followed by a summarizing discussion.

Illustrations that doesn't reference to an author or source have been made by myself, and only have a description of the content.

2. Research

2.1 History

The Stereoscope was the first instance of 3D-images, or stereo vision, and was invented ca. 1840 (Stanković, 2015). It consists of two overlapping pictures that are slightly different from each other. One of the images is viewed by the left eye and the other by the right eye, giving depth to the image.

Moving forward to 1957, the first head mounted display (shortened HMD) was invented — The Sensorama. It had 3D-slides, sound, and even smell and can be referred to as the father of Virtual Reality. It did not have interaction in any way though.

Aspen Movie Maps (1978), the prequel to Google Street View, was the first to include immersion, interaction, and user controlled navigation. It consisted of pre-recorded videos of the streets of Aspen, Colorado.

Virtual Reality as a term, in its current meaning, was first used in 1989 and it became very popular in the 90's. The development and interest stagnated, and it was silent for a long time about the subject. But in 2012, in a Kickstarter campaign, Oculus Rift put the headlights back on the technology once again. Since then HTC, Playstation, and others have made their own HMD. There are also devices using smartphones as displays.



Figure 1. Davepave. (2006). Holmes stereoscope [photography].

2.2 Technology



Figure 2. Minecraftpsyco (2016). The Sensorama machine [photography].

You could say that Virtual Reality is a way to trick the mind into thinking it is somewhere else. There are several ways the mind can be tricked, it can for example be schizophrenia or drugs (Stanković, 2015), however VR aims to delude it with vision and hearing. The difference between VR and ordinary media and software is the immersion and ability to interact beyond keystrokes and mouse movements.

Some of the uses for VR in architecture is talked about by Portman, Natapov, and Fisher-Gewirtzman (2015), for example; collaboration over distances, comparing design options, simulate user behaviour, grasping spatial concepts, and testing the validity of design proposals.

Nichols (2016) talks about how environments is the main thing in VR, that we can experience anything we can't do or can't afford in the real world. And with the environments the architect enters the picture. We know rooms, spatiality, and visualization. The technology also let us go past this, into abstract spatiality that simply cannot be achieved in real life.

The main goal of VR is to provide an experience inseparable from reality. Stanković (2015) goes on to state that this is an utopia. However, others believe that we are already living within

a simulation. Bostrom (2003) claims that either; humanity dies out before we can simulate our ancestors lives; we simply choose not to simulate our ancestors; or that we most likely already are living in a simulation. In a simplified example Reichle (2017) goes on to imagine that someone in the future have created a replica of our reality (in the example it is called "Party like it's 2017.exe"). If this is true, there's a 50% chance that you are living in that simulation. Should there be 3 versions, the odds are 3 in 4 that you are living in a simulation. And if this game was sold, and became as popular as Minecraft, the odds that you are living in the real world is a mere 1:100'000'000.

2.3 Present and Future

We are closing in on photorealism in computer generated Virtual Environments, VE (Sweeney, 2016). One big step towards photorealism is that we now can calculate how light acts on materials micro structures. The next big step on the way is 8k-resolution per eye, which is needed for the eye not to see the pixels. Sweeney (2016) goes on to claim we will have this within 10 years. Photogrammetry will be of a great help to provide VE

that are detailed enough to seem real. The next step is to build environment directly in VR.

Renderings can already today be hard to distinguish from photographs of real objects. However, photorealism in people is harder to achieve, since the brain is tuned to read expressions and intentions in faces and quickly detects when something is off. This is referred to as the "uncanny valley" (Stanković, 2015), a hypothesis that human-like things that act almost but not exactly as real humans is perceived as uncanny, or unsavoury. Sweeney (2016) states that this likely will be solved within 10 years.

The social aspect of multiplayer games and collaboration will change more in the coming two years than in the last 20 years. With cameras that capture arms, fingers and facial expressions - which is then translated into movements and expressions in your VR persona - lets you interact with others in a much more immersive way. The practical implication can provide another dimension to cooperation and meetings over the internet.

According to Sweeney (2016) we can soon experience anything and own anything — in VR. The future of the human-computer interaction lies in Virtual Reality.

2.4 The Tools

During this thesis I have used a variety of different hardware and software. The main tool used, on the hardware side, is the HTC Vive. It is one of the top of the line (2016-2017) VR head mounted displays. It has excellent tracking, meaning how it tracks the HMD and controllers movement in 3D space, with an accuracy down to a couple of millimetres (Lang, 2016). This makes it possible to provide the image you see so that it corresponds to the image your mind expects. But since this is one of the first consumer versions it is far from perfect. The low resolution, high weight and cost, and the screen door effect are some aspects that can be critiqued. The screen door effect is when the space between pixels become visible, giving the impression that you are looking through a screen door. The two main problems will in other words be solved with better displays with a higher resolution.

As far as software goes, the main ones used are Googles Tilt Brush, Unity3D, and Agisoft PhotoScan. The last one is used to make real world objects into a mesh with an applied texture. This is particularly useful when you want to bring objects from real life into VR. Googles VR-software, Tilt Brush, lets you paint and sketch in a 3D environment, while not being restricted by

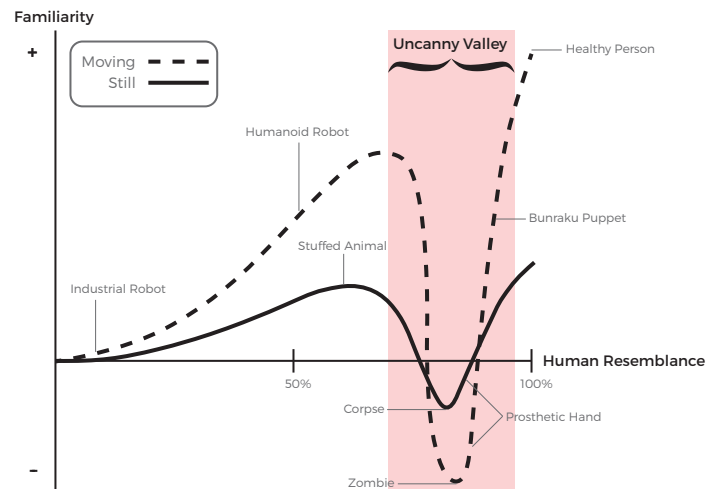


Figure 3. Smurrayinchester (2010). Mori Uncanny Valley [reworked and translated illustration].

a flat canvas or scale - opening up a whole new way of designing. In Unity3D is where it all comes together, the site model, the architecture, and all the experiences you want to have in VR. Depending on your programming skills, you can have almost any experience desired.



1. HTC Vive headset - 2160 x 1200 pixels @ 90Hz (1080 x 1200 pixels per eye).

3. Controllers - used for navigation and interaction in Virtual Reality.

2. Lighthouse base stations - IR Tracking system that tracks the position of the headset and the controllers in 3D space with mm precision.



Figure 4. BagoGames (2016). HTC Vive Now Up For Pre-Order [photography].



Unity3D is the one of the key software used in this Master's Thesis. It is a game engine in which you can make 2D-, 3D-, and VR-games. And it is by far the most used one on the market.

Here we can combine all the different "assets"; buildings, site model, relevant detail models,

materials, lighting, and scripting to make the controllers do what you need and the VE behave the way desired.

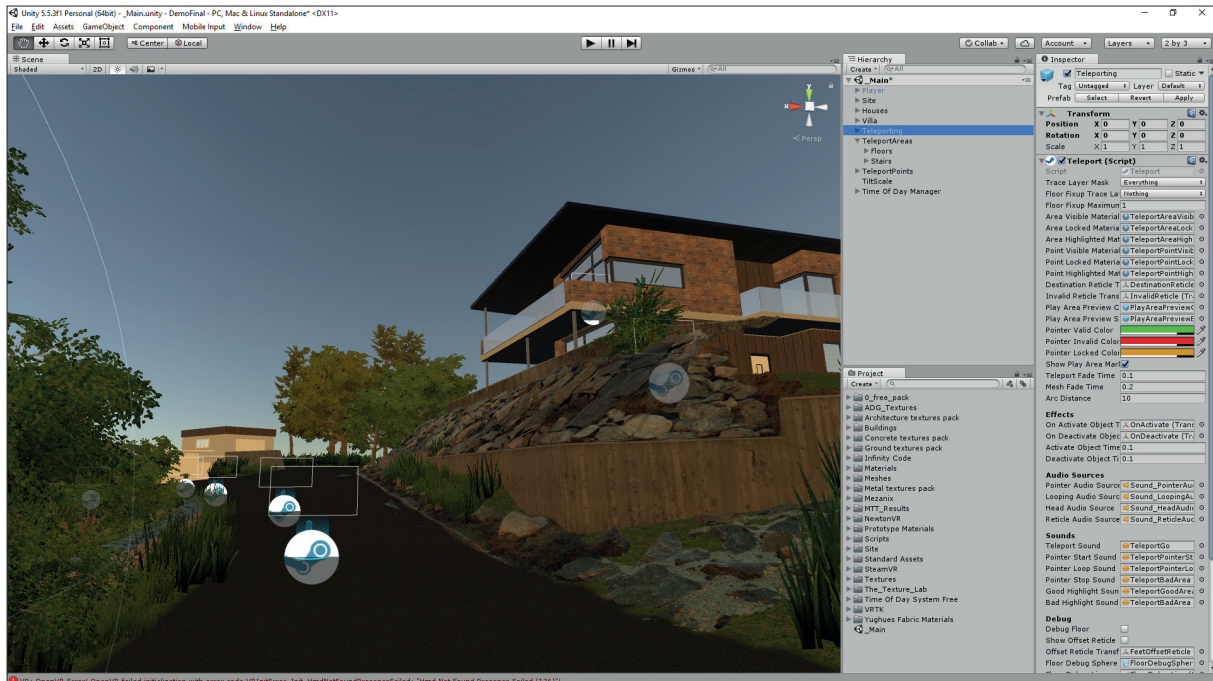


Figure 5. Unity3D interface, making of the VR demo.



Tilt Brush is Google's own VR sketching program. It is very simple and intuitive, but can be quite rough. There are several different surroundings that you can sketch in, and since recently you can import models to sketch on. Thanks to this, it is now possible to import a computer generated

site model to sketch on. This helps in keeping the sketch somewhat accurate, and the relation to the context seen in real time as you are sketching. The sketch can then be exported and further worked on in other software.

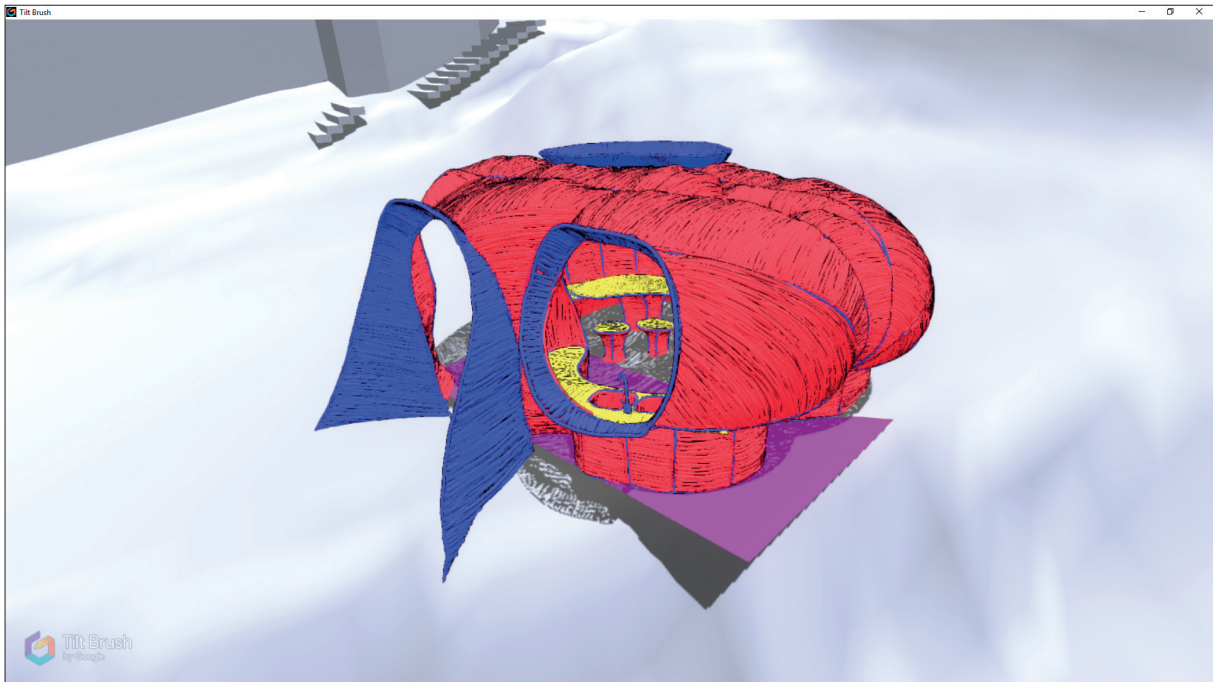


Figure 6. View inside of Tilt Brush, first iteration of the villas design.

Agisoft

Agisoft PhotoScan is a software that is used to stitch photographs together into a 3D model. You take a large number of photos of your target in different angles, the software then calculates the position of the camera in each photo. It makes a cloud of points in 3D-space, which is

then built into a mesh. Finally, the mesh is given a texture from the photographs. This is particularly useful for objects that are hard to make a model of in 3D-modeling software.

I have used this for a stone wall on the site, close to the villa.

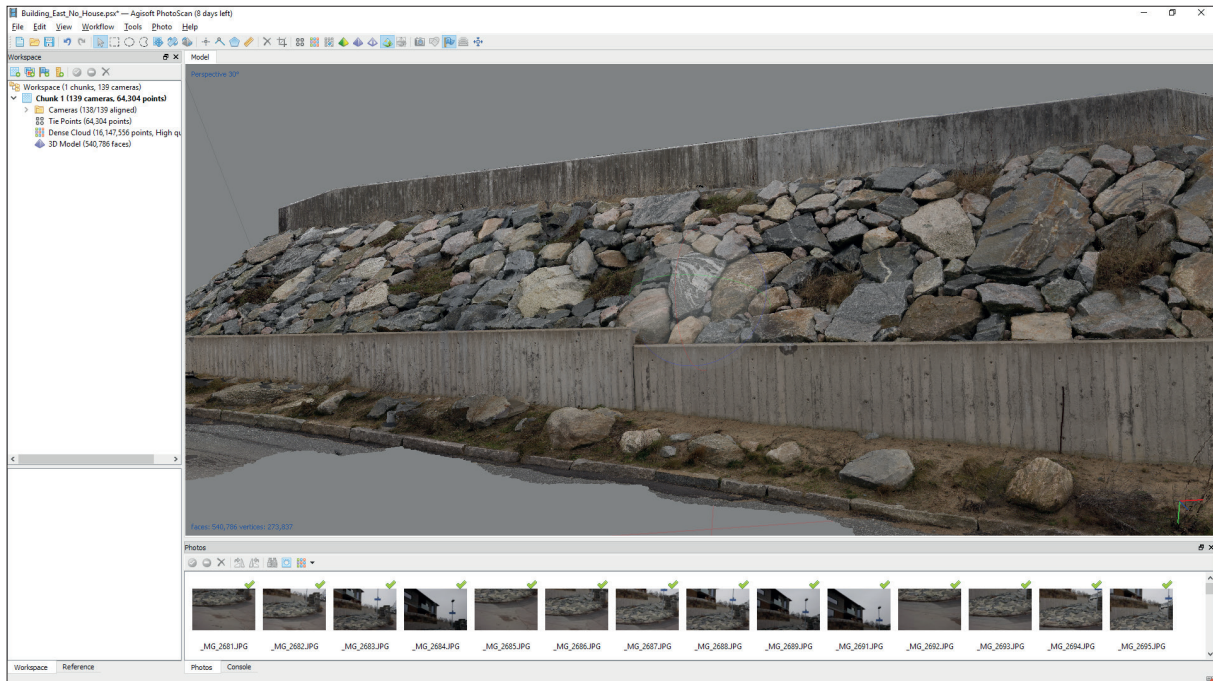


Figure 7. Agisoft PhotoScan interface, making of the stone- and concrete wall from site.

3. The Experiments

3.1 About

The experiments follow something of a natural progression - one experiment leading to the next. Starting with how to have an architectural experience in VR, which lead to looking closer at materials and getting them lifelike. The experiment with different perspectives is looking closer at how you can benefit from not being bound to a specific scale. And the villa-experiment examines more about scale and the effects on design.

In VR there are a variety of ways to move about. In the demos that follow, teleportation is used, which is simple, intuitive, and less prone to cause nausea compared to some of the others.

3.2 Azuma House

The first thing related to architecture that I experimented with in VR was Tadao Ando's Azuma House. Partly since I already had a model that I previously had built, and partly because I wanted to experience the building and see it with my own eyes.

The first thing that I noticed was how the spatiality was hard to grasp. I hadn't applied any materials – and the walls, ceilings, and floor all blended together.

After adding materials, the orientation became much better, and the experience with that.

One thing that did show was how the ability to visit any place in the world, as long as someone have made a digital model of it, now is possible.

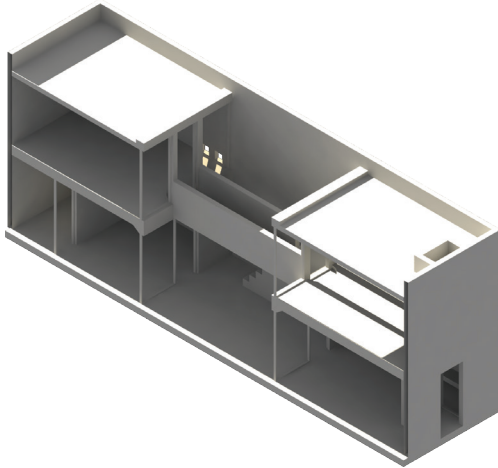


Figure 8. Azuma House, without materials the space is hard to read in VR.

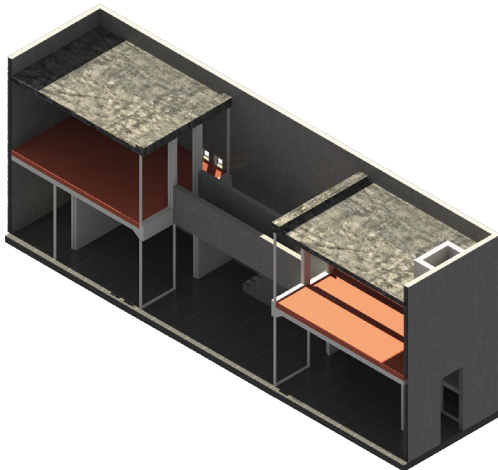


Figure 9. Azuma House, with good textures the VR experience gets a lot better.

3.3 Materials

Trying to experience the Azuma House in VR, I noticed that materials had to be applied to be able to get the spatial awareness wanted. However, there are different types of materials with varying level of realism.

One of the lower levels of realism only consists of a flat texture image applied to a surface. To make it more lifelike you can apply a normal-, displacement-, occlusion-, and specular map. These maps let the computer calculate how light should reflect of the surface, how "bumpy" it should be, as well as the shine and reflectiveness.

To make a good material you also need to make sure the texture is seamless, i.e. you shouldn't be able to see where one image ends and the next begins when putting them together.



Figure 10. Unknown author (n.d.) Untitled image of a brick wall [reworked: added normal map].

3.4 Photogrammetry

Some objects can be very hard and time consuming to make a 3D-model out of. Objects with many irregular faces and varying colour and texture can easier be made by using photogrammetry. Correctly done, it can also make your virtual environment more realistic.

Photogrammetry is a way of building a 3D representation of a desired object. It can be small things like for example toys. Or it can be large things, like the stone and concrete wall which I included in the site model to make it more realistic.

The way it works is by taking a large amount of photographs of the desired object, in various angles and distances. The software then calculates where in 3D space you have taken the photographs by comparing common elements

and matching them together. With the different angles the software then calculates the shape of the object.

Photogrammetry has some problems when it comes to reflective objects, and before you get your 3D-file there is some cleaning up to do. The photographs always capture things that you didn't intend to include.

When the 3D-file is ready, the software makes a texture that you can apply, so that each face of the object get a small part of one of the photographs, making it look real.



Figure 11. 3D-model of wall, made with photogrammetry.

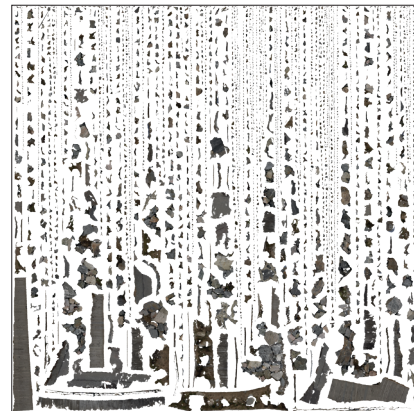


Figure 12. Texture for photogrammetry model.

3.5 Scale

3.5.1 Predetermined Scale

The main idea behind this experiment was to take something either already built or at least something already designed, and see what I would do differently when using VR. At first I tried to build a model of something already built - the Naturum höga kusten. It proved to be difficult when not having all the details needed to make a representation close enough to reality. Instead, I chose to examine something from an earlier studio - one of the apartments of the housing inventions studio.

The first step was to walk through and experience the apartment in Virtual Reality, seeing what I would have done differently if I had used VR in the studio.

Since you are not bound to scale in VR, I could also walk through the apartment as someone else. I chose to view the world through the eyes of a five year old, ca. 110 cm high. What changes would suit the child?

The next step was to make two new iterations of the apartment, one for each point of view.

Then I repeated the first step, viewing the child's iteration as myself, and the adult iteration as a child.

This second view, gave some increased insight in ways you can think and see the world.

This can be a valuable tool for making architecture to a specific client or user of the space.

On the following pages views from the different perspectives can be seen; from the hallway, kitchen, and bedroom. As well as a description of the impressions for each case.

Following this is the plans for the apartment, before and after the design changes.



Figure 13.

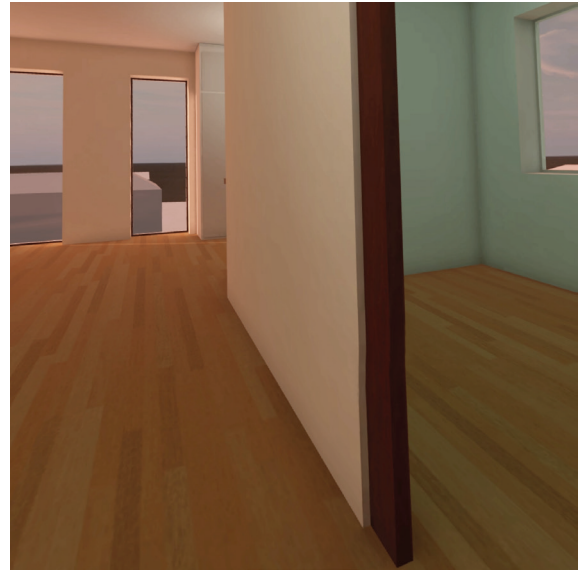


Figure 14.



Figure 15.



Figure 16.

Figure 13. Hallway, from an adults perspective.

I wanted to make the hallway a bit narrower, which came in handy when moving the bathroom – two things solved at once. One of the windows beside the kitchen should be turned to the side, was my impression here, giving a more balanced feeling and more field of view from the dinner table.

Figure 14. Hallway, from a child's perspective.

As a child, I enjoyed windows that goes all the way down to the floor. However, the windows in the bedroom to the right was far to high.

Figure 15. Child's iteration, from an adults perspective.

Seeing how much lower the child would like his windows, you get another understanding of how you can reason when placing them.

Figure 16. Final version, from an adults perspective.

In the final version, the window in the smaller bedroom has been lowered slightly, not to the full extent that the child would have wanted. The hallway is now narrower, with a more balanced feel to it. One of the windows straight ahead has been centred in regards to the front door, and the other one has been flipped to its side.



Figure 17.



Figure 18.



Figure 19.



Figure 20.

Figure 17. Kitchen, from an adults perspective.

In the kitchen, it was mainly the window that needed some change. Raising it a bit, and making it a bit larger.

Figure 18. Kitchen, from a child's perspective.

As a child, on the other hand, I wanted to lower the window, as well as the kitchen counter top.

Figure 19. Kitchen adapted in a child's point of view, from an adults perspective.

Seeing the child's preferred view, I could see that raising the window was not a good option, even though it only would have been a few centimetres.

Figure 20. Kitchen final version, from an adults perspective.

The window instead got to be higher, but still stay in the height of the kitchen counter top. Which by the way will not be lowered for the sake of a child. Now there is more light, and a better view for everyone.



Figure 21.



Figure 22.



Figure 23.



Figure 24.

Figure 21. Bedroom, from an adults perspective.

As an adult, one of the things that seemed appropriate to change was the closet space in the larger bedroom. By moving the bathroom slightly, we could instead have a built in closet on that wall. Also I decided to add a window sill on the large window in both bedroom and living room.

Figure 22. Bedroom, from a child's perspective.

As a child, being able to run around the centred bathroom seemed like positive aspect of the architecture. Also having spaces to hide behind was enjoyable.

On the balcony the railing was placed just in eye height, obstructing the view. However, being able to see through the glass was good.

Figure 23. Bedroom adapted in a child's point of view, from an adults perspective.

When viewing the "child adapted" version of the same apartment, I got a different perspective on things. In the bedroom, it was mainly the ceiling height and the changes on the balcony railing that were in focus. As well as the door sizes.

Figure 24. Bedroom final version, from an adults perspective.

In the final version, when taking previous experiences in consideration, some changes were made. In the bedroom, the closet was moved and built into the wall against the bathroom, that had to be moved a bit. The railing on the balcony was changed slightly, to make it easier for young, or even seated, people to enjoy the view.

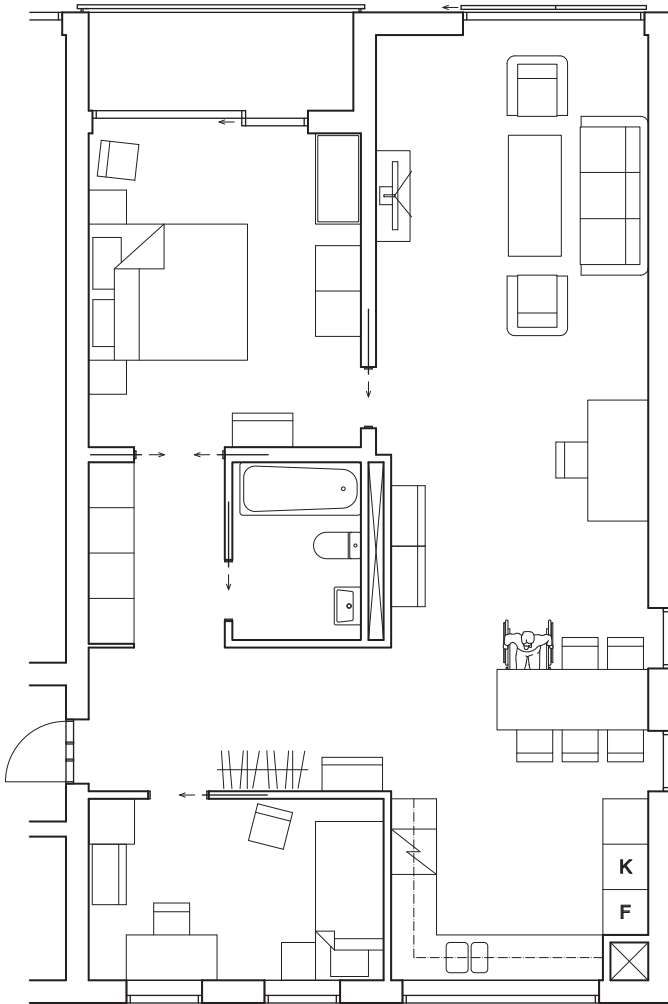


Figure 25. Plan of apartment before changes (1:100).

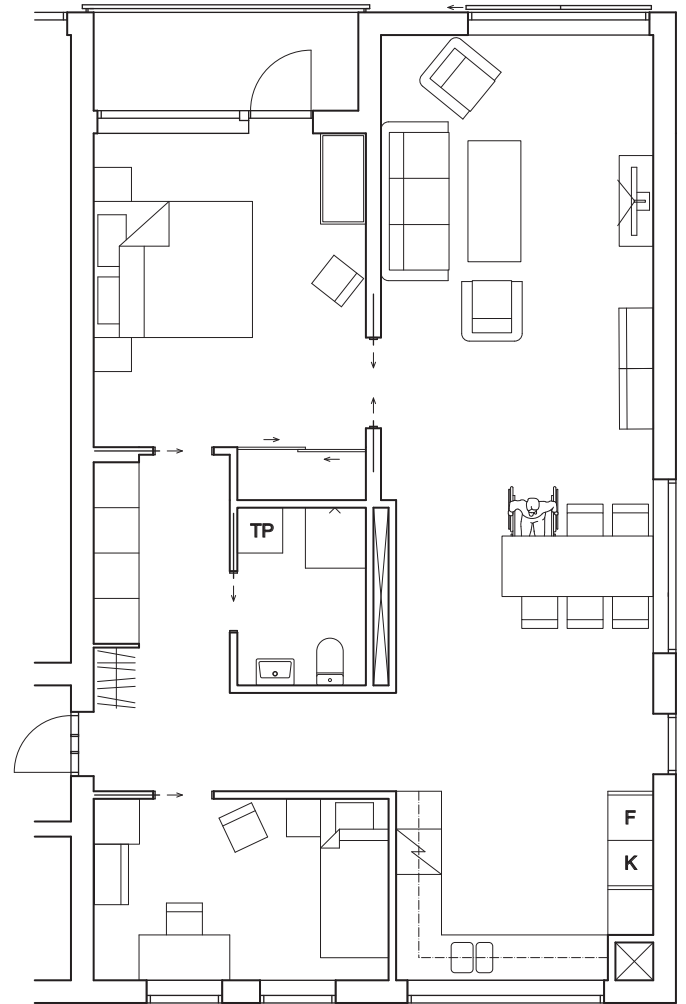


Figure 26. Plan of apartment after changes (1:100).

3.6 Design in Tilt Brush

3.5.2 Free Scale

In contrast to being bound by a specific scale, an experiment in which you can freely change scale was the natural next step.

To design in a first-person view, free from the shackles of any scale, put things in a different perspective. A perspective that cannot be experienced by conventional means. Imagine doing a painting, but you can zoom in to get the details and zoom out for the larger strokes. And the painting isn't bound to a flat surface, instead you have all space around you as your canvas.

When designing the exterior of the villa in the following chapter this method is used.

3.6.1 The Site

When selecting a site for this project the attributes I was searching for was:

- A view of the sea
- No buildings on the plot
- An interesting topography

The site that I ended up with have all of these qualities. At Saltholmen, in the western part of Gothenburg, the site can be found. Located just by the sea, with a great view and a topography with some challenges.

The process of getting the site into VR began with contacting the city planning office for a CAD-file of the location, containing height curves and general shapes of the roofs of surrounding buildings. With these curves and shapes I had a good basis for the 3D-modeling. Using a script in Grasshopper, I could cover the height curves with a surface. And then with simple shapes making the surrounding buildings. I now had a model that could be used for sketching, with a good representation of the general shape of the site and distance to neighbouring houses.



Figure 27. Map of Sweden and Gothenburg, showing location of the site.

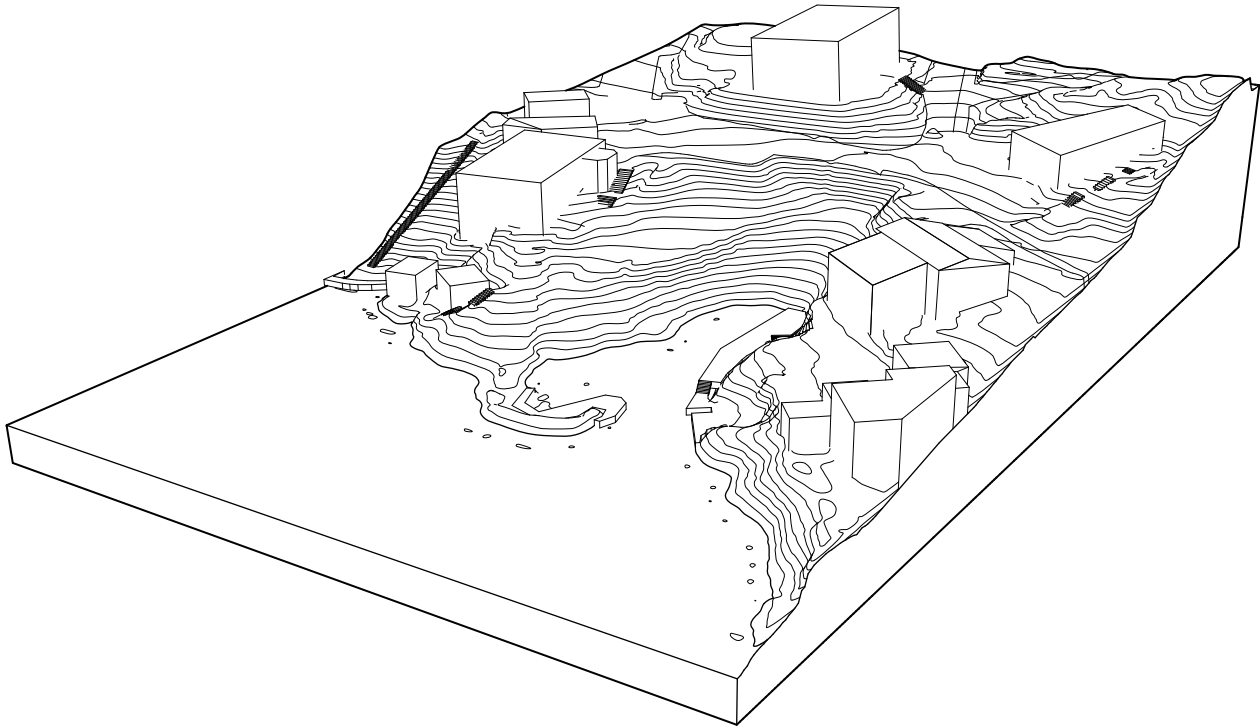


Figure 28. Illustration of site model, showing level of detail used in the early VR-sketching process.

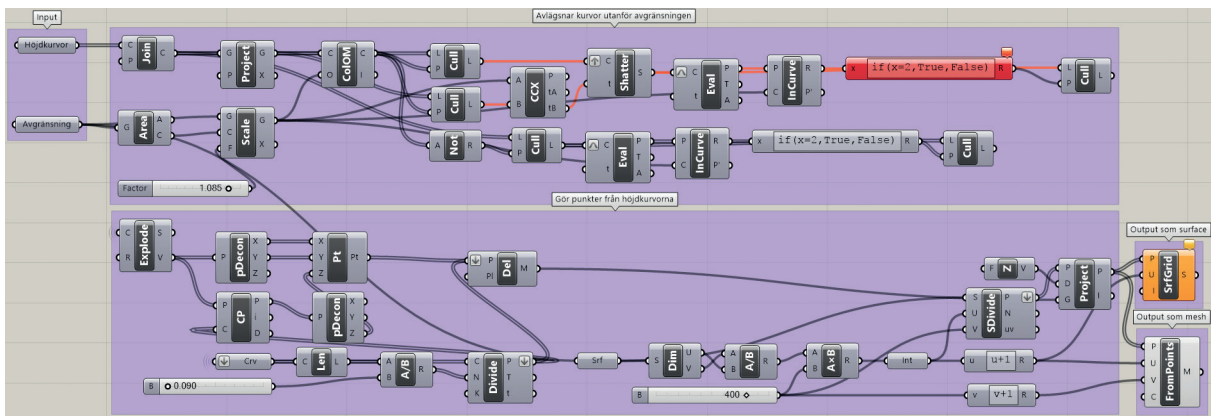


Figure 29. Grasshopper script used to extract a surface from height curves.

3.6.2 The Design

3.6.2a Organic Architecture

Hugo Häring was one of the generation of architects born in the 1880s that formed the modern movement in the 1920s, together with Walter Gropius, Ludwig Mies van der Rohe, Le Corbusier and others (Jones, 1999).

Häring, together with Hans Scharoun was leading an alternative modernistic tradition in Germany. This was an organic design philosophy with the ideas of rejecting formalism, to put emphases on function and plan rather than facade, and to work from the inside and out – from essence to appearance.

Jones (1999) goes on to state that Häring called his approach to architecture "New Building", and his theory is that functional form is determined by life, that it is natural, timeless, and anonymous. The opposite being expressional form that is a product of our senses, is bound to culture, and changes depending on time and place.

Häring thought that to move from the geometric to the organic is to let things evolve from the inside to the outside, like in nature. He felt

that we should let things show us its form, and that we should not impose a form onto it. In his late theory, Häring said that we never should imitate biological form, but rather follow the principles of nature.

Javier Senosiain, another organic architect, states that organic architecture is looking for three integrated aspects; the function, the construction, and the aesthetic. In contrast to Häring, Senosiain (2003) claims that organic architecture is characterized by consideration to culture, geographic location, and peoples cultural identity.

Senosiain also talks about how we can improve the human dwelling by integrating the three-dimensional quality of space and the fourth dimension, time. To do this, he states that we need to put aside the limitations of 2D-plans, and instead use a 3D-model. Then the fourth dimension is the time that the architect spends moving about, capturing the spatial experience.

3.6.2b The First Iteration

The first few sketches was a failure due to letting preconceived notions of how to draw come in the way. But when dropping these ideas, and embracing Häring's and Scharoun's thoughts on working from the inside and out, things began to fall into place.

In the first iteration of the villa, I began sketching from a spot that I had chosen for the kitchen — or rather the kitchen window facing towards the sea. With the site model to sketch in, together with photographs taken there, I could start by framing precisely the view desired. This precise framing is tuned to me, the architect, and my perspective. However, it can be adjusted to fit someone else, with the previous scale experiment in mind.

From there it was a matter of working my way through the rest of the kitchen, trying to let the context show me the way.

The result of everything in this way of working is very much connected to the body — how I move, how agile I am, and the length of my limbs.

This iteration turned out to not be feasible due to becoming overly heavy for the computer and being time consuming — sketching all walls in a 1:1 scale (see next page for illustrations).

With this in mind, I moved on to a simpler second iteration in which the focus lies on the outlines and general shape — that is then turned into surfaces on the computer.

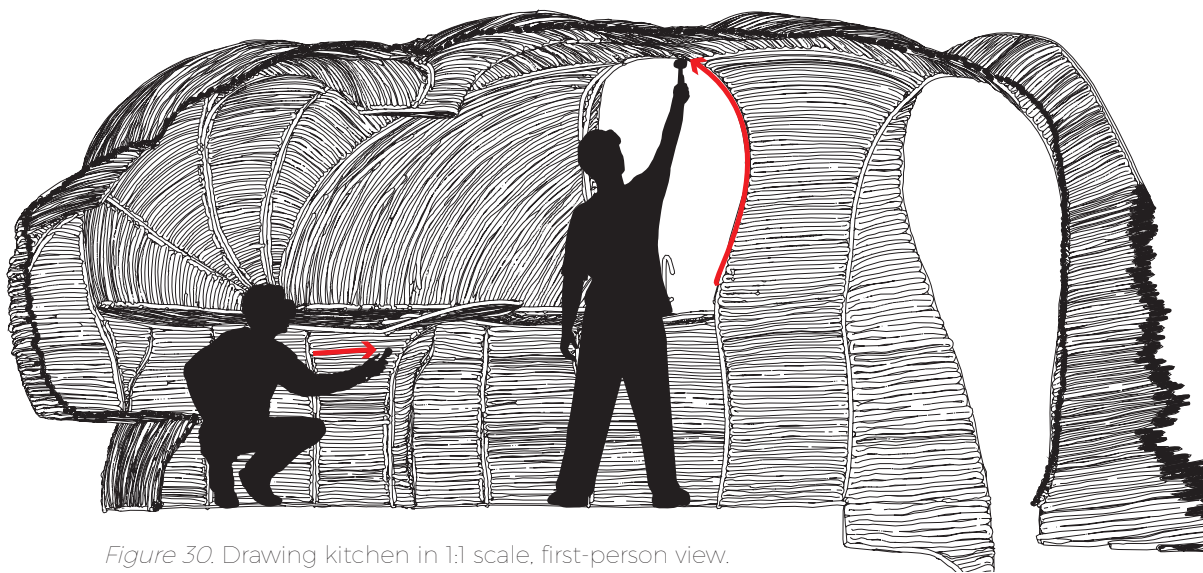


Figure 30. Drawing kitchen in 1:1 scale, first-person view.

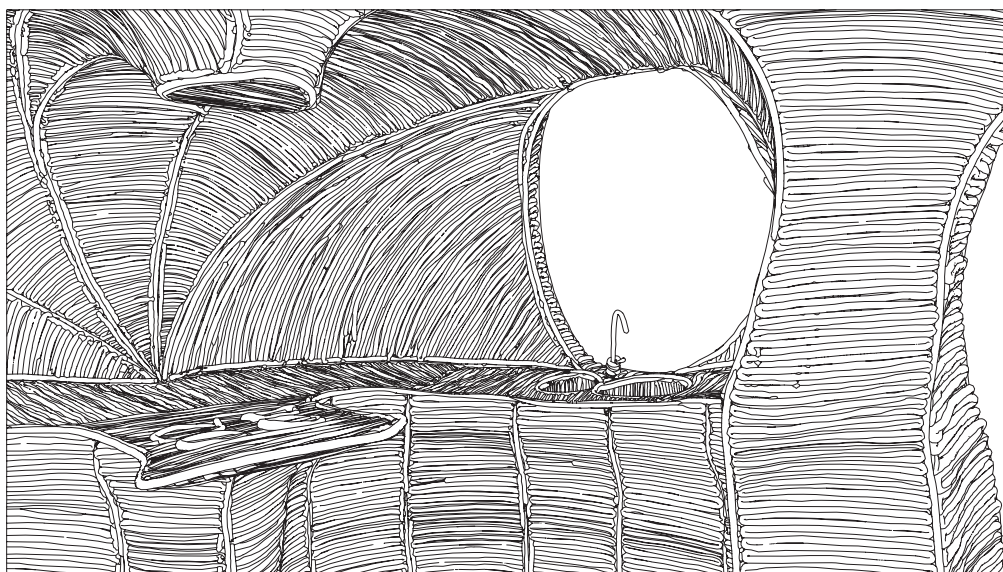


Figure 31. View inside kitchen, showing surfaces drawn in VR.

3.6.2c The Process

Taking the site model into Tilt Brush, we can sketch inside of a simple representation of the real world. This lets us do some of the site analysis simultaneously as designing. With direct feedback on spatial relations to the site, the views and what neighbours might see — if blocking their views or if they can see straight into the villa — we have the ability to instantly adapt to new conditions.

With a finished sketch, the next step is to export the model into Rhinoceros. Here we can trace the outlines and shapes with curves. These curves are then used to make surfaces. By making a small part at the time, the resulting surfaces are very close to what was intended from the start.

With the interior surfaces done we can import them back into Tilt Brush, and see if there are some changes that need to be done. If not, the exterior of the villa can be drawn. While the interior was drawn in 1:1 — to keep it related to the human scale — the exterior can be free from these limitations, since it is more connected to protecting the inside than to relate to the use of people.

In this case, another import into Tilt Brush was done to sketch the ground covering the villa. When this then is made into a surface in Rhinoceros, the experience is brought to VR, for others to see. The wanted features are added, for example free scale, VR-drawing, and others.

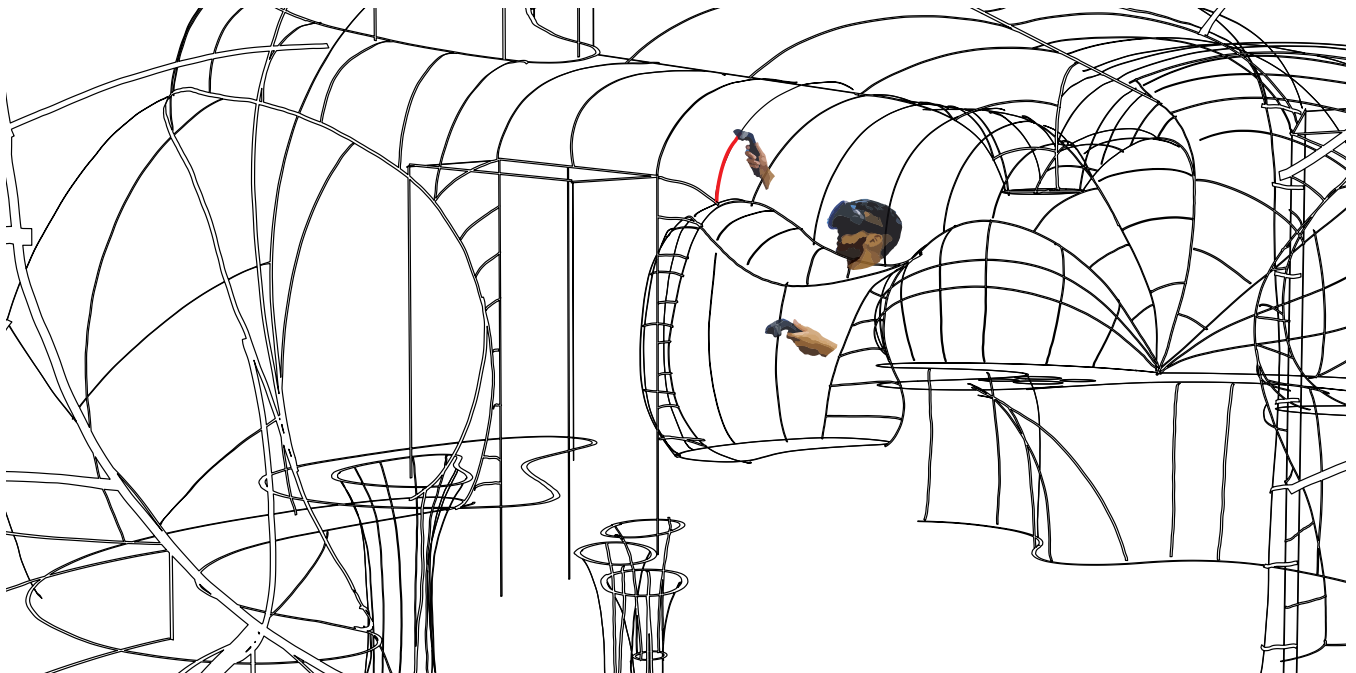


Figure 32. Second iteration of VR-sketching, this time only drawing outlines.

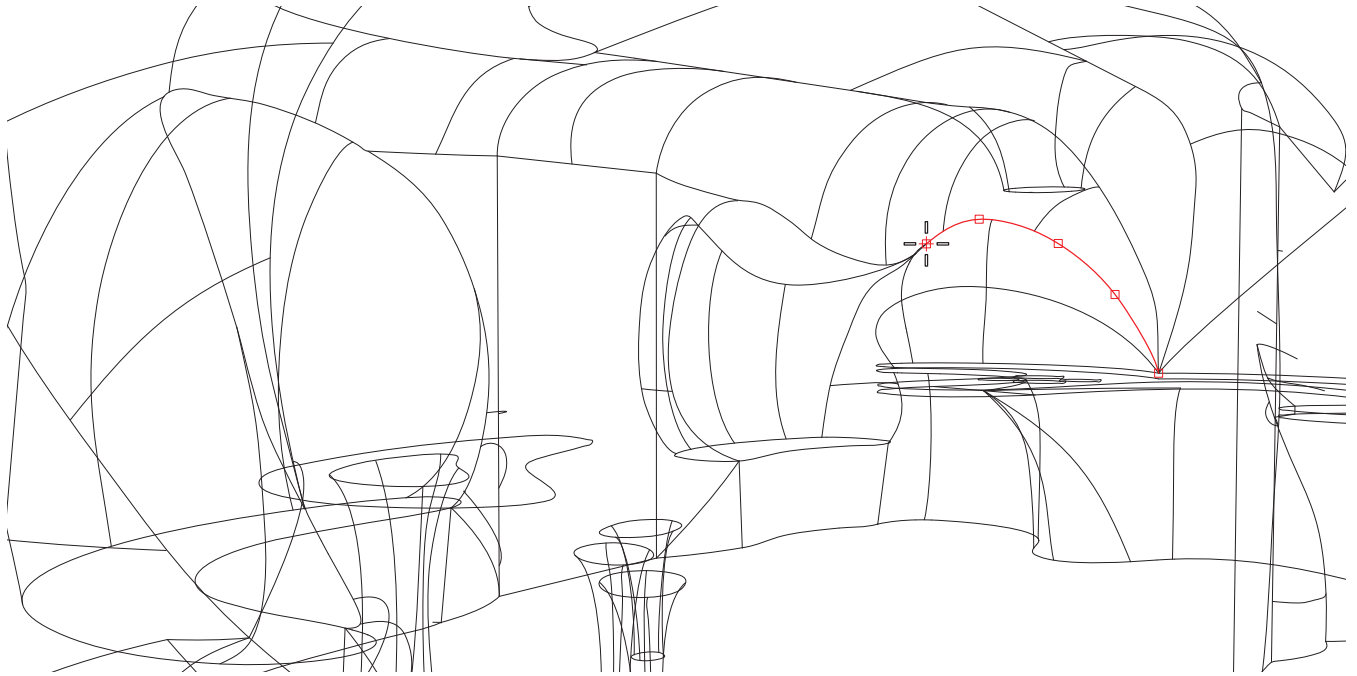


Figure 33. Tracing the sketch with interpolated curves in Rhinoceros.

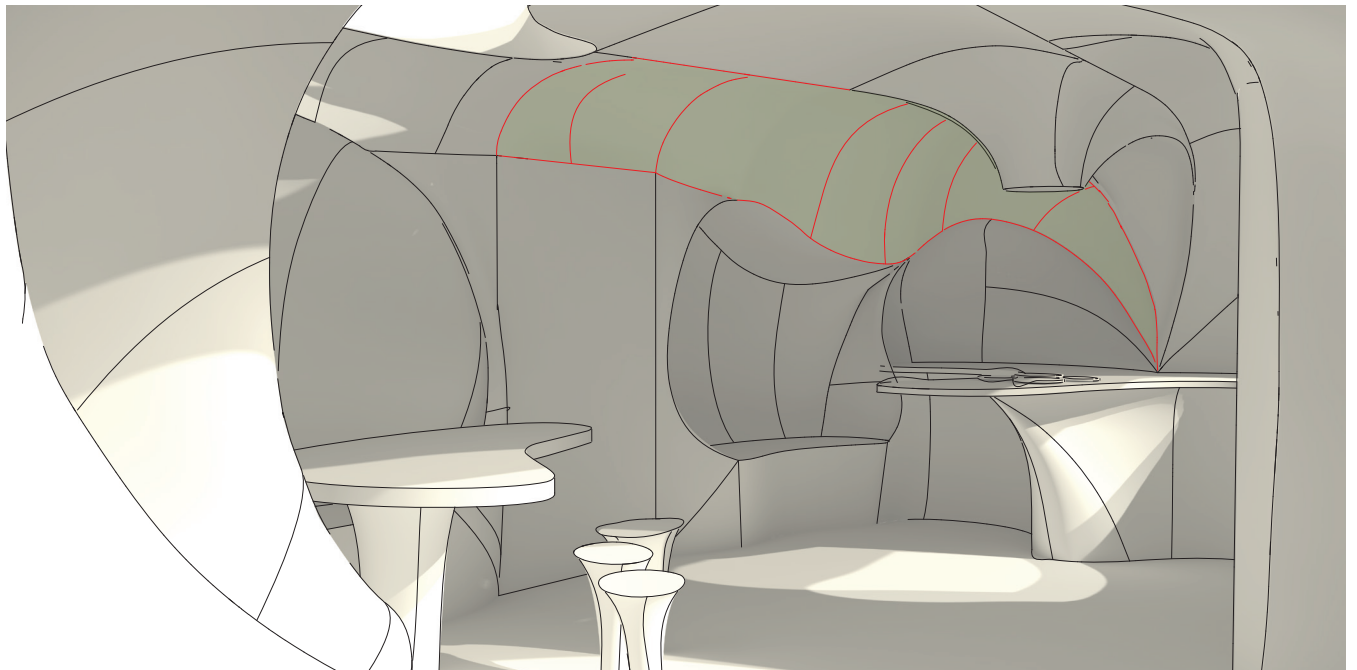


Figure 34. Making surfaces using a network of previously traced curves.

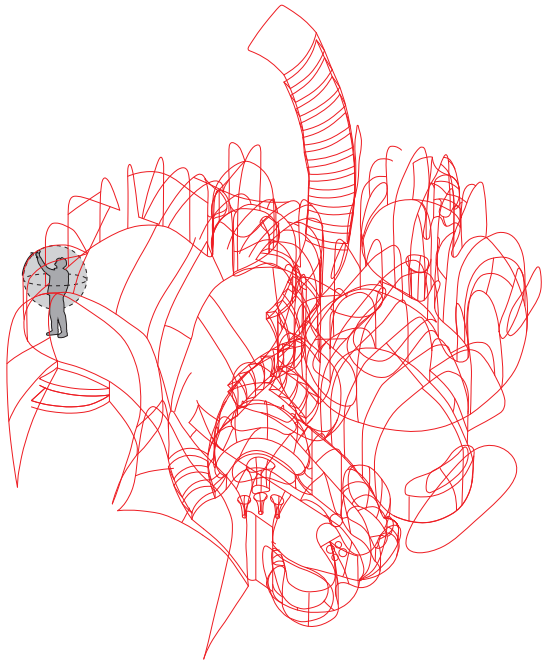


Figure 35. Interior of villa sketched in scale 1:1.

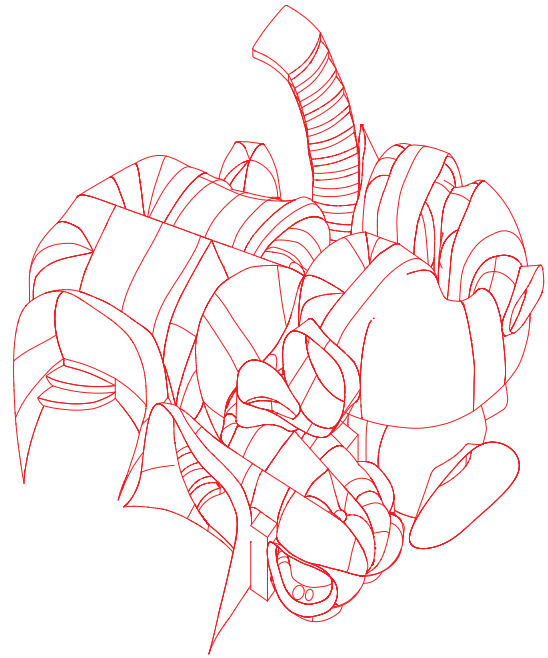


Figure 36. Sketched lines made into surfaces.

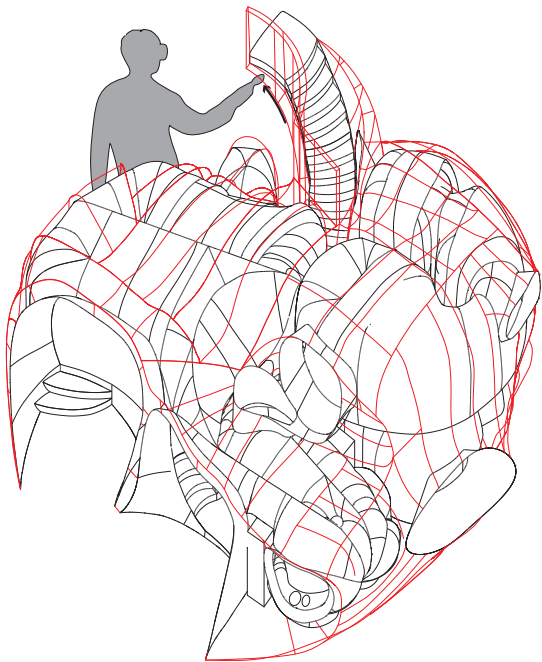


Figure 37. Exterior of villa sketched in varying scale.

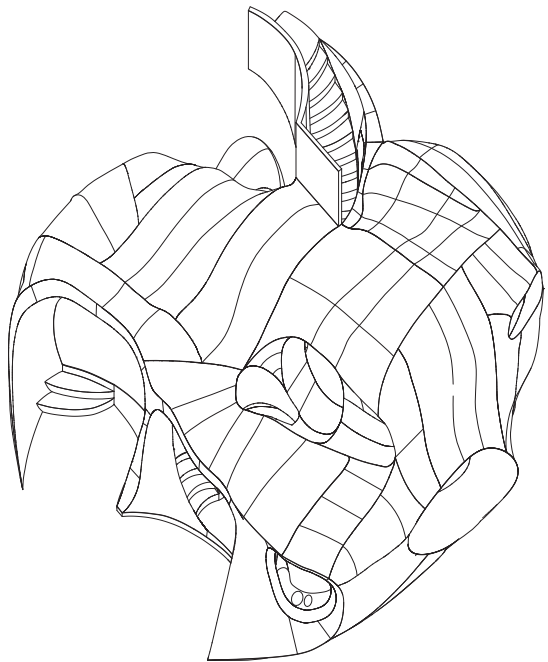


Figure 38. Sketched lines made into surfaces.

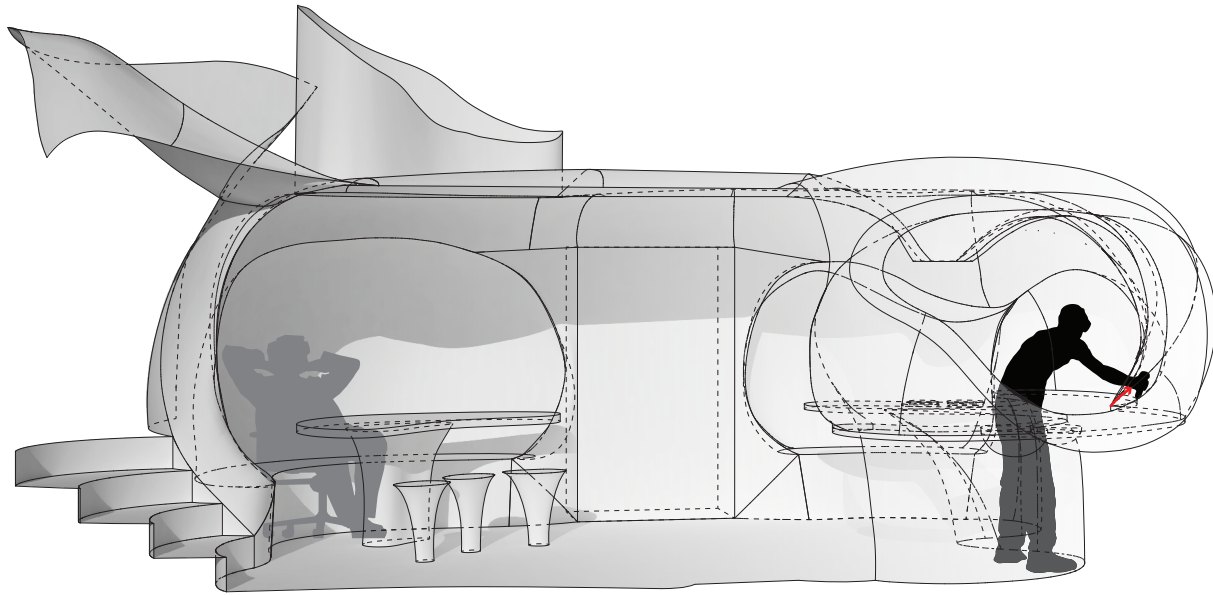


Figure 39. Illustration showing the concept of design, and how to use real objects as a frame of reference.

3.6.2d The Result

The resulting villa is a flirtation to the organic architects in many ways. The way it was designed — letting the shape grow from the inside to the outside. Covering the villa with earth, like some of Senosiain's work, protecting it from exterior fires, sounds and impacts. Also relating the interior to the human scale, optimizing the function of things to your own body.

The architecture is oddly shaped, almost without 90° angles. The plan took its shape starting in the kitchen, the first things being the window, sink, and counter top. Then making seating spaces by using my chair as a reference, and a table using my desk. Then moving on to the living room which is a few steps higher due

to the topography. From there the stairs up to the master bedroom follow the curved shapes. The bedroom's window is connected to the skylight of the kitchen. Around the corner there is space for clothing and the en suite bathroom. The design of the downstairs bedroom then took its shape. When doing the entrance stairs I could connect both the downstairs bedroom and the en suite bathroom, providing daylight even though most of the building is buried.

By this stage the appearance of the site model and the plot's neighbouring buildings have been made closer to that of the real world.

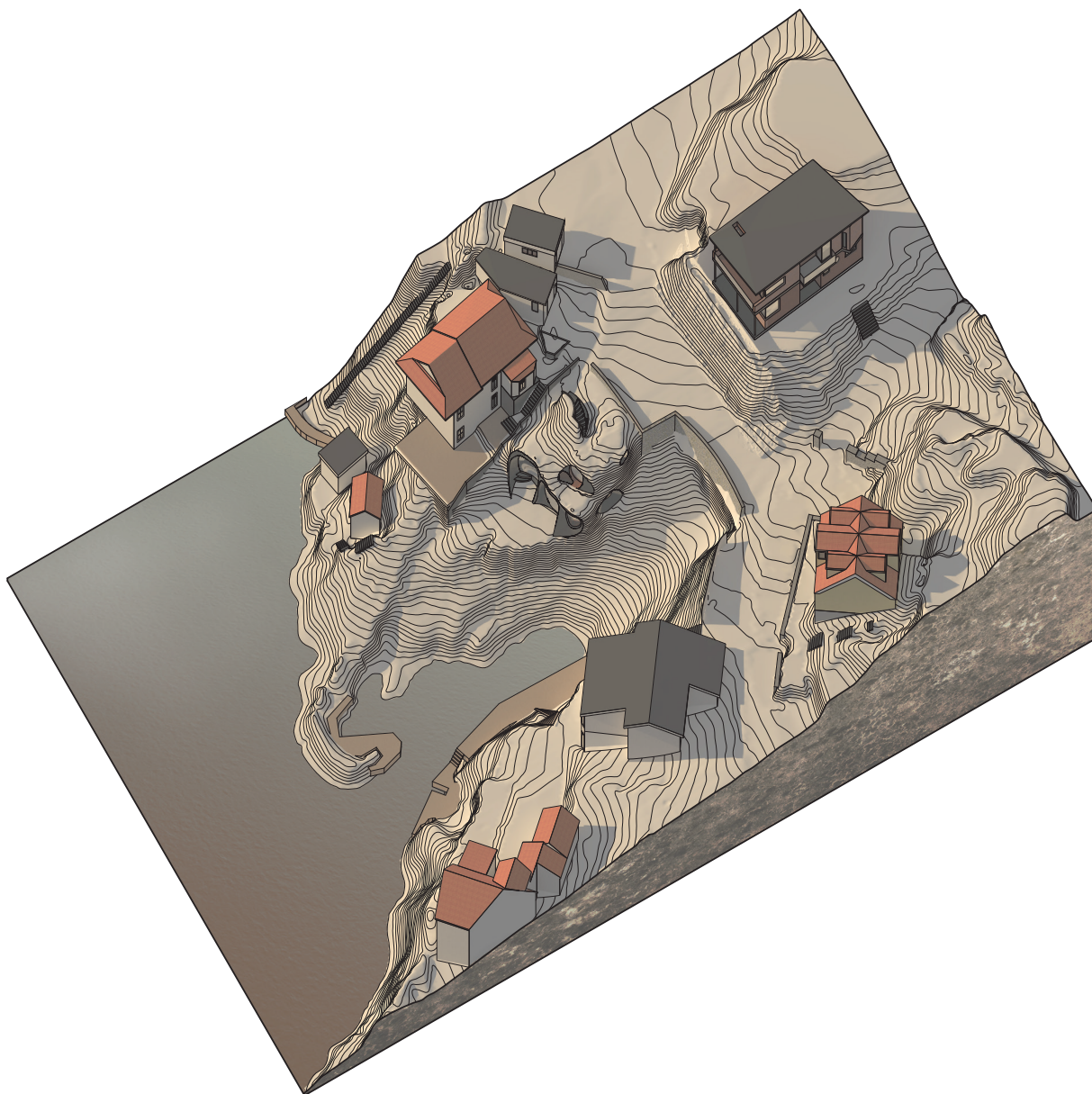


Figure 40. Axonometric view of site, showing the partly hidden villa in its context.

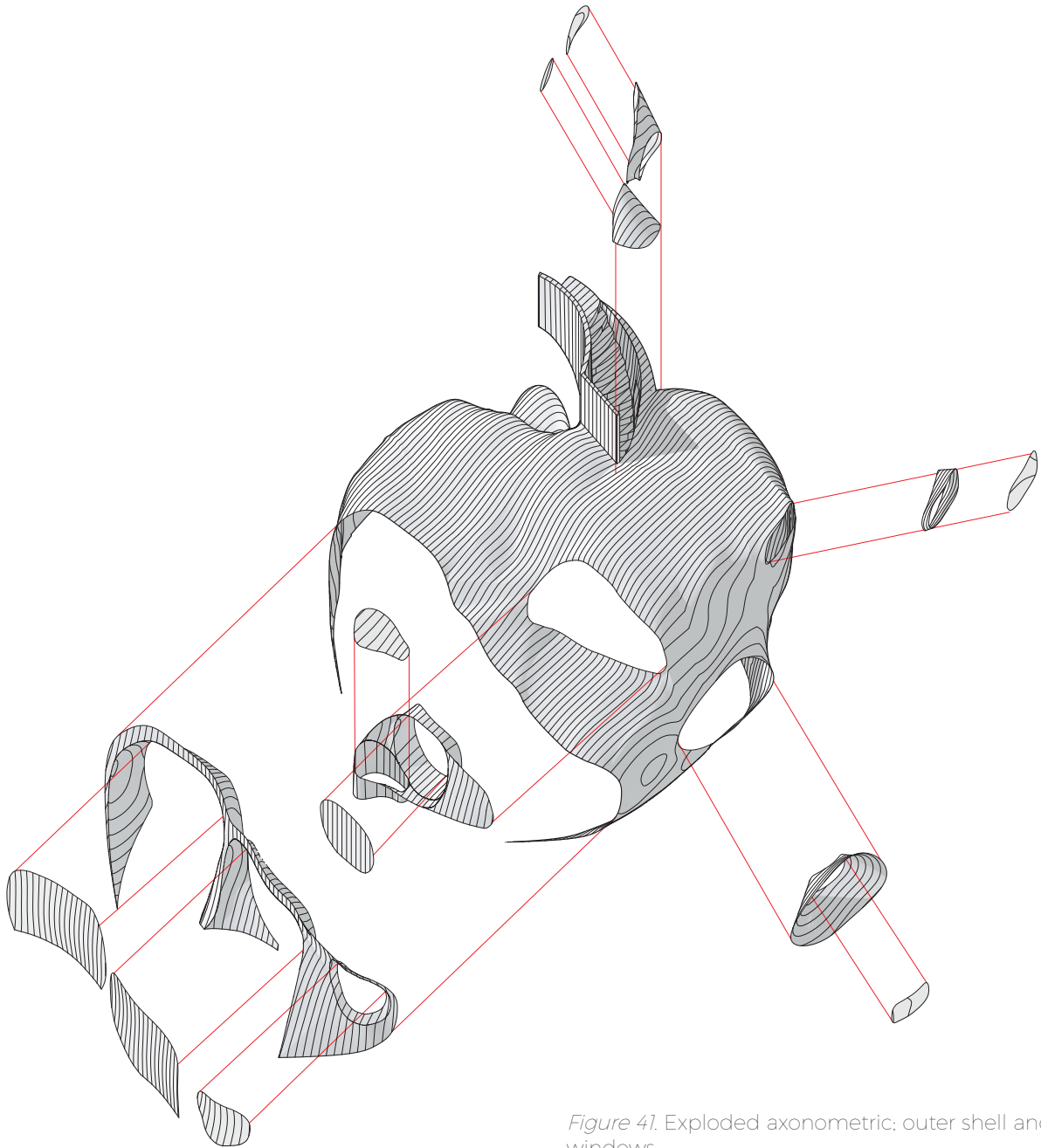


Figure 41. Exploded axonometric; outer shell and windows.

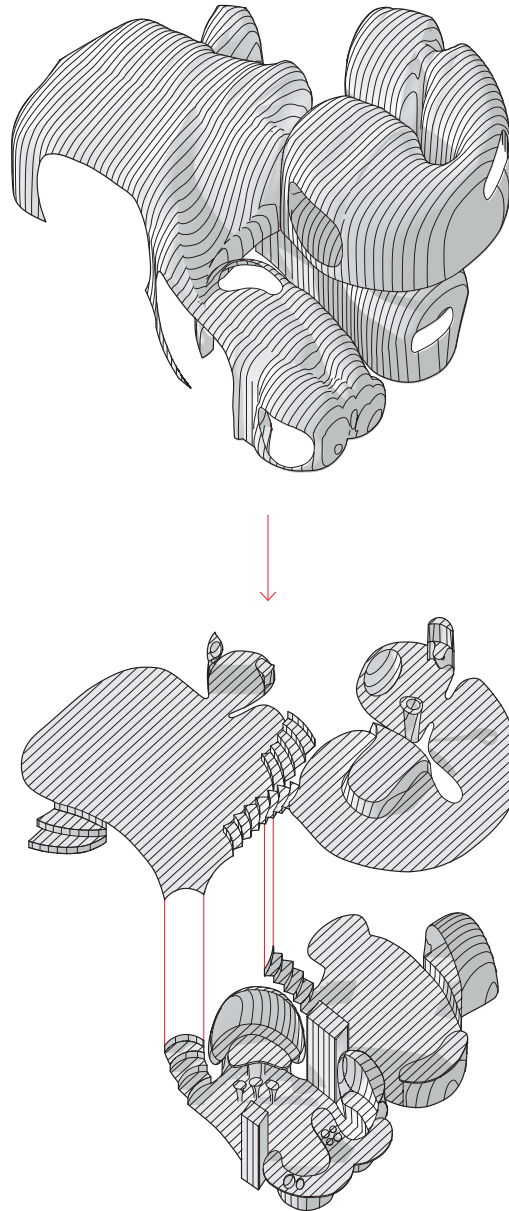


Figure 42. Exploded axonometric; inner shell and interior surfaces.

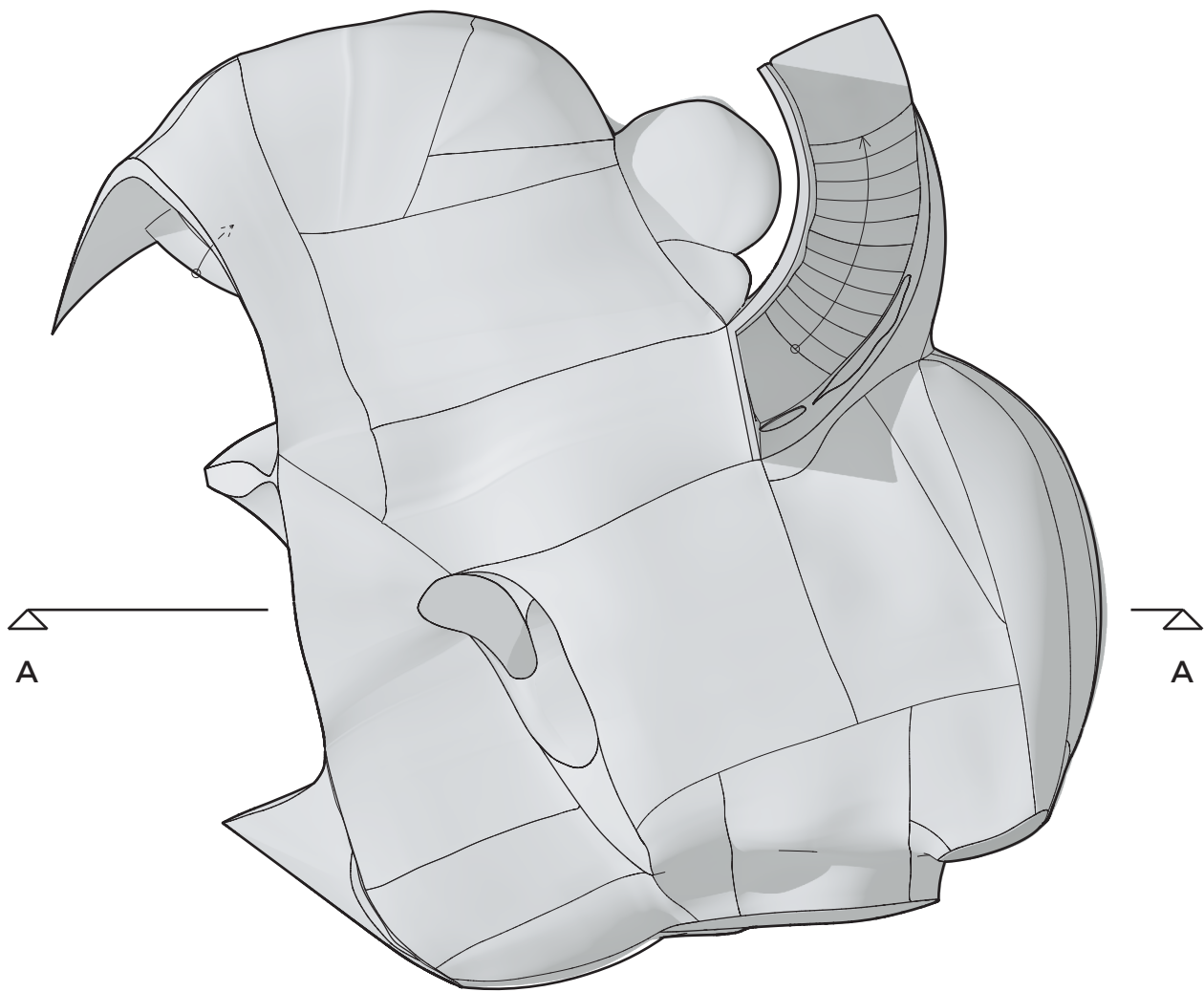


Figure 43. Villa from above (1:100).



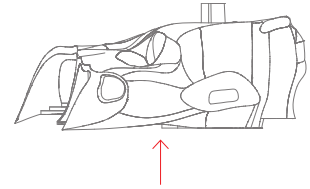


Figure 44. View of ceiling from underneath (1:100).



0 5 m
1:100

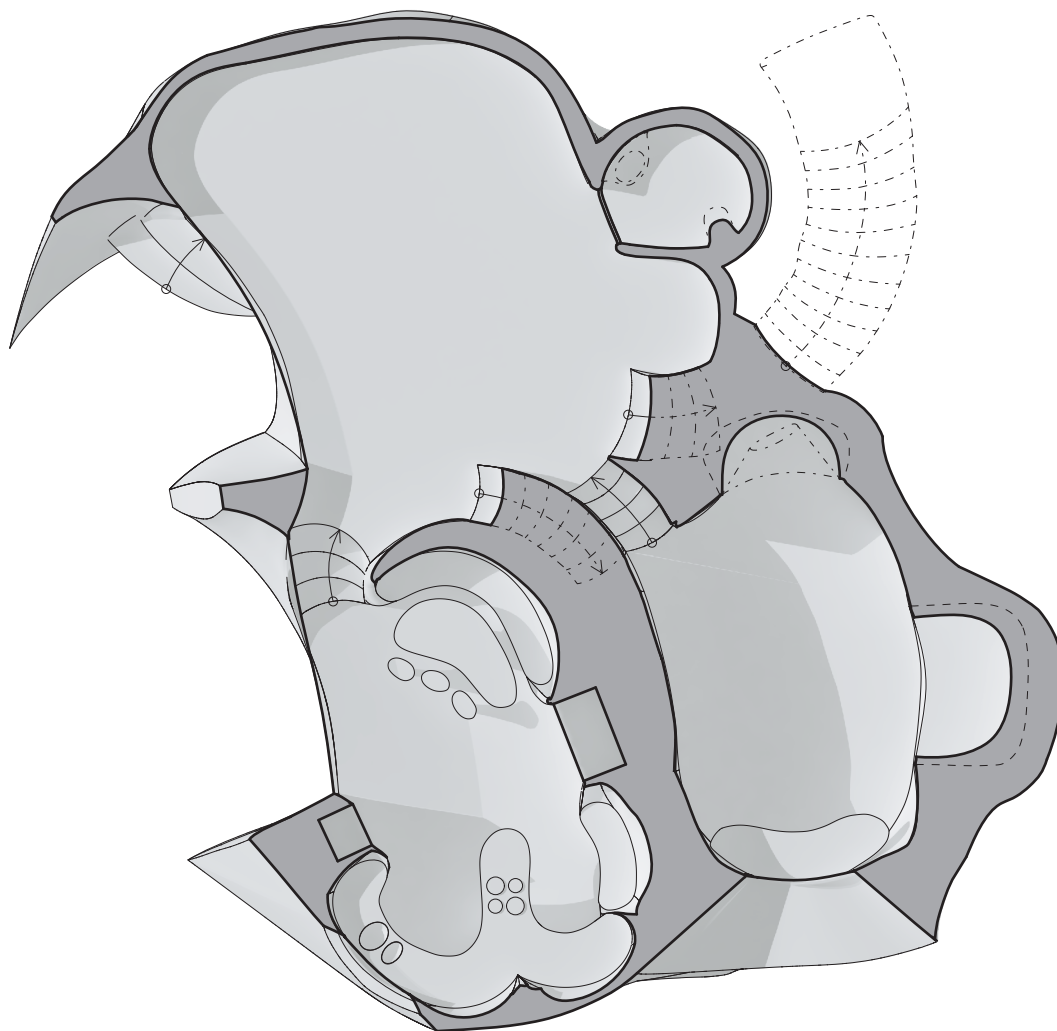
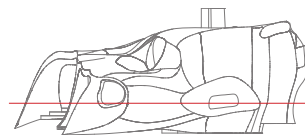


Figure 45. Plan of living room, kitchen, and bedroom (1:100).



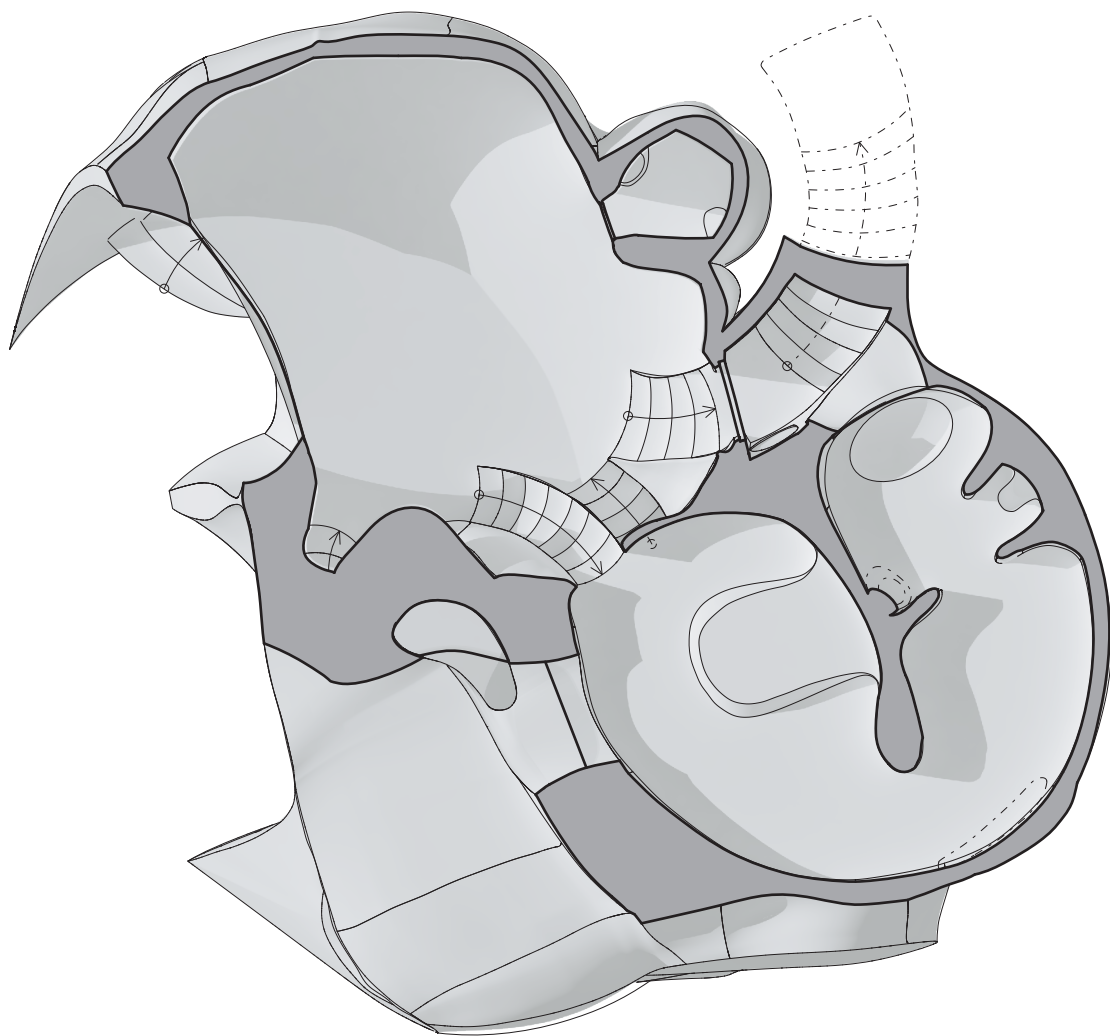
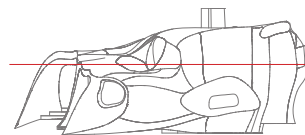


Figure 46. Plan of living room, and master bedroom (1:100).



0 5 m
1:100

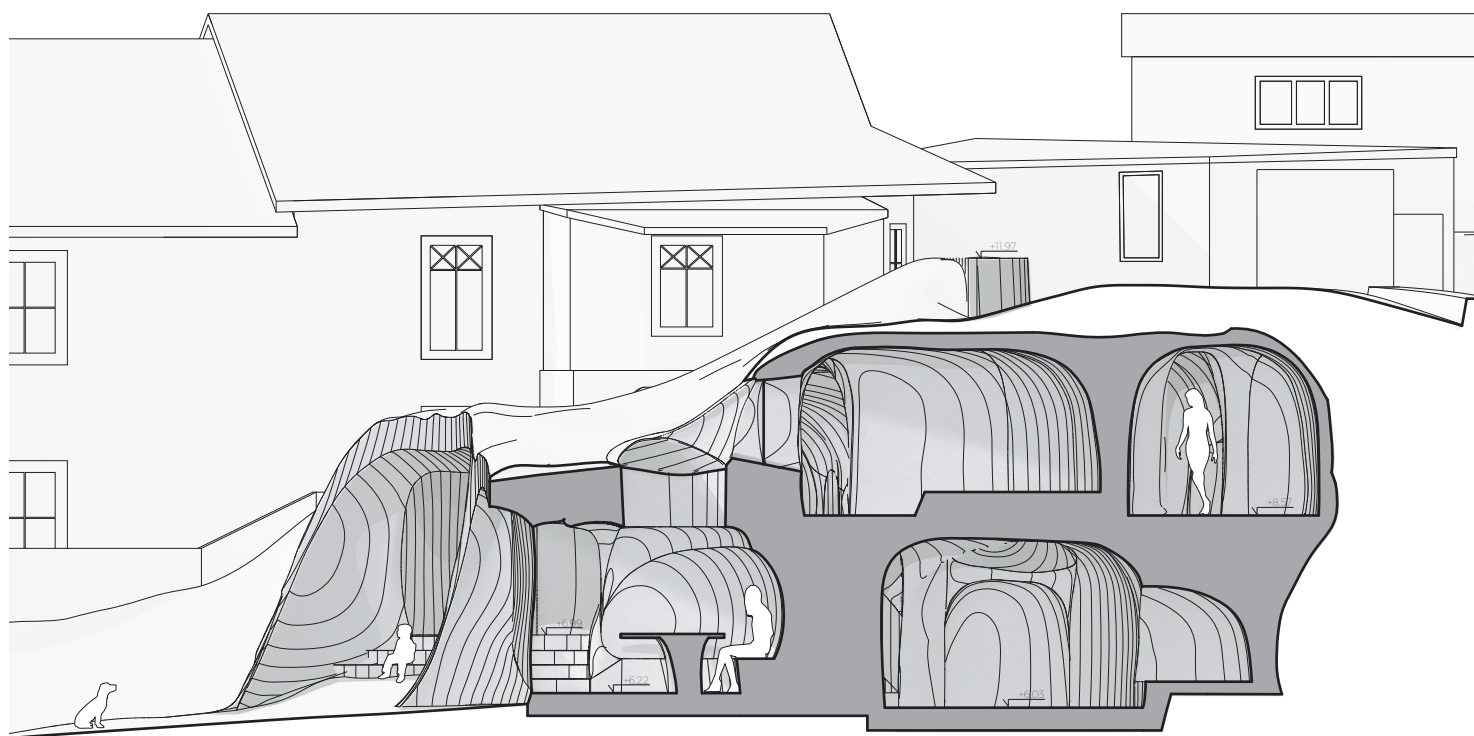
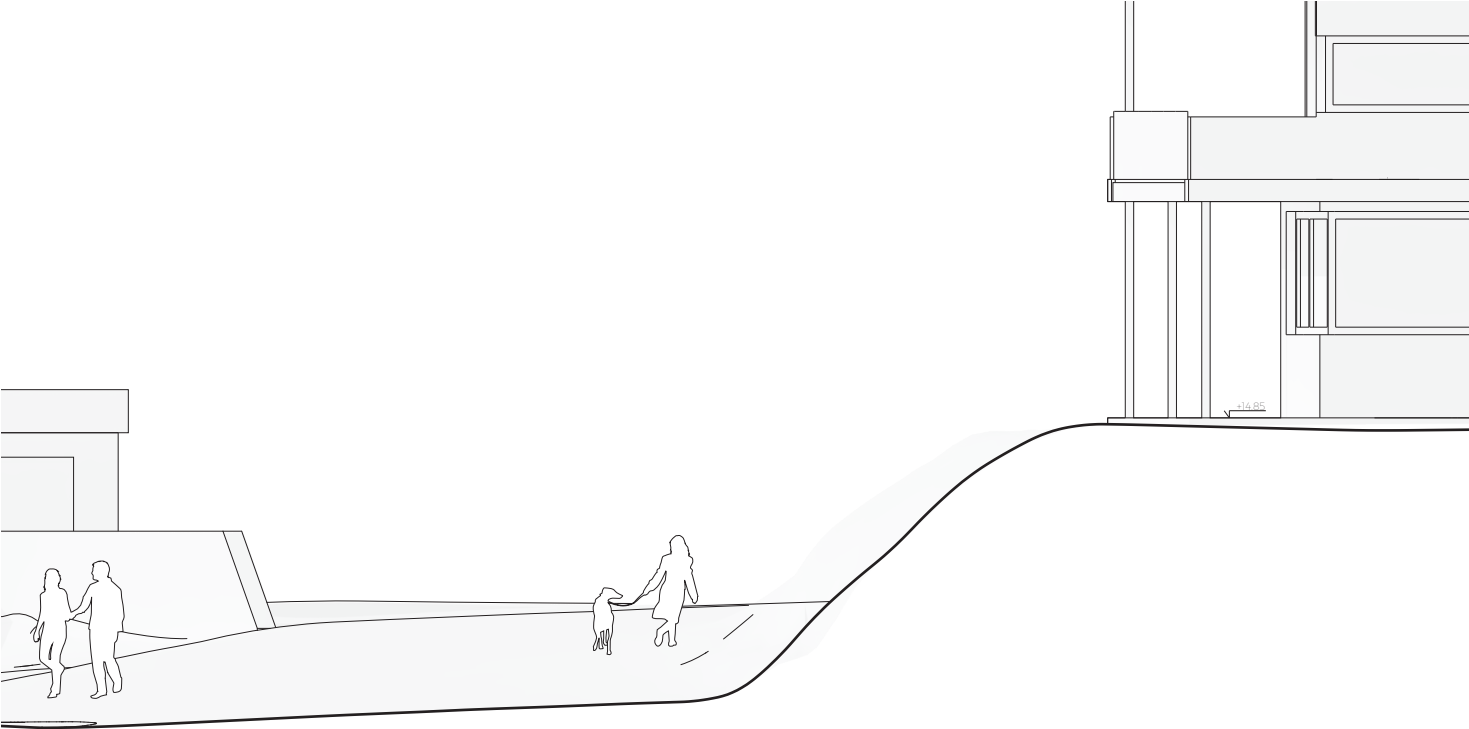


Figure 47. Section A-A (1:100).



4. The Demo

4.1 Immersion

To experience immersion is to perceive that you are physically in another place. In VR you can be immersed in almost any situation and place if done right.

The idea of the demos is to give the reader the chance to experience not only immersion but also get a better understanding of the experiments from previous parts.

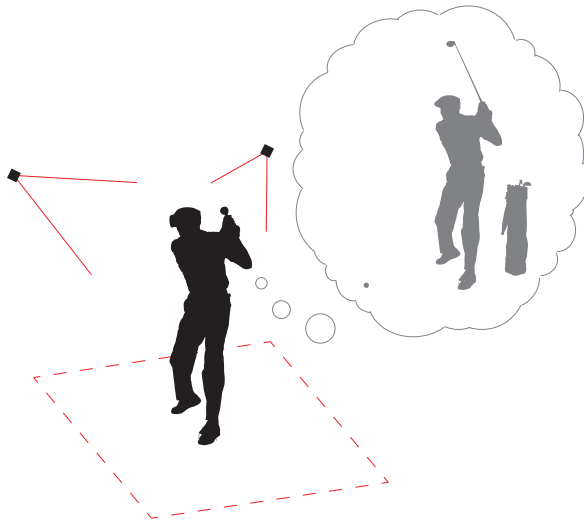


Figure 48. Illustration of immersion.

4.2 Different Scales

This demo (download link can be found under 4.4) aims to show the thought process when making changes to the apartment in part 3.5. It also lets the viewer experience some of the iterations in person.

4.3 The Villa

The villa-demo aims to show process, experiences and the resulting architecture.

In the demo you can test how VR-painting lets you sketch in new ways, and reflect over possibilities and limitations of the media.

The demo will also let you experience scale, from small to large in a step-less transition.

Like the previous demo, you can enter and exit a progress model to see an earlier stage in the design process.

And of course, the demo lets you see what the experiment led to architecturally.

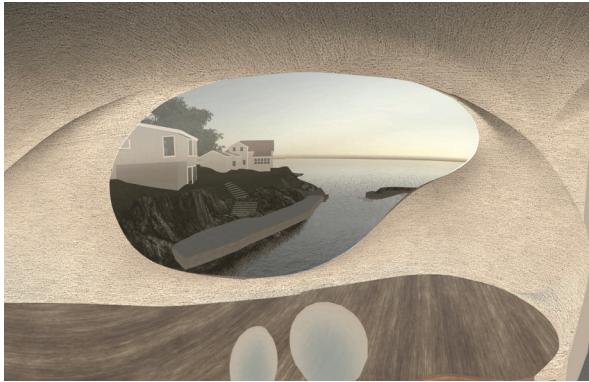


Figure 49. View in VR, kitchen window.



Figure 50. View in VR, kitchen.

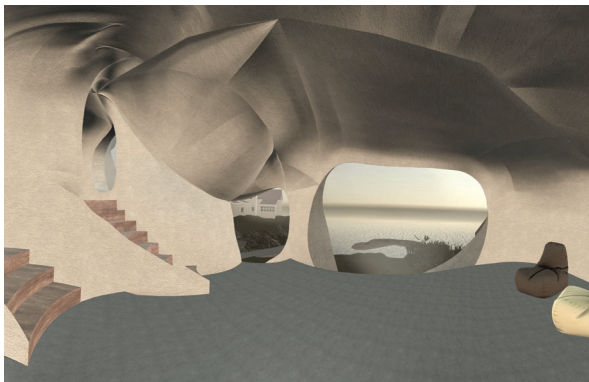


Figure 51. View in VR, living room.

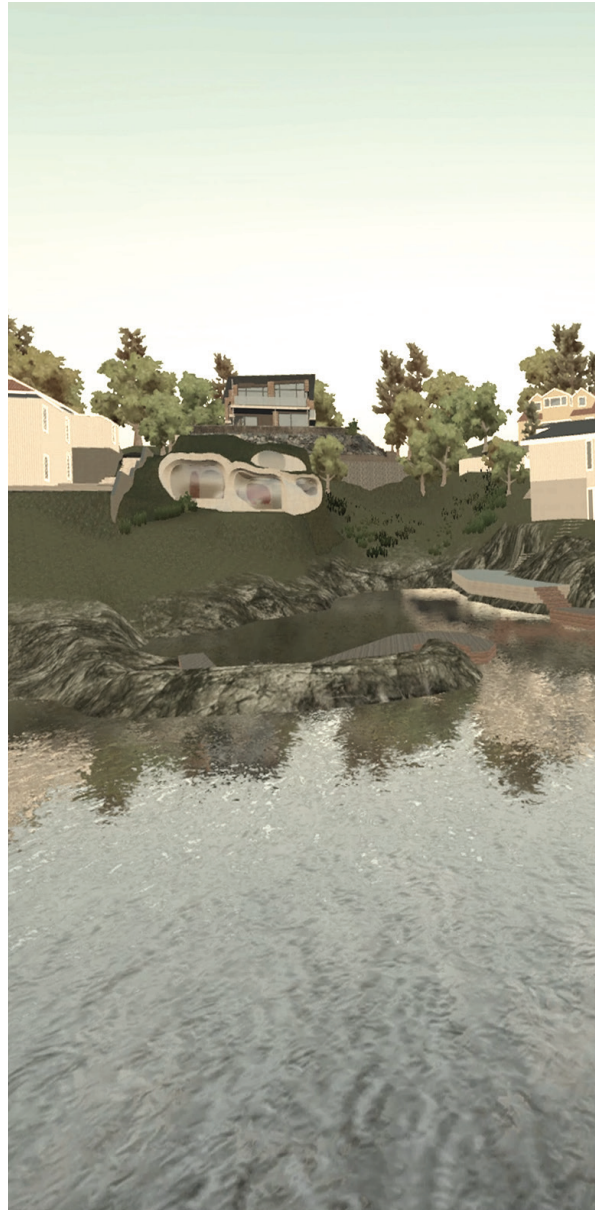


Figure 52. View in VR, site from sea.

4.4 Download Links

Different Scales, size: 285 MB

<https://tinyurl.com/y9bumkay>

In this demo you will be presented with a model of the apartment with the original design. On either side there are models with VR-sketched remarks, followed by models with changes applied. The last model shows the final design.

Models above the green mark can be viewed in full scale by pressing both trigger buttons when standing close to desired model. To return, press both trigger buttons again, anywhere in the apartment.

Models above the red mark have no interaction programmed.

How to use the controllers in the scales demo:

- 1 Teleportation.
- 2 Press on both controllers to enter/exit models.
- 3 Not used in this demo.

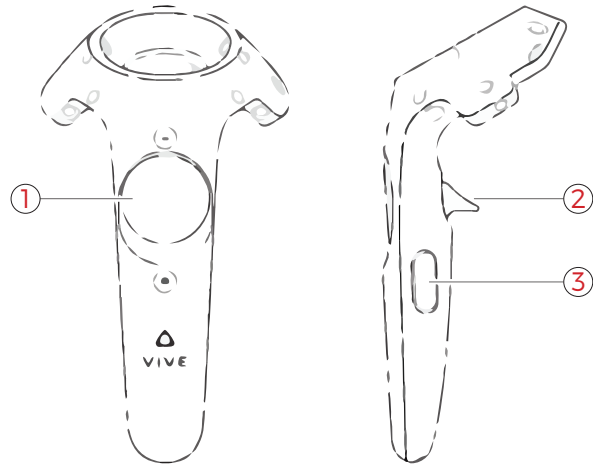


Figure 53. Illustration of HTC Vive Controllers.

The Villa, size 445 MB

<https://tinyurl.com/y79zghoc>

In this demo you start by standing outside on the road where you can see the photogrammetry stone wall from part 3.4 on one side and the sea on the other. Following the path of teleportation points you are led to the villa.

In the villa you can experience not only the architecture, but also how it was drawn in VR. You can also experience everything when being between one tenth to ten times your size.

How to use the controllers in the villa demo:

- 1 Teleportation.
- 2 Reset your size by pressing on left controller. Draw in 3D-space by pressing and holding on right controller. Press on both controllers to enter/exit models.
- 3 Change your size by holding on both controllers while moving hands together or apart.

5. Discussion

One of the main things VR brings to architecture is to connect the design and sketching to function and form in the human scale in an unparalleled way. There is no way to compare drawing on a computer screen to actually using your body to find the proportions needed if the functions sought is connected to the use of humans. One of the natural consequences of using the body to find forms is that it will be adapted to the architect. Since no two persons are exactly alike, the design might be too individualistic.

The design of the villa turned out to be something I had never imagined from the start. I could never have made this design with any other means than through VR. The intricate shapes of the interior could not be repeated with 2D-drawings, considering the way the walls and roofs intertwine.

Perhaps VR-sketching is the contemporary way of following Senosiain's ideas of leaving 2D-plans for three dimensions and implementing the fourth dimension in design — the time spent making the spatial experience.

Since the field of VR is rapidly developing, things that could not be done during the experimentations might now be possible. The process of the design might to some seem unnecessar-

ily complicated, but at the time there were no options available. Some of the thesis came to be about finding a new workflow as a consequence. But with the speed things are progressing the technology might soon catch up to conventional tools.

One of the strong points with this workflow is the connection to the context. With a detailed model, the feedback regarding site specific conditions is instant. Both positive effects as well as negative can quickly be discovered.

Designing in VR can influence the result in different ways, in this case the shape, layout, furniture, and more was affected. Contributing factors was of course the influence of the organic architecture and the software used. The result could have been something totally different with other influences, but working with VR will always be different from working on a computer screen, no matter if it is 2D-drawings or 3D-modeling.

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Image References

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Figure 1. Davepave (2006). Holmes stereoscope [photography]. Available from https://commons.wikimedia.org/wiki/File:Holmes_stereoscope.jpg (CC BY 2.5) <https://creativecommons.org/licenses/by/2.5/>

Figure 2. Minecraftpsyco (2016). The Sensorama machine [photography]. Available from <https://en.wikipedia.org/wiki/Sensorama#/media/File:Sensorama-morton-heilig-virtual-reality-head-set.jpg> (CC BY-SA 4.0) <https://creativecommons.org/licenses/by-sa/4.0/>

Figure 3. Smurrayinchester (2010). Mori Uncanny Valley [reworked and translated illustration]. Available from https://commons.wikimedia.org/wiki/File:Mori_Uncanny_Valley.svg#/media/File:Mori_Uncanny_Valley_sv.svg (CC BY-SA 3.0) <https://creativecommons.org/licenses/by-sa/3.0/>

Figure 4. BagoGames (2016). HTC Vive Now Up For Pre-Order [photography]. Available from <https://www.flickr.com/photos/bagogames/25845851080> (CC BY 2.0) <https://creativecommons.org/licenses/by/2.0/>

Figure 10. Unknown author (n.d.). Untitled image of a brick wall [reworked: added normal map]. Available from <https://i.pinimg.com/originals/ea/00/62/ea0062963b8e1dd2af03497cec8eb4bf.jpg> (CC0 1.0) <https://creativecommons.org/public-domain/zero/1.0/>

