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&ADAPT TO NATURE
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An exploration of design in consideration with immediate surroundings

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Department of Architecture and Civil Engineering

Examiner: Daniel Norell

Supervisor: Emil Adiels

2020

ADD & ADAPT TO NATURE

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Master Thesis

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Department of Architecture and Civil Engineering

Master Program: Architecture and Planning Beyond Sustainability
Direction: Matter Space Structure

Examiner: Daniel Norell
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QUOTES

“Man has been here 32,000 years. That it took a hundred million years to prepare the world for him is proof that that is what it was done for. I suppose it is. I dunno.
If the Eiffel tower were now representing the world’s age, the skin of paint on the pinnacle-knob at its summit would represent man’s share of that age; & anybody would perceive that that skin was what the tower was built for. I reckon they would. I dunno.”

-Mark Twain

“We can not solve our problems with the same thinking we used when we created them.”

- Albert Einstein

“In order to change an existing paradigm you do not struggle to try and change the problematic model. You create a new model and make the old one obsolete.”

- R. Buckminster Fuller

“Nothing is invented, for it's written in nature first.”

- Antoni Gaudí

“Nature is a much smarter architect than us. As we continue our collective quest for a more responsive ‘living’ architecture, we will increasingly blur the boundaries between the worlds of the natural and the artificial. What if tomorrow we might be able to program matter to ‘grow a house’ like a plant?”

-Carlo Ratti

‘If the age of the Earth were a calendar year and today were a breath before midnight on New Year’s Eve, we showed up a scant fifteen minutes ago, and all of recorded history has blinked by in the last sixty seconds. Luckily for us, our planet-mates --the fantastic meshwork of plants, animals, and microbes-- have been patiently perfecting their wares since March, an incredible 3.8 billion years since the first bacteria. ...After 3.8 billion years of research and development, failures are fossils, and what surrounds us is the secret to survival.”

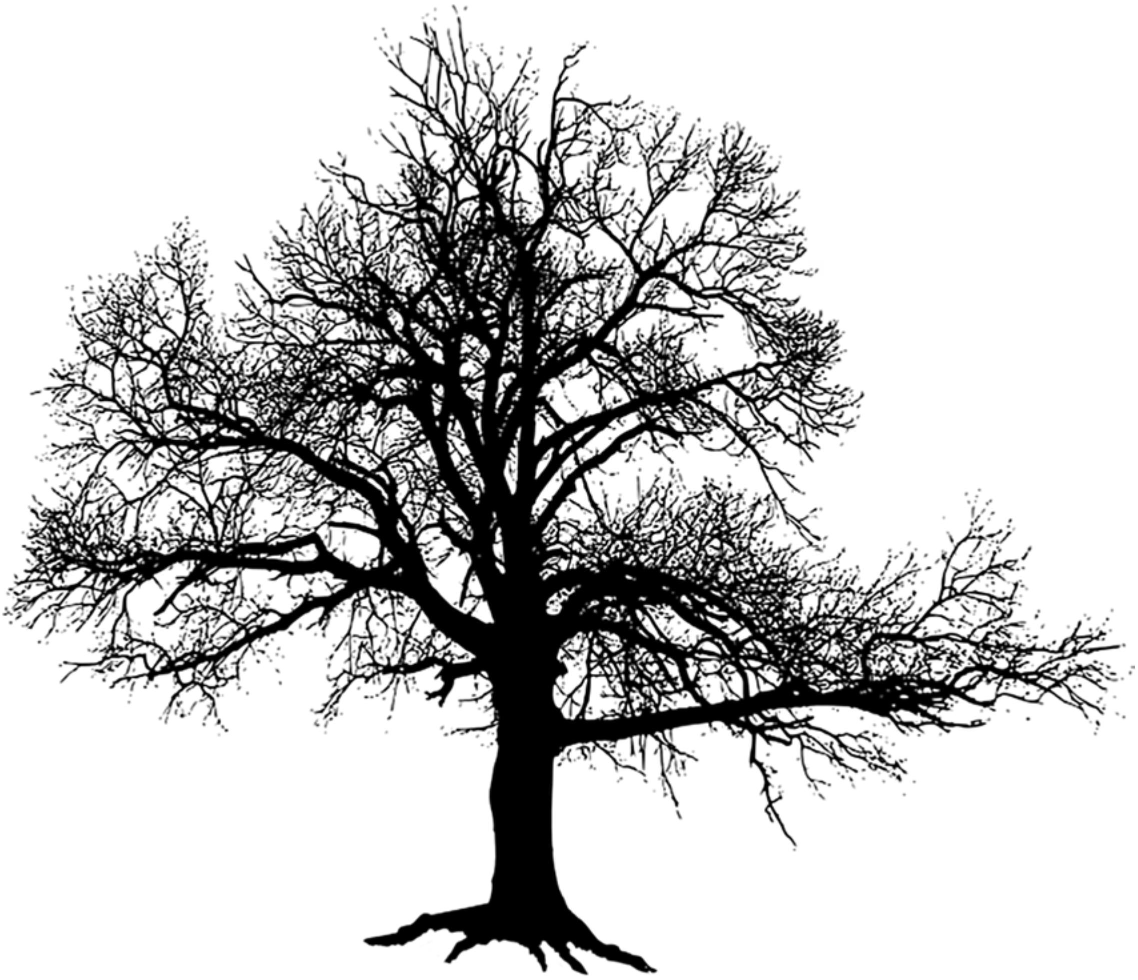
“What if, every time I started to invent something, I asked, ‘How would nature solve this?’”

- Janine Benyus

”Nature is much better at designing things than we are. Gardens should be integrated seamlessly into everything; there is a reason being banished from a garden was the most terrible fate God could think to inflict on humankind.”

-Brianna Rennix & Nathan J. Robinson

The surrounding context is involved in the decision of shape for a tree. What if buildings were designed this way? (Birch tree at Mossen)



Add & Adapt to Nature

ABSTRACT

Albert Einstein famously quoted -"We can not solve our problems with the same thinking we used when we created them".

For thousands of years humans have looked upon themselves as apart from nature and since the industrial revolution this misconception has increased even further. It is shown very clearly through the way we build today.
Opposite to the way nature works, through adding and adapting to the existing context, humans adapt the context to suit the building, by first clearing the site to start with a clean slate.

This thesis explores a new way of designing and building with the use of high tech equipment in difficult terrain. It is an exploration covering 3D scanning with the use of a depth camera to build a highly detailed digital model of a site. Computational design of three buildings adapted to what exists on the site and finally, full scale 3D printing with the use of a mobile 3D printer using alternative additive building materials such as clay and biopolymer basalt composite.

The end result is a prototype of a 3D printed extension to a preschool tightly intertwined with its site, while also adding to the ecosystem through walls and roofs clad in greenery.

Research shows that there is a correlation between mental health and time spent in nature. If buildings and nature are weaved together, could this have a positive effect on our well-being?

The purpose of the thesis is to expand the concept of sustainable building and to blur the distinction between building and nature.

Keywords:
3D Scanning, Computational design, 3D printing, Alternative materials, Sustainability, Building Development.

ABOUT THE AUTHOR

As a kid growing up on a farm, I had great freedom in exploring and playing out in the wild nature. I think this is one of the reasons why I have always felt a strong connection to it.

I have also from early years been interested in how things work and always tore my toys apart and then rebuilt them just to understand their functions.
This led me into to a 13 year fling with the electronics industry where I worked with repairing and fixing broken things.

When I was on parental leave in 2010 I started to re-evaluate my choice of profession and decided to go back to school to become an architect. I had come to the conclusion that maybe here I could make an impact on an industry that leaves a huge footprint on the planet. So once again I am trying to fix something. This time hopefully before it is fully broken.

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I also wish to thank my supervisor Emil Adiels and my examiners Morten Lund and Daniel Norell for believing in my ideas and helping me putting them together.

CLAIM

For thousands of years humans have looked upon themselves as apart from nature and this shows clearly through the way we build today.

If we draw inspiration from how nature grows and translate this with the help of today's available technologies, we can work with nature instead of against it.

With this project I hope to produce new knowledge within the realm of sustainable building.

READING INSTRUCTIONS

DISCOURSE
An explanation of the overall theme of this master's thesis.

PURPOSE AND AIM
Here the aim with the exploration is explained.

QUESTIONS
The thesis questions.

BACKGROUND
A deeper explanation to the reason why I choose to write this master's thesis.

METHOD
An outline of the methods chosen as tools to work forward

THEORY
Reference projects.

DELIMITATIONS
Explanation of the delimitations to keep the thesis on track.

ANALYSIS
This chapter covers information about the specific site and the technology used to build a 3D model of it.

DESIGN
In this chapter I explain about the building and how I have worked with modeling and the process towards the final design.

3D PRINTING
This chapter covers the full scale 3D printing technology as it is used today and how it might be used in the future.

RESULT
Here the complete project is shown and explained.

DISCUSSION
This chapter wraps up the project and the conclusions made in the process..

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A decaying leaf with its tree like pattern showing fractals of nature

PART I

INTRODUCTION

DISCOURSE

With the use of bulldozers and explosives we carelessly start the building process with the site as a clean slate. If we draw inspiration from nature and how it grows and translate this with the help of today's available technologies into new ways of building, we can transform the industry to become more humble. We add and adapt to what already exists on site.

Through research and experimentation, I will design a building that is adapted to its surroundings with minimum interference on the existing inhabitants of the site. The purpose is to expand the concept of sustainable building and to blur the distinction between building and nature.
In detail, I will explore a way of designing buildings with the use of 3D scanning in tough terrain, to produce a detailed site plan. With the site plan as input, a building is designed and then produced using 3D printing.

3D printing technology within architecture has endless opportunities and this could make us look at architecture in a whole new way and create a more holistic building development where buildings are not foreign objects but rather part of the environment.

Keywords:
Computational design, 3D Scanning, 3D printing, Alternative materials, Sustainability, Building Development.

Drone photage of the site straight from above.

PURPOSE AND AIM

The aim is:

- to investigate an alternative way of building.
- to build without leaving imprints on the surrounding nature.
- to explore a new way to relate to the context.
- to produce new knowledge

The method should be applicable to any context, and the reason why a site with tough terrain is chosen is to challenge the methods used. A forest site is very complicated with multiple obstacles like trees and tough terrain that needs consideration. If the methods work in the forest they will work in most land-based contexts.

With a scan of the site, the buildings created get a diverse design and mass-production is possible without uniformity. Another reason to the scan is that the structures can be placed in or at the edge of forests or places inappropriate for farming. The 3D scan also works as a way to mimic the limits that a tree finds during its growth and through this the building is adapted to the site without affecting existing inhabitants like trees and other growing plants in a negative way.

Rather than a limitation to the architects work these methods can be used as tools so the architect can focus more on the final design.

Due to the absence of chemicals used in production the building can be left to decay and go back into the ground without affecting the life of microorganisms and plants after its intended use.

Through the methods used I hope to better understand the way nature designs and from this inspire others to build with respect for the existing nature on site.

QUESTIONS

Can the existing landscape be used as canvas for a building i.e. no leveling of the ground needed?

What are the limitations within geometry for 3D printing in full scale?

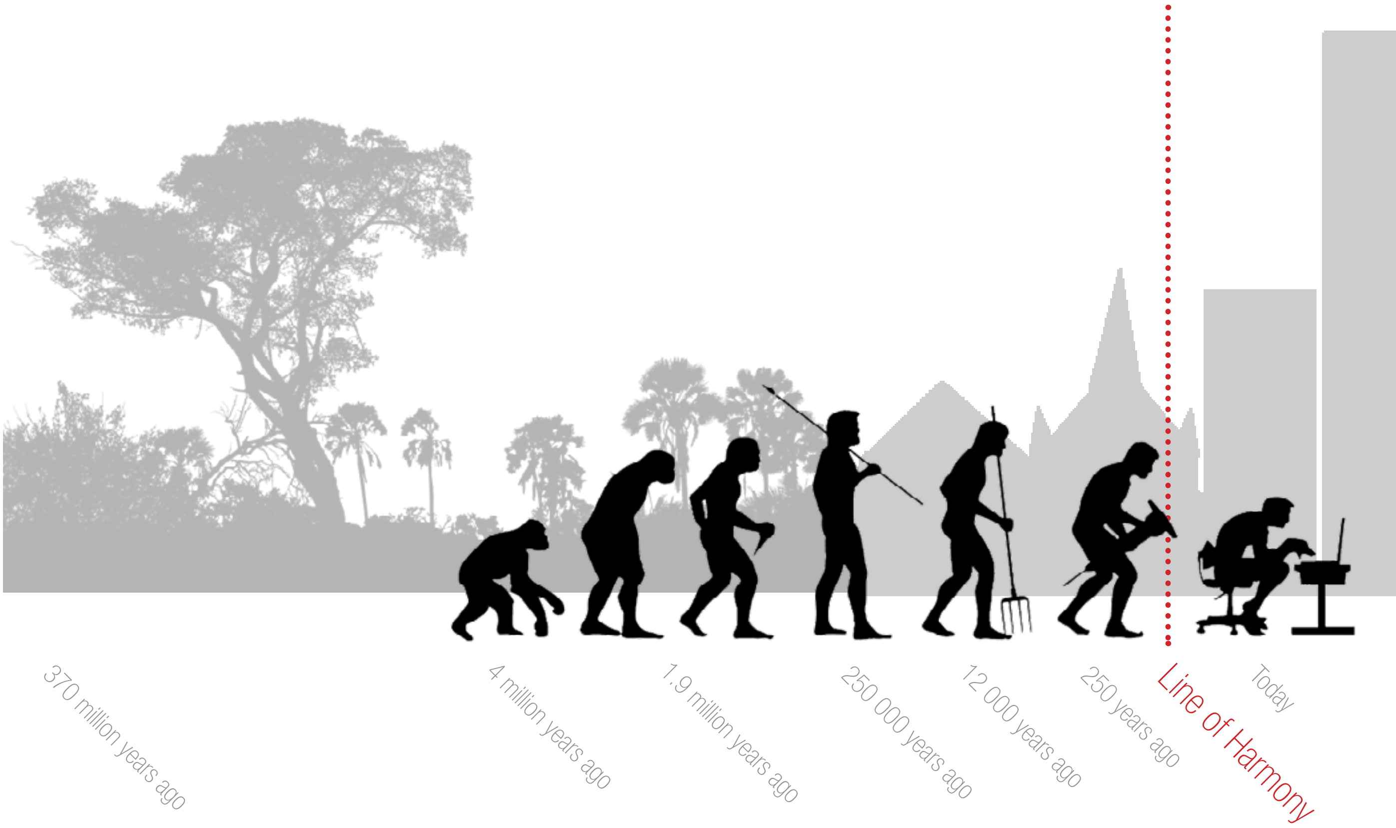


Fig. 01. Evolution

BACKGROUND

Trees have been around on earth for 370 000 000 years and humans for 250 000 years but the agricultural revolution was just 12 000 years ago, and it was with this the humans started to cultivate the land and build houses (Harari, 2018). Compared to the knowledge existing in nature humans are only novices when it comes to design. With the industrial revolution humans completely forgot that the world has limited resources and the anthropocentric way we have lived the last 250 years has pushed the planetary boundaries to its limits. The construction sector alone contributes to 39% of energy related carbon emissions (*World Green Building Council, 2017)*, and even though changes are being made towards the better, there is still a long way to go.

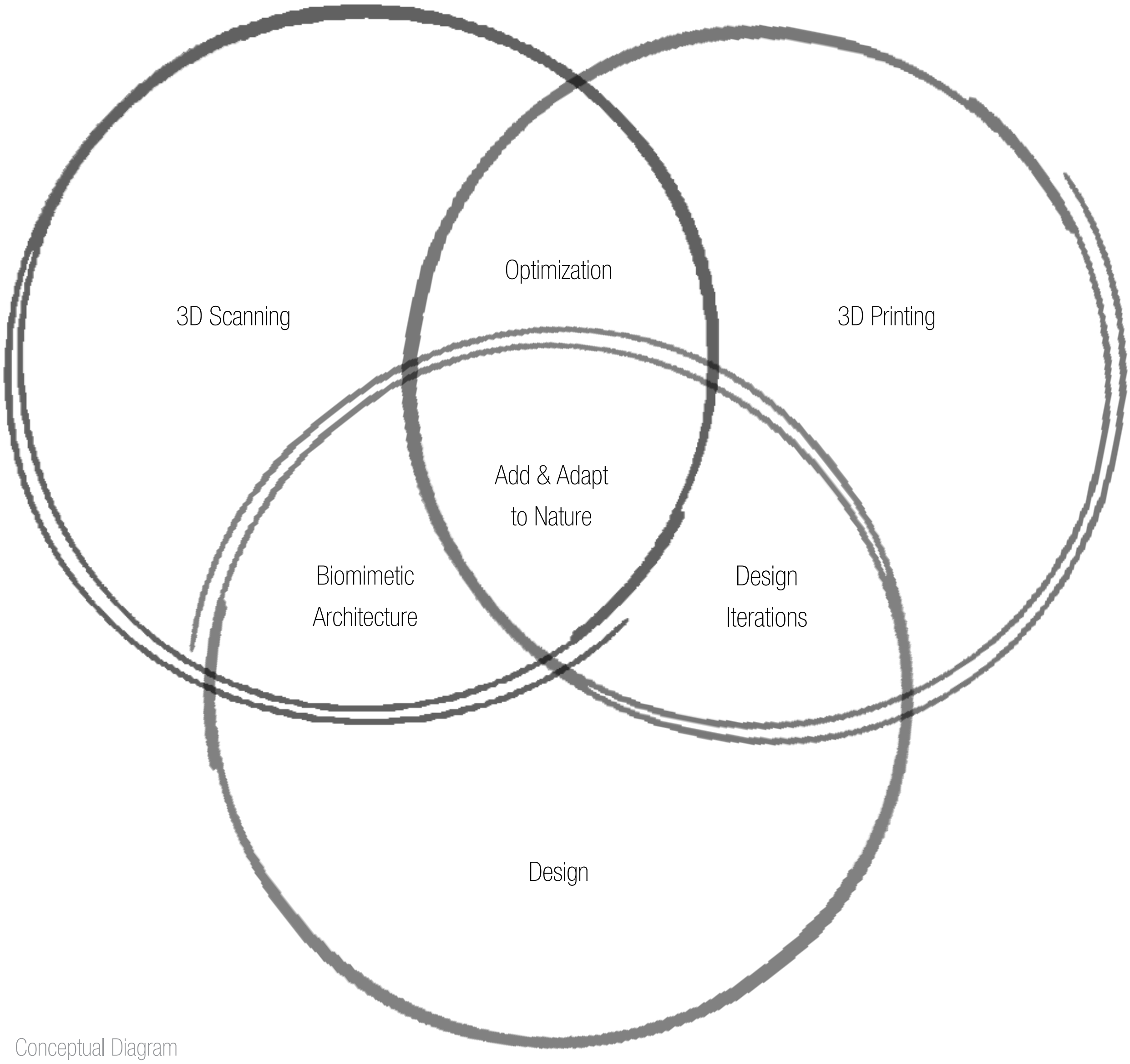
Einstein once quoted; "We can not solve our problems with the same thinking we used when we created them", and this is the essence of this exploration. The transition to a sustainable building industry is mostly focused on the material used during production and the energy performance of the building during use. In many cases concrete is exchanged to wood, but the traditional way of building persists. Today we use bulldozers and blasting to get a clean slate before the building starts and no regard to existing trees and other valuable nature is taken. This leaves deep scars in the landscape. I want to challenge this and explore how we can build and design with much more consideration to the direct context.
Can we use the context as an active part in the design of our buildings, making them adapted to their surroundings, as seen in how threes grow in relation to their surroundings?

Another thing to consider is that everything in nature works in cycles, for example on the short term seasonally where dead leaves become nutrition in the ground and in the long term where dead trees give nourishment.

Today we deplete the nutrition in the grounds because never let it recuperate. Before the agricultural revolution we lived as nomads, adapting to seasons and did not use permanent settlements. This way we never exhausted the surroundings. What if we, as food for thought, only built temporary buildings with a lifespan of 10 years, and after this a new one was built a couple of 100 meters away for the next 10 years etc.

The use of 3D printing in the building industry is still in its infancy and most existing projects have used concrete as its main material, but there are alternative materials. Clay is one of these materials which is abundant and can be found almost anywhere. Other materials are being developed, 3D printed wood is one of them with the use of hemicellulose as an adhesive instead of plastic the material becomes carbon neutral (Chalmers, 2019). Basalt composite polymer is another one said to be 15 times stronger than plastic 5 times lighter than steel and 1.5 times stronger and lighter than aluminum while at the same time being recyclable (3D Printing Media Network, 2019). With 3D printing technology within architecture there are endless opportunities, and this could make us look at architecture in a whole new way and create a more holistic building development where buildings are not foreign objects but rather part of the environment.

In the days before the industrial revolution humanity had to adapt to the resources at hand and this led to a more responsible way of handling the planet. With today's high tech society we have moved even further from nature and sometimes even lost connection to it. But there is also an opportunity in this technology to help us find a way back to a symbiosis once again. Biomimcry and computer technology, are two of them and combined these two methods could help us build even more sustainable buildings than today.



Conceptual Diagram

METHOD

The main method for this thesis will be research by design and also research for design, and through experiments three different areas will be explored:

- 3D scanning of a site using a depth camera and photogrammetry to find the most effective way to build a digital 3D model of the direct surroundings of where the building is to be situated.
- Computational modelling of a building optimized for the site by using the input of the digital site model as canvas.
- 3D printing of a building using eco-friendly and preferably local material.

The result will be a test case for the exploration in the above mentioned areas

TECHNIQUES

- Computational design
- Prototyping
- Material investigation
- Physical models

REPRESENTATION

- Prototypes
- Models
- Animated visualizations

SOFTWARE

- Rhino + Grasshopper
- VRay
- Enscape
- TwinMotion
- Quixel Megascans
- Illustrator
- Photoshop
- Indesign
- Dot3D
- Pointfuse
- CloudCompare
- MeshLab
- Blender
- Autodesk ReCap Photo

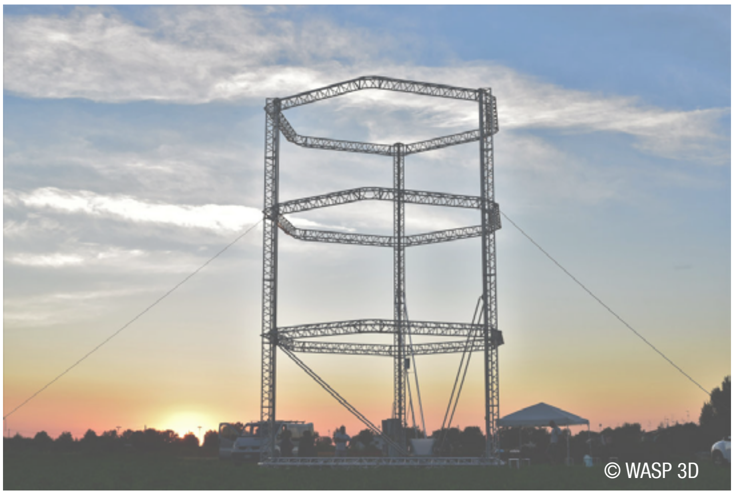


Fig 02. The Big Delta 12m printer from 3D wasp

Fig 03. Vulcan II printer from ICON

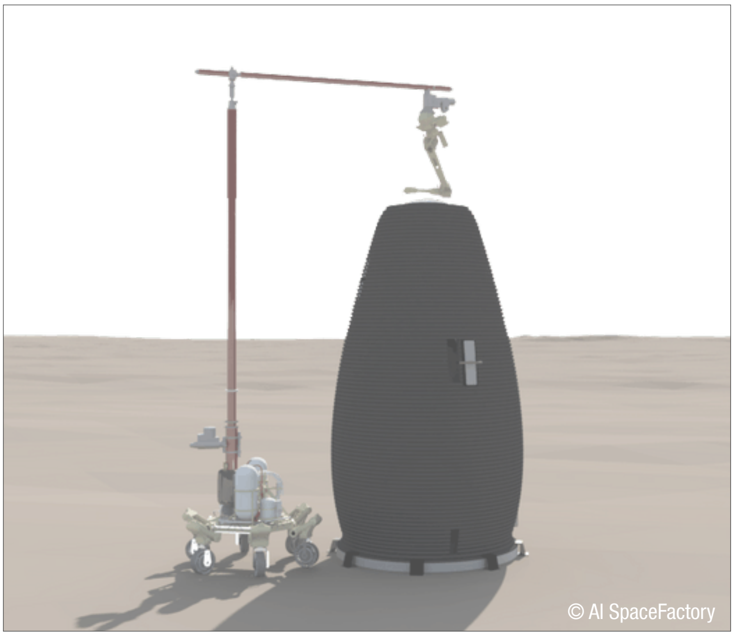


Fig 04. Conceptual 3D Printer on Mars from AI SpaceFactory

THEORY

3D printing as a tool for model making within architecture is becoming more and more widespread but so far only a few examples of it in life-size scale exists. The following companies work with 3D printing on a big scale.

https://www.3dwasp.com/
https://www.iconbuild.com/
https://www.aispacefactory.com/

Of these companies WASP 3D is the only company that has implemented clay as material. Iconbuild use a cement-based material called Lavacrete and AI Spacefactory use biopolymer basalt composite consisting of sugar cane and corn which makes it biodegradable. It has also been validated by NASA to be 50% more durable and stronger than concrete (Carlota V. 2019) and the basalt fiber embedded in the material has similar properties to glass fiber (Dhand et al. 2015).

All three companies use 3D printing technology where the printer itself is static or at least not easy to move. WASP uses a big Delta printer, ICON a cartesian printer and AI SpaceFactory a robotic arm printer.

AI SpaceFactory and 3D Wasp apply designs that can be fully 3D printed i.e. round igloo or cone shapes with vaulted openings that utilizes compression to be stable while ICON apply a composite design where the walls are printed, the square shaped windows have timber headers and the roof is made of a timber frame.

One limitation is the possibility of overhangs during the print especially when it comes to printers using paste that doesn't solidify immediately after extrusion. In that case a support has to be built manually or printed in a material that easily can be removed. Another thing to consider is that no rebar is used in the structures which limits the shapes to only work with compression except for AI SpaceFactory and their biopolymer basalt composite which has basalt fibers in the material giving it more tensile strength.

Opportunities given through 3D printing is the freedom of more organic shapes than the traditional way of building using timber, bricks or concrete. Another example of this is to print staircases or prepare for them at the same time as the walls which 3D Wasp has tested in the picture below.

Fig 05. 3D Printed wall with embedded staircase

DELIMITATIONS

Since three different areas are explored (see methods; 3D Scanning, Computational modeling and 3D printing), In this thesis I will not cover the details in any of the technologies but instead explore how they could work together in a design process. The goal is to find a concept for a new way of designing and building.

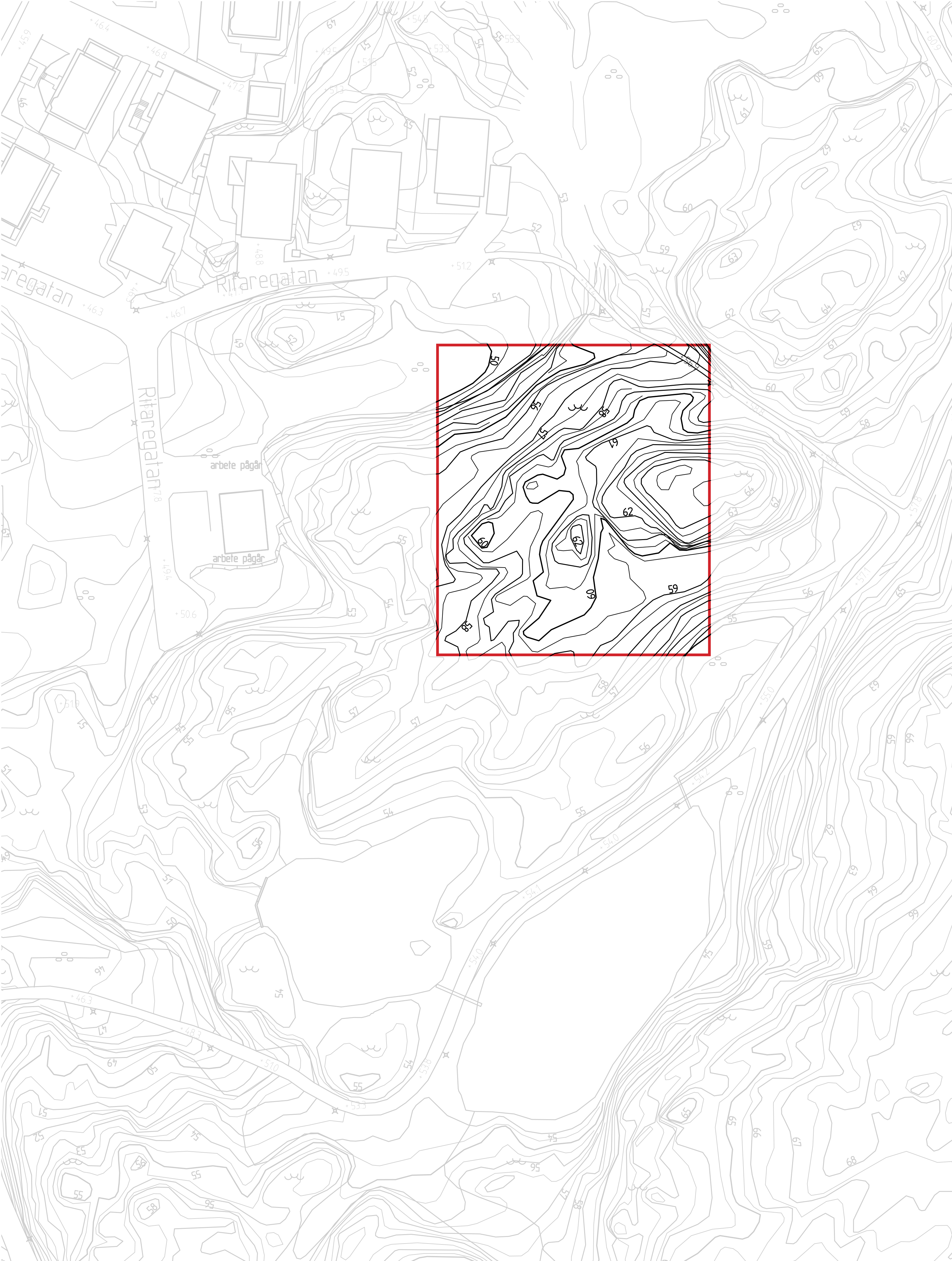
Accessibility will not be considered.

Energy calculations will not be performed.

Material characteristics testing will not be performed.

PART II

ANALYSIS



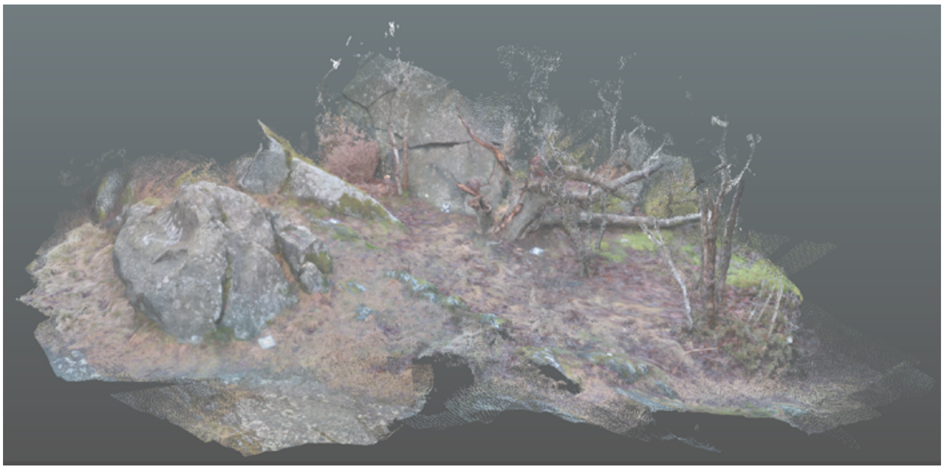
Site plan 1:1000

THE SITE

The site chosen for this project is on the western part of Högsbohöjd in Gothenburg, near my home because I wanted to be able to easily reach it to add 3D scans and expand it if necessary. Though it could have been any site where there is tough terrain and trees so the method could be tested thoroughly.

It is partly bright and open and has rocks sticking out of the ground here and there and also different height levels of the ground. There are a couple of pine trees located at the spot with enough space between to place rooms. This was the perfect test site for the project.

The Intel Realsense D415 camera connects via USB 3.0 to a computer or tablet.



The first test outdoors with the D415 camera and a program called Dot3D

3D SCANNING

If photogrammetry, LIDAR or a stereo/depth camera is used to scan a site instead of using a dwg plan, a highly detailed 3D model can be used to better understand the direct context where the building is to be situated. This way the design can be adapted to the existing nature like trees and rocks instead of what the building industry normally do when blasting and digging to create a clean slate for the building. That way the context is adapted to the building. In the method I am testing the building is adapted to its context.

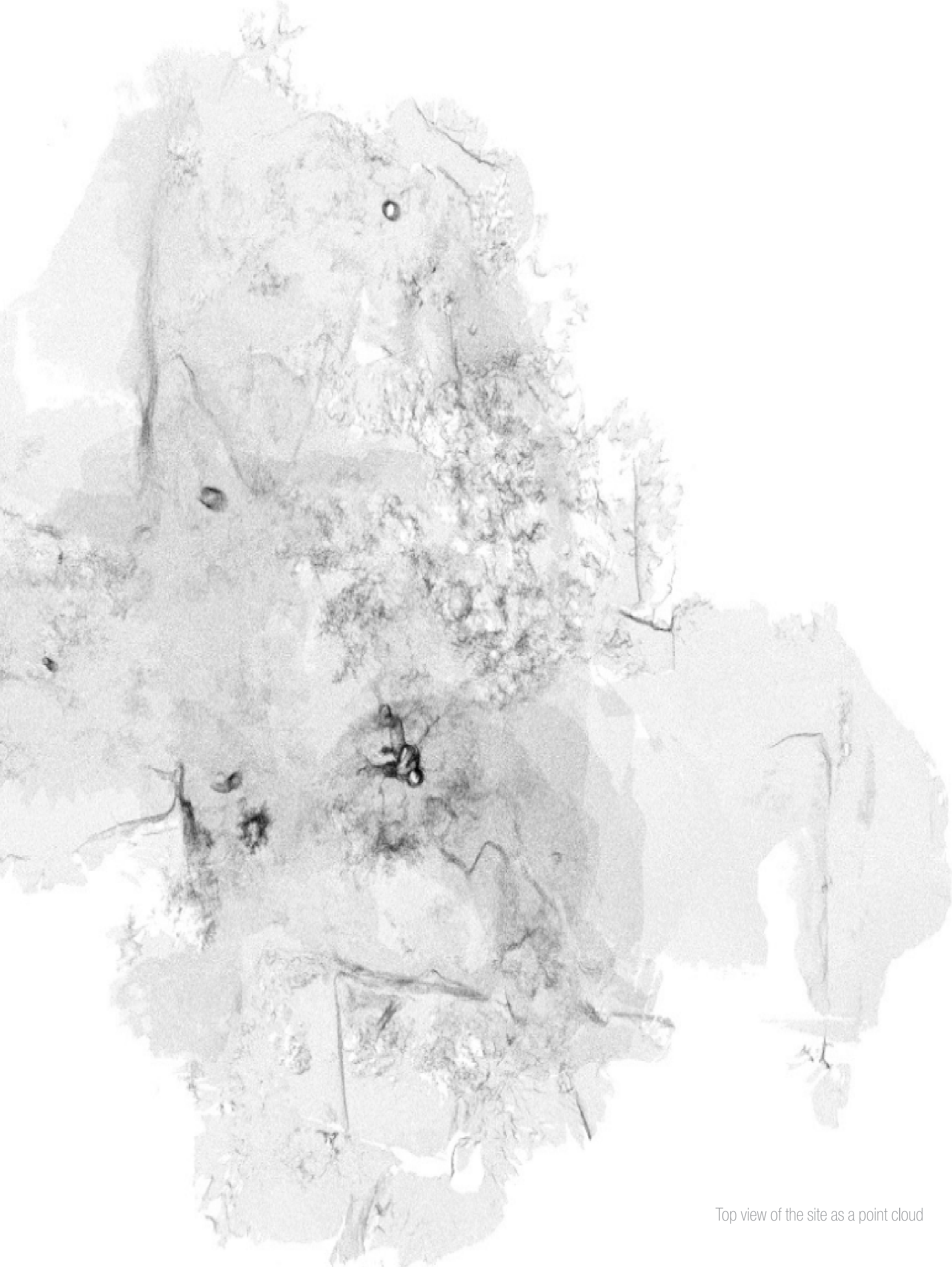
I put a lot of research into how to build a spherical LIDAR device (light detection and ranging), which is extremely accurate when using lasers, since buying a unit would cost around 250 000 SEK. In the end I concluded that to build one I would have to put in a couple of weeks work and buy material for 10 000 SEK, without the guarantee that it would work. Instead I researched further and found out about a program called RTAB-Map (Real-Time Appearance Based-Mapping), where a RGB-D camera is used to scan an environment, normally used in robotics and UAV or self-driving cars (Moroni, J. 2018), but I realized that this could be used to get a highly detailed scan of my site. In the end I found a program called Dot3D which works as RTAB-Map but is much more refined, and after contacting them I was approved a trial license for the duration of my master thesis.

An RGB-D - camera (Red, Green, Blue - Depth) is a 3D camera that gives not only a color image but also the depth information of every pixel. It works by registering the object through a stereo camera in real-time, where the images from each camera are compared and processed with calculating the difference in position of each pixel and from this extracting the depth information.

Until recently this was a very limited technique since it only worked on short distances and on highly textured objects. Now Intel has released a new type of Depth camera called the D400 series which simultaneously as registering the stereo vision also projects an IR pattern on the object which means that it works on objects with very little texture and in bad lighting (https://www.intelrealsense.com/). This is the type of camera I used for my scans.

Photogrammetry is another technique that instead of ranging light beams to objects uses photos to make a point cloud and from this build a 3D model. It does this through finding the same points in different photos and then stiches the photos together making a mesh.
Through working with photogrammetry in both Meshroom and Autodesk ReCap Photo, i learned the strengths and weaknesses of both programs. ReCap photo is a great program for capturing smaller objects and with its cloud based rendering it works very fast. The strength of Meshroom is that if you notice that the 3D model is missing some detail at certain places you can add more photos of that place and let the program iterate these into the exiting model without having to redo the full model once again. The weakness is that the program works locally on your computer and eats all the processing power it can get. Photogrammetry works great on small areas up to 20sqm, but looses detail after this. There is also a bigger risk for errors in how exact it is. That is why I chose to work with the RGB-D camera.

While real-time 3D scanning is becoming more and more used within many fields it is still not commonly used within architecture except for scanning interiors before renovations. The most common use as of today is within the steel industry, forensics and by insurance companies.



Top view of the site as a point cloud

SCANNING THE SITE

The site had to be scanned in four parts with Dot3D since I wanted the raw data from the site to be as detailed as possible. During the scan four april tag-boxes, where put at different positions on the site and this helped the program to stitch the scans together and align them properly. To be able to get all the point clouds merged, another program called CloudCompare had to be used.

After the merge I had a point cloud consisting of 352 000 000 points (11,5GB of data), which is extremely heavy for the computer to work with, so a reduction of the points where made down to 50 000 000. Different distances between the points made big differences in the amount of data. When the spatial resampling was set to a minimum of 10mm between the points. The point cloud was reduced to 2 000 000, which became 1 900 000 faces and 950 000 vertices after meshing in Meshlab. (182MB as .obj, 94MB as .stl),

20mm between points took it down to 564 000 points which became 535 000 faces and 268 000 vertices after meshing in Meshlab. (50MB as .obj, 26MB as .stl),

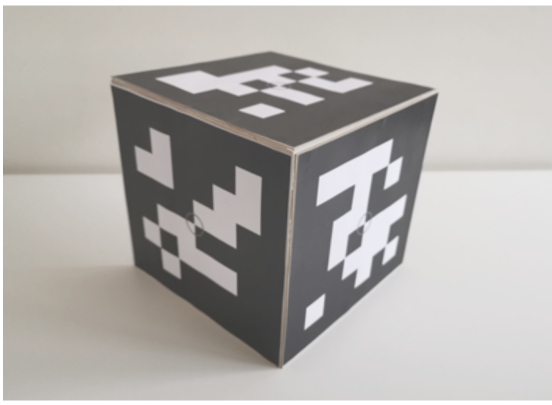
50mm between points took it down to 96 000 points which became 120 000 faces and 60000 vertices after meshing in Meshlab. (11MB as .obj, 6MB as .stl)

I decided to use the point cloud with 20mm between the points. Since this gave a very good level of detail without being overly heavy for the computer to handle.

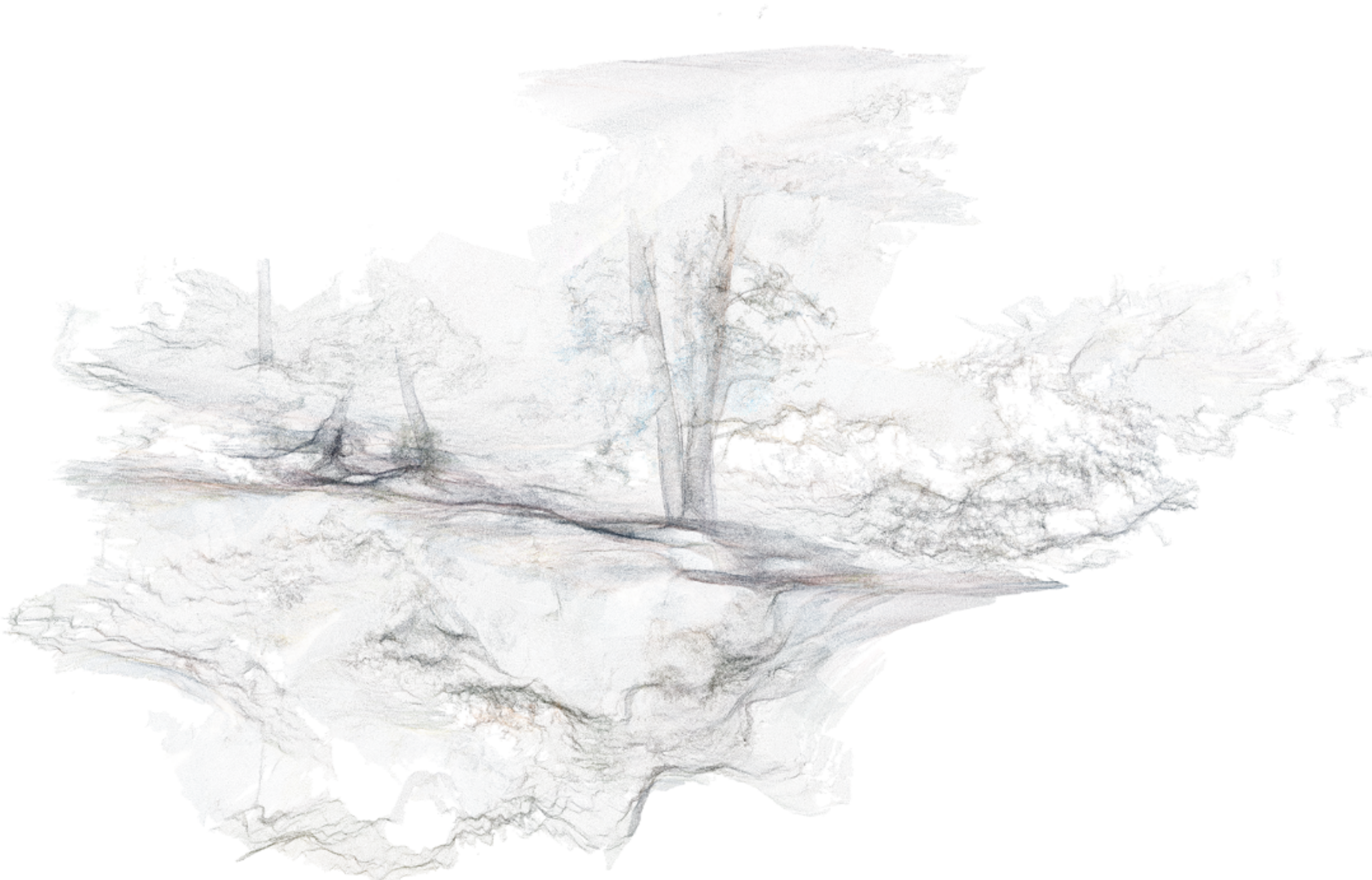
Due to bushes and shrubbery on the site which also is captured in the scan, there are problems meshing the point cloud. It is also hard to clean up and even out the mesh once it is done. Next time I will use these techniques, I will first make sure to clean up the site from bushes, brushwood and thickets.

After my initial trials with meshing I found another program called Pointfuse which worked excellent directly with the point clouds extracted from Dot3D, and this is the program that I will continue to use in the future.

I also ordered a point cloud from Stadsbyggnadskontoret with 11 million points (10 points per sqm), this gave a good overview of the site, but since it is scanned with LIDAR from an airplane it mostly shows the crowns of the trees which rendered it useless for my purpose.



April tags were used during the 3D scan with the depth camera



The site seen from the side as a point cloud. It is hard to understand the information inside a static picture of a point cloud, but when seen in the program where the image of the cloud can be rotated and tilted it becomes very clear.

The QR code shows the cloud in 3D.

THE BUILDINGS

Since the main focus of this thesis is the method of scanning and constructing a building, the type of building is not the most important. I decided to design an extension to a preschool since this type of building nowadays very often is a temporary and uninspiring module building, at least in Gothenburg. At the same time, it provides me the perfect testing ground since it gives me the opportunity to try out more playful shapes which in turn tests the limits of the 3D printing technology.

With my explored method the children will get a much more interesting space to play and learn intertwined with the forest. Studies has shown that closeness to nature enhance creativity, physical activity and well-being (The Conversation, 2018). It also creates a connectedness to nature for the children which they carry with them into the future.

The buildings will work as complementary buildings to a preschool module, where they offer extra space on days not suited for outdoor activities. A condition for this is that a preschool module containing necessary facilities is placed nearby. The buildings are passively heated by the sun and the children inside. The walls and roofs are well insulated and store heat in the solid inner clay walls.

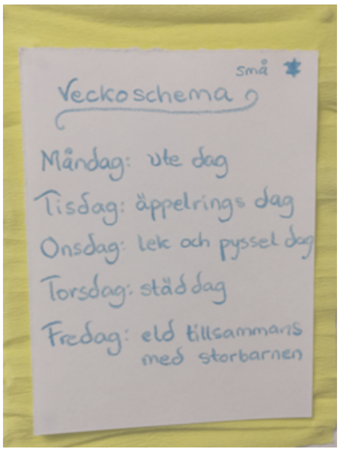
The roofs are covered with sedum and grass and parts of the walls have clinging plants and moss adding to the biodiversity since the area is much bigger than the footprint of the buildings seated on the rock.

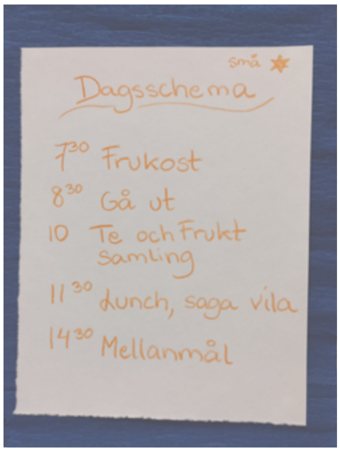
Just like the preschool modules, the extension buildings are temporary, and after the intended use they can be recycled instead of moved and since all of the material is eco-friendly it can be also be left on the site adding to the biodiversity and maybe have a second life filling another purpose.

Preschool at Sjupundsgatan. Many preschools in Gothenburg are situated in temporary modules like this today.

The Week | The Day

Small children
1-3 years old





Bigger children
4-6 years old

Spring Schedule at Västanvind Waldorf Prechool

From Gothenburg municipality's framework programme (Göteborgs Stad ,2014):

What does the curriculum say?

- The preschool's overall mission is to offer the children a safe environment that at the same time attracts play and activity. It shall inspire children to explore the world.

How should the yard be designed to achieve this?

- The yard should be large enough and be made up of different characters - natural characters are especially important, be rich in loose material allowed to be messy, physically challenging, semi-shady and safe.

A typical day at the preschool

06.00 - 09.00 Handover from the parents
7.30 - Breakfast
8.30 - Outdoor activities/Play
11.30 - Lunch
12.00 - Storytelling/Rest
13.00 - Play
14.30 - Snack
15.00 - Outdoor activities/Play

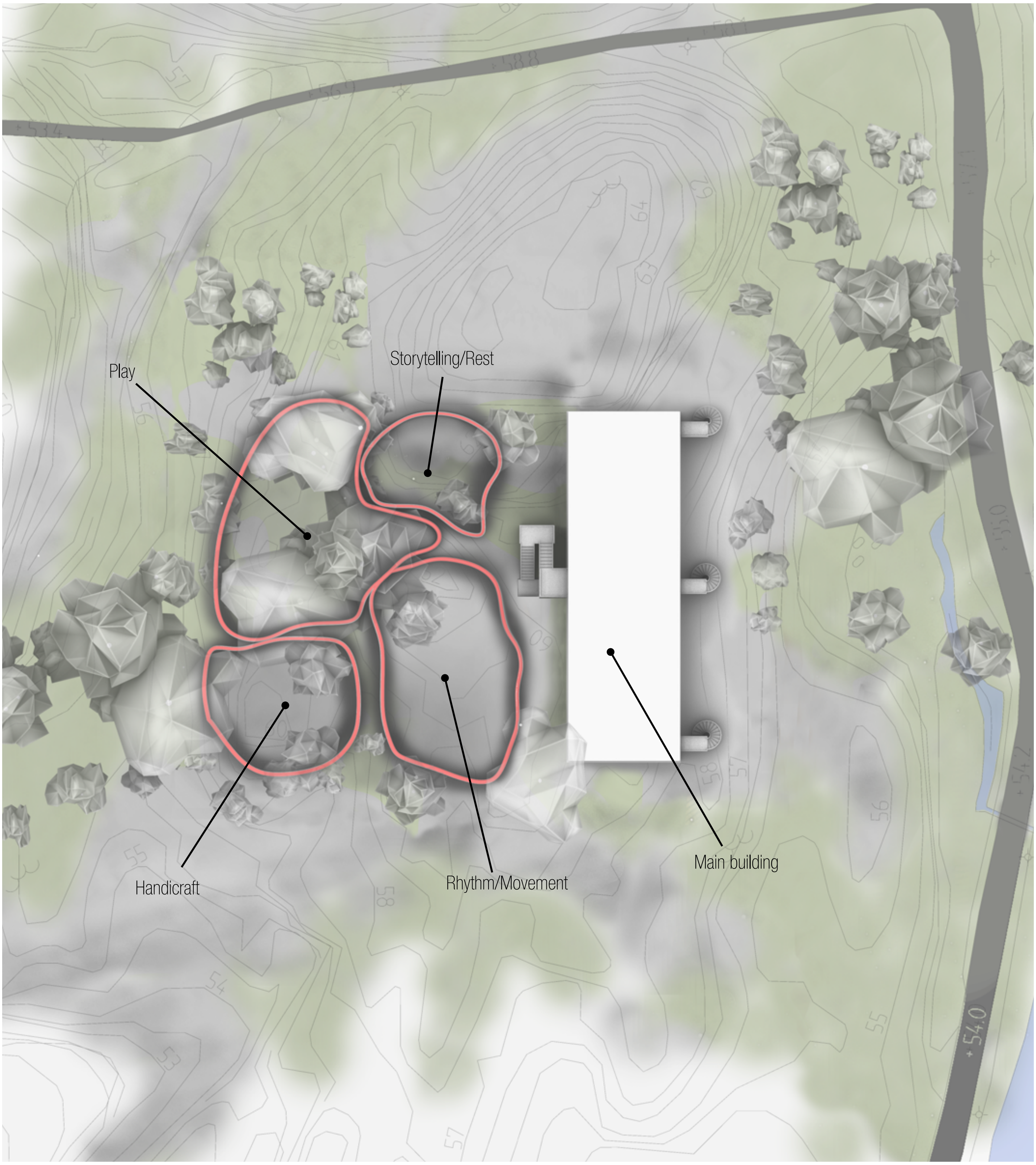
The times are based on the schedule used in the Waldorf Preschool Västanvind in Gothenburg.

BUILDING PROGRAM

The four main activities found through interviews with personnel at the preschool was play, rhythm or movement, handicraft like knitting or clay sculpting and finally storytelling and rest. So, these are the main focuses in the buildings while the main building contains bathrooms, kitchen and other necessary facilities.

First the best suited position for the main building was set. The terrain had to be as flat as possible for the least action on the site for the modular preschool building.
Then a study of the site helped to find the right natural positions for the other buildings according to the different activities. This way the terrain helps the buildings, shown in the picture and explained with bullet points below.

- Play - Hilly terrain, Hiding-places, Climbing, Jumping
- Rhythm/Movement - Flat terrain, possibility to have a flat floor with much space to move around
- Handicraft - Possibility to sit and easily see the teacher. Teacher should easily reach to help the children.
- Storytelling/Rest - A cozy space where the teacher can sit and read for the children and a flat floor with mattresses for rest.



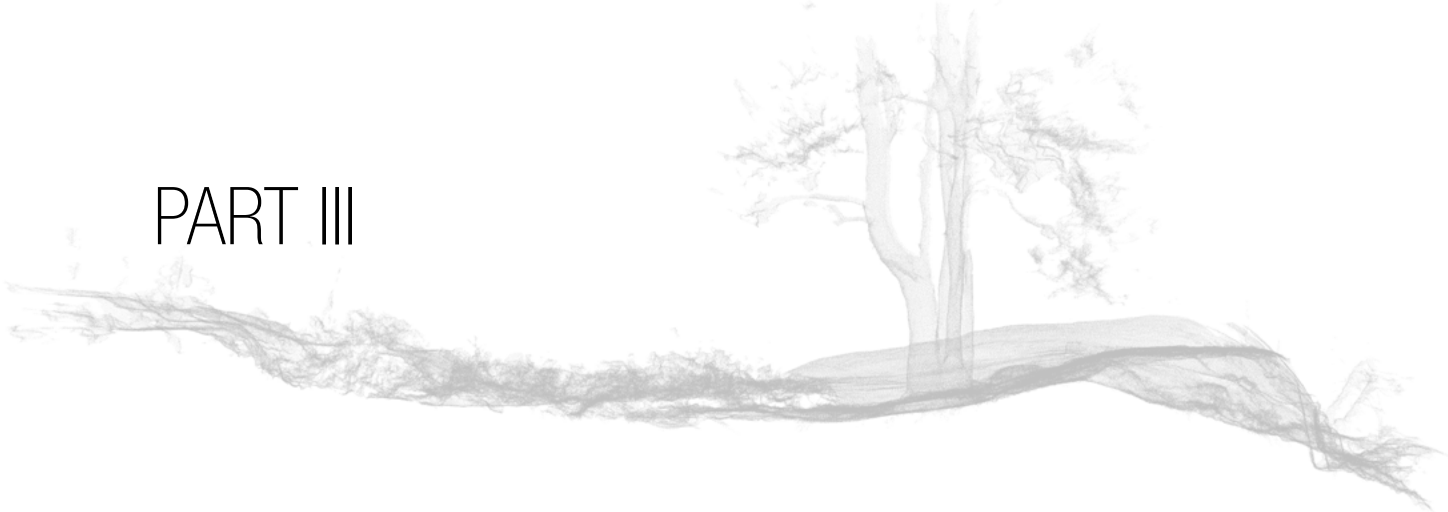
Play - Unlimited outdoors

Rhythm/movement - 75sqm ground level, 70sqm top floor

Handicraft - 78qsm in total divided in different etages

Storytelling/rest - 60sqm

PART III

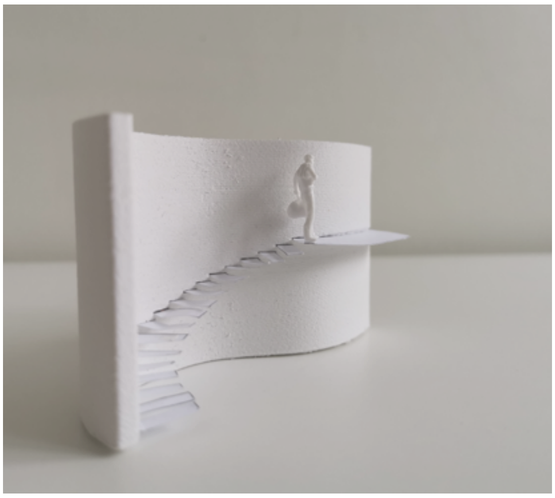


DESIGN EXPLORATION

DESIGN EXPLORATION
Testing the Limits


A two storey building that could be fully printed in clay


How big openings would be possible to have? If the arch would reach over where structure is no longer vertical it would start to be unstable.


A staircase were the steps are fitted straight into the 3D printed wall. 3D WASP has made a full-scale test of this with a clay wall. https://www.3dwasp.com/en/3d-printed-wall/
In this test I imagine using a couple of layers of basalt composite in the wall around the steps to get a slender expression.


To investigate printing techniques, vase mode printing was tested. Here each layer of filament is spiralling upwards instead of as it is normally done where each layer is horizontal on top of each other. The wall thickness is only one layer of filament but it still is very robust. The left print was a failure due to the angle and the height of each layer.
With this technique two shells could be printed simultaneously with a distance that can be filled with insulation. This way there would be no heat bridges in the walls, only by the windows and doors.

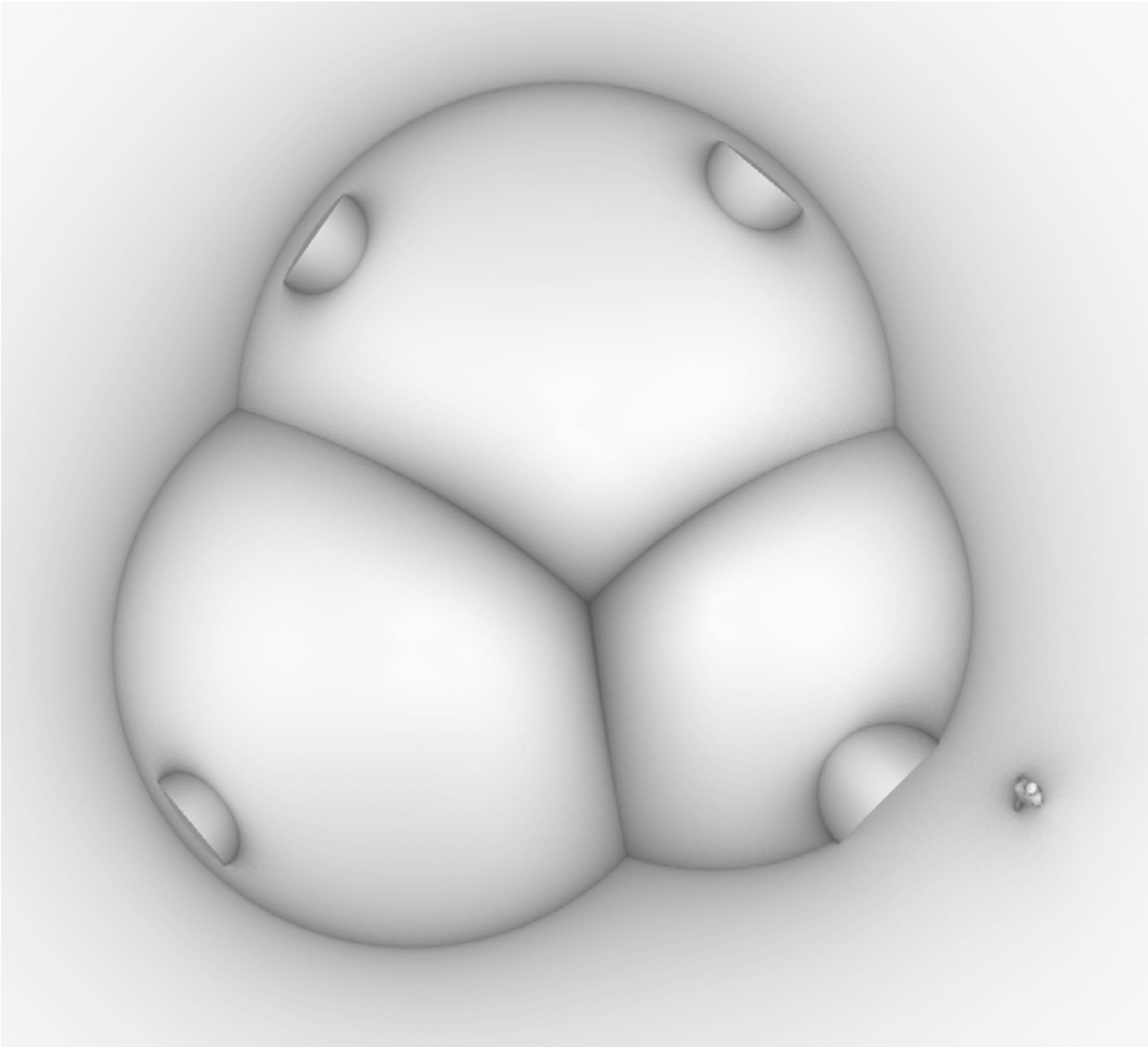
This is a test print to see how a filament that solidifies immediately after extrusion can be printed without supports. This opens up much more possibilities with overhangs and overall freedom of design.

It is possible to also print structures with a square footprint as long as the openings are still vaulted.

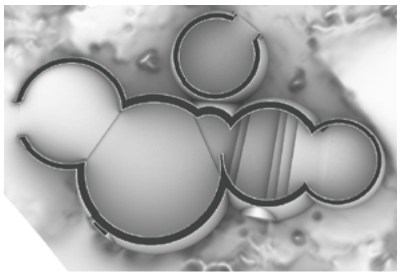
Going from a square footprint to a vaulted roof testing the limits of how flat the roof can be printed.

Pushing the boundaries with the same concept as the left picture. Here the indent and the curve of the roof is causing a bit of trouble with the low angle. A higher angle would make the structure more stable.

DESIGN EXPLORATION
100% 3D Print

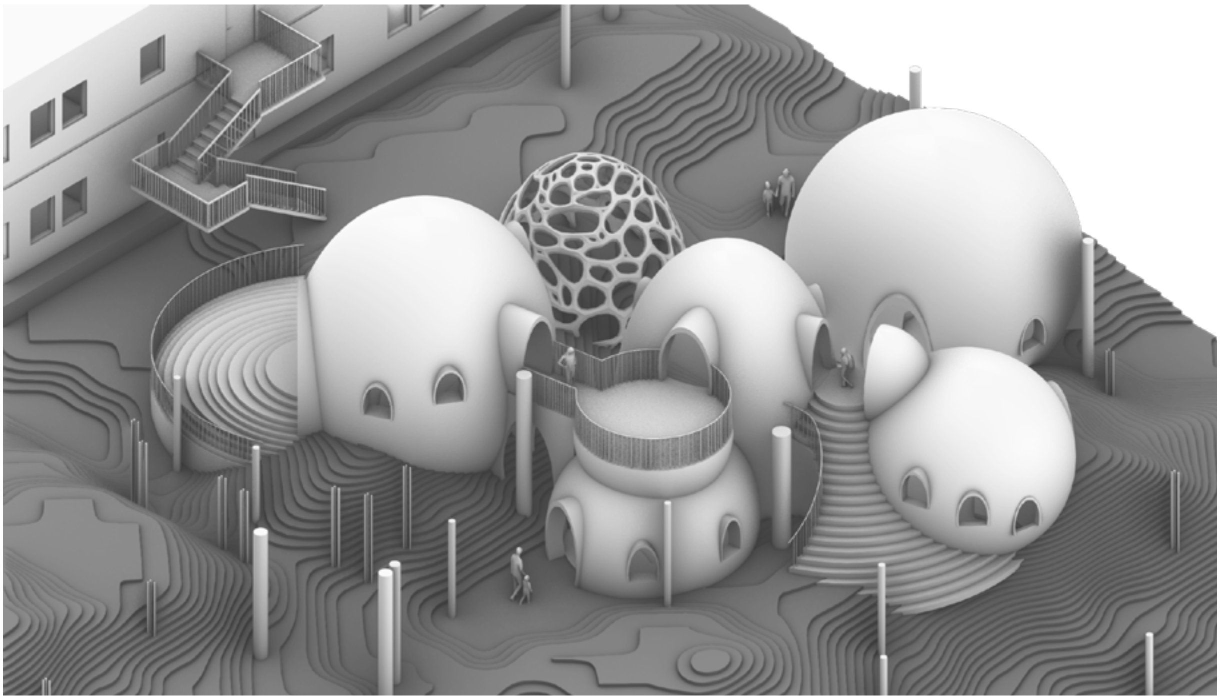


The first trial of a fully 3D printed structure. This structure would have to be printed with a pillar in the middle where the three domes meet. There would also have to be rainwater drainage there.

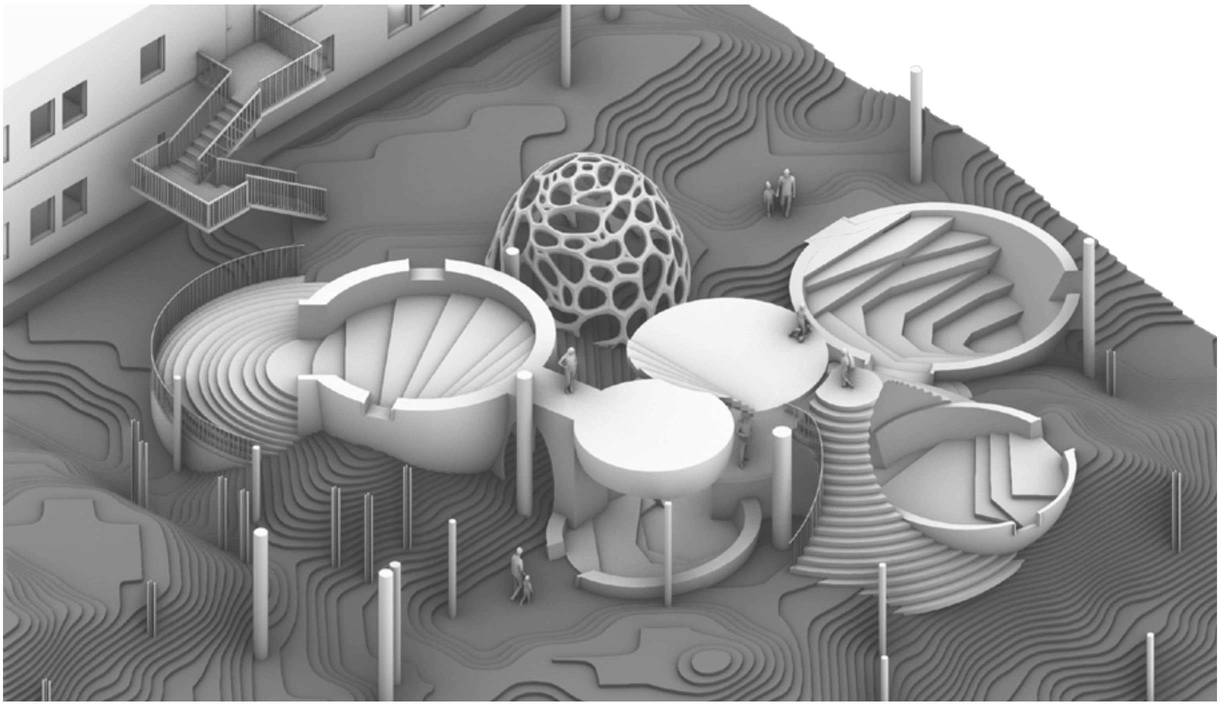


This is the first print trial where the building climbs on the terrain. This structure would also be self supporting through its dome shapes. Here the rooms are in different levels and stairs are printed straight on the ground.

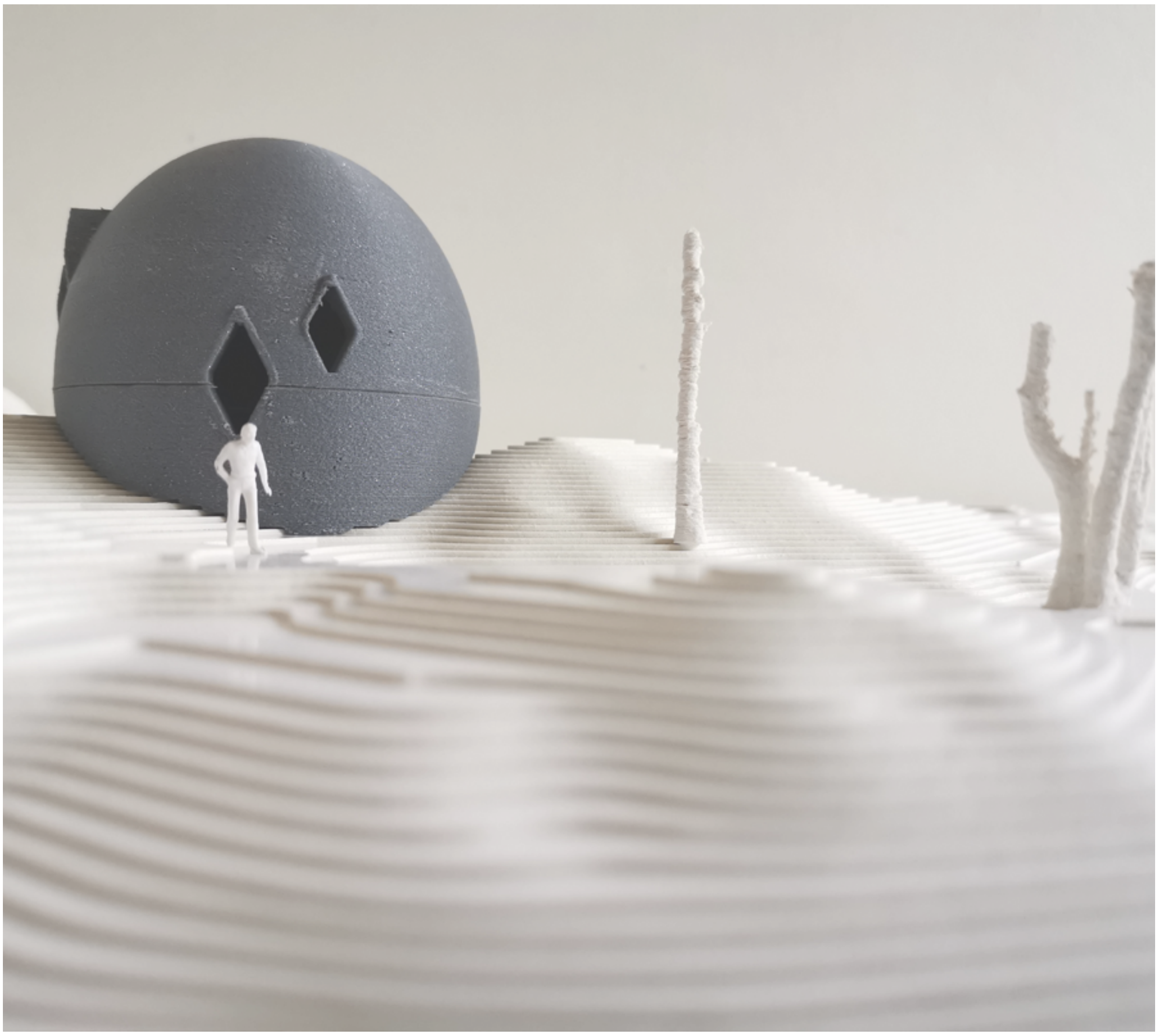
DESIGN EXPLORATION
100% 3D Print

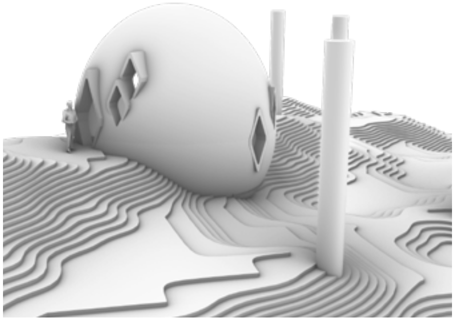


A proposal where everything is printed on site with no supports except that two of the rooms have intermediate timber floors.
Here I started to realize that the round shapes were not optimal around the trees.



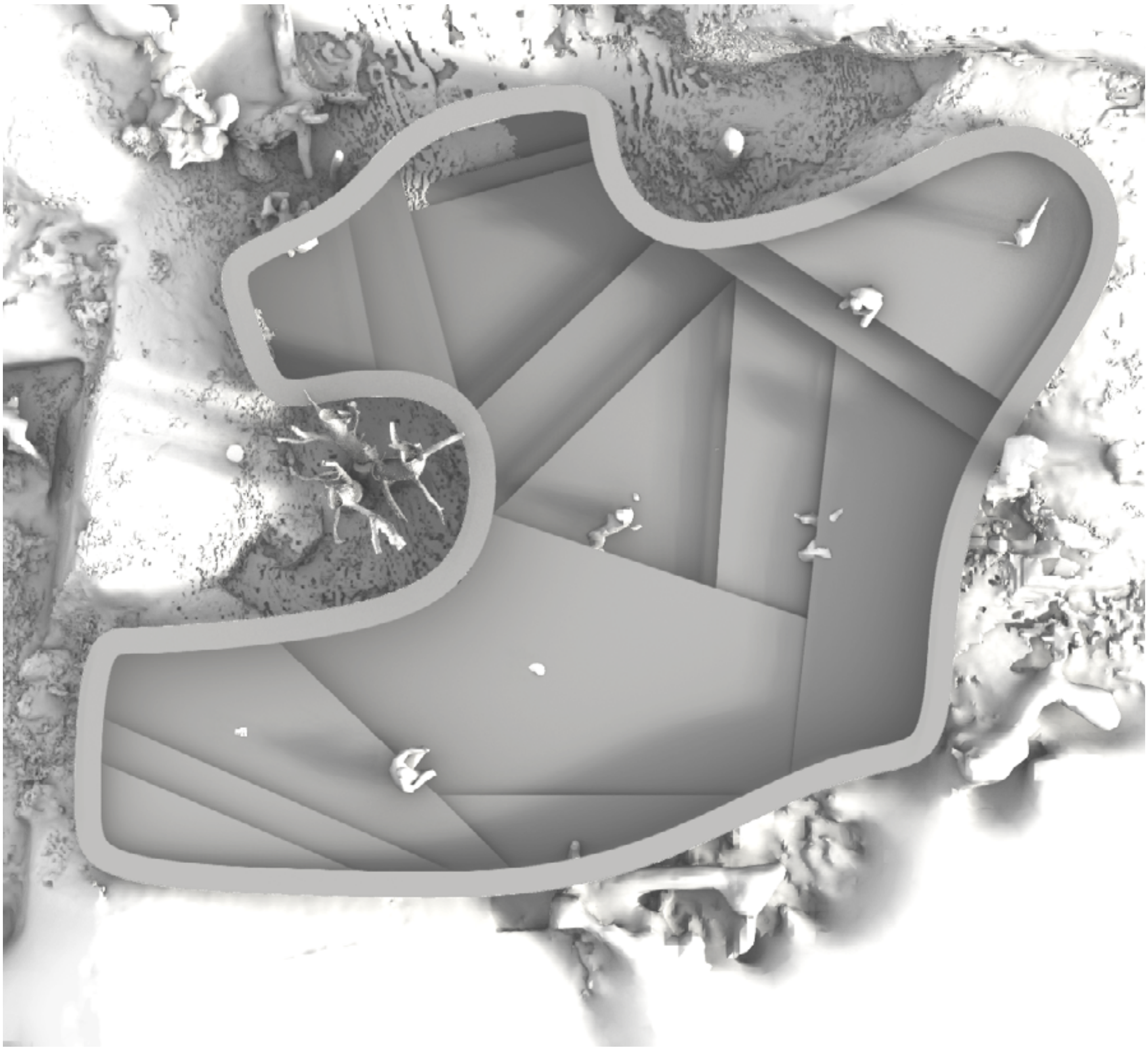
3D View of the plan of the above buildings.

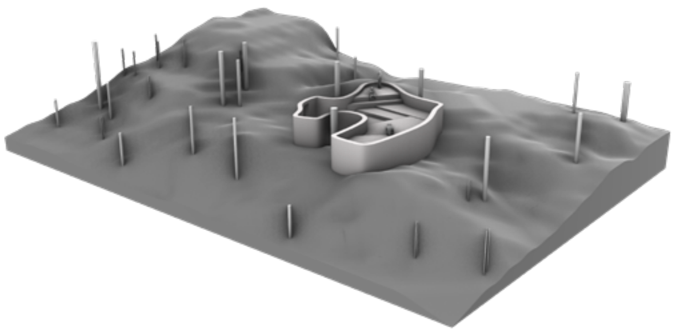




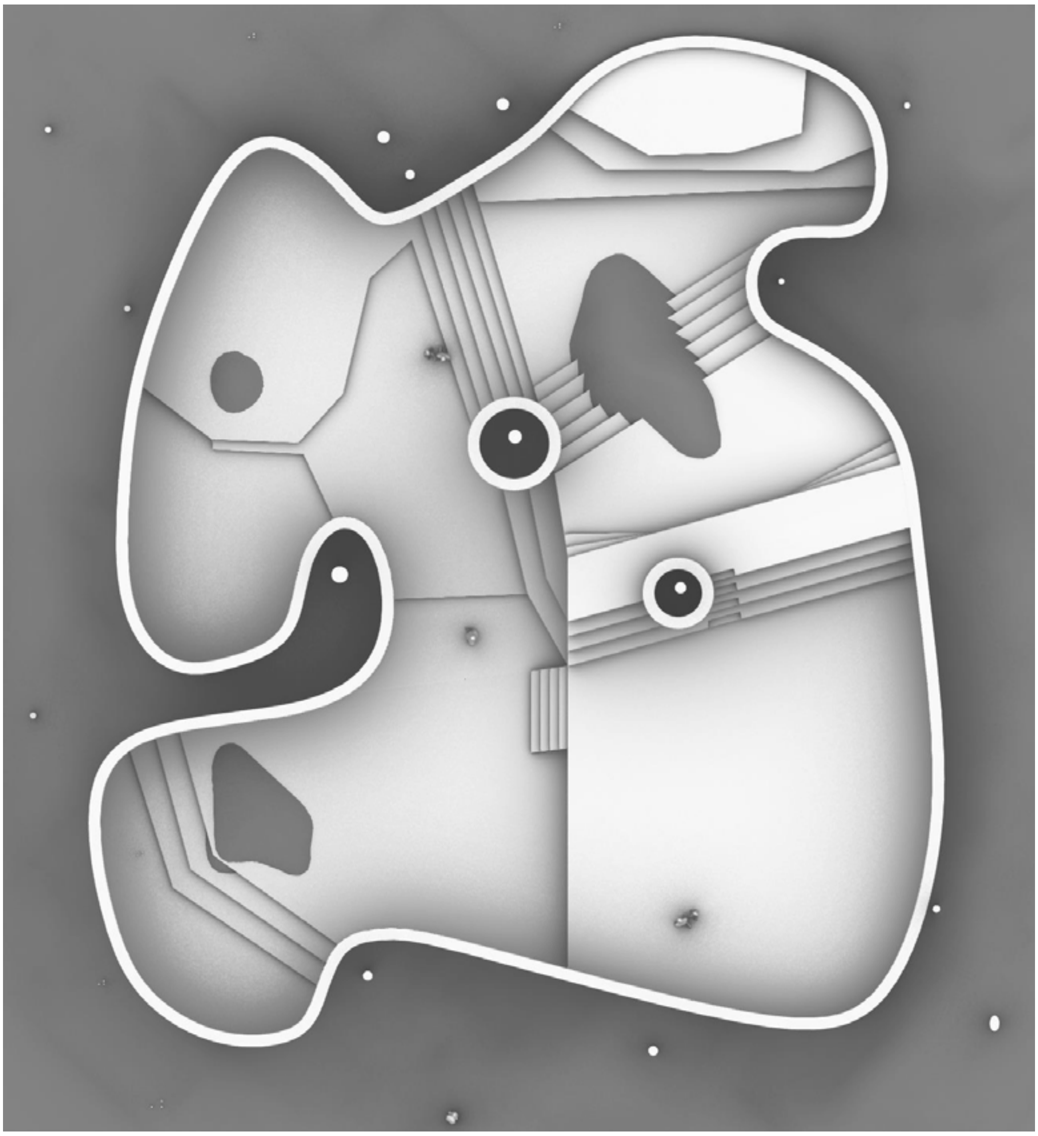
After a bit of testing I managed to print a building that could be fitted into the site model. This was at the same time a test of another design idiom where the openings had gotten rhomb shapes. But here I fully realized that the round shapes would not blend in neatly with the surrounding trees since it would be hard to go from convex to concave shapes to give space for tree crowns etc.

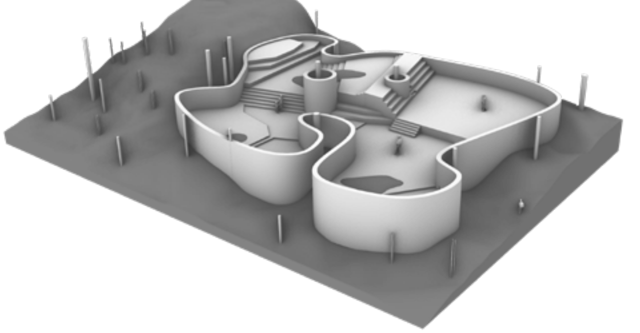
DESIGN EXPLORATION
Organic Shapes





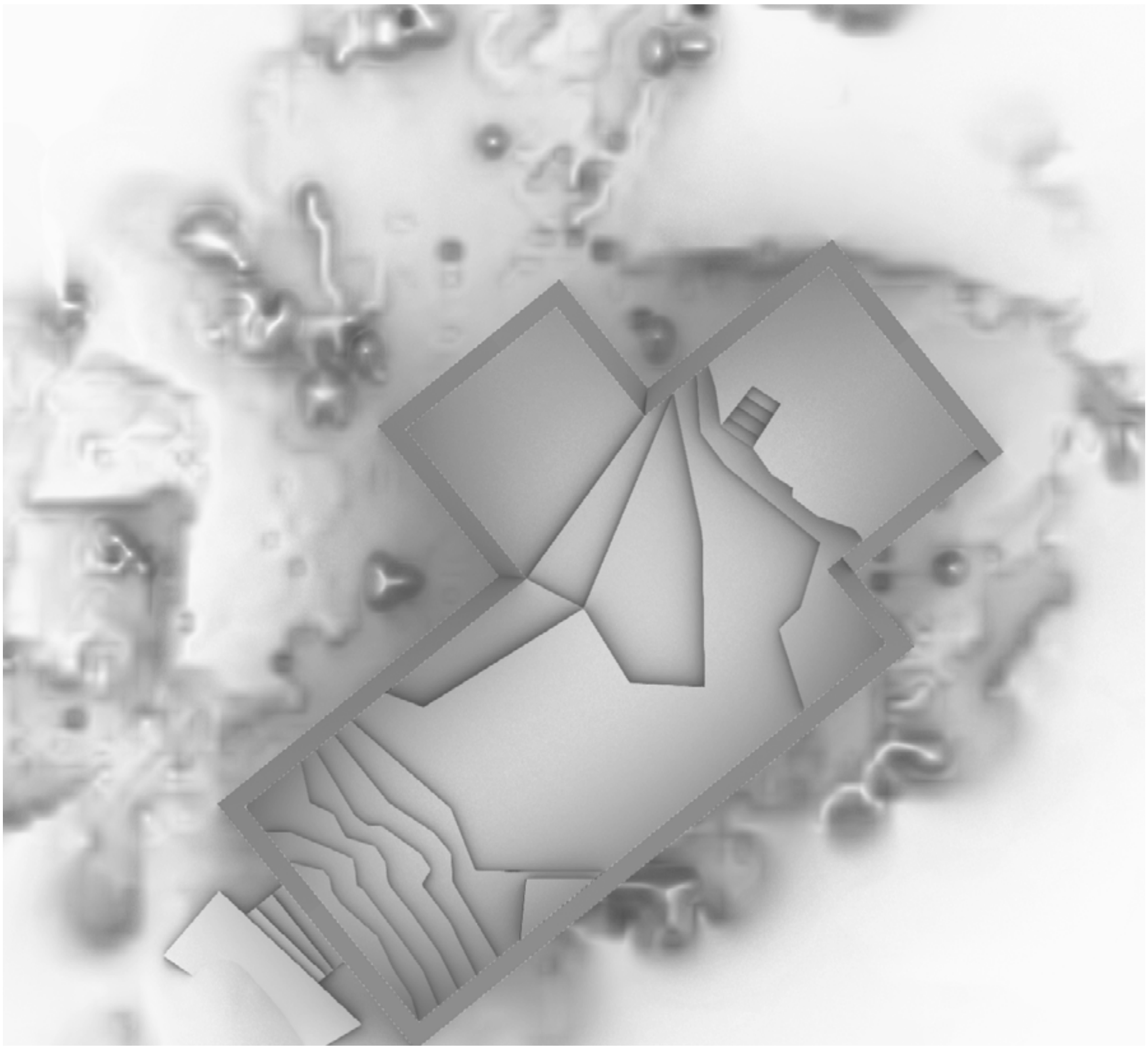
It is possible to print vertical walls that has organic shapes but problems occurs when reaching the roof where the construction would have to have another solution, unless the roof gets a couple of dome shapes that rests on inner walls as well as the exterior walls. But there will be problems with the transition between convex and concave shapes.



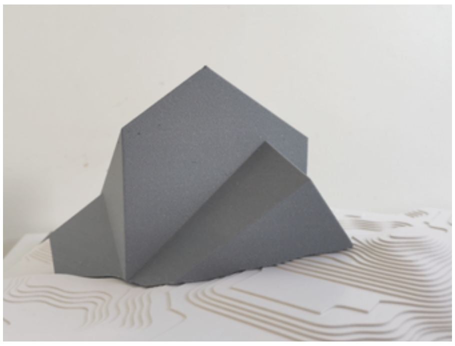


A test to house all the functions within the same building where the trees are left growing through the structure.
The same problem occurred here when reaching the roof. It would be possible to make a space frame of timber in an organic shape but the idea of a simple and easy to build structure would fail.

DESIGN EXPLORATION
A New Approach

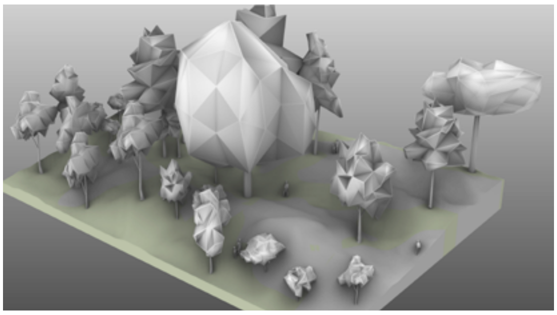


It works very well to 3D print vertical walls with 90 degrees angles but the most effective roof in this case is a normal timber frame.

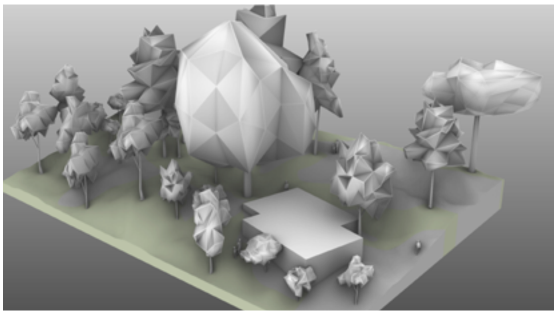


With a new approach inspired by salt crystals and its sharp angles a new design idiom sprung out.
There is something in the tension between the soft curves of nature and the rigid straight lines of the human made that speaks to the eye.

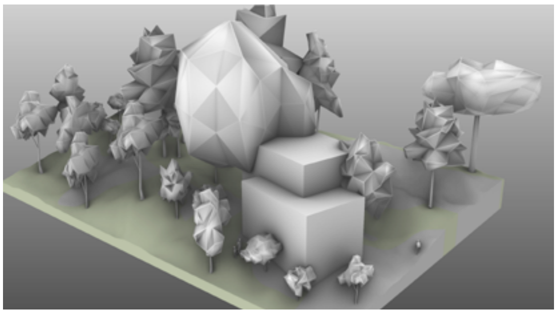
FINDING THE SHAPES



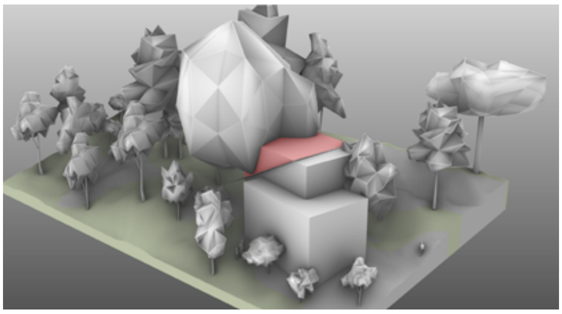
1. The site decides where the building is to be situated through where the rock is sticking out of the ground.



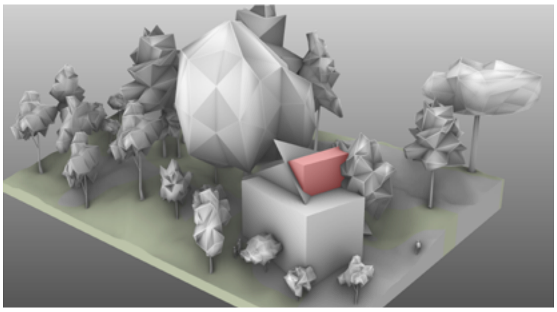
2. A simple geometry is created on the rock



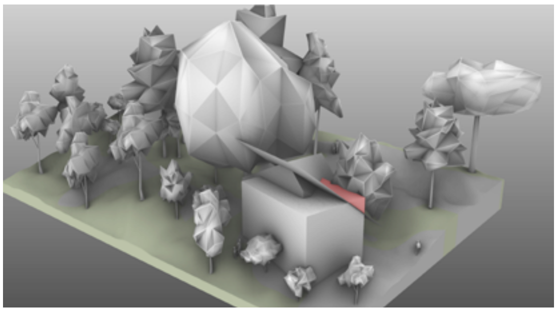
3. The geometry is extruded



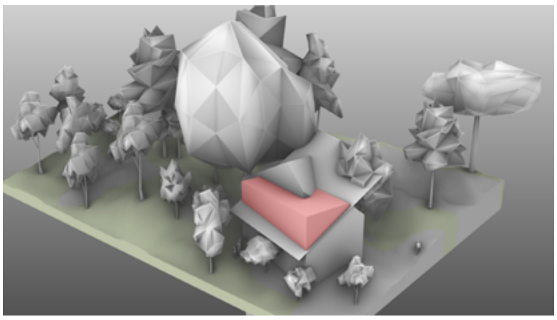
4. The volume interferes with a big tree so a slice has to be taken away



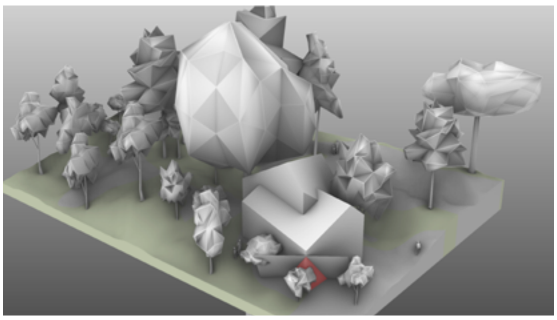
5. The volume also interferes with the smaller tree so another piece has to be deleted



6. A part of the big base volume also interferes and is sliced away



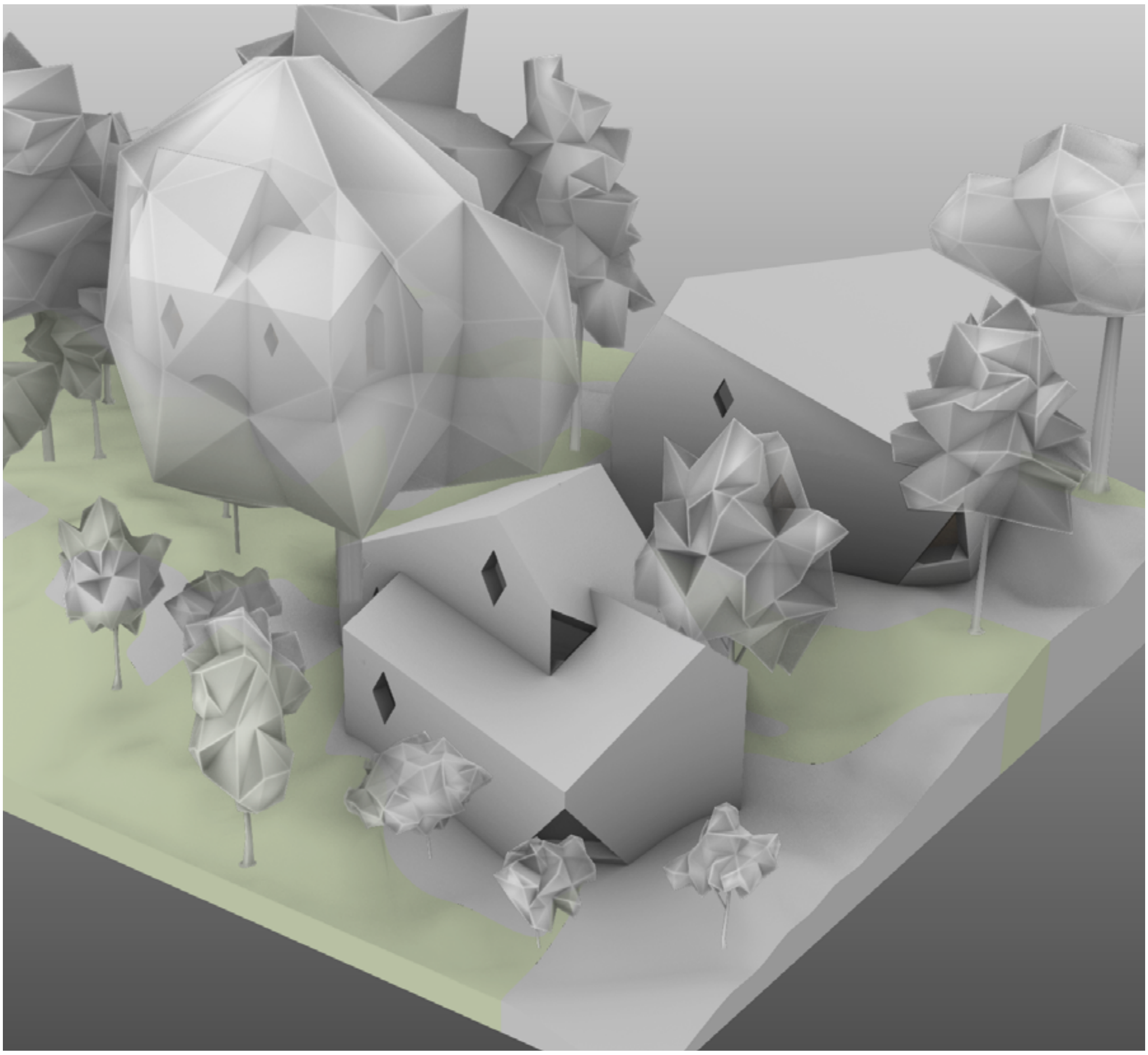
7. The roof angle is adjusted so that debris from the surrounding trees can fall off easily.



8. Finally a corner is cut away to give space for a window where the light can get filtered through a bush.

The buildings must not interfere with the existing tree crowns on the site so therefore parts of the volumes are sliced off. This gives the final shape of the buildings.

QR code showing an animation of the form finding.



9. The final shapes gives space to the surrounding trees and bushes and will not hinder the growth of them.

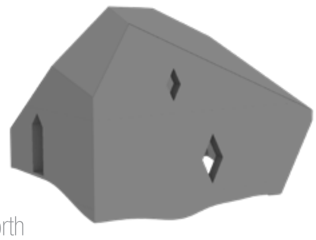
FINDING THE SHAPES

The salt crystal inspired shape was the one chosen to be refined. To be able to fit the building in between the trees it had to be split up in three different buildings leaving the play space outdoors.

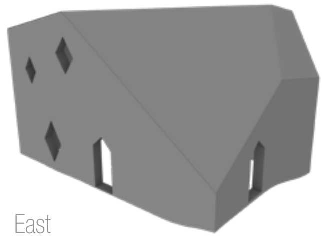
The solid rock sticking out of the ground on the site decides where the foundation of the building is to be placed. Then the primary volumes are positioned.

All vertical walls are 3D printed and angled roofs are built of timber frames.

Rhythm/Movement Building



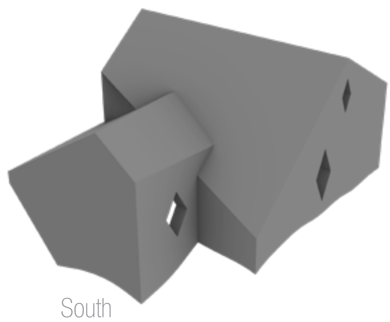
North



East

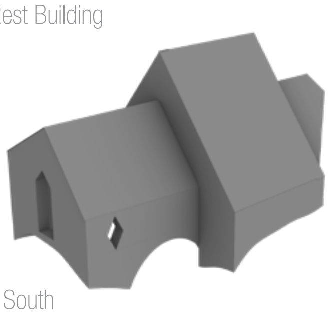
Handicraft Building

North

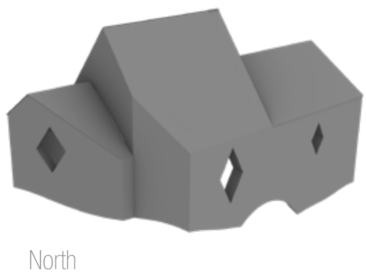


South

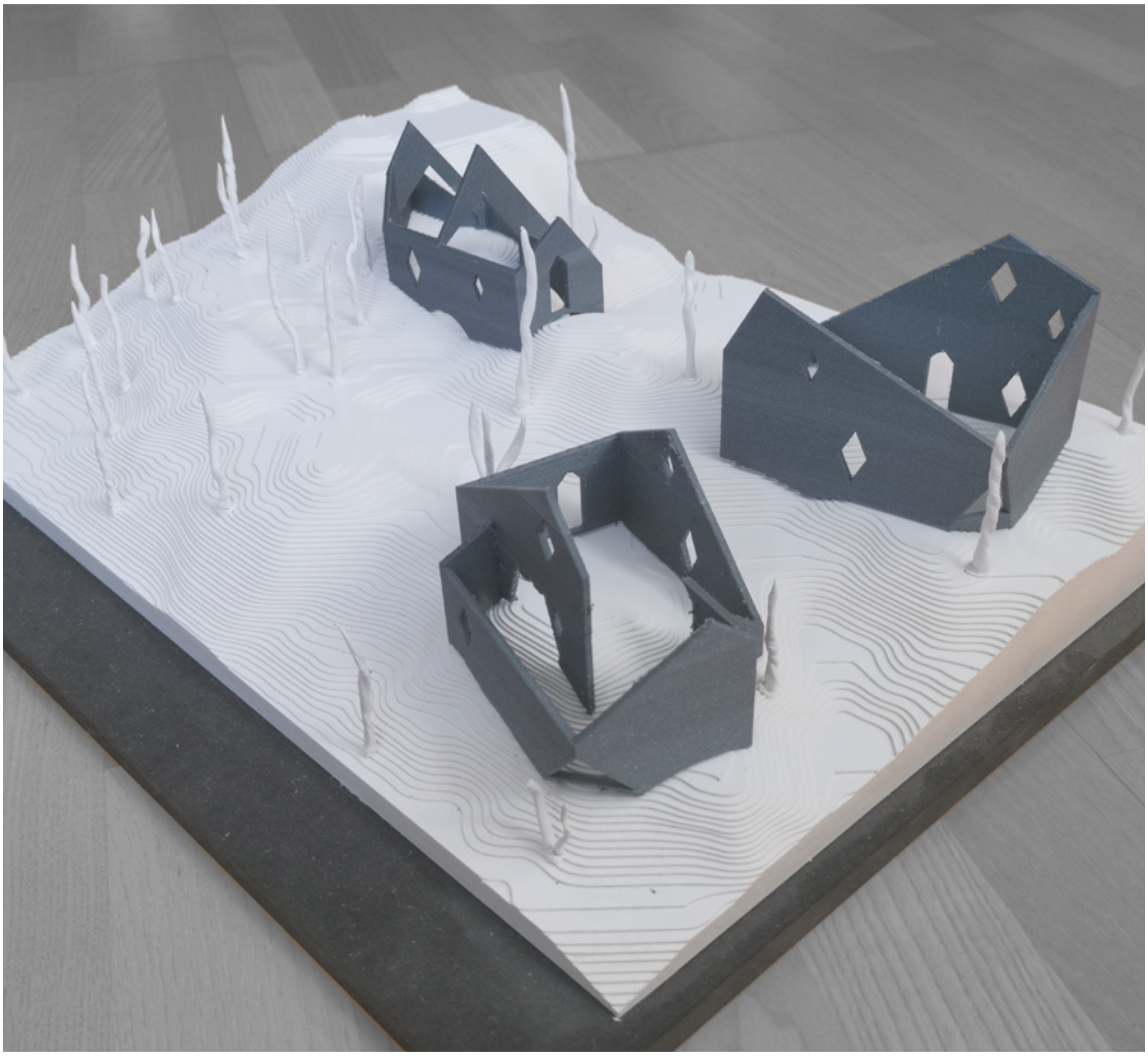
Storytelling/Rest Building



South



North



The walls were test-printed in scale 1:100 and positioned in the site model. This proved to me that the digital model was matching the real model and this would also be the case in full scale.

FINDING THE SHAPES

WINDOWS AND OPENINGS

To 3D print a square window without support is impossible. The only solution is to place a header above the window once the walls on each side of it is printed.

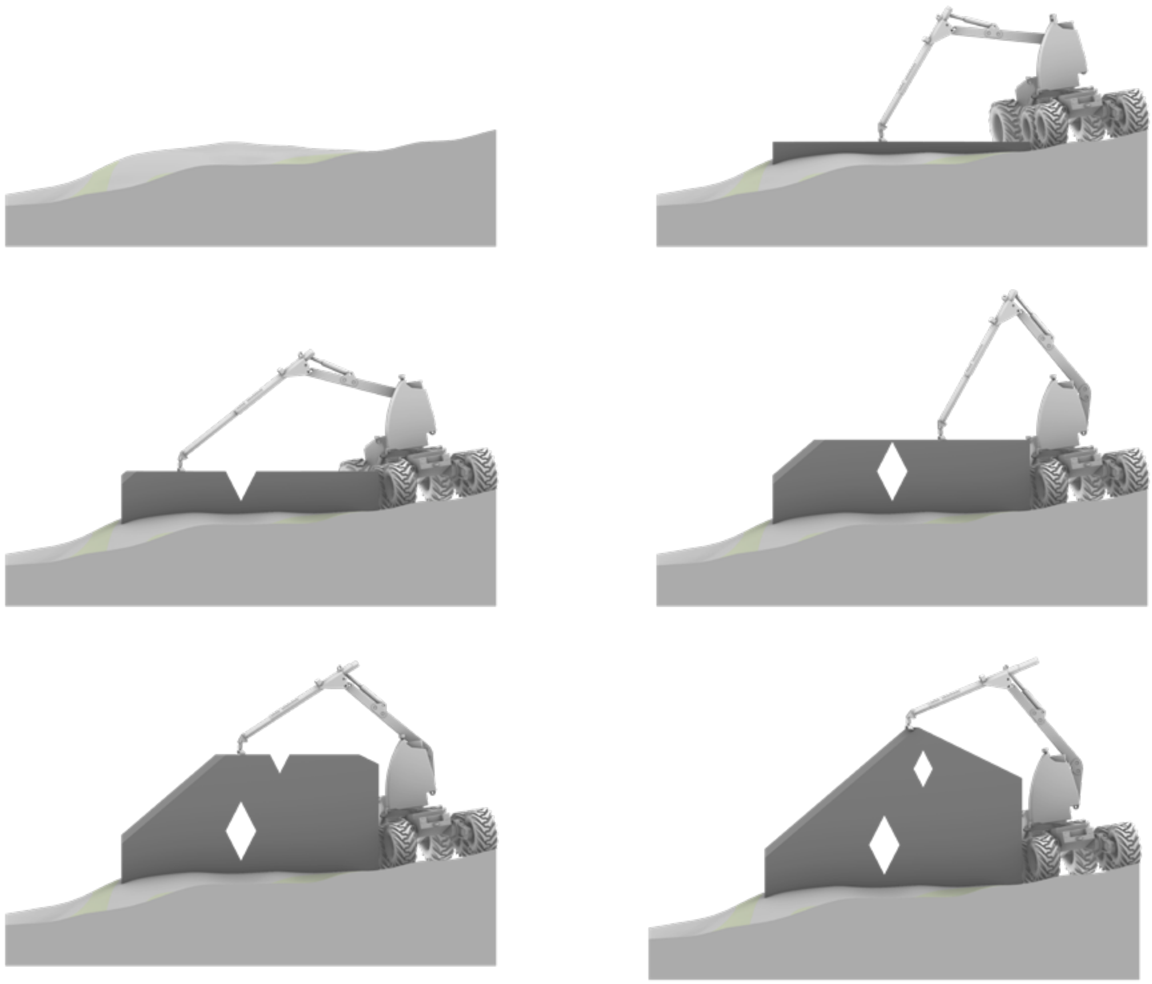
A rounded arch takes the forces down along the sides of the opening. This solution is used with load bearing brick constructions and can be applied to 3D printing as well.

Similar to the example above is the pointed arch which is used in gothic architecture. This solution is also applicable to 3D printing.

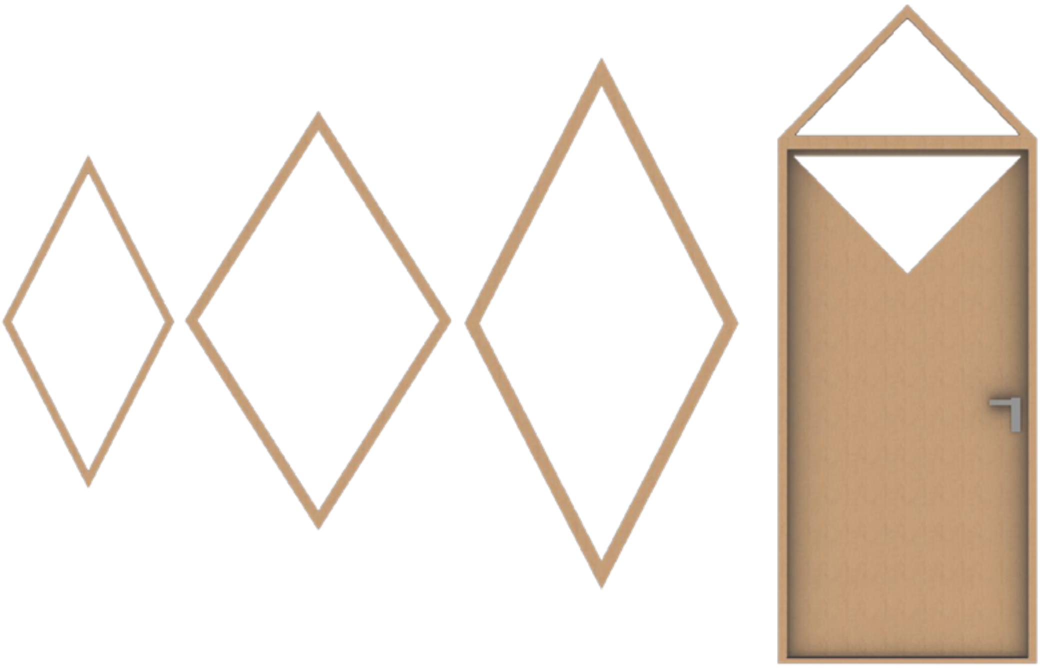
A simple solution would be to rotate the window 45 degrees, this would bring all the forces down the sides of the window. The more narrow the window is, the straighter the forces are taken down. This was the shape best suited to the buildings.

FINDING THE SHAPES

WINDOWS AND OPENINGS

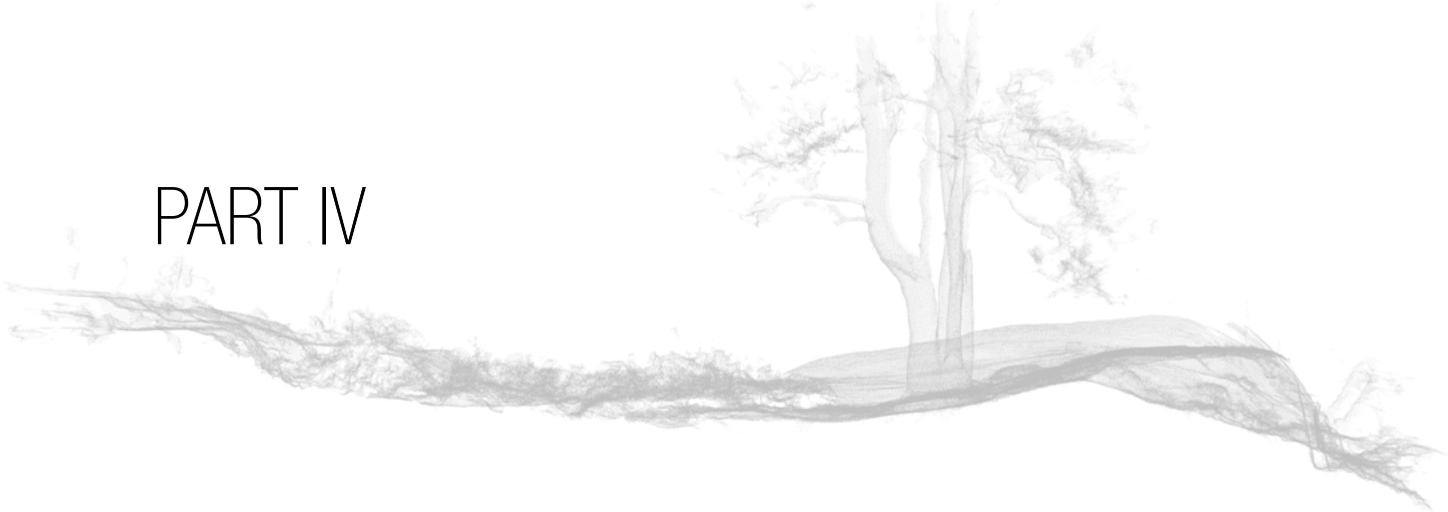


The holes for doors and windows are made during the print so no manual labor is needed except for mounting the window frame.



The openings for windows and doors have a rhomb shape to handle the loads and work for 3D printing. To have the same design idiom as the windows the doors has a triangular window mounted at the top and the second half inside the door.
To keep costs down there are 3 standard sizes of windows and one standard size of door.

PART IV



3D PRINTING

3D PRINTING

A New Idea

Fig 06. John Deere 1170E. In a near future we might see machines like this printing houses instead of just taking down trees

The idea is to attach a print head to the crane tip.

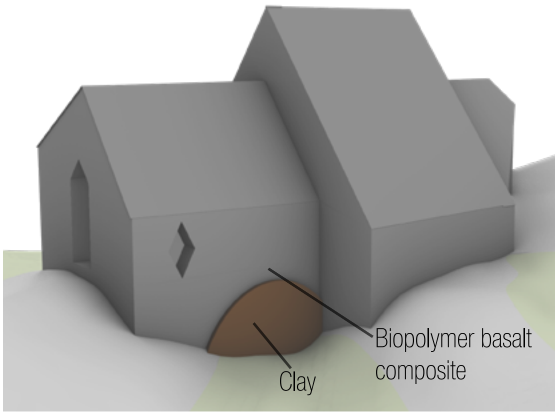
I want to explore the possibilities of rebuilding a forest harvesting machine and replace the grip of the crane with a 3D printhead. The problem with this today is that the crane has a precision of between 10-50cm depending on the how far it reaches. I see two solutions to get a higher precision. Either the crane is rebuilt to a robotic arm using servo or stepper motors or a smaller robotic arm is attached to the tip of the crane which can compensate the precision using a gimball.
I think the latter would be the easiest and cheapest solution since it would also compensate for any unsteadiness of the forestry machine itself. Today there are many forest harvesters that have a reach of 11 meters which is enough to 3D print a dome with 8 meters diameter and 4 meter height. There is also a possibility to move the machine and make the print in sections where you put the tip of the crane at the origin point and let the 3D scanning device calculate how to continue the print. This technology is non-existent as of yet, but with the rapid development within both the 3D printing industry and the forestry industry with the newly developed crane tip control (Skogsforsk, 2016) I see great possibilities emerge. Also within the excavator technology things are getting more and more automated and onboard computers control the bucket to help the operator.

A second way of printing is to use the same idea as 3Dwasp where the 3D printer is attached to rails on a big frame system, but this solution would need a bigger workforce than the forestry machine or excavator which can be controlled by one person. In this case a better idea would be to print the parts off-site and assemble them on-site since you would get perfectly fitting parts from the 3D-scan.

When 3D printing in large scale with paste there are limitations to which shapes that work and the overhangs can not be big. There is much more freedom to the shape when using a normal FDM printer, which use a thermoplastic filament that is melted just above its glass transition temperature. This means that the filament hardens immediately after extrusion, making bigger overhangs possible.
A solution to the use of paste, would be to cut out all openings after the walls are finished and printed, but in this thesis I want to limit manual labor as much as possible and also minimize disturbing noise.

One natural advantage of making the print straight on the rock is that this makes a solid foundation for the building, the other advantage is that there are no trees growing straight on the rock which makes it possible to fit the building in under the crown of the tree.

For test purposes, the Storytelling/Rest building is situated on top of two different rocks. This meant that a solution on how to bridge them had to be found. Since the angle of this bridge is quite low a temporary support was needed. The easiest way was to print the support with clay and then add a thick layer of biopolymer basalt composite on top, before continuing the print of the walls. After the walls are finished the clay can be washed away.

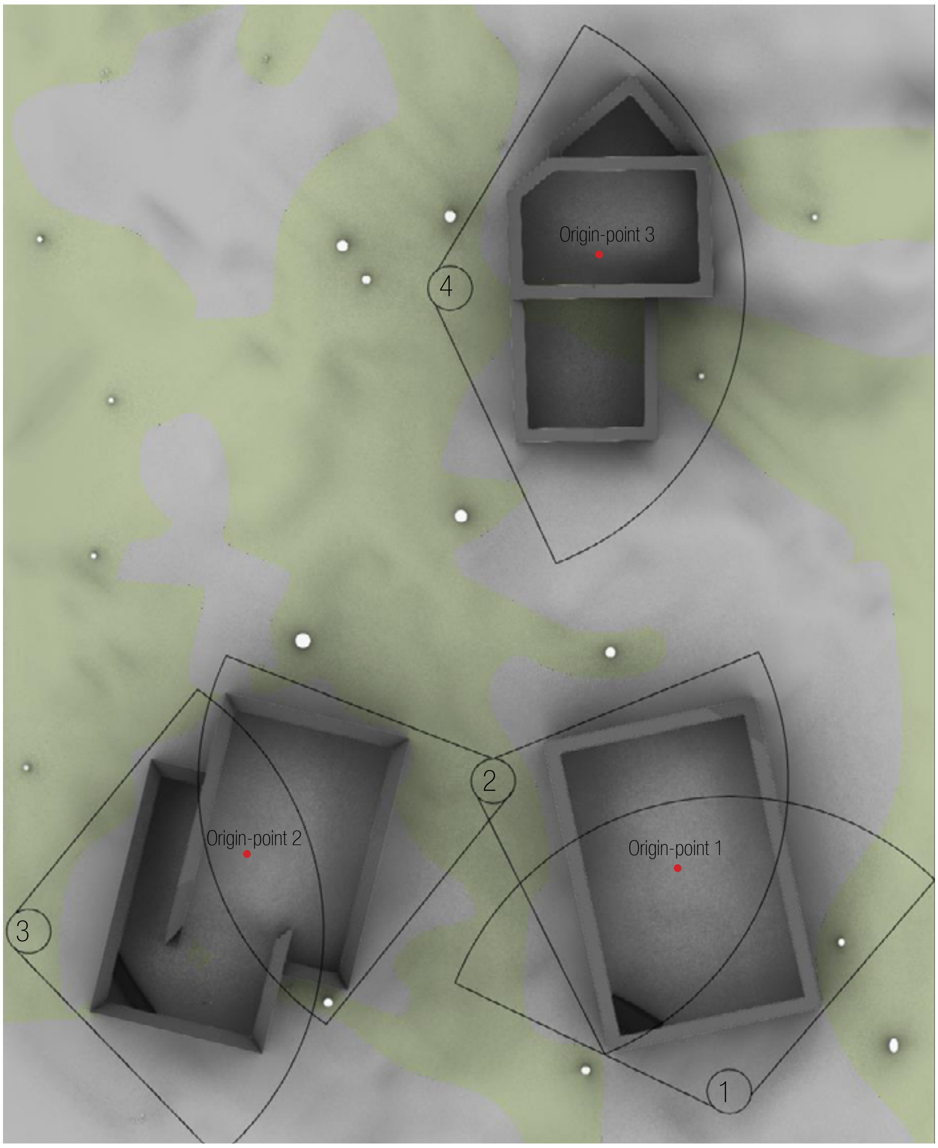


The Storytelling/Rest building and the vault between the rocks.

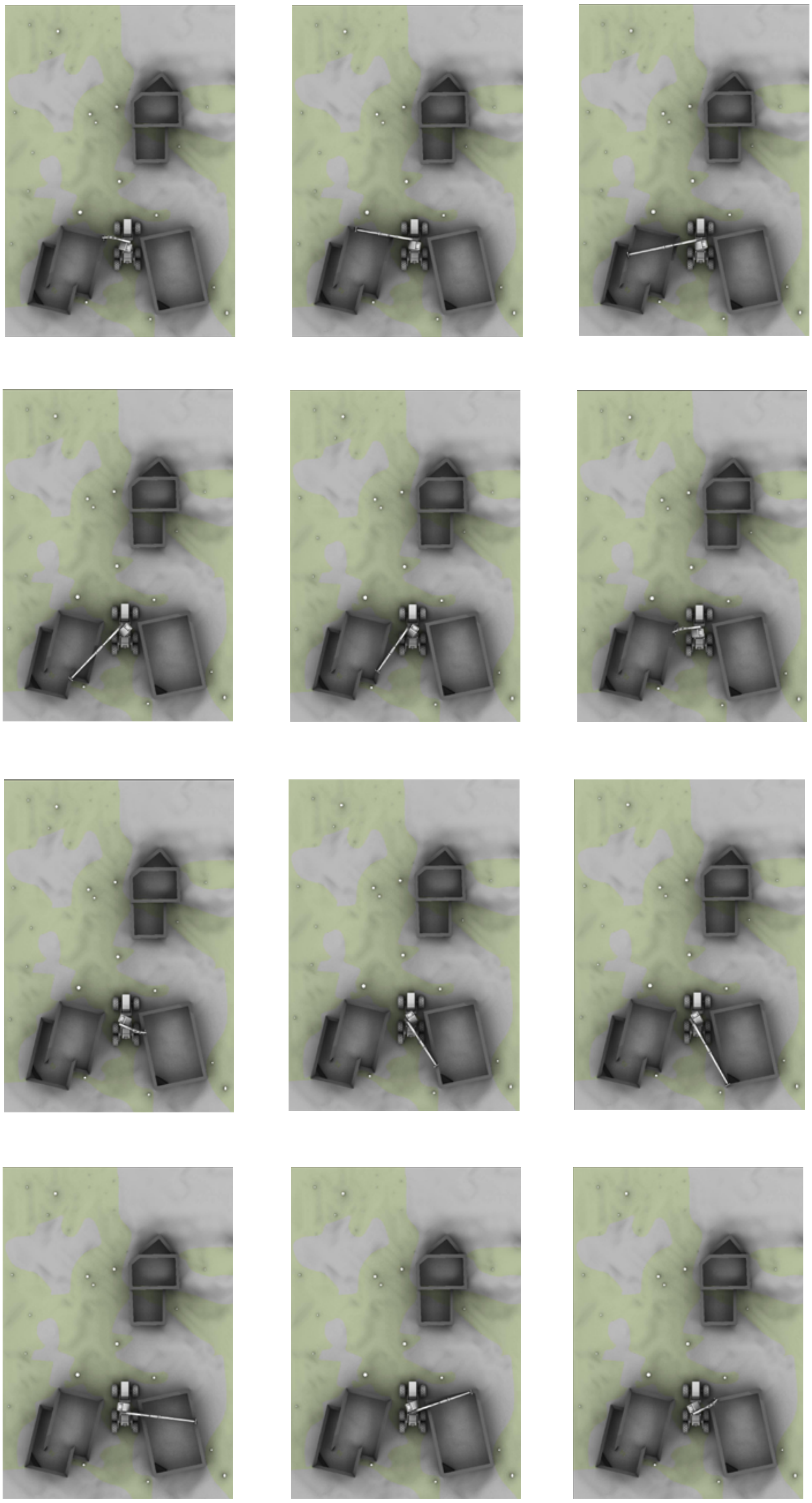
3D PRINTING
The Method

When the area is scanned, a metal pole for each building is firmly fixated in the ground (preferably rock) in the center of where the building is supposed to be situated. The pole also has a square metal plate showing the X and Y axis. This is the origin-point of the whole print so it needs to be reached from all around and it is very important that it is scanned in high detail to be able to read the axes.

When the print is started, a magnet is attached to the pole. This triggers a sensor in the 3D print head and sets the origin point in the real world while also reading the X and Y axis. The 3D print can through the 3D scan of the rock follow the contours and this way the foundation is resting directly on the rock and no blasting is needed. This makes the construction more silent and less disruptive to neighbors and wildlife.

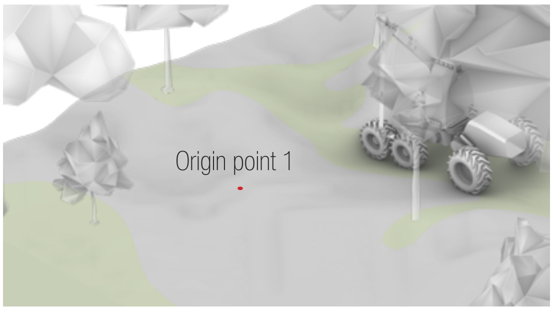


Positions and reach of the printer

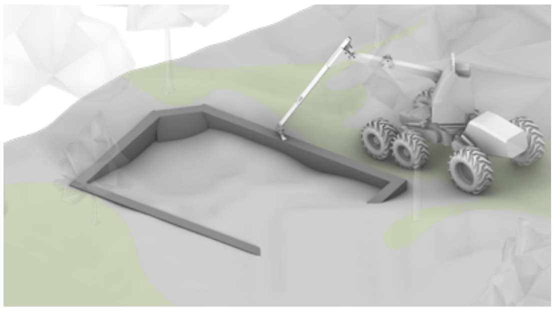


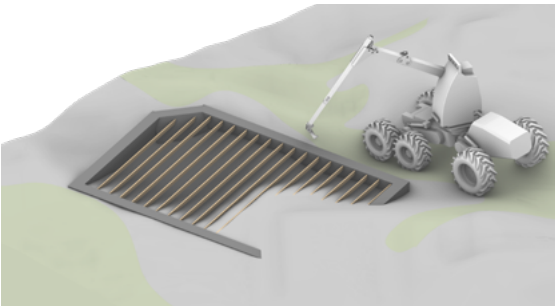
Examples of the printer working in position 2

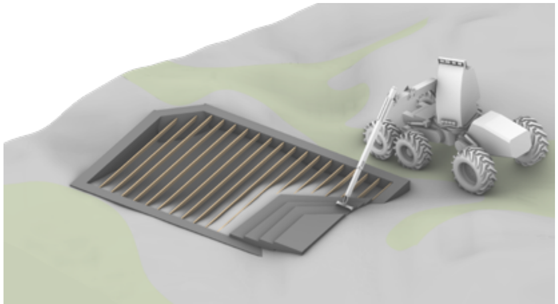
3D PRINTING
The Method

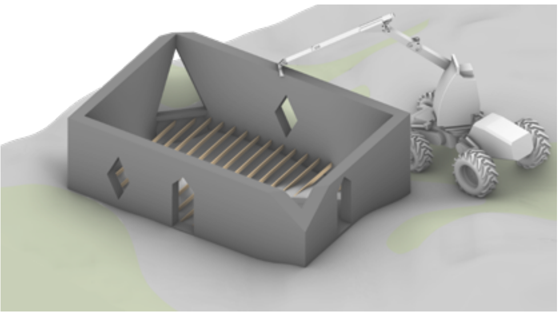


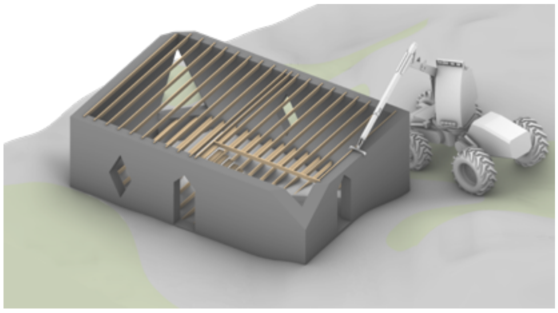
1. The printer is set in position 2 and calibrated with origin point

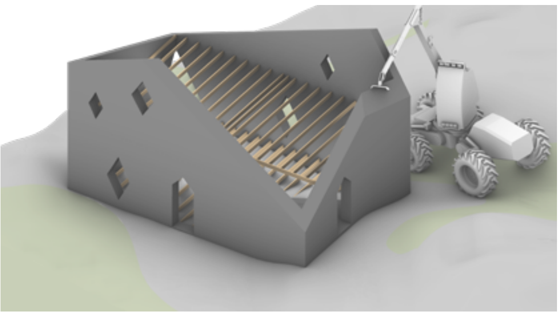

2. The foundation is printed with biopolymer basalt composite straight on the rock

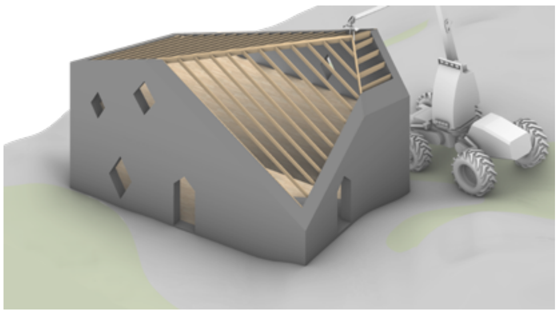

3. Floor beams are mounted in the biopolymer basalt composite


4. Interior stairs are printed straight on the rock


5. The inner and outer layers are printed simultaneously with an air gap in between.


6. The intermediate floor beams are mounted in the inner layer

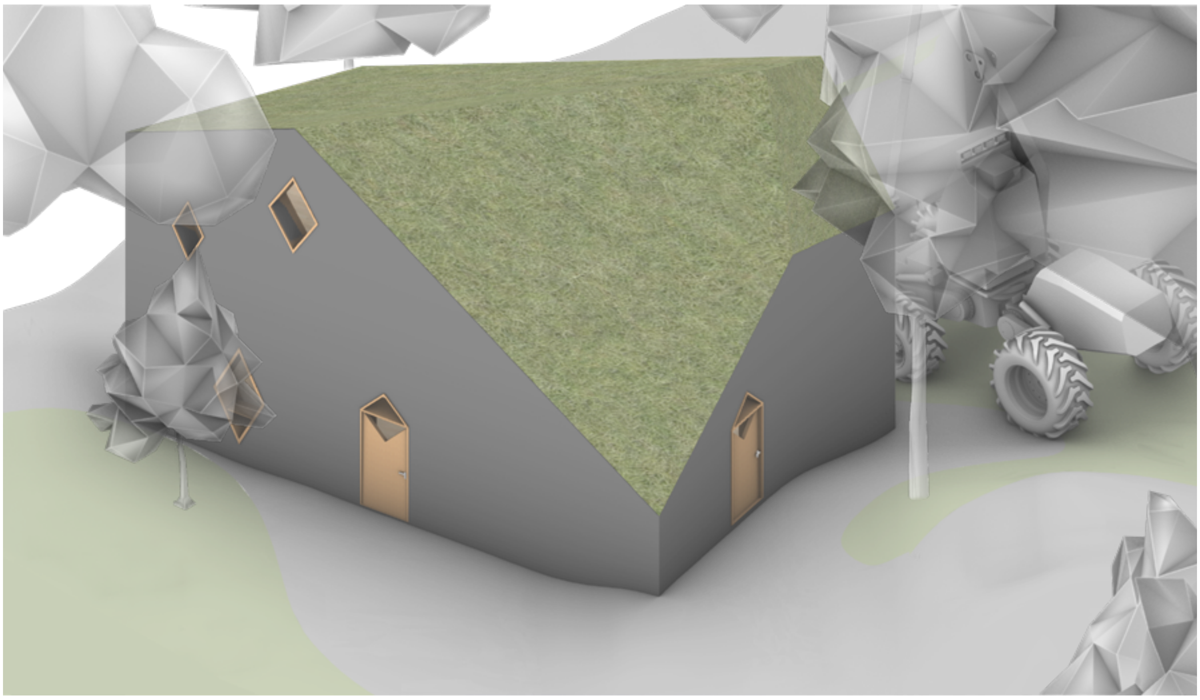

7. Before the last layers are printed the air gap is filled with insulation.


8. Now the printer helps lifting the roof beams in position

To minimize manual labor the printer also helps lifting the floor and roof beams into position and can lift heavy material like sedum mats on to the roof. It can also help blowing in the insulation into the gap between the inner and outer walls.

QR code showing an animation of the build up

Figure 07. Forest Harvester Modeled by Ivo Jardim

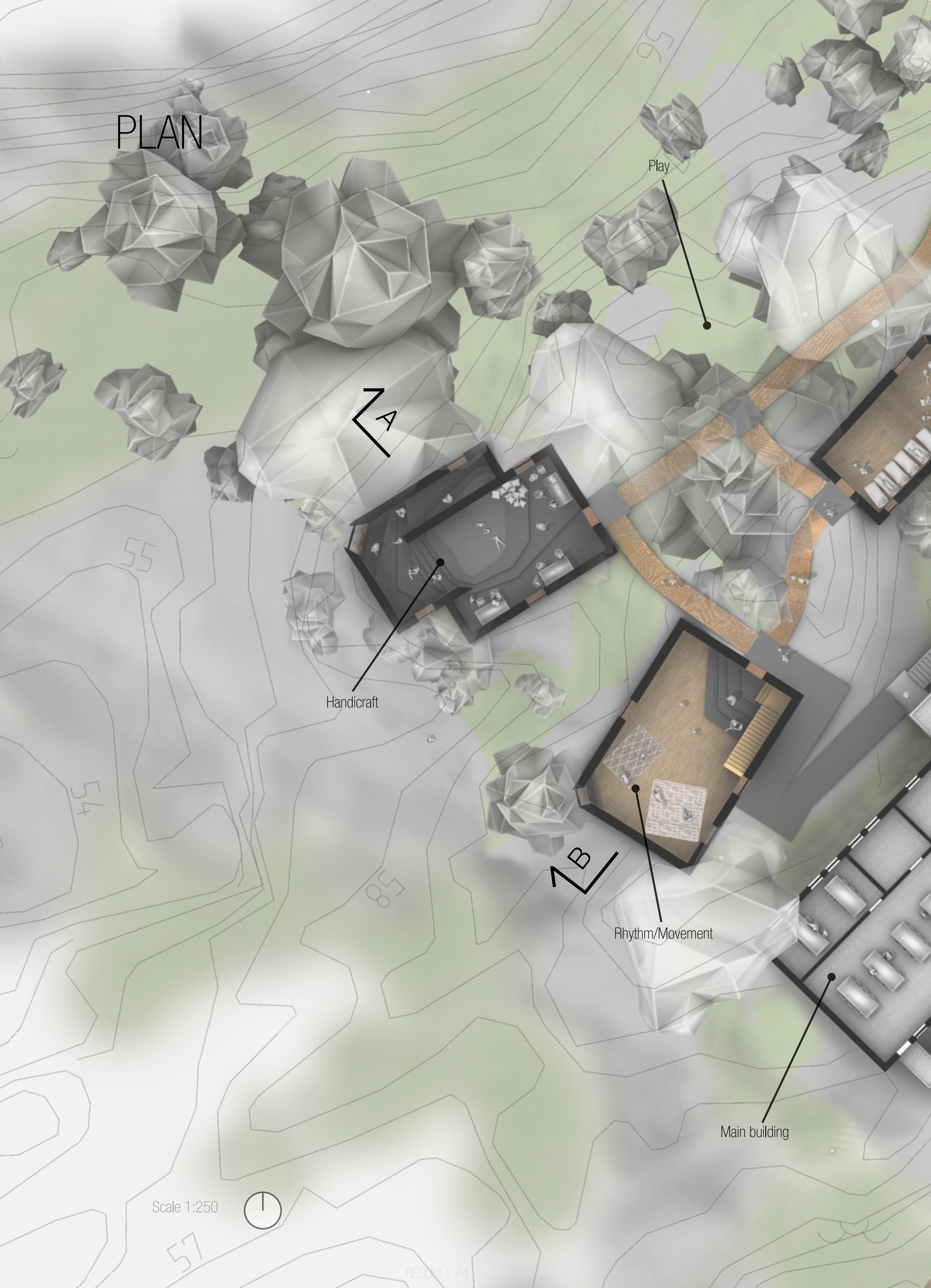


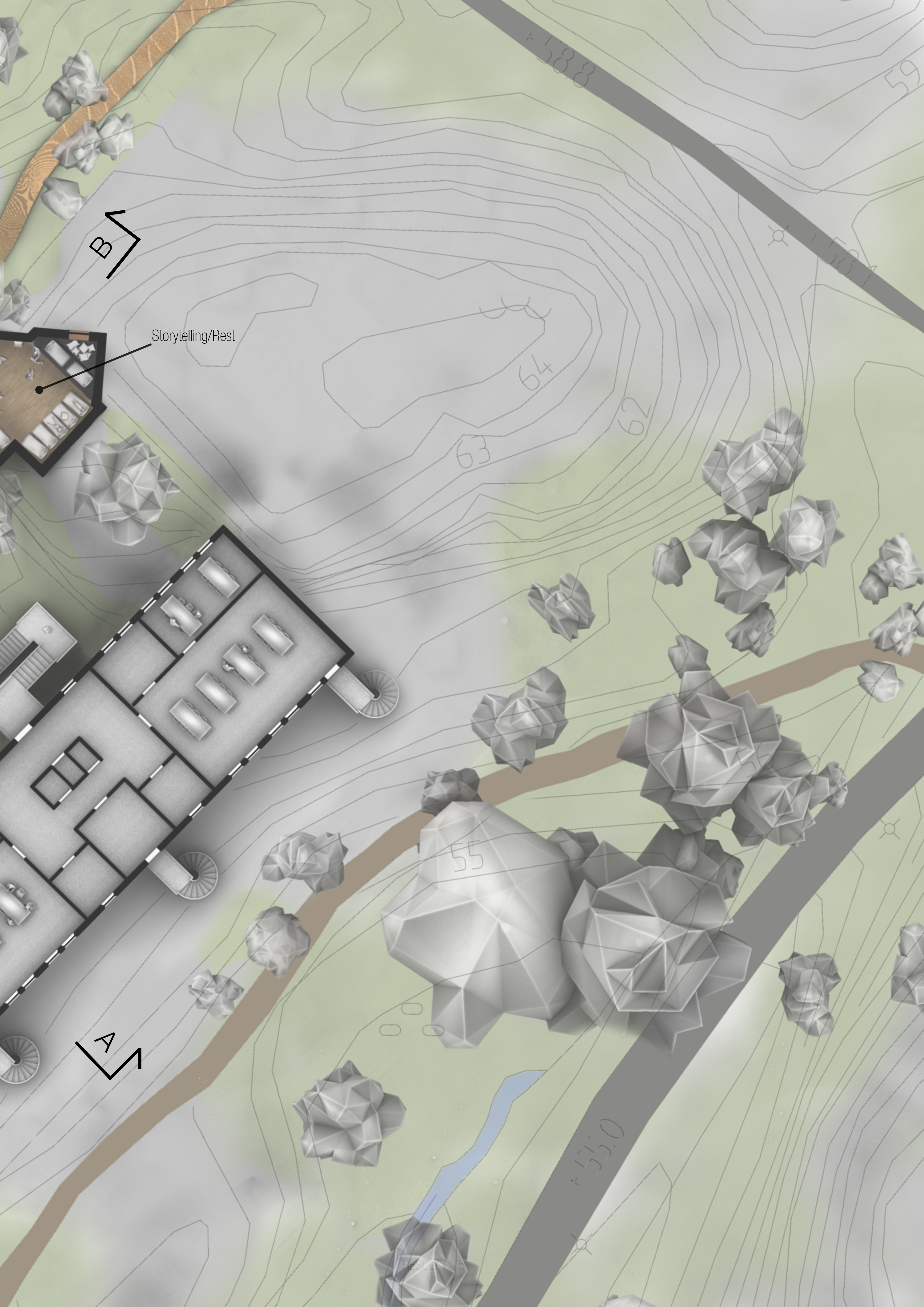
9.Sedum roof, windows and doors are mounted.

PART V

RESULT

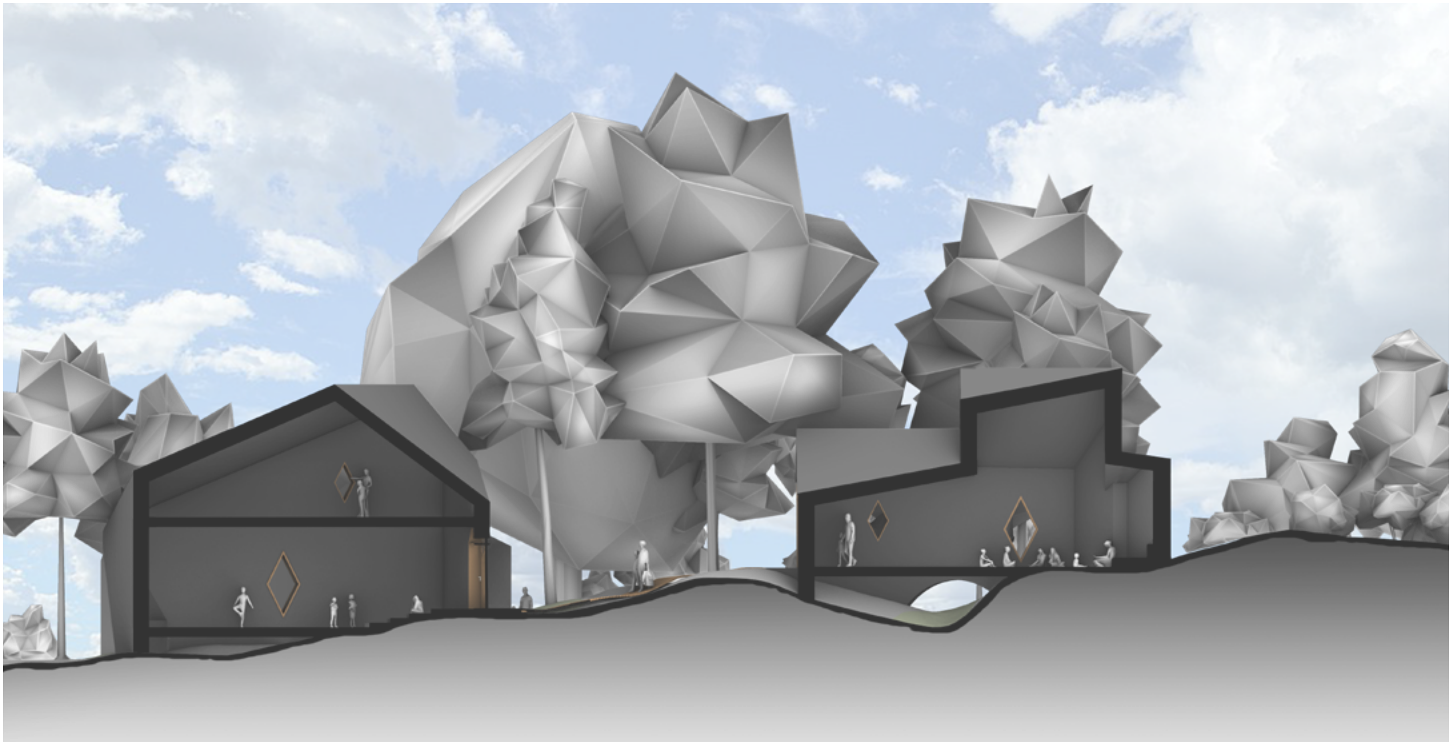
PERSPECTIVE


PLAN
Play
A
Handicraft
B
Rhythm/Movement
Main building
Scale 1:250


B
Storytelling/Rest
64
62
63
55
A

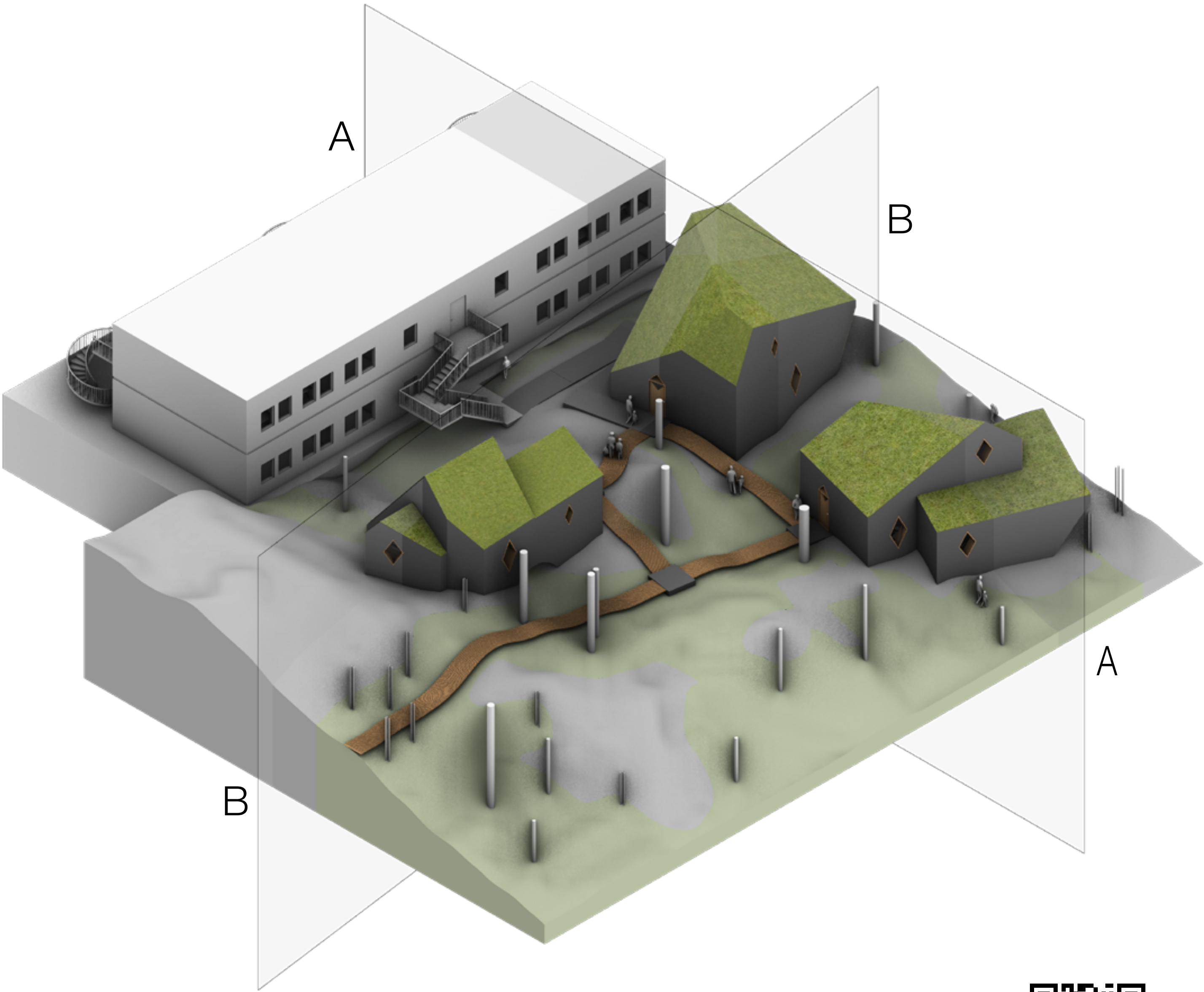
SECTION

Section A-A Scale 1:250



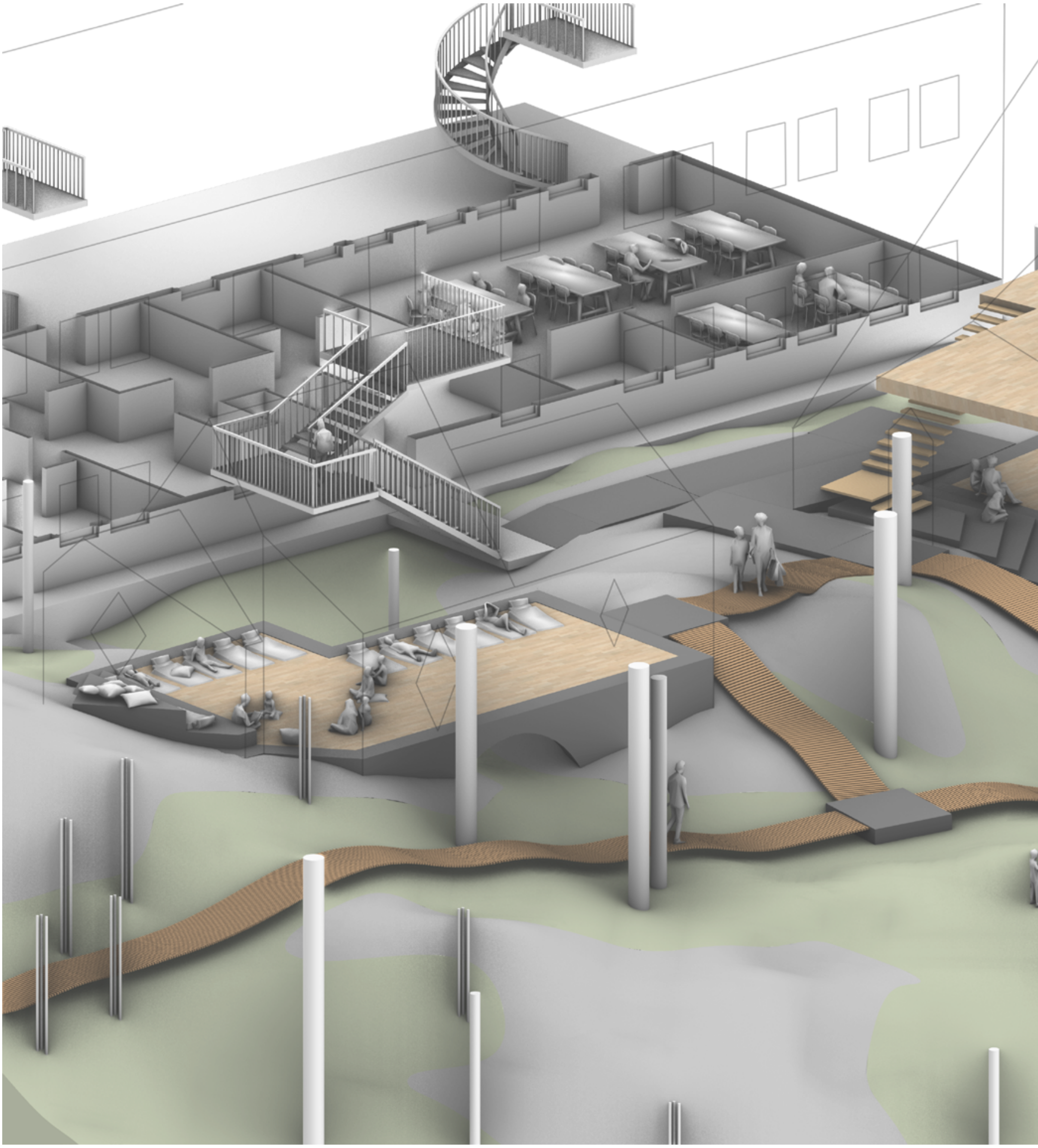
Section B-B Scale 1:250

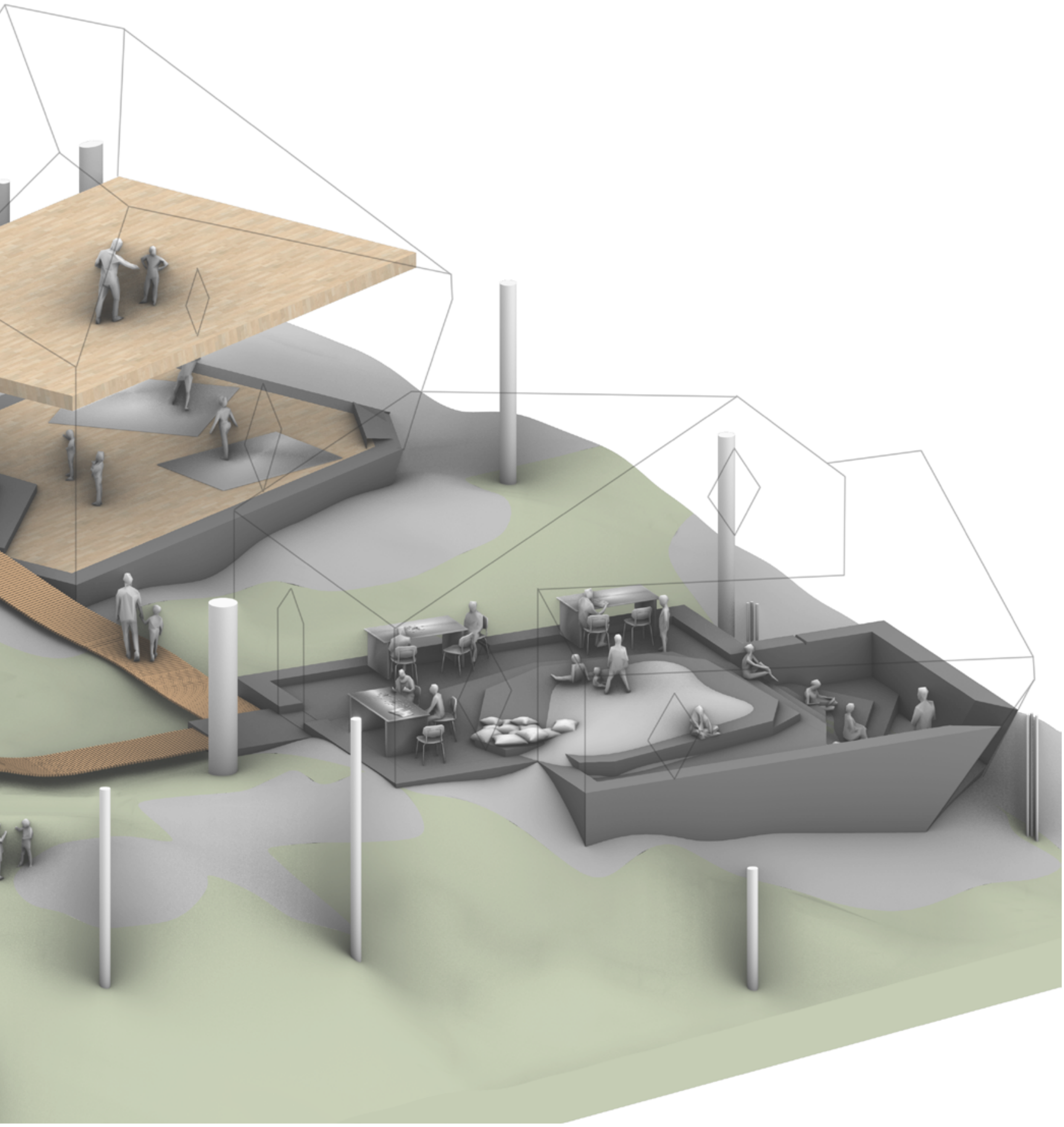
ISOMETRIC



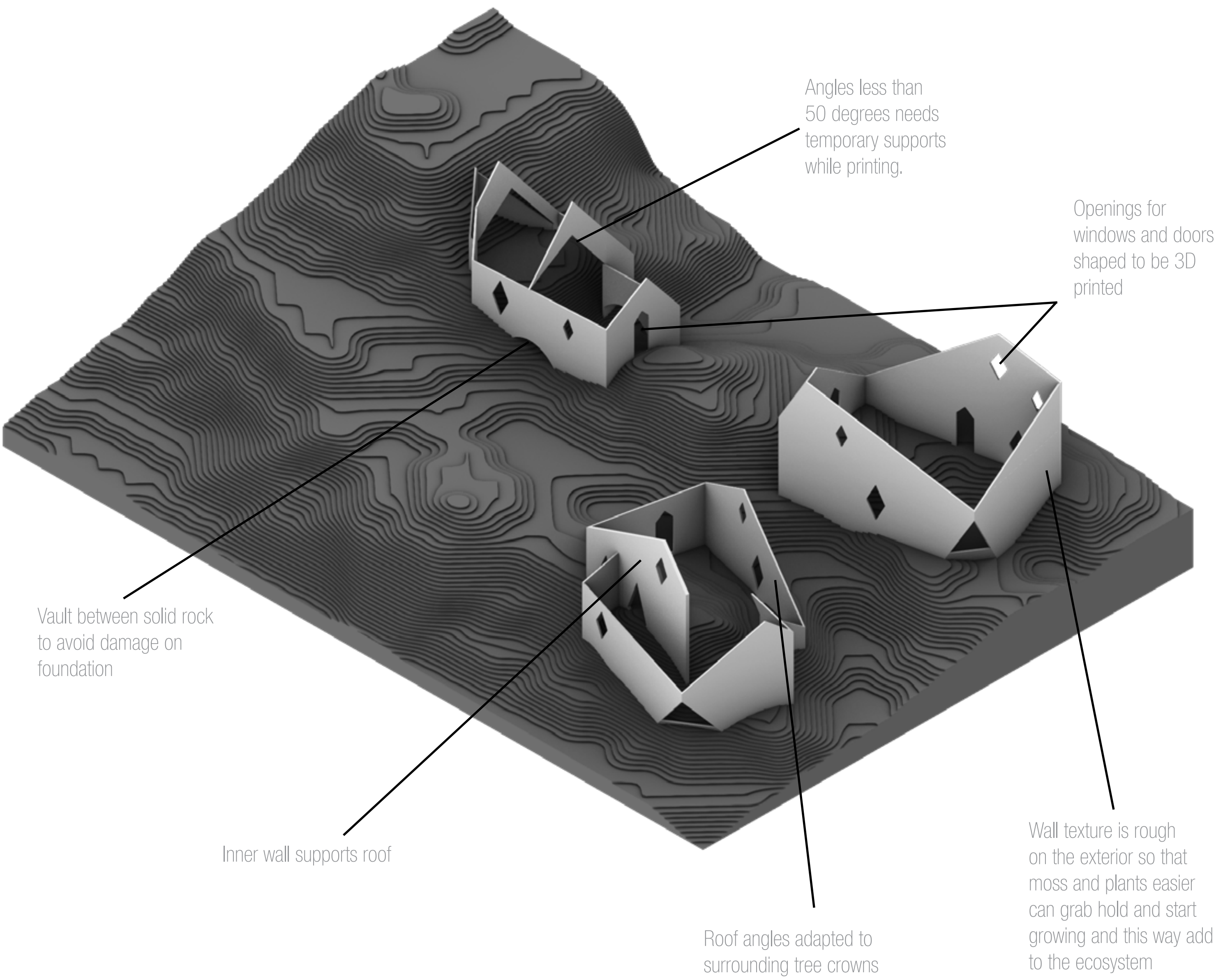
QR code showing
a model of
the buildings
embedded among
the trees

3D FLOORPLAN



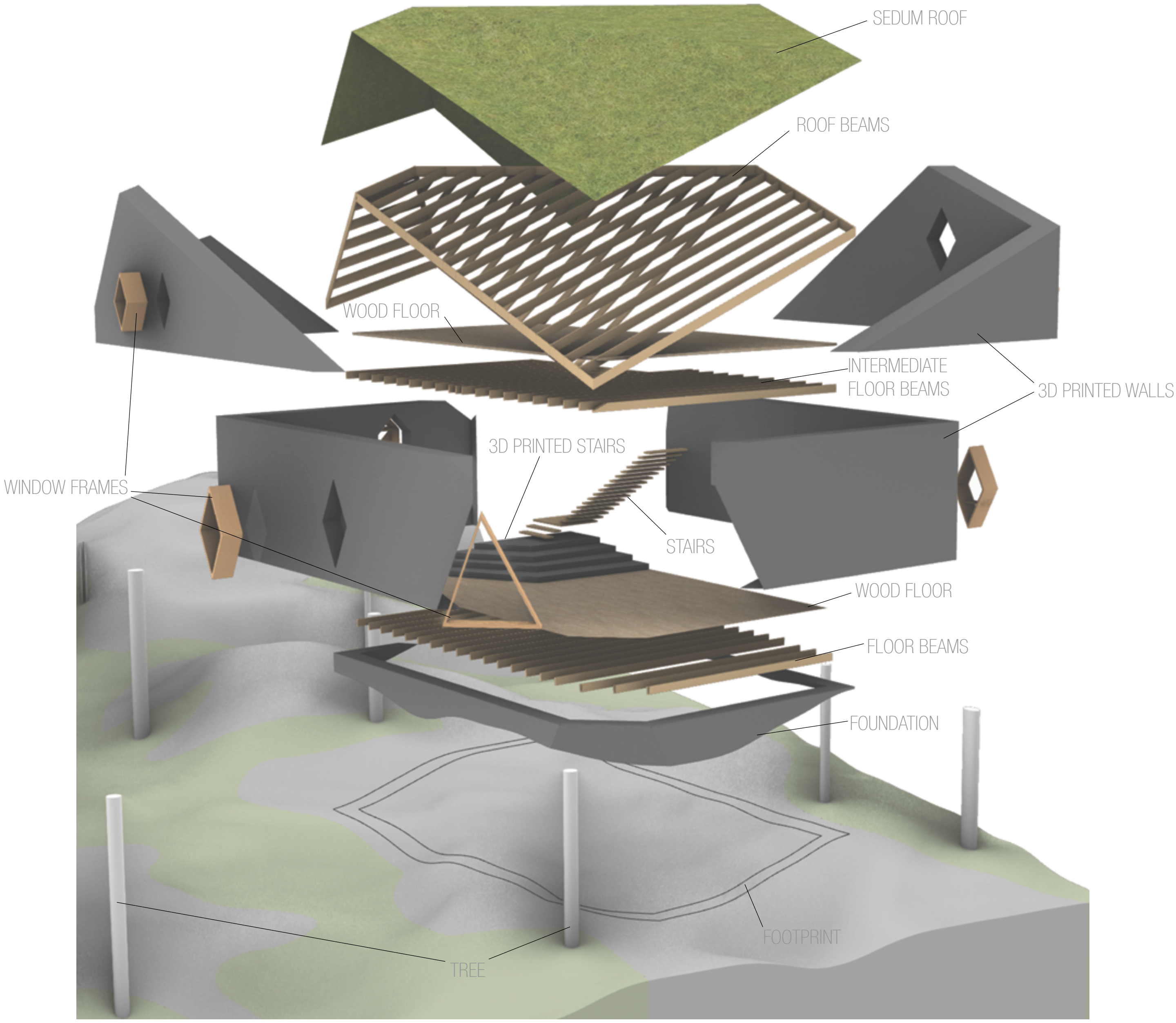


3D PRINTED CONSTRUCTION



The main characteristics of the 3D printed parts of the buildings

EXPLODED VIEW

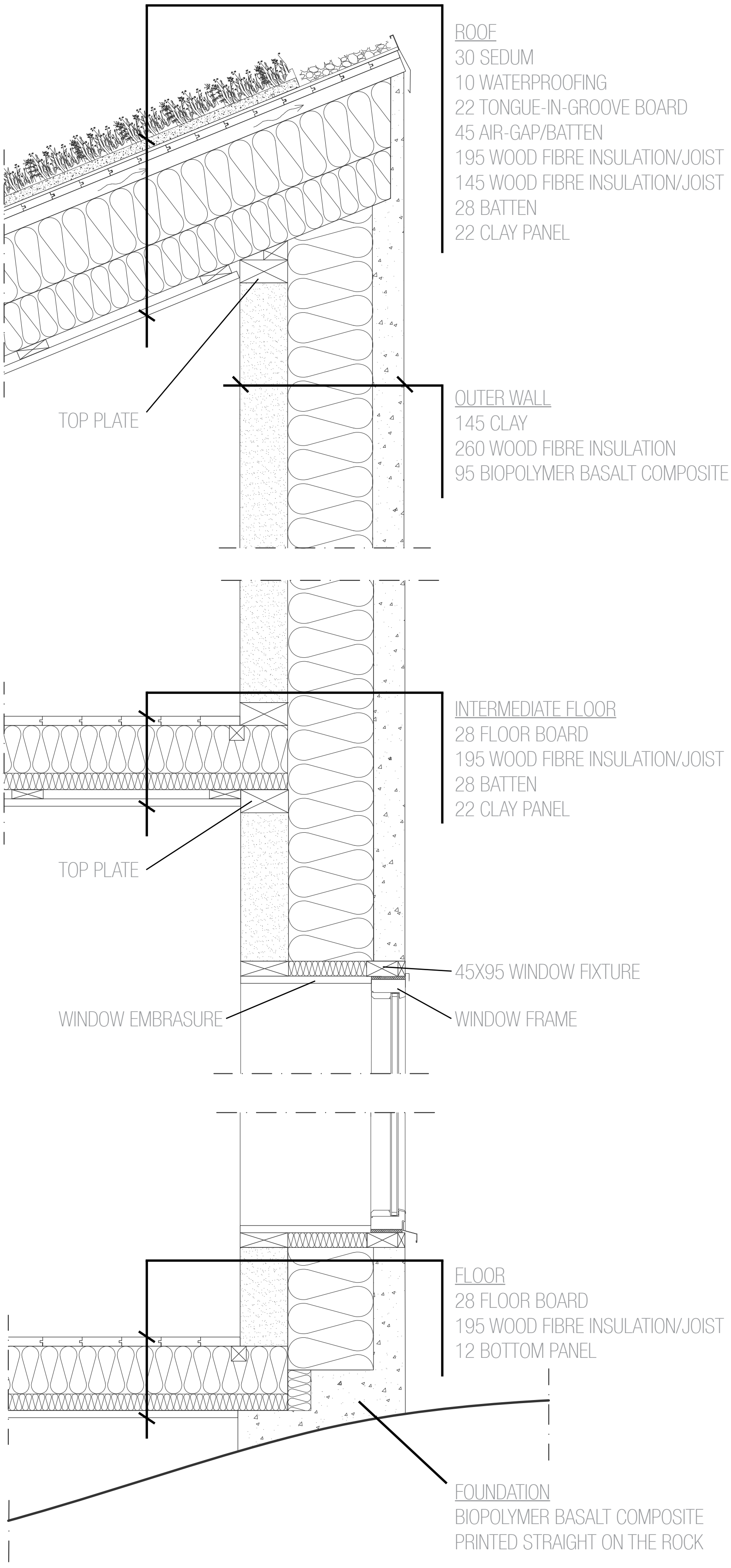


All three buildings have the same construction and main assembly

CONSTRUCTION

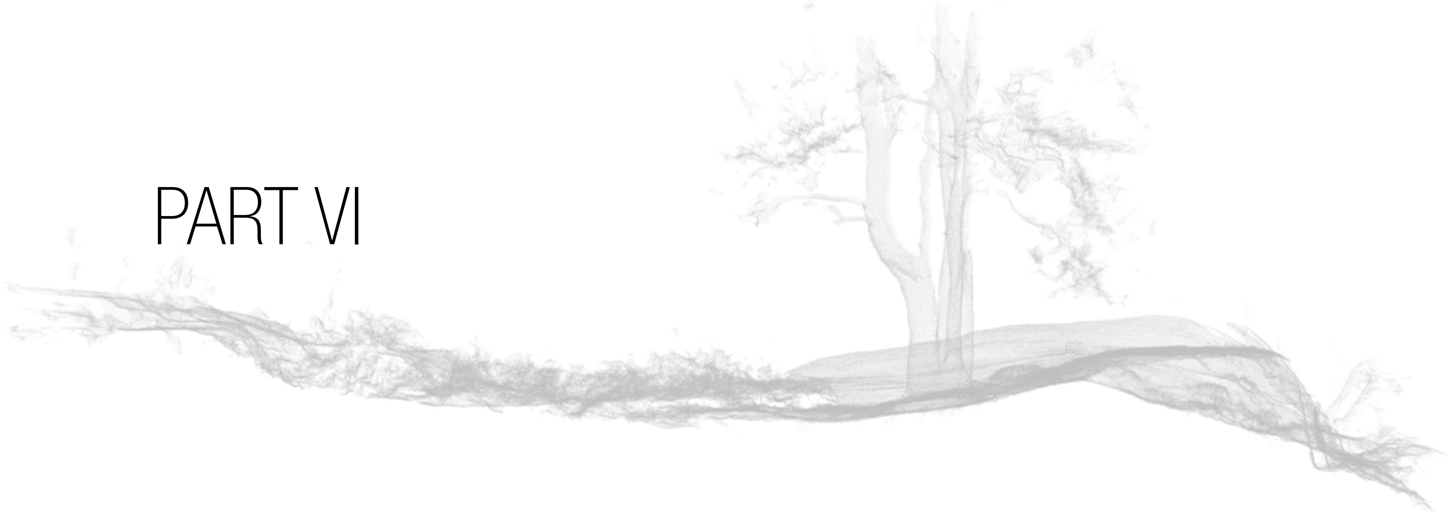
The walls are printed straight on the rock in two separate layers where the outer layer is made of biopolymer basalt composite to withstand rain and wind. This layer is printed with a rough texture for plants to be able to cling to it. The inner layer should be printed with normal clay from the site. Insulation is blown in between the two layers and should be a natural material such as wood fiber or hemp.

DETAIL



Scale 1:20

PART VI



DISCUSSION

CONCLUSION

Looking back historically labor was cheap and material expensive. Today it is the opposite. Material is cheap (and mostly unsustainable) while labor is expensive. In this thesis I speculate that one or two people and a machine will be able to build a whole house in a short amount of time. While the industry is trying to implement a greener approach, an obstacle is that materials that are more ecofriendly also often needs more labor for example a timber frame vs concrete. The techniques are always refined over time and get more and more automated and the development is getting faster for every day. During the time spent on this thesis things happened in the 3D printing world where for example now ICON collaborates with Bjarke Ingels Group while funded from NASA to design an "Off-World Construction system for the Moon" (ICON Team, 2020).

While the technology for 3D printing is breaking ground there are still laws and regulations that keeps it on an experimental level and as long as the traditional building industry is not adopting it, it will take a lot more time. Though the ongoing environmental crisis opens up opportunities for funding it still takes time to standardize and evaluate a totally new way of construction.

Add and adapt to Nature is a holistic way of building where consideration is taken to both the site and the materials used in the construction. It is an attempt to look at construction in a new way and also adapting appropriate traditional techniques.

This thesis has a focus on exploration and therefore the design of the buildings is not the main focus. It is a tool for different techniques and design methods and the result is a consequence of the process. It is also a way to provoke the standards of the building industry and its design idioms and the main objective is to find a more sustainable way to design and build without leaving deep scars on the surface of the planet.

The 3D print can through the 3D scan of the rock follow the contours and this way the foundation is resting directly and securely on the rock and no blasting is needed. This makes the construction more silent and less disruptive to neighbors.

The resulting shapes are consisting of composite buildings made by 3D printed walls and a normal wooden frame. With irregular roof angles adapted to the surrounding tree crowns and a foundation printed directly on and adapted to the solid rock. To compensate for the loss of ecosystem due to the footprint of the building, and even increase it since the prints are done on the rock which doesn't have much vegetation from the start, the walls and roofs are clad with appropriate vegetation. This also helps the buildings from overheating in the summer and adds extra insulation in the winter.

The design of the building is adapted to its surroundings in the same way as we would design in a city, where we let inhabitants in the old buildings surrounding the site stay and live as they used to. Though here we let the old inhabitants of the site (the trees, rocks and ecosystem), stay as undisturbed as possible and maybe even add to the ecosystem. We let nature be a stakeholder in the project.

Thanks to the power of computation today a highly detailed model of a site can help setting the boundaries of a building but it also adds limitation in the freedom of design, since the exterior surroundings also affect the indoor design, with ceiling heights and position of walls and window positions etc. Maybe these limitations to space and function is something architects will have to consider in the years to come as nature is becoming more and more valuable.

So finally:

Can the existing landscape be used as canvas for a building i.e. no leveling of the ground needed?

- Yes, this is possible and has been used historically before we started using explosives. Hopefully we will apply new technologies and add to what exists on site instead of removing before adding.

What are the limitations within geometry for 3D printing in full scale?

- The limitations depend on what material is being printed. There are 3D printers using steel as material and this, is as good as limitless. When using clay it is necessary to use supports depending on the overhang. Biopolymer basalt composite gives more freedom than clay but less than steel. With the evolution of new materials who knows what the limits are in ten years.

Perspective of the Rhythm/Movement and Storytelling/Rest building from outside the door of the Handicraft building.

REFLECTION

The main objective of the thesis is to try and create architecture with as little impression on the site as possible. This can of course be done with existing technologies and manpower but since most existing technologies demand heavy machinery which would affect the terrain of the site and since manpower is expensive, I wanted to speculate what would happen if I crossed two technologies from different fields i.e. a forest harvester (designed to make a minimal impression of the ground) and a 3D printer. Further I realized that I had to translate the site to a language that the printer would understand, hence the 3D scan.

The expectation was that when a detailed 3D scan of the site was made and I had it as a digital model, the shapes of the buildings would come naturally, since I would “capture” the rooms already existing on the site. This was not the case and a lot of design work had to be added to the process.

The first iterations had to do with the evaluation of if the buildings would be 100% 3D printed. To be able to do this they had to be igloo-shaped or spherical. When trying this on the site, problems occurred when the buildings reached a certain height and interfered with the crowns of the trees or if a wall had to be printed around a stem of a tree. This would mean that the roof or wall had to change from a convex shape to a concave which ends up not supporting itself. When trying spherical shapes away from trees, thus avoiding concave shapes, the buildings ended up looking as foreign objects on the site, opposite to the goal with the thesis.

When further iterations were made I came to the conclusion that a composite construction including a timber frame would be the best way to go in consideration with the limitations of the 3D printing and the restraints of removing trees on the site. This also limited the freedom of organic shapes since the transition to a timber frame from an organic shape is more labor intense than from an angular shape.

The reason why I chose to print a foundation under the walls in combination with a crawlspace instead of just letting the building rest on plinths was that I decided early on to explore how to 3D print walls and through my chosen design I also made full use of the 3D scan. Also, since the building is positioned straight on the rock where nothing but moss grows it would be better to seal it off so that moist air can be controlled to not ruin organic material in the crawlspace. The exterior walls are printed with a rough texture for nature to easily get hold of and start growing to add to the ecosystem.

Regarding the scanning I found that due to bushes and shrubbery on the site, the scan gets hard to mesh because of the high detail. It is also hard to clean up and even out the mesh once it is done. Next time I will use these techniques, I will first make sure to clean up the site from bushes, brushwood and thickets.

I think the first future uses of 3D scanning and 3D printing technology in unison within the building industry is in the production of foundations for houses on existing terrain. Then a more traditional building technology can be added on top. Later when cheaper and better printing materials emerge I think that it will affect the overall architecture of buildings.

Thinking about temporary buildings like the modules used as preschools in Gothenburg today and their lack of care in detail and boring expression, a thought that has crossed my mind is that building permanent buildings really is what makes modern humans differ from nature, since most animals only use their shelters for one season and then leaves them quite like humans lived 12 000 years ago. This way nature gets time to recuperate.
Does a temporary building have to be boring just because it is temporary? Maybe this is a consequence of traditional building techniques and maybe we will see a less monotone expression of these kinds of buildings in the future when printing is more common.

One thing I learned during the work with this thesis is that it will be very hard to replace the design work of the architect with an automated script since there are so many things to take into consideration. This really showed me the complexity in the art of architecture and the skill of the human mind.

In the end it does not matter how much we wish to mimic nature or automate the design process. As humans we will always affect the design and in the bigger picture we are part of nature and maybe the things we design will somehow be considered natural when looking back from a distant future.

Perspective of the Storytelling/Rest building from the Main building

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IMAGES

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Figure 01. Evolution. Retrieved from https://pixabay.com/sv/vectors/natur-liggande-siluett-träd-afrika-4440363/, https://www.vexels.com/vectors/preview/71108/evolution-of-human-work-silhouettes, https://pixabay.com/sv/vectors/city-siluett-new-york-atlanta-1765954/

Figure 02. The Big Delta 12m printer from 3D Wasp. Retrieved from https://www.3dwasp.com/en/giant-3d-printer-bigdelta-wasp-12mt/

Figure 03. Vulcan II Printer from ICON. Retrieved from https://www.3dnatives.com/en/vulcan-ii-140320195/

Figure 04. Conceptual 3D printer on Mars from AI SpaceFactory. Retrieved from https://www.aispacefactory.com/marsha

Figure 05. 3D Printed Wall with embedded staircase. Retrieved from https://www.3dwasp.com/en/3d-printed-wall/

Figure 06. John Deere 1170E. Retrieved from https://upload.wikimedia.org/wikipedia/commons/a/ab/Harvester_John_Deere_1170E.JPG

Figure 07. Forest Harvester Modeled by Ivo Jardim. Retrieved from https://grabcad.com/library/forest-harvester-1

View of the rough surface of the exterior walls allowing plants to climb.

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