Niklas Nordström

Digital Fabrication of Wood

A Lookout Tower for the Gothenburg Jubilee Exhibition 2021

Studio: Material Turn

Supervisor: Jonas Lundberg
Examiner: Daniel Norell

Abstract

In light of environmental challenges architecture is facing, wood is no longer regarded as outmoded, nostalgic, and rooted in the past, but increasingly recognized as one of the most promising building materials for the future. Recent years have seen unprecedented innovation of new technologies for advancing wood architecture.

The 300th years anniversary of Gothenburg was celebrated with the Gothenburg Exhibition with many new buildings. One of them was a lookout tower that was placed on the hills of Johanneberg overlooking the city. Today the tower is long gone but a bit of the foundation can still be found telling the story of what once was. The 400th anniversary will take place on 2021 and therefore this master thesis proposes to build a new lookout tower for the exhibition at the same location as the previous tower was situated.

The thesis is based on a method of research by design. The design project started out with an analysis of context, history and a reference studies but also through hands on digital fabrication of a landscape model in wood with an industry robot, KUKA 150. Through understanding the mechanics of the robot, communicating with the robot, writing a definition that automate the process of generating machine-code and finally running the machine with a milling tool I got an understanding of pros and cons with digital fabrication.

The thesis investigates if digital fabrication and a clear logic between material behaviour, detail of assembling and overall structure can create a finer grain in wood architecture. In the design the thesis has benefited from the freedom of mass customization through the close link between parametric modelling and digital manufacturing.

Examiner: Daniel Norell
Supervisor: Jonas Lundberg

Bachelor Degree:
BSc Architecture and Engineering

Master´s Programme:
Architecture & Urban Design

Background

Why digital fabrication?

This is important because digital fabrication is about to enter the building sector in a large scale, a change that was done many years ago in many other production sectors, like the car industry for example.

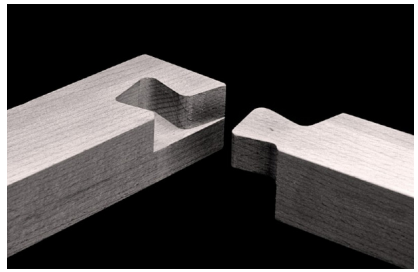
Digital fabrication is a broad term referring to production tools, for example a milling machine, that simplified is controlled through a computer, often referred to as CNC, Computer Numerical Control. The technique with CNC is not new and can be dated back to year 1952 (Gershenfeld,2012). What makes this to a hot topic in architecture today is that CNC machines recently have become possible to control for anyone with standard modelling programs like Rhinoceros and Grasshopper.

Digital fabrication brings new possibilities to architecture that architects should benefit from. One of these possibilities is a very high level of precision in the production of three dimensional geometries. Another is the advantage of mass customization, the possibility to produce unique pieces without a lost in downtime for the production machines.

Digital fabrication is often associated to an expressive or blobby architecture but it can be so much else. What if high level of precision and mass customization instead could lead to a renaissance for exposed joints and high precision details like the one seen in furniture or boat industry? What if digital fabrication could lead to a finer grain in the weave of architecture that today due to the cost of skilled workers seldom is being realized.

There are a few research groups around Europe that focus on material research and digital fabrication in architecture, Gramazio Kohler Research in Zurich, IBOIS in Lausanne and ICD in Stuttgart is among the leading ones.

CNC production



Wood joint

Why a lookout tower?

The typology of the lookout tower is chosen because it has a strong focus on structure at the same time as the program is limited. This will give time to investigate the structure, materiality, details and production.

Important for the design is to keep a clear relation between the production methods, material properties, detail of assembling and the overall structure.

Year 1923 Gothenburg was celebrating its 300th year anniversary with the Gothenburg Exhibition. One of many buildings that was realized for the exhibition was a lookout tower that was placed on the hills of Johanneberg with great views over the city. Today the tower is long gone and a bit of the foundation can still be found telling the story of what once was.

The city is currently planning for the 400th anniversary will take place year 2021, therefore this master thesis will propose to build a new lookout tower at the same location as the previous tower was built in Johanneberg. The tower will be a manifestation of how digital fabrication methods allows a higher complexity in wood constructions.

Fyrtornet 1923,
Johanneberg, Gothenburg

CNC produced pavillion
Tverrfjellhytta, Norway

Thesis Question

Can digital fabrication and a clear relationship between structure, material behavior and production logic bring a finer grain to wood architecture?

Digital Fabrication Workshop

Producing a landscape model using a KUKA150-industry robot

To get an understanding of what digital fabrication was and how to work with it I started my thesis by producing a landscape model in wood using digital fabrication methods, in this case an industry robot.

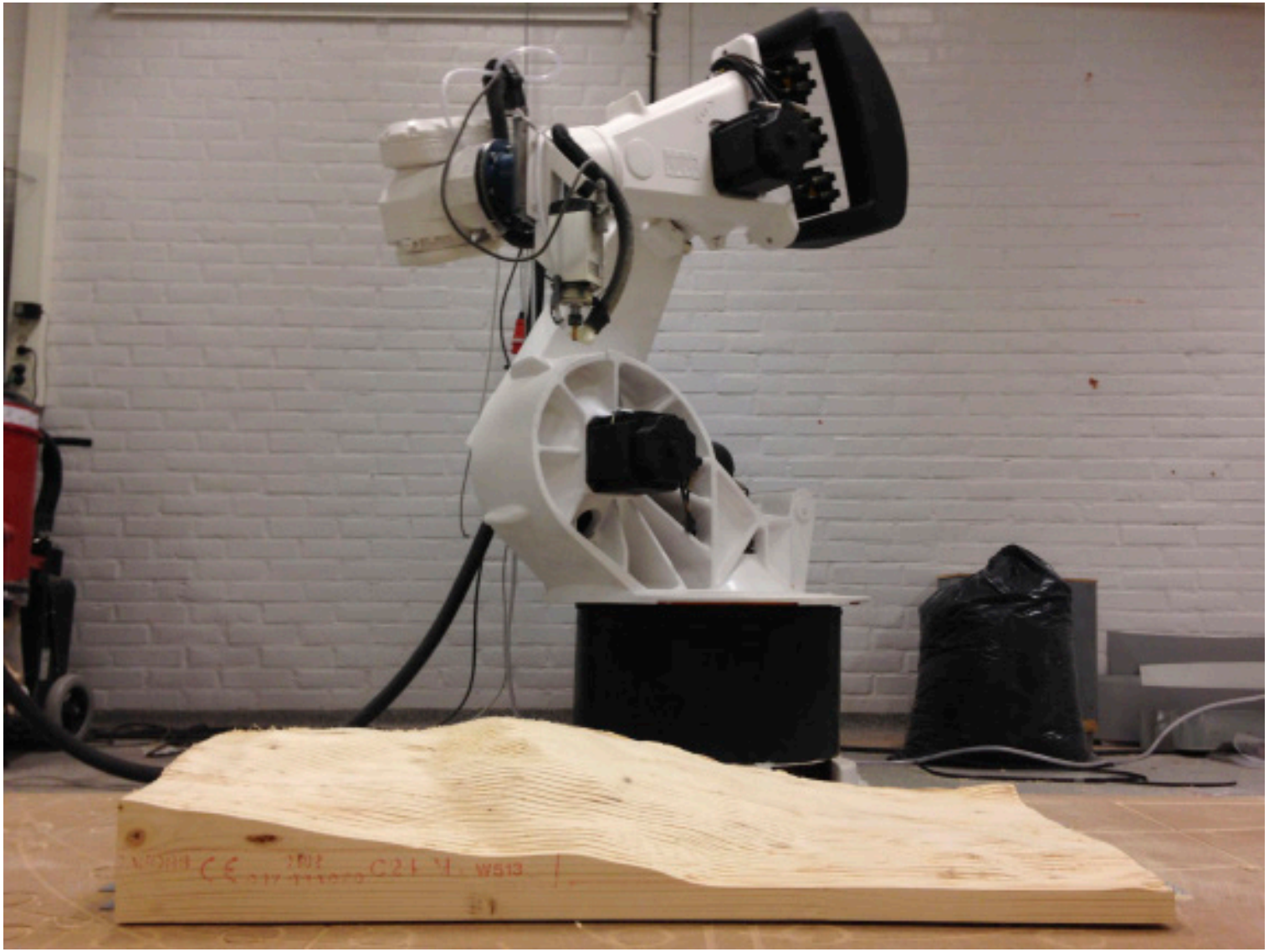
I got in contact with Stig Anton Nielsen, a PHD student who last year started up the Maker Lab at Chalmers Architecture School. Stig Anton Nielsen explained the mechanics of the robot and how I could communicate with the robot, in this case a KUKA150 a six-axis industry robot with a range of 3.6 meter.

The KUKA150 runs with G-code, a code that basically transforms virtual coordinates in the computer to coordinates in real life. The G-code is a text file with a list of points, each point is associated with a given velocity and a vector describing from which direction the robot should point at the point. The kinetics of the robot is a result from the robot moving from one point to the next in the list.

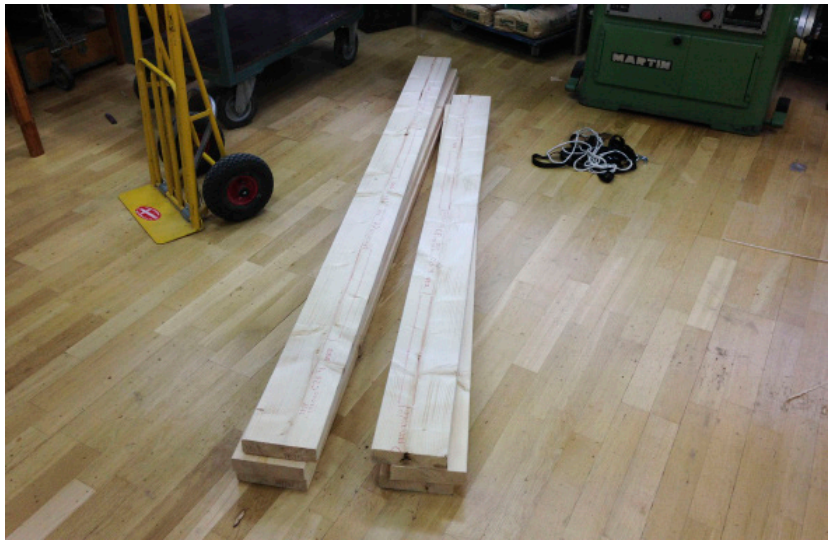
The G-code that was used to produce the landscape model was described by around 20 000 points so I had to find a way to automatically generate the code.

By working with a program called KUKAprc which is a plug in program to Grasshopper, a parametric modeling tool, which itself is a plug-in program to the 3D-modeling program Rhinoceros, I could write a definition that with a surface as an input automatically could generate the G-code for the robot.

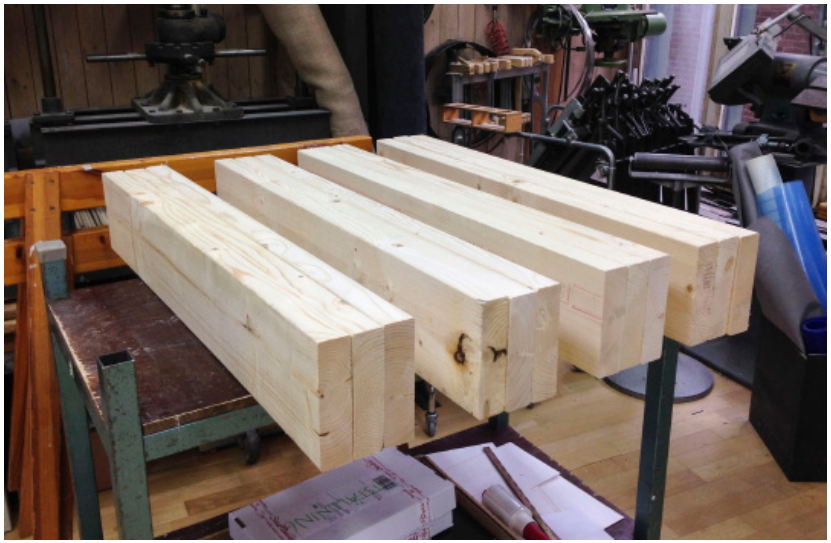
The problem with working with such strong machines is that the consequences of making mistakes are radically. A KUKA150 robot can easily carry around objects over 100 kg so if one point in the list of points are at the wrong location the situation quickly becomes very dangerous.



Gaining experience from digital fabrication methods

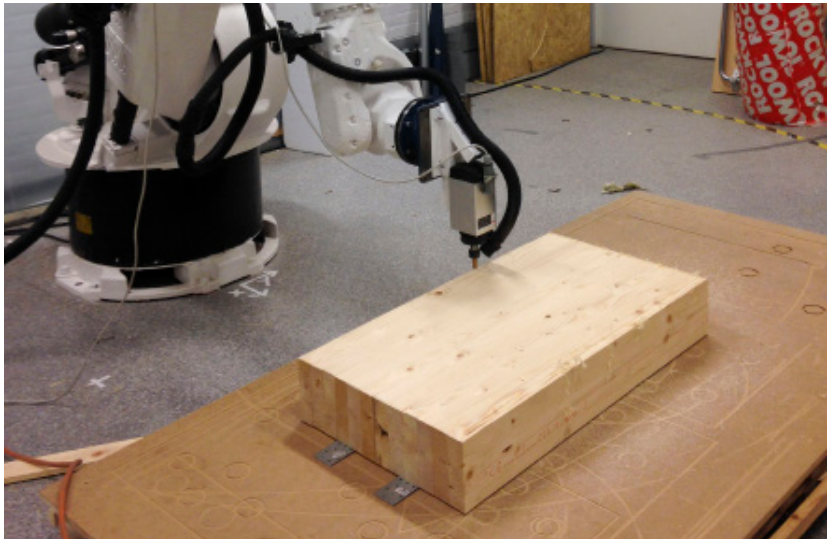


Started out from 45 x 170 mm Pine

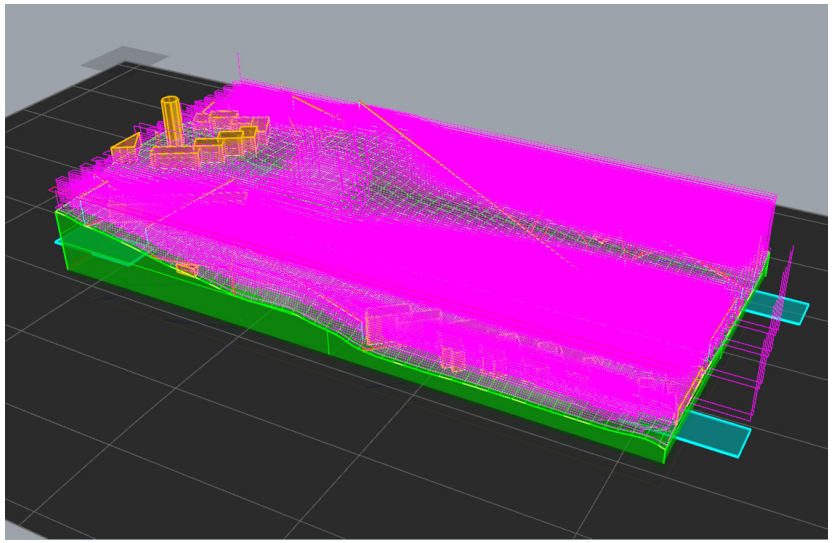


Cutted the wood in 1000 mm length

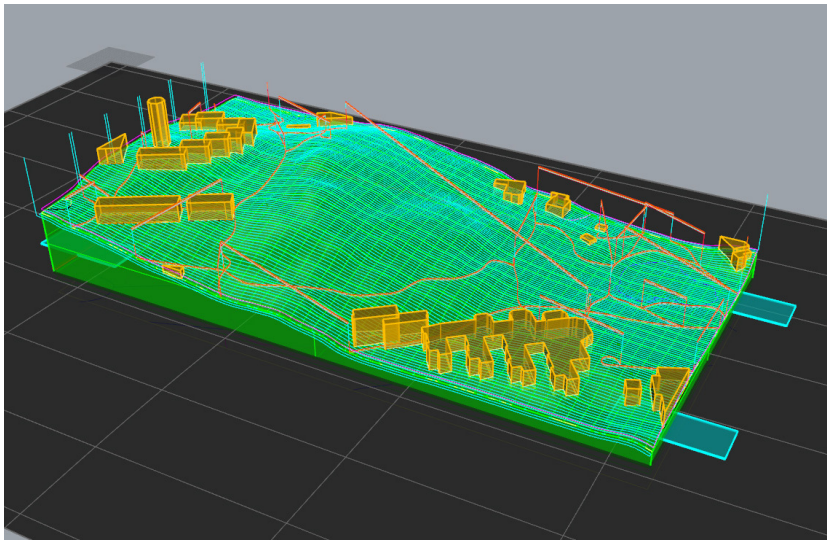
Glued the wood together



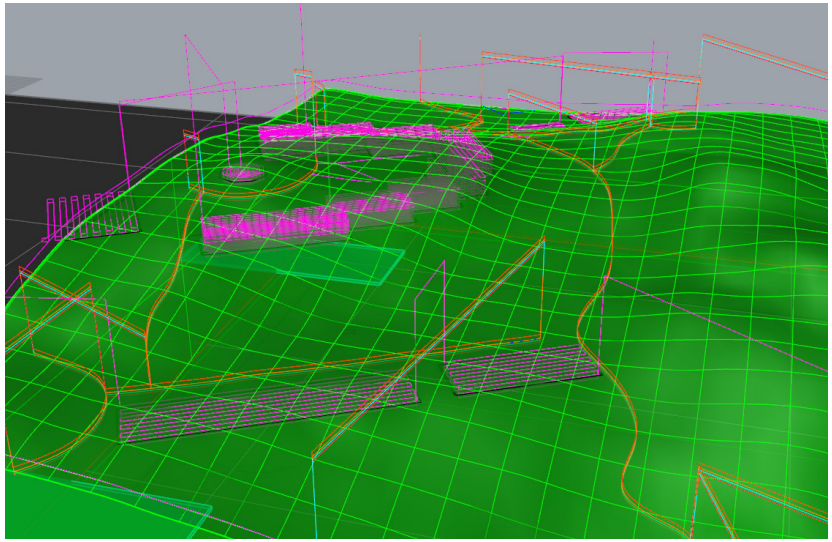
The wood pice was processed using a
KUKA150 industry robot



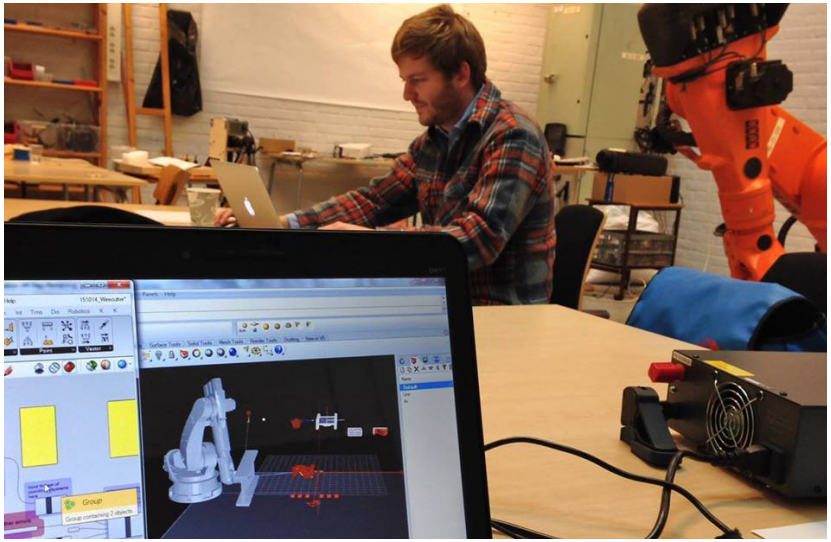
Virtual model, pink lines are the paths for the firt part of the milling called roghening



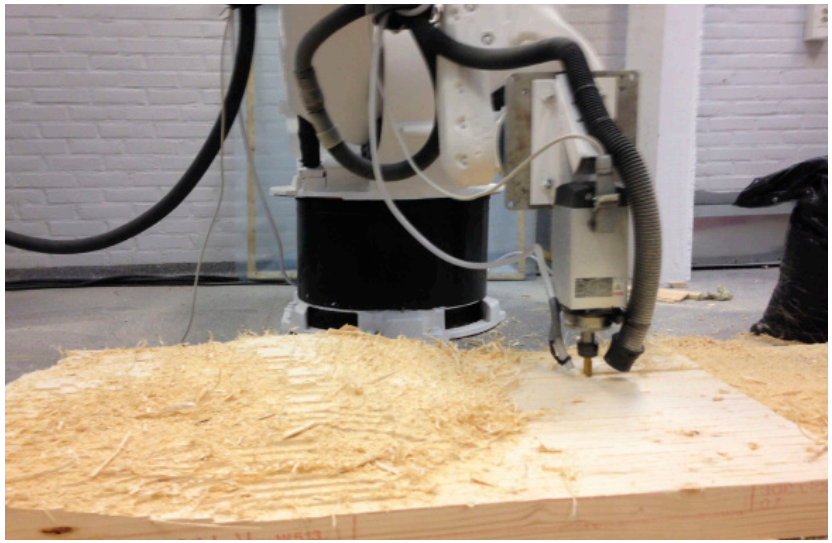
Blue lines are the paths for the second part of the milling called surfacing



The last program of the milling was to engrave roads and make planar surfaces were to plce buildings

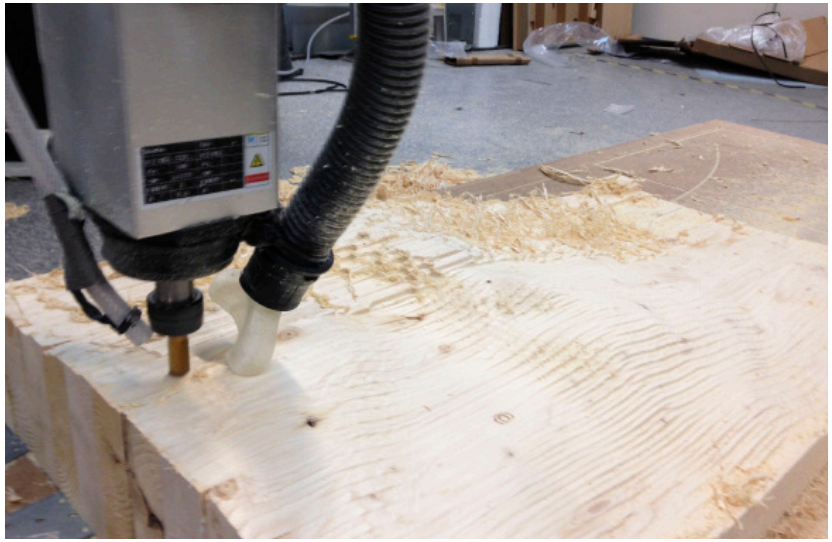


Communicating with the robot using KUKAprc for Grasshopper



First part of milling process called roughening, using a wide drill bit to get an approximate surface

Finished with the roughening part

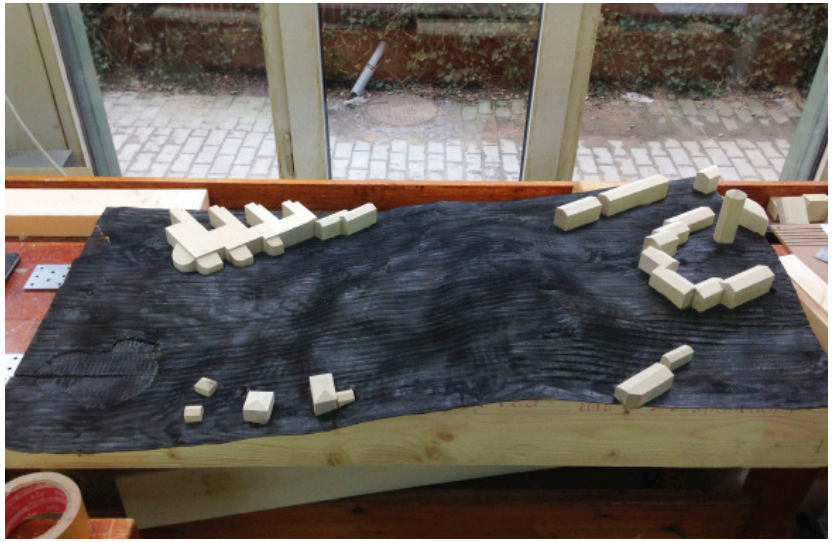


Second program of milling process called surfacing, resulting in a smoth surface

Result after the surface program

Finished to planar the surfaces under buildings

Burnig the model to get a dark surface



Adding building volumes of solid wood

Final model after adding trees and 3D-printed Lookout Tower

Result of Digital Fabrication Workshop

From the process to produce a landscape model using digital fabrication methods I realized a few pros and cons with the process.

1. Digital fabrication with a subtractive logic is resulting in a lot of waste material when starting from a solid piece. This is why research labs as Gramazio Kohler at ETH in Zurich mainly work with an additive logic.

2. Mistakes when producing the G-code can result in very dangerous situations. Important to find a way to test the code before running it.

3. For this model I limited myself to work with three out of six axes. I set the vector to all points in the G-code to Z-negative, if working with all the six axis of the machine mistakes is much more likely to happen and the consequences of them much more radical.

4. Comparing the process of digital fabrication to an analog process the result from the digital fabrication is at a level that is impossible to produce with analog techniques.

5. By working with digital fabrication techniques you have a real object and an exact copy of it as a virtual option. The direct relation between the virtual and real object makes it very easy to make changes during the process.

The Lookout Tower in the City

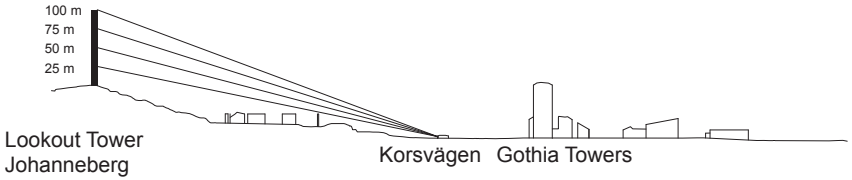
Context - Main axis of Gothenburg

The site is located on the hills of Johanneberg in a green oasis called Näckrosdammen close to Götaplatsen. Götaplatsen is the main square for culture in Gothenburg and today it marks the end of the city's main axis that stretches through Östra Hamngata and Avenyn.

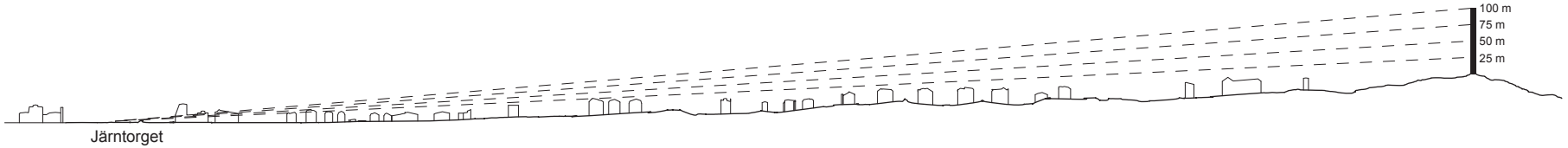
Näckrosdammen is today under planning to become a main campus for humanistic and artistic education in the city. Close to the site is also Korsvägen that after the huge infra-structure project Västlänken is done will become one of two main hubs for public transportation.

The Lookout Tower of Gothenburg will become a new land-mark that extends the main axis beyond Götaplatsen al the way up to Johanneberg linking the city with the new Campus Näckrosdammen and Korsvägen.

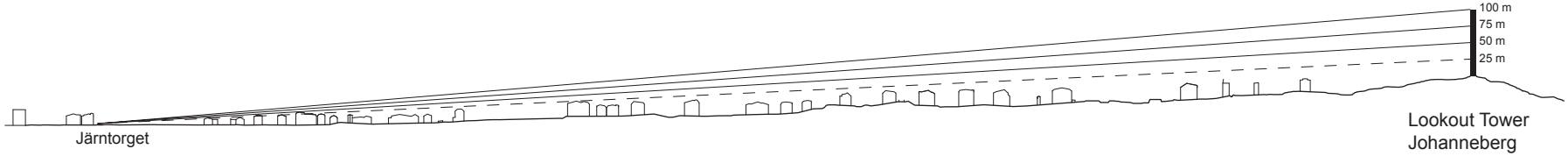

KUNGSPORTSPLATSEN
STORA TEATERN
SKANSEN KRONAN
GÖTAPLATSEN
NORTH
SUN SET
WEST
SKANSEN KRONAN
STIGBERGET
EAST
SUN RISE
Delivery Road
SOUTH
CHALMERS
SUN 12 AM



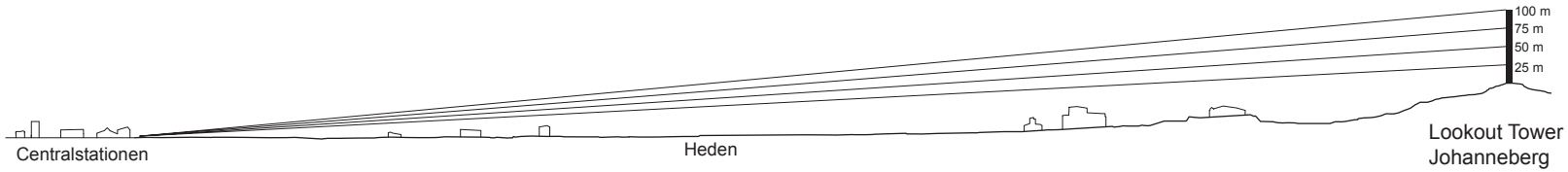
Section from Korsvägen to the Lookout tower at Johanneberg. The tower has to be higher than 20m to be seen from the main square at Korsvägen



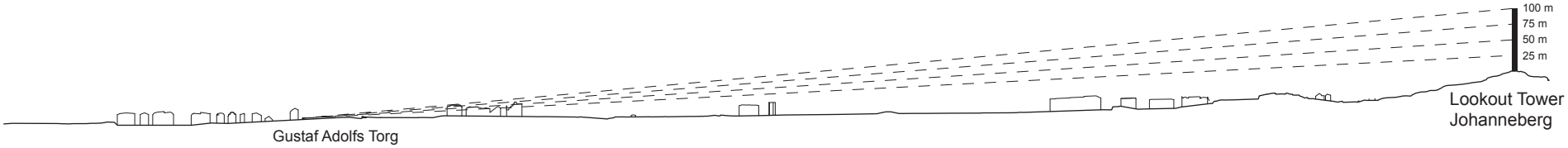
Section from Järntorget to the Lookout tower at Johanneberg. From this part of Järntorget you can not see the tower.



Section from Järntorget to the Lookout tower at Johanneberg showing that it isa possibility to see the tower if it is higher than 40 m



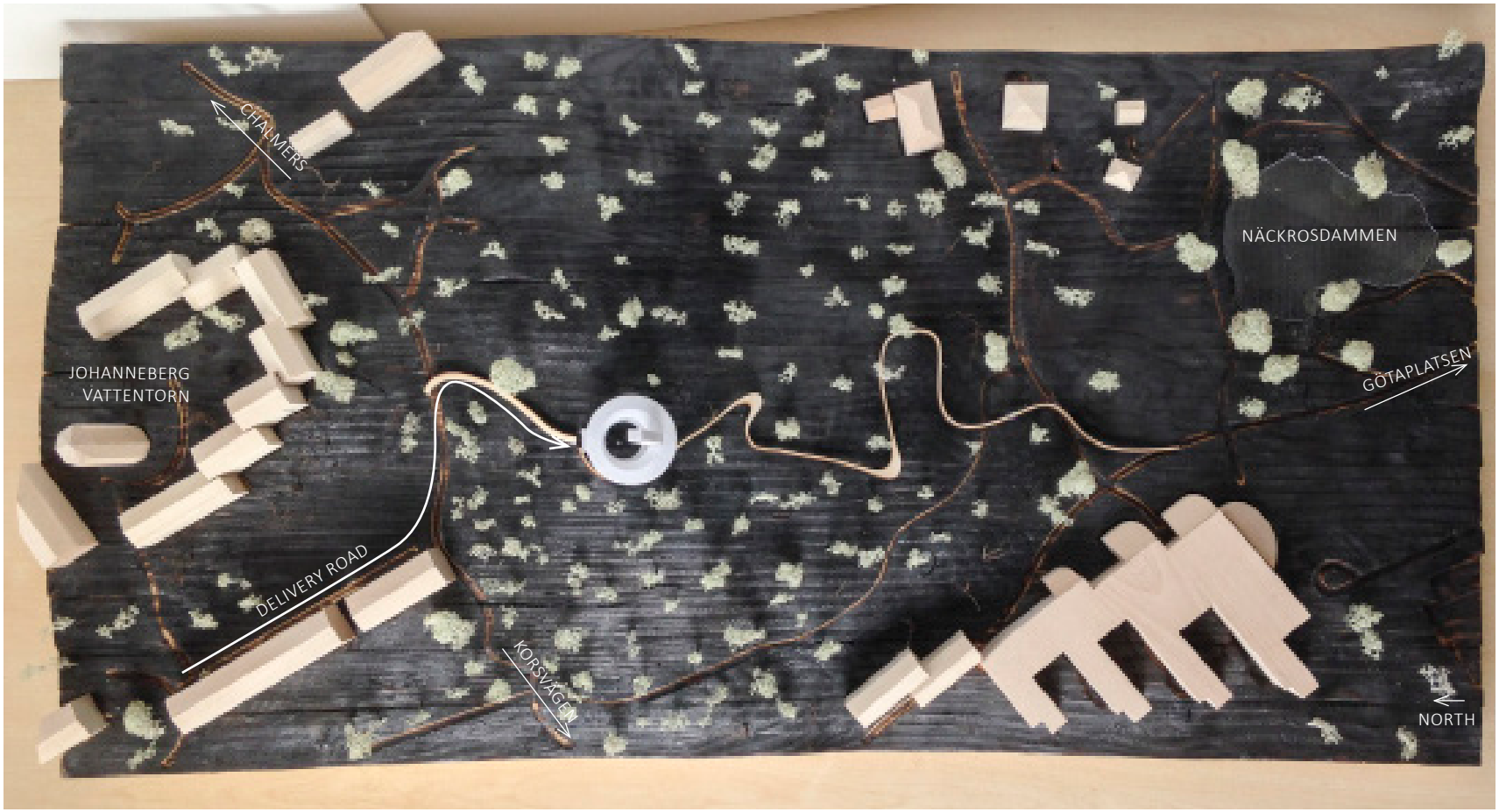
Section from Centralstationen to the Lookout tower at Johanneberg. The tower will be seen from the main entrence at centralstationen.



Section from Gustav Adolfs Torg looking along Östra Hamngatan to the Lookout tower at Johanneberg. Can not be seen from the square.

Accessibility

The Lookout Tower can be reached from South and from North. The new walkway from the south will not be possible to access by wheelchair due to the steep slope. From the North the Lookout Tower is possible to reach by the existing paved walking paths. The path will be connected to Olof Rudbecks-gatan and will provide the Tower with a possibility to deliver material by motor driven vehicles. The South entrance are also possible to reach by wheelchair.



The Lookout Tower from Gothia Towers

The Lookout Tower from Götaälvsbron

Chapter 4
THE LOOKOUT TOWER IN THE CITY

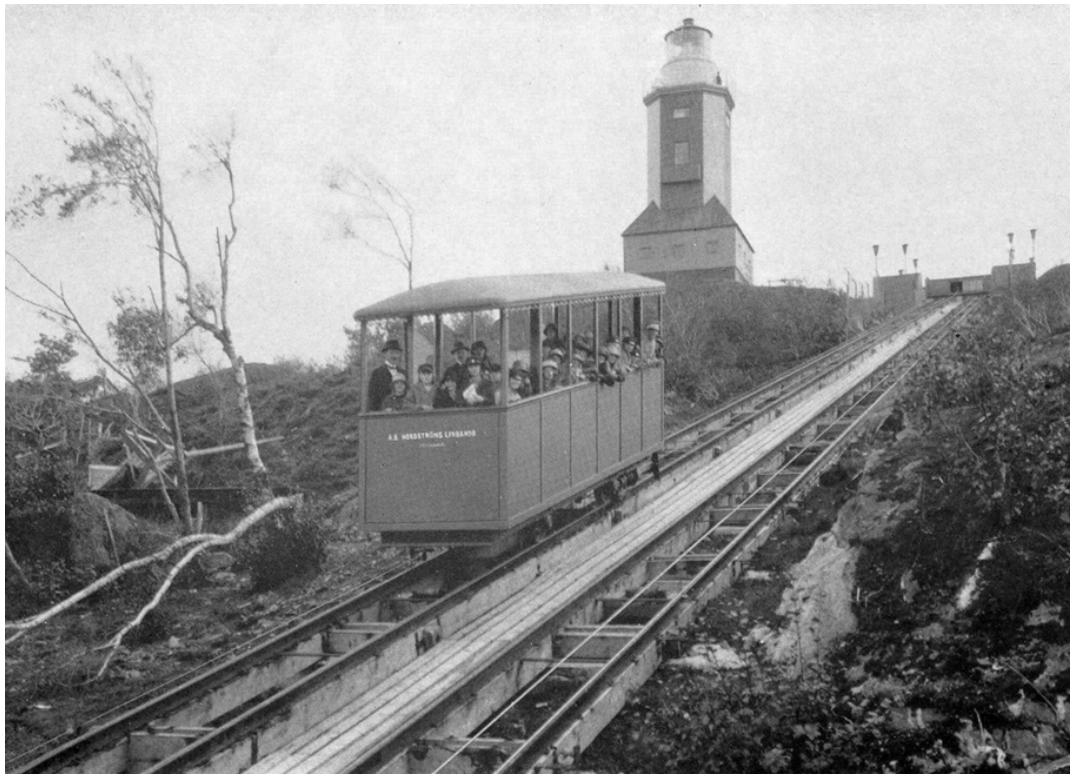
The Lookout Tower

Johanneberg Lookout Tower

A manifestation of contemporary Swedish wood architecture for Gothenburg jubilee exhibition 2021

History

Year 1923 Gothenburg celebrated 300 years with a jubilee exhibition. The exhibition had its center around Götaplatsen and Näckrosdammen. For the exhibition a lookout tower was constructed on top of Johanneberg which visitors could reach via a cable car from Näkrosdammen to look at the great views over the city. Today the foundation from the tower is still to be found together with the concrete supports from the cable car. 2021 Gothenburg is celebrating 400 years, this master thesis propose a new lookout tower at Johanneberg.

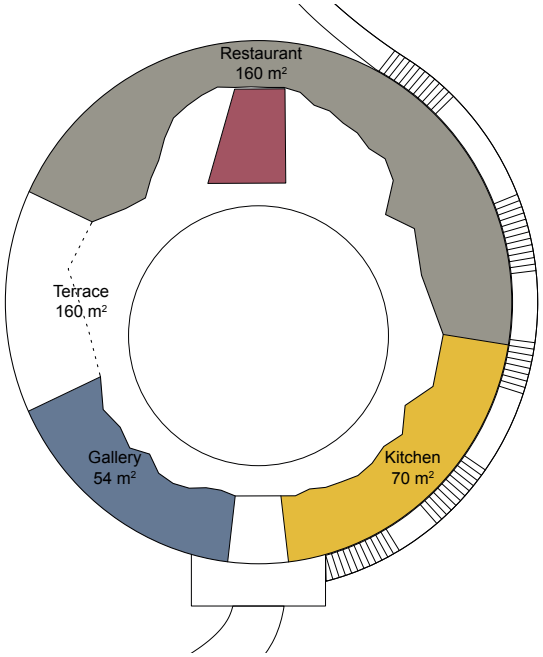


Fyrtornet was built for the 300 year Jubilee Exhibition held in Gothenburg year 1923

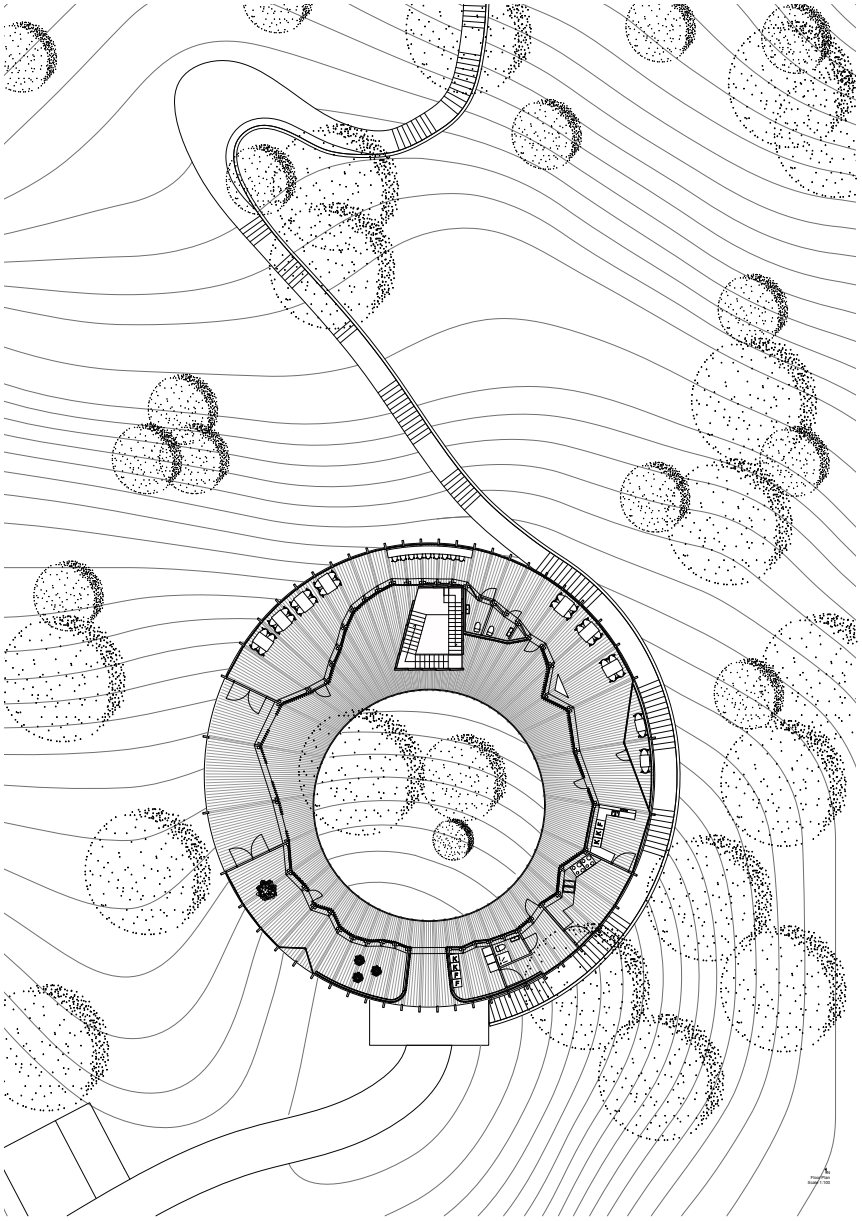
Program

The lookout tower will be built for the Gothenburg Jubilee exhibition 2021 to offer great views over the city. Inspired by Guldhedens water tower the lookout tower will also have a café with spectacular views over the city. To offer variation in the program the building will also have a small art gallery for the upcoming art school.

The café have seating for 50 people inside and 20 people outside. For events like midsummer the doors between the cafe, terrace and art gallery can be arranged with one long table fitting up to 80 people.



Program distrubution



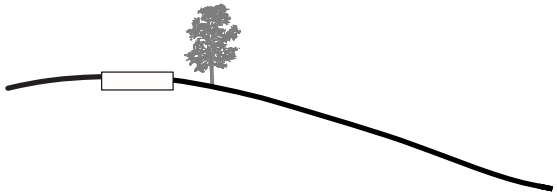
The final floorplan

Concept - A bridge between present and past

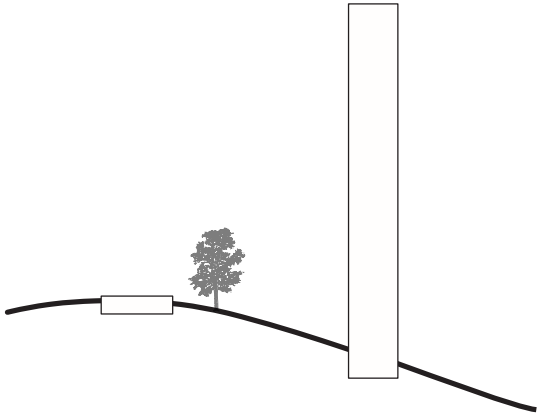
The site has a very strong character due to the historical concrete foundation giving clues about the history

The new tower consists of two elements, one vertical tower that is placed just below the historical concrete foundation and one horizontal structure reaching out through the treetops forming a bridge between present and past.

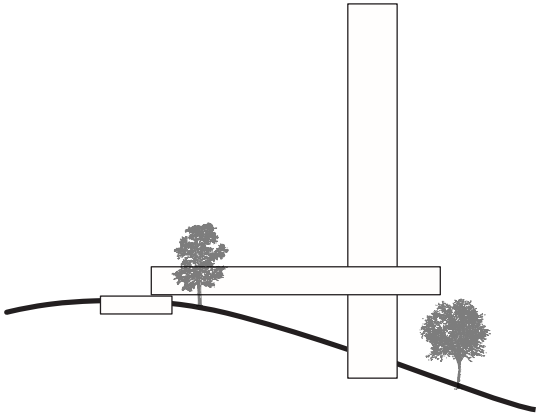
The vertical structure is a pragmatic structure with a solid character and the horizontal structure has the functions and has a transparent character.



The foundation from the old lookout tower built for Gothenburgs 300 years jubilee exhibition 1923



A new lookout tower is built for Gothenburgs upcomming 400 year jubilee exhibition



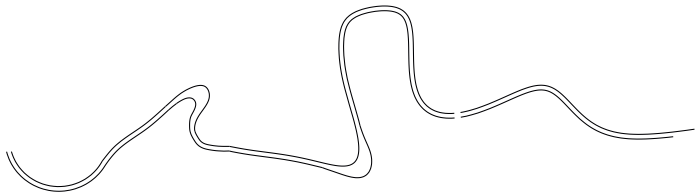
A vertical building stretches through the treetops forming a bridge between the present and the past

Circulation

Today the site can be reached from Johanneberg in the south, but many winding trails through the sloping forest in the north tells the story of a need for a conection to the city. The old tower was built with a cable car that brought visitors from the main exhibition space at Näckrosdammen up to the tower.

The new lookout tower has a long winding wooden stair reaching all the way down to Näckrosdammen. The stair is built on columns leaving the ground underneth untouched. The star is inspiered by the walkways in the old english gardens arranging the views of the vistor. Along the path the stair gets wider at some points to form lookout platforms.

The walkway follows the typology and windes its way so the visitor sees the tower from different angles on the way up. The walkway flows around the circle to the entrence in the north.

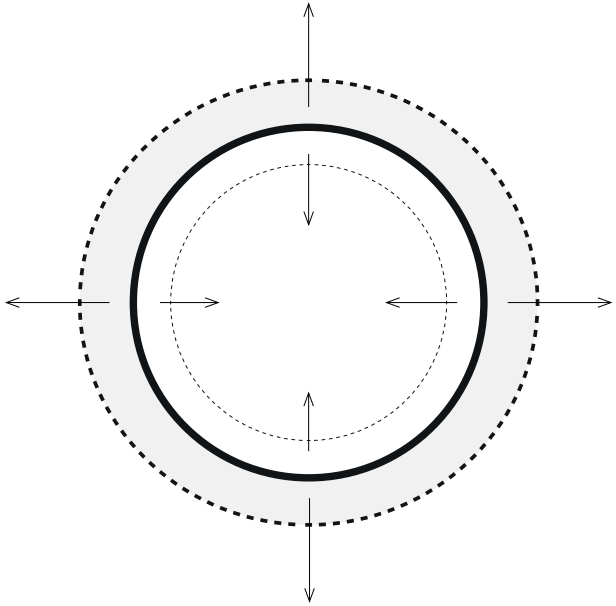


The Lookout Tower is connected with Näckrosdammen through a new walkway raised 50 cm above the above the ground.

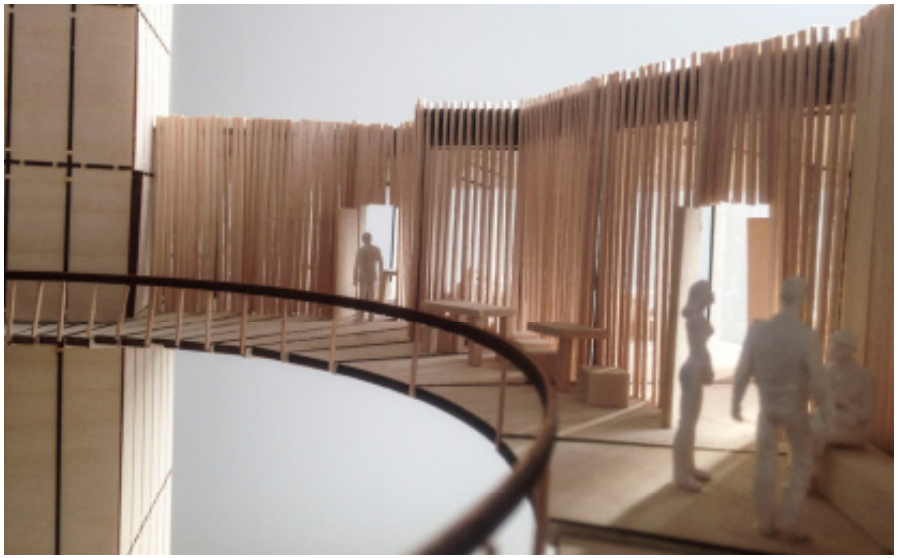
Horizontal

The horizontal part of the tower has a cicular shape to form and inside and an outside. The continous circular room is divided in the middle by a semi transparent wall that only gives hints of what can be seen on the outside.

The visitor will first enter the inside space which has focus to the centre of the circle shelded away from the city and the surroundigs. When the visitor then stepps through the dividing wall to the outer room she suddenly can enjoy the views over the city.



Concept diagram
To enhance the experience of the great views the experience is divided into two steps, first you enter the inner courtyard were you focus inwards, then when you step through the middle wall the fantastic views opens up.



The inner yard is shield of from the view, this room is focusing inwards. In the niches along the south façade visitors can sit down enjoying a coffee.

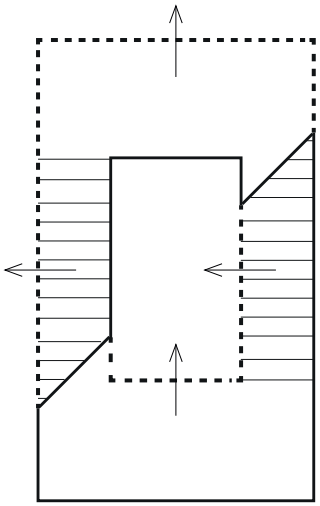
When passing through the middle wall the room opens and the visitor can enjoy great views over the city.

Vertical

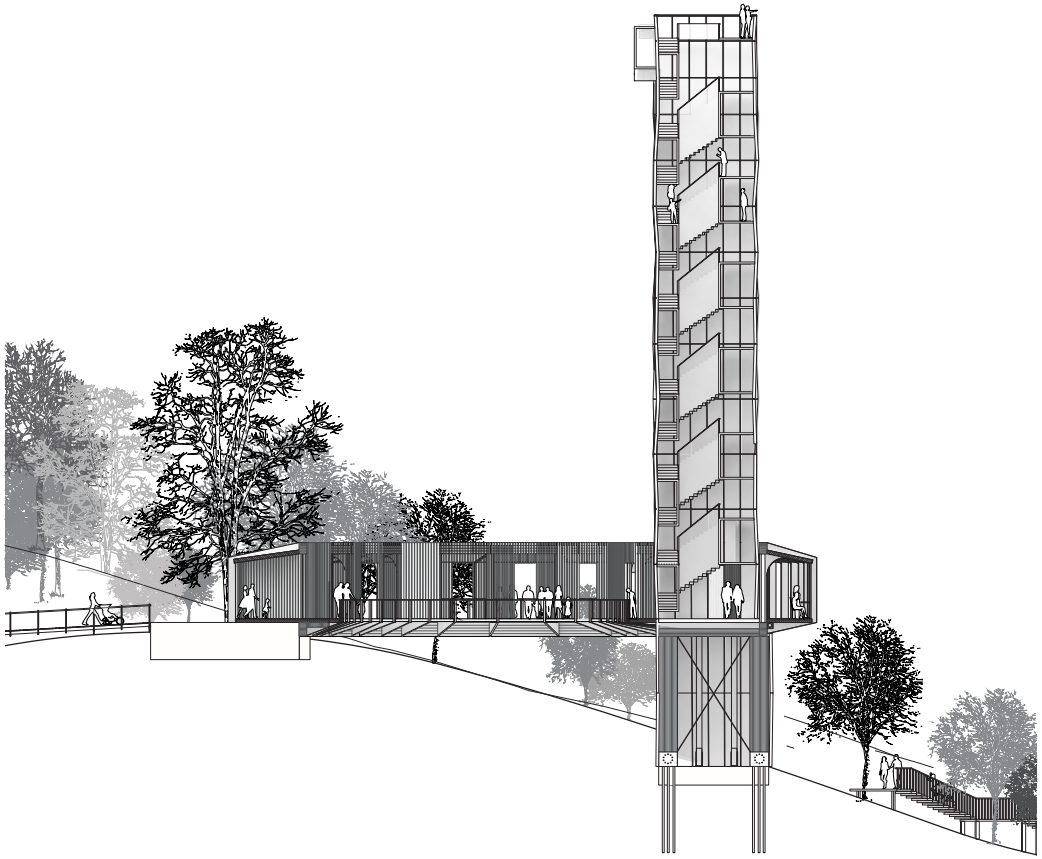
The vertical tower is 40 meter high, has a rectangular top and base were one of the corners are moved along the side to form a geometry that appears different from various directions. The towers is planned as a double helix with one stair up and one down to avoid meeting in the stair, give a feeling of being more alone and a variation in the walk up and the walk down.

The way up is introvert inspired by light houses and minarets were you often are shelded from the surrounding on the way up, almost lose orientation and starts to wonder when to reach the top. The way up windes around a central lightshaft so you can see other people walking in the same direction.

On the top platform visitors can enjoy panoramic views all the way to the ocean in the west. The walk down is extrovert were the visitor can look out through the gaps between the tower panels.



The tower follows the same logic as the horisontal structure,

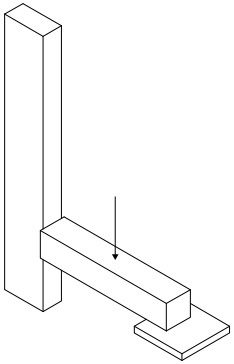


The tower is constructred like a double heilix , the way up is inspired by lighttowers and the views are focusing inwards. At the top the visitors can enjoy a 360 degrees panoramic view.

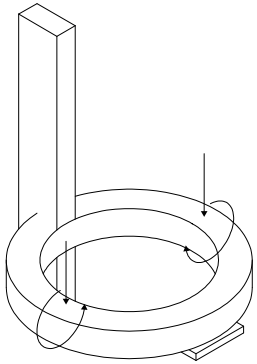
Structure

Structure concept

The horizontal structure can be seen as a bridge spanning from the old concrete foundation to the new tower. The beam is made to a circle create a structure with two different spacious characters. This result in a momentum force around the axis between the tower and the concrete foundation. The continuous Virendeel beam takes forms the structural height of the circle and the roof and floor slab acts as top and bottom flenge that prevents the beam from buckling.

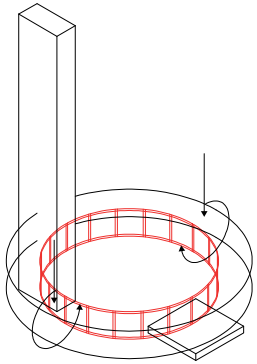


1. A beam spanning from old fondation to the new tower.

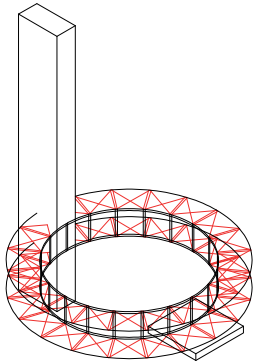


2. The beam gets stretched into a circle to form an inside and an outside.

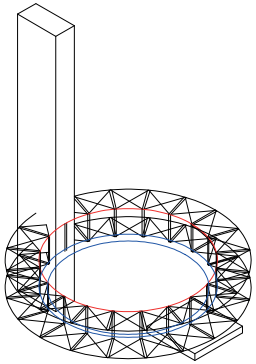
Structurally this results in that the load gets split up in two forces. The distance from the load to the center of the circle results in a momentum.



3. Globally the structure is held up by a continuous Virendeel beam spanning from the old foundation to the new tower.



4. To prevent the Virendeel bream from buckling the roof and the floor is used as flanges.



5. The deformation of the Virendeel beam results in a compressed upper part of the beam and a tensed underside.

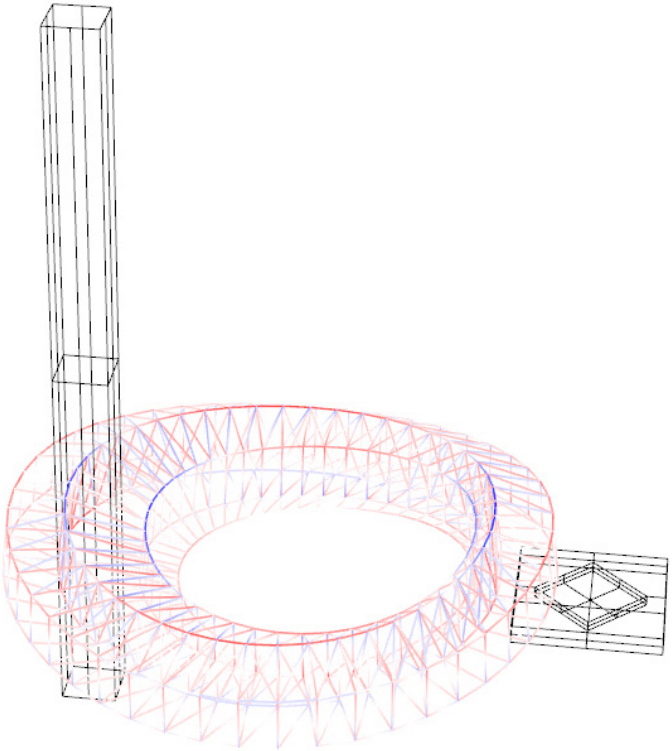
To reduce the deformation the circular structure has a tension band at the top and compression ring at the bottom.

Structure analysis

The project has been design parametrically in Grasshopper that is a parametric modeling plug-in for the 3D modeling program Rhinoceros. This has given the possibility for quick iterations as well as the possibility for structural analysis using Karamba, a plugin for Grasshopper.

The structural tests confirmed that the structure is not a mechanism, it has enough loadbearing components to be stable. The analysis shown a high concentration of tension forces in the top part of the Virendeel beam and a concentrations of compression force in the lower parts of the beam.

To minimize the deformations the structure has been reinforced with a tension band in metal at the top of the Virendeel beam and a compression ring in wood at the bottom.

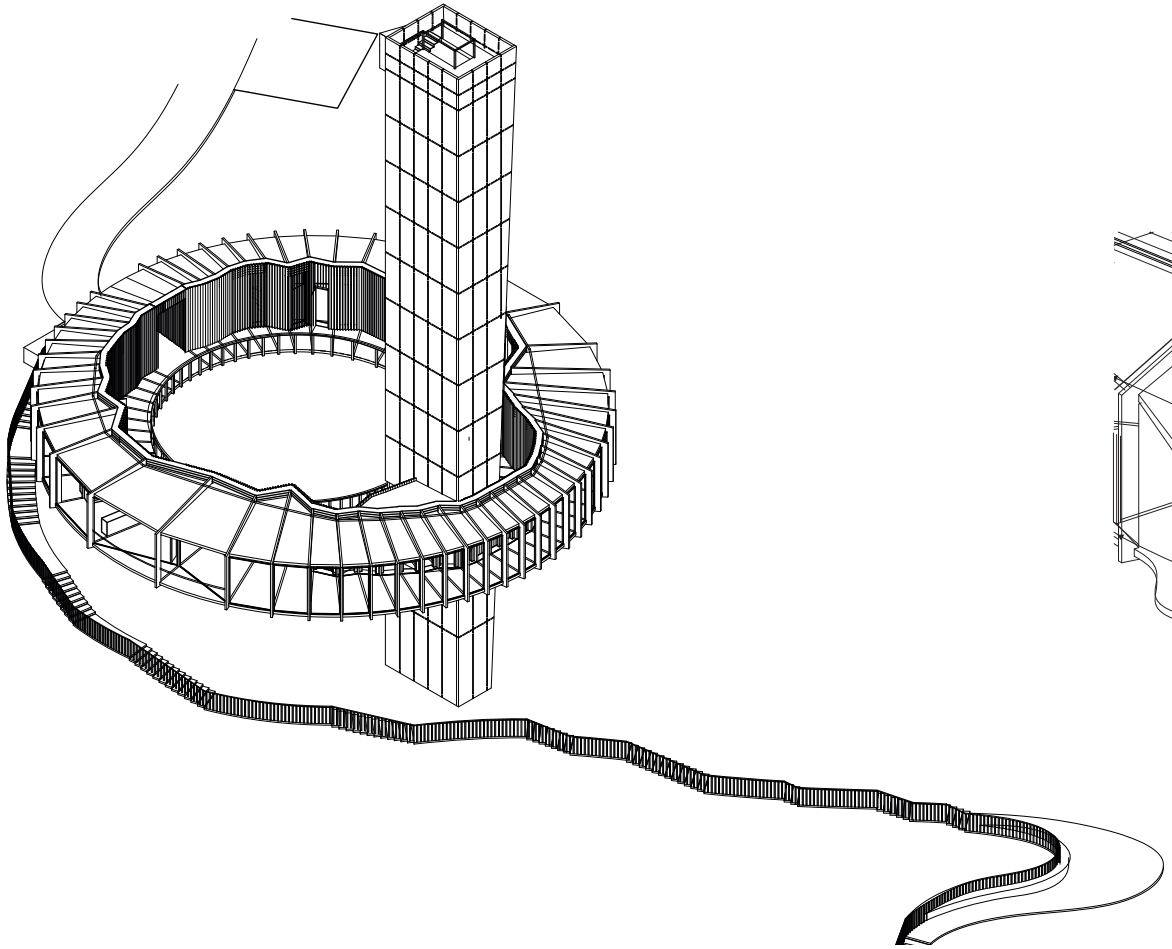


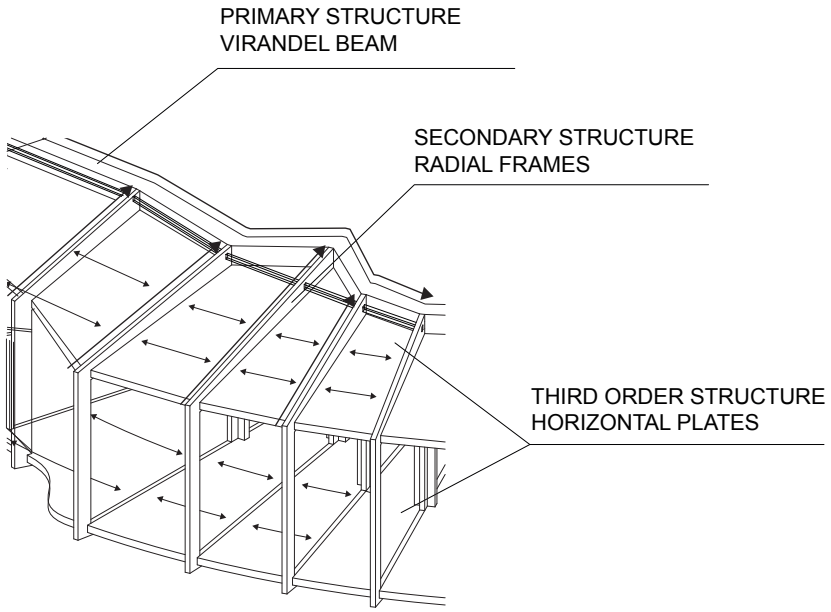
Structure analysis using Karmaba

Structure principle

The horizontal structure is held up by a virandel beam spanning from the historical concrete fondation to the new tower. The circular structure becomes bridge through the treetops linking the past with the present.

The virandel beam gives a transparency to the structure that allowes for both movement and views through the beam.



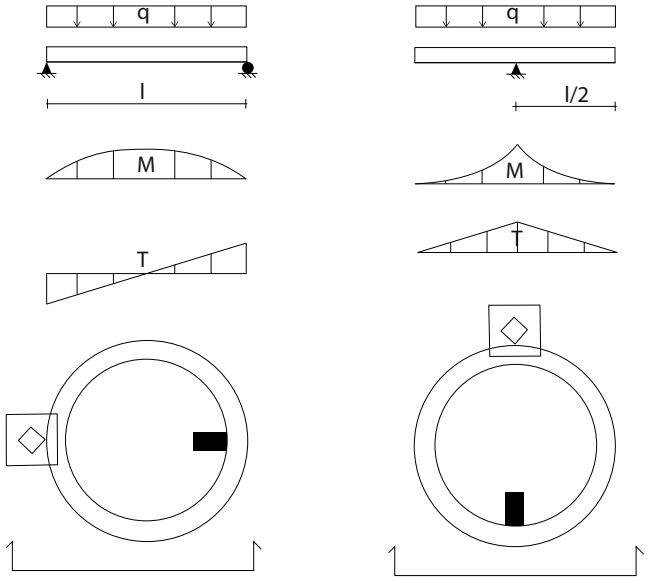


Primary structure - Virendeel Beam

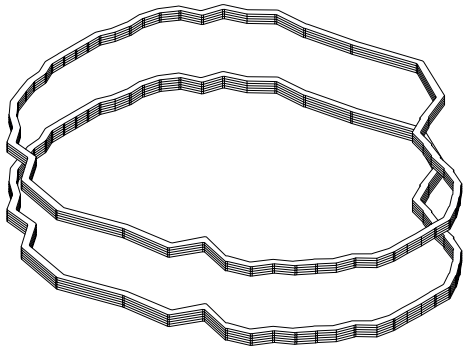
The Virendeel beam is chosen to get a transparent structure that allows for both movement and views through the beam.

The the Virendeel beam has the highest concentration of shearing forces close to the supports, to optimize the beam the distance between the verticals area therefore shorter closer to the supports.

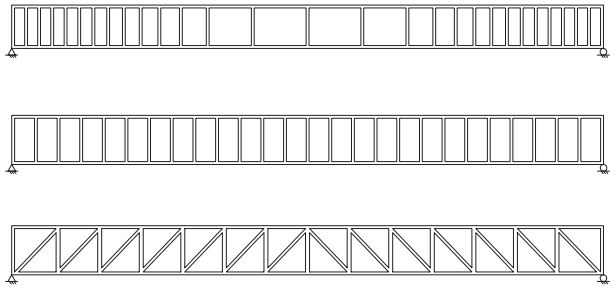
The Virendeel beam has momentum stiff connections between the vertical web and the flange. The isotropic properties of wood makes it week agains momentum forces, the joint between the web and the flange therefore has to be reinforced by metal plates.



Structure analys



Primary structure

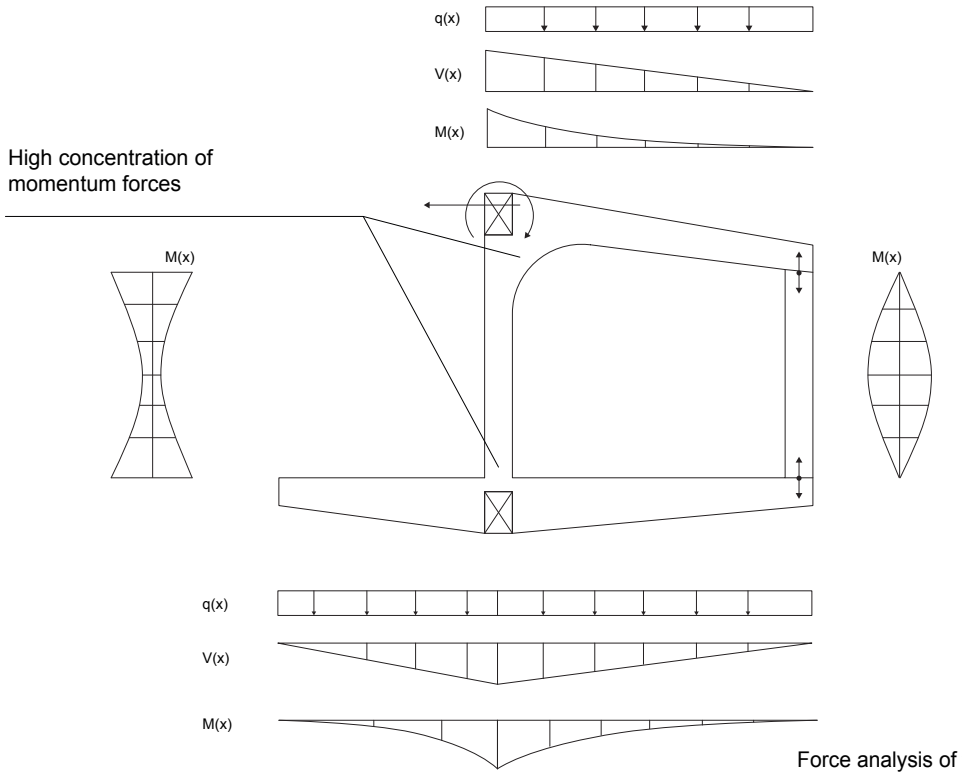


Beam options

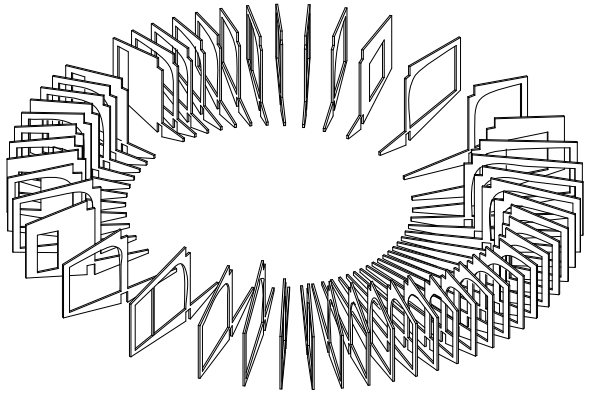
Secondary structure - Radial frames

The radial frames works both as verticals for the primary structure and as secondary structure to hold the floor and roof plates. The frames are constructed of cross laminated timber that has a high strength against momentum forces since it is cross laminated which prevents the local weakness of wood due to its isotropic properties.

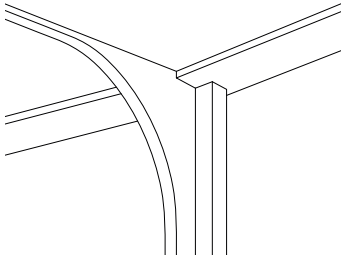
The vertical part of the frame that is closest to the center of the circle also works as vertical in the Virendeel beam. Since the vertical has momentum stiff connections it will deform as an Euler 4, therefore the verticals are reinforced with two 150 x 150 mm wood elements to form a cruciform cross section to prevent from buckling.



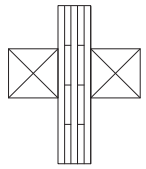
Force analysis of frame



Secondary structure
Radial Frames of CLT



Radial frame supported with two wood elements

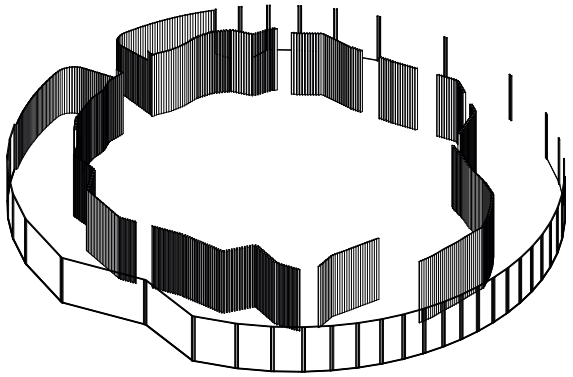


Cruciform cross section
Cross laminated timber 95 mm
2 x Spruce, 150 x 150 mm

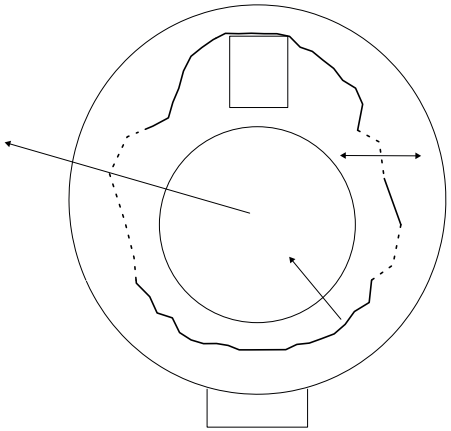
Directing views

The wooden curtain is made up by wooden planks that are rotated at a specific angle to direct the views according to context and function. The wooden curtain breaks through the outer ring at the entrance to welcome visitors inside the lookout tower.

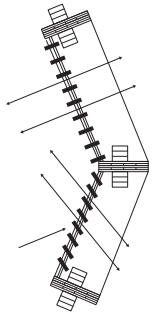
Connecting



Climate layer



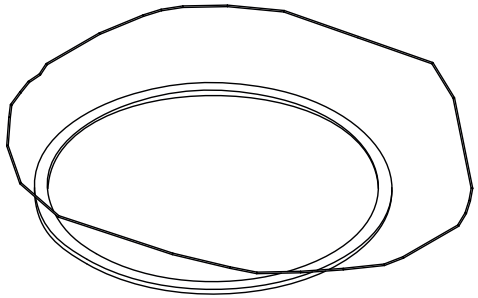
Principle of directing views



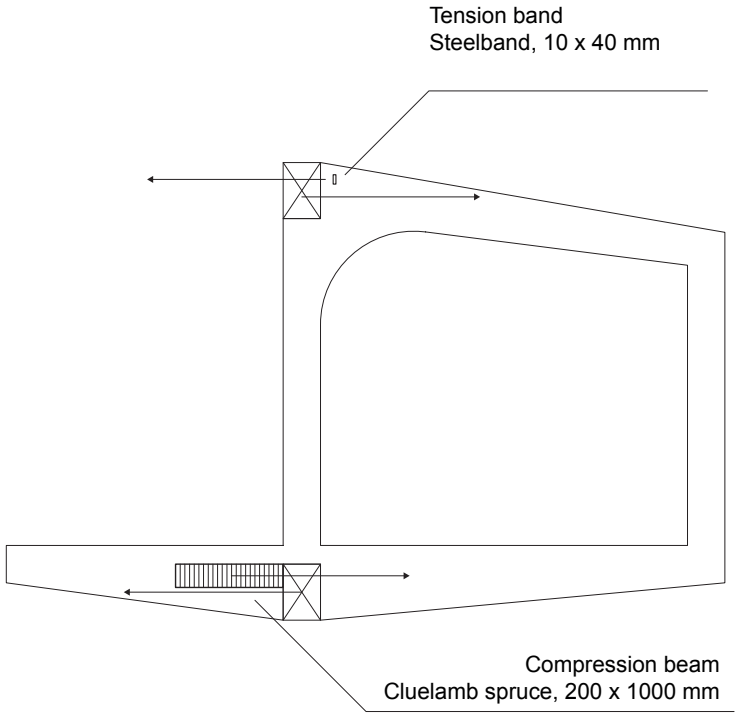
Principle of directing views

Tension band and compression ring

The lower part of the virendeel beam will be tensioned and the top part compressed. To prevent deformation the structure has a iron tension band in the roof and a gluelamb compresseion ring in the floor. The tension band has a width that prevents it from deforming the wood.



Tension band and compression ring

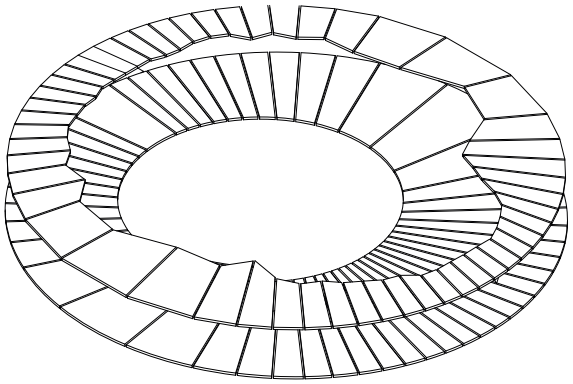


Detail of compression band and tension ring

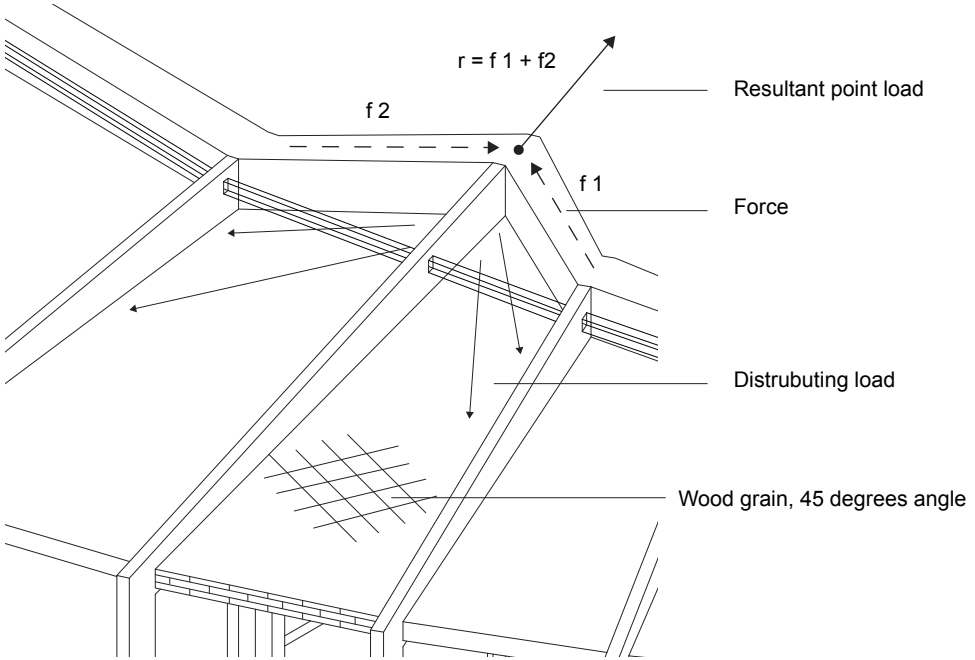
Third order structure - Plates

The roof and the floor plates transfer the local loads to the frames and further to the Virendeel beam. The roof and floor plates also works as flenge and prevents the virandel beam from local buckling.

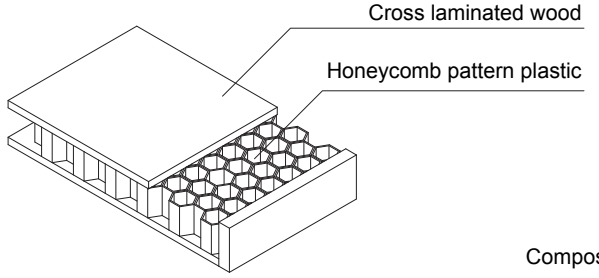
The lightweight composit plates has surfaces of 30 mm cross laminated plywood and a core of honeycomb plastic.



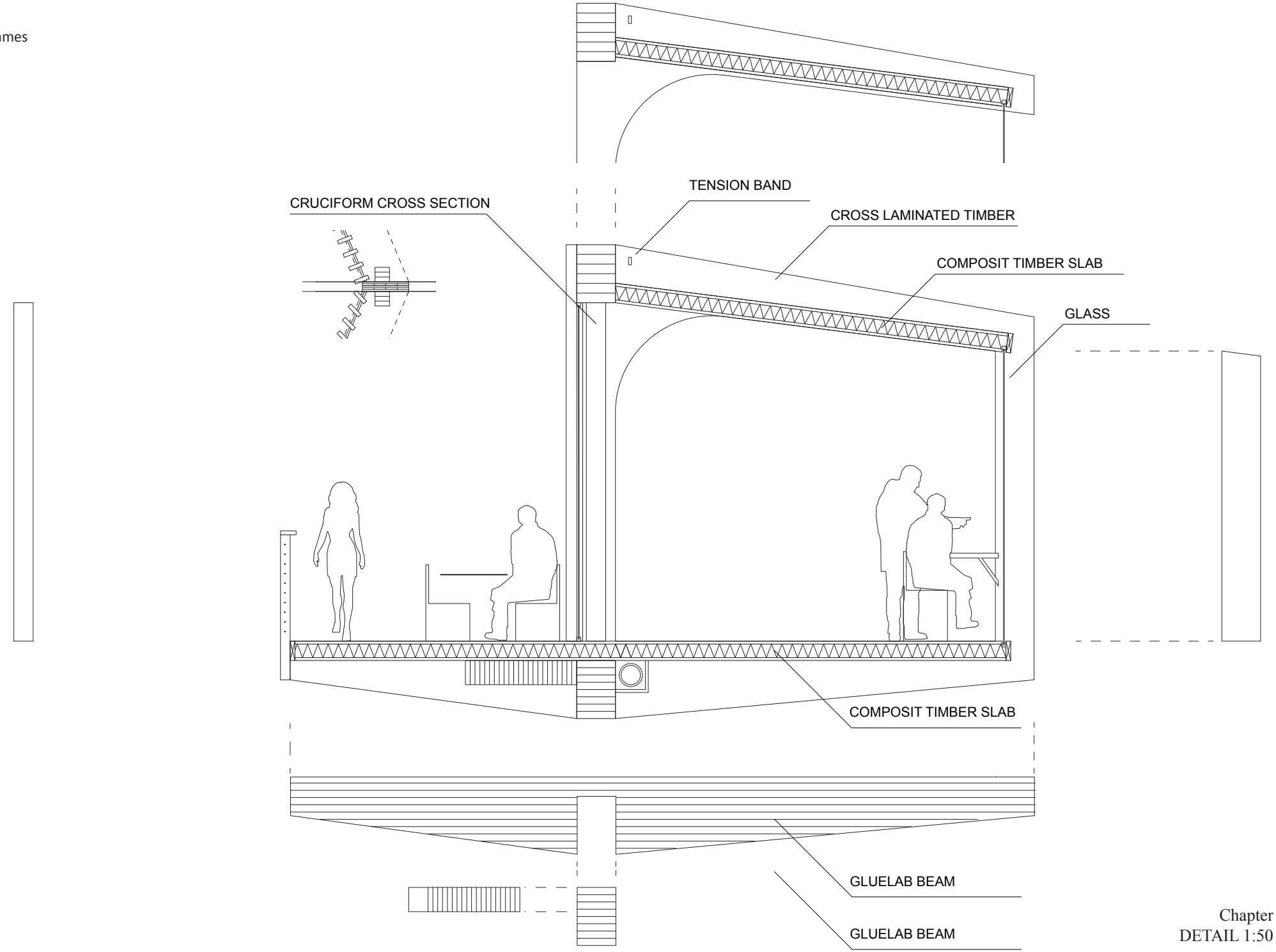
Third order structure



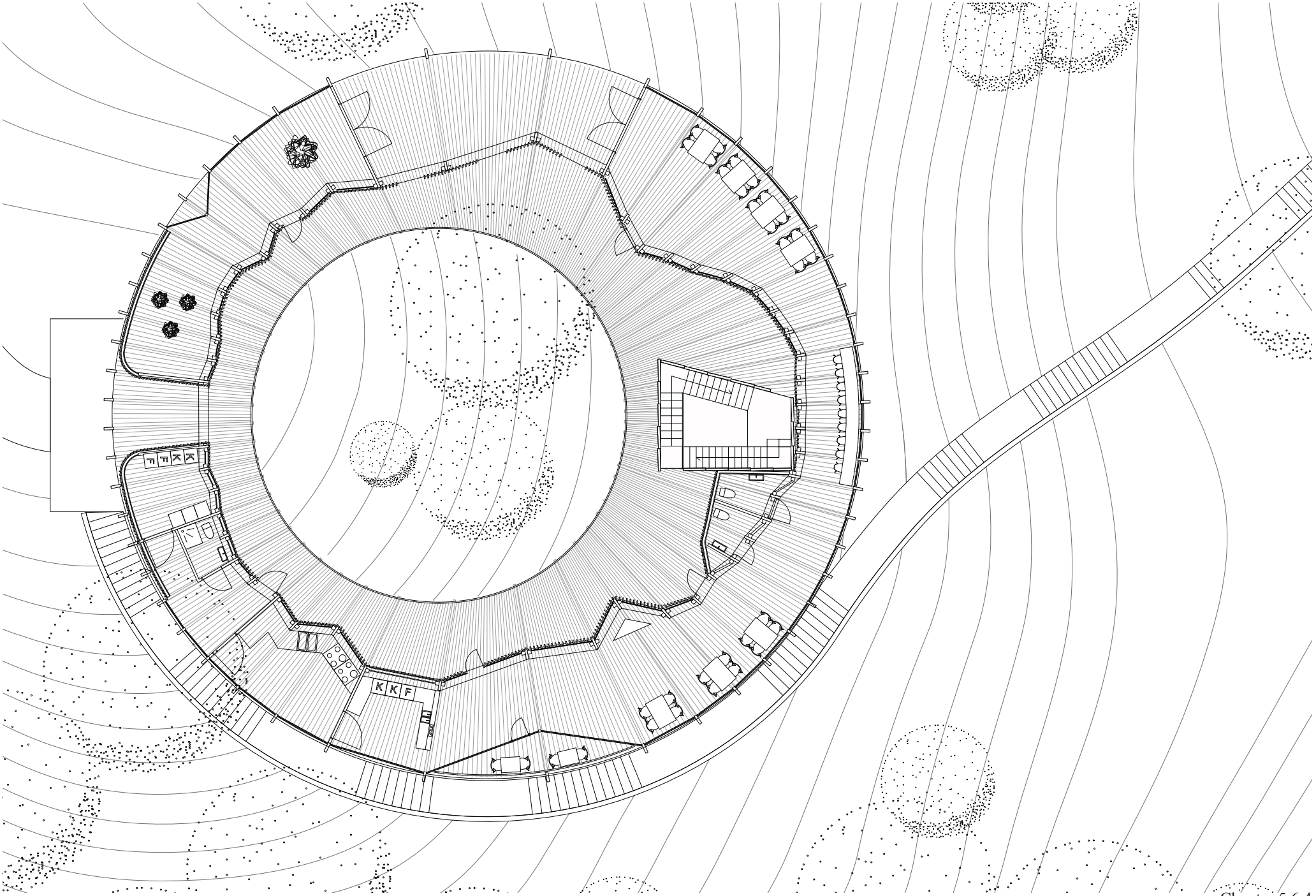
Principle that alow buckling of Virendeel beam



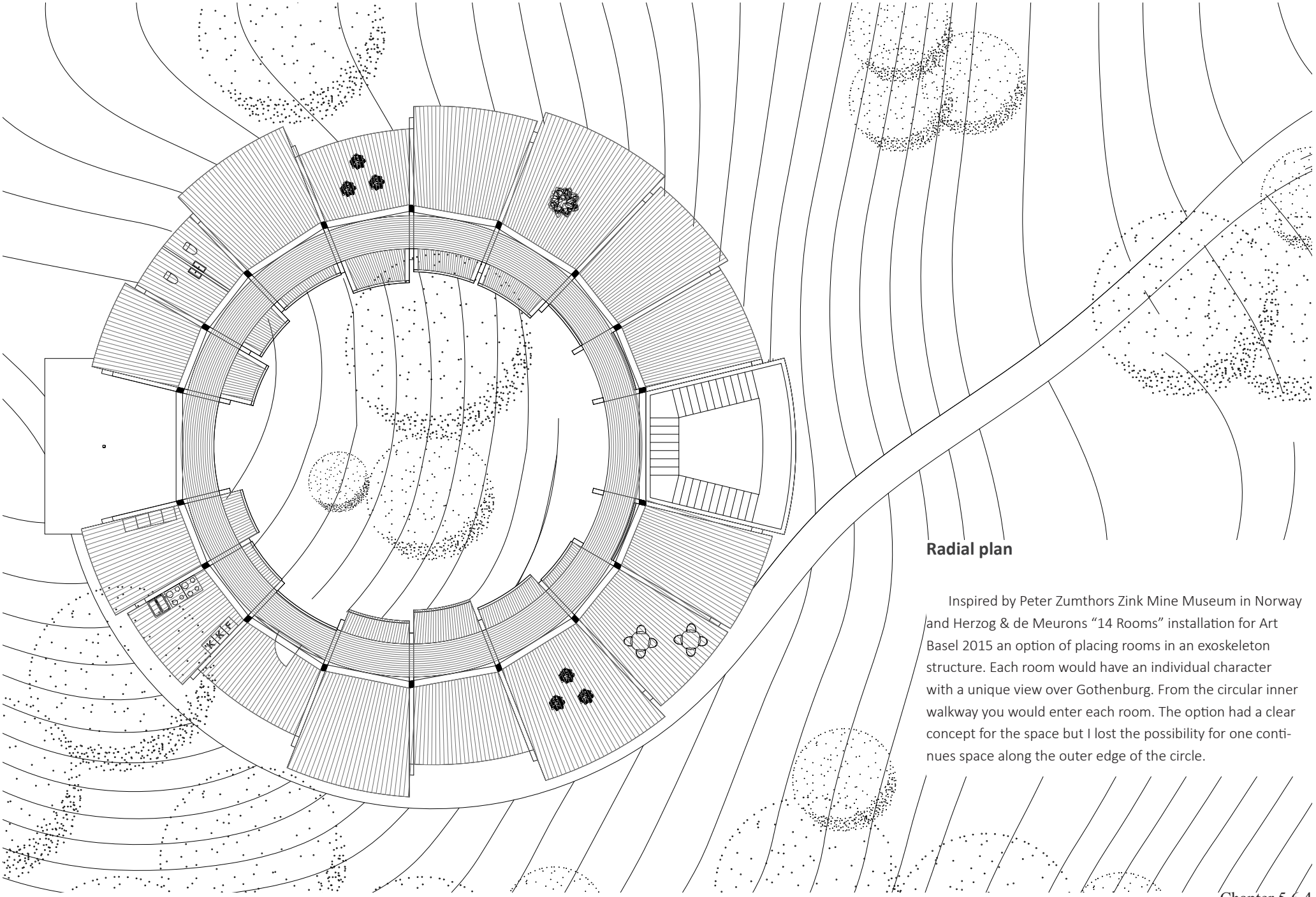
Composit panels


TENSION BAND
CRUCIFORM CROSS SECTION
CROSS LAMINATED TIMBER
COMPOSIT TIMBER SLAB
GLASS
COMPOSIT TIMBER SLAB
GLUELAB BEAM
GLUELAB BEAM

Plan itterations



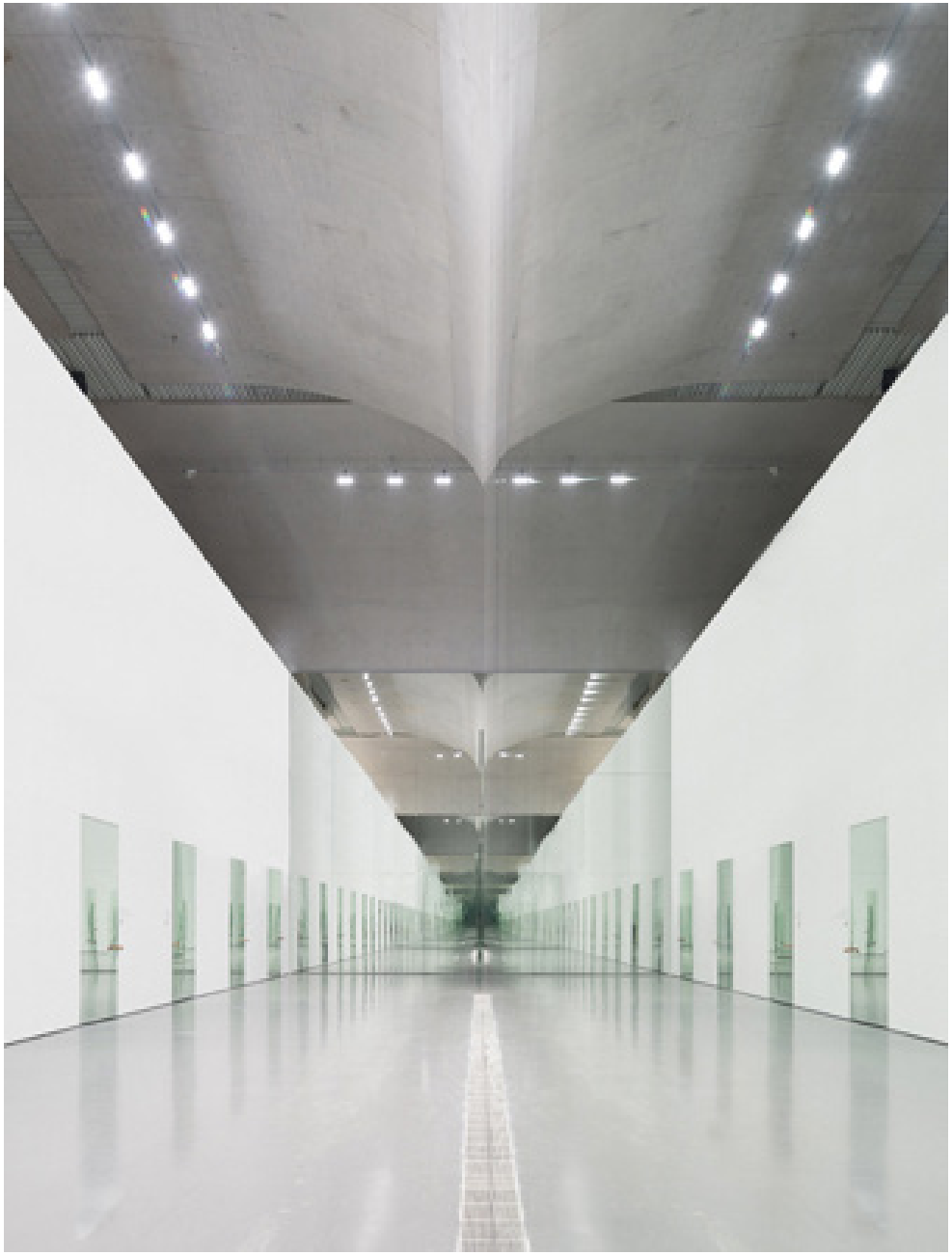
Chapter 5.6.4
ITTERATIONS, FINAL PRESENTATION SCALE 1:200



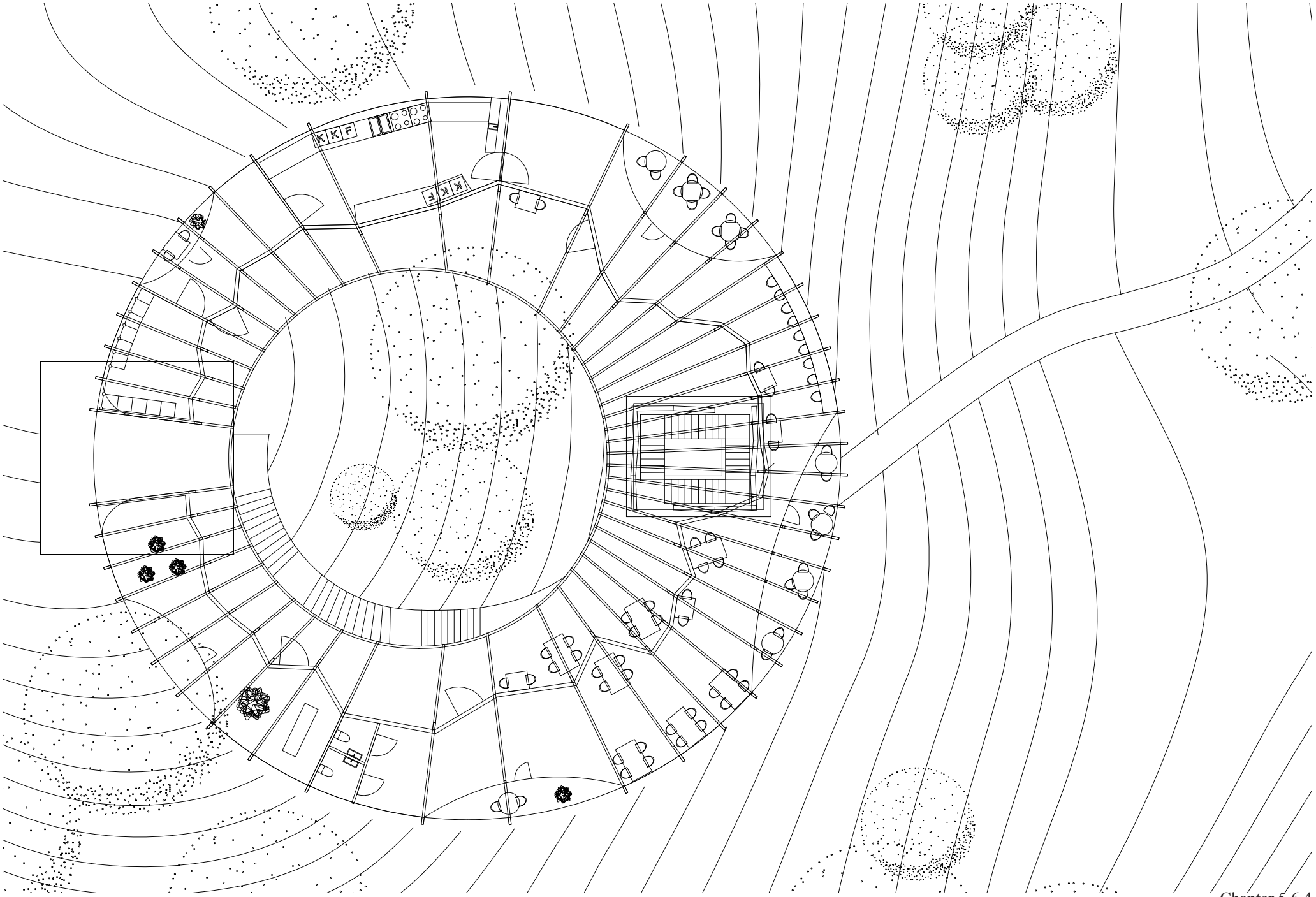
Radial plan

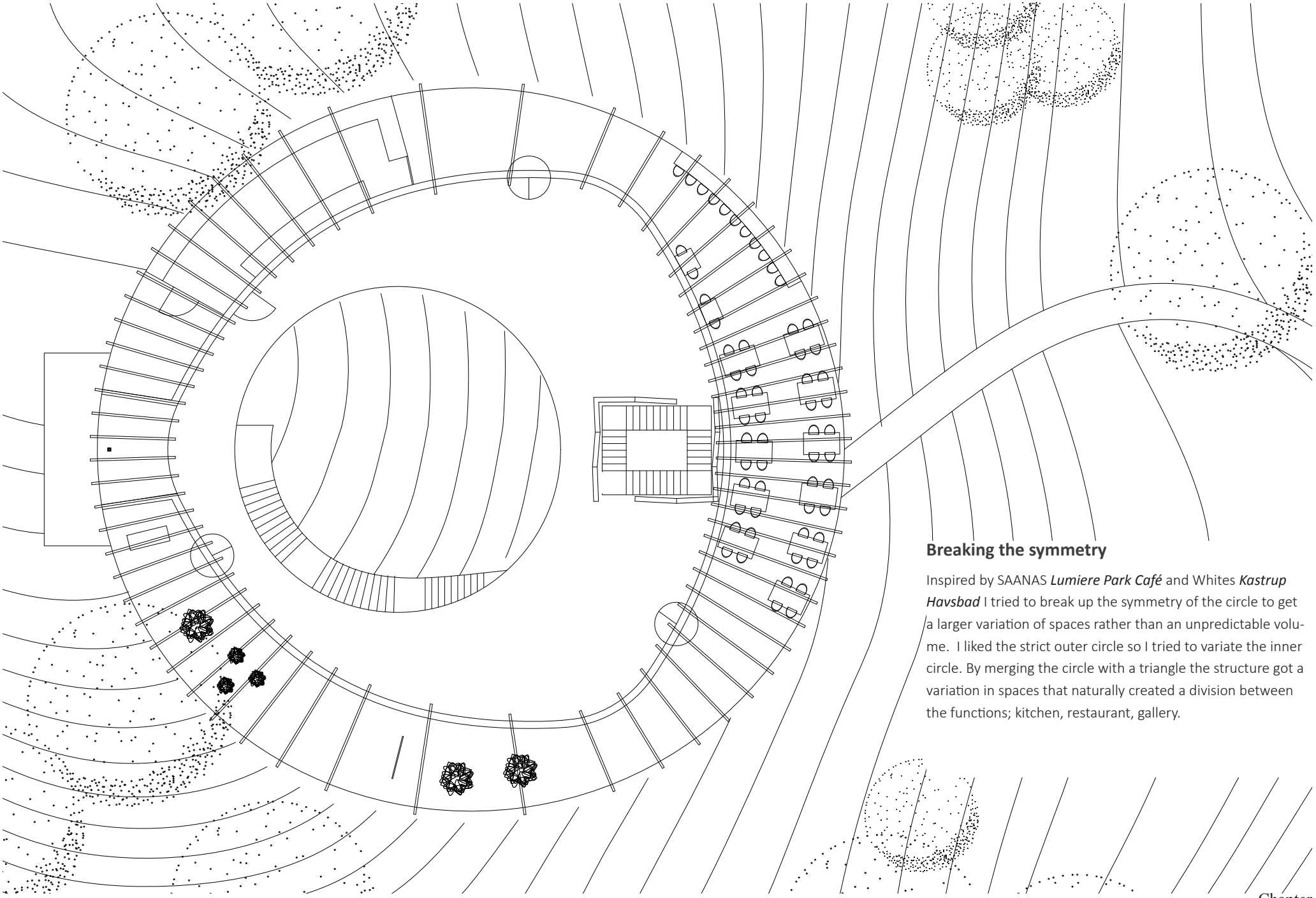
Inspired by Peter Zumthors Zink Mine Museum in Norway and Herzog & de Meurons “14 Rooms” installation for Art Basel 2015 an option of placing rooms in an exoskeleton structure. Each room would have an individual character with a unique view over Gothenburg. From the circular inner walkway you would enter each room. The option had a clear concept for the space but I lost the possibility for one continues space along the outer edge of the circle.

Zink Museum, Peter Zumthor, Norway
http://aasarchitecture.com/wp-content/uploads/Peter-Zumthor-s-Zinc-Mine-Museum-next-open-in-Norway-04.jpg



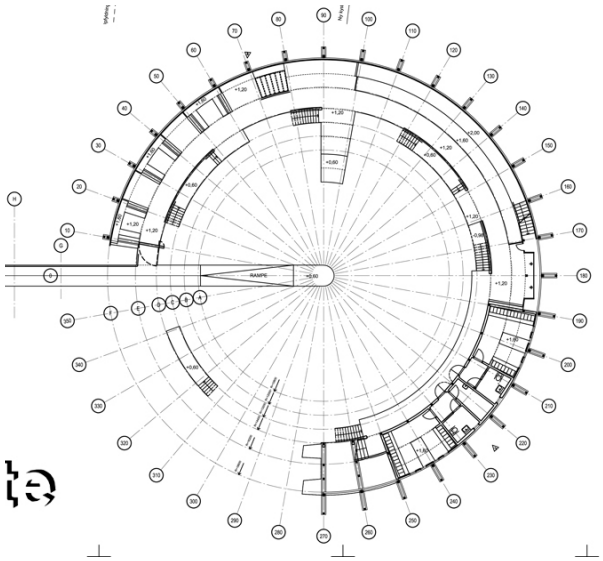
14 Rooms, Art Basel, Herzog de Meuron
www.herzogdemeuron.com

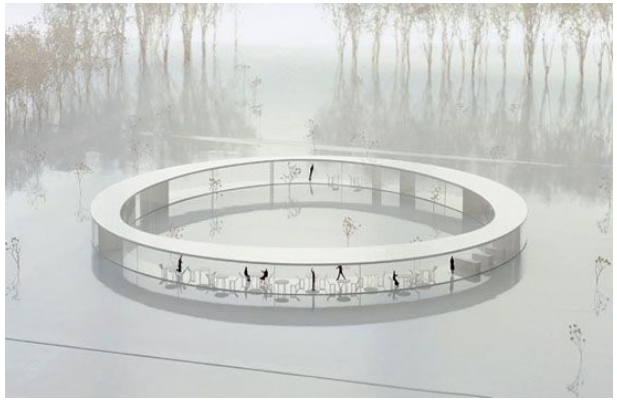

K K F
K K F



Breaking the symmetry

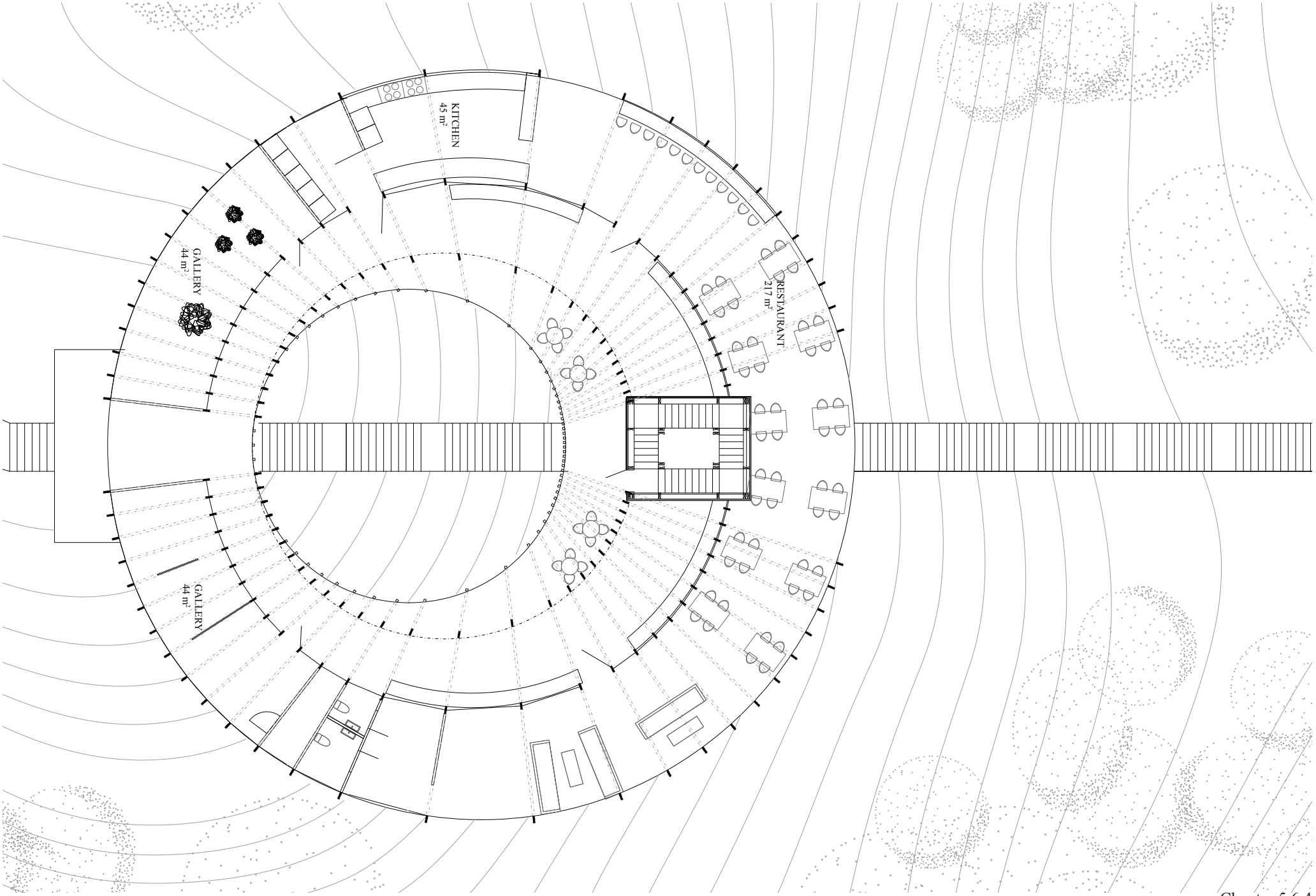
Inspired by SAANAS ***Lumiere Park Café*** and Whites ***Kastrup Havsbad*** I tried to break up the symmetry of the circle to get a larger variation of spaces rather than an unpredictable volume. I liked the strict outer circle so I tried to variate the inner circle. By merging the circle with a triangle the structure got a variation in spaces that naturally created a division between the functions; kitchen, restaurant, gallery.

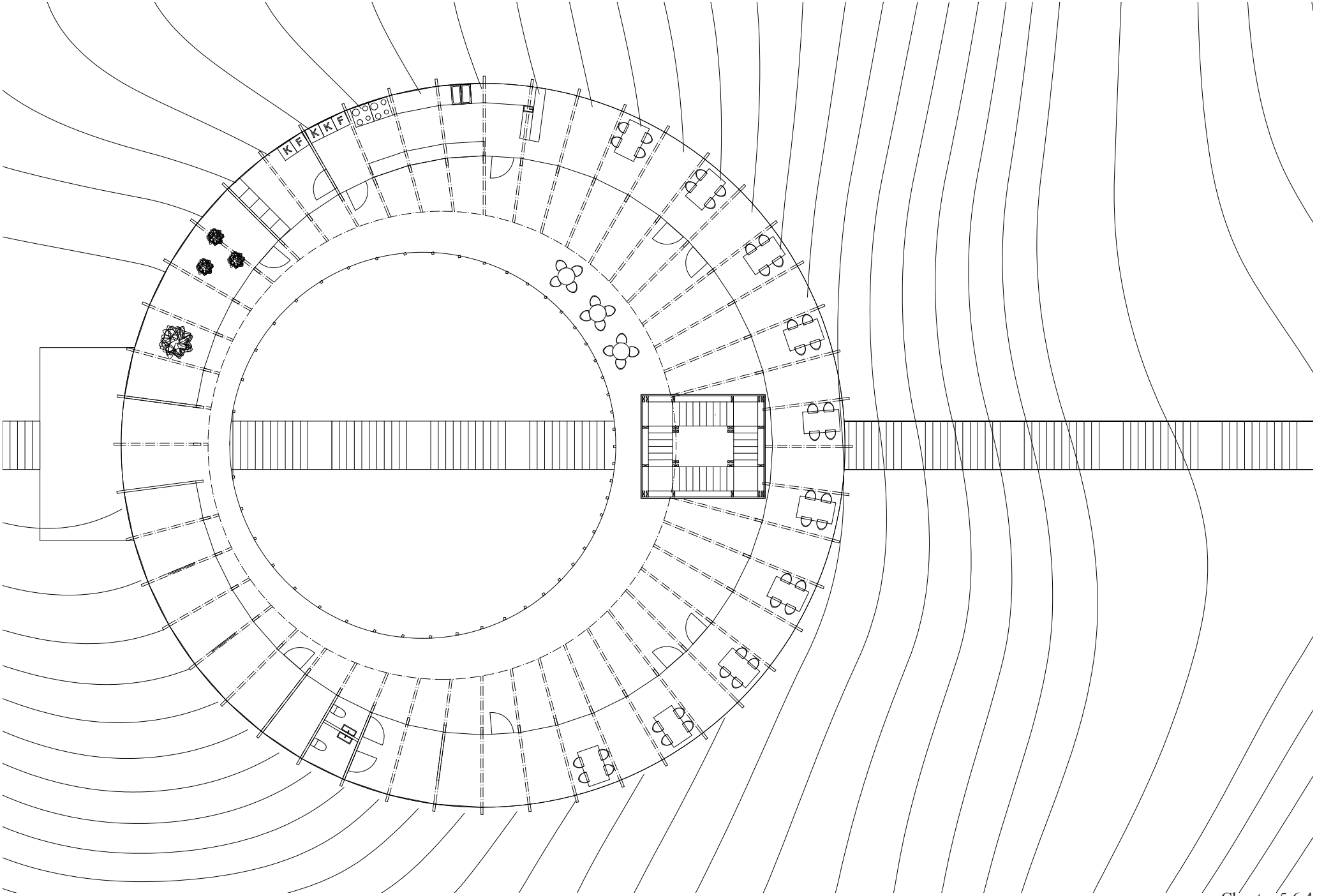




Lumiere Park Café , SAANA, UNBUILT
http://www.sanaa.co.jp/

Kastrups Søbad, White, Copenhagen
www.white.se


KITCHEN
45 m²
GALLERY
44 m²
GALLERY
44 m²
RESTAURANT
217 m²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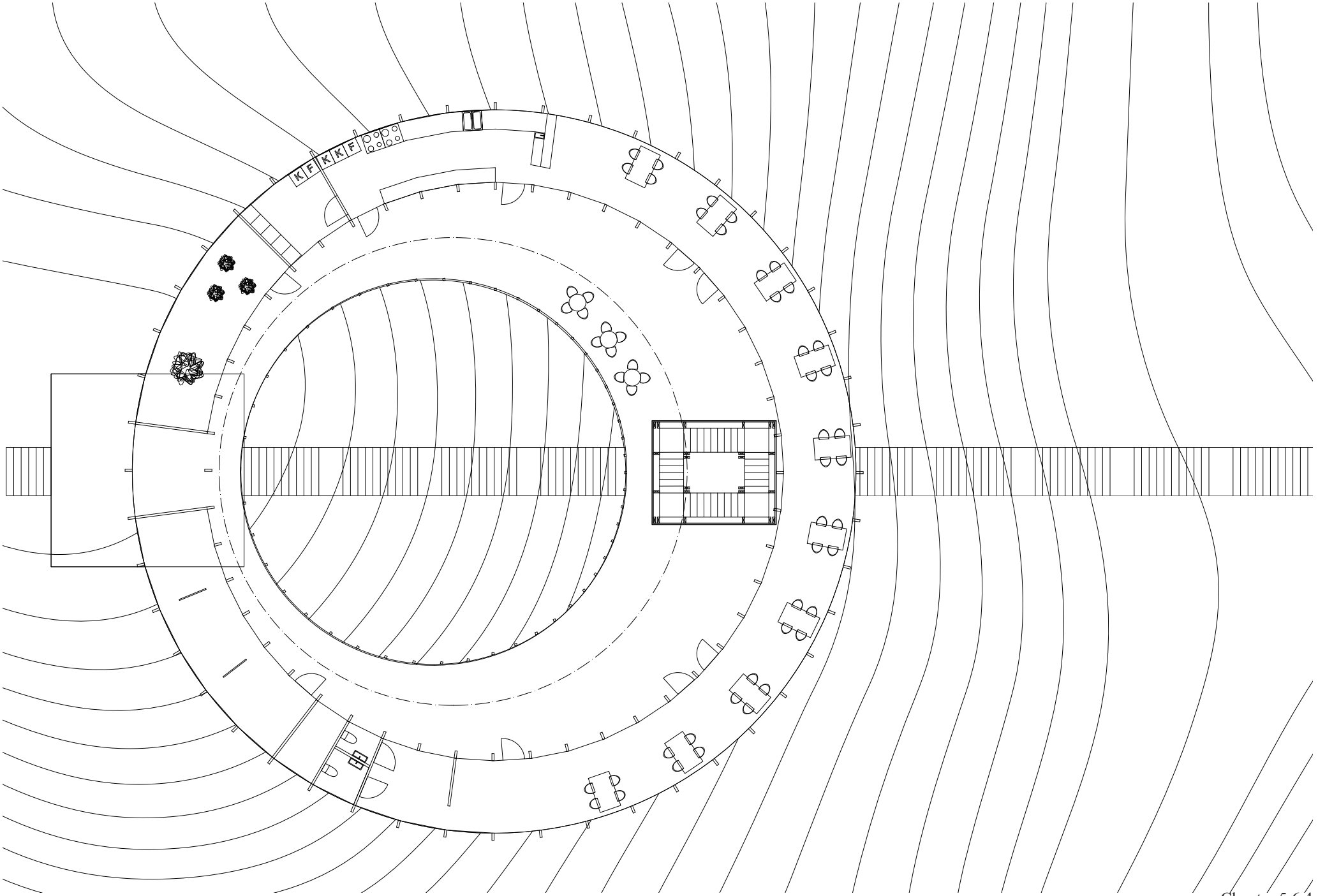
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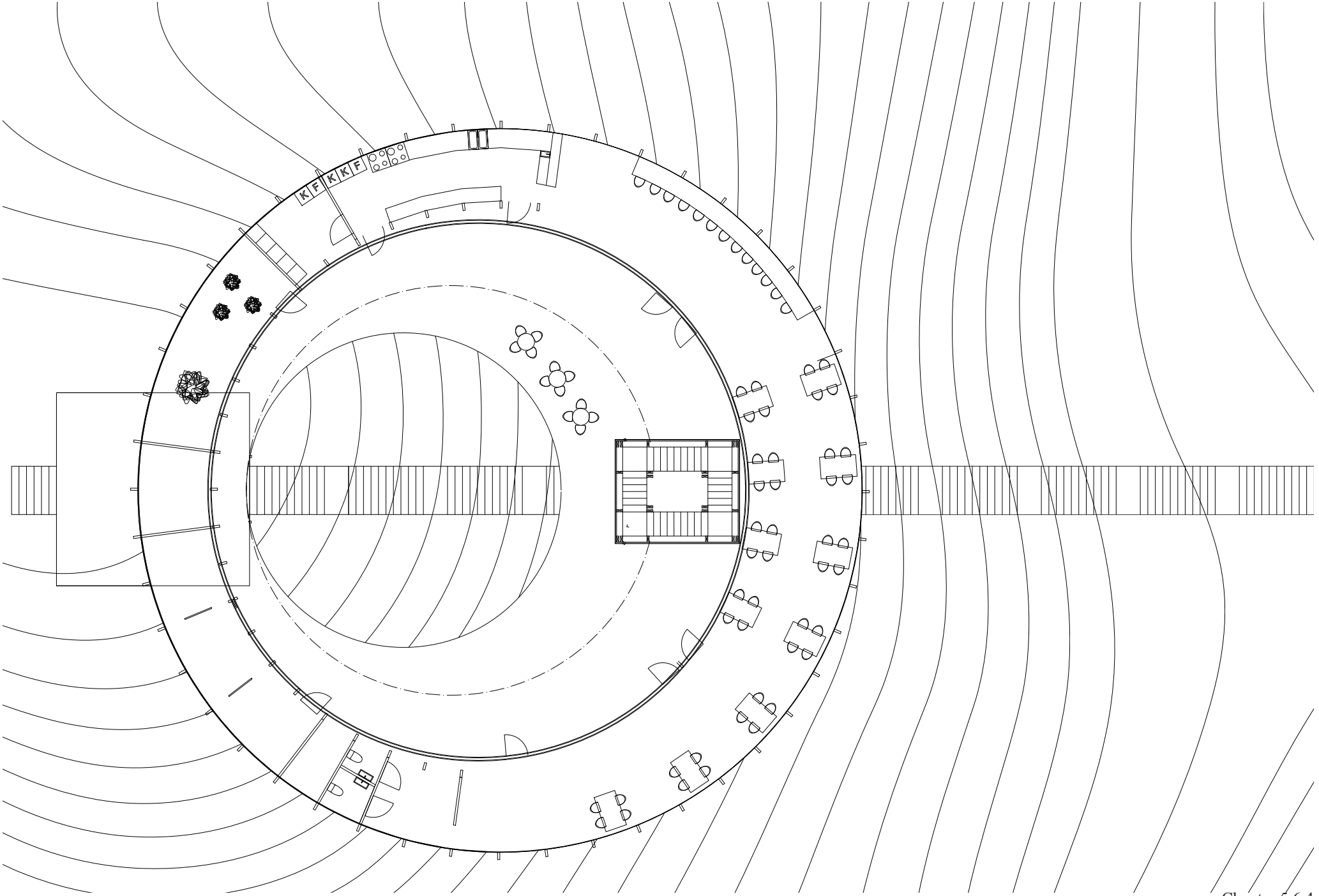
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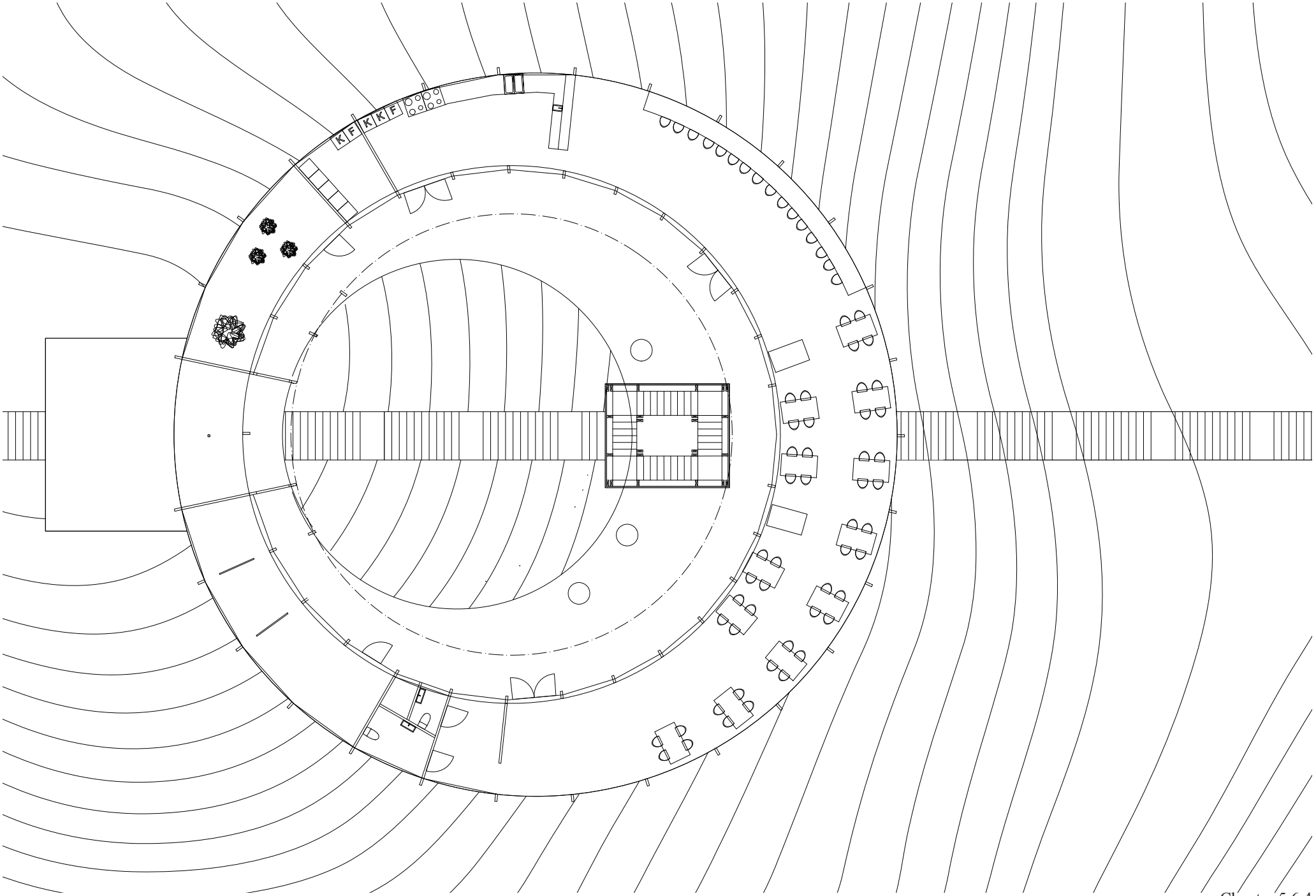
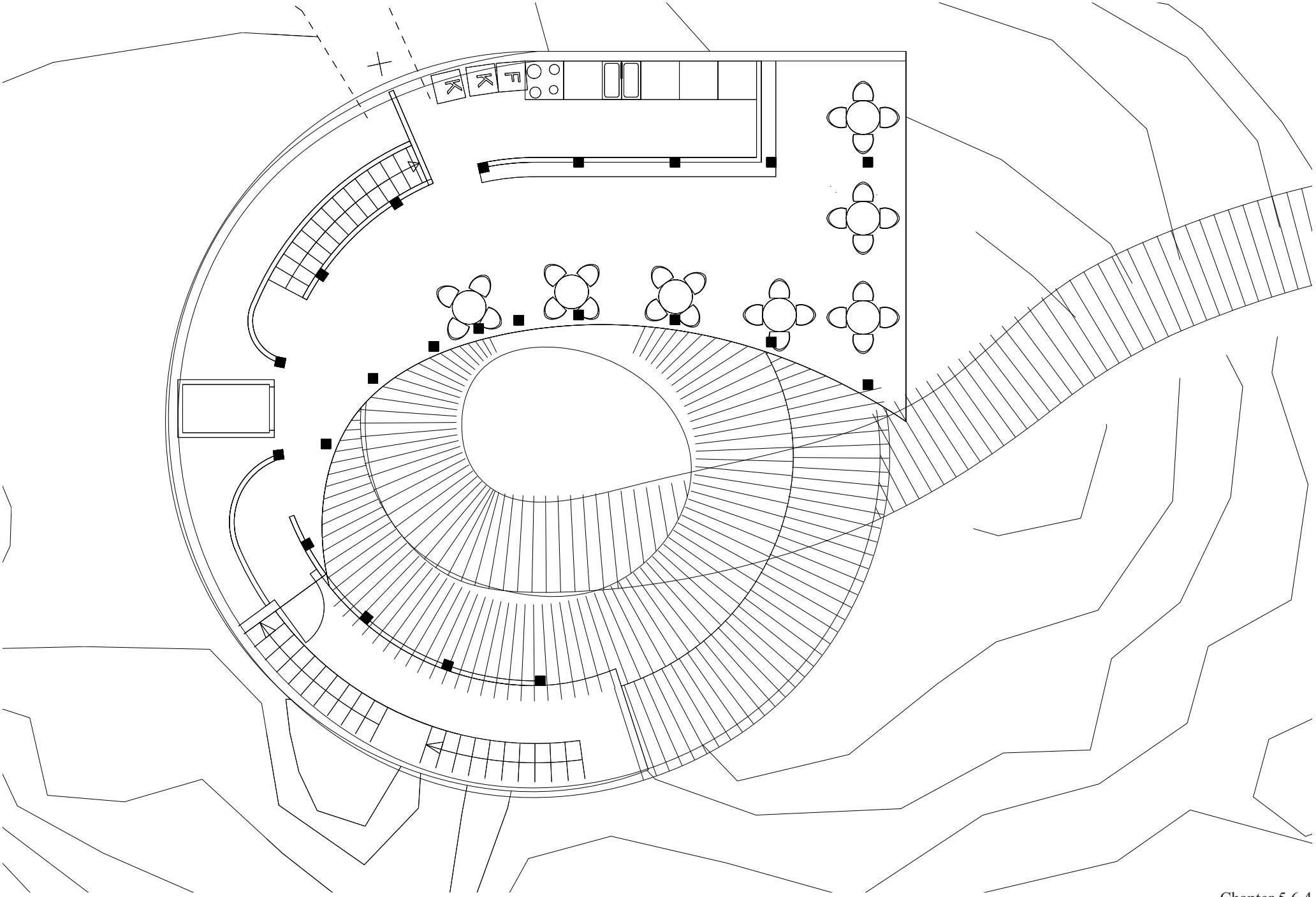
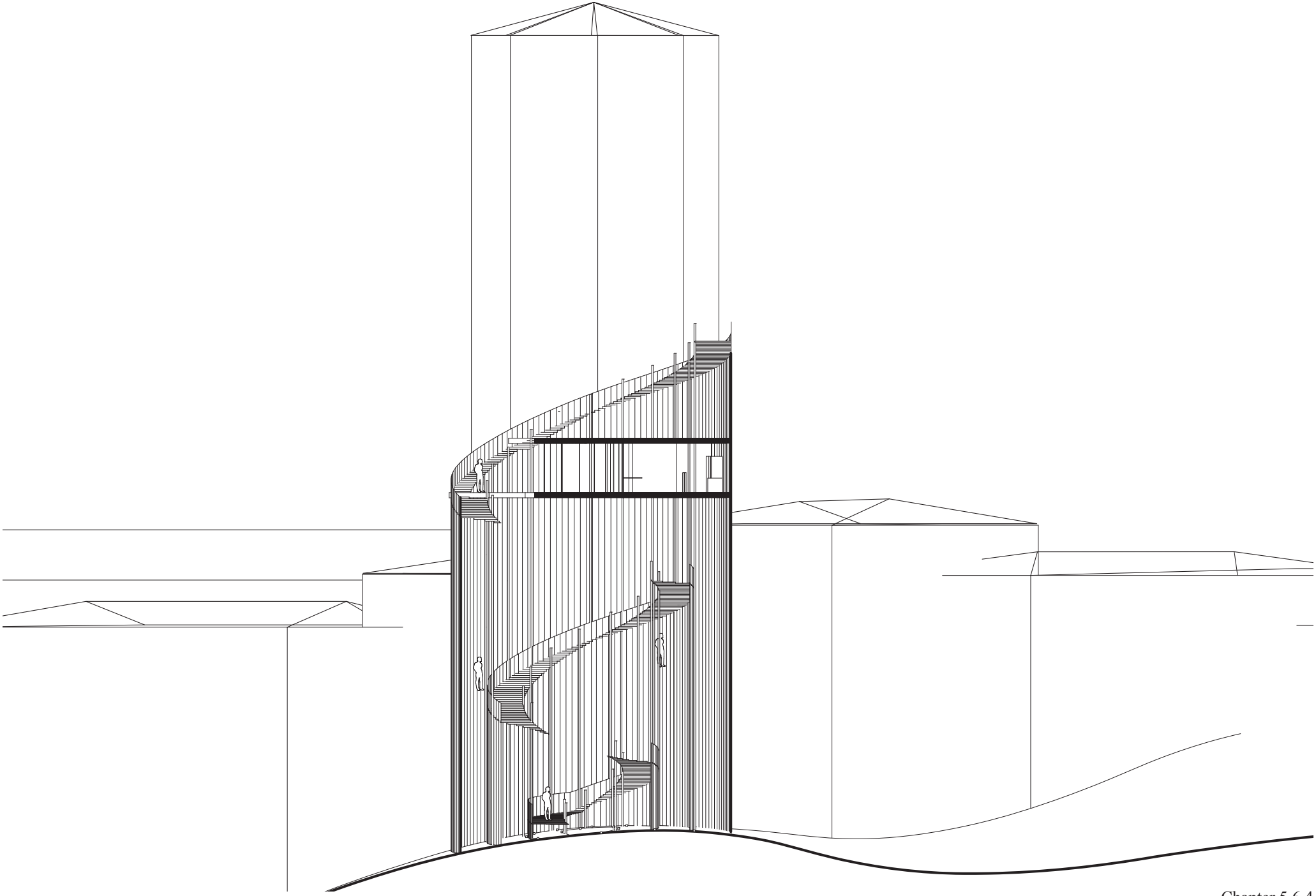
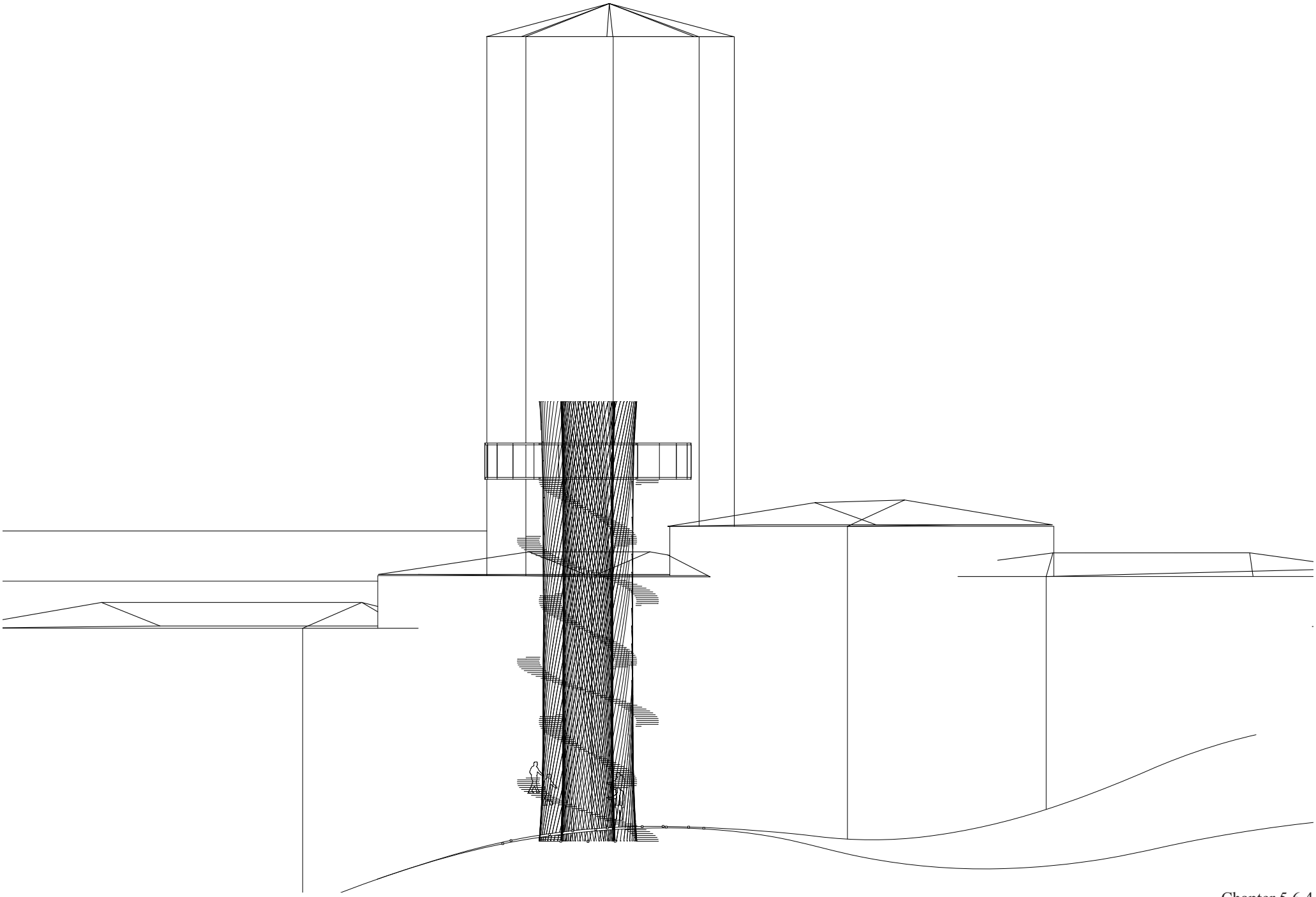

K F K K F





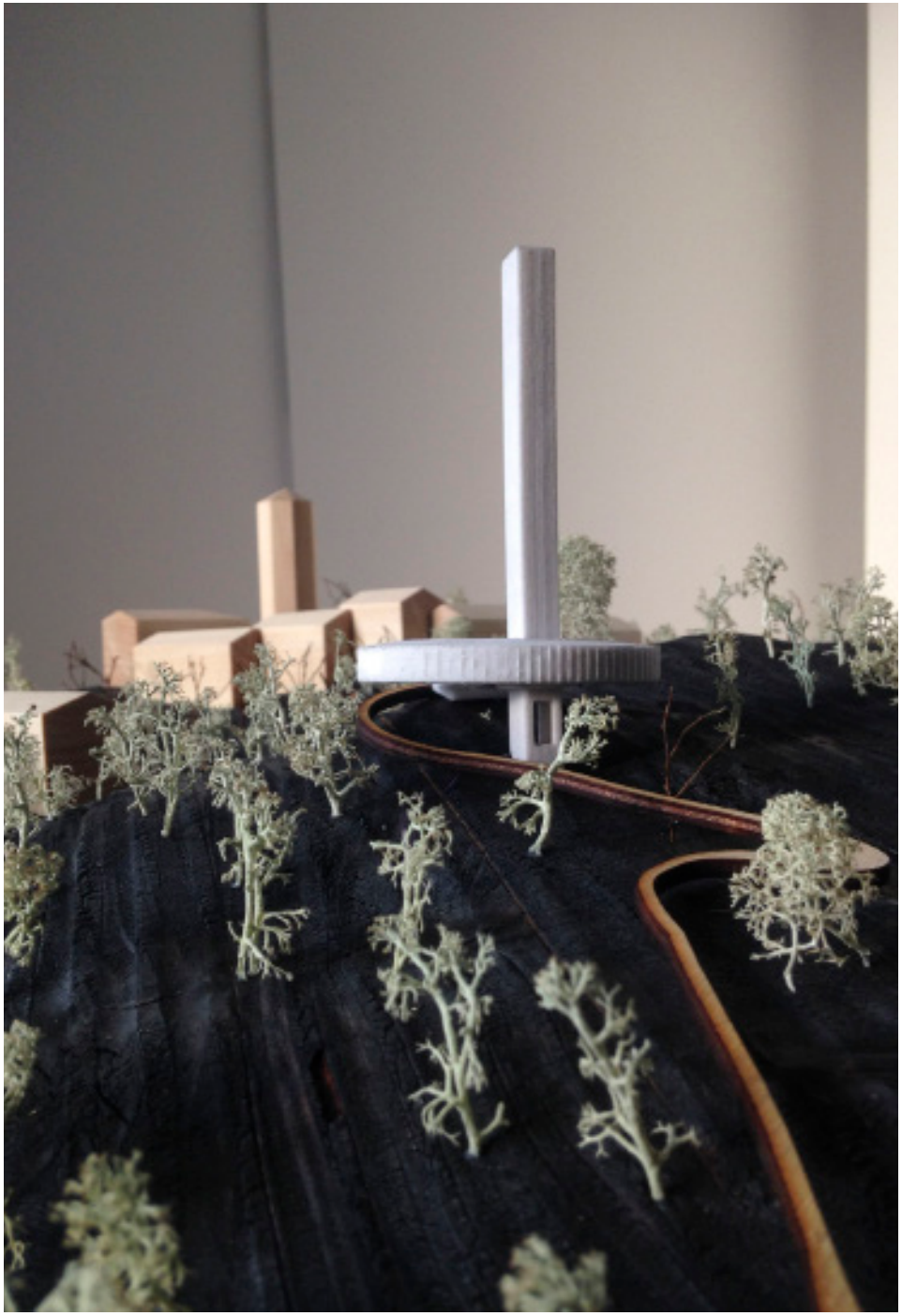
Chapter 5.6.4
ITTERATIONS, 160223, PRE MID CRITIQUE

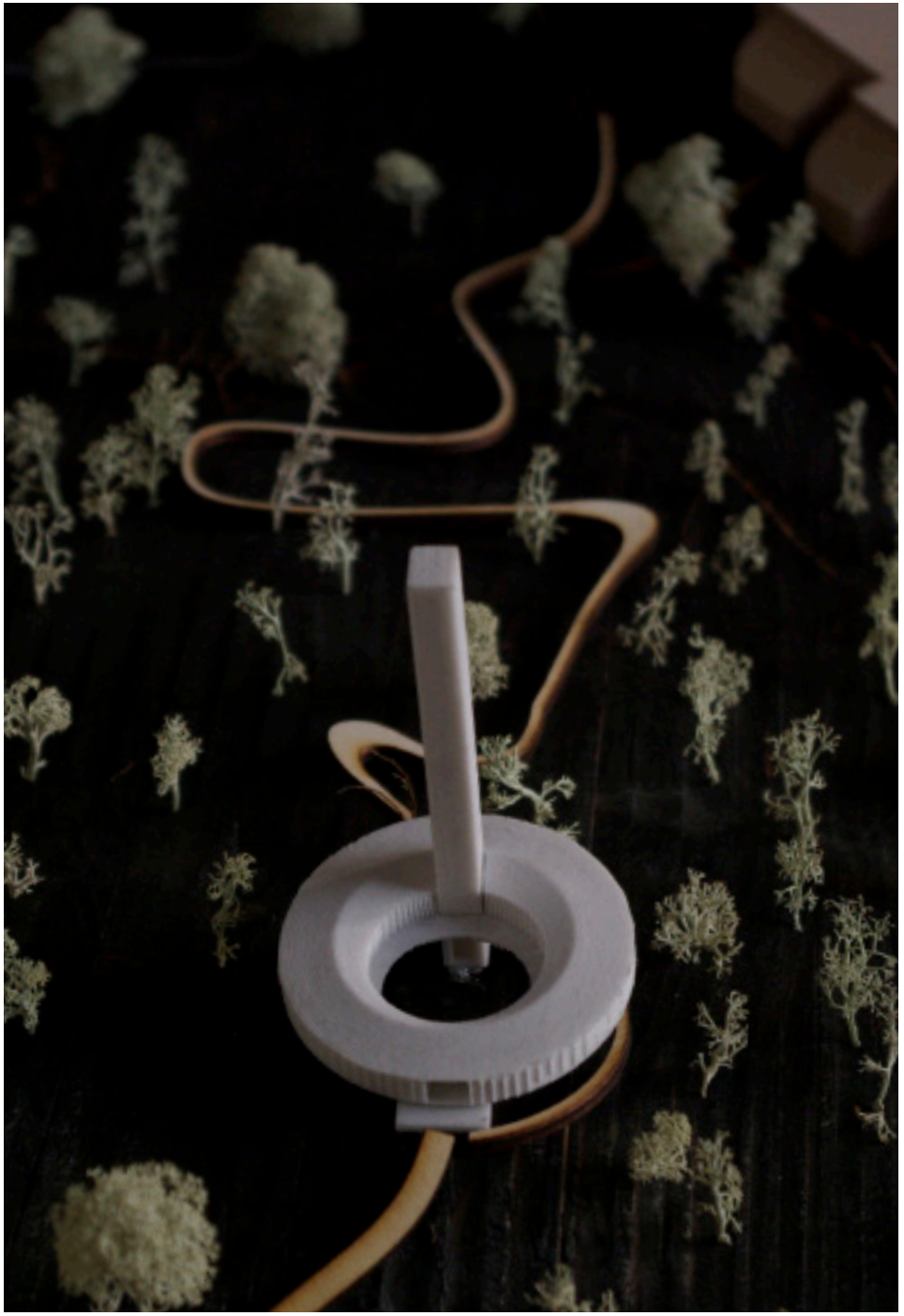


Chapter 5.6.4
ITTERATIONS, 160223, PRE MID CRITIQUE

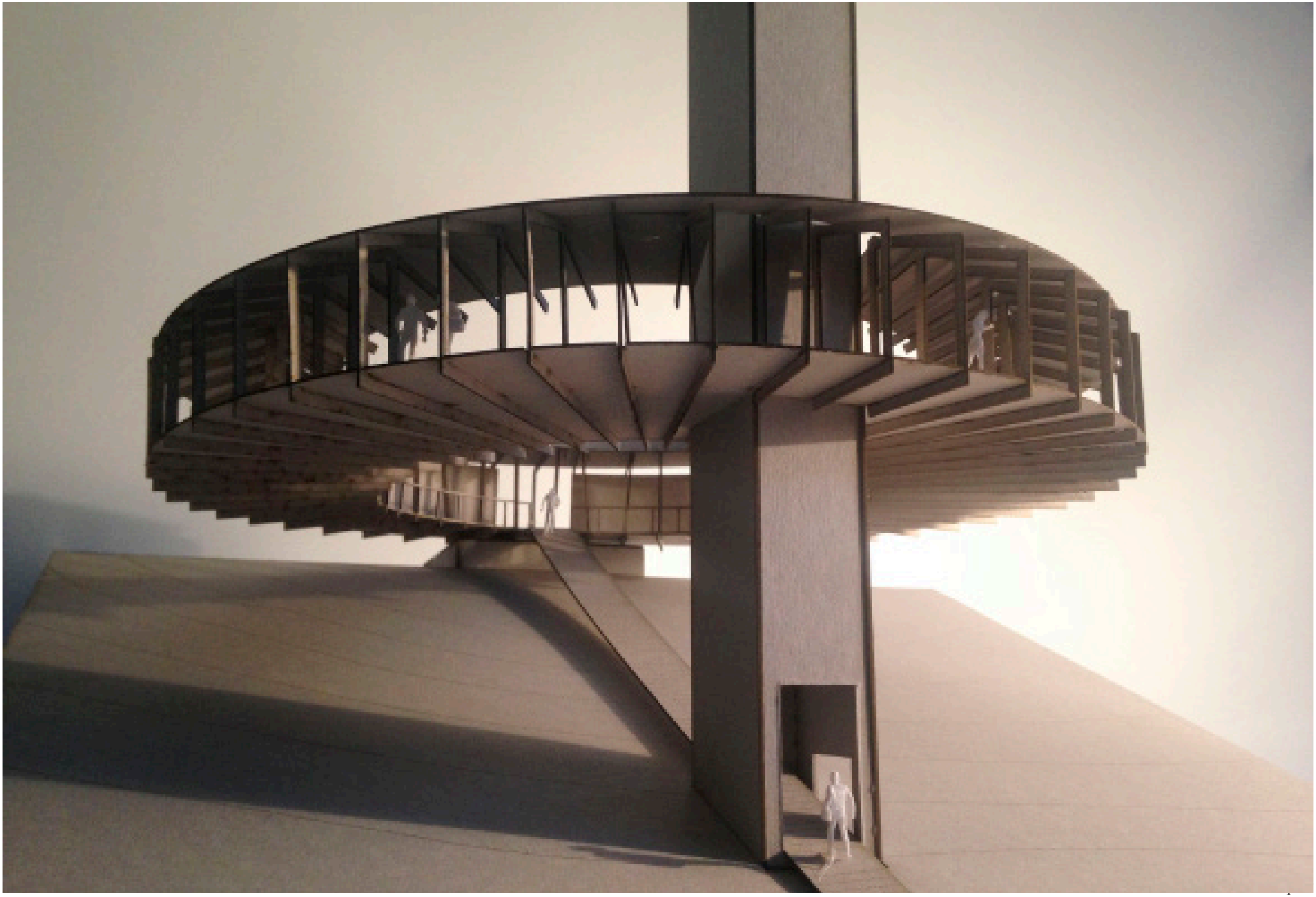
Models

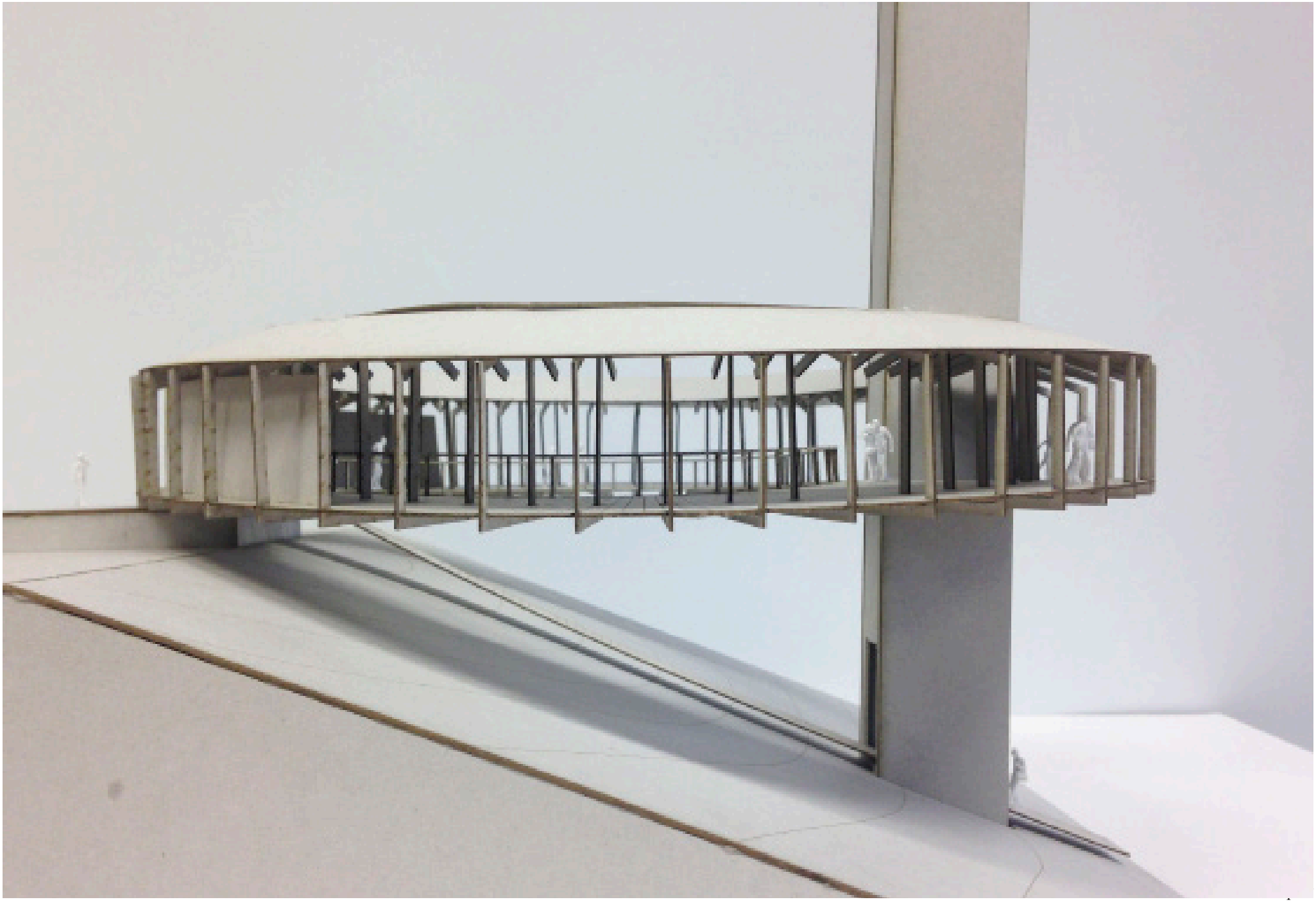
Model 1:500

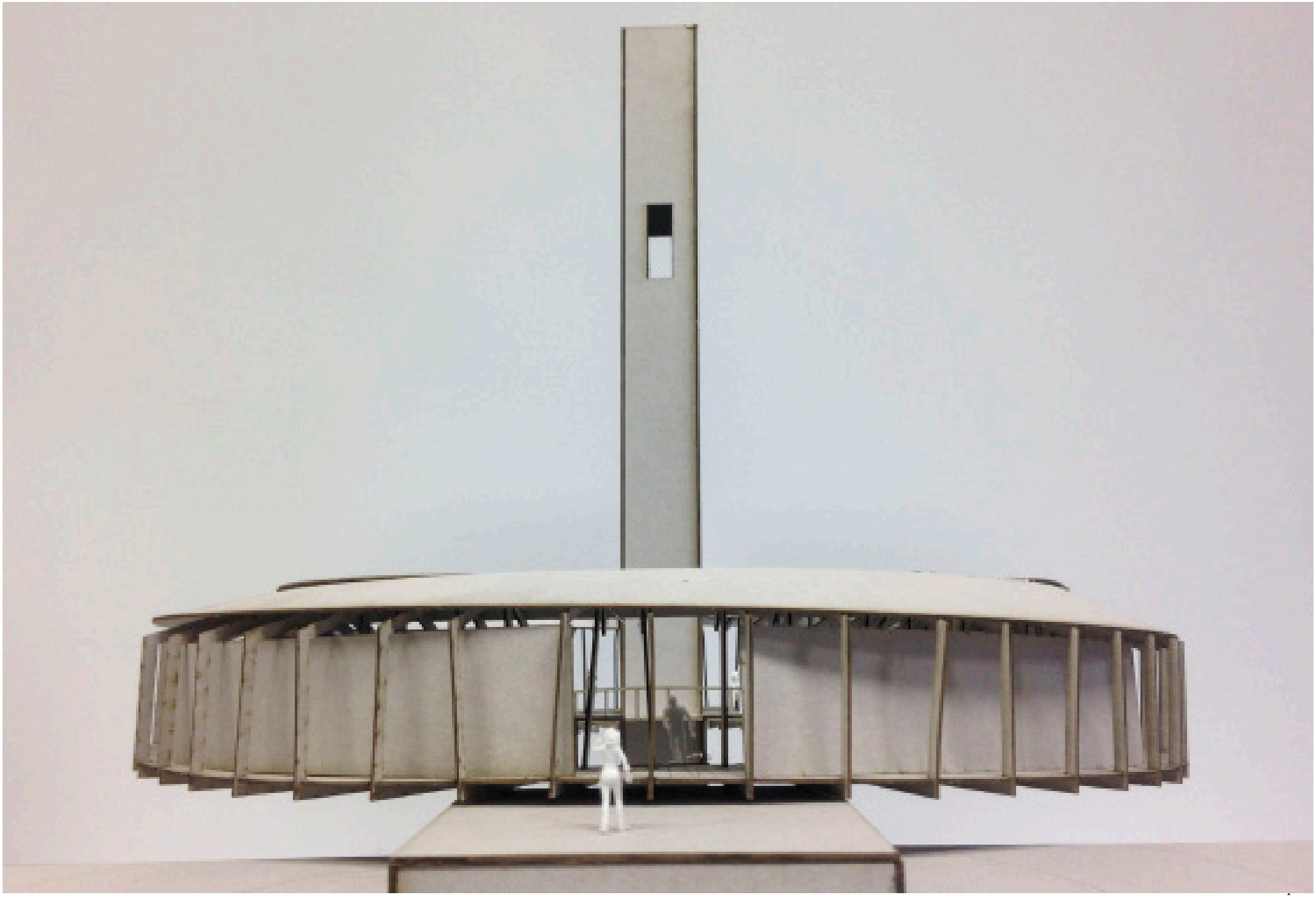


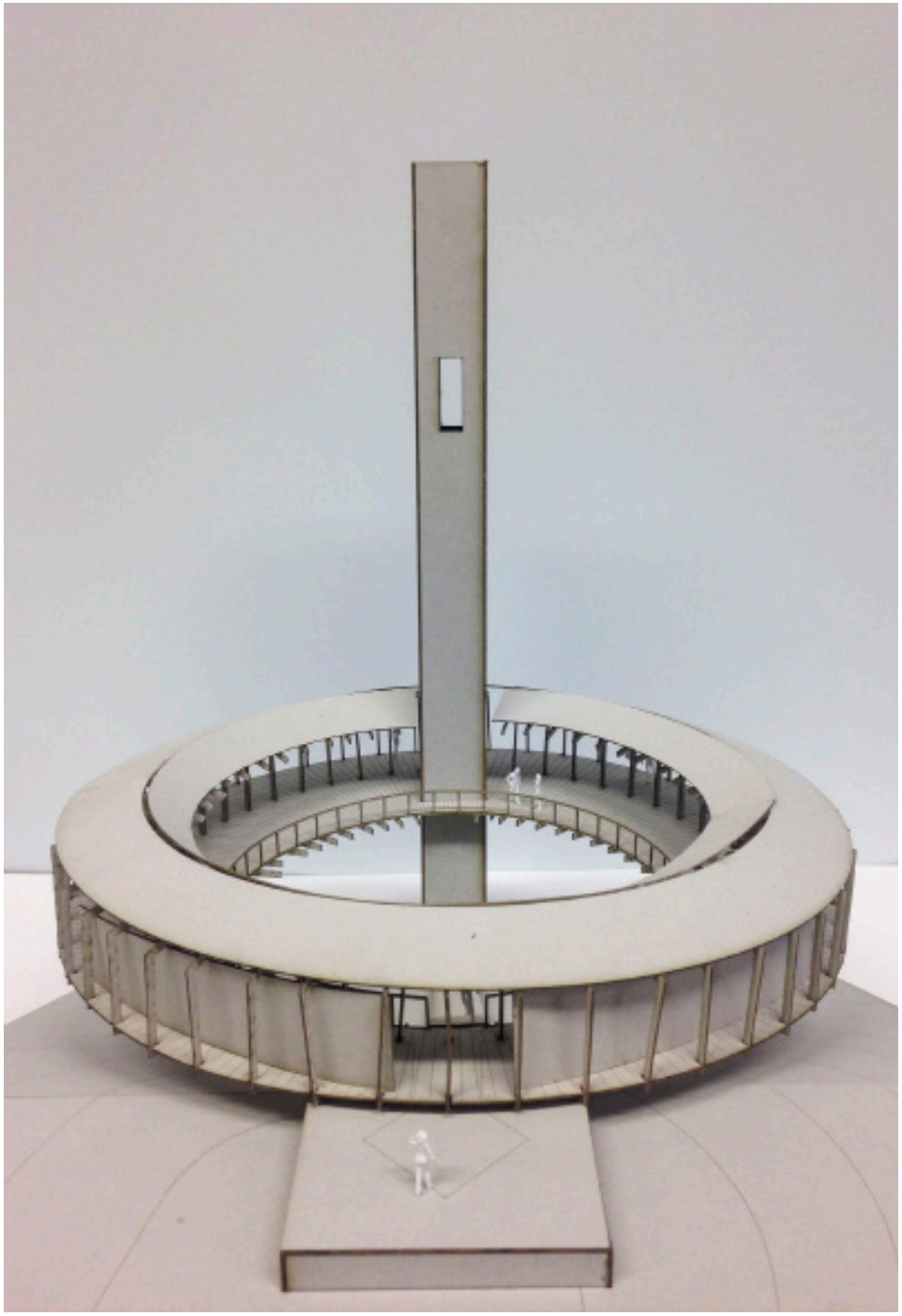


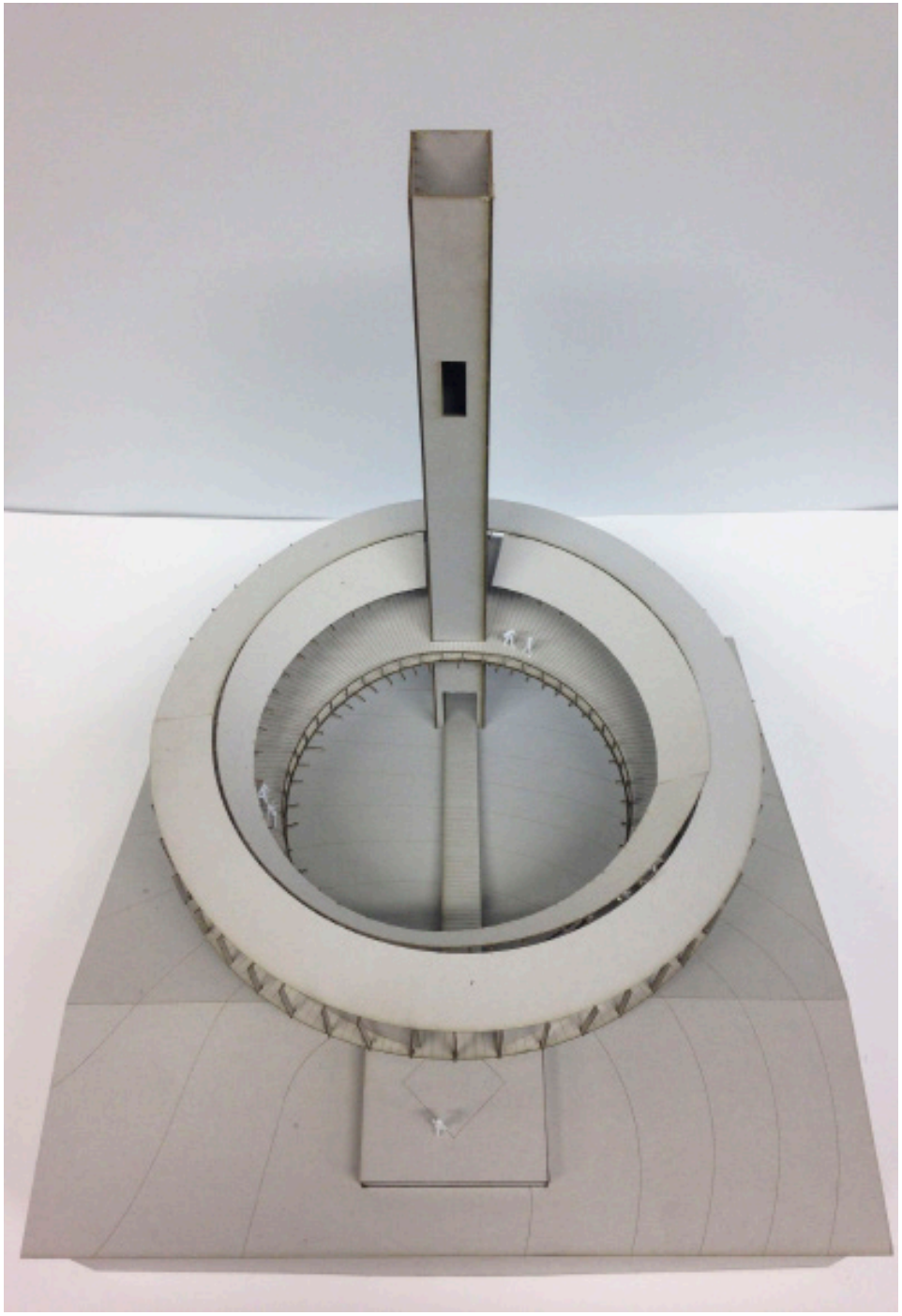
Model 1:100

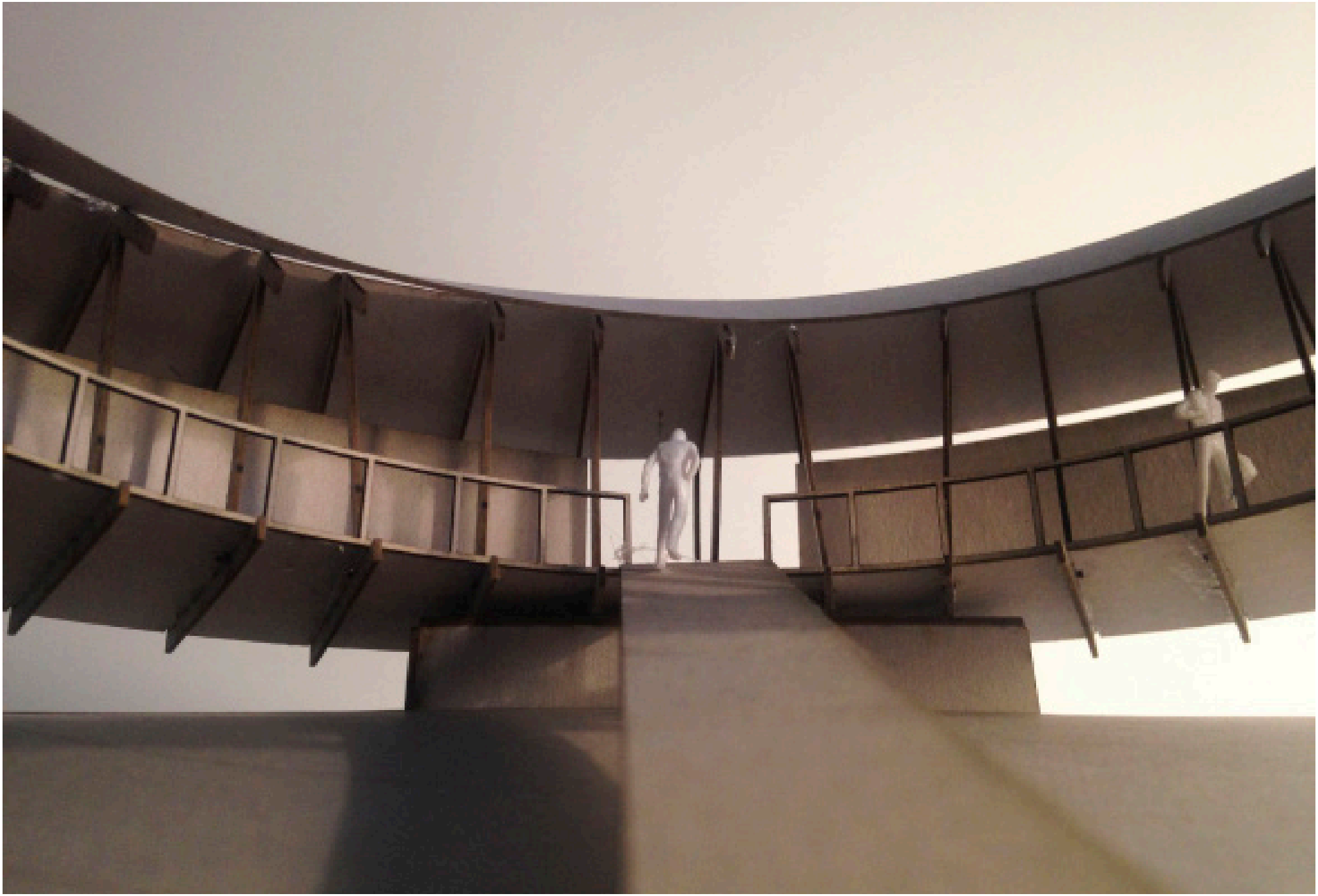




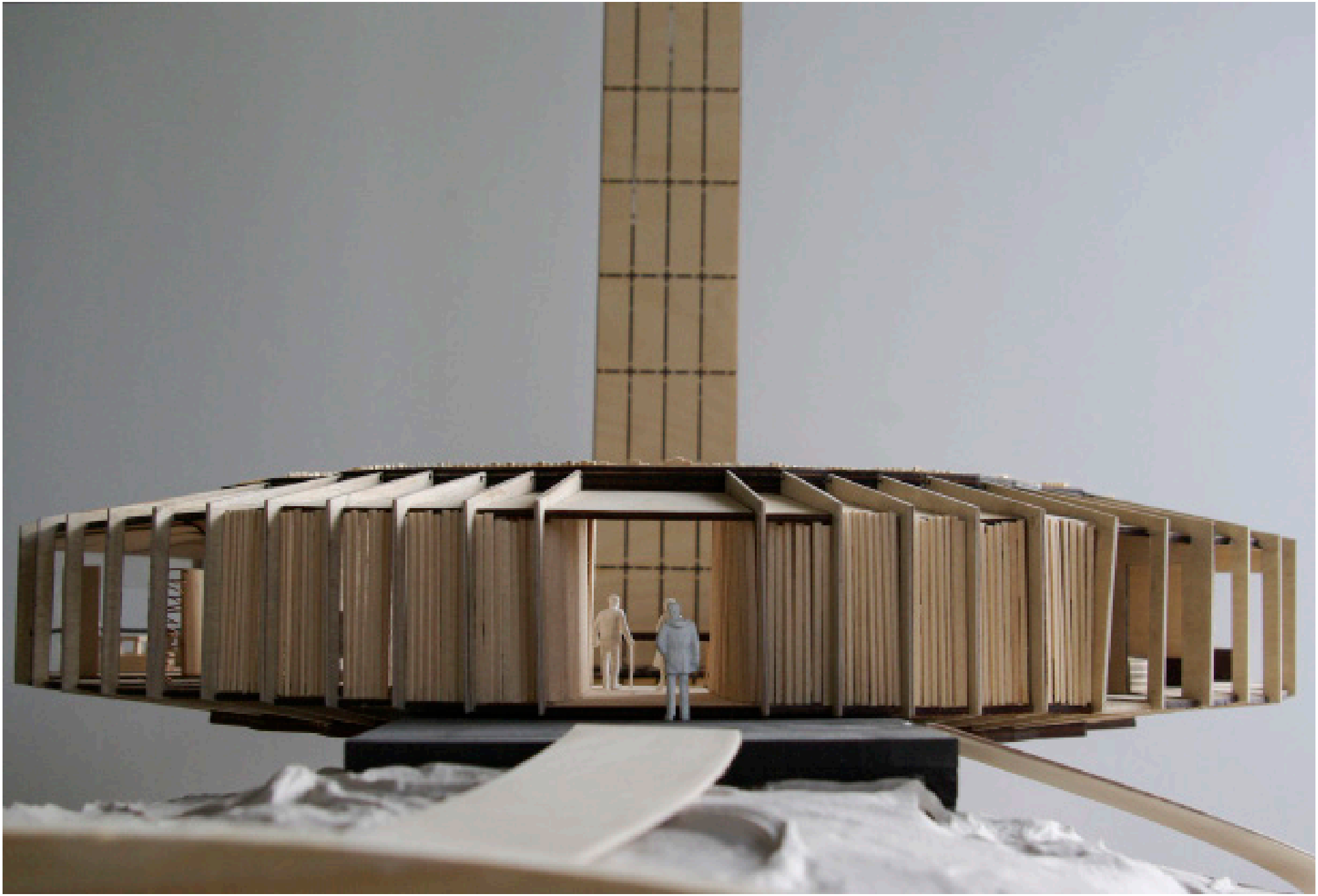


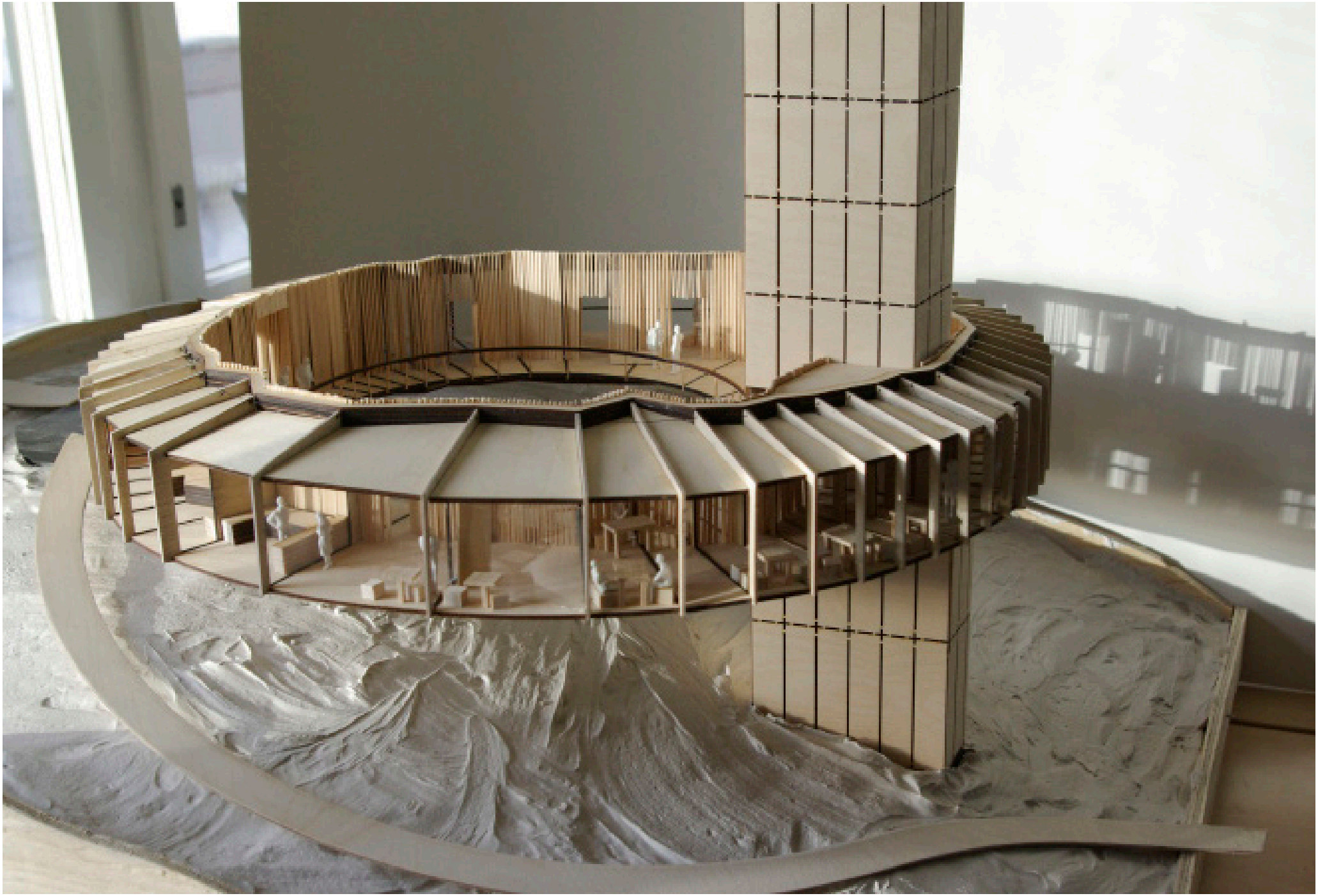


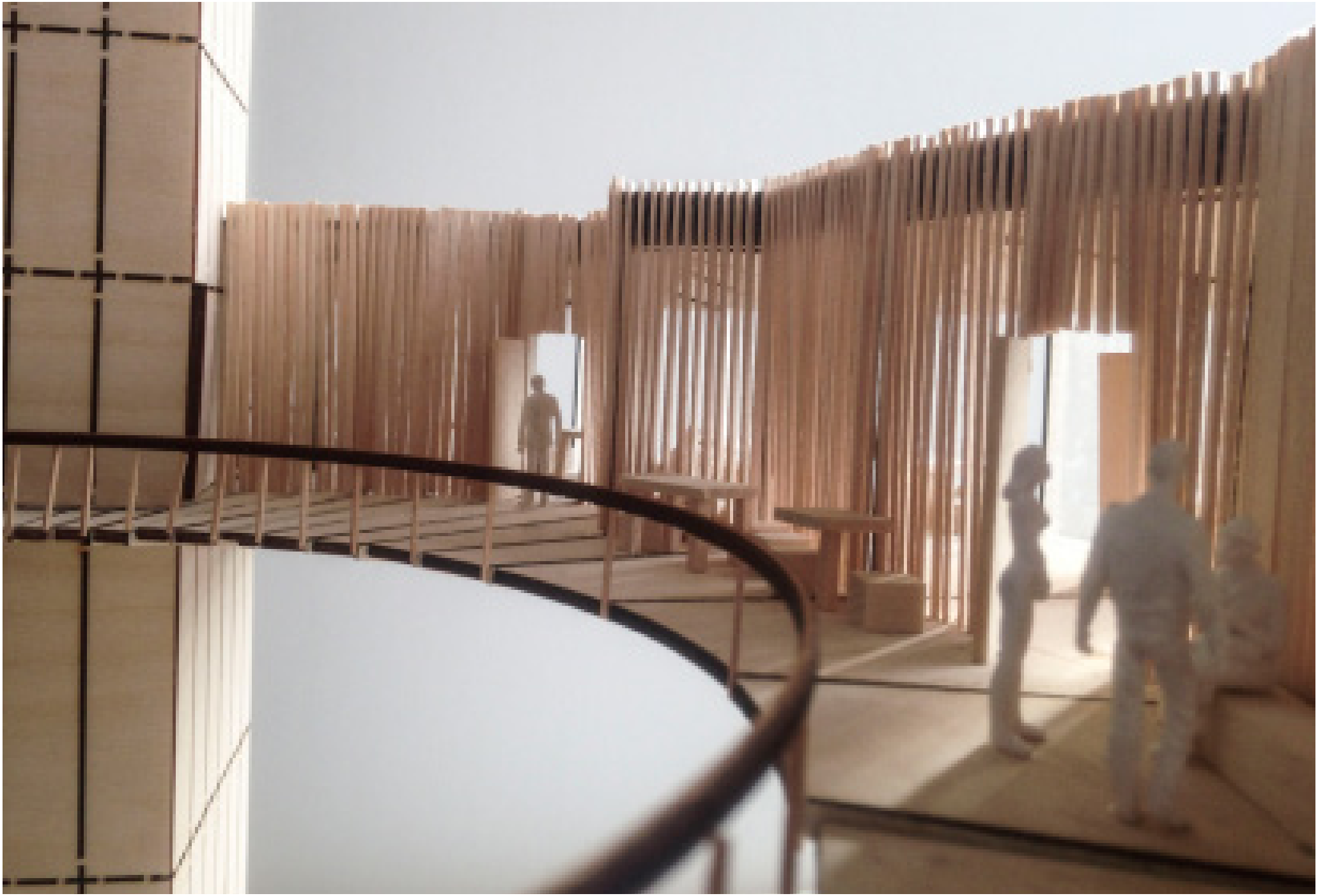


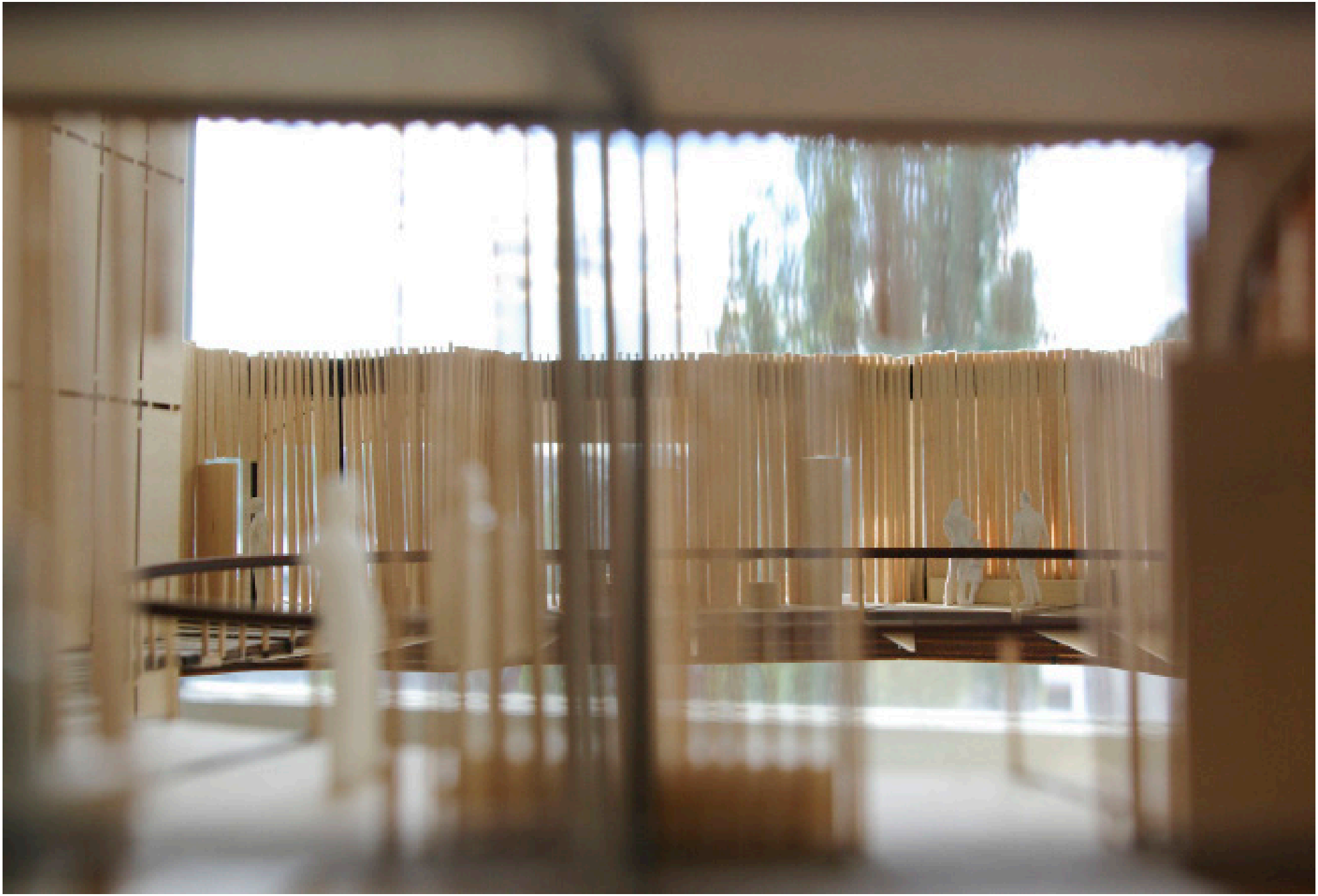


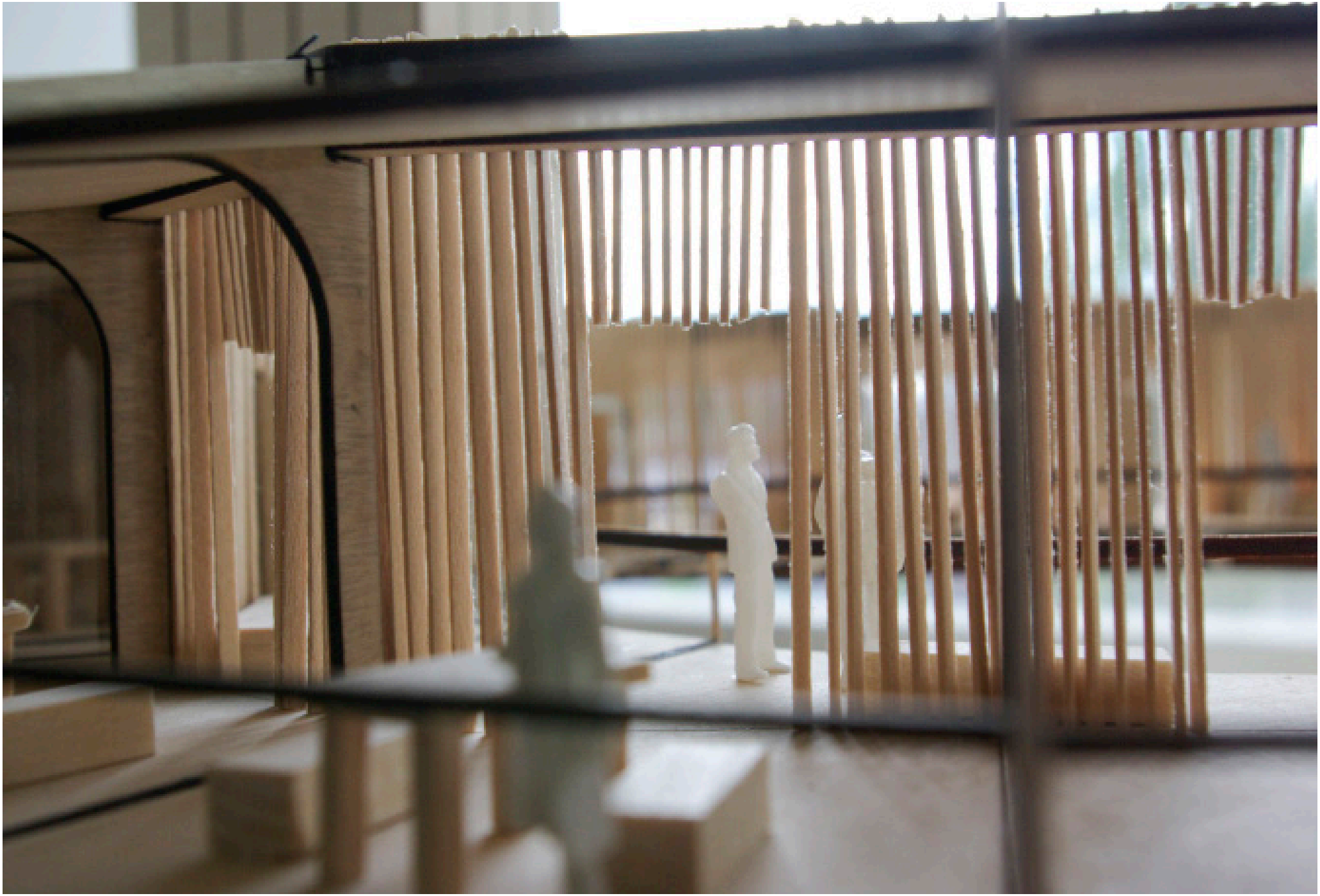
Model 1:50











Chapter 5

THE LOOKOUT TOWER IN THE CITY

Chapter

part