TRANSFORMATION OF THE MIDDELGRUND FORT

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May 2016

Ill. 1 View from the Middegrund Fort

PROJECT TITLE

Transformation of the Middelsgrund Fort

PROJECT MODULE

Master Thesis in Architectural Design Aalborg University

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PROJECT PERIOD

01.02.16 - 25.05.16

NUMBER OF COPIES

6

NUMBER OF PAGES

159

SUPERVISORS

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ATTACHMENTS

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PREFACE

This project is the final outcome of a Master Thesis at Architecture and Design, Aalborg University. The project takes its point of departure in the transformation of the Middelsgrunds Fort in Copenhagen focusing on architectural qualities and sustainability, achieved through an integrated design process.

ABSTRACT

This thesis project deals with the design of a museum of modern art, established through the transformation of the Middelgrund Fort. By utilizing an integrated design process, sustainable, functional and aesthetics aspects have been considered and implemented throughout the design process. The final design considers and explores the balance between the existing structure and a series of new additions, in order to both maintain and emphasize the identity of the site.

Natural light is employed as one of the main parameters in the design process, where it is investigated and utilized both in terms of function and sensory experience. Through the use of light, specific existing structures are showcased, with the new additions providing a different way of experiencing the fort. Several punctures are placed throughout the island, creating a connection between the fort and the surroundings. Functioning as light wells, these structures are implemented to optimize indoor conditions as well as enhancing aesthetic qualities. As such the light voids and a reinterpretation of the preexisting lighthouse sets the frame for the integrated solutions.

In addition to the aesthetic development, a significant sustainable transformation secures a lower energy consumption as well as raised indoor conditions optimizing the building envelope to modern standards. Utilizing the site and adding modern attributes transform the island from an old heritage military fort to a modern art museum.

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INTRODUCTION

The overall theme of the project will be to investigate how to create a strategy that facilitates an optimization of old heritage buildings, in terms of architectural quality and sustainability. To create an example that can be the first step of salvaging other heritage buildings.

This strategy will be applied to our specific site, so a design proposal will be developed with the focus to add a new architectural quality to the site, whilst still acknowledging the history and character of the space. The Middelgrund Fort has a unique possibility to showcase its old identity. The history of the place creates its character and will remain intact, while the function will change in order to maintain the identity for generations to come.

A sustainable solution will be sought in terms of the social, historical and cultural significance of the place. But also when considering energy optimization of a building that was not designed to be energy efficient. The demands for low energy housing will not be applied, due to pure defragmentation of the original structure, if it were to succeed. This strategy will be exemplified through the transformation of the Middelgrund Fort, and thereby put more focus to social sustainability. The theoretical field will address sustainability, transformation, context development and the creation of atmospheric spaces.

Ill. 3 View towards Copenhagen

METHODOLOGY

INTEGRATED DESIGN PROCESS

The 'Integrated Design Process', developed by Mary-Ann Knudstrup, is a method used throughout the entire project. The process is divided into five phases:

The problem phase in which the initial problem is established.

The analysis phase involves case studies, site analysis, historical analysis, climate analysis.

The sketching phase involves investigation of ideas through sketching, graphical tools and physical models in order to develop a form. This phase involves iterative loops where the constant development of knowledge optimizes the project according to structural, functional and aesthetic considerations.

The synthesis phase combines parameters, intentions and solutions which are explored in previous phases to be combined into a symbiotic whole.

The presentation phase produces material in order to convey the final product, this occurs through plans, sections, elevations, renders, physical models and diagrams.

The 'Integrated Design process' is an iterative process where the different phases influence each other to create a well informed project. Hence, this is not a chronological process, but one consisting of loops in which phases affect each other on equal terms (Knudstrup, 2005).

KEVIN LYNCH

In the analysis phase the Kevin Lynch method is used. The method is compiled by Kevin Lynch as a result of his investigations upon how pedestrians orientate themselves in a specific context. The analysis is therefore used to map and analyze the site. According to Kevin Lynch, the pedestrians use five different parameters to orientate themselves; districts, edges, paths, nodes and landmarks. The districts describe how the site is divided into different areas and how these are connected by distinctive characters. The edges describe how spaces can be experienced as precluded from one another; this is often experienced between districts. Paths describe the infrastructure on the site whereas nodes describe the junctions that are created in connection to the infrastructure. The last parameter, the landmarks, is described as those higher parts of the specific context, the reference points which makes orientation on the site possible. (Lynch, 1960)

The method can both be seen in as subjective and objective. It can be subjective due to the pedestrians own perception of orientation in the context by using the five parameters. More broadly, the analysis can be used to map out infrastructure, nodes, edges and landmarks and therefore become more objective. This more objective approach is to create an overview of the structures in the area of the site.

THEME ANALYSIS

The following is an exploration into the themes which influence this project. The theories concerning transformation, sustainability and atmosphere will be discussed and analyzed according to their relevancy to this project.

TRANSFORMATION

DEFINITION

Existing buildings are of utmost importance to future architectural endeavors. Most cities around the world can be recognized by specific architectural expressions, as such historical buildings help define the identity of the space which they are situated in. Cramer and Breitling state that historic buildings hold a particular importance not only in terms of their cultural impact, but also in regards to how they can influence the environmental and economical aspects of architecture (Cramer and Breitling, 2012). Cramer and Breitling also explain that by utilizing and restoring existing spaces, the extreme environmental and economic costs associated with the destruction of historic buildings as well as the construction of new ones can be minimized. (Cramer and Breitling, 2012). They also argue that restoring and/or refurbishing historic buildings is becoming a devalued art form within architecture, with many architects preferring to focus on creating and designing new structures. Modern architecture's focus on sustainability disregards the fact that there is a certain value in restoring or transforming these historic buildings. However by working within the constraints of renovating and reusing already built architecture, Cramer and Breitling argue that new heights of creativity can be reached, bringing together people across generations. (Cramer and Breitling, 2012).

THE FOUR KEYS

Johannes Exner describes four keys for which to evaluate the quality of a given set of restoration or transformation. These include Originality, Authenticity, Identity and Narrative. (Braae and Hansen, 2007)

Originality is defined as the amount of authenticity the building possess at that point of its life. This is compared to the buildings genesis, which is the only point in time when it was completely original.

Authenticity is defined as the level of validity that the building exudes. This is shown through the structure, details and surfaces, which also documents the history of the building.

Identity is defined as the appearance and character of a building at a given point of its lifespan, which it has acquired and as such displays.

Narrative is defined as the building's ability to tell its own story. A story that is shown through preserved historical entireties, building components, archeological traces, details and remnants from earlier time periods and events. The building itself is the direct and original source of its history.

Furthermore Exner describes the term reversibility as a strategy that can be used

when confronted with the challenges of transforming or restoring an older building. ‘Reversibility is the physical form that is a result of the action, while facilitating, that it can be removed at a later point without having damaged the building, so it here on after appears as intact as before the action’. (Braae and Hansen, 2007) Being too afraid of losing the authenticity of the building can however be problematic and often results in a state of paralysis. Using added structures enables the architect to create something with a clear distinction in comparison to the original building, while still retaining and emphasizing its original character and substance. (Braae and Hansen, 2007)

Ill. 4 View of platform

SUSTAINABILITY

DEFINITION

The three aspects of sustainability which will be focused on are environmental, social and economic. These can be drawn from the Rio-declaration of 1992 in the definition of sustainability.

Environmental sustainability covers the technical aspects related to the building, including energy efficiency, saving of resources and optimizing equipment related to the building.

The social aspect covers the user's behavior and experience of the building. It looks at the user's sensory experience, well being, movement and accessibility.

Economic sustainability covers the higher cost required to minimize the future building maintenance prices in terms of operational costs. Economic sustainability will also create stability in terms of future expenses like maintenance, rent and so on. However for this project this is not considered in the same way as environmental and social sustainability, but is only applied conceptually.

How do these three aspects contribute sustainable architecture? Environmental sustainability is the dominant concern in terms of the development of modern sustainable architecture. The energy consumption should be minimized, and active and passive solutions should be integrated in the design. Furthermore the Building Act ensures a certain quality via regulations and guidelines for sustainable building design. This is a very technological approach towards sustainability, however a completely sustainable building has to perform better than numbers on a spreadsheet. Building with strong materials that will last for centuries and maintaining a dynamic in the building is perhaps even more sustainable. A low energy house, is very sustainable from the moment it is being built, but when the function needs change in 20 years and the building is renovated or demolished, the sustainable approach is ruined.

Often existing buildings have a value both in terms of material resources and culture. This effects the economic sustainability of the building, in terms of reusing the materials and social sustainability in terms of an identity. Several studies estimate that between 50% and 70% of all future construction work will concern existing buildings. (Cramer and Breitling, 2012)

Social sustainability is also about ensuring buildings for the future. The beauty of a building is making it sustainable as well as maintaining a site specific character to ensure that people recognize it as a part of their city. The effect of cultural heritage buildings in terms of uniting different cultural groups and communities across generations is something that we cannot take for granted. (Tweed and Sutherland, 2007)

ADAPTABILITY

Integrated design is a complicated process. Creating a balance between parameters is required to obtain the best result. Passive strategies must be integrated in the early part of the sketching phase in order to secure an integrated and complete aesthetic look of the future buildings without compromising the identity of the site. Too many active solutions could have a negative impact on the character of the building. Spatial experiences, functionality and indoor environment quality will provide the base of the holistic approach in terms of sustainability. It is crucial to loop between sketching, design and analyzing phases. (Kirkegaard Bejder et al., 2014)

Ill. 5 View from path

ATMOSPHERE

DEFINITION

Atmosphere cannot be easily defined. It is a mixture of sensory qualities that space portrays to the user. It is recognized as the influence of aesthetics on emotions and senses and is perceived through emotional sensibility. Therefore it can be stated that quality architecture happens when a building can be emotionally moving. In a fraction of a second you have a first impression of a place, and sometimes the building manages to move you with its beautiful presence. It is a feeling, an expression, the intensity, a sense of the place, and so much more that portrays a certain feeling. The perception of the place is instant and can be described as the atmosphere of a space. (Zumthor, P., 2006)

Peter Zumthor asks: 'What exactly is the thing that moves us?' (Zumthor, P., 2006) The sound, people, colors, textures, air, forms, it is everything. It is up to architects to create an atmosphere in architecture, to give people feelings, expectations, creating intensity and the sense of the place. It is a great secret in architecture how to combine all these elements, materials, forms, sounds, light and create a space that will give the user an emotional experience.

Regarding every material as being unique, possibilities of usage are endless. It is of vital importance to know how to make compositions with different materials and how to combine them, without ruining them. There is a critical proximity between materials, depending of its type and weight. (Zumthor, P., 2006)

Adding to this it is important to study the sound of a space. Interiors collect, amplify and transmit sounds in different ways depending on the material surfaces and on the shape of the room. Sounds can be associated with certain types of rooms. As such the kind of noise a building will produce has to be considered. How it will react when people walk through it or talk to each other? What sort experience is desired from a certain place? (Zumthor, P., 2006)

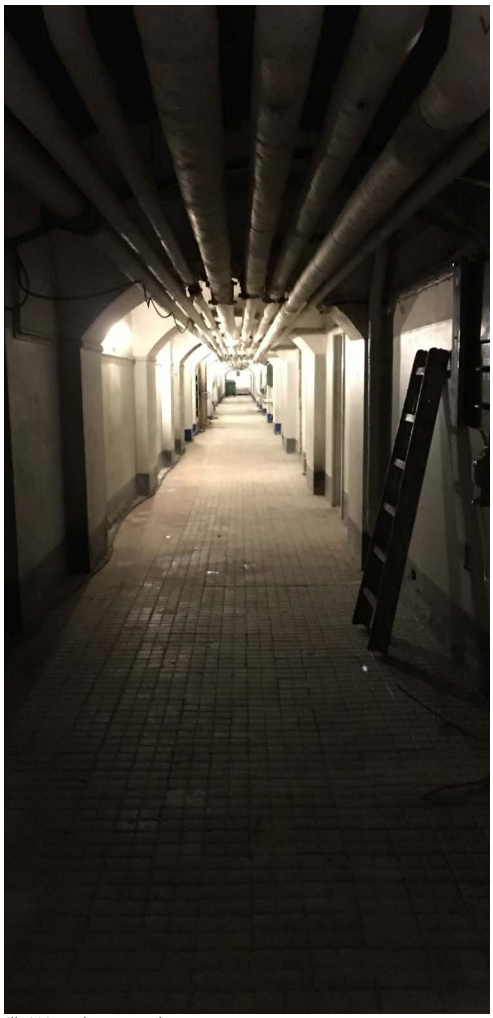
Movement around the spaces is critical when experiencing a building. It can be perceived as the way users are guided through different rooms, creating a sense of direction, and enticing exploration of the building. (Zumthor, P., 2006)

Another vital aspect is the scale and dimensions of space. The building scale compared to human scale and what the building scale tries to portray. Tall and monumental, wide and impressive, small and intimate etc. The interplay between different types of scale can create curiosity, and constructing a unique experiences. (Zumthor, P., 2006)

Light plays a huge role in experiencing a building and has to be closely studied. There

are two ways in which Zumthor brings light to his projects. First is to plan the building as a pure mass of shadow, completely dark, adding light to hollowing out the darkness. The second way is to light materials and surfaces systematically and look at how they reflect light. This way the choice of materials will have a huge influence on the complete atmosphere of the space. (Zumthor, P., 2006)

When a building is built it will become a part of its surroundings and a part of the human environment. Architecture is most beautiful when a building can create its own identity. It creates a coherency throughout the building and the concept only makes sense in its entirety. Making it is impossible to remove a single thing from the design without destroying the whole. (Zumthor, P., 2006)



Ill. 6 View down corridor

Ill. 7 View towards the pier

INITIAL CASE STUDIES

The following initial case studies seek to investigate three main ideas; transformation, sustainability and atmosphere in relation to architecture.

FRAC DUNKERQUE

LACATON & VASSAL

The enormous industrial hall AP2 is an old shipyard factory built in 1949. An additional building volume, FRAC, was added in 2013. This massive 11.130m^2 building completely turns the original AP2 hall experience upside down in an elegant way. By duplicating the shape and dimensions and leaving the AP92 hall almost untouched, the new addition compliments rather than taking attention away from the original building. The addition reverses the heavy and enclosed look of its counterpart, into an almost see-through construction via a transparent polycarbonate building envelope. Both interior and exterior materials remain true to the original industrial look. This occurs by building in heavy concrete and steel, and contrasting with a light and new expression externally.

The narrative character and authenticity remains intact throughout this transformation 60 years after. Furthermore it works together with the old hall attached via the length of the facade, which creates easy access and visibility from one side to the other. FRAC functions as a gallery and exhibition house, with rooms differentiating in size. However, the AP2 hall offers a huge six story room for large exhibitions, concerts, shows, sport, fairs etc. (Archdaily, 2016)

The use of the original built form, while still creating a clear contrast, celebrates the original spacial quality of the building and adds new design possibilities. This creates a design method that the Middelgrund Fort can take advantage of.

Ill. 8 FRAC Dunkerque

REID BUILDING - GLASGOW SCHOOL OF ARTS

STEVE HOLL ARCHITECTS

The Seona Reid Building is created as an extension to the Mackintosh's Glasgow School of Art. The original building was built in 1909, and rather than trying to recreate the old form of the existing building, the new building is designed to be a complementary contrast. Utilizing the thin translucent materiality as opposed to the masonry of the Mackintosh building, it enables the building to showcase the schools activity.

With inspiration from the existing buildings ability to manipulate light in inventive ways, the design is focused on creating a plan of volumes influenced in different ways by light. As such spaces within the building are placed, not only according to their interdependent relationship but also their varying needs and utilization of natural light. Large inclined glazing is placed on north facade, providing the required amount of diffused lighting for the drawing studios. Spaces that do not require a large amount of natural light, such as the refectory and offices, are strategically placed along the south facade where the need for natural light can be balanced with the use of dynamic shading. Large scale light shafts ensure that light is distributed throughout the buildings interior. These shafts guide the light through the depth of the building, creating a connection between interior and exterior, through the changing intensity of light and the colour of the sky. Beyond this they provide vertical circulation through the building, servicing the flow of people along with natural ventilation. (Archdaily, 2016)

The Seona Reid Building implements a series of light wells in an effort to guide light into the building. A design solution of high quality, when considering how to bring natural light into an otherwise dark space.

Ill. 9 Reid Building - Glasgow School of Arts

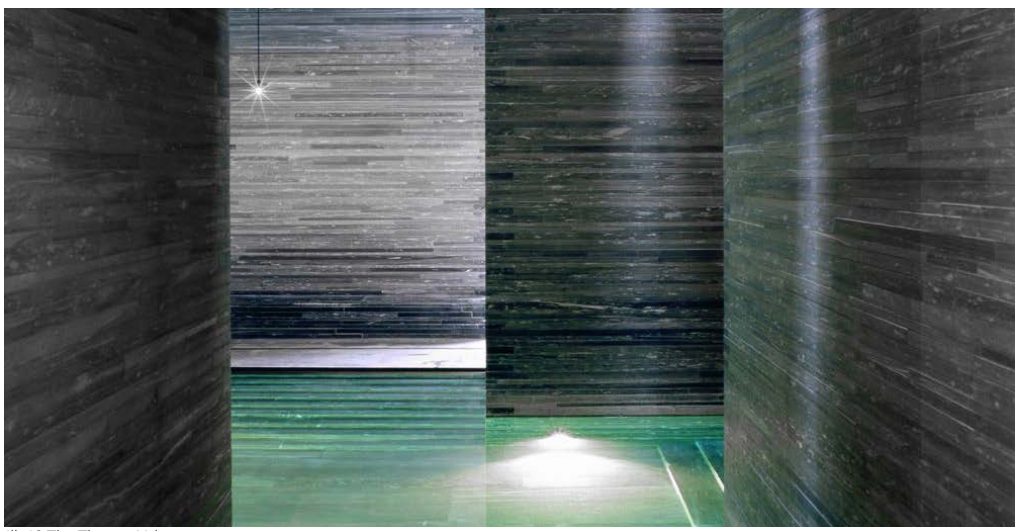
THE THERME VALS

PETER ZUMTHOR

The Vals Thermal Baths are located in the small village of Vals surrounded by mountains in one of the most picturesque locations in Switzerland. The Therme Vals is a hotel and spa complex that is most known for its unique atmosphere and sensory experience. Within the space he creates a sensory experience through materiality, lighting, massing, and stimulation of the senses. It is not so much an architecture of forms as an architecture of senses. (Archspace, 2016)

The built form creates a dialogue with the mountains framing the valley, where the building is an extension of the landscape itself. The building only emerges slightly from the natural topography in search of light. The building consists of fifteen rectangular stone blocks, based on a strict grid that each supports part of the roof. The area in-between is where the movement happens. This is the path of circulation, which leads bathers to predetermined points. The negative space between the blocks creates a rhythm, a flow that guides the user but also promotes self-exploration. Light is channelled in order to create lighter and darker areas, creating different experiences throughout the space. Relaxations, purifications, peace, ritual, and serenity are experienced with just the use of water. With variations of lighting, colours, temperature, materials and sound, different experiences are introduced. (Archdaily, 2016)

Guiding the user along with the use of light and varying sensory inputs, creates a unique atmosphere where spaces are defined not by their look, but rather the atmospheric experience. These are the tools that can be utilized to better emphasize the character of the Middelgrund Fort.



Ill. 10 The Therme Vals

THEME CONCLUSION

Through this analysis process three main principles: transformation, atmosphere and sustainability, have been researched in order to define how to best deal with the specific design challenge of the thesis.

The act of transforming an old structure into a piece of modern architecture is a multilayered task. One has to consider the function, history and character of the place. But the most important factor is perhaps to consider how to actually formulate a design solution, one which emphasizes the qualities of the existing structure, while not being afraid of doing a radical intervention.

When visiting the Middelgrund Fort it becomes clear that the island is infused with a very unique character and atmosphere. Utilizing this fact and perhaps emphasizing it, will be a mayor design criteria in the further development of the project.

Sustainable building culture is not just the practice of designing low energy housing, but rather also creating constructions that are socially sustainable as well. Here, the focus is to develop solutions that can work for years to come. In this specific instance the starting point will be an existing structure, so as to ensure the future for a Copenhagen landmark.

SITE ANALYSIS

The following is an analysis of the site. It will explore features such as pathways, functions and climate through the use of mapping. It will also provide understanding of the history and the character of the Middelgrund Fort.

Ill. 11 Map of Denmark

THE SITE

THE PLACE

The Middelgrund Fort is located in Copenhagen, Denmark. Placed on an 50.000 m^2 man-made island, approximately 800 meters off the Copenhagen coast.

BETWEEN SEA AND LAND

Øresund divides Denmark and Sweden, while connecting the Baltic Sea with the Atlantic Ocean. With its long coastline, compared to the area of the land, it is one of many seas that characterizes Denmark. A multitude of bridges, like the Little Belt Bridge, the Great Belt Bridge and the Øresund Bridge, connect the different regions.

COPENHAGEN

Copenhagen is the capital of Denmark, situated on the east coast of Sealand and is characterized by its large amount of water both towards Øresund and by the canals going through the city center. Right outside the coast of Copenhagen lies a handful of man-made islands including the Middelgrund Fort. Situated between Copenhagen, with more than 550.000 residents, and Malmø, with more than 300.000 residents, it relates to a large amount of people. The only traffic in Øresund are a few cargo ships and the occasional ferry going to and from Norway.

INFRASTRUCTURE

Water buses connect cultural institutions along the Copenhagen waterfront, from Teglholmen to the Refshalvøren, via the stops at The Royal Library, The Opera and Nyhavn amongst others. These water routes create a more direct connection through the city, compared to the regular bus routes. While also facilitating views of some of the cultural landmarks of Copenhagen, making them very popular for tourists who use them as sightseeing buses. When it was open for public-use, there was a ferry route from Langelinje to the Middelgrund Fort, but currently public connections are non-existent.

Ill. 12 Infrastructure

CULTURE

Copenhagen offers a multitude of cultural activities. When considering transforming the Middelgrund Fort into a cultural asset as well, it is important to see what options the city offers. The many museums attract people from all around Denmark as well as the world, making the Middelgrund Fort an attractive site due to the relative short distance from Copenhagen.

Ill. 13 Copenhagen Museums

POLLUTION

NOISE POLLUTION

The distance to the mainland of Copenhagen is only around 800 meters. Nevertheless there is no traffic to or around the island. The absence of cars along with planes and boats not traveling close to the island creates a very quiet environment.

LIGHT POLLUTION

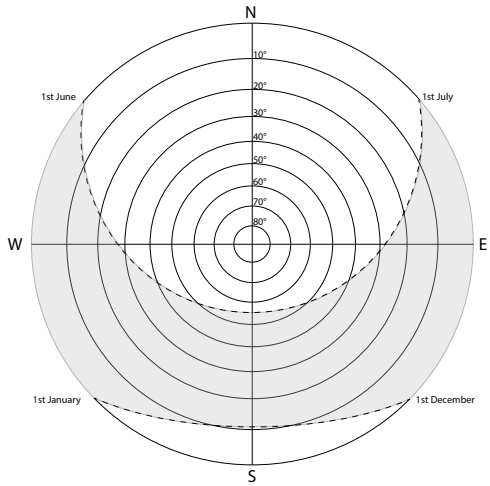
Inside the city, there is a lot of light pollution. Residents, shops and cars, all contribute to the light pollution, both during the day and night. This can affect sleep and makes the night sky very hard to see, with the center of Copenhagen being the worst. Light pollution decreases when moving towards the sea, meaning that the Middelgrund fort is almost undisturbed by it. (The Danish Environmental Protection Agency, 2016)

Ill. 14 Light pollution

CLIMATE

SUN

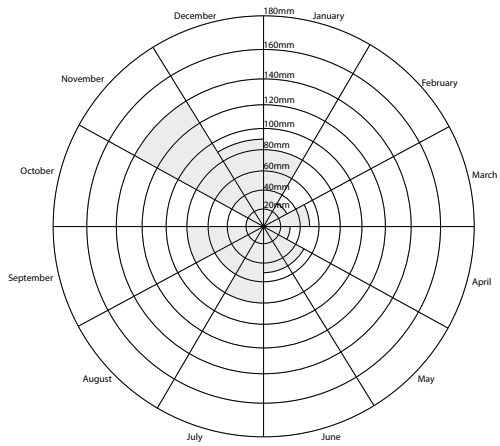
The sun has a large range of angles. From June and July where it rises in Northeast and sets in Northwest to January and December where it rises in Southeast and sets in Southwest. Due to the solitude of the island there are no obstacles nearby creating shadows, making it very exposed. Furthermore the sea surrounding the island reflects the sun, increasing the sun exposure. The height of the sun varies from almost 60° in the summer to only around 10° in the winter, which again is an advantage because of the lack of surrounding buildings.



Ill. 15a Solar exposure

RAIN

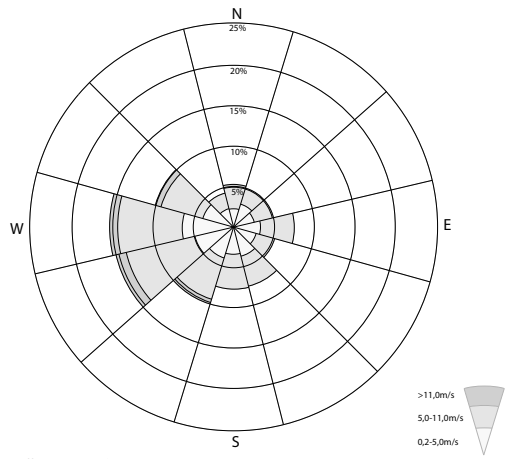
Rain is very common in Denmark, occurring all year round with the highest intensity in the winter months. The islands highest point is in the middle, which distributes rain to the sea or absorbs it in the large volumes of grassy hills.



Ill. 15b Rain conditions

WIND

The wind in Denmark is most often coming from the west. This is the same situation in Copenhagen. But because of the Middelgrund Forts location in the sea, it is more exposed from several sides, compared to inside the city center with buildings creating cover.



Ill. 15c Wind rose

VIEW LINES

The island has a 360° view, which allows you to look towards the coast of both Sweden to the east and Denmark to the west. This allows the sky and the horizon to dominate. The Middelgrund Fort is filled with old platforms from previous military use, creating directed views towards the sea, wind mills and the Øresunds bridge.

Ill. 16a Open view

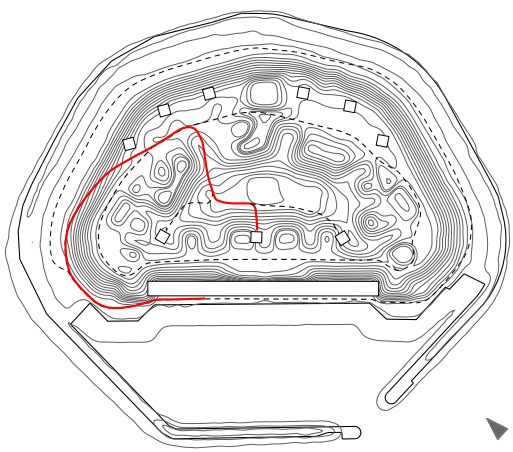
Ill. 16b Framed view

Ill. 17 View lines

KEVIN LYNCH

EXTERIOR

The island is very functionally programmed, due to its military past, so moving around the site feels very guided. A paved road creates a path guiding users between small artificial hills, which create small intimate pockets. This path ends at the highest point on the island, at a helicopter pad where the old lighthouse was previously situated. An old missile platform is connected inviting users to a unique view of the Copenhagen harbor.



Ill. 18 Exterior path

Ill. 19a View point 1

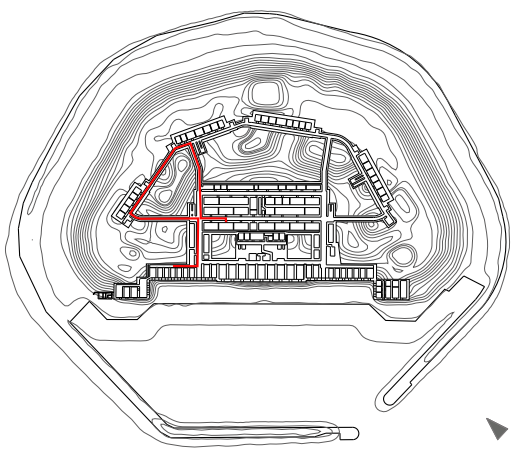
Ill. 19b View point 2

Ill. 19c View point 3

Ill. 19d View point 4

INTERIOR

Long dark tunnels guide the users into the depths of the building. Walls become ceiling in a rounded form, creating hallways reminiscent of submarine tunnels. Moving further into the building, natural light disappears with the walls only being lit up by old lamps. This creates a somber and dynamic relationship between light and dark, where dimly lit hallways are substituted with rooms covered in complete darkness.



Ill. 20 Interior path

Ill. 21a View point 1

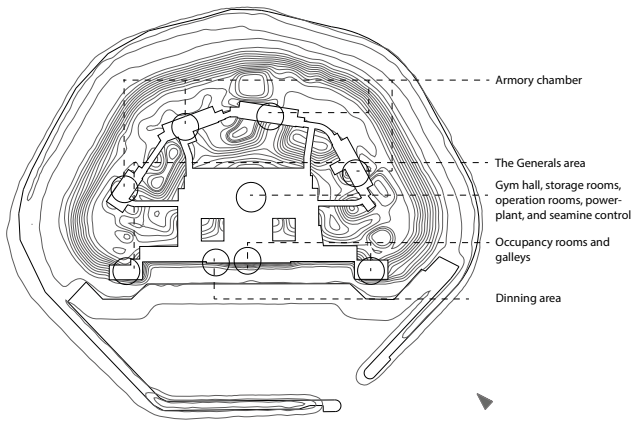
Ill. 21b View point 2

Ill. 21c View point 3

Ill. 21d View point 4

FUNCTIONS

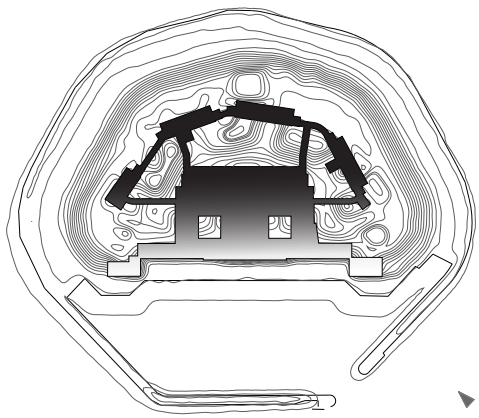
The existing rooms are a compilation of old military facilities, along with a more modern restaurant and hotel functions. The main house was used as sleeping areas and kitchen/dining facilities on the ground and first floor. The western part of the front house was used as the generals private quarters, while the eastern part was utilized as sleeping areas for other personnel. Through the hallways, underneath the island, storage rooms, deposits, machine rooms and gyms were located. The gyms were later restored into meeting rooms. Finally the hallways lead to the armory rooms which had an additional first floor connected with both stairs, elevators and armory elevator.



Ill. 22a Original functions

LIGHT

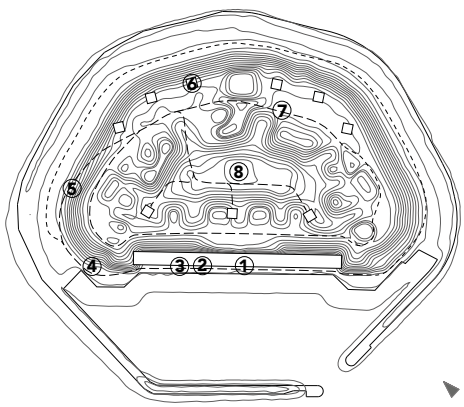
Due to its original status as a fortress, the Middelgrund Fort has a very clear difference in light conditions throughout the building. Common, dining, and sleeping areas are placed in the front house of the island towards Copenhagen, where a large amount of windows provide natural daylight. Further into the fortress the walls thicken and the natural light disappear. Due to the possible attack towards the seaside the back of the island is in completely darkness, only providing some light from artificial lighting.



Ill. 22b Graduation of light

MATERIALS

The materials around the Middelgrund Fort have a strong character due to it originally functioning as a military fortress. Stone, steel, concrete and tiles are used both inside and outside to make it as resistant from an attack as possible. The grass hills on top of the fortress are the only soft material, contrasting the rough materiality that infuses the rest of the island.



Ill. 22c Materials on the island

Ill. 23 Materials

CHARACTER OF THE ISLAND

SECLUDED

Being so close to the city gives the Middelsgrund Fort a unique placement. A relative small distance from the stressful and busy city, but still enough to retain a secluded atmosphere. The waves give a particular character to the place, becoming the dominant sound on an otherwise quiet island and creating a strong contrast to the bustling city. Everything is slowed down and the impressions of the city are maintained at a distance, with silence, stillness and solitariness dominating the small island landscape.

BUNKER

Due to the forts military past, old defensive structures are scattered around the island enforcing a unique and special character. The built structure expresses its function in the materiality, placement, way of building, construction technique and raw simplicity. The old remains of different structures such as cannon decks, elevators and missile platforms are still present and give the island a special, army-like character. Its roughness and functionality is expressed in the underground tunnels which are completely hidden in the terrain and are meant as a defense against invaders. These elements give the place unique appearance, which is essential for its quality. They make the place more rough and rigorous, while bringing a rare and particular spirit to the place.

Ill. 24a View towards Copenhagen

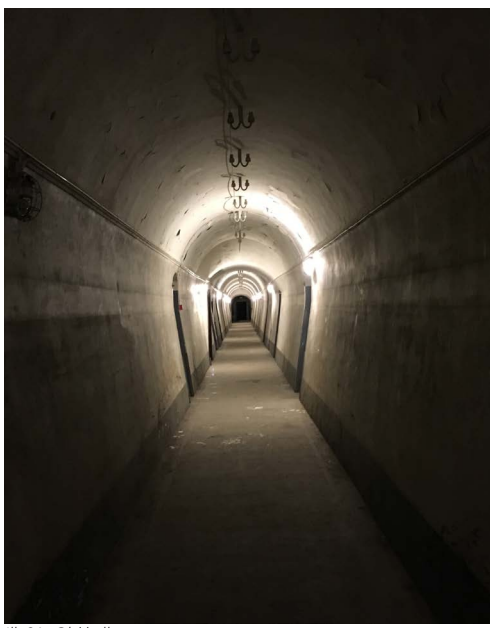
Ill. 24b Old canon placement

LIGHT TO DARK

For defensive purposes, the island is filled with long underground tunnels that move from open to totally enclosed, giving the place a strong definition of light and dark. The only sources of light are the artificial light bulbs that light up the long underground hallways and gives the space a particular quality. The long seemingly never-ending tunnels are infused with an ominous feeling of being trapped under ground, while still retaining a curiosity to explore. When entering the main building there is a clear contrast between rooms with a greater amount of light, and the rest of the building which lays in darkness. A contrast that is to be explored and exploited.

THE VIEW

The sea has a strong influence on the place. The vastness of it creates a feeling of being small. Old missile platforms create viewpoints to the surroundings of the island. The western view is dominated by the Copenhagen shoreline, while Malmø can be seen from the east. South of the island the Øresunds bridge can be seen in the distance, with a line of windmills placed in between. The windmills add to the atmosphere, showcasing the force of the nature surrounding the island.



Ill. 24c Old hallway

Ill. 24d Old platform

HISTORY

The Middelgrund Fort was built from 1890 to 1894 by King Christian IX as part of the Copenhagen navy fortification alongside two other fortresses, the Trekrone Fort and the Flak Fort. It was and still is the biggest manmade island in the world not connected to the mainland. It measures 50.000 m^2 with additional 20.000 m^2 including the breakwater construction. It has 15.000 m^2 in the basement/ground floor and 1.500 m^2 on first floor. It was closed as a navy fortress in 1962. Later on, it became a military ground for HAWK rocket batteries before it was open for the public in 1988 and sold to a private investor in 2002 who turned it in to a hotel with restaurant. With its very secluded but yet close and exclusive location it was thought to be a success. However it was not, and in February 2015 it was sold to the Danish Scout Council. With the short distance to the new buildings at Nordhavn and only 20-30 minutes from Nyhavn it has great possibilities for future development. (Middelgrundsfonden, 2016)

Ill. 25 Old entrance

SITE CONCLUSION

The Middelgrund Fort is an old military fortification, with differentiating functions through the years. Due to its unique placement, being only 800 meters from the Copenhagen shorefront and with views to Sweden and the Øresund Bridge, it presents an exciting challenge to design a cultural meeting spot.

Being placed on an island means, that the fort has no shelter for wind or rain, however with no nearby structures obstructing sunlight, it means shadow conditions are very favorable.

It is also relatively secluded, meaning that the island contains a rare and particular atmosphere. Grassy hills and old missile platforms provide great 360° views of the surroundings, while the intimate corridors of the bunker below, where natural light is rare, provides a powerful contrasting feeling.

PROGRAM

The following is an explanation of the overall concept and vision of the project. It will provide the framework for a future design process, based on function diagrams and room program. Furthermore two additional case studies have been made in order to investigate different ways of creating art galleries. They will serve as inspiration of organizing functions, materiality, relation to space, light studies and spatial experience.

AROS

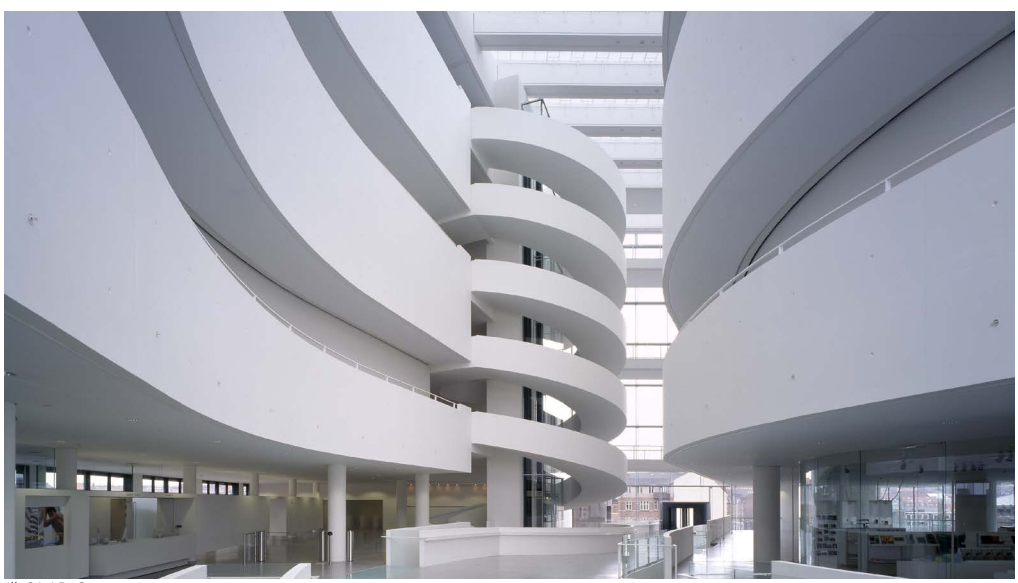
SCHMIDT HAMMER LASSEN ARCHITECTS

The 17.700 m^2 modern art museum ARoS, in the heart of Aarhus, has become a trademark for the city. The rigorous brick character of the exterior dissolves into the smooth curving cut of the interior. Splitting the geometry with an organic atrium, divides the museum in two parts; one side being exhibition and the other attributed to services, such as a restaurant, administration, workshops etc. With 10 floors of various functions, the staircase becomes an essential part of the building. More than merely functioning as a means of transportation, it actively utilizes the natural lit atrium, becoming a sculptural and aesthetic piece of the museum, while also creating visibility throughout the 39 meter tall museum.

The 6 exhibition spaces sum up to almost 6.500 m^2, when divided vertically, thus allowing each exhibition to actively utilize the individual specific space. By having the practical functions on the entry floor it leaves more free space for the exhibitions on other floors.

Besides showcasing more traditional art exhibition, ARoS also facilitates sensory experiences inside the museum. In the basement level there are 9 rooms, each with a focus on a specific sensory experience.

None of the exhibition spaces have any windows, which intensifies the focus at the art. At the same time it creates a clear hierarchy between the dark exhibition spaces and the well-lit atrium.



Ill. 26 ARoS

CHICHU ART MUSEUM

TADAO ANDO

Chichu Art Museum was constructed in 2004. Designed by Tadao Ando, the building aims to explore the relationship between nature and people. The museum is situated mostly underground in order to avoid affecting the beautiful natural scenery of the Seto Inland sea. Despite being primarily subterranean, large voids are dug into the landscape, letting in an abundance of natural light, changing the appearance of the artworks and influencing the atmosphere of the space itself with the passage of time, throughout the day and all along the four seasons of the year.

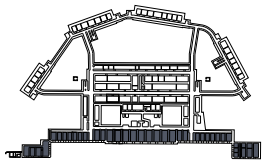
The intricacy of which the museum has been placed in the landscape along with the large geometrically shaped voids creates an interplay, where the museum in its entirety can be seen as a very large site-specific artwork.

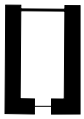
Using mainly concrete, a characteristic in Ando's architecture, combined with steel, glass and wood, the design of the Chichu Art Museum is reduced to the very minimum, creating a beautiful coherence with the surroundings. Built almost entirely underground, the museum balances the contradictory qualities of being both non-monumental but highly architectural.

By utilizing the coherence of the materials and respect for nature, the aim is to generate a design solution for the Middelgrund Fort, that emphasis the characteristics of the site.

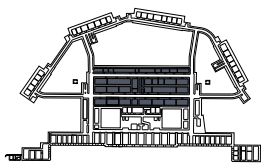
Ill. 27 Chichu Art Museum

ROOM PROGRAM

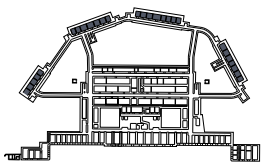




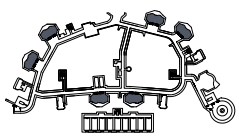
Functions	Potential of rooms	Existing number of rooms	Existing size	Required space
Restaurant Conference rooms Foyer Bedrooms	Easy acces View Daylight Conncted	48	1387 m^2	250 m^2 150 m^2 200 m^2 600 m^2



Exhibition room	Secluded Darkness Centered	33	1345 m^2	3000 m^2



Exhibition space	Sensory light Darkness Secluded Natural flow	27	566 m^2	3000 m^2



Exhibition space Workshop	Sensory light Secluded Natural flow	8	770 m^2	3000 m^2

Toilets				80 m^2
Extra Storage				150 m^2
Wardrobe				40 m^2
Service/Cleaning, Laundry				100 m^2
Office				100 m^2
Total			4168 m^2	5020 m^2

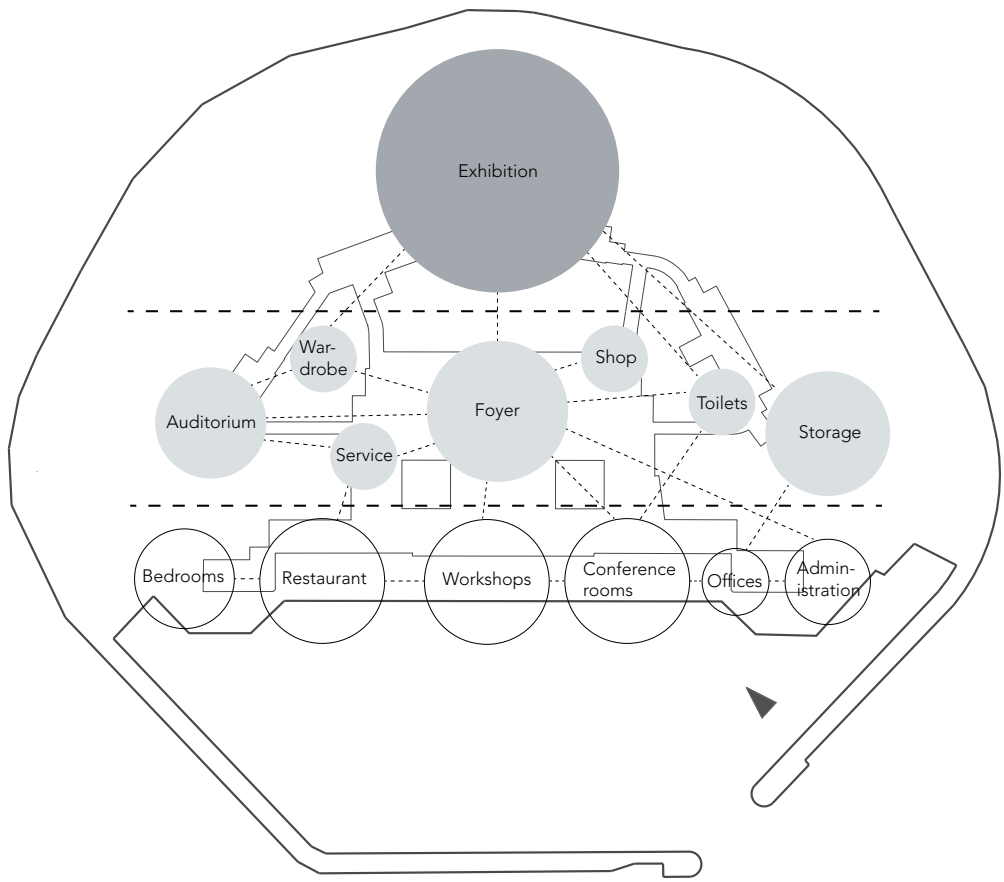
FUNCTION DIAGRAM

Placement of rooms and functions has been determined on a basis of how the original fort was organized. As a large part of the building is placed underground, making daylight and exterior openings some of the main benefactors to the overall programming.

Due to the facade openings in the front building, administrative functions such as offices and conference rooms along with bedrooms, have been placed here. The large window openings help secure a satisfactory indoor climate.

The middle section of the fort is reserved for semi-public functions such as a foyer, bookshop and wardrobe along with technical rooms and storage. This part of the building functions as the main hub of the museum, an organizational stating point from which most of the flow goes through.

The old armory chambers and canon placements, placed deepest in the fort, will form the main part of the exhibition spaces. Due to their underground placement, most of these rooms are ideal to showcase art. Security for the artwork is guaranteed, while atmosphere and the interplay between light and dark will create unique sensory provoking spaces.



Ill. 28 Function diagram

Ill. 29 View of old structures

DESIGN PARAMETERS

TRANSFORMATION

This project will deal with how to use or transform an old building into contemporary architecture without losing its original character/identity. This will be done by exploring how to add new structures or subtracting when necessary in order to enhance characteristic features of the Middelgrund Fort, thus turning it into a piece of modern architecture.

SUSTAINABILITY

The project will also address how to create sustainable solutions for existing structures. Specifically how to modernize the Middelgrund Fort so it meets modern energy and lighting standards. It will also be an exploration into creating highly sustainable solutions that can facilitate a dynamic set of functions within the building, both in terms of current and future use.

ATMOSPHERE

Atmosphere will be a vital part of the final design. This will be done through a strategy to recreate and emphasize the specific phenomenological experience of the Middelgrund Fort. The interplay between light and darkness will be a main benefactor, as a means to guide users through the building, creating differentiating sensory experiences.

Ill. 30 View from the top

VISION

This Master Thesis aims to design a museum for modern art by developing an understanding of the specific architectural style used at the Middegrund Fort. Additionally it will address how to utilize a transformation strategy to not only influence a specific atmosphere, but also to create a sound sustainable design solution.

PRESENTATION

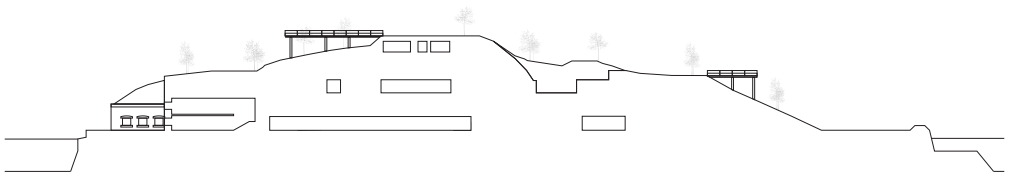
The presentation is devised as a journey, showcasing how a visitor would experience the island and the museum. From approaching the island, walking through the museum, experiencing the unique viewpoint from the redeveloped lighthouse, before finally finishing the journey on the exterior path.

CONCEPT

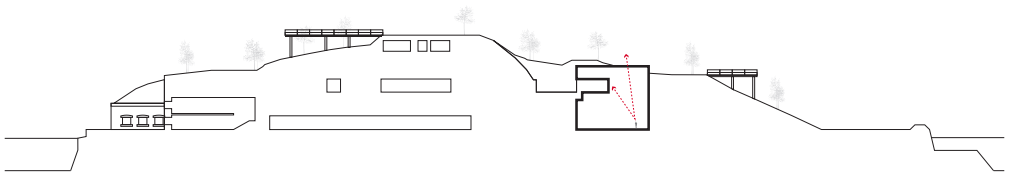
The concept combines the idea of a modern museum and a heritage military fort, through a transformation with a focus on sustainability and atmosphere. By utilizing the attributes on the island, the visitor becomes aware of this rare gleam of secluded atmosphere in the middle of Copenhagen.

Empasizing the original structure, the new additions serve as both staging and sustainable factors. By using a graduation of daylight throughout the underground spaces, unique impressions meet the visitors in each room. These new additions provide the basis required to heighten the quality of indoor climate and energy consumption to a modern standard. Added structures provide a clear contrast between old and new, through form, materiality and light. Providing a dynamic backdrop for exhibiting both art and the character of the fort.

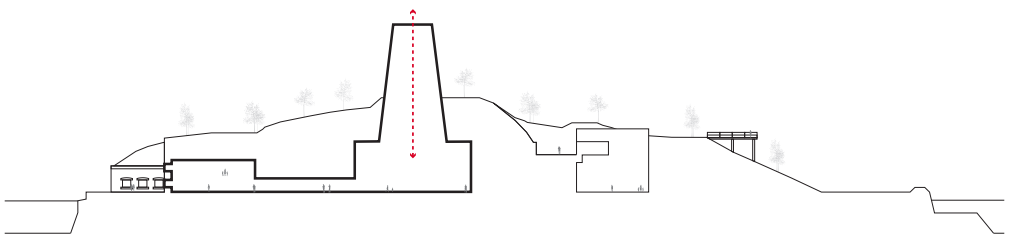
The balance between historical emphasis and modern additions work hand in hand as a reinterpretation of the lighthouse crowns the top of the island, creating a new landmark for the Middelgrund Fort and Copenhagen.



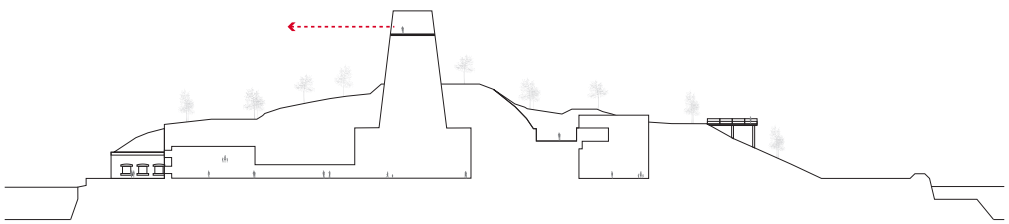
Ill. 31a Original fort



Ill. 31b Added volumes emphasize old structures and brings in light



Ill. 31c New lighthouse brings in light



Ill. 31d New lighthouse secures views

APPROACHING THE MUSEUM

The island is characterized by its solitude. The old brick facade gives a glimpse into the past, telling visitors a story of the Middelgrund Forts' past before ushering them into its future.

The glass lighthouse rises on top of the highest point of the island, creating a new landmark. The tower is made out of a combination of glass and steel, contrasting the existing materials of the island without overpowering them. Reflecting light in daytime and emitting it during the night, the lighthouse becomes an attraction point from afar, while also showcasing the museums main connection point; the spiral staircase. This gives approaching visitors insight into the activity of the island, facilitating a curiosity that will ultimately lead them into the museum.

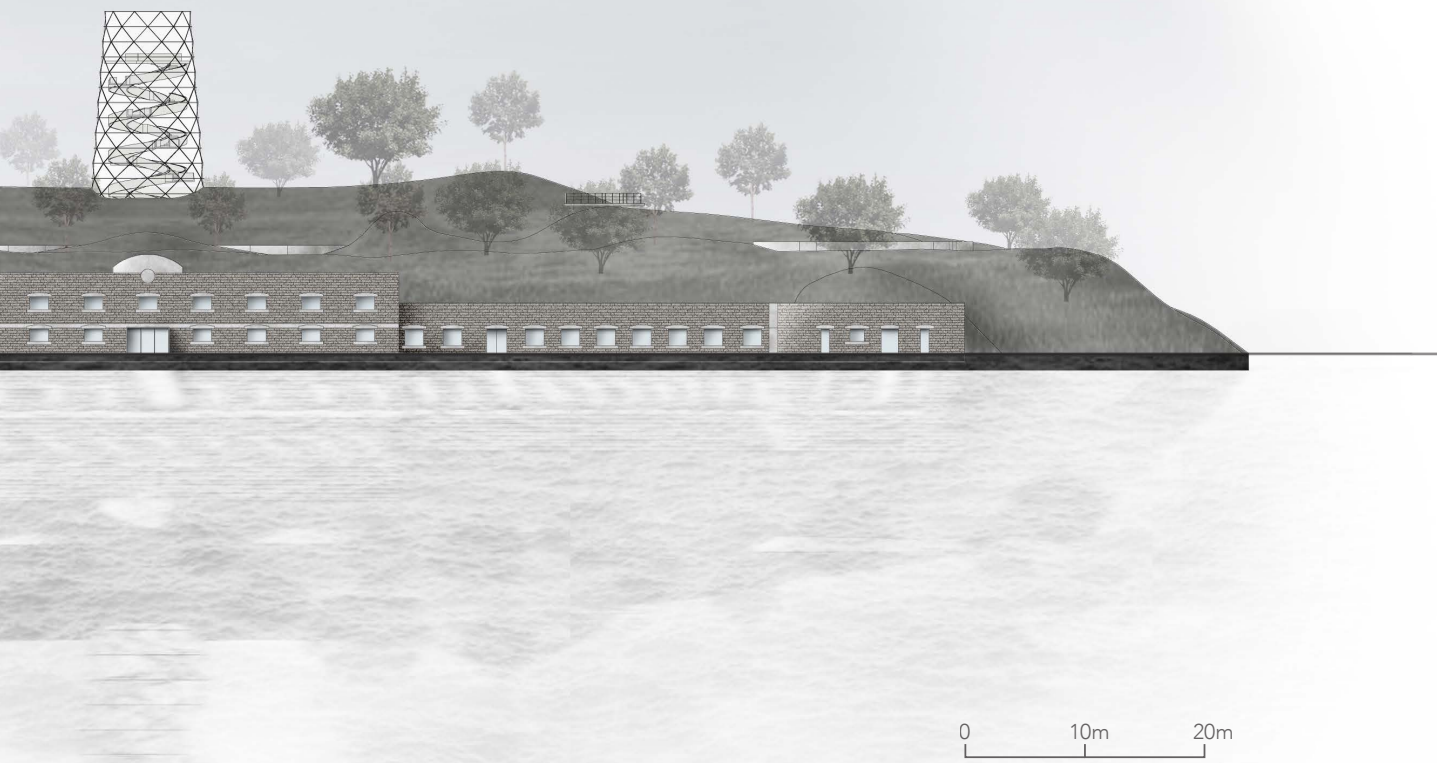
Ill. 32 Approaching the museum

THE FRONT BUILDING

The front building is the only original part of the fort with natural daylight, therefore all the functional rooms that need daylight for working conditions are placed there. To ensure the sufficient daylight factor in the offices, some of the windows had to be made larger. The original expression of the brick facade was maintained, while minimal changes were made in order to fit these windows in.

The building is divided in two parts, one for the museum staff and the other for visitors. The top floor is mixed-use and includes conference rooms and workshops, while being accessible from both ends. The visitors' area contains living quarters, a restaurant and a cafe, while the staff area consists of offices, meeting rooms, administration rooms, kitchen and storage.

Ill. 33 Elevation of the island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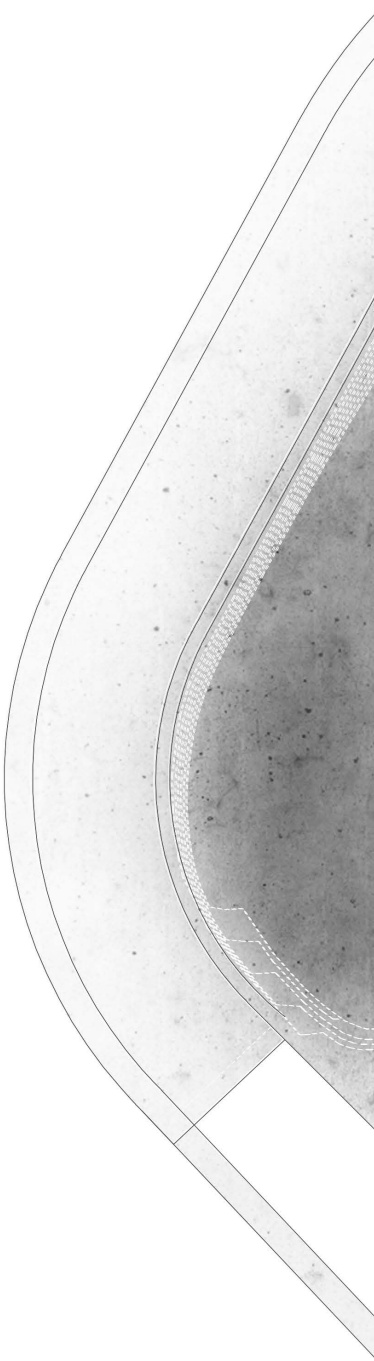
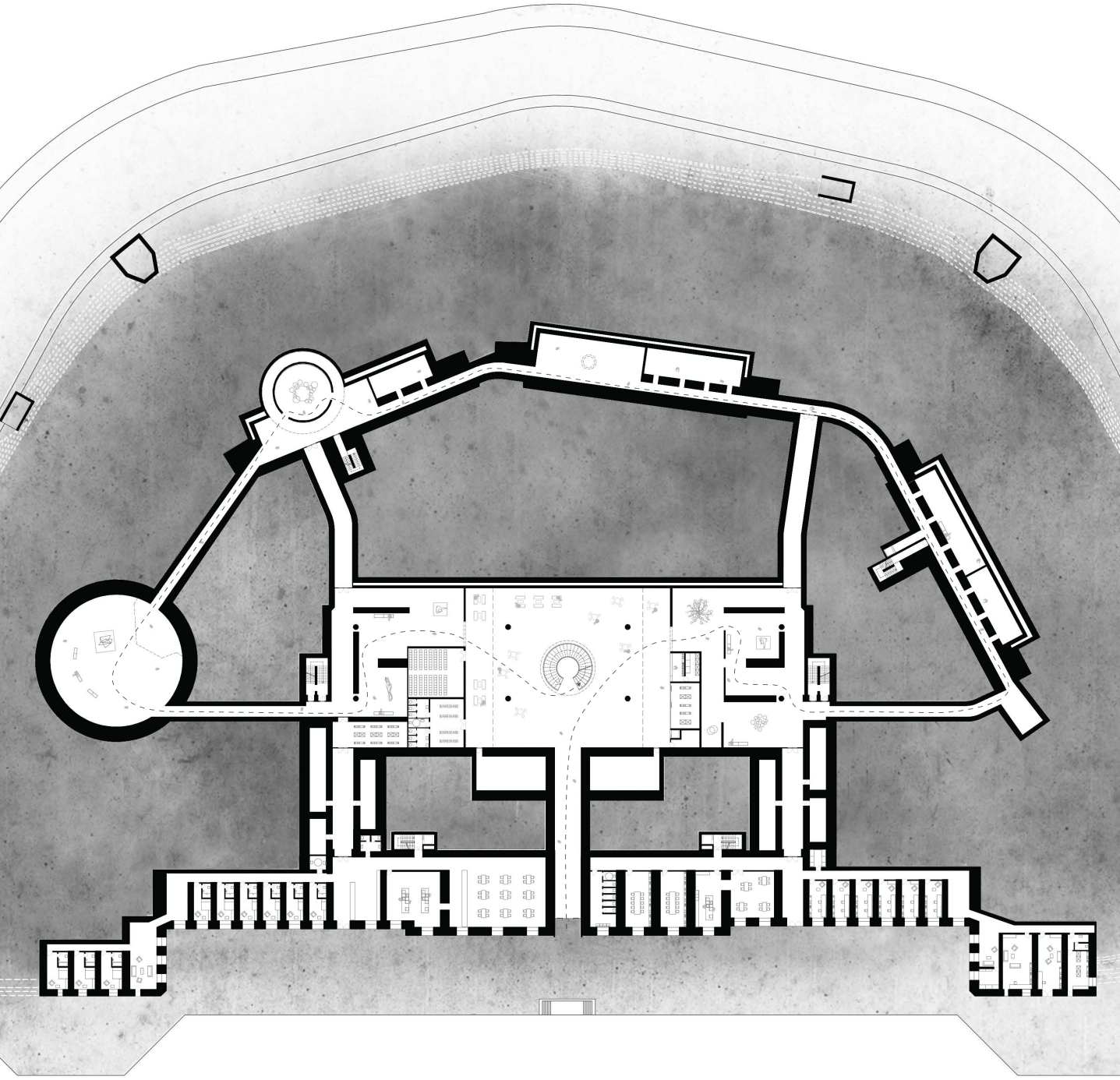
THE GROUND FLOOR

The museum works as a atmospheric journey from darkness to light. Gradually going from spaces with no natural daylight, to a single point of light, and then a wall of light, before ending in a completely open exhibition room with a glass roof. Through these exhibition rooms, where distinctive atmospheres are created, different art installations are placed, creating a multitude of experiences while walking through the museum. The contrast between light and dark emphasize the original character of the underground fortress, with the old structures being showcased in the interplay between materials and lighting.





Ill. 34 Ground floor plan

FOYER

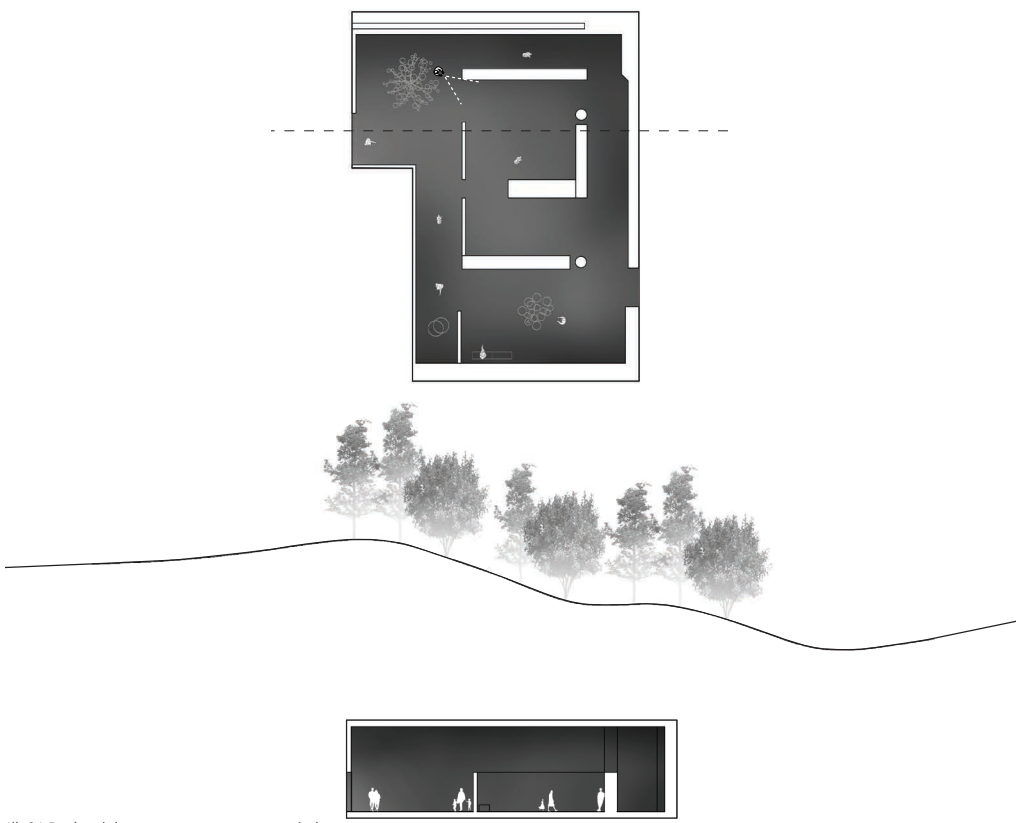
The dark corridor from the main entrance leads into a large open foyer. The room opens up into a double height interior with natural light coming through the opening above the spiral staircase. It creates a central point for the foyer, while also becoming the main vertical connection through the museum. It generates a simple orientational element for the museum, where all the paths to the exhibition rooms start and end at the main staircase and the adjoined atrium.

Inside the foyer, an auditorium is placed for conferences and lectures with wardrobe and toilet facilities right next to it, so as to be easily accessible. The ticket office is placed on the opposite side along with a small bookshop. This marks the start of the path, taking visitors through the museum.

Ill. 35 Foyer area

EXHIBITION ROOM

The first exhibition rooms are kept in their original enclosed state, without any natural daylight, only lit up by artificial light. This creates the perfect conditions for light-sensitive exhibitions, such as paintings, digital or sound installations. The original concrete walls divide the interior, making it possible to have different exhibitions. These walls are kept in their original state, with the raised roof creating a space around them, making the structures of the old fort as much part of the exhibition as the artwork. Ceilings have been fitted with perforated concrete, optimizing the acoustic conditions of the museum. This will ensure a lower reverberation time, while still retaining a high enough value that visitors will naturally lower their voices, to avoid noise. As these rooms are placed completely underground, CO2 concentration and relative humidity are controlled by a ventilation system in the ceiling.



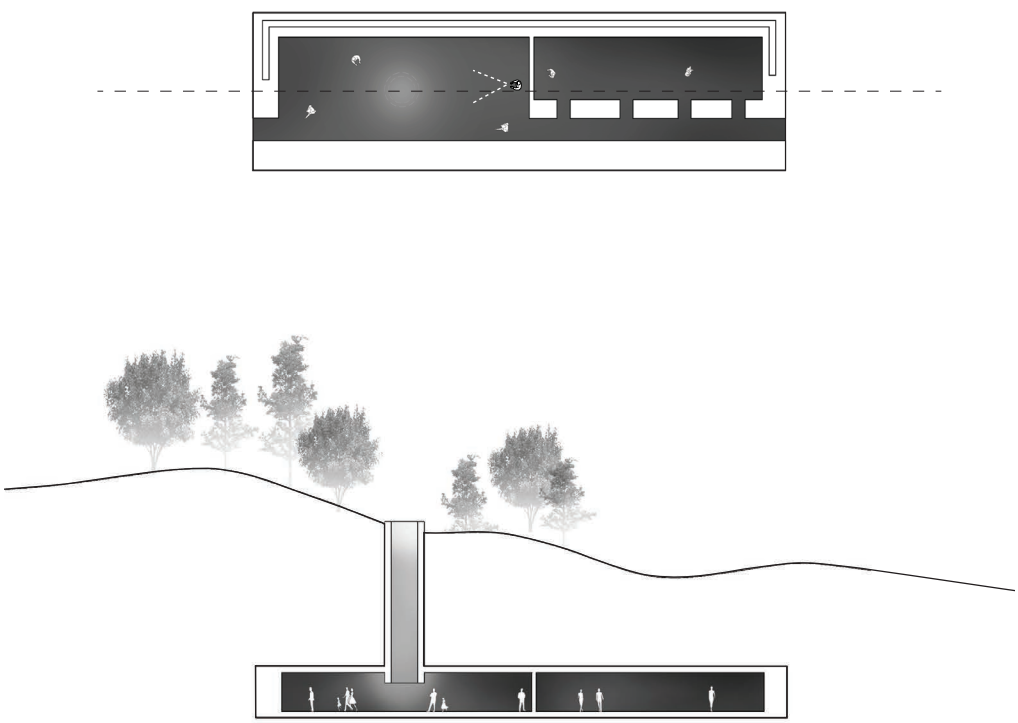
Ill. 36 Dark exhibition room in section and plan

Ill. 37 Dark exhibition room

LIGHT WELL

Moving along the bunker hallways, the old ammunition rooms have been refurbished into dark exhibition spaces, consisting of only artificial lighting, as such the third exhibition room acts as an introduction to natural light. A single spotlight of natural light coming through a light well directs all attention to the middle of the room. The walls of the circular light well cut into the room, creating a frame for the artwork placed under it. Where there was previously only artificial light, a connection to the outside world is now defined, with the time of day, season and the weather conditions determining the atmosphere of the space. As the feel of the space changes, so does the exhibition, creating conditions where artwork becomes alive.

Outer walls have been insulated in order to protect the artwork from the moisture of the surrounding ground, while significantly lowering energy demands.



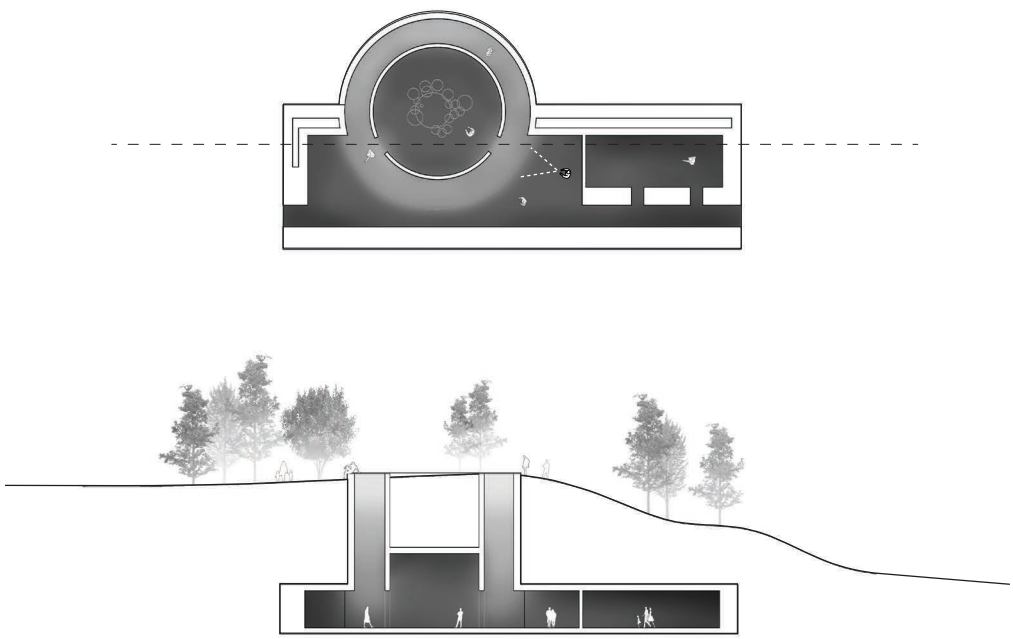
Ill. 38 Light well in section and plan

Ill. 39 Light well

WALL OF LIGHT

Continuing on the path of the tightly spaced corridor, the space again opens up. The interplay between light and dark is again displayed, but where there was only single source before, a linear wall of light now presents itself.

The geometry of the space changes as there is a circular extrusion of the otherwise rectangular room with an opening on the edge of the cylinder. The opening is a ring that lets natural daylight into the space. Curved walls surround an interior space that is almost hidden behind the ring of light. This creates a sense of curiosity, inviting visitors in to explore. The interior walls and the opening on top create a dialogue between light and architecture in the specific built form. The ring of light surrounds an interior space, but also creates a different sense of space and matter.



Ill. 40 Wall of light in section and plan

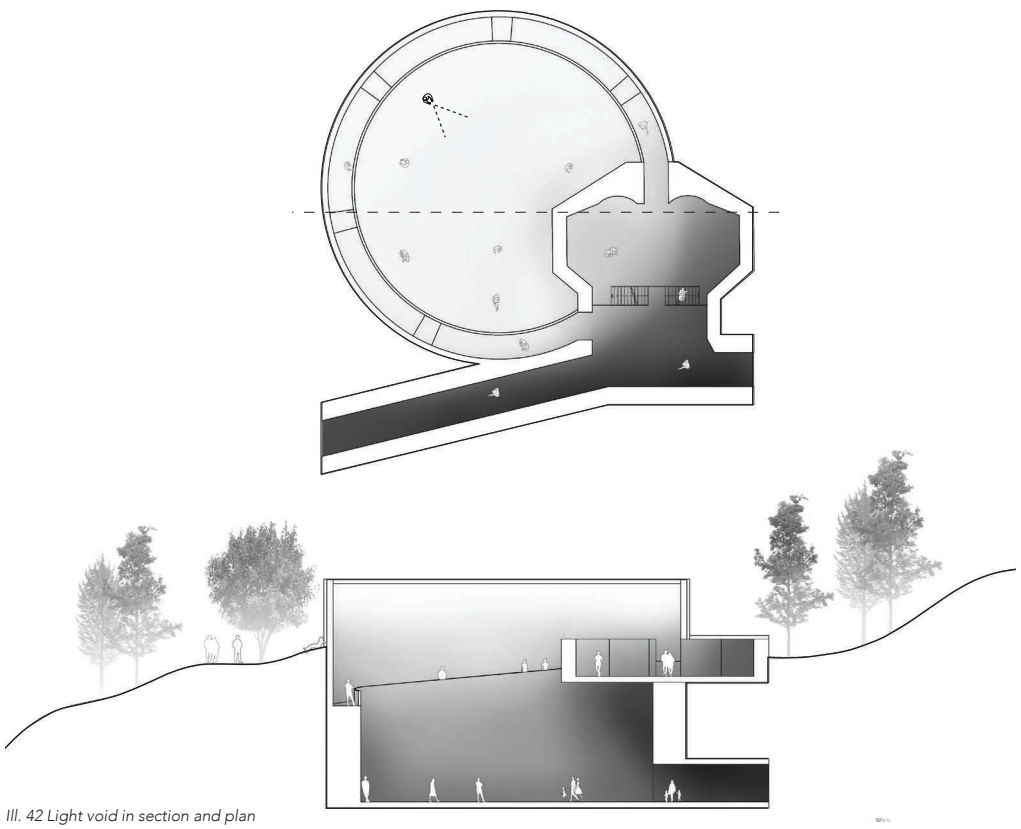
Ill. 41 Wall of light

LIGHT VOID

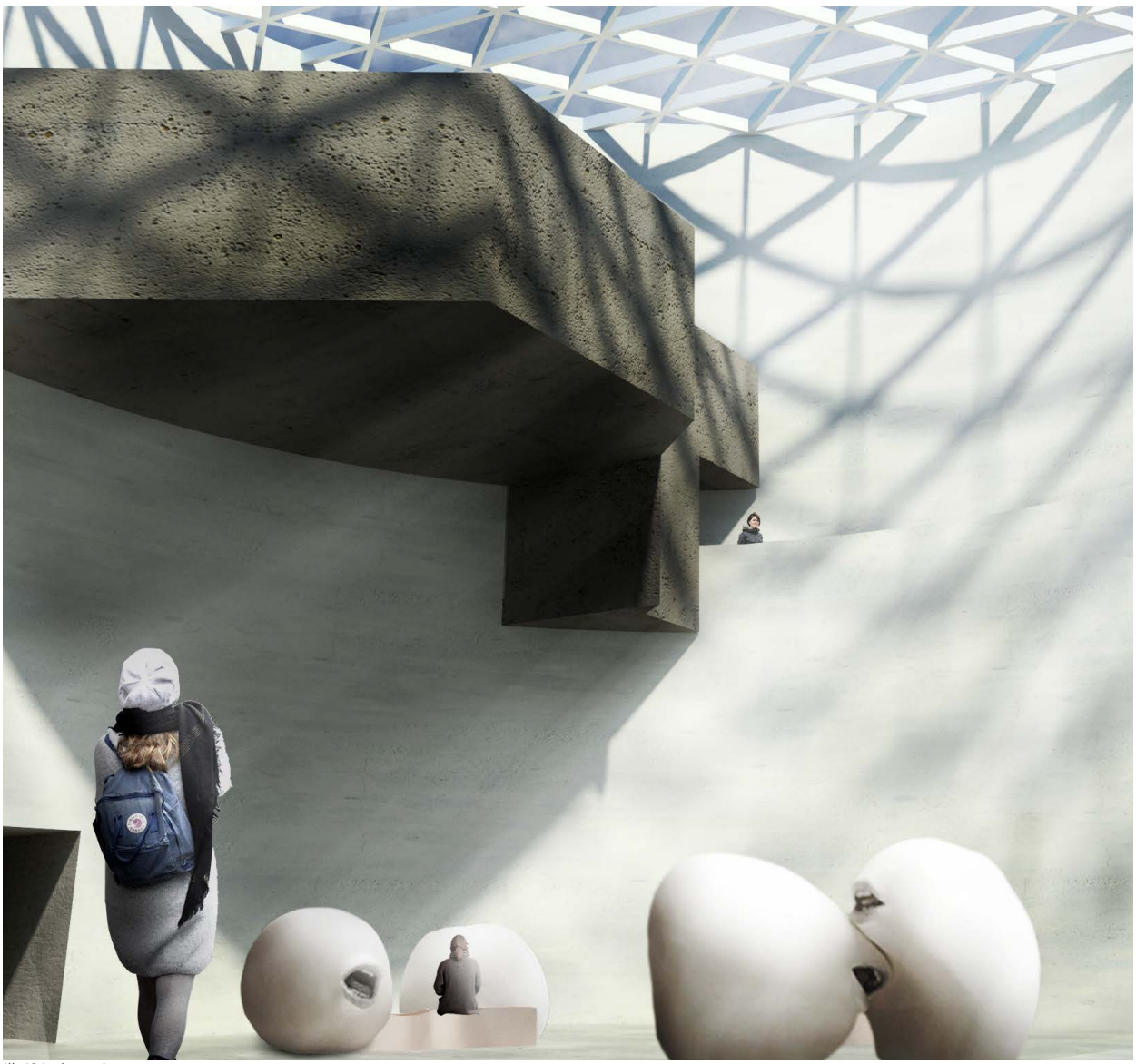
Going deeper into the island, the largest open exhibition room awaits. Extruded through 2 floors, the voluminous scale is lit up by the natural light, creating an embracing atmosphere. With the new light colored concrete and glass roof, the existing and new structures contrast each other emphasizing the old canon courtyard. A sense of history is in focus and hierarchy between what is old and newly built is clear.

The movement of the visitor changes as they can walk through and around the space. The height and natural daylight from above creates a unique feeling, reminding people of how far below ground they actually are.

The glass roof and scale ensures that the thermal conditions remain under control, avoiding overheating and massive transmission loss.



Ill. 42 Light void in section and plan

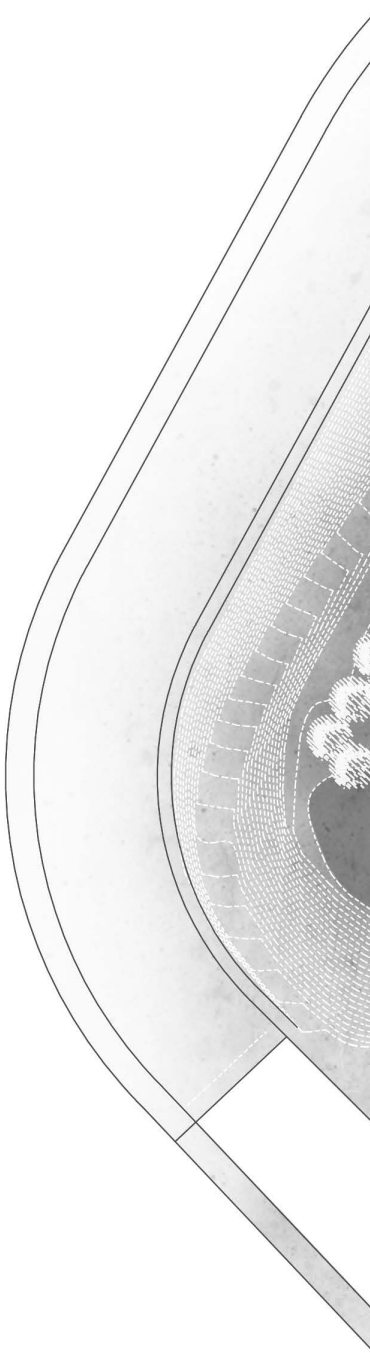


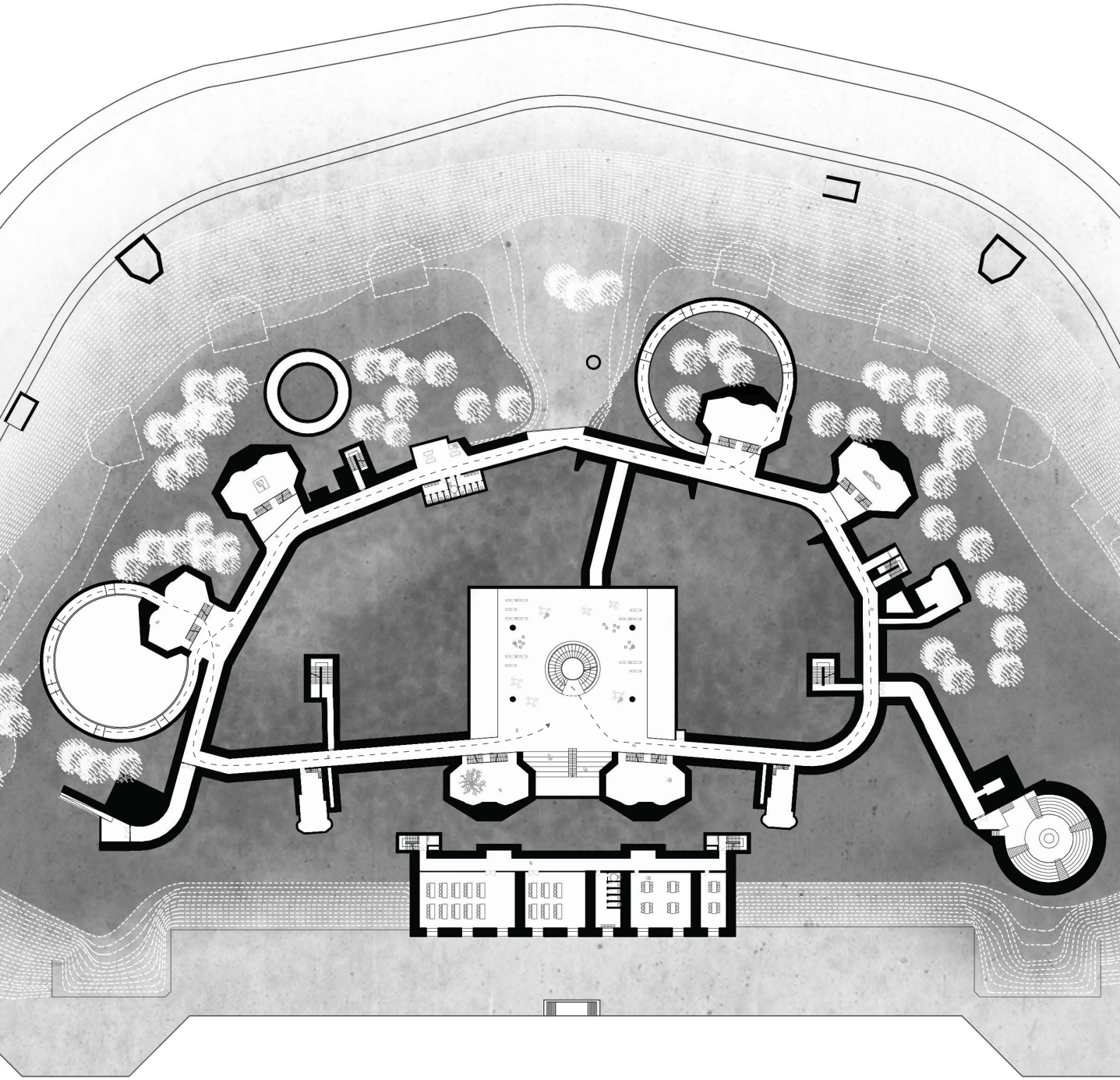
Ill. 43 Light void

1ST FLOOR

Consisting of the old canon courtyards, the 1st floor functions as an exploration into the relationship between the existing structures, new functions and the exterior spaces. The functions of the old courtyards are explored, with some showcasing art, others working as workspaces for artists, while some act as exhibitions themselves. Walking along the hallways, the connection between nature and the old fortress is emphasized and exposed. The courtyards are exhibited in both their original state and showcased in new ways, where added structures allow visitors to experience them from different angles.

This also adds to the types of installations and exhibitions that the museum can offer. With rooms below ground focusing on the interplay between light and dark, these spaces allow artists to explore the relationship between art and nature.





Ill. 44 1st floor plan

1ST FLOOR FOYER

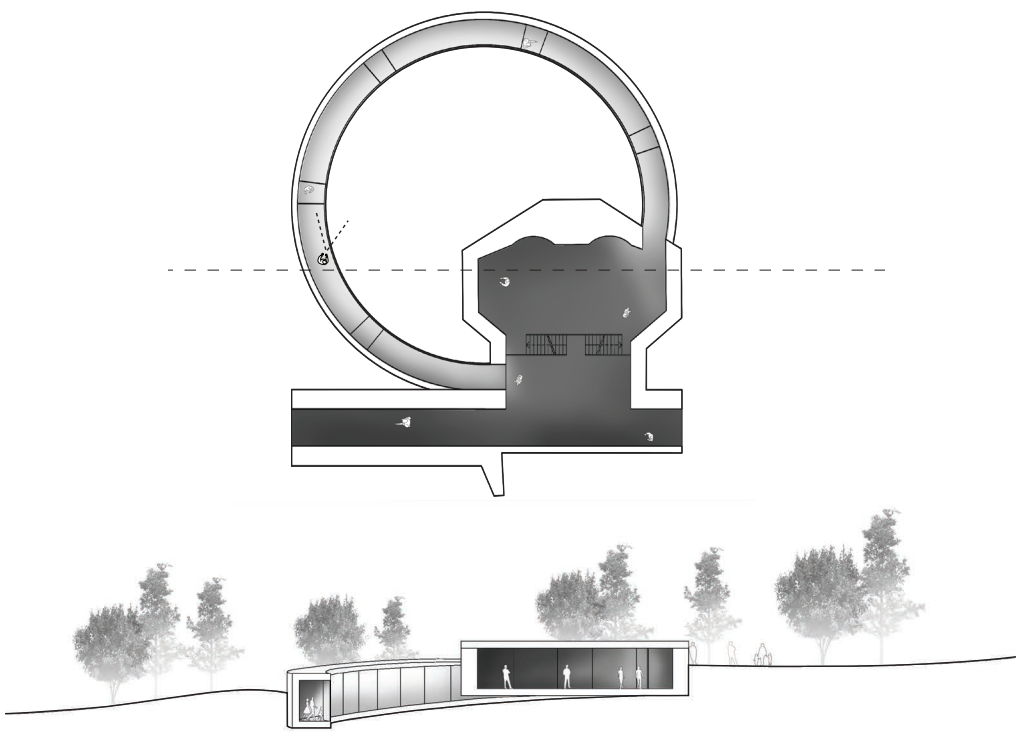
As with the foyer on the ground floor, the space functions as a centralized starting point. Visitors enter through the spiral staircase. A large staircase leads visitors to temporary exhibitions, while also functioning as seating spaces, creating resting and meeting spots along with the foyers furnished areas.

Curtain walls give visitors their first introduction to the old courtyards. Showcasing them in their original state, showing a clear contrast between old and new, turning the old structures into exhibition pieces themselves.

Ill. 45 1st floor foyer

EXPOSED COURTYARD

An enclosed path surrounding the old courtyard, creates an opportunity to experience the contrast in materiality of the concrete structure and the greenery. This facilitates a new way of showcasing the character of the island, and adds an element, that has so far been excluded; nature. Bringing the softness of greenery into these hard concrete walls, generates a new atmosphere very different to the enclosed underground experience sought in most of the other exhibition spaces. This also marks the second phase of the journey of the museum, exploring not only darkness and light, but the relationship between interior and exterior.

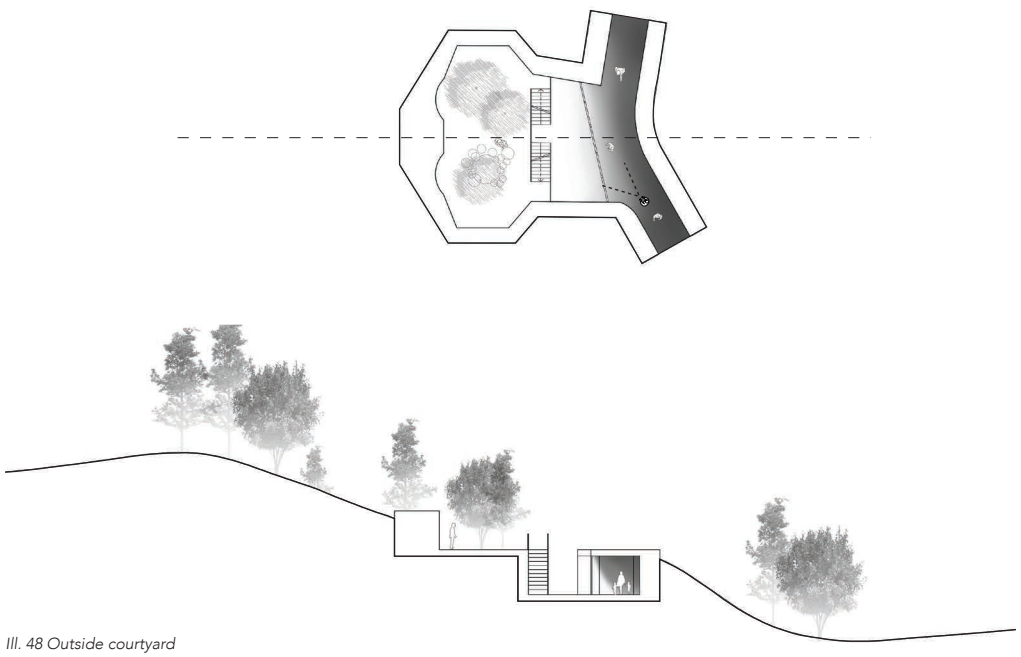


Ill. 46 Exposed courtyard

Ill. 47 Exposed courtyard

OUTSIDE COURTYARD

Moving along the hallways, insight into the original structures is offered. The courtyards have been kept in their original state, thus showing the original appearance of the fort. These spaces can be used as both a representation of the original fort, but also as unique exhibition spaces. The weathered concrete creates a backdrop for the likes of sculptures and digital art, not found in other contemporary museums.



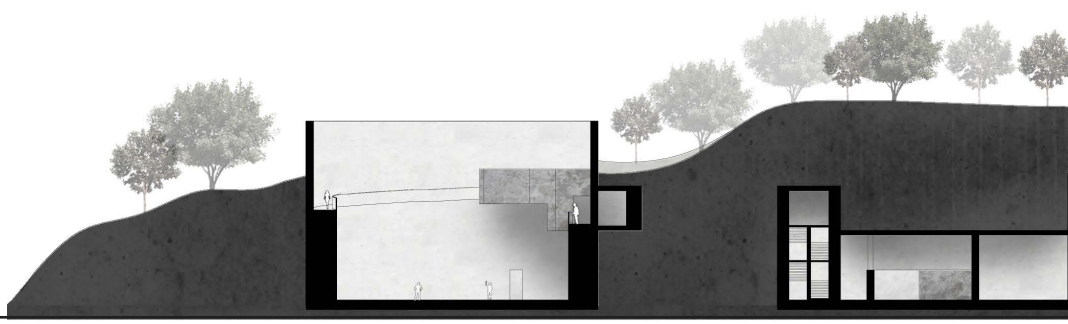
Ill. 48 Outside courtyard

Ill. 49 Outside courtyard

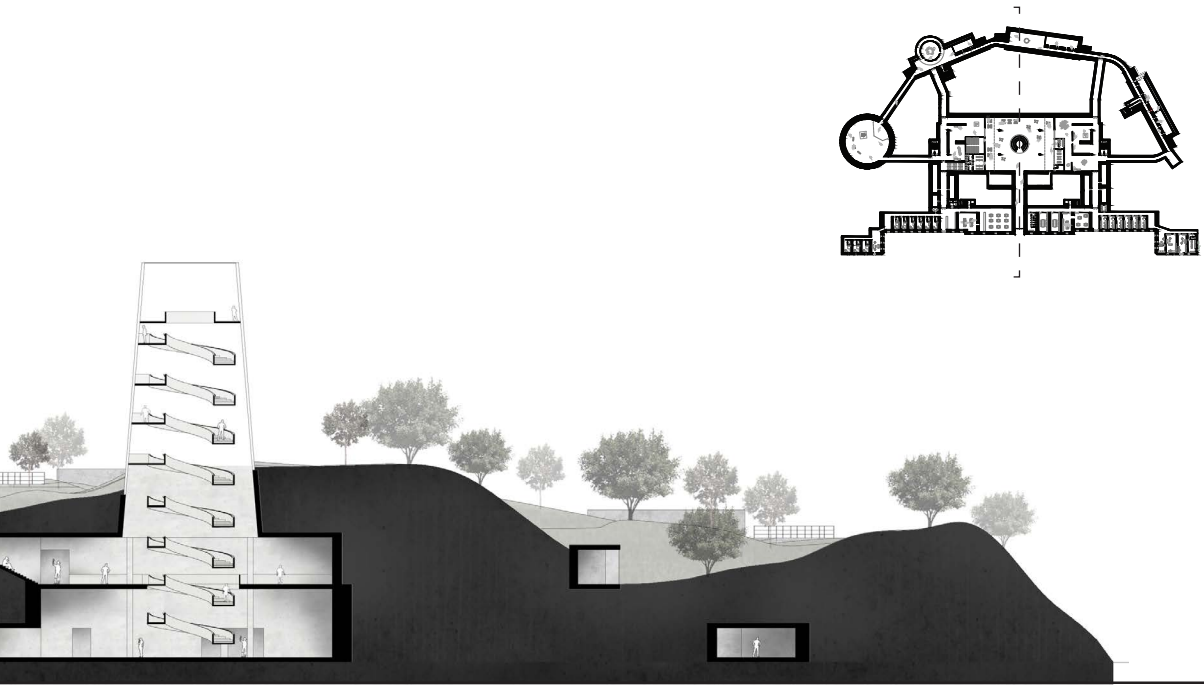
SECTIONS

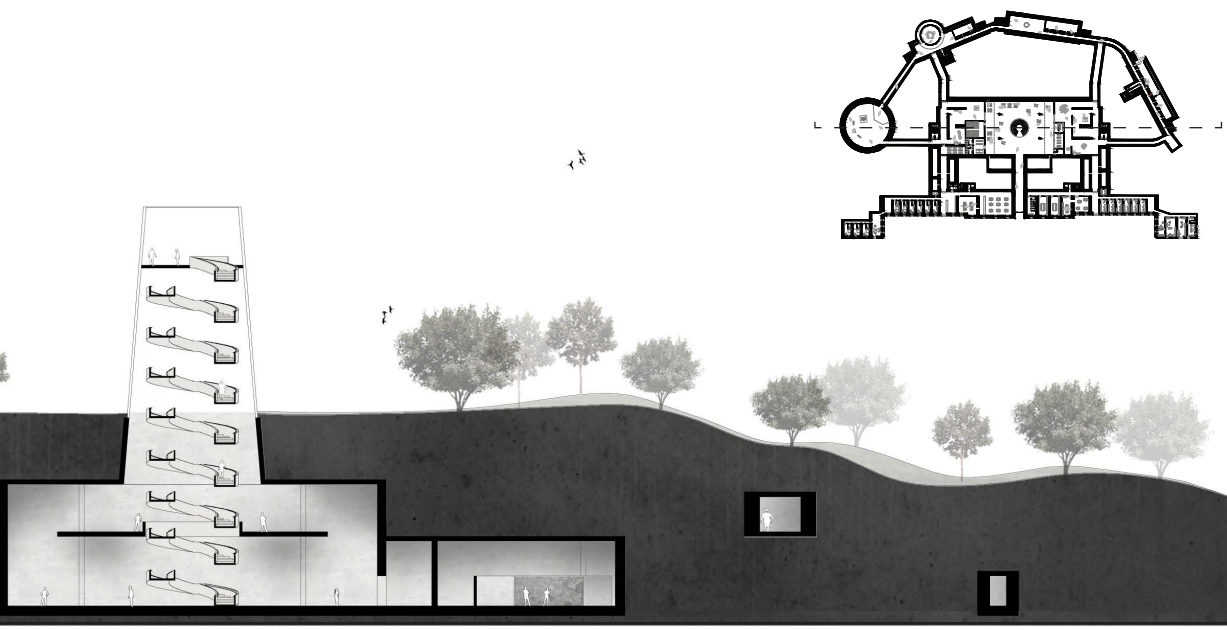
The reconstruction of the lighthouse creates a main hub for movement throughout the museum. The centrally placed spiral staircase functions as a waypoint, optimizing orientational awareness while creating a connection between the two floors and the viewing platforms of the lighthouse. Daylight punctures through the lighthouse, ensuring dynamic daylight conditions in the foyer areas, while additionally emphasizing the spiral staircase as one of the main ornamental elements of the museum.

Ill. 50a Section 1



Ill. 50b Section 2





0
10m
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LIGHTHOUSE

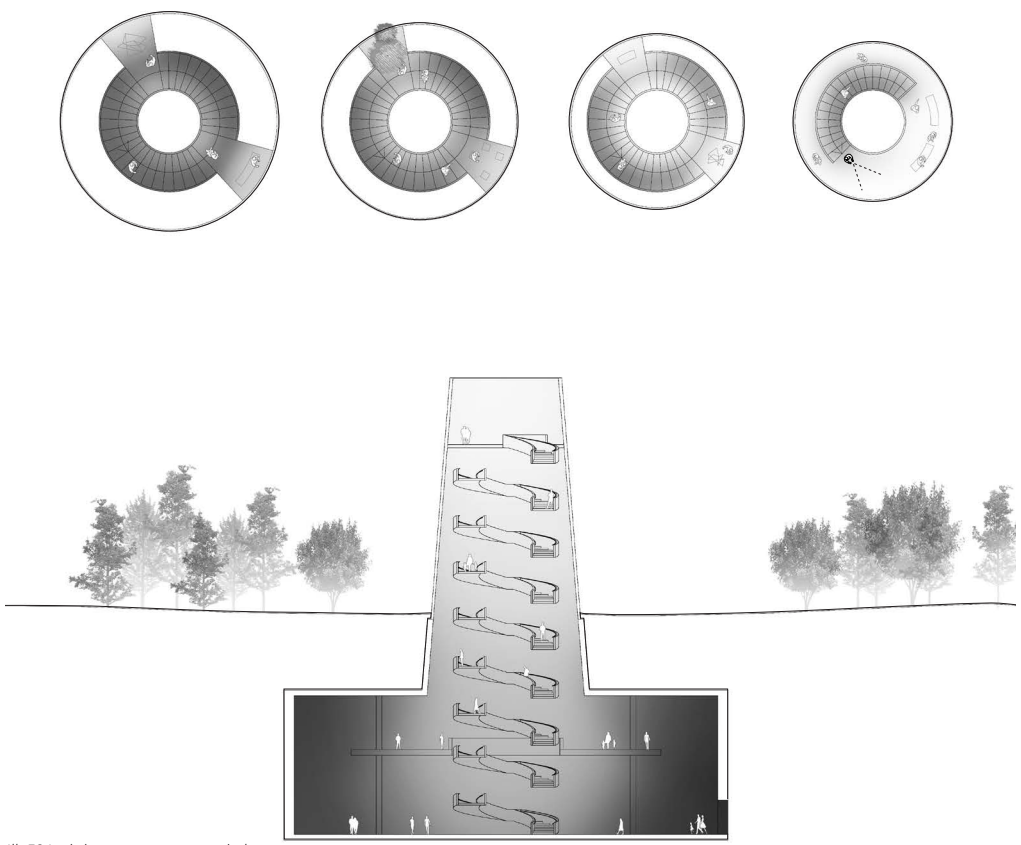
Moving towards the top of the lighthouse, the staircase tells a story along the way with platforms containing different themes, differentiating between artwork, framed view platforms and simple benches. These spaces are generated through enlarged platforms that also function as stabilizing elements in the structure, while ensuring that the staircase is not just used as transition, but rather becomes part of the museums exhibition spaces. Reaching the top, visitors are rewarded with a 360° view, 20 meters over the ground, making it possible to see Copenhagen, Sweden and Øresund. At night the glass roof and absence of light pollution from the city gives visitors a unique view of the night sky.

Ill. 51 View next to lighthouse

PLATFORMS

The combination of glass and steel grants views from every step of the spiral staircase, while also allowing light into the museum. It showcases the activity of the museum, generating curiosity and draws people to the island.

Consequently, the lighthouse reinterprets its original function, where light was beamed out to warn nearby ships, it now works as a catalyst for generating light and life.

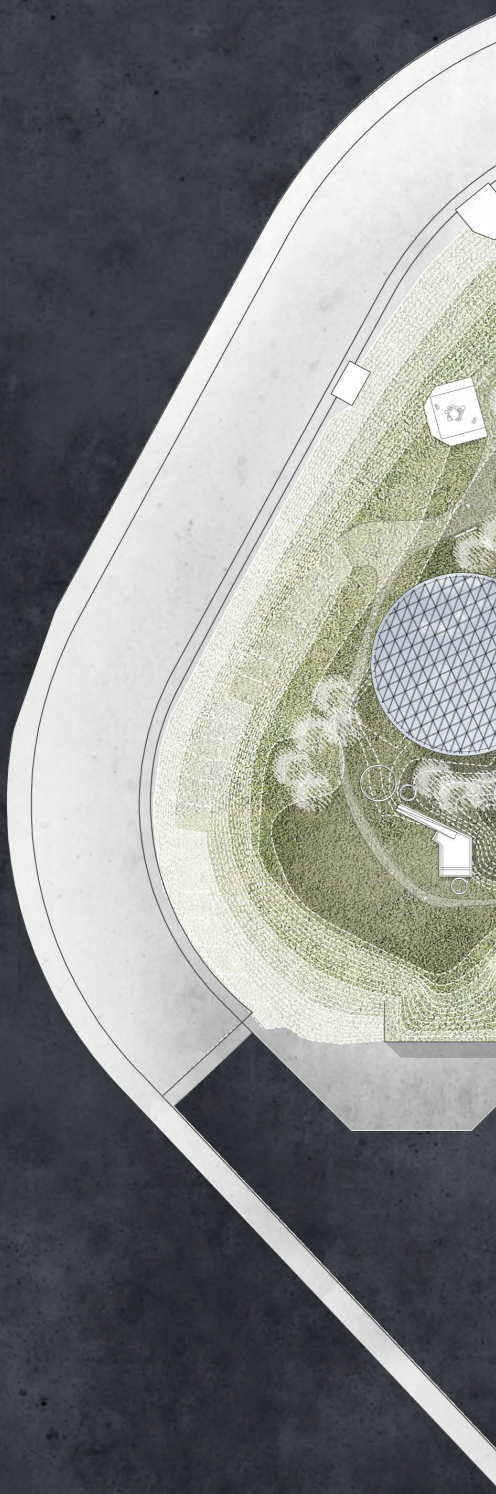


Ill. 52 Lighthouse in section and plan

Ill. 53 View inside lighthouse

SITE PLAN

Exterior spaces are kept subtle, keeping them in the character of the original fort, which generates a distinct contrast between bunker and nature. By letting wild growth and greenery be the main contributor of the landscape, the dark concrete of the old fort along with the light colored concrete of the new structures stands out, creating large monolithic volumes on the island. The contrast between nature and museum, creates an environment where the man-made structures are exhibited like artwork.

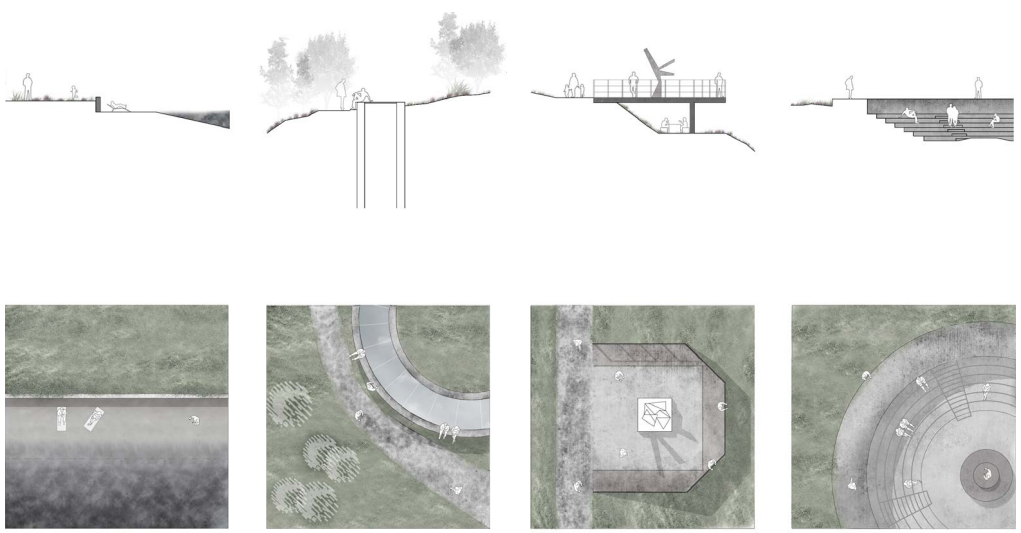


Ill. 54 Site plan

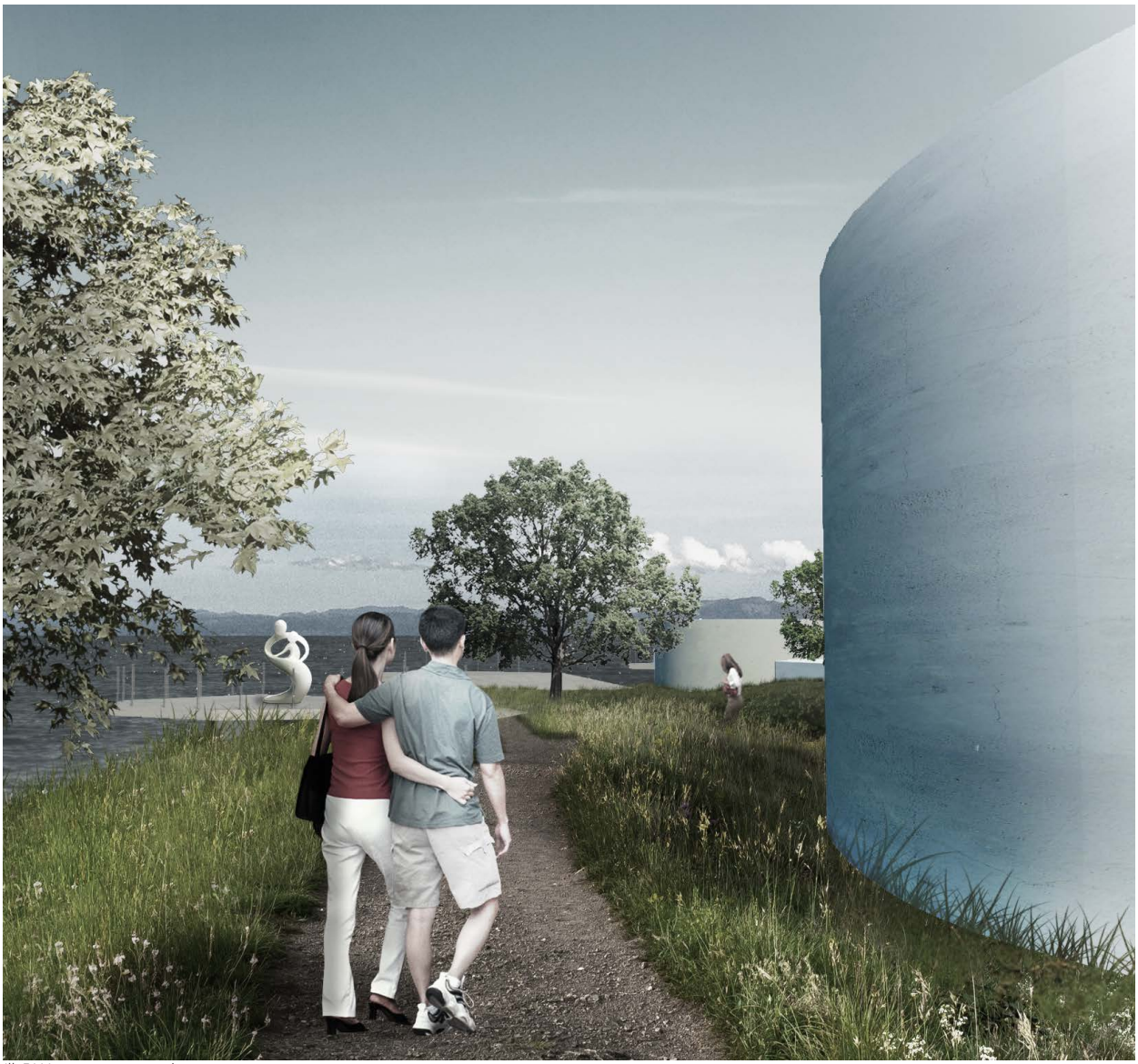

0
10m
20m

OUTSIDE PATH

A pathway connects the exterior spaces guiding visitors past the large scale structures of the museum that rise like sculptures out of the ground. Meeting spots with benches are placed throughout the pathway, creating stopping points where outdoor exhibitions or views can be enjoyed. The old missile platforms are optimal for views of the surrounding mainland as well as exhibition spaces, while also creating more intimate spaces beneath them. The added structures allow for views into the museum, adding to the connection between exterior and interior. An old circular shaped canon courtyard, acts as a natural stopping point for the path. An amphitheatre is placed within, generating a gathering point, where visitor can enjoy temporary exhibitions, lectures or plays.



Ill. 55 Path functions in section and plan

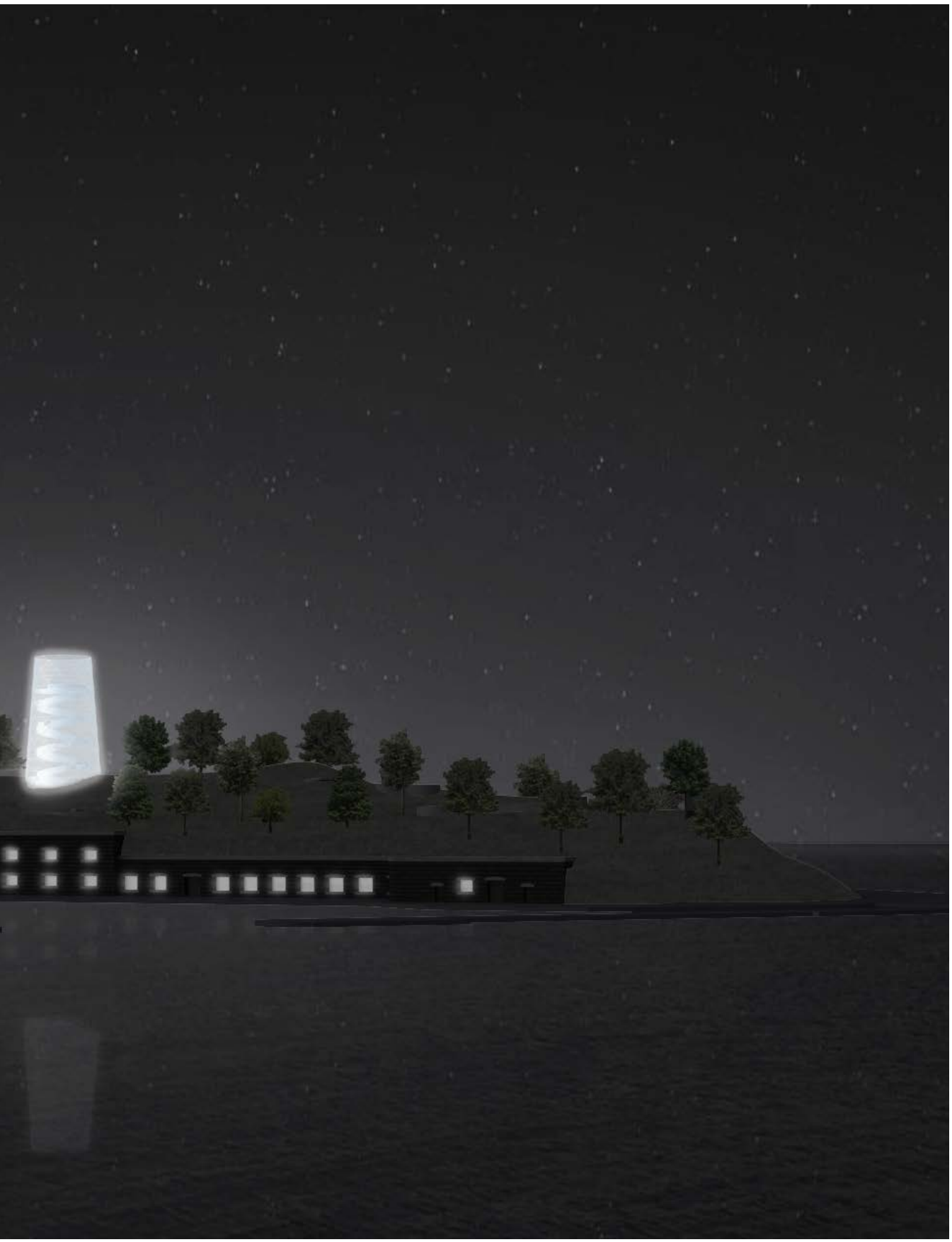


Ill. 56 View on exterior path

LEAVING THE ISLAND

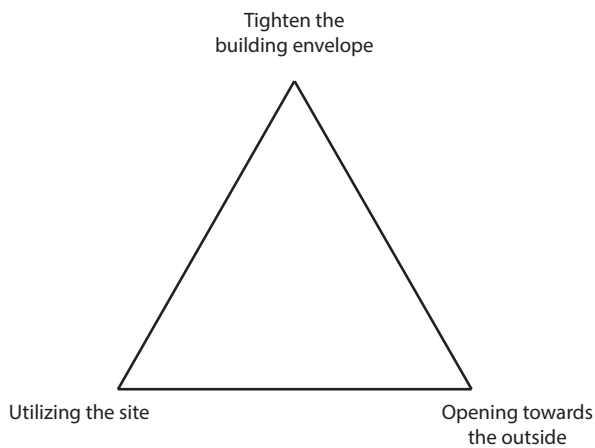
At night the original purpose of the lighthouse is reinstated and redeveloped. Lighting up the night sky, the position of the island is revealed. Shadows and silhouettes moving in the glass tower structure will catch the attention of curious onlookers, showcasing the activity of the island. The monolithic lighthouse illuminates the island, while establishing the solitary nature of the Middelgrund Fort and creating a shinning landmark for the Copenhagen harbor.

Ill. 57 Leaving the island



SUSTAINABILITY

By implementing three simple strategies, the building has renewed its sustainable profile. Tightening the building envelope, opening up spaces towards the outside and utilizing the site has secured a minimal energy consumption, resulting in a better condition for the indoor climate while still maintaining the social sustainability. Natural daylight, heat from solar radiation, natural ventilation, low relative humidity, low reverberation time, low transmission loss and more efficient heating system is integrated in the renovation of the Fort. Accessibility within the museums walls, a reinterpreted landmark and maintaining the raw character of the space are all part of the social aspect of the sustainable transformation.



Ill. 58 Sustainability diagram

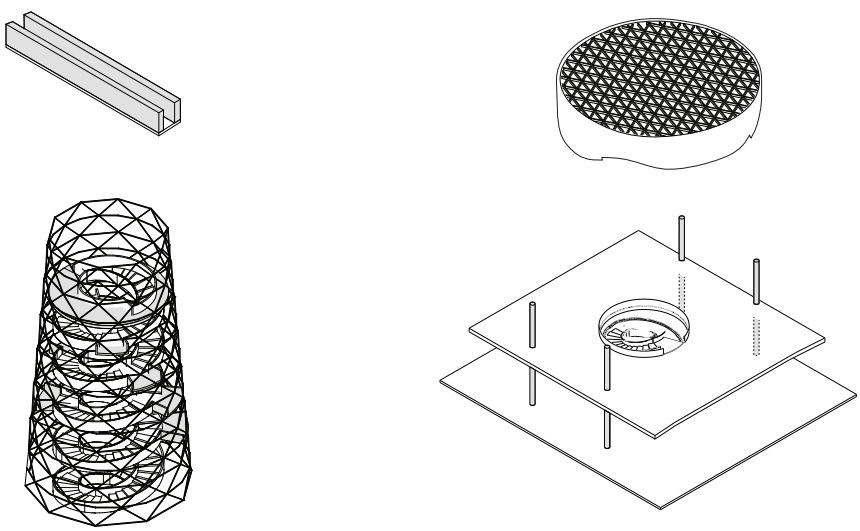
STRUCTURAL PRINCIPLE

The fort was built to withstand the impact of enemy attacks, meaning that the defining features are thick walls and relatively low hanging ceilings. The halls distribute the extreme load of the ground overhead onto the 1,5 m thick concrete walls.

In order to emphasize these features, lightness and height are introduced giving the added structures contrasting characteristics. Roofs in these new structures consist of glass and steel, keeping them light and ensuring that the large exhibition rooms are kept very open without bearing columns. In order to withstand loads and carry the long span, an interlocking grid system was utilized, where multiple steel beams carry the glass roof.

The foyer and centrally placed exhibition spaces have differentiating room heights, with the ceilings being supported by columns. Columns are placed in a fixed distance in order to evenly distribute loads into each column. The columns also add to the verticality of these rooms, directing views upwards, while ensuring that part of the old walls can be retained in their original appearance and height, emphasized by the new room heights.

Stabilizing the lighthouse, the stairs platforms work as seams, making sure the lighthouse is retained in both directions. The lighthouse structure helps to support the staircase, making the combination of the two structural parts independent of each other. By masking the steel beams in the concrete platforms, the aesthetics of the is more integrated.



Ill. 59 Structural principles

MATERIALS

The selection of materials is based on emphasizing the difference between the old and the new structure while keeping them simple and minimalistic. Existing structures are made mostly of raw concrete. New walls inside the museum will be of a combination of different types of concrete. Concrete is the main material used as it is ideal for construction and can also be treated in many different ways, resulting in a variation of concrete surfaces while still maintaining the same language of the space.

Interior walls that are insulated, will be covered with smooth concrete resembling the materiality of the original fort. New additions, that contrast the old structures in term of form and scale, are made of light colored concrete. This ensures they enhance the tactility and rigorous character of the existing structures, while creating an optimal background for the artwork. Polished concrete is used for floors, to keep them simple and coherent.

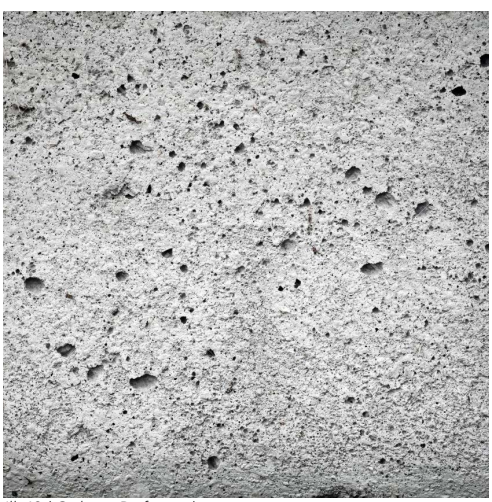
The ceiling is made of perforated concrete, due to its acoustic function. The perforation lowers the reverberation time while still maintaining that coherent look wanted. Due to the hardness of the interior materials it forces people to lower their voice or remain quiet and enjoy the art in a still, peaceful environment.

As most of the materials are kept simple the lighthouse is a dominant structure that is supposed to stand out of the background creating a landmark. It is made of a steel construction of beams and covered with energy efficient glass with a solar shading film on the outside.

Ill. 60a Existing walls - Rough concrete

Ill. 60b New additions - White concrete

Ill. 60c Steel construction

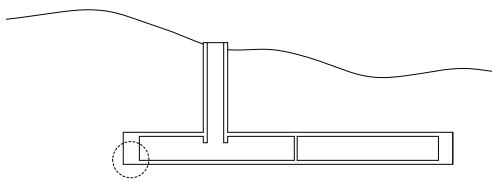


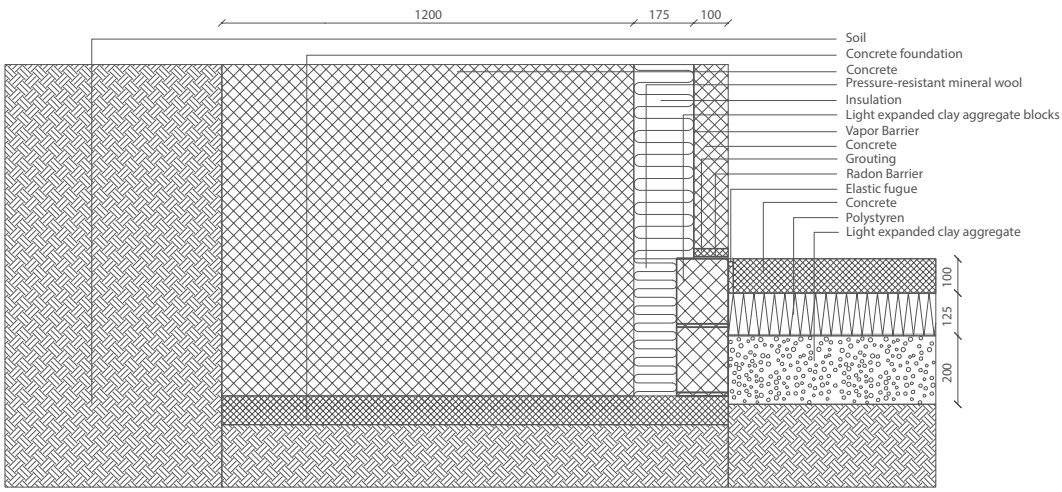
Ill. 60d Ceiling - Perforated concrete

DETAILING

FOUNDATION

The existing heavy 1,2 meter thick concrete wall is insulated on the inside. A vapor barrier is added to prevent moisture in the underground hallways. A concrete wall added secures the original expression of the existing concrete walls. The added insulation thickness can be reduced due to the higher temperature of surrounding soil compared to outside air, releasing inner space to other functions. In the floor, polystyrene is added to tighten the envelope even further and thereby reduce the energy consumption. Again concrete floor finishing is preferred to maintain the original atmosphere.

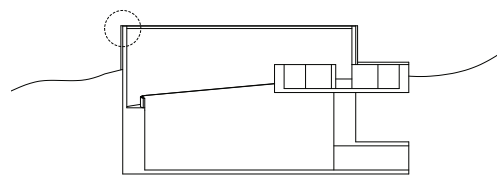


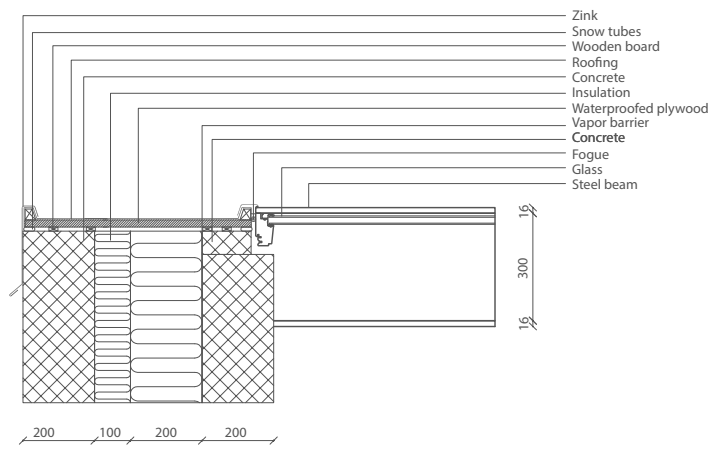


Ill. 61a Foundation detail

ROOF CONSTRUCTION

The new glass roof on top of the exposed structure is aligned with the concrete walls to prevent rain and snow gathering on the roof construction. Furthermore it appears more integrated. The steel beams are resting on the concrete wall, which works as a support. The new walls are provided with 300 mm insulation to lower the U-value as much as possible due to the transmission loss through the roof, which is also reduced by using energy efficient glass.





Ill. 61b Roof detail

DESIGN PROCESS

The design process is not linear, but has undergone several iterative loops, while testing different aspects. Various tools have been used in the process, such as physical models, sketches, 3D modelling, technical calculations, all with the purpose of designing and evaluating the functions, technical and aesthetic parameters.

CONCEPTUAL PERSPECTIVE

SHOWCASING THE FORT

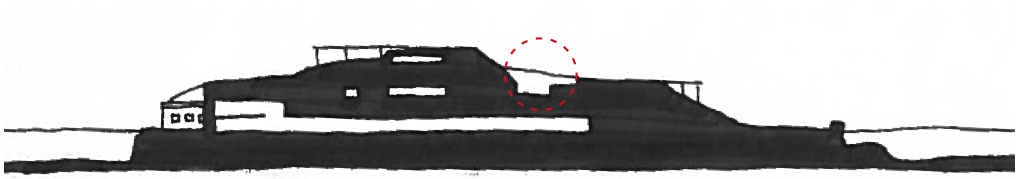
A fundamental part of the transformation strategy, utilized in the design process, was to successfully modernize the old fort while emphasizing the characteristics that make this place unique such as the old concrete structures, courtyards and underground hallways. Due to the technical optimization that the fort required, it is important that the old fort is renovated with better insolation and ventilation provided. As such it became apparent that in order to showcase the history and character of the fort, certain elements should be retained and kept in as much of an original state as possible. The aim is to make the Fort as much a part of the exhibition as the artwork.

UTILIZING THE SITE

The fort has a unique placement, being close to the Copenhagen harbour and having a view to both Sweden and Øresund Bridge. Additionally, there are no immediate neighbouring structures of any kind, meaning that view lines are kept unbroken and sunlight is plentiful. These features are not very apparent in the existing structure, due to most of the building being placed underground away from views and sunlight. These elements will be implemented in the museum, combining the characteristics of the fort with the qualities of the site.

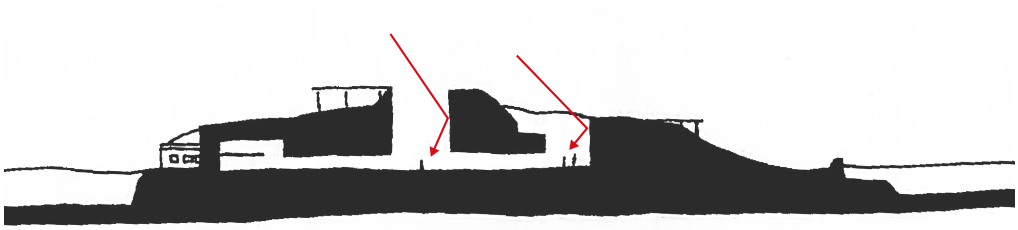
BRINGING IN THE LIGHT

In a structure that is placed primarily underground, daylight is non-existent in most of the building. Thus letting natural light in creates a connection between exterior and interior spaces and adds a new dimension to the atmospheric experience of the fort. Light can be used as a guiding factor or to enhance a certain feature of the space. Utilizing a fleeting element such as daylight, as one of the main tools used to create an atmospheric experience of the spaces, means that the expression of the museum will change according to daytime and season, creating a more living and dynamic building.



Ill. 62a Showcasing the fort

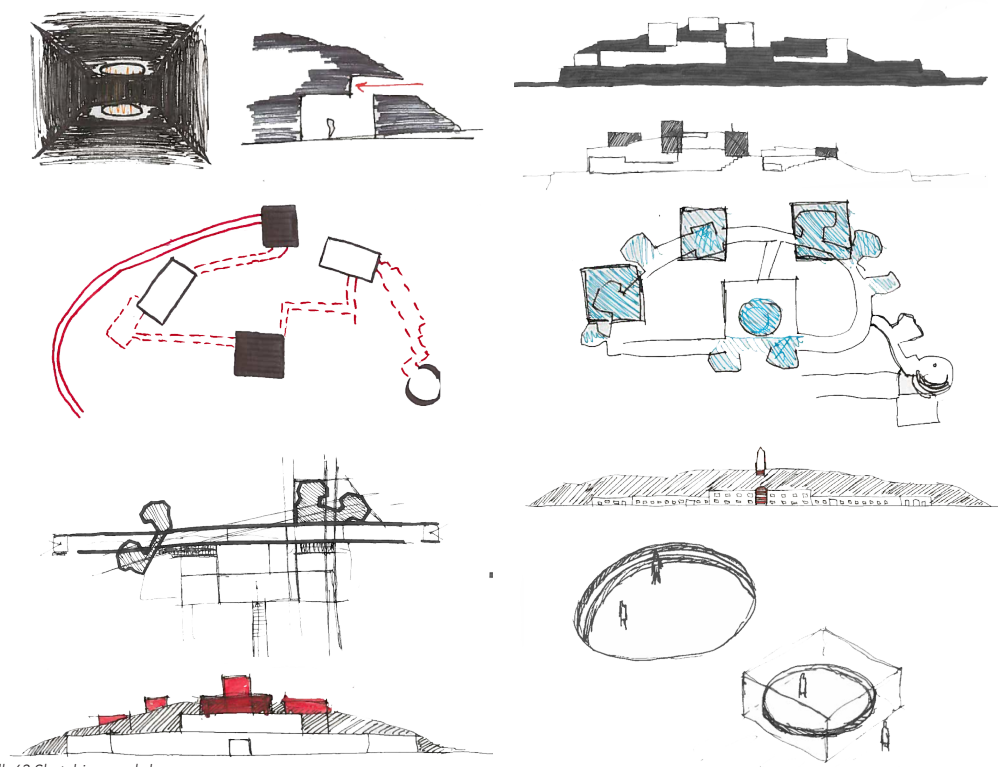
Ill. 62b Utilizing the site



Ill. 62c Bringing in the light

SKETCHING WORKSHOP

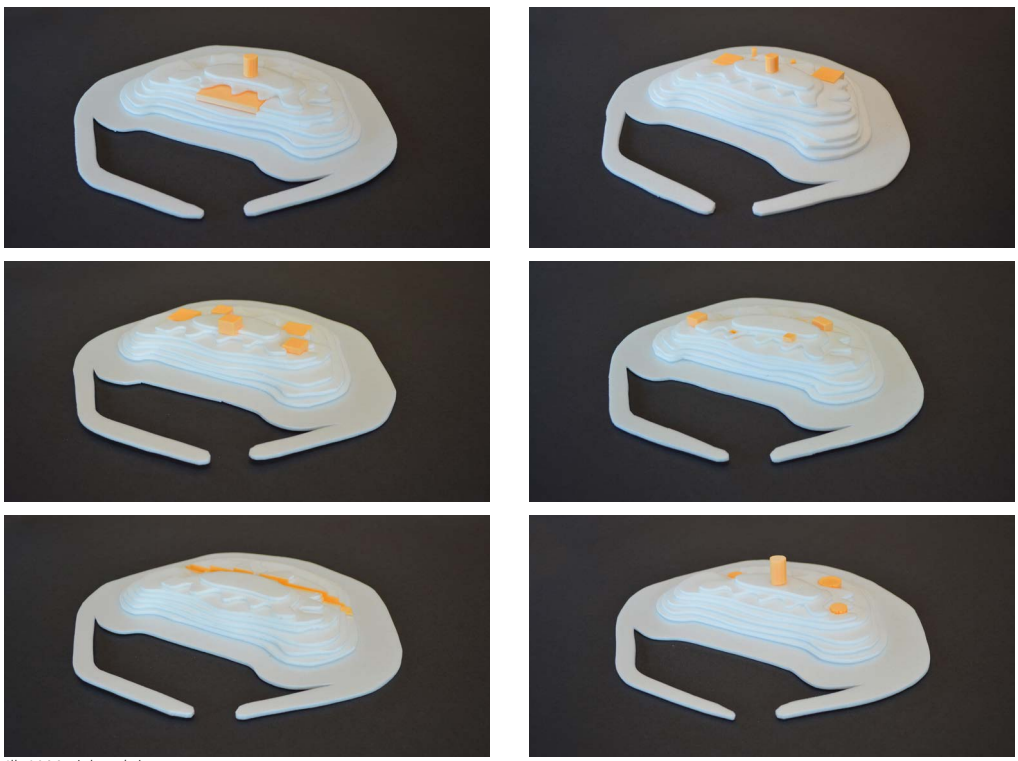
The island was explored from plan and section through a sketching workshop. Many different parameters were considered, some were focused on and led to the development of initial ideas.



Ill. 63 Sketching workshop

MODEL WORKSHOP

After establishing the first few parameters a model workshop was initiated. Foam models investigated the potential for placing different compositions of volumes in the landscape. Several proposals were tested according to shape, placement and connection between them as well as interaction with the terrain. Three concepts emerged from the exploration during the sketching and model workshop, each with unique potential and expression.



Ill. 64 Model workshop

THE SLITH

A drastic slit divides the island in two specific functions, administrative and exhibition. The clear hierarchy makes it easy to navigate inside each part. The slit lets in an abundance of light providing the functions next to the slit with diffuse daylight without the risk of overheating from direct sun, due to the height difference from ground floor to the top of the island.

The change would however be too drastic in the natural landscape of the island. Getting sufficient light in the back rooms would not be possible with this solution. There was also a desire to create a landmark on the island and this option would in no way show that there is something new happening.

THE VOIDS

Voids are pushed both in and out in order to bring the daylight into specific rooms. Different volumes would create internal atriums and external courtyards surrounding the existing structures. This creates unique spaces which alternate between different types of atmospheric lighting in each exhibition room. Contrasting the very strict symmetry of the original plan, these voids create a clear distinction between the old and the new structure. By having these voids strategically placed it is possible to ventilate all around the building, and secure a better indoor climate.

Creating too many voids would create confusion with no clear hierarchy between functions and different programs.

Ill. 65a The slith

Ill. 65b The voids

THE LIGHTHOUSE

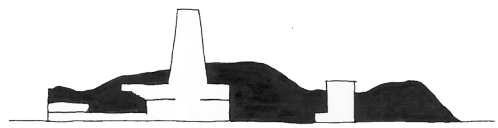
The resurrection of the lighthouse is a romantic gesture that would create a landmark on the island and bring back its historical value. It will welcome both people arriving to Copenhagen with boat, and visitors to the island from the city centre. The lighthouse would create a central element of the island, an orientation point and be a centralized hub from where all other paths would lead. It would be able to provide a lot of daylight to the rooms under it, and also provide a view over the entire island.

If not dimensioned right it can easily take attention away from the other features of the island. The shape and the height would need to be developed further in order to seem elegant and in harmony with the scale of the island.

Ill. 65c The lighthouse

THE COMBINATION

The following final concept includes some of the advantages from the three preliminary studies that were investigated. The lighthouse will be a clear landmark, a jewel on top of the island, seen from afar and inviting people to the island. Adding voids that surround or puncture existing structures will bring light in the back rooms, while creating different atmospheres in the exhibitions rooms, based on both geometry and light. Furthermore the voids and the lighthouse can be used for natural ventilation through thermal buoyancy. The slit is interpreted as the hierarchy of the functions and their placement across the different parts of the building.



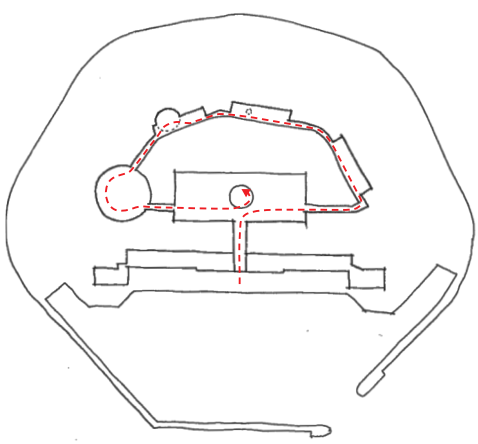
Ill. 65c The combination

ORGANIZATION

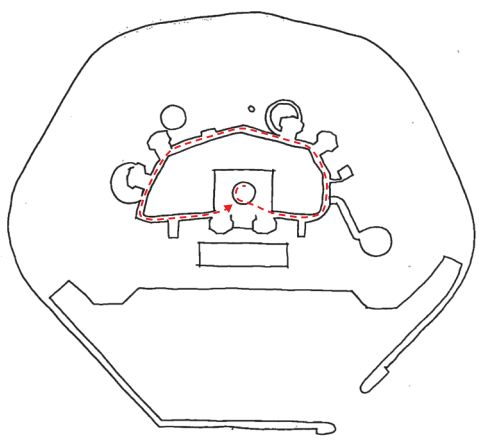
Through the design process, different room organization proposals were investigated. Particularly looking at the placement of functions according to how much daylight they require. Due to the fact that the front building is the only existing part of the fort with natural daylight, all the functional rooms like offices, restaurant and conference rooms will be placed there. Exhibitions rooms that do not require any natural light will be placed underground, in the back.

The original facade includes two smaller entrances on either side of the main house. These two openings would be kept as entrances to the offices and restaurant. Creating a new main entranceway, which is placed in the exact middle of the front house would add a centralized and symmetrical opening to the museum.

The central point of the foyer is the spiral staircase that leads to the lighthouse, creating the only source of natural light. The staircase functions as the main connection to the top floors and as the element of orientation. The journey through the museum is a circular loop, making the path clear and fluent, without distractions or disorientations along the way. Inviting and guiding the visitor via the unique sensory effecting spaces was hugely important for the concept of the museum.



Ill. 66a The organization ground floor

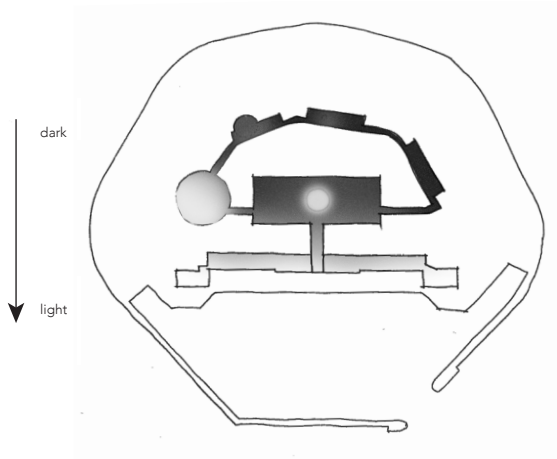


Ill. 66b The organization 1st floor

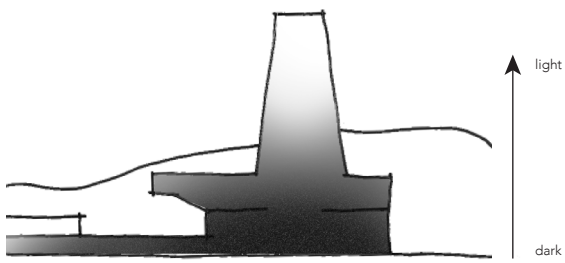
The path leads through all the exhibition rooms on the ground floor, where distinctive experiences are created in each room and peaking interests along the way. The light gradually increases, adding to the connection between natural light and the visitors, as they move through different exhibitions rooms.

The path continues on the top floor, with the central point being the spiral staircase. Here the visitor moves from dark to light spaces more frequently, with daylight becoming much apparent. Old canon placements can be viewed in their original state, emphasizing the interplay between old and new.

The museum draws upon a sense of movement from darkness to ligh, in a horizontal and a vertical perspective. Moving from a semi dark foyer and exhibition rooms, to spaces with more natural light and finally ending the journey moving up the lighthouse where the view is clear and surrounded by light.



Ill. 66c Graduation of light in plan

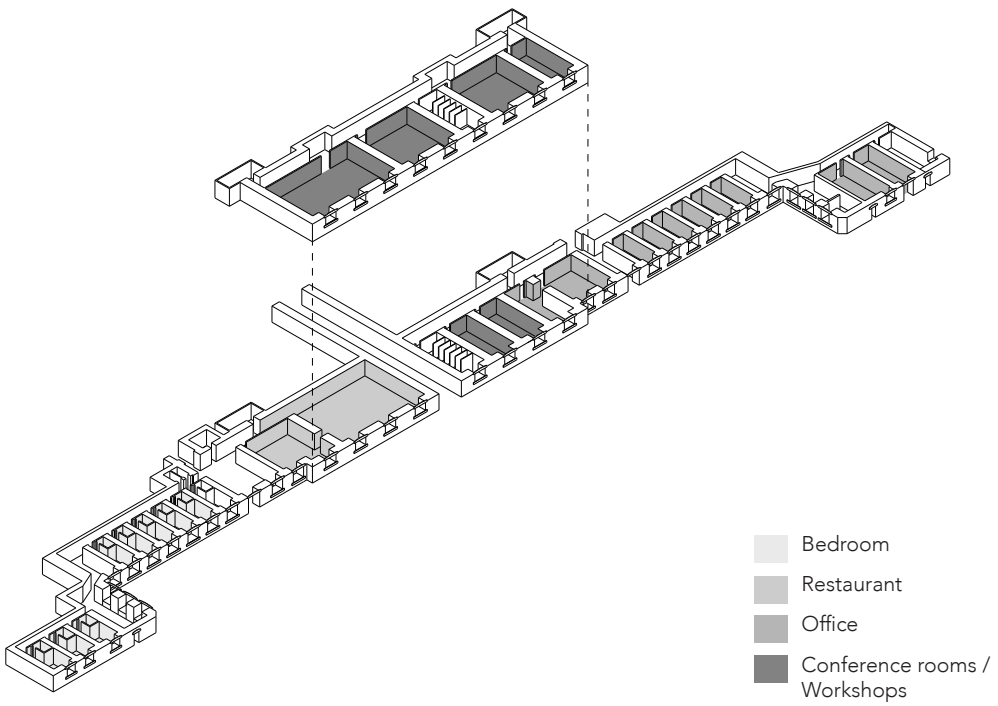


Ill. 66d Graduation of light in section

THE FRONT BUILDING

ROOM PLACEMENT

Due to the entrance of the museum cutting the building in half, functions were also divided in two: the visitors and staff areas. The top floor is mixed use and accessible from both sides. Some considerations regarding placement of the restaurant were made, whether it should be placed on the top floor due to the nice view. However because of accessibility issues and possibility of having outside areas, it is placed on the ground floor in the visitors building. Some interior walls had to be removed in order to make larger spaces for conference rooms, meeting rooms and classrooms. The staircase had to be replaced with the addition of an elevator for accessibility to the top floor.

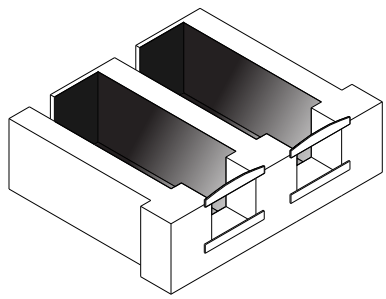


Ill. 67 Room placement of front building

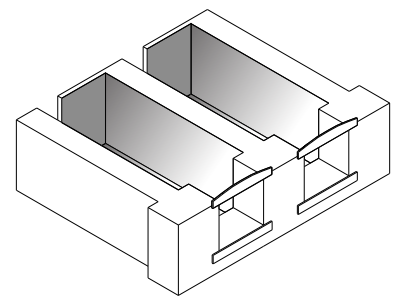
TECHNICAL CONSIDERATIONS

The next step was to check and ensure the sufficient daylight factor in offices and living rooms. The problem was focused on the windows, their size and depth. Many of the rooms look very similar, which is why an office space was chosen as a base model, the changes are then applied to the rest of the rooms in the front building. Lack of daylight is due to the thick wall depth which creates shadows. By increasing the window height half a meter, the solar radiation is increased by 68% and the daylight factor is increased from 1,8% to the requirement of 2,2%. The deep windowsill now provides passive solar shading, ensuring that the offices are not overheated. The increased window area maximizes the possibility for natural ventilation in order to reduce the CO_2 concentration. The airflow demand is therefore only 0,4 l/s pr. m^2. (Appendix A, Appendix E)

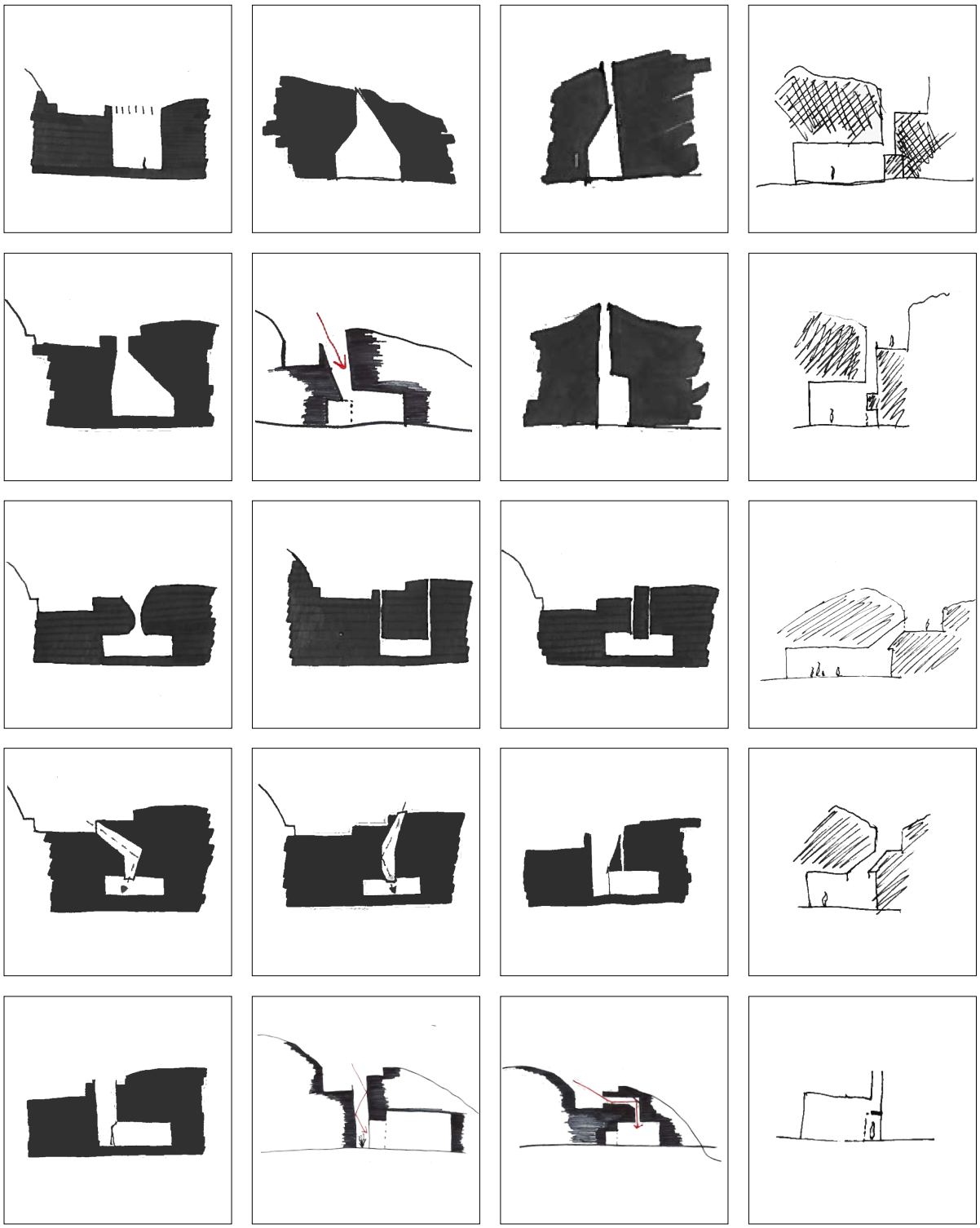
Although the changes to the windows mean a part of the original facade has to be changed, the intention is to keep in the same architectural style as before. To ensure that the expression of the old stone facade is kept, interventions are be kept as minimal as possible.



Ill. 68a Daylight with old windows



Ill. 68b Daylight with new windows



Ill. 69 Exhibition room investigations

EXHIBITION ROOMS

When considering the exhibition rooms the creation of unique and special atmospheres was the main design parameter. Spatial experiences would differ throughout the rooms through the use of materiality, lighting, massing, and stimulation of the senses. Here, light would be a main tool used to create a phenomenological experience for the user.

The atmospheric experience of each room is unique due to utilizing the graduation of light from a completely dark room to space bathed in daylight, with a particular theme in each room.

Several parameters were tested and explored in how to incorporate light and what atmospherical effect it has.

LIGHT WELL

Having a single spotlight in an otherwise darkened room puts a lot of attention on the light well. A lot of shapes, sizes and directions were tested in order to determine the best solution. A smaller beam of light will concentrate the light more, which works better as a spotlight than one large hole. This will give full attention on the artwork under the specific light well. Having a more direct beam makes it brighter, which is why the simple circular light well is preferred.

Ill. 70a Lightwell option 1

Ill. 70b Lightwell option 2

Ill. 70c Lightwell option 3

WALL OF LIGHT

The increase in light from the spotlight is used for guidance along the circular walls. The investigations focus on the placement of the circle and on the difference in the diameter of the inner and outer circle. It has to be narrow enough to get the feeling of an enlightened wall, but big enough to pass through light. The final width of 2 meters was chosen to find a balance between the light and space.

Ill. 71a Wall of light with roof

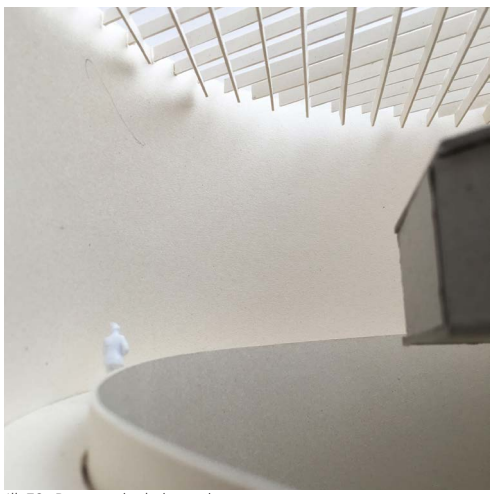
Ill. 71b Wall of light without roof

LIGHT VOID

The last of the ground floor exhibition rooms is punctured with a circular volume that creates a courtyard around the existing structure. This way the old structure of the fort is showcased, while creating an interesting space with a unique light experience. The placement and size of the circular volume depends on several parameters, such as accessibility and structural integrity. The existing courtyard is in two floors which are connected by two sets of stairs. Accessibility is increased by incorporating a ramp, that goes along the curvature of the circular volume. This ramp creates a path around the circle, where art can be exhibited, whilst also appreciating the old structure. The length of the ramp dictates the size of the circular volume, as it had to be wheelchair accessible.

Ill. 72a Light void without roof

Ill. 72b Scale of the old courtyard



Ill. 72c Ramp in the light void

EXPOSED STRUCTURE

This enclosed exterior ring surrounding the structure, is created in the same size and concept as the open exhibition room. The tests have primarily focused on the roof and the contrast between indoor, outdoors, light and dark. By placing a solid roof on both the ring and the existing courtyard, the connection to the outdoor via the circle is amplified through a glass facade.

Ill. 73a Exposed structure without roof

Ill. 73b Exposed structure with roof

Ill. 73c Ramp in the exposed structure

ROOF TESTS

Different types of roofs were explored in order to achieve the best option in terms of light, structure and aesthetics for the visitors and the exhibited art. After testing an open, semi open, closed and lifted roof, the open roof with interlocking beams was chosen. This decision opened a question regarding the material, where glass, solar shading glass and polycarbonate were investigated. The thermal consideration was, as earlier mentioned, not an issue with the choice of modern glass types. Due to this and the coherency with the lighthouse, the solar shading glass roof was finally chosen. (Appendix C)

Ill. 74a Roof option 1

Ill. 74b Roof option 2

Ill. 74c Roof option 3

Ill. 74d Roof option 4

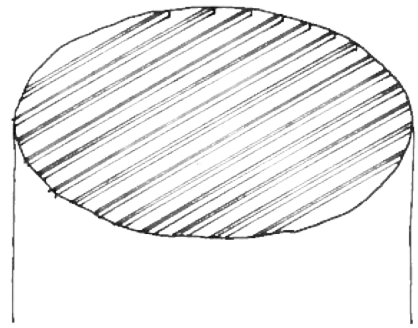
ROOF INVESTIGATIONS

A structural investigation was employed when finding the right grid structure for the open exhibition room. The structure was explored in a parametric setup through the Rhinoceros plug-in Grasshopper, enabling iterative feedback loops that were then used to find the proper structural system and profile dimensions for the load bearing beams.

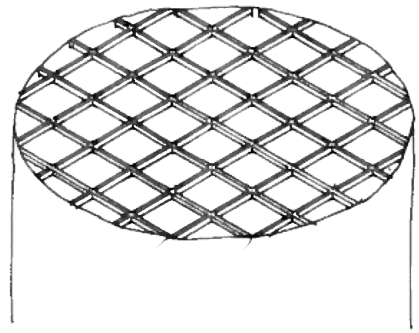
The studied construction is a grid of steel beams where the aesthetic quality and deformation were the main instigators.

The maximum defection allowed for roofs is given by: dmax = L/200 = 140 mm.

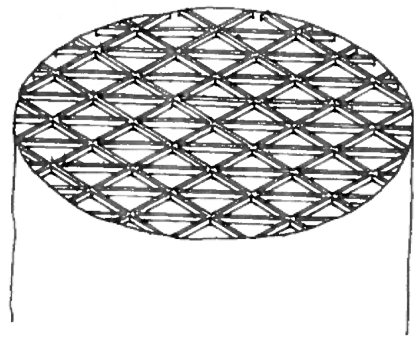
The illustrations show a selection of the studies where different structural systems were tested. In the end a system of interlocking beams were chosen, as they kept the roof profiles lighter and add a coherency with the structure of the lighthouse. (Appendix F)



*Ill. 75a Roof construction 1 (480 mm*178 mm)*



*Ill. 75b Roof construction 2 (360 mm*143 mm)*



*Ill. 75b Roof construction 3 (300 mm*125 mm - chosen option)*

BSIM

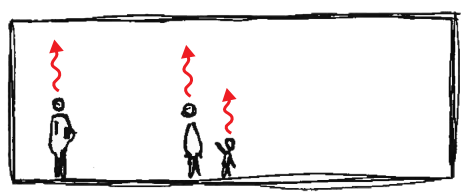
ENVELOPE

With the ground floor exhibition rooms placed under 15 meters of soil, the indoor environment, CO_2 concentration and in particular the relative humidity, were among the primary focus points. As the project centres around the design of an art museum, it was important to maintain consistent internal conditions. This meant reaching for a relative humidity around 50 - 60%. A single exhibition room was investigated in Bsim, with the strategy then applied to the remaining rooms. The existing building envelope is not sufficient in terms of modern standards, as it primarily consists of pure concrete and soil. By adding insulation in the old engineering shafts between the walls, the transmission losses and infiltration are drastically lowered. Furthermore the walls without engineering shafts are insulated on the inside, then followed by a vapor barrier and finished with concrete, matching the original material. (Appendix A)

INDOOR CLIMATE

The ceiling height was investigated, trying to increase the volume and thereby minimizing the humidity and CO_2 concentration. While the increase in ceiling height lowered the problems slightly, the heating demand and transmission loss increased. In the end it all came down to the ventilation and its ability to maintain a steady condition. Adding a humidifier and cooling the inlet temperature, the relative humidity was held at a difference between 47% and 73%, with an airflow demand of 0,87 l/s pr.m^2, closing in on modern museum conditions (Condair, 2016). The CO_2 concentration was not as influential, as the relative humidity and was held to a max of 837 ppm. (Appendix A)

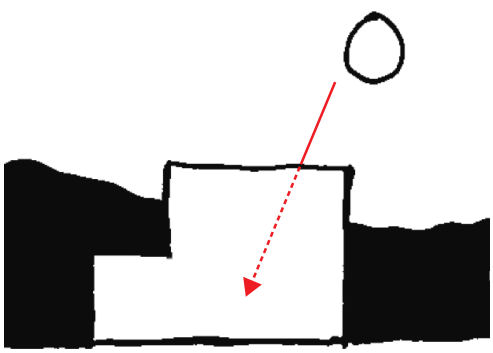
Ill. 76a Building envelope



Ill. 76b Indoor climate

DAYLIGHT AND VENTILATION

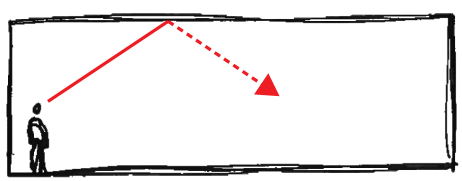
As stated earlier the daylight was used not only quantitatively but also qualitative. While the front building requires a 2% daylight factor, the exhibition rooms are mostly based on atmospheric light. With new structures used to enhance these qualities. By placing a huge glass roof on top of the light void exhibition room, overheating will occur. Tests of clear glass, energy efficient glass with solar shading film and polycarbonate were made. The possibility of opening some of the windows in order to ventilate naturally will be a factor in avoiding overheating. Energy efficient windows with a solar shading film were chosen as the final material, to fully avoid overheating. Furthermore this strategy keeps the direct sunlight out, improving the indoor climate conditions for the artwork, while creating a connection with the exterior. The choice of glass with solar shading film also creates a visual coherency with the lighthouse. (Appendix A, Appendix C)



Ill. 76c Daylight and ventilation

ACOUSTICS

The existing concrete on floors, walls and ceiling are not ideal for the desired acoustic conditions. Investigations with a different ceiling height show that increasing the ceiling only makes it worse according to reverberation time. By adding more surface area but maintaining the volume or a softer material, the reverberation time will decrease. Perforating the concrete ceiling minimized the reverberation time from 3,7s to 1,2s with 20 people inside the room. This is the same acoustics as in a small theatre or a cinema. This was preferred as it would naturally effect visitors to lower their voices, in order to make it pleasant inside the exhibition rooms. Very high reverberation time would have made it almost impossible not to make any noise.
Based on all these investigations the ceiling height is maintained as the original 3 meters, both as a sustainable and an aesthetic choice, where the low height will enhance the underground feeling. The ceiling is however lifted a bit to make room for ventilation, with a perforated concrete ceiling placed underneath. (Appendix D)



Ill. 76d Acoustics

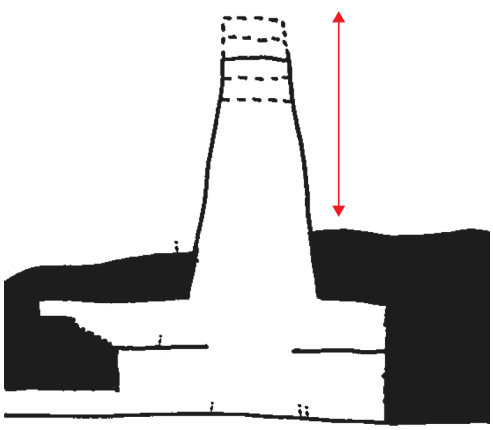
Ill. 77 Lighthouse models

THE LIGHTHOUSE

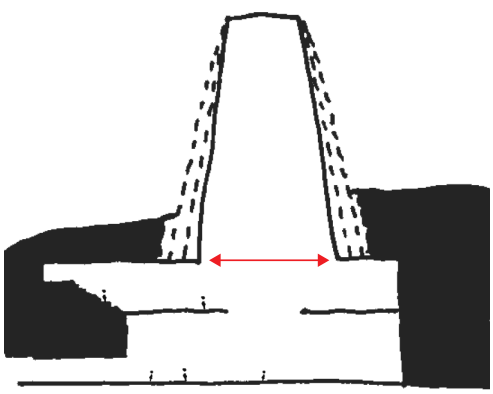
Being over a 100 years old, the fort has gone through a number of changes, meaning that it has constantly changed its character. One of the main characteristics of the island was the old lighthouse that worked as a focal point on the highest point of the island. Reminding passers-by and Copenhagen inhabitants of the Middelgrund Forts presence. Laying in solitude, but keeping a watchful eye on the people it was meant to protect. The lighthouse was eventually torn down in exchange for a helipad and the fort seemed to lose its connection with the city, being left to decay. Early on in the design process it was determined that the museum would require a landmark to recreate the relationship with the Copenhagen harbour. By designing a new lighthouse-like structure a landmark would be established, showcasing the island in a new way, through the use of one of its forgotten qualities. This structure was also designed to determine the overall flow through the building, heightening its importance, while creating a connecting between exterior and interior spaces. By using this tactic, the whole museum would be oriented around a central focal point, distributing the flow of people through the whole building, and ensuring that there was always a control point from which visitors can orientate themselves.
(Appendix H)

DAYLIGHT

The function of the lighthouse, distributing light out and warning boats of the impending landmass, was to be redefined in order to better connect with the underlining museum structure. Where a typical lighthouse projects light outwards, this specific structure would also collect daylight into the interior space, scattering light in the once completely dark fort. During daytime, daylight flushing through the lighthouse enlightens the foyer area, illuminating the central spiral staircase and thereby making it the focal point the room. This relationship switches at night, with the internal lights of the museum shinning up through the lighthouse creating an illuminating beacon in the night. In order to ensure an adequate amount of daylight in the foyer, several tests were applied using the daylight simulating program Velux Visualizer. Variations of height, opening sizes and materials were tested in order to help shape the final appearance of the lighthouse. In order to reach a satisfactory height, which would ensure a landmark stature without breaking the scale of the rest of the island, a truncated cone shape was chosen. This allowed the lighthouse to keep a light expression, while reaching a suitable height, while also ensuring the right amount of daylight. A height of 20 meters, with an opening of 13 meters where the tower meets the ground, was found to give the most satisfactory results whilst also meeting the aesthetic requirements that were desired. (Appendix C)



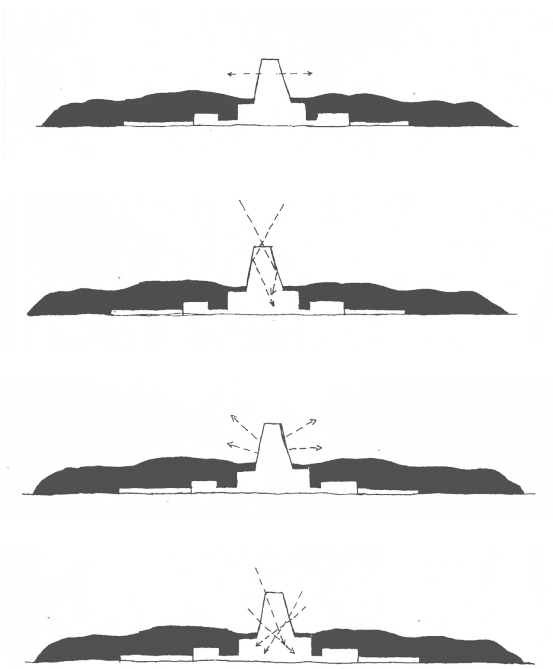
Ill. 78a Investigations of lighthouse height



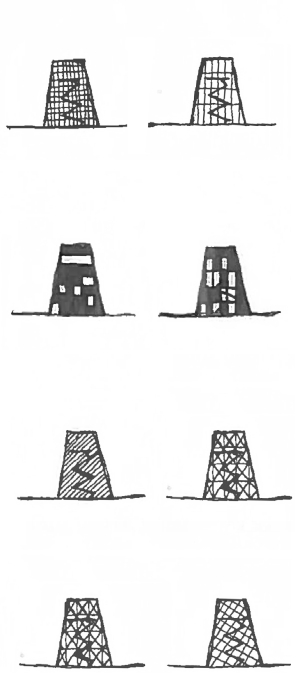
Ill. 78b Investigations of lighthouse width

MATERIALS AND STRUCTURE

To determine the appearance of the lighthouse, several different options of material and structure were tested. Using glass as the primary material would benefit the amount of light, that could enter the building, while creating a crystal like structure on the island, that would establish it as a landmark. A skeleton-like structure, adds to the light appearance of the lighthouse, while facilitating a huge amount of daylight to come in. Taking advantage of the transparency of the tower, visitors will get a 360 view while traveling up the concrete spiral staircase. The transparent appearance also provides a dynamic expression, where the amount of activity of the museum, will be showcased throughout the day. Platforms between the lighthouse and stairs provide stability to the whole structure, while creating resting places, that can be used for exhibitions or guided views of the surrounding area. The top of the tower is designed to be the final destination point for any visitor. Rewarding them with unique panoramic views, while the see-through roof, enables stargazing during night time. The transparent and light tower provides a romantic gesture of bringing back an old lighthouse to the island, creating a landmark and reestablishing connection between the Middelgrund Fort and the people of Copenhagen.



Ill. 79 Utilizing light and views in the lighthouse



Ill. 80 Structure and material options

BE15

The 16.000 m^2 buildings original use did not prioritize energy consumption. The walls, floors and ceiling are all in solid concrete to withstand bomb attacks. Even with the several meters of soil covering the building envelope, it would never live up to modern energy demands. To fulfill the modern demands, the old engineering shafts were filled with insulation and a vapor barrier to control moisture. This way the original structure can be left untouched, yet it reduces the transmission loss significantly. The walls that do not have engineering shafts have to be changed by adding a layer of insulation followed by a layer of concrete, to lower the U-value creating a tighter building envelope. By having the thick walls, the cold surface is pushed as far as possible from the inside, which lowers the heating demand.

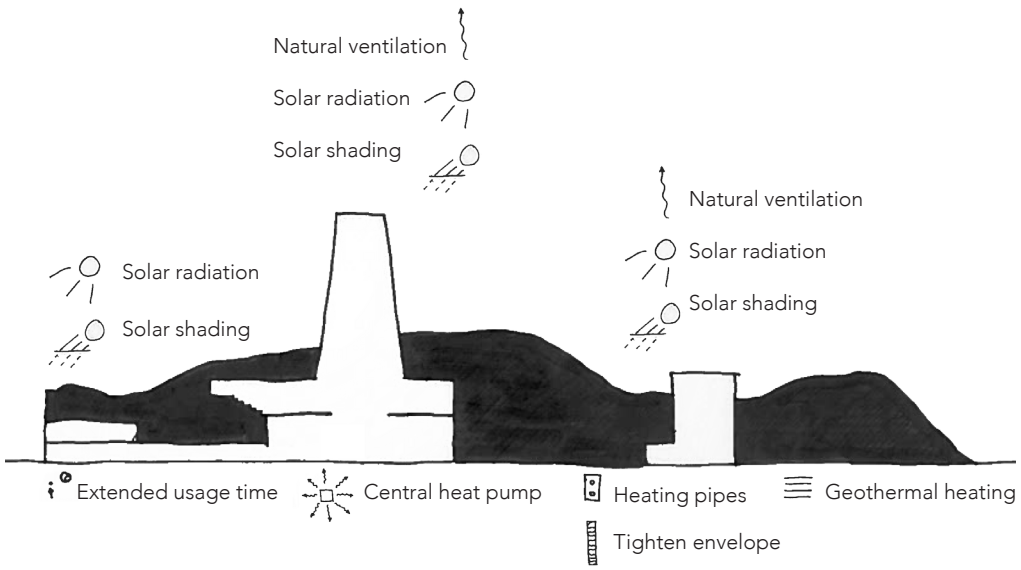
The roof is lifted due to ventilation pipes, but the ceiling height is kept, which makes it possible to put in more insulation and lower the U-value even more. The new glass roofs allow sun to contribute to heating the building up in periods.

District heating is not that efficient or economically sustainable, when it has to be transported more than 800 meters off shore under water, by new pipes. A central heat pump is preferred alongside a geothermal heating system to lower the energy consumption.

Having interior piping would heat up the air inside, securing that the heat loss from pipes would benefit the room temperature. Furthermore the walls would store some heat and thereby heat up the air inside the room gradually.

Finally, it is possible to supplement the energy frame, if the building has a higher usage time than a regular week of 48 hours. By having usage time of 56 hours, which is reasonable considering that artists can rent rooms on the island, the energy frame takes into account the difference between the actual and the regular usage time, which is the supplement. Due to this, the energy demand can be raised with 5,9 kWh/m2 pr. year.

These initiatives and the added supplement will restore the fortress to the modern energy demands, making sure it will uphold both renovation class 1 and 2015 demands. (Appendix B)



Ill. 81 Energy section diagram

EPILOGUE

CONCLUSION

The Transformation of the Middelgrund Fort deals with the design and redevelopment of an old military fort, located approximately 800 meters from the Copenhagen harbor front. Through analyzing the site conditions and discovering the unique character of the island, it was determined that designing a museum for modern art would be ideal to harness and showcase these qualities.

A defined architectural style has been utilized in order to stage and develop the specific character of the fort. Through the themes of transformation, sustainability and atmosphere, the building is reborn with a new expression based on the original character. By respecting the existing structure and adding volumes according to the architectural style the new added structures not only maintain but also heighten the identity of the island. The balance and priority between the existing building and the demand for new design solutions enhanced the contrast between the two. Showcasing the old fort by emphasizing certain qualities ensures the original building becomes as much a part of the exhibition, as the art that is displayed there.

The site is the foundation in redeveloping the Middelgrund Fort, bringing it back to its original status of being a landmark for Copenhagen towards the sea. As the island originally included a lighthouse, centrally placed on the island, a new lightweight steel and glass structure have been added. This structure creates a central gathering point for the whole museum, while referencing the history of the fort and creating a new landmark for the island.

Strategically placed voids are subtracted to provide sensory light in the darkened corridors, creating a contrast that reveals a story not previously told, and empowering the image of the old military fort. By limiting the openings to a few specific spaces, the original character of the place is maintained and enhanced. Visitors undertake a journey of graduating light as they move through the spaces. A more fluent and natural connection to the exterior spaces of the island has been created, through the added structures. By bringing in natural daylight into a previously enclosed bunker, a new element is added to the characteristics of the old fort, creating a dynamic and uniquely atmospheric experience more in line the islands' new function.

With the museum being primarily situated underground, the site conditions have had as much of an influence on indoor comfort as it has for the architectural expression. Lighting conditions have been divided into two strategies; atmospheric and technical. Exhibition rooms differentiate between enclosed with artificial lights to open spaces with an abundance of natural daylight. That ensures that in some interior spaces the focus can be entirely placed on the art work and in other rooms the fleeting nature of daylight provides a dynamic backdrop.

Optimal working conditions for staff and visiting artists were achieved by placing these functions in the front building, the only part of the old fort that already had access to natural daylight. The windows of the facade were slightly enhanced in scale, thus meeting the requirements for indoor climate and achieving a minimum daylight factor of 2%.

The soil surrounding the structure acts as an insulator affecting both humidity and temperature. To ensure optimized indoor conditions, mechanical ventilation assisted by natural ventilation was utilized, thus addressing the museums two biggest problems; relative humidity and CO_2 concentration. Despite the presence of the thick existing concrete walls, extra insulation and vapor barriers have been strategically placed to insure that the indoor climate requirements of a public building are met. This, alongside the use of a central heat pump, has lowered the energy losses and secured an energy frame which meets the requirements of building class 2015.

The project can serve as a reference point for future developments of other heritage buildings. Every building and interconnected site has their own unique details and atmosphere. This creates possibilities for development that can fuse these qualities with modern architectural expressions, securing their relevance for future generations. The social aspect of creating something that joins architectural qualities from different ages, makes this project more than a transformation. It becomes a reminder of the role that heritage buildings can have in the modern cityscape.

REFLECTION

A 100 year old military fortress that was built to serve a single purpose, namely defending Denmark against incoming attacks, would always provide a multitude of challenges. Particularly when optimizing it for modern use and requirements.

Throughout the design process there has been an apparent balancing act between maintaining as much of the original character of the fort, while still optimizing indoor programming and climate in order to ensure that the building could facilitate a new function.

Due to the desire of using the island as a museum, a design strategy was chosen where certain elements would be kept intact and showcased, while much of the remaining building would be altered by adding elements such as ventilation and insulation. As such it can be argued whether or not the final product has lost too much of the forts' original character. This has been a balancing act between optimizing the building for future use and utilizing the apparent aesthetic qualities present.

Moisture and indoor temperature would always be a problem in a bunker, that is

situated beneath 15 meters of soil and without any insulation of note. This is of even more importance when considering that this building would contain a large amount of artwork, a commodity that is normally very sensitive to moisture. The final design and ventilation system would keep the humidity level of 47-73 %, which are satisfactory values for most modern museums, however the fluctuation between the values, would mean that not all types of artwork can be exhibited on the island.

During the process of optimizing the building, in effort to meet modern energy standards, it became apparent that 2020 demands would only be reachable if a very large part of the fort was demolished and rebuilt. This would again effect the overall design strategy, as most of the original identity would be lost. Thus, it can be argued that modern demands would not be sensible to apply when dealing with a heritage building such as this.

By implementing modern technologies such as wave turbines, PV's and windmills, the island could lower its energy consumption even more and perhaps even become self-sufficient. However, the aesthetics of these attributes were thought to destroy the identity of the space, where atmosphere and energy demands should be merged instead of contrasting each other.

When considering the type of site conditions and functions required for the museum to work as desired, it would seem that economically the project would not be beneficial. However, it could be seen as being socially viable, as the design strategies could be implemented in other building cases. Therefore the project not only concerns this specific site, but can be seen as a blueprint for future heritage transformations. Socially these types of transformation can make sense, in an attempt to retain the story each building tells.

Early on in the process of this project, there was an established desire to create a very dynamic set of building functions. Creating a building that could be interchangeable according the functions needed at a certain point in time. But due to the intricacy of building layout and the desire to retain and showcase as much of the original character as possible, strategies were utilized, such as the light wells and lighthouse, resulting in the final product being more fixed than what was originally intended.

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Ill. 8: FRAC Dunkerque, http://www.edgargonzalez.com/2014/02/26/gemelo-de-piel-transparente/
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Ill. 9: Reid Building - Glasgow School of Art, http://www.dezeen.com/2014/03/06/glasgow-school-of-art-reid-building-steven-holl/
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Ill. 60a: Existing wall - Rough concrete, https://dk.pinterest.com/pin/392376186261589507/
(Assesed 03. Apr. 2016)

Ill. 60b: New addition - White concrete, https://dk.pinterest.com/explore/concrete-texture/
(Assesed 21. Apr. 2016)

Ill. 60c: Steel construction, https://dk.pinterest.com/pin/140807925828294179/
(Assesed 21. Apr. 2016)

Ill. 60d: Ceiling - Perforated concrete, https://dk.pinterest.com/pin/317855686171882906/
(Assesed 21. Apr. 2016)

Illustrations and photos not mentioned above are authors own.

APPENDIX

APPENDIX A

BSIM

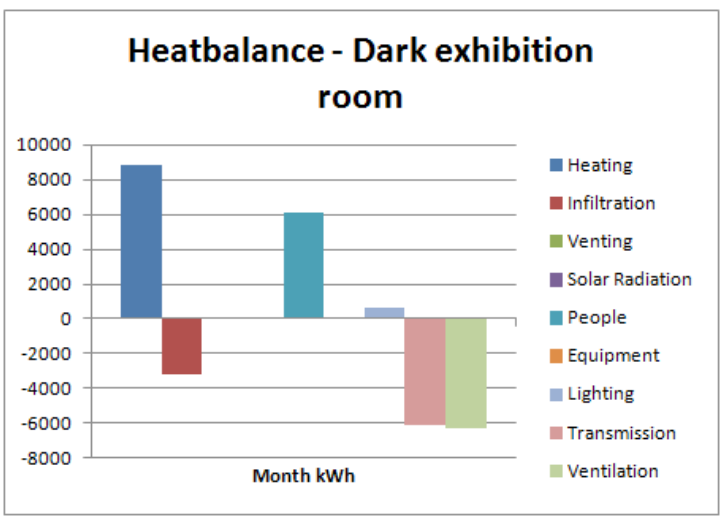
DARK EXHIBITION ROOM

The three rooms investigated in BSim are the light void, a dark exhibition room and an office space.

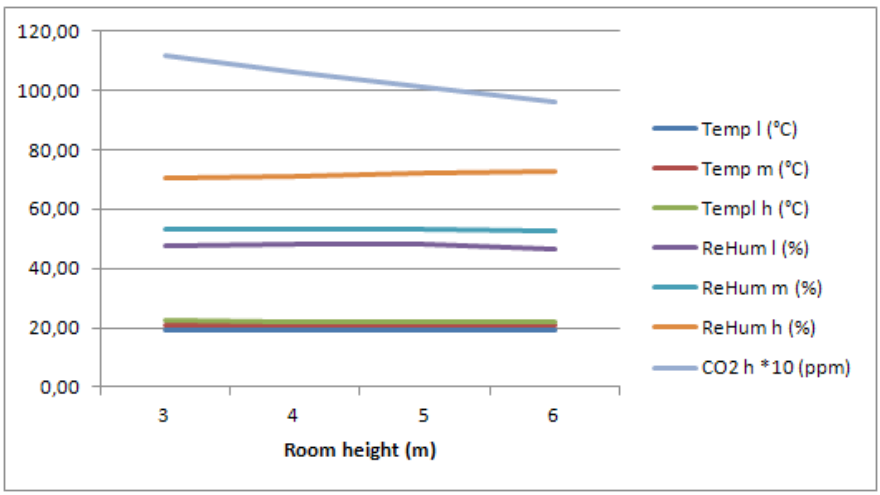
The dark exhibition room has been used as a reference for the other exhibition rooms in terms of reaching the demands of relative humidity and CO2 concentration. The ventilation and acoustic materials are based upon these results as well. An investigation of the ceiling height showed that the original 3 meters was preferable, based both on energy and indoor climate. The humidity is concentrated between 47% and 76%, which prevents moisture damage on the artwork. The CO2 concentration was not as demanding, as the requirements were met before the desired relative humidity values.

Hours > 20	8760	744	672	744	720	744	720	744	744	720	744	720	744
Hours > 26	47	0	0	0	2	0	14	15	15	1	0	0	0
Hours > 27	14	0	0	0	0	0	4	4	6	0	0	0	0
Hours < 19	0	0	0	0	0	0	0	0	0	0	0	0	0

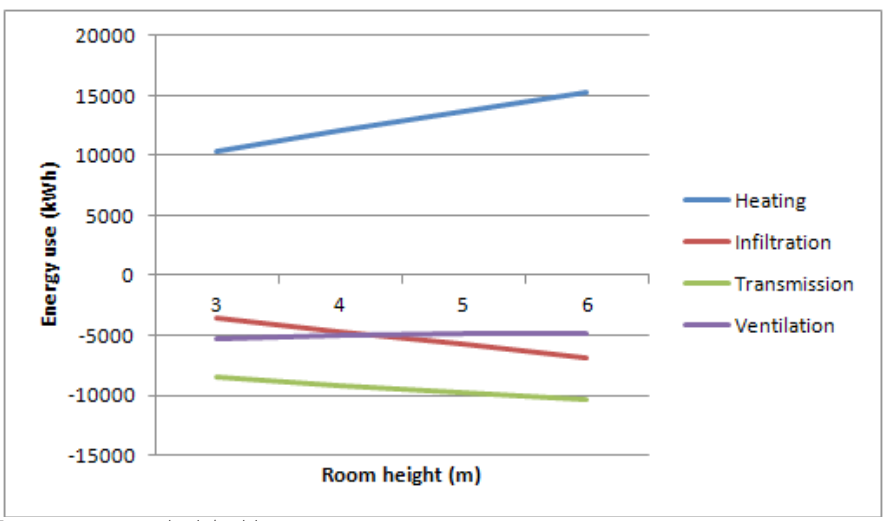
Ill. 82a Relative humidity, temperature and CO2 concentration in the dark exhibition room



Ill. 82b Heat balance in the dark exhibition room



Ill. 82c Indoor climate in the dark exhibition room



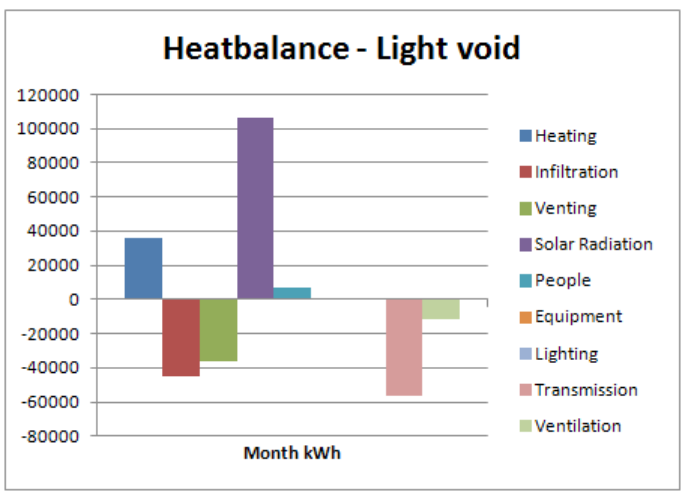
Ill. 82d Energy consumption in the dark exhibition room

LIGHT VOID

The light void was investigated regarding overheating due to the glass roof. The investigation shows, that solar shading film and energy glass can maintain an acceptable temperature. Only exceeding 26 degrees for 47 hours and 27 degrees for 14 hours, which is within the requirements.

Hours > 20	8760	744	672	744	720	744	720	744	744	720	744	720	744
Hours > 26	47	0	0	0	2	0	14	15	15	1	0	0	0
Hours > 27	14	0	0	0	0	0	4	4	6	0	0	0	0
Hours < 19	0	0	0	0	0	0	0	0	0	0	0	0	0

Ill. 83a Hours above 26 and 27 degrees in the light void



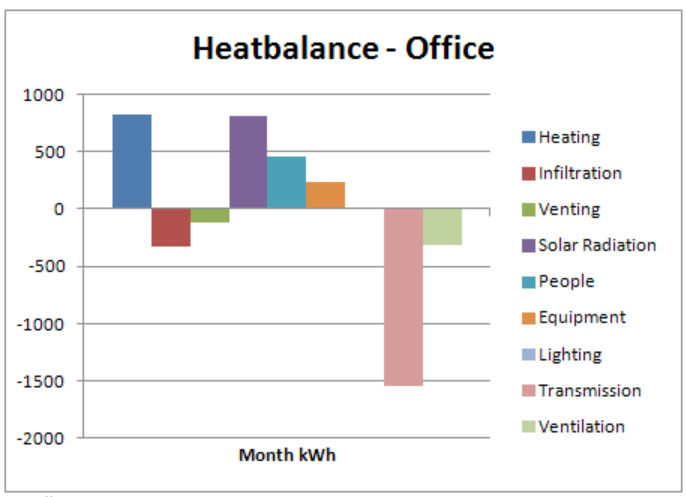
Ill. 83b Heat balance in the light void

OFFICE

The office spaces biggest problem was daylight. By implementing larger windows the temperature is raised without overheating the space, while the sun is up, lowering the heating demand. This does however mean an increase of the transmission, lowering the temperature significantly when the sun is away. However as this happens outside working hours, it was perceived as not being a problem.

2011	Min	Mean	Max	1	2	3	4	5	6	7	8	9	10	11	12
Ti(ThermalZ	16,68	20,99	26,70	18,95	19,22	19,49	19,74	20,54	22,14	23,56	24,43	23,66	20,90	19,78	19,36
Co2(Therma	350,0	537,3	1002,7	486,5	494,4	499,8	491,3	632,3	644,9	559,1	540,1	621,8	487,0	497,2	492,8

Ill. 84a Temperature and CO2 concentration in the office



Ill. 84b Heat balance in the office

APPENDIX B

BE15

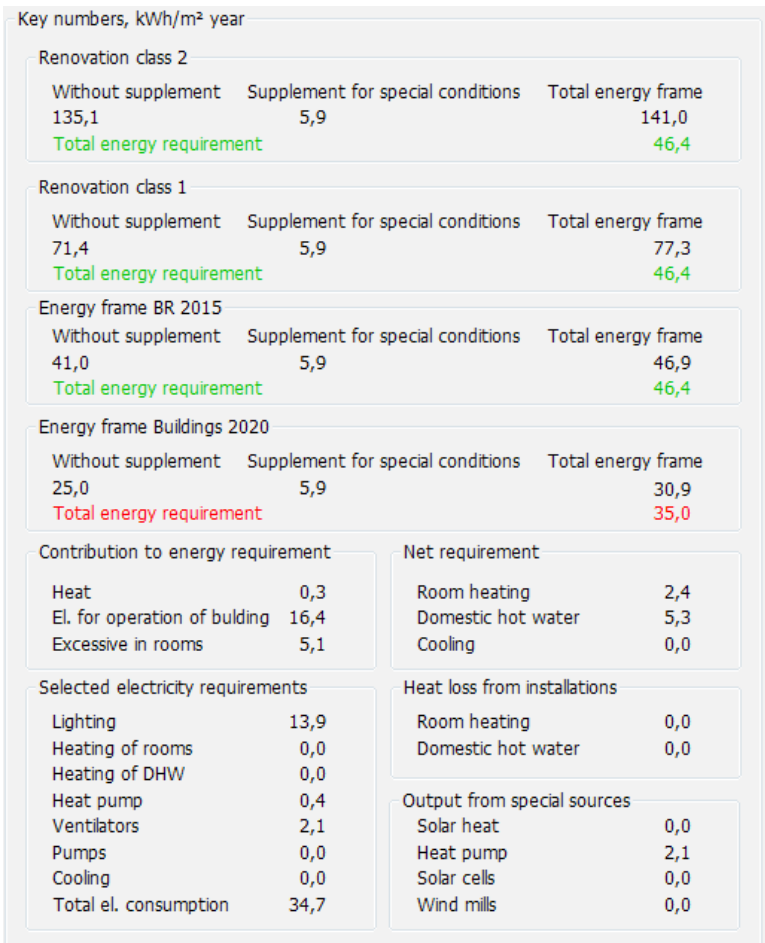
The energy consumption meets the renovation class 1 and the 2015 demands, with the addition of a supplement due to the higher usage time. The most influential factors utilized to reach these demands are:

- Tightening of the envelope and openings, to lower transmission loses.

- Getting solar radiation in, to lower heating demands.

- Providing natural ventilation, to decrease mechanical ventilation demands.

One of the largest negative factors in the energy consumption is artificial lighting, due to the huge floor area, and the fact that the building is situated mostly underground, with sparing natural daylight. The lighting is also the reason of the small overheating indicated. This however is not a concern, when constructing a more detailed investigation via BSim, showing that overheating is not an issue. Reaching the 2020 building demands would require a lot of technical additions as well as extensively interfering with the existing structure, which was not desired.



Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total energy frame
135,1	5,9	141,0
Total energy requirement		46,4

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
71,4	5,9	77,3
Total energy requirement		46,4

Energy frame BR 2015

Without supplement	Supplement for special conditions	Total energy frame
41,0	5,9	46,9
Total energy requirement		46,4

Energy frame Buildings 2020

Without supplement	Supplement for special conditions	Total energy frame
25,0	5,9	30,9
Total energy requirement		35,0

Contribution to energy requirement

Heat	0,3
El. for operation of bulding	16,4
Excessive in rooms	5,1

Net requirement

Room heating	2,4
Domestic hot water	5,3
Cooling	0,0

Selected electricity requirements

Lighting	13,9
Heating of rooms	0,0
Heating of DHW	0,0
Heat pump	0,4
Ventilators	2,1
Pumps	0,0
Cooling	0,0
Total el. consumption	34,7

Heat loss from installations

Room heating	0,0
Domestic hot water	0,0

Output from special sources

Solar heat	0,0
Heat pump	2,1
Solar cells	0,0
Wind mills	0,0

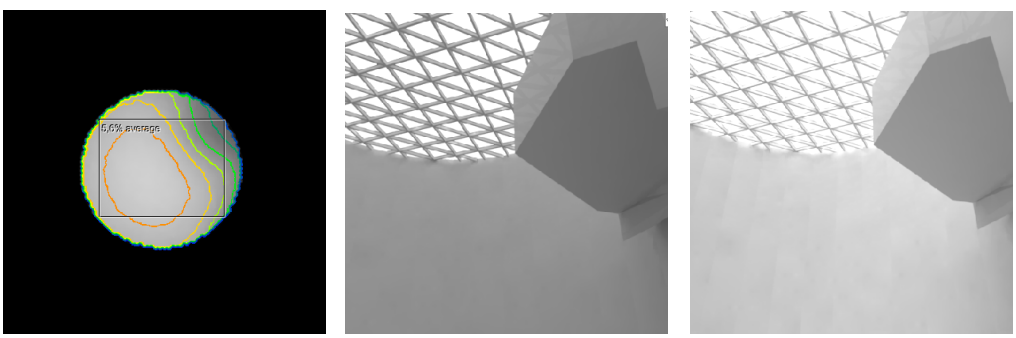
Ill. 85 New energy consumption in the Middelgrund Fort

APPENDIX C

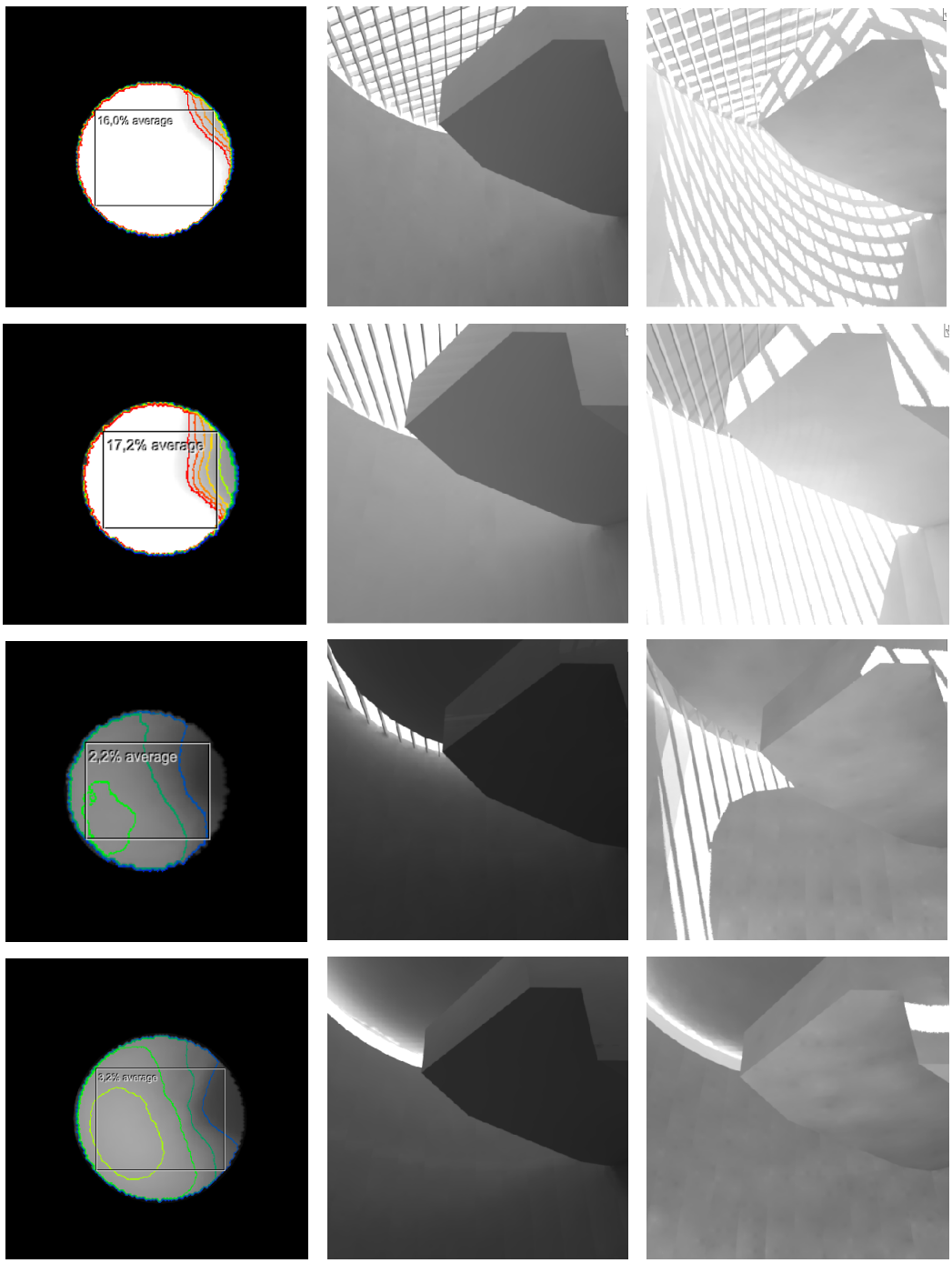
VELUX VISUALIZER

LIGHT VOID

Indoor lighting conditions, in both overcast and sunny weather, is investigated in the light void using Velux Visualizer. The daylight factor shows a range from an average of around 2,5% to 14,8%. Both the overcast and the sunny visualizations exemplifies how large of an influence daylight and along with the roof structure, has to the overall appearance in the space. A daylight factor above the regular 2% is desired. Investigations made with a roof containing purely glass, show that the room would not be able to sustain a satisfactory the indoor climate, as the amount of solar radiation would be too high. As such a solar shading film is implemented, lowering the daylight factor to a more comfortable level and preventing overheating.



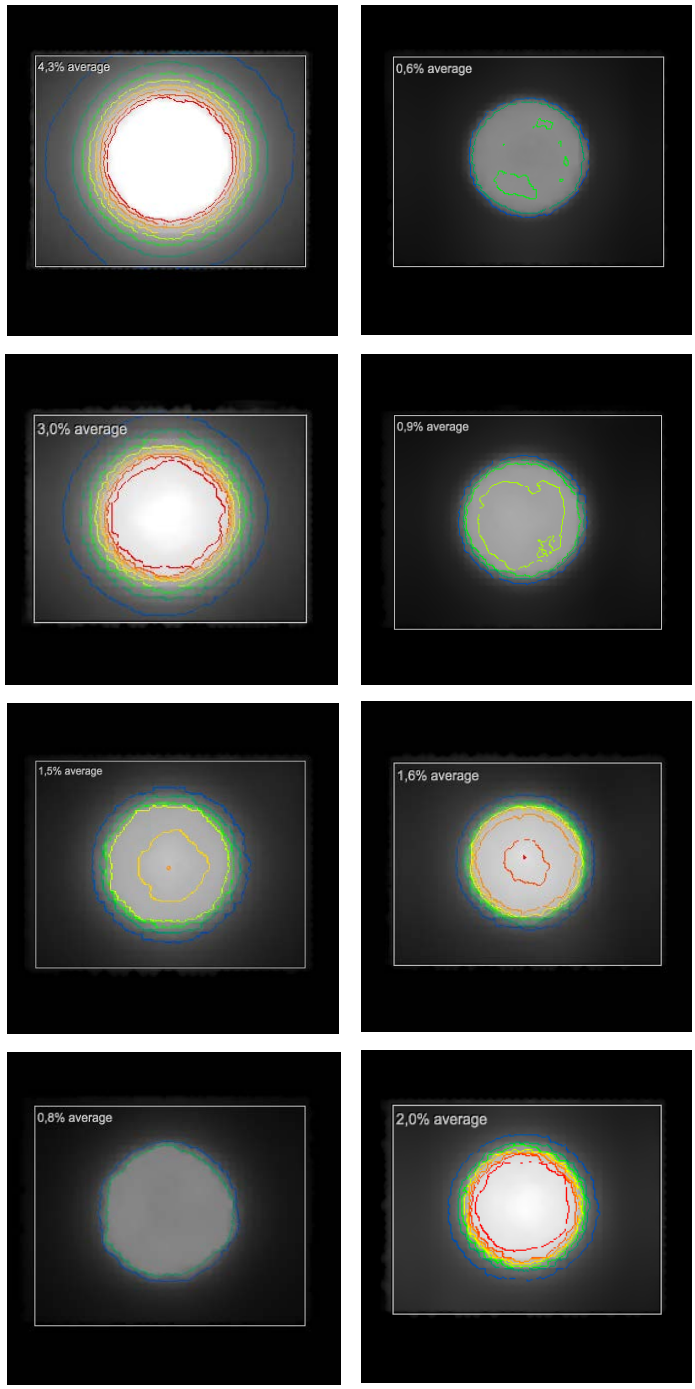
Ill. 86a Left: Daylight factor with final roof. Middle: Overcast illustrations with final roof. Right: Sunny illustrations with final roof.



Ill. 86b Left: Daylight factor with different roof types. Middle: Overcast illustrations with different roof types. Right: Sunny illustrations with different roof types.

LIGHTHOUSE

Differentiating heights and openings of the lighthouse is tested, to ensure a satisfactory daylight factor. Tests show that when using a closed facade with a roof opening, the results differ greatly, depending on the height and width of the structure. By replacing the closed facade with glass, the dependency on a low height is removed. This ensures a solution with a height of 20 meters and 14 meter width, supplying enough daylight while retaining a slim and aesthetically pleasing look.



Ill. 87 Left: Daylight factor with increasing height (0m, 5m, 10m and 15m). Right: Daylight factor with increasing bottom opening (Diameter: 10m, 12m, 14m and 16m).

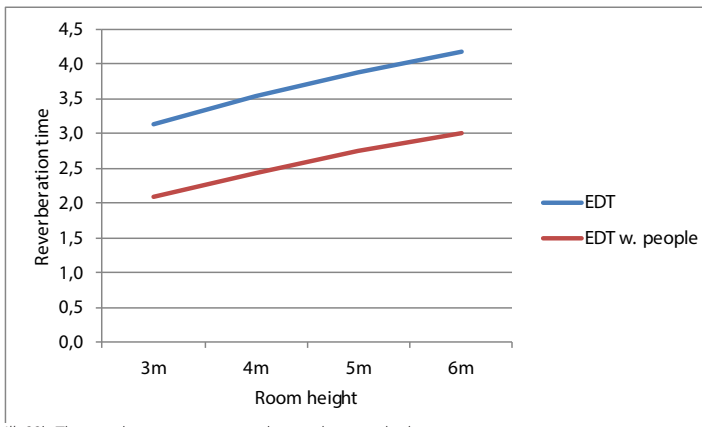
APPENDIX D

ACOUSTICS

As concrete is the main building material, acoustical investigation are required. With the amount of hard surfaces, reverberation time test are important to obtain satisfactory sound conditions. Reverberation time is defined, as the time it takes the sound level to drop 60 dB. Using Sabines method for reverberation time, via a plug-in for Rhino called Pachyderm, the exhibition spaces are optimized. Changing the ceiling height proved to raise the reverberation time, due to the time it takes the sound to reflect. Furthermore different materials were investigated on the ceiling to lower the value. An estimated reverberation of 1 second was desired, as this would naturally force visitors to lower their voices. This was achieved through the use of perforated concrete, while additionally guarantying a a coherent aesthetic look. The diagrams show the result of these investigations as well as the absorption coefficients used in the simulations.

	Frequency Hz					
Material	125	250	500	1000	2000	4000
Rough concrete	0,02	0,03	0,03	0,03	0,04	0,05
Perforated concrete	0,36	0,44	0,31	0,29	0,39	0,25
Perforated plasterboard	0,45	0,70	0,80	0,80	0,65	0,45
People	0,25	0,35	0,42	0,46	0,50	0,50

Ill. 88a Absorption coefficients



Ill. 88b The reverberation time according to the room hight.

Ill. 88c Test 1 - The reverberation time according to material.
Test 2 - The reverberation time according to material with people in the room.

APPENDIX E

VENTILATION PIPES

When calculating the pipe dimensions for the ventilation, the flow rate found to be 0,26 m^3/s in Bsim is used. The ventilation rate cannot exceed 2 m/s in order to avoid noise from the system.

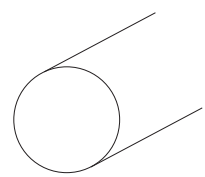
By isolating the radius in the flow rate formula the radius can be found:

$\pi * r^2 * v = q$
$r = \sqrt{(q/(\pi * v))}$

Adding the numbers multiplied by 2, the diameter of the pipes can be found:

Exhibition room:

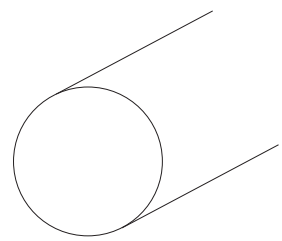
$r = \sqrt{((0{,}26\ m^3/s)/(\pi * 2\ m/s))} = 0{,}14\ m * 2 = 0{,}28\ m \approx 28\ cm$



Ill. 89a Pipe size for exhibition room: d=28 cm

Light void:

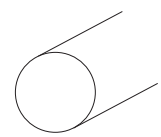
$r = \sqrt{((0{,}37\ m^3/s)/(\pi * 2\ m/s))} = 0{,}21\ m * 2 = 0{,}42\ m \approx 42\ cm$



Ill. 89b Pipe size for light void: d=42 cm

Office:

$r = \sqrt{((0{,}018\ m^3/s)/(\pi * 2\ m/s))} = 0{,}06\ m * 2 = 0{,}12\ m \approx 12\ cm$



Ill. 89c Pipe size for office: d=12 cm

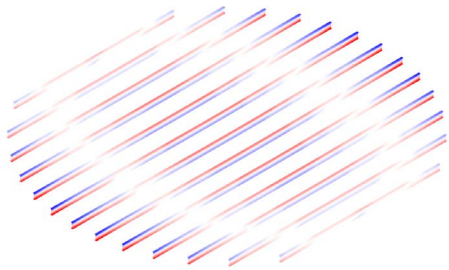
APPENDIX F

KARAMBA

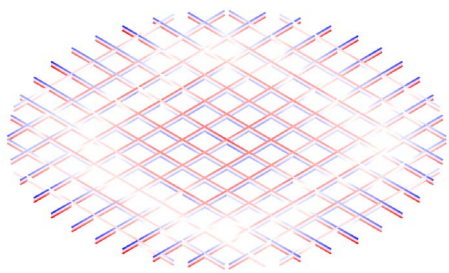
To ensure the structural integrity of the roof construction in the light void exhibition room, a 3D model was constructed in the parametrical design tool Grasshopper in cohesion with the structural analysis plugin Karamba. Three different models were made. The first being constructed only through a series of parallel beams. The second with a series of interlocking beams placed perpendicularly to the original beams, creating a square grid. In the third option, diagonal beams were added, which created a triangular grid system. A maximum deformation was determined to be:

dmax: L/200 = 140 mm

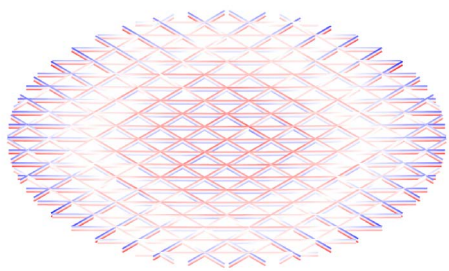
Steel IPE profiles were chosen, to keep the coherence of materials, while utilizing their structural strength. Size and width of the profiles were then tested in each structural analysis case. As the desire was to determine which system, would require the smallest profiles, the triangular grid system was chosen. This also established a coherence between the roof and lighthouse structure.



*Ill. 90a Perpendicular beams: 480 mm*178 mm*



*Ill. 90b Square grid system: 360 mm*143 mm*

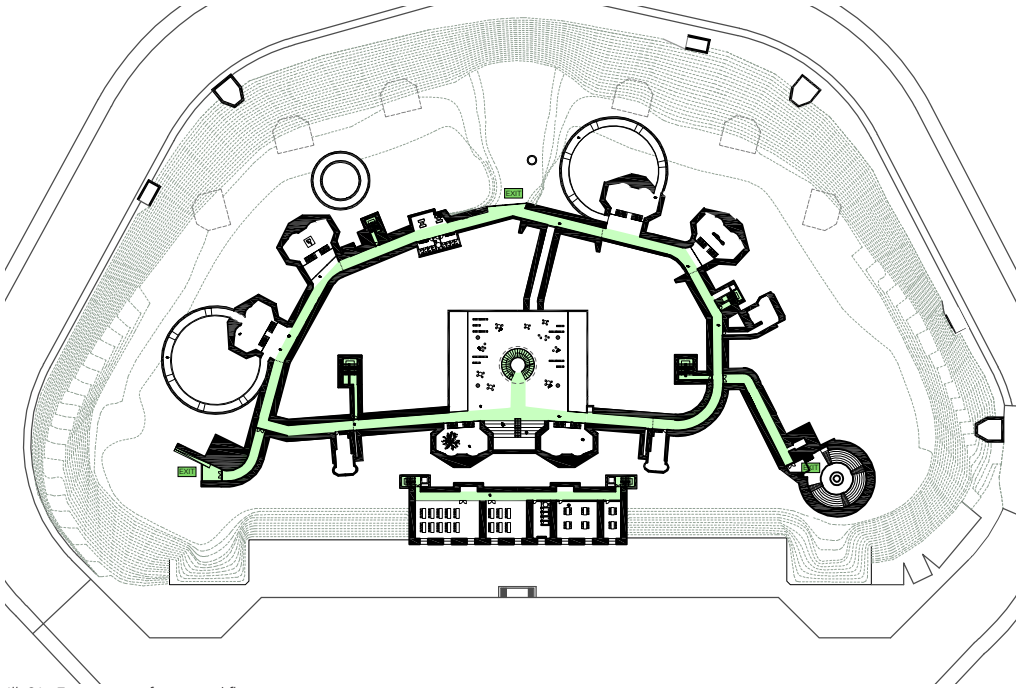


*Ill. 90c Triangular grid system (chosen option): 300 mm*125 mm*

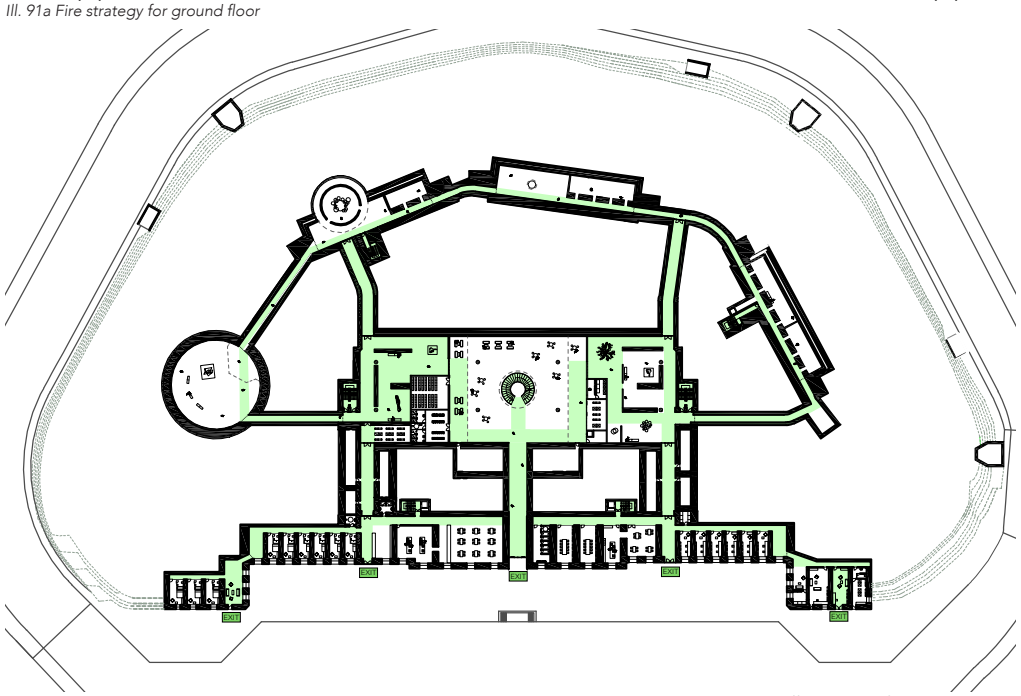
APPENDIX G

FIRE STRATEGY

Due to the fact that the building is underground, fire is an obvious concern. In case of fire, multiple exits are available on both floors, securing two escape routes from every room, as the requirements state (SBI 230, 2014). All doors open outwards in order to avoid panic, while dead-ends in hallways are avoided, making it easy to navigate to the exits, thus preventing visitors to get caught inside. All exits lead to terrain with a width of over 1,8 meter, making it accessible for wheelchairs, as well ensuring accessibility all around the museum. Each exhibition room is provided with smoke doors, to prevent smoke from spreding to other rooms. This will still, as mentioned earlier, keep the two escape routes from each room possible. On the first floor an exit is located towards three directions, where the ground floor exits are all facing the facade. Due to the size of the foyers, its central placement, it functions as a hub connecting all rooms providing three independent escape routes. These routes assure optimal conditions in case of fire. The plans are marked with green to indicate the escape routes.



Ill. 91a Fire strategy for ground floor



Ill. 00: Fire plans

Smoke doors

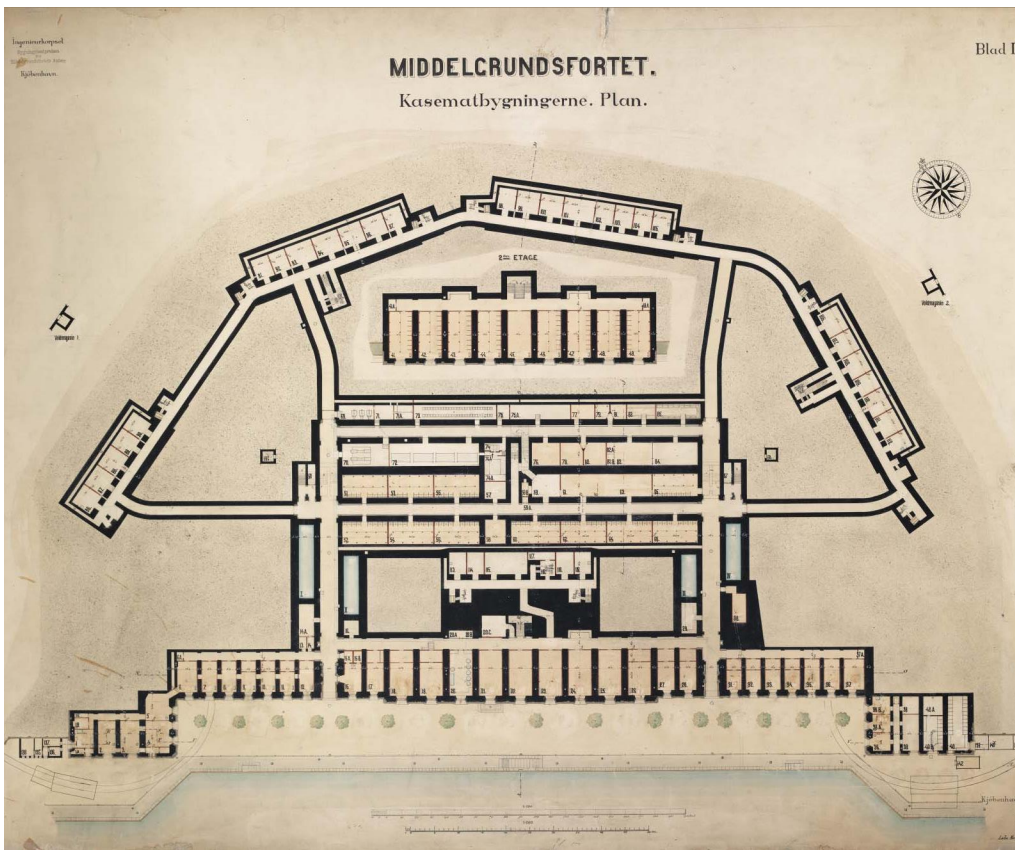
Escape routes

EXIT Exits

Ill. 91b Fire strategy for 1st floor

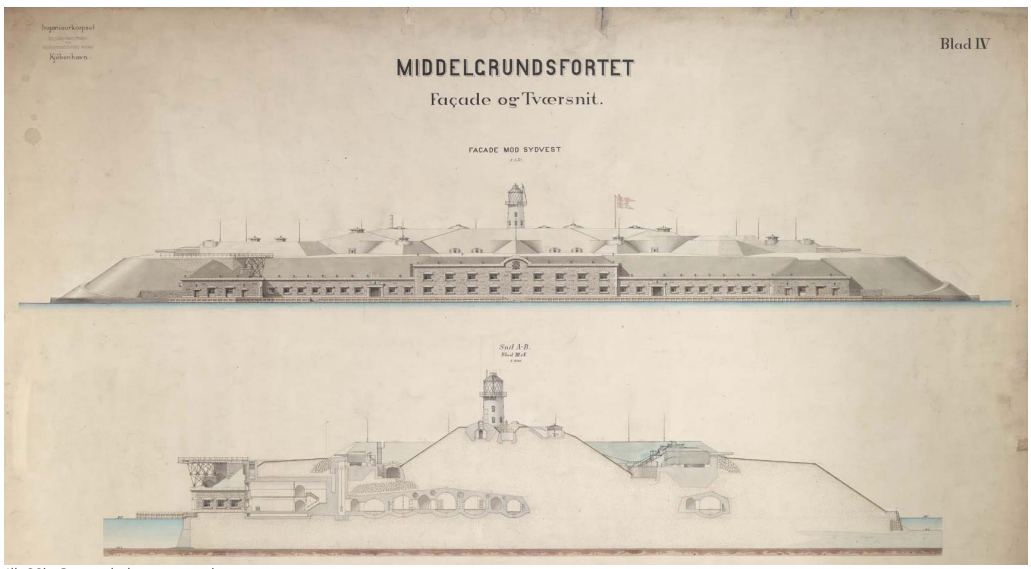
APPENDIX H

ORIGINAL PLAN - GROUND FLOOR



Ill. 92a Original ground floor plan

ORIGINAL ELEVATION, SECTION



Ill. 92b Original elevation and section