MORAS

Museum of Resilience and Sustainability

3rd of February 2016 - 25th of May 2016

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ABSTRACT

This master thesis proposes a museum of resilience and sustainability, as a response to a growing need for knowledge distribution. An empty site on Refshaleøen, in Copenhagen harbor, is excavated to place the museum within the water, giving the building a monumental expression, and actively integrating water as part of both building and exhibition design, creating an immersive experience. The water is used to display examples of resilient and sustainable solutions, and, through symbolic visual experience, increase awareness of the problematics. The museum utilizes the immersive experience, in combination with a characteristic narrative, to build an emotional journey through the museum. The goal is to inspire visitors to embrace the knowledge gained in the museum, and inspiring them to take action. The design integrates a tectonic approach to architecture to create a unique expression, making the museum in itself worth a visit, and creating a mood that emphasizes and amplifies the narrative.

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Content

INTRODUCTION

The inherent need for sustainability in architecture is slowly becoming acknowledged within the field, and as such, sustainability as a distinctive feature to market and showcase in a project is becoming less and less of a trend. In their resent book, Beim and Madsen (2014 p. 20-21) argue that the political agendas have forced changes upon the architectural practice and building trade is eliminating the proper empirical approach, and that the retrofitting required by these agendas also causes an unintentional, yet significant change in historical building culture. Recently an equal focus on resiliency has begun to emerge, and especially the resiliency towards a changing environment, but also resiliency in terms of social development in an urban environment, and as a result thereof, in an economical point of view. This focus is very visible in the recently finished competition 'Rebuild by design' (Rebuild by Design, 2016), which is a direct response to the devastation caused by hurricane Sandy, in the state of New York, and an immediate attempt to prepare for similar environmental events in the future.

Ill. 1Reflection of winter light in water at site

Motivation & Objective

In continuation of the abolishment of proper empirical construction, as discussed by Beim and Madsen (2014 p. 20-21), the tectonic approach, and the mindful integration of these future resilient solutions, can be seen as key elements in upholding some of the most important aspects of architecture, and what it provides for people, as the trade is influenced by global environmental consequences, and the strong responses by political instances that follows. These aspects are described in the following passage about the tectonic field, from Beim and Madsen's book.

"Defined by different terms throughout history, fundamental elements of building constitute central parts of the tectonic field: the material properties, the interaction between the physical dimension of construction and the creative force of construing, and the very technologies involved – tools, methods and ways to communicate. … one of the most significant aspects referred to in recent theories is its cultural dimension, given by its ethical importance and "its power to embody human situations", as voiced by Hvattum" (Beim & Madsen, 2014 p. 23).

It is in the collision between century old empirically accumulated knowledge of process and construction (and the construing, the thought that lies before), and modern and innovative technical solutions that a challenge emerges, a challenge that provides opportunity. The opportunity to adapt and utilize the technical solutions, and possibly even the issues, that caused the need for solutions, themselves. By seeing utilization and integration as a means to affect form and empower the narrative of the design, it might begin to assimilate properties and qualities usually ascribed to vernacular architecture, qualities that are equal or similar to that of the empirical approach in tectonics.

The objective is to utilize the knowledge and information center described in the COP21 agreement (United Nations, 2015 article12 p. 28) not only as a collection, but also as an exemplary institute in itself, an example of the architectural possibilities of the very knowledge it holds. Similarly, the climate adaptation plan by the municipality of Copenhagen acknowledges the fact that understanding of climate change and resilient solutions are both continuously developing, and therefore state a desire to focus on the knowledge sharing in connection with the climate adaptation work. The municipality sees the sharing of knowledge with the local community and the users as a key element in successful adaptation (Municipality of Copenhagen 2011, p. 7). While the climate change prognoses for the next 30-40 years are relatively accurate, after this point the estimations are characterized by uncertainties, based upon the variables of human interaction and intervention (Municipality of Copenhagen 2011, p. 9). This emphasizes the importance of continuous research, development and an underlying knowledge sharing, to ensure an optimal and successful adaptation, providing substance for a museum and information center. The museum should contain exhibitions that are informative and didactic at the same time, ranging from the background knowledge on global warming, that has made sustainability and resiliency a necessary step in the architectural development, to the exemplary knowledge on how to effectuate solutions.

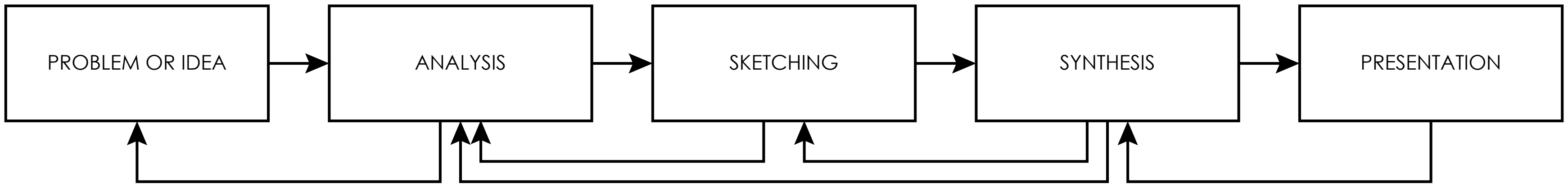
METHODOLOGY

Problem based learning

Problem based learning, PBL, is the basic educational model for Aalborg University. The main principle of the model is to educate students capable of identifying problems and creating rational solutions for these problems (Knudstrup, 2004 p. 894-895). PBL serves as a very effective gateway to the architectural industry, as the working methods are directly related to the way architectural offices approach their projects. The educational model has a large focus on teaching the tools to further investigate and understand research and developments at the highest level, and for the Architecture and Design degree at Aalborg University this includes successfully integrating technical engineering solutions in an architectural project, the design process is further explained below, as described by Mary-Ann Knudstrup (2004 p. 894-896).

Integrated design process

An integrated design process is the holistic incorporation and development of architecture and engineering to create a more throughout integration of technical aspects in building design, in a both aesthetical and functional point of view. This diagram, which is a simplification of a much more complex mental process, illustrates the five phases of the integrated design process, and how knowledge gained creates loops in an iterative process, as the acquired knowledge is used to redevelop and reconsider previous statements, parameters and ideas. (Knudstrup, 2004 p. 895)



Ill. 2. Integrated design process

Problem

The first step in creating a framework for the project, is to identify and describe a problem and/or define and describe an idea. One shape of such a description could be a design brief from a competition. The problem or idea is accompanied by investigations and research on the focus areas of the project, in this particular project; a tectonic approach and a focus on the integration of resilient solutions in architecture. This phase consists mainly of hermeneutic analyses of documentation.

Analysis phase

During this phase the information relevant to the design must be gathered and processed. The analyses can be further investigations in the problem background, which help elaborate on the need for a solution and maybe even begin to specify the type of solution required. The analyses phase consists of both a hermeneutic analysis of documentation and relevant information such as microclimate, mapping of infrastructure, historical context, local plans etc., and empirical observations and phenomenological studies of the site and context, and possible reference cases. One such method could be Serial Vision developed by Gordon Cullen (1971)The analysis phase is a means to informing the design, and covers both architectural and engineering aspects, and the result is a programme for the building and the overall aim of the project.

Sketching phase

In the sketching phase the goal is to combine the knowledge and information, gained in the previous phase, into an idea, which, based on architectural and engineering professional knowledge, seeks to solve the problem, determined in the first phase, in an integrated way. The sketching phase relies heavily on an iterative process, where the knowledge gained from sketching one idea, helps inform and better the development of the next sketch proposal. Evaluation of different ideas must be based on the degree of which they fulfil the architectural vision, as well as how well they comply with functional and technical demands for the building. It is imperative to repeatedly estimate how choices in plan, form etc. will affect the buildings capability to meet the technical and functional requirements, and how these choices and requirements inspire each other. As ideas are further developed, various modifications should be evaluated through simple means of calculation and estimation, and the results used as a baseline to gain insight in which parameters are affected, and how, when the form and layout changes. This insight serves as a tool to make well-founded design decisions. This phase is based upon both analogue methods, such as physical models and hand sketching, and digital sketching tools, incorporating technical evaluation tools such as those taught by professor Dario Parigi in the Performance Aided Design course on the first master semester.

Synthesis phase

Through the synthesis all requirements and ambitions are attempted merged into one, and the building finds its final form. The synthesis phase should be an iterative process interlocked with the later stages of the sketching phase, ensuring that a holistic project is created, which considers the contributions to the atmosphere and narrative that forms the architectural vision, right down from the scale of the joint to the scale of the entire building. All parameters of the project should be optimized, and more throughout technical calculation models are applied to document the qualities of the technical solutions of the project.

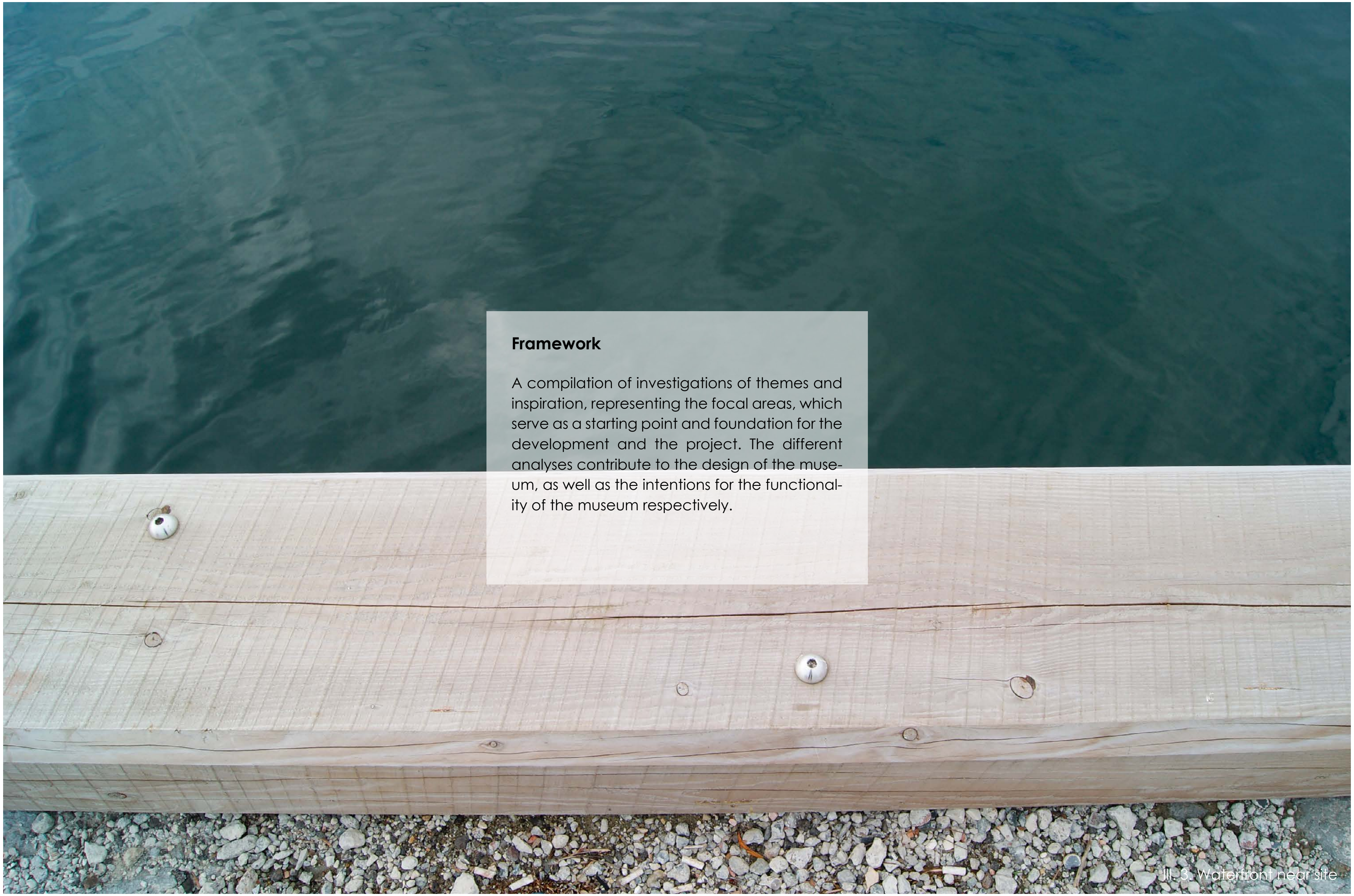
Presentation phase

The final phase utilizes all the traditional architectural presentation methods, such as section, plan and perspective, to display the final proposal and its qualities. The presentation must elaborate on how the original problems and idea were addressed, as well as an evaluation of the integrated design process and its intermediate results. The choice of presentation material should reflect the atmosphere and narrative of the building, staging both its architectural, functional and technical qualities.

ANALYSIS

Framework

A compilation of investigations of themes and inspiration, representing the focal areas, which serve as a starting point and foundation for the development and the project. The different analyses contribute to the design of the museum, as well as the intentions for the functionality of the museum respectively.



Ill. 3. Waterfront near site

THE ARCHITECTURE OF MUSEUMS

A place in society

Historically the museum began as publication of private collections. Art and archeologic ensembles made increasingly available to the general population, at first in their original habitat or first place of gathering, the home of the owner, and later in reinvented, yet dedicated, palaces. Art was no longer just a means for pleasure, it was also expected to be instructive, fulfilling the ambition of an ability to improve humankind itself, culminating with the first national collection at the Louvre in 1793. Inspired by the collections made public, new, designated and purpose-built museums began emerging in the 1820s, heralding a new way of considering art, it was no longer just a pleasurable leisure, or a didactic tool, it was becoming a secular religion in itself. As a church is a place of worship for God, the museum would become the place of worship of art (Newhouse 2006, p. 46-47).

"However, unlike church chapels and altars, modern museums eventually banned all architectural articulation for fear that the eye might stray from the art; also frequently banned was natural light—so often inspirational in its effect in religious buildings." (Newhouse 2006, p. 47).

Contradictory to this genuine dedication to the purity of art display, the public museums were, at first, criticized for their sterility and lack of context, a huge contrast to the display of art in a palace, to which the art was originally commissioned.

"Particularly in Italy many of the greatest works of art were to be found in sacred spaces in cathedrals, churches, even small rural chapels—where they were an integral part of daily life." (Newhouse 2006, p. 47).

Again the Louvre was on the forefront of the creation of the term museum, as it established the precedent for abducting artwork from its intended context, and collecting it in an isolated location. Not only the sterile, modern, purpose-built museums were under critique for lack of context, even palaces as rich with history as the Louvre were argued unable to provide sufficient recompense for what was lost when art was removed from its original context. A contemporary Italian poet, Filippo Marinetti, even went as far as describing museums, and libraries, as cemeteries, which must be destroyed (Newhouse 2006, p. 47-48).

The sacred space

The puritan development in the architecture of museums continued into the 20th century, and the interiors became decreasingly contextual. A development that resulted in extremes, such as the Museum for a Small City, by Mies van der Rohe, 1942, in which an open floorplan, freestanding white walls and a glass box exterior would completely abstract any resemblance to the palaces, intending to provide the optimal conditions for a clearing of mind, to not just view, but think and contemplate. In the following decades multiple approaches to the museum were explored. Connection between the exterior and interior, supporting a

Ill. 4 Solomon R. Guggenheim Museum, New York, Frank Lloyd Wright

revival of entertainment as a basic purpose for the institution. A postmodern attempt to restore visual context. Dynamic interaction between the content and the frame and space, between art and architecture. But above these changes in approach, lies an overall idea of the museum as a sacred space. To this day museums are sometimes still designed as sacred spaces, but not always with positive results, as the purity can often result in anonymity (Newhouse 2006, p. 49-50).

"The handling of light, scale and texture plays a part in determining the fine line between a museum that works and one that doesn't, and nowhere are these more important than in museums created as sacred space." (Newhouse 2006, p. 51).

Entertainment

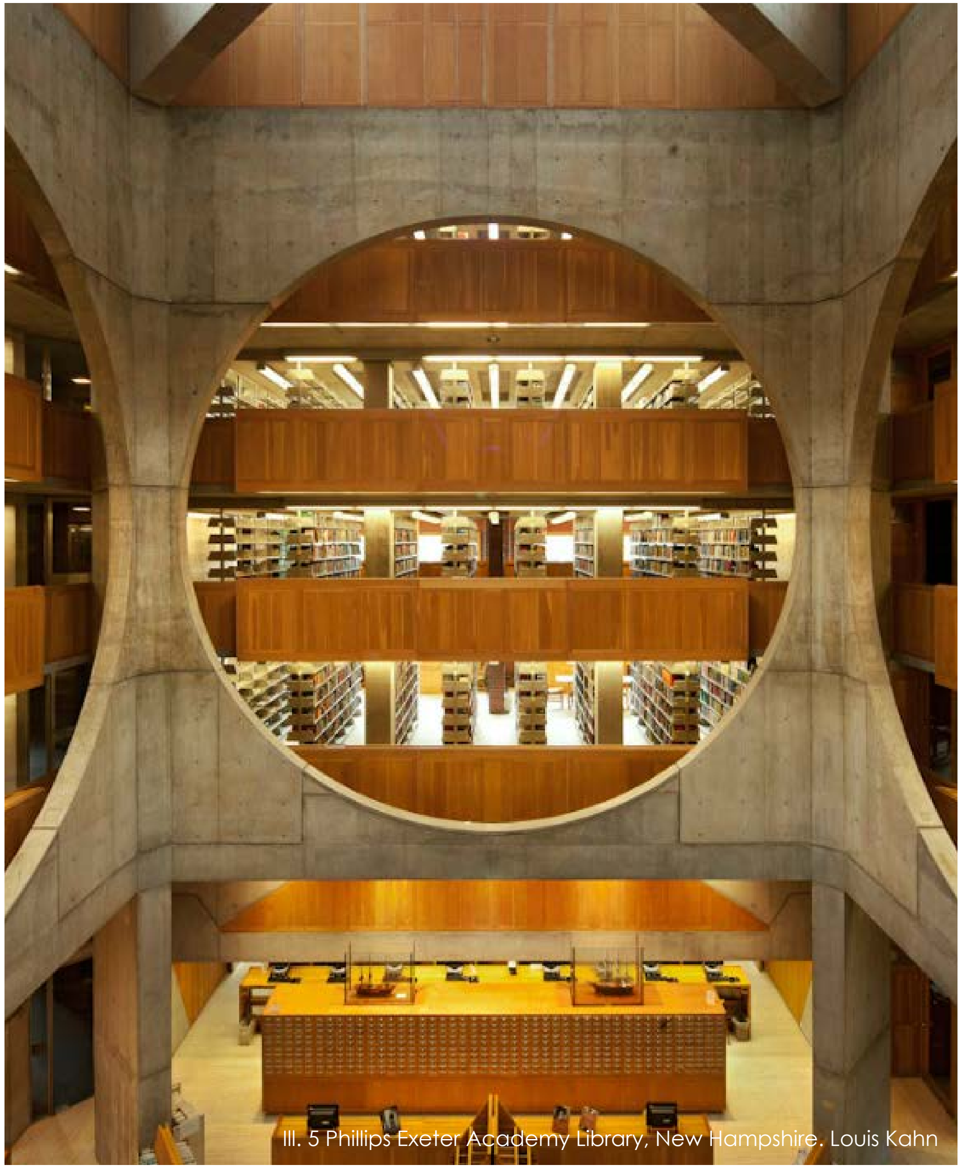
Despite the intrinsically didactic history of collecting art in a neutral space to embellish a focus on the artwork and the underlying lesson, museums are now widely perceived as institutions for entertainment. This perception is, in a way, coming to terms with the museum origin, as a private collection devoted to amazement and delight. However, it does not entirely part with the duty of enlightenment, as endorsed by the sacred space museum, as historian Yve-Alain Bois explains; "If it's odd enough, interesting, strange or funny it will make the beholder want to know, to think." (Newhouse 2006, p. 191). In part a necessity due to economic situations, the entertainment value of a museum is a contrastingly different approach to museums, compared to the sacred spaces. The line between dignified entertaining and commercialism is a thin one (Newhouse 2006, p. 190-192), and one could argue that the integration of the entertainment and information exhibited in (and collaboration with) the architecture is crucial to keeping this line.

"Museums are no longer places to preserve works that have lost their social, religious and public functions, but places where artists meet the public and the public becomes creative." Pontus Hulten, the first director of the Pompidou (Newhouse 2006, p.193.)

Neutral or active

The discussion whether museums should actively address the exhibition at hand, or passively highlight the work itself is ongoing, and has been since the very first purpose-built public museums. A perfect example of the new immersive approach to the relationship between artworks, architecture and the viewer is the Guggenheim in New York, by Frank Lloyd Wright. In his museum Wright focuses on the movement of the viewer, rather than the geometry of the space, allowing viewers to observe artwork in a rectilinear-free context, while also allowing the possibility to observe other viewers, and doing so from a multitude of perspectives (Newhouse 2006, p. 220-222). The active museum is gaining ground, it attempts to establish dialogue between the content and the container, a dialogue that will enrich both simultaneously, in doing so it resembles the historical context of artworks created for a specific space, such as the frescoes of Italy (Newhouse 2006, p. 312).

TECTONIC APPROACH



Ill. 5 Phillips Exeter Academy Library, New Hampshire. Louis Kahn

In a way, the tectonic approach can be described as simply as the means to transform the construing into the constructed (Frascari, 1995). As an architectural definition, it covers the process of turning an idea, a sketch or an expression only existing in thoughts into something physical, a building, a construction detail or a chair, but doing so with a special focus on the connection between the idea and the finished result, a special focus on the process itself. Tectonic architecture is the creation of spatiality that interacts with people, inspiring a very specific reaction and atmosphere; it is the materialization of a gesture. In her Ph.D., Marie Frier Hvejsel (2011 p. 71) uses the term 'gestures', to spatially describe the interior's inherent ability to create a unique 'stimmung', as first explained by Praz (1964). In this thesis, the expression is used, and broadened in meaning, to cover the entire building's ability, through materiality, detailing and space, to create atmosphere and reactions in people, not just the interior.

Tectonic architecture, in its modern form, emerged as a counter-reactive response to a series of events in the modernization of society. Industrialization, with the focus on prefabrication and mass production that it brought, and increasing specialization of many competences within the building trade, has changed the way architecture is practiced. The architect is facing an increasing amount of administrative work in the office, while on-site project and construction management and quality control is now often performed by specialized consultants. This means that the construction and the constructed is being distanced from the architect, and thus from the construing. The increasing specialization also means that large parts of technical construction problems are often being solved entirely without involvement of the architect and the design process that goes with. This exclusion is strongly related to the increased lack of architectural companies that immerse themselves in the development and advancement of new construction techniques and materials. In a trade where standardized solutions are mass-produced, this is having a vast effect on the general expression of modern architecture. This poses the question whether architectural design controls building practice, or the other way around? (Beim, 2004 p. 11-19). If you rewind to the origin of the word 'tectonic', you arrive in ancient Greece, and it is in the etymology the word that you will find the essentials of the tectonic approach. In Greek the word was used as a description of an artisan, a 'tekton' was a builder. In the works of Homer, it appears as a reference to the very art of construction (Frampton, 1995 p. 3-5). So the word implies a general concept of creation, the specific method is not the focus, as it was used to describe everything from poets, to carpenters and even animal breeders, the real focus was on the process of manufacturing, producing and creating. (ed. Beim & Madsen, 2014 p. 26-27).


Ill. 6 Bagsværd Church, Bagsværd. Jørn Utzon

"A process is initiated in a way that goes beyond what is customary, applying an elevated awareness and understanding. It refers to a creative process of a particularly high status: the work of a skilled carpenter, a master, a master builder, an artist. That is, someone who constructs, assembles or processes his material in such a way that something which surpasses the specifically pragmatic is created." (ed. Beim & Madsen, 2014 p. 27)

The tectonic continues to be, in spite of a continuously more complicated and diverse building trade, the masterful processing of materials, of the detailing and often the natural properties of the building materials, and even the natural properties of the construction itself, and its details. It is the utilization and processing of the construction and construction method, particularly in the detail, on a level where it becomes something more, something that creates gestures capable of embodying human situations.

NORDIC ARCHITECTURE

Nordic architecture is known globally for its elegant use of natural materials, with an unwavering focus on detail, quality of daylight and a strong connection to the surroundings (Lund, 2008). When creating a museum, which exemplifies good sustainable architecture, it is important to look beyond the newest solutions and developments of building materials and methods, and to understand building traditions. Local vernacular architecture serves as a lecture on how to deal with environmental and climatic conditions, and therefore it is very relevant to explore the essence of Nordic architecture.

The harsh climate conditions in the Nordic countries meant that there was a need for producing solid and long lasting constructions. By sharing nearly the same history and profession through time, the Nordic countries have developed close to the same building traditions, traditions that revere a rationalized and functionalistic approach to design (Lund, 2008). In the countries closer to the North Pole, like Sweden, Norway and Finland, the main traditional material is, due to its vast abundance and easy accessibility, timber and thus they have evolved a great skill for woodworking. In Denmark a tradition for building with bricks emerged, but timber wins more and more ground, with its unique potentials in the form of glulam. The style has stayed relevant because of a combination between the functionalistic and rational approach and the architectural development through the industrial revolution, with new technologies, modernism and welfare. This formed Nordic architecture, as it is seen today, with its unique attention to simplicity, yet strong focus on elegance (Sommer, 2009)

As a consequence of the long winter months, the light in the Nordic countries is a limited resource, and therefore the architecture has evolved into almost worshipping this needed light and it has become one of the intrinsic essences of Nordic architecture. The light has an important role in a building and how you experience it. It can set the mood in room, entirely alter the human perception and create spectacular dramatic effects in rooms or materials, by creating contrast between shadow and light (DAK. 2014). Light is very important for the overall impression of a building and especially in a museum/knowledge center, where, both artificial and natural, light plays a pivotal role in staging exhibitions, and setting the proper atmosphere, depending on which mood and reaction the exhibition seeks to inspire in the viewer.

Some of the Nordic masters in controlling light in buildings are for example Jørn Utzon and Alva Alto, who was the first to get international recognition with their Nordic regionalism. It was the contrast between the devotion to the quality of tactility and materiality of the Nordic style, and the impersonal International Style, that first opened the eyes of the world to this style, which continues to inspire to this day (Kjeldsen et. al. 2012.).

One of the other prime elements in Nordic architecture is the sensing of place. Capturing the special relation to the site, historic and contemporary, and especially to the nature around it, which is a theme that all the Scandinavian countries emphasize (Kjeldsen et. al. 2012). The theorist Christian Norberg-Schulz calls this ability to sense the place Genius Loci, and the Nordic aptitude for understanding this

Ill. 7 Private Residence Vega, Norway, Kolman Boye Architects

Ill. 8 Juvet Landscape Hotel by Jensen & Skodvin

is based on the humble notion that the place is something bigger and more than the inhabitants.

"The experience of a place thus is not just a question of taste. Place is an objective thing: it is the way it is, whether we like it or not, and it will reveal its secrets and its riches if we ourselves open up and listen to its spirit." from Norberg-Schulz, A Place to Be: An Afterword, 1986, p. 309 (Kjeldsen et. al. 2012, p. 36)

The place shapes and defines the inhabitants and shapes the foundation for life around it, but is in turn defined by the identity and lives of the inhabitants (Kjeldsen et. al., 2012). It falls to the architect to understand and interpret this relation between place and inhabitant, and to translate it into architecture that will strengthen this bond.

GLOBAL WARMING

Since the beginning of the industrialization, the human population has been increasing rapidly, and so has our consumption of natural resources, specifically the use of fossil fuels. Fossil fuels are unsustainable due to a limited supply and, more urgently, due to their pollution of the environment. The emission of greenhouse gasses is now widely recognized as being the cause of global warming, which in turn is causing severe climate changes, which can already be measured and felt across the planet. The climate changes include record breaking high temperatures and an increase in intensity and frequency of intense rainfall events (Nasa 2016). While progress in sustainable green energy production is being made, in order to combat the emission, a majority of the global transport and energy production still relies heavily on fossil fuels. In 2014 only 30% of Europe's total electricity production was from renewable sources (Enerdata 2015), and the situation in many of the world's developing countries is much worse, and a sustainable future is even more distant for them. Between 40 and 50 percent of the total European energy consumption comes from the construction and operation of buildings (ed. Beim, A. & Madsen, U. S., 2014 p. 21)

Ill. 9 Flooding in the streets of Copenhagen

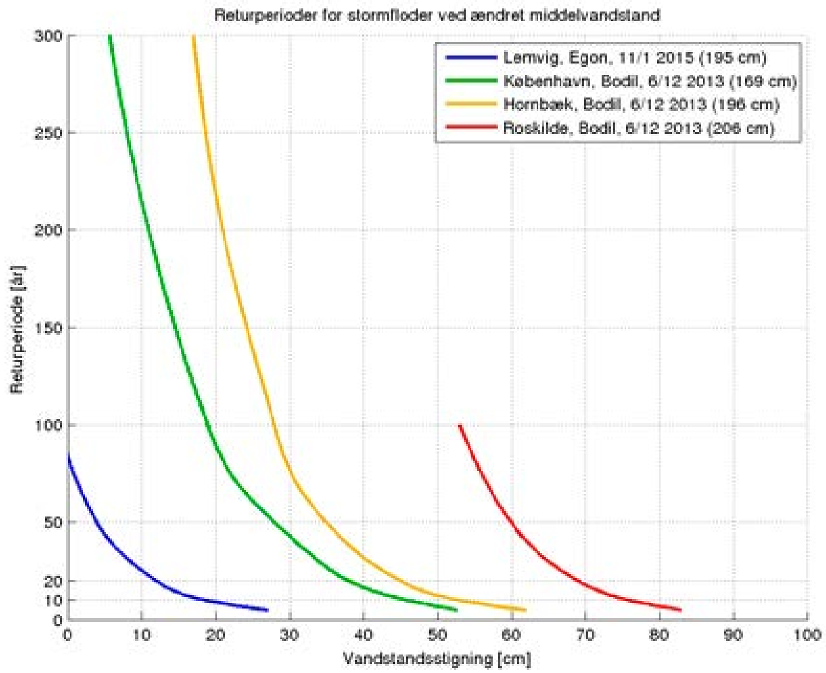
Danish context

In Denmark the average temperature change, in itself, is unlikely to have a direct critical effect, yet the consequences of the effect on the global environment will be noticeable. The country will not only get warmer, but will also see an increase in average rainfall, increase in intensity and frequency of intense rainfall events and powerful storms (Climate adaption, 2015). DMI (2016) base their estimates of the climate change impact on multiple different scenarios, the two extremes being; In a best-case scenario, the emissions top by 2050 and then begin to reduce.

In a worst-case scenario, the emissions continue to grow long with the increasing population and consumption.

This means that the sea level can be expected to increase by 34 to 64 cm before 2100, depending on which emission scenario is used for calculation. While this might not sound like an extreme consequence, the result of a 0,5m sea level rise, would mean that a 100 year event in Copenhagen, would now be a 2 year event (Climate adaption, 2015).

In a relatively flat country as Denmark, the threat of flooding and rising sea levels is considered the most severe consequence. The Danish government has identified 10 places in high risk of flooding, and have throughout documentation of the effects on the areas, one of these areas being Køge bugt, which includes the southern parts of Copenhagen. In a risk estimation, risk defined as the probability of a flood multiplied with the estimated damage cost in such an event, the government evaluates that the risk will increase almost exponentially within the next 100 years, resulting in astronomical damage costs (Municipality of Copenhagen 2011). In order to minimize the impact of the environmental changes, especially in the 10 risk zones, the government has developed an action plan for the climate protection of Denmark, which will be explained in analyses, elaborating on the specific actions planned for the local areas.



Ill. 10 Risk of flooding

SUSTAINABILITY

Sustainability, in its current form, was first described in the Brundtland report from 1987, which was the first time global sustainability was addressed. The report split sustainability into three major categories; environmental, social and economic (DAC, 2014). In one form or another, it has always been a part of architecture; however, the form-defining focus that it is receiving in the current era is unprecedented. Countries, among these is Denmark with its 2050 plan, are applying a growing regulative pressure to reach emission reduction through the building sector. Recently the UN climate panel finalized the historical COP21 agreement, which sees a large portion of the world's governments pledging to commit, and reduce their emissions.

Holistic Approach

As a response to global warming, the building industry has been focusing increasingly on sustainability in the past years. Systems have been developed, to rate buildings on how sustainable they are. Most of these systems are based on the holistic approach set forth by the Brundtland report, with its three main categories of sustainability. The variety of criteria has been ever growing since, in order to improve the holistic view on the building process, and thus attempting to work towards a better and more sustainable future, that considers the entire life cycle of a building, its inhabitants and its surroundings, both locally and globally.

When looking at a Holistic approach for sustainability in the museum, the DGNB certification system can be used as a basis of approach (DGNB System, 2016). The system is flexible towards different building typologies. It rates the sustainability of a building through five main categories; environmental, economic, sociocultural and functional aspects, technology, processes and site. In the system, the first four categories are all weighted equally when rating a building, promoting the holistic approach, avoiding a tunnel vision on any specific category. The use of a combined rating system encourages management of all categories simultaneously. A different approach could be the one applied by Lendager Group. A central focal point of their approach, which is otherwise based on the DGNB system, is a resource awareness. The resoureces are divided into five categories:

Biodiversity, this could be a green roof or opportunities for self-sufficiency for the cafeteria.

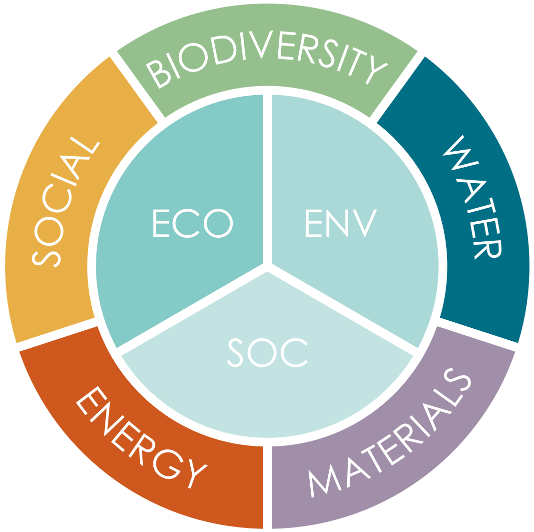
Water, an example is rainwater collection for toilet flushing.

Materials, here it could be recycled materials or designing for disassembly.

Energy, Solar energy, natural ventilation etc.

Quality of life, which is about a good indoor climate, common functions, individuality, accessibility, etc.

A key aspect of all five resource categories is that they attempt to provide both social, environmental and economic advantages for the inhabitants. E.g. upcycle materials benefit the environment, as the production thereof emits less CO^2 compared similar products, the materials have no toxicity, and thus provide a healthier indoor climate, and in addition they can be produced cheaper than equivalent newly-produced materials (Lendager Group, 2016).



Ill. 11 Resource awareness wheel


Ill. 12 Habor front on Refshaleøen

CASE STUDY: ØKOLARIET

Økolariet is a science- and experience center in the city of Vejle, in Denmark. Here visitors can acquire knowledge of community related subjects, through exhibition, education and events, informing on both local, regional, national and international problems and solutions.

The center is one of the many initiatives birthed by Vejle municipality's ambitions as a resilient and smart city. The city is a member of the "100 resilient cities" network, and recently published their strategy plan, the first of its kind in northern Europe. The city is one of 10 critical zones appointed by the Danish government as being particularly vulnerable to the effects of climate change. Vejle is situated in an area threatened by water on all sides, as the fjord, downhill streams and a generally low elevation leads water into the city during storms. Vejle, much like our project, therefore has a strong focus on the city's resiliency towards water, and Økolariet is a means to educating the inhabitants on the consequences, as well as the solutions planned, but also as a means to collaborating with students and industry alike, in order to develop new methods of adapting. The architects of Vejle municipality state a strong desire to always use the necessary solutions to add soft value to the city, e.g. a new dike through the harbor, could also serve as a biking track.
The permanent exhibitions involve nature, climate, water, resources in a variety of scales. They teach about the forest, ocean, how groundwater is processed to become drinkable, climate change, waste and much more, in an immersive, experiencing way. By stimulating the senses in different ways, e.g. experiencing how it is like to be flushed out in the toilet, or trying to clean polluted water with different filters, the exhibitions are very accessible and comprehensible, even for young children. With the wide range of exhibitions, Økolariet provides a, in Denmark, one of a kind experience, with focus on climate change and resilient solutions.

Through a visit to Økolariet, and a meeting with the architects at Vejle municipality, we established an idea and intention for the contents of the museum. Especially the interactive and immersive approach was an inspiration, and the same approach is utilized in the museum, where workshops and lectures are mixed with exhibitions, to create a diversified experience, that, coupled with immersive exhibitions, strive to enhance learning. Through the insight in the city's resiliency plan we gained an increased understanding of what kind of problems cities in Denmark are going to face, and what they see as the optimal way of addressing the issues.

Ill. 13 Workshop


Ill. 14 Interactiv exhibition

Ill. 15 økolariet Vejle

CASE STUDY: UTZON CENTER

The Utzon center was built in 2008, and drawn by Jørn Utzon, and his son Kim. It is situated on the central waterfront in Aalborg, and contains exhibition areas, a café, staff area, a conference room, an auditorium and an architecture student workshop all in one. The museum has focused on architecture and art, with the use of workshops and a lecture room also revolving the subject, and in that way, it works as a knowledge center with a focus on art and architecture.

All the functions are arranged around a central courtyard, which provides a visual connection across the building, and a break area for visitors of the café, the exhibition, the auditorium, the staff as well as the architecture students. This merging of functions is also reflected in a visit to the center, where visitors are encouraged to experience the auditorium, with its large, curved glue laminated beams creating a unique spatial experience, framed by an unhindered view of the fjord. The student workshop connects directly, through glazed doors, to the hallway that circulates around the courtyard, inviting guests to include the students work as a part of the experience.

The center has served as a direct reference in terms of building scale, serving as a guiding example with room heights in the hallway surrounding the courtyard, and the scale of the roof height and façade in the auditorium. The successful combination of different functionalities serves as an inspiration for what to include in the museum, and how to successfully combine it all into a positive experience, regardless of which function is the reason for the visit.

Ill. 16 Utzon center courtyard and hallway

Ill. 17 Utzon auditorium

CASE STUDIE: HAFENCITY HAMBURG

Hafencity is a new district in Hamburg, Germany, and is one of Europe's biggest, current city development projects. Hafencity, as the German root of the name suggests, is located in an old industrial harbor area, much like Refshaleøen. It is under continuous development, with the first neighborhood finishing in 2009, and is expected to continue development until 2025. The district is subject to severe flooding risks during storm floods, causing an extreme local rise in sea level of up to 8 meters. The gradual development, which is financed by a large amount of individual, private developers, has caused the development plan to opt for each project to individually protect itself against the water, rather than constructing a new dike to protect the entire area all together. This was done to ensure that the district only grows at a speed, which it can be financially supported, and at which a society can grow in the new neighborhoods, and also to maintain existing sight lines, and connection to the water.

The individual protection is done by raising the buildings on 9 meter plinths, used primarily used for car parking. Large parts of the infrastructure has also been raised, in order to ensure that the district does not become disconnected from the rest of the city, and within itself, when storm surges do occur. Some of the buildings are fitted with 'flood gates', which, when closed off, protect the interior from the rising water. Long strips of historic quays along the water, have been restored, and the large areas of public urban space are well used, however they do completely flood during storms, and as they are lined by rows of private buildings, the public access to the waterfront is almost completely lost, until the water completely recedes.

Hafencity provides an example of large urban scale solutions for working with flooding. There is a large contrast between how the historic Speicherstadt and the new Hafencity address the problem, where the historical buildings prioritized the public domain remaining intact in its daily use, by intentionally designing the buildings to let the lower levels flood during storms, the new neighborhoods are all elevated, including infrastructure, to raise themselves above the water.


Ill. 18 Raised base


Ill. 19 Raised base

Ill. 20 Private buildings along the quay

CLIMATE ADAPTATION

In the already developed climate adaptation plans for Copenhagen, the municipality expresses a desire to maintain flexibility through the adaptation, creating synergy with other plans, creating investments that give returns in the shape of green growth and that the climate adaption solutions in themselves provide quality for the citizens and businesses. The mentioned flexibility covers the consideration of the scale of solutions compared to the probability and cost of, for example, a flood, combined (the risk).

Examples of qualities could be increased recreational options, new jobs, improved local climate and more green (Municipality of Copenhagen 2011, p. 9).

The plan is developed based on calculations by the FN climate panel, adjusted to a Danish context by DMI, which, among other, foresees an increase in the intensity of torrential rain by 20-50%, depending on the frequency, with the lowest intensity combining with the lowest frequency, and vice versa. E.g., a 10-year event rainfall will be increased in intensity by up to 30% progressing towards year 2100. In general, the rain will be condensed in smaller periods of the winter, meaning less rain in summer, but a larger yearly average, and therefore higher intensity when it does rain. The surplus water that the sewage systems cannot handle, even for normal rainfall, is lead through safety valves to lakes, streams and the harbor. To reduce the strain of unfiltered wastewater being lead into nature, the plan comprises an overall agenda to increase the temporary storage and delaying of rainwater, until the sewage, system can handle it, and it can be processed at the water treatment facility. The aim is to reduce the occurrence of wastewater running on the surface to once every 10 years (Municipality of Copenhagen 2011, p. 13-15).

This delaying and surface handling of the surplus water is commonly addressed as LAR (Lokal Afledning af Regnvand – Local diversion of rainwater). Calculations made by the municipality of Copenhagen (2011, p. 22) show that the implementation of LAR, redirection of water and high-water-valves in all basement has a large economical advantage as compared to increasing the capacity of the sewage system. It is both cheaper and has a larger potential in damage reduction, especially when including, but not limited to, the positive social capacities usually accompanied with LAR. In optimal situations, LAR detaches the rainwater entirely from the sewage system, and instead cleansing the water before redirecting it to existing water bodies, or percolating the water on site.

	Level 1	Level 2	Level 3
Geography/Actions	Lowering probability	Reduce extent	Reducing vulnarability
Region	Delay of rainfall in the river basin, pumping water to the sea	Delay of rainfall in the river basin, pumping water to the sea	
Municipality	Dikes, elevated building bases, inc. drainage capacity, pumping water to the sea	Preparedness Warning Ensuring infrastructure	Information , Moving the vulnerable features to safe places
City-district	Dikes, "plan B", elevated building bases/threshold	"Plan B" Ensuring infrastructure	Moving of vulnerable functions to secure places
Street	Managing stormwater runoff, elevated byggekote/threshold, local management rainwater	Managing stormwater runoff, elevated building base/threshold sandbags	Moving of vulnerable functions to secure places
Building	Backflow blocker, increased building base/threshold	Sandbags	Moving of vulnerable functions to secure places

Ill. 21 Climate adaption plan

	Scenario 1 sewer	Scenario 2 sewer backflow blocker	Scenario 3 sewer backflow blocker surfaces	Scenario 4 backflow blocker surfaces	Scenario 5 LAR backflow blocker surfaces
Base damage costs	15,552	15,552	15,552	15,552	15,552
Damage costs with measures	5.458	2.471	1.785	4.316	1.785
Savings	10.094	13.081	13.767	11.236	13.767
Actions	10.372	11.108	13.374	3.001	6.268
Net savings	-278	1.973	394	8.235	7.499

Ill. 22 Savings estimation of different scenarios

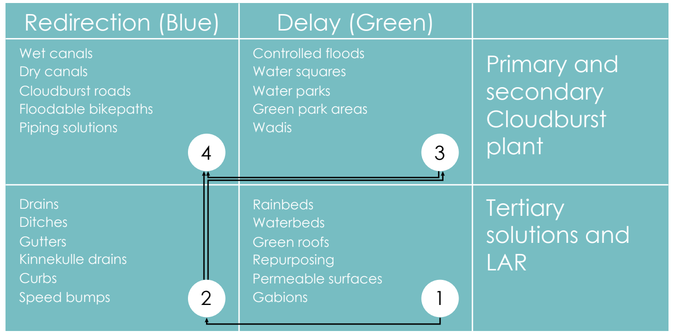
The municipality estimates that roughly one third of the water deposited in the sewage systems comes from roofs and paved areas, another third from roads and the last third from household wastewater, and therefore the major action required by individual buildings in the climate adaption plan, is the detachment of rainwater from the sewers. (Municipality of Copenhagen 2011, p. 26-27).

In an analysis of the combined risk of flooding, the municipality has deducted that the dominating factor now, and for the next 50 years, will be rainwater, as opposed to rising sea level. By 2010, the risk was assessed at 350 mil. DKK per year and by 2060 it will have increased to 570 mil. DKK, and to 1.050 mil. DKK by 2110 if no preventive measures are taken (Municipality of Copenhagen 2011, p. 24).

The municipality prioritizes tertiary and LAR delay solutions for the handling of storm water, however recognize the possible need for more drastic solutions in the more severe cases. The prioritized (green) solutions include gabions, green walls & roofs and permeable coatings (Municipality of Copenhagen 2013, p. 14).

While storm surges currently are not considered a high risk, the rising sea level will cause what is now a 100-year occurrence of 160 cm (storm surge increase in water level compared to average sea level) happen more than every 20 years, by 2060, and by then a 20-year occurrence would be 180 cm (Municipality of Copenhagen 2011, p. 30).

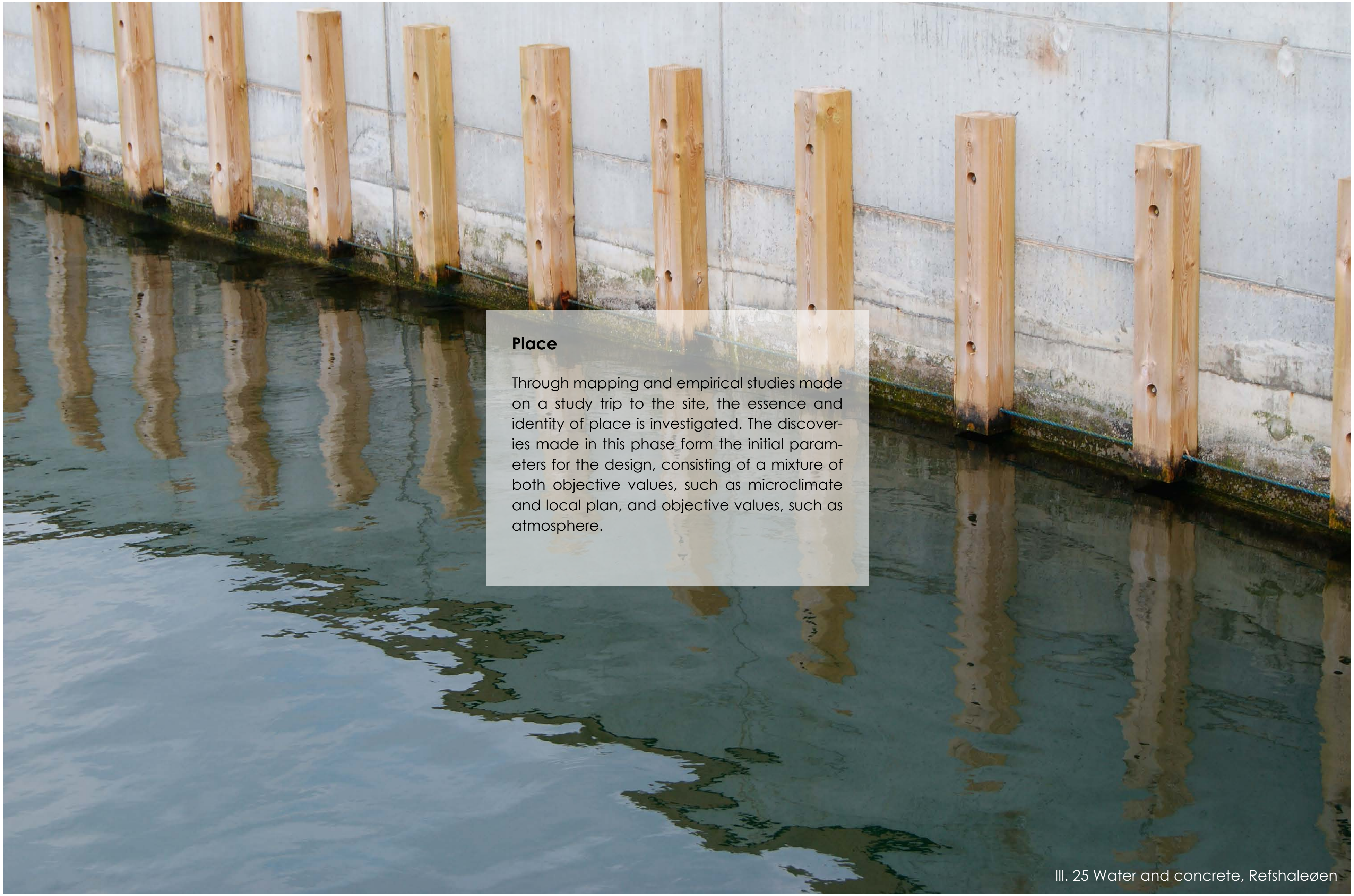
For the inner harbor, the municipality proposes to erect dikes, in order to prevent substantial damage to the city. However, for certain parts of the city, the establishment of dikes to protect everything would be too substantial, and in these areas the only other solution is increasing the elevation of the ground level of exposed building sites, or otherwise securing the exposed lower floor within the building itself, or in the immediate surrounding. Refshaleøen is within the boundary of the proposed barrier of dikes.



Ill. 23 Adaption priority schedule

Water level in relation to sea level (DVR90)	2010	2060	2110
20-year floods	139 cm	180 cm	233 cm
50-year floods	151 cm	194 cm	247 cm
100-year floods	160 cm	205 cm	263 cm

Ill. 24 Schedule showing how floding will change with sea level



Place

Through mapping and empirical studies made on a study trip to the site, the essence and identity of place is investigated. The discoveries made in this phase form the initial parameters for the design, consisting of a mixture of both objective values, such as microclimate and local plan, and objective values, such as atmosphere.

Ill. 25 Water and concrete, Refshaleøen

Ill. 26 Denmark

SITE

Refshaleøen was originally just a bunch of sandbanks sticking out from Christianshavn in Copenhagen (Refshaleøen, 2016), but the Christianshavn based shipyard Burmeister & Wain was growing rapidly, and from 1868 to 1872, Copenhagen's port authority filled out the banks to create an artificial island (Gyldendal, 2016), allowing the company to move to new buildings on the island in 1872. The company grew to be one of the biggest employers in Denmark, serving as a cornerstone in the foundation of Denmark as an industrial nation, and in the heyday of the shipyard almost 8.000 people were employed on the island (Refshaleøen, 2016). The island continued to grow along with B&W, and today it measures around 500.000 m^2, which, since the shipyard went bankrupt and shut down in 1996, has seen a dramatic change in function. Refshaleøen is now home to various different cultural events and recreational facilities, ranging from a paintball arena to the Copenhell music festival.

In the aftermath of WWII B&W established themselves as the world's leading supplier of large containerships, and the necessary sectioned production method is seen reflected in the size and character of the large industrial factory halls still present on the island today (Københavns Kommune, 2015). Refshaleøen still retains a lot of its industrial expression, as the water treatment plant Lynetten is still active on the site, and the powerplant Amagerværket is located just south of the area, but the character of the island has changed to become a something of a cultural hotspot, with a gourmet restaurant, an innovative workshop community, galleries, a great view and much more. A desire to continue this change is materialized in the new addition to the local plan.

The new addition to the local plan for Refshaleøen is very ambitious in terms of the potential for the island, although it is a designated perspective area, which means that until 2021 the focus should be on temporary interventions. The real-estate company, Refshaleøens ejendomsselskab, which owns the majority of the island, has a goal that the part of town will become Copenhagen's first CO^2 Neutral neighborhood by 2020 (Københavns Kommune, 2015).

Ill. 27 Overlooking the site

Ill. 28 The placement of the site within Christianshavn

CULTURE

The site is placed in a long line of cultural buildings and historic monuments in Copenhagen, and gives a great exposure for the proposed museum. The site can be seen from a lot of the most important Danish attractions and sites. With a view from the little mermaid, the old fort Kastellet and tourists who are taking a canal tour around the waterfront are going to see and experience the site. These sites are only those within immediate proximity. The site can be seen from the entire western waterfront, from Langelinie all the way down to the Royal Danish Playhouse. At other side of Copenhagen canal, close to the site, is Holmen where the Opera and the Danish school of fine arts are located, with the close connection to the museum (approximately 1,5 km) the students can visit, experience and learn about sustainability, and the importance for reducing the carbon dioxide emissions in the near future.

Refhaleøen is already a place of culture and history with the old B&W shipyard, and after the shipyard was closed, the area was slowly developed into the island we know today, with some food festivals, music festivals, concerts and events. It still keeps the history alive with tours around the Island and a lot of the old buildings from B&W's time are still there, hosting new functions. It is Copenhagen muncipality's plan to further developed the area with a new initiative to make more temporary culture places and events. (Københavns Kommune 2015, p. 15)

Ill. 29 Cultural sites in proximity to the site

INFRASTRUCTURE

Refshaleøen is connected with the rest of Copenhagen by only a few connections. Three roads are the primary connection for vehicles; Kløvermarksvej, Forlandet and Refshalevej. It is possible to get to the site with public transport, with at normal bus or with a the harbor ferry, from Nordre Toldbod to Refshaleøen, which stops right on the site. For pedestrians and cyclists the fastest way to get to the site is to take a route which crosses through Holmen.

The municipality of Copenhagen has plans to improve the infrastructure on Refshaleøen, before any urban development's takes place, but the peninsula is not the first priority, in the long term city plan, as it is currently classified as a perspective area. (Københavns Kommune 2015, p. 3,15)

Ill. 30 Local infrastructure

LOCAL PLAN

The new addition to the local plan for Refshaleøen aims to create opportunity for a more flexible and diverse use of the areas previously owned by B&W (Københavns Kommune, 2015), yet the intention is not to begin the actual urban renewal before 2023, as the city is currently focusing on development in Ørestaden and Nordhavn.

The main reason behind this delay is the cost and administration requirements for improving infrastructure and services in the area. This means that the current focus is on temporary installations and usage of existing buildings, while the area is in a transitional stage.

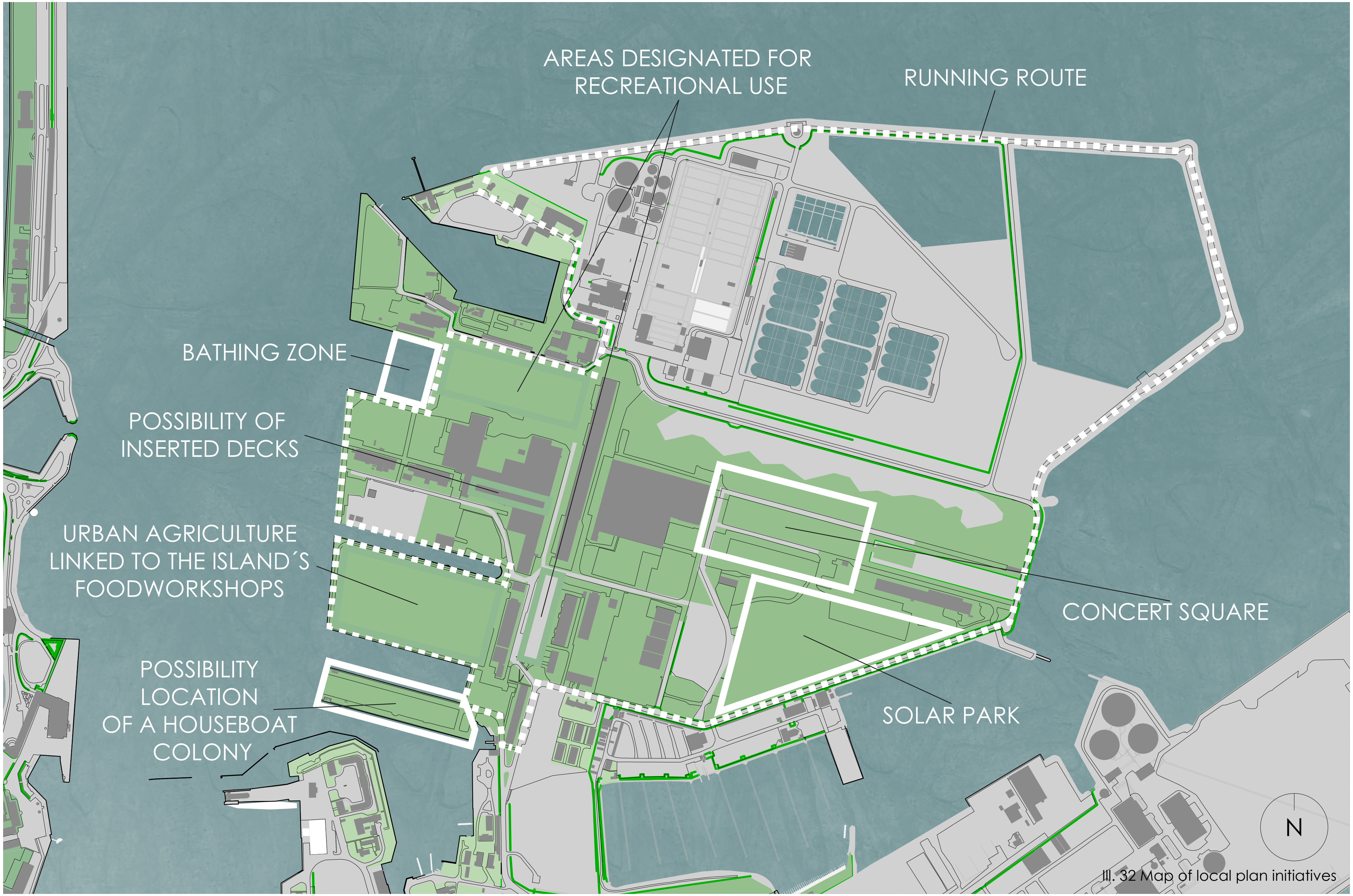
However, we feel that the construction of a museum for knowledge on sustainability and resilience is very much in line with the current owner's ambitions of becoming the first CO2 neutral neighborhood. The building itself may serve as an example of good practice for the further renewal of the area, and could even become a force of attraction for other sustainable and resilient initiatives, ensuring that the ambitions are embedded in the future identity of the area.

The local plan specifies the establishment of a solar cell park and urban gardening to help support the island's food workshops, both as key features in the sustainable approach for the neighborhood. Both of these have the potential to collaborate with the museum in regards to sharing of knowledge and researching and developing innovative solutions, from both a technical or social perspective.

In addition, the local plan contains large areas designated for recreational uses, a new scenic running/biking path, as well as a harbor bath.
In general, the real-estate company wishes to open up the area and add new life and identity to it.

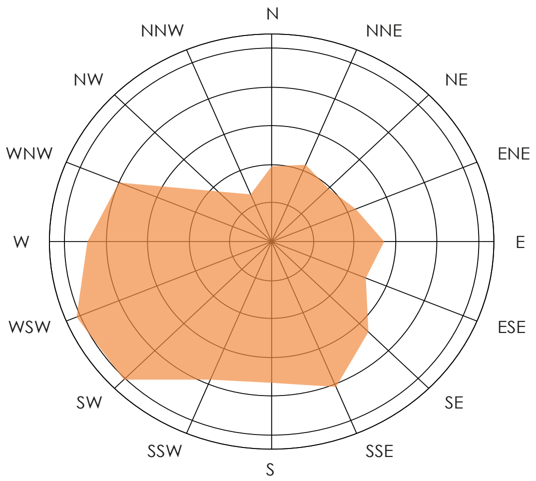
"Refshaleøen can either be seen as an industrial area in decay, or as an exciting area with the temporary as a permanent feature and with the potential for an urban development that can fulfil all the dreams for a human city." (Københavns Kommune 2015, p. 15)

Ill. 31 The section halls as seen from the site

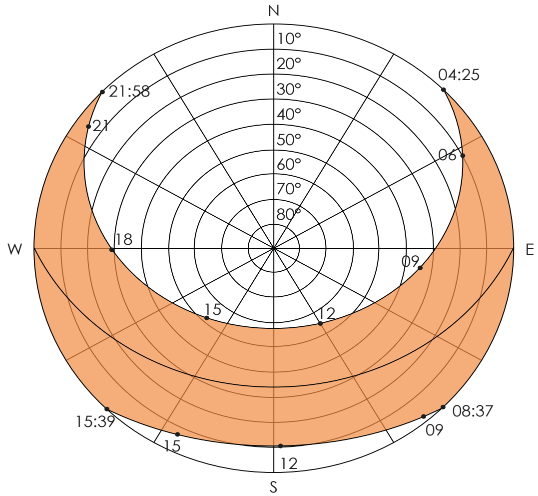


Ill. 32 Map of local plan initiatives

MICROCLIMATE



Ill. 33 Wind diagram



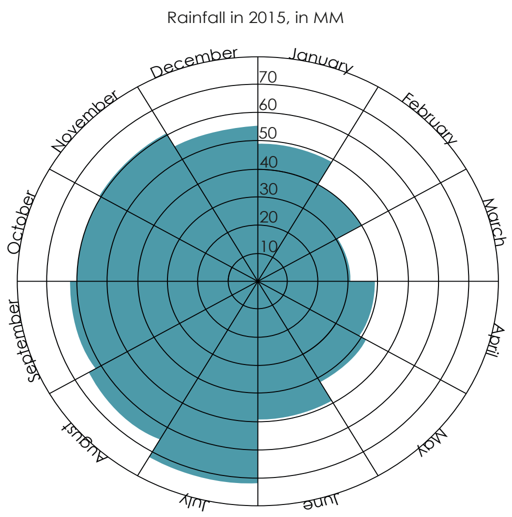
Ill. 34 Sun diagram

WIND

This wind data is from Kastrup Airport, which is the closet detailed weather data in the area, the information is directly applicable on the site on Refshaleøen, where the conditions are similarly open as the plain site of the airport. The data shows the wind direction distribution in percentage, for a year. The predominant wind direction is southwest/west, from the Copenhagen canal. Due to the general wind direction, and the possible natural wind tunnel created by the open areas over the water, the site is very exposed to wind (Wind finder, 2016).

SUN

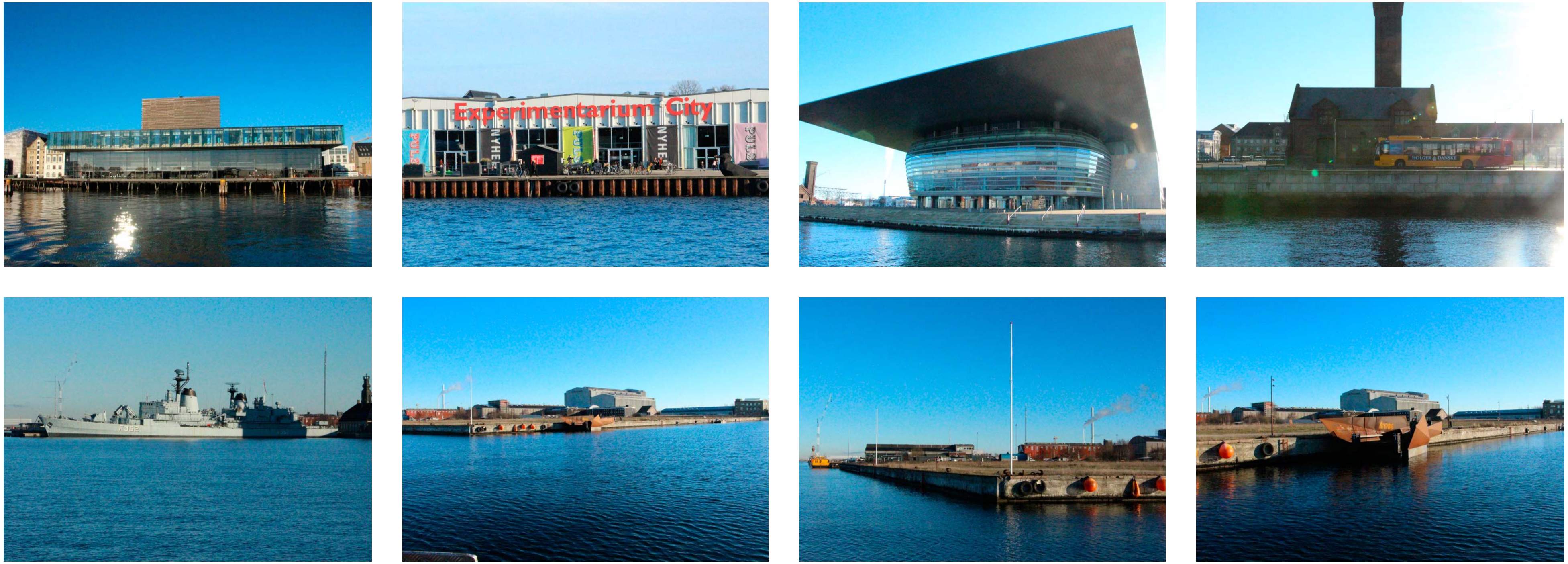
The open character of the site and its proximity to the open waters allows for a full exposure to sunlight, giving the full experience of the Nordic climate, with very dark winters and long summer nights. On the shortest day, the sun rises at 8:37 and sets at 15:39, on the longest day, it rises at 4:25 and sets at 21:58, a change from 6 h 58 m daylight to 17 h 33 m over the seasons (Gaisma, 2016)



Ill. 35 Precipitation diagram

PRECIPITATION

The frequency and sum of precipitation increases in late summer through autumn. When comparing data from 1961-90 and collected data from 2001-2010 a tendency emerges, that Denmark in general is getting more rain in average. (DMI, Precipitation, 2016)



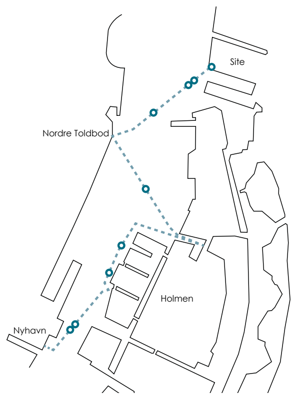
Ill. 36-43 Pictures displaying arrival by water

SERIAL VISION

Arrival to the site can happen in two ways. From the water by the harbor-bus, or by land through a single road.

Arrival by water

The habor-bus starts in the inner city at Nyhavn, but it can be boarded at nine different spots, from Teglholmen in the south, to Refhaleøen in the north. The docking station for the bus in Nyhavn is right beside the Royal Danish Playhouse (picture 1) and the Paper Island (pic 2) is located on the other side of the channel. Further up the waterfront there is a stop at the Royal Danish Opera House (pic 3), from there you go further up Holmen (pic 4) and it stops close to the Royal Danish School of fine arts. On the way to the site the bus sails past Peder Skram (pic 5), which was a part of the Danish Navy from 1966 to 1988. After a stop at Nordre Toldbod you go towards the final stop on the route, Refshaleøen (pic 6), and from the habor-bus you can see a wide-open field, which is the site (pic 7 & 9). The doc is made of corten steel, and gives a raw first impression of the site on the former industrial area.

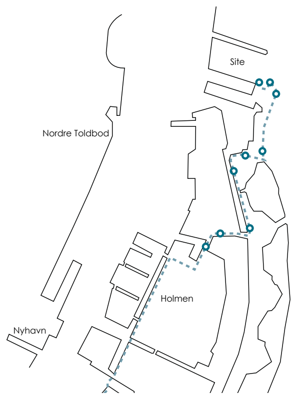


Ill. 44 The route of the harbor-bus

Ill. 45-53 Pictuers displaying arrival by land

Arrival on land

If arriving to the site on land, in a car, bus, on cycle or just as pedestrian, you must pass through Christianshavn. If on bike or as a pedestrian, you can go through Holmen, to get to the site. Banneskjold-Samsøes Allé, (pic 1) will take you all the way through Holmen and then a right turn at Kongebrovej (pic 2) and then a left at Krudtløbsvej (pic 3). Close to the end at Krudtløbvej the architecture firm Vandkunsten's office is situated (pic 4). After following Krudtløbvej for a bit, it starts to narrow (pic 5), and at the end of a corridor formed of big trees surrounding the road, you arrive on Refshalevej (pic 6), which leads to the site. Refshalevej is also the main road if you are going there by car or bus. At the start of the peninsula the road splits and to the left is the bus stop (pic 7), to the right the road continues into to the old industrial area, now a cultural zone bustling with life, home to shops, workshops and a wide specter of recreational opportunities. Another road extends out to the marina and the water-treatment facility. When arriving on Refshaleøen, you just have to go around the restaurant Amass (pic 8), to access the site (pic 9).



Ill. 54 Arrival by foot

REGISTRATIONS FROM THE SITE

Atmosphere

Even the name of the site indicates a strange grasp from the past that won't quite let go. In part it refuses to acknowledge the course of history, as what is still referred to as an island, long ago became a peninsula, and the reference to a fox's tail is both forgotten due to change in spelling and pronunciation, as well as a geological change to the expression of the place. In much the same way the industrial and industrious character of the once was shipyard still clings to the area, with its immense scale and rough materiality, yet at the same time a bush of new activities and initiatives are sprouting in between the rubble.

Buildings, machinery, tools and materials are seemingly left as they were last used, almost as if the people who left it there expected to return the very next day to continue where they left off. At the same time new recreational experiences are introducing brand new expressions all over the place, a new atmosphere is introduced, that in essence carries a tremendous contrast to the history of the place, but, almost paradoxically, at the same time embraces it and utilizes it to empower the development.

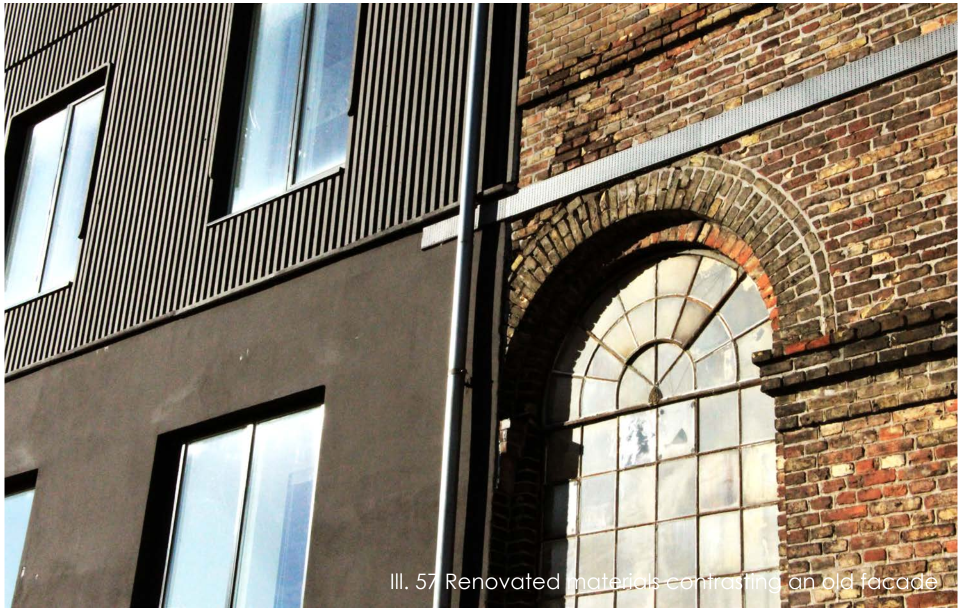
This time-portal to the golden era of industrialism lies tugged away between a modern water treatment facility, a hyper-modern (still under construction) waste-plant and even older historical naval buildings. The site is almost like a chronological history book, exemplifying how Copenhagen as a city developed from a strong naval power, to an even stronger industrial harbor, to the point where the consequences of industrialism on the environment and society eventually caught up with it. Much in line with this very visible transition from industrialization to the modern focus on environmental sustainability is the ambition to become the first CO^2–neutral district in Copenhagen (Refshaleøen, 2015).

Ill. 55 Abandoned rope on the wharf next to the site

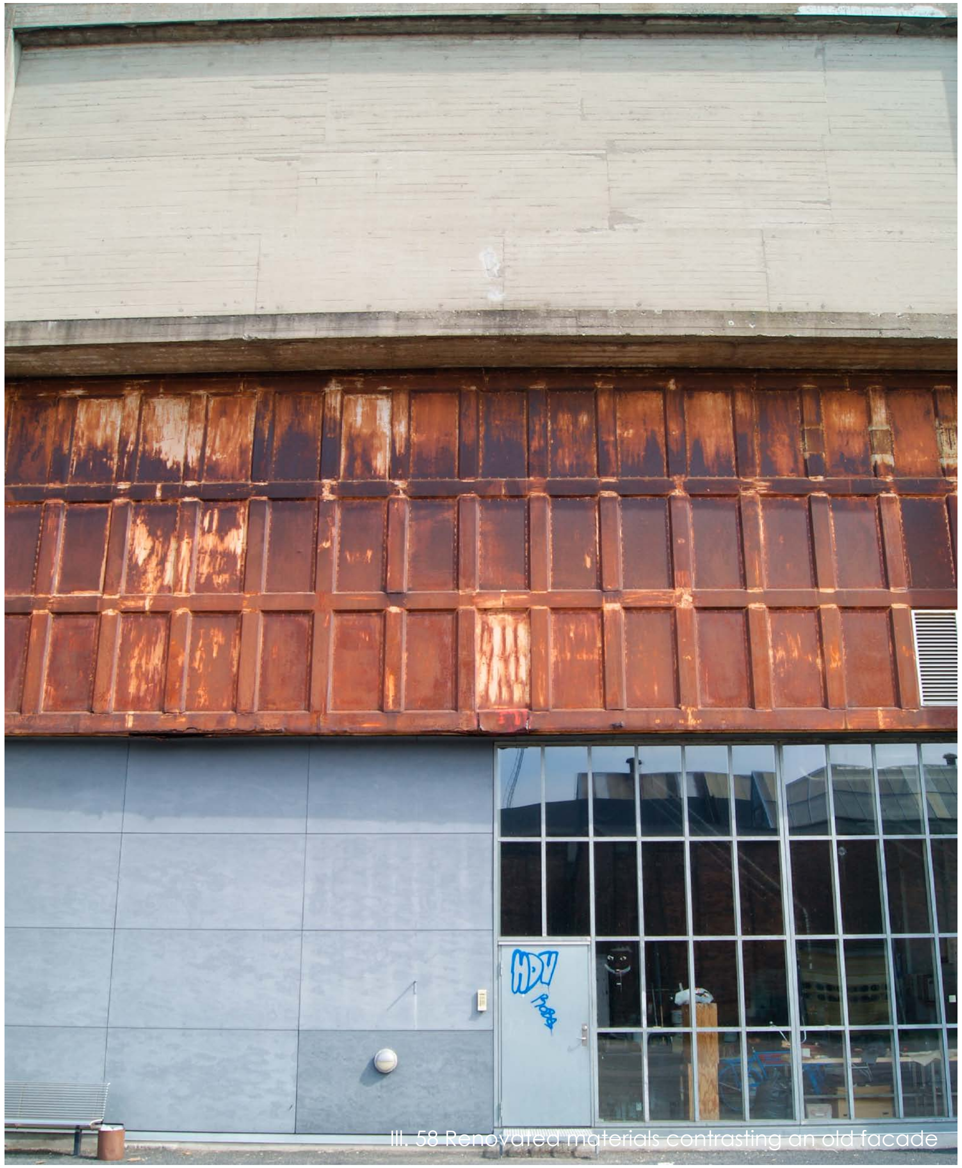
Ill. 56 Harbor ferry docking

MATERIALITY

The island is home to many scenarios of old meets new, unused meets reused, and a general theme that indicates a transitional stage. A transition from the forgotten, the outdated, decay and roughness, to the hopeful, the modern, progress and innovation. Common for what was and what is intended to be, is a focus on the all-present element of water. Vicinity to water is crucial for a shipyard, but is also an important element in the socially sustainable approach that the local plan takes to the site, through houseboats, public harbor bath and a running path along the water. The water becomes a softness to take the edge off the otherwise rough expression of the island's current tactility.



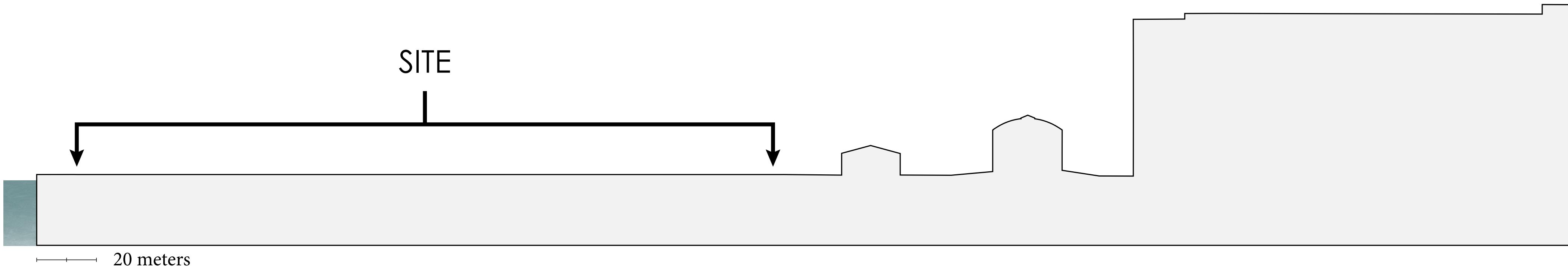
Ill. 57 Renovated materials contrasting an old facade

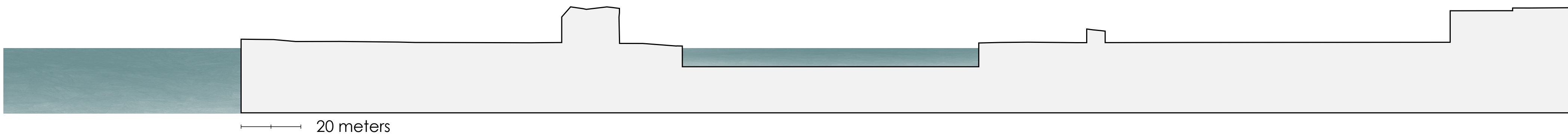


Ill. 58 Renovated materials contrasting an old facade

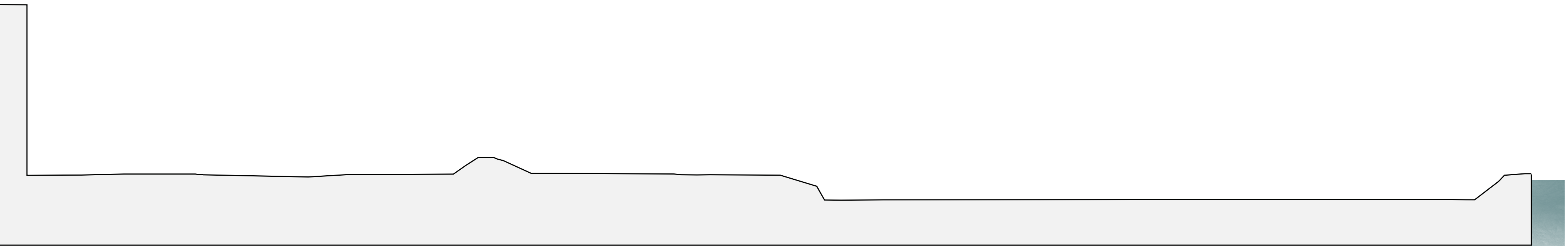
SCALE

The immensity of the old section halls dwarfs everything else on the peninsula, and only the nearby, new waste-plant by BIG is even comparable. The halls function as a central focus point when approaching the peninsula, and from there everything steps down in scale, and flattens out towards the water, deescalating entirely into the completely flat quay, which holds the docking station for the harbor bus.

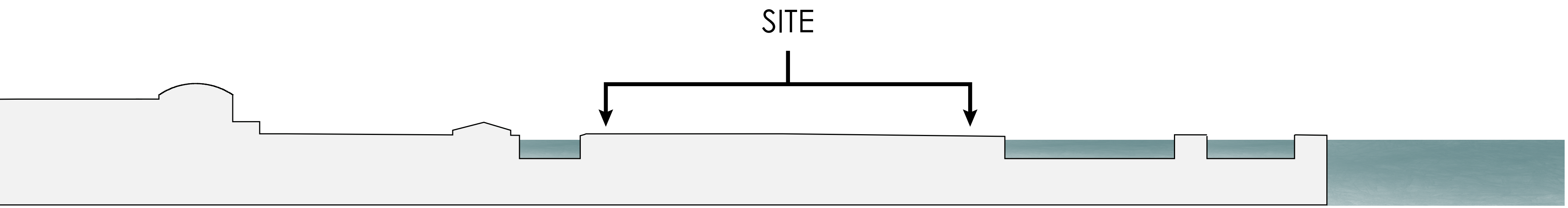




Ill. 59 Location of sections



Ill. 60 Longitudinal section AA of site showing scale and topography



Ill. 61 Cross section BB of site showing scale and topography

Programme

The project is based upon a self-made design brief, which is inspired by the visions for knowledge sharing on the subject of sustainability and resilience, both in the COP21 agreement, as well as in the Copenhagen climate adaption plan. The specified functionality of, and room programme for, the museum is developed upon these ideas, using reference projects as inspiration for size and content.

Ill. 62 Grass and water on the site

PROGRAM AND FUNCTION DIAGRAM

A museum to inform

In line with the expressed intentions of the UN (United Nations, 2015 article 12) and the Danish government (Municipality of Copenhagen, 2011) to inform and educate the general population in the consequences of global warming, as well as the measures needed to adapt to the changing climate, the aim is to create a museum that fulfills a role of public service. This prompts an openness and public accessibility in the design, which is reflected in the function diagram that only isolates general building services and administrative staff from the public, all other functions, such as the auditorium are to be available to any visitor.

Functionality

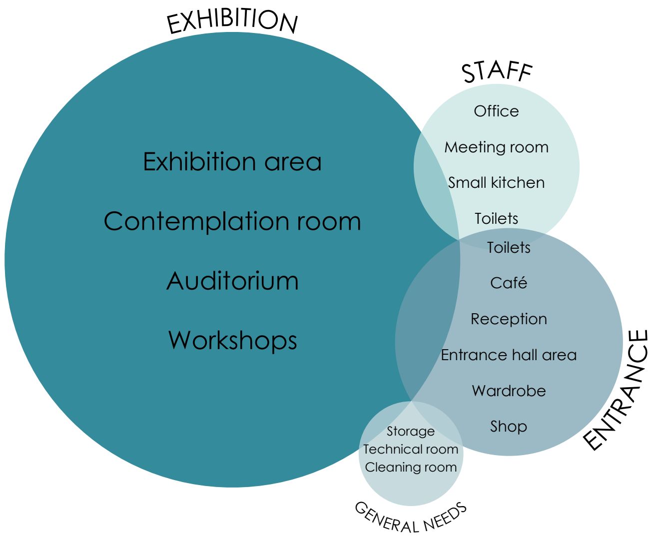
The museum is based on content similar to what is seen in Økolariet in vejle, set in a combination of functionalities similar to the Utzon center, and seeks to combine immersive, educational exhibitions with hands-on workshops and lectures by leaders of industry and research. Through this combination, the content should carry appeal for all age groups.

The complete story

A problem, the cause, the consequence and the adaption. These are the aspects to be covered in the content of the museum, thus providing a full picture of sustainability and resilience, starting from the cause, and ending with the solutions to minimize, prevent or adapt to the problem.

Informative and immersive exhibitions

The museum aims to not only inform the general population on climate change and sustainable and resilient adaption, but also aims to inspire to take action. In order to do this, the aim of the exhibitions is to create an experience that takes guests through an informative journey from the large scale context of global warming, explaining the cause and consequences of climate change, to the household scale, with immersive and interactive exhibitions providing easily accessible knowledge of sustainable and resilient solutions, and just as importantly, knowledge of how to live sustainable and adapt resiliently.



Ill. 63 Fu nction diagram

Zone	Functions	Area
Entrance hall	Reception, Wardrobe and Shop	465
Exhibition Area	Global warming, Danish context Contemplantion room Urban/building scale and Indiviual	3912
Café	Dining area and Kitchen	420
Toilets		192
Auditorium		262
Workshops		430
Staff office	Meeting room ,Small kitchen Storage and toilets	240
Technical Room		120
Hallway		295
Total		6336

Ill.64 Programme

SUMMARY

The site is in a continued line of large cultural institutions in the inner harbor of Copenhagen. A few minutes on the harbor ferry takes a visitor from the play-house, to the opera, the royal art academy and finally to an already established docking stations on the south-western corner of the site, making the site a desirable option for the city's newest addition of culture.

The site stands as an entirely open option, surrounded by water on three sides, overlooking the old fortress, Kastellet, and the little mermaid on the opposite of the harbor, and on the southern side, it grants a view to the historical Sixtus battery and other buildings owned by the Danish navy. The openness and proximity to the harbor provides the site with ample opportunity for direct sunlight, however it exposes it to the predominant wind from the west-southwest.

While the surrounding area still, in scale, materiality and style, resembles its industrial history in its expression, the current usage takes on a mostly recreational character.

The country and the municipality have already begun preparing for the future climate changes, and have developed detailed proposals for the planning and implementation of citywide solutions and measure, which has a focus on the delaying and redirection of excess water. In the scale of individual buildings, this means LAR and disconnection from the sewer system.

Ill. 65 City gardens and benches in front of Amass - overlooking site

REFLECTION

While the site on Refshaleøen provides obvious qualities through its geographical position, with a close vicinity to other culturally central points of Copenhagen and the city center itself, it is in the transitional stage, from industrial factory grounds to cultural and creative hub, that the island (now peninsula, but still named as an island) is currently developing a unique expression.

The site is a remnant of the large shipyards requirement for open areas towards the wharf, used as a final transitional space for the finished ships. As such, it provides a special opportunity to both work with the existing structure and context on the site, and at the same time creating something new that may help inspire a certain direction for the coming revitalization of the area. The real-estate company that owns most of the area, Reda, and the municipality of Copenhagen, both see a substantial potential for the area, and has expressed an ambition to see the site become the first CO^2 neutral district in the capitol. A museum of sustainability and environmental change provides the opportunity to exemplify and display these intentions, while continuing to build upon the cultural and recreational atmosphere that has evolved on the peninsula.

The local plan for the area designates the chosen site as a place to further develop, and establish new, kitchen gardens, that have helped provide sustainable produce for restaurants on the island. This can be seen as an opportunity for the building to merge with its surrounding neighbors, and create active displays of good sustainable measures. Similarly, the Lynetten water-treatment facility is located on the northern end of the peninsula, which will be playing a crucial role in the rainwater handling in Copenhagen and immediately adjacent municipalities. This provides an opportunity to collaborate with the facility in the display and explanation of the community's involvement in rainwater delay and storage, and what effect it will have on reducing the strain on the facility.

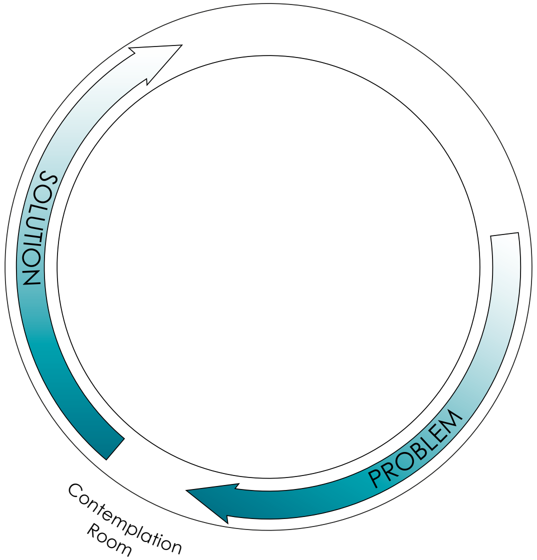
With its enclosure in water and the Danish focus on flooding in the climate adaptation plan, the site presents itself as an opportune case for investigating the design possibilities of water, and especially storm water, and the solutions to cope with it, as an integrated part of building design. The focus on water as an integral element in both the aesthetic and technical aspects of the building, calls upon the traditions of Nordic architecture, with a focus on materiality, the tactile and the genius loci. As well as a tectonic approach, which, through a strong relation between a gesture and a principle, bridges the gap between the construing and the constructed, enabling the museum to inspire an atmosphere, which empowers the learning capabilities and the experience in the museum. Although the municipality has developed extensive plans for the implementation of flooding focused climate adaption, it is within a large-scale preparation, which does mention solutions on building level. This leaves space for the interpretation and integration of the proposed solutions, and possibly of new and innovative measures, in buildings, from an architectural, aesthetic and socially sustainable point of view.

VISON

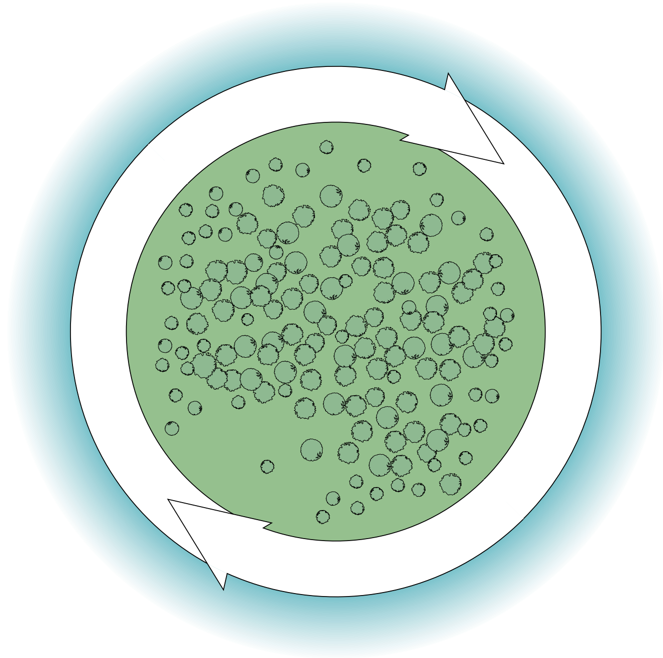
Through the design of an expressive, yet flexible museum, which through a monumentality in character reflects the monumentality that is imposed by the content within. The project should provide the frame for a combination of functions, all serving the same purpose through different means. The purpose is to inform and educate on the subject of sustainability and resilience, through an immersive and interactive experience. The museum should, through tectonic architectural quality, become an attraction in itself, an attraction that adds to the experience of the exhibition and museum, and allows for the possibility for integrating sustainable and resilient solutions in the design and exhibitions. Water, being the focus of the Danish climate adaption plan, will be the primary element in the experimentation with resiliency. With which, by exemplifying solutions and staging the problematics, the project should utilize a holistic approach to educating, and thus inspiring to take action, while emphasizing a spirit of seeing the potential within the problematics of water.

PRESENTATION

Ill. 66 Render from water approach to site



Ill. 67 Narrative diagram



Ill. 68 Symbiosis diagram

CONCEPT

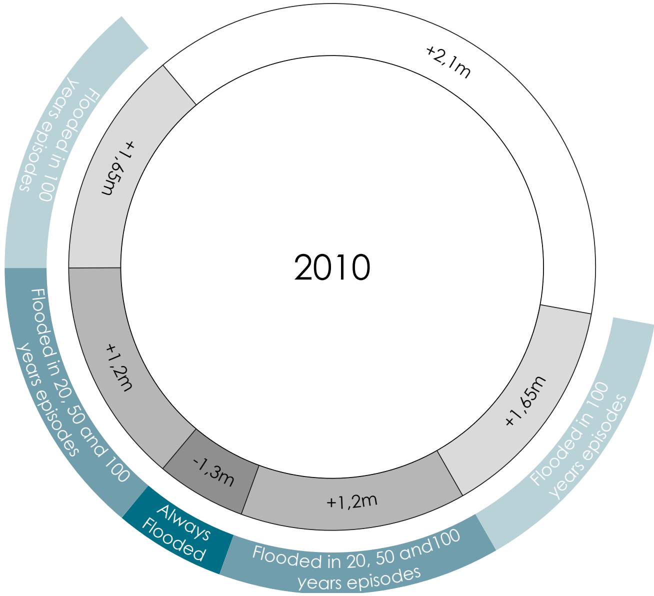
Narrative

The circular shape and the forced directionality of the plan naturally emphasize the strong narrative throughout the exhibitions, and the building as a whole. The narrative progresses along with the scale of the exhibition content, moving from global warming, to Danish context, to urban scale and finally concludes in the individual/household scale.

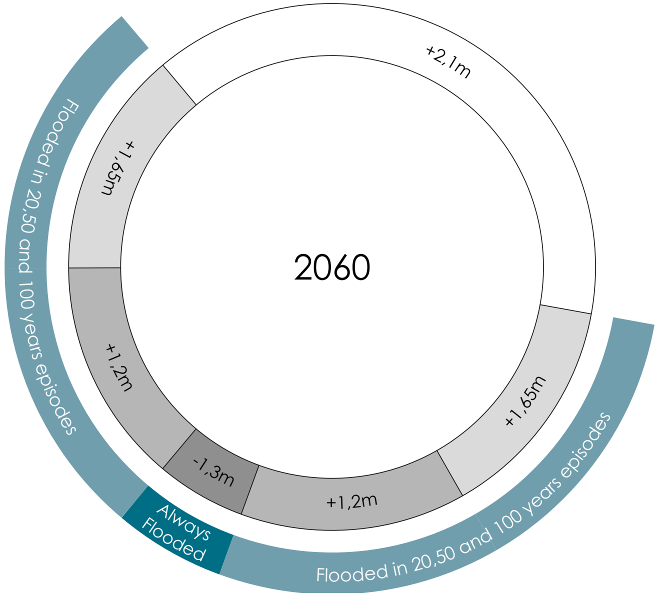
The narrative is split into two parts, starting with a problem part, and ending with a solution part. The split is materialized by a contemplation room, a turning point in the narrative, symbolizing the low point in the mood imposed by the monumentality of the climate change issues explained in the problem part, the point where the definitive decision and will to take action occurs. From the contemplation room the mood turns, and guests progress through the solution part, realizing that there are solutions to the problems, and start to learn how they can be realized.

Symbiosis

By removing all of the site not included in the circle, a monumentality is imposed upon the building, in an otherwise large scale context, that would dwarf the low, but wide building. The removal of the site also serves to expose the building to the environment, and the water in particular. This creates a symbiosis, where the building protects the nature in the courtyard from storm surge floods, and the green in the courtyard area protects the building from excessive rainwater during cloudbursts. Both the exposure and the symbiosis emphasize the problematics explained within, and the solutions to them, often involving local delay of rainwater, and elevated building sites. Exposing the building to water in the full 360 degrees of the circle, creates a unique experience that greatly adds to the symbolism of water as a threat, which also contains a positive potential.



Ill. 69 Flooding diagram 2010



Ill.70 FLooding diagram 2060

Utilization of water

The contemplation room is lowered to -1.3 meters below the sea level, bringing water up against the façade. The room becomes a time machine, taking you to a not too distant future, allowing you to, symbolically, experience the consequences of unhindered global warming, adding to the strong atmosphere in the contemplation room, inspiring to take action, in order to avoid the dire future which the room lets you peek into. Statistics placed at the edges of the façade will provide information on the change in sea level, and by displaying prognoses for future rises in sea level it also creates a very vivid explanation of the consequences of global warming. To add to this effect, the exhibition rooms, also lowered compared to the entrance, will also be slightly flooded during 20, 50 and 100 year storm surge flooding events. With the current design, the upper exhibitions will only be flooded during 100 year events, however, following the predicted rise in sea levels, by 2060 it will be flooded during 50 and 20 year events as well.

The gradual lowering through the exhibitions, from the entrance to contemplation room, emphasizes the emotional journey the exhibitions seeks to impose upon its guests. When moving through the problem part exhibitions, as the problem starts to become more and more unmanageable, and the situation looks increasingly dire, the level of the building burrows symbolically, further into the ground, culminating in a drop down into the contemplation room, the low point and turning point.

After the contemplation room, when the will to take action has been invoked, the level starts to rise again, symbolizing the mood of the guests lifting. They are now inspired to make a difference, and prevent the disastrous future they glimpsed in the contemplation room, and the solution oriented exhibition provides them with affirmation that there are ways to adapt to, and prevent future climate changes.

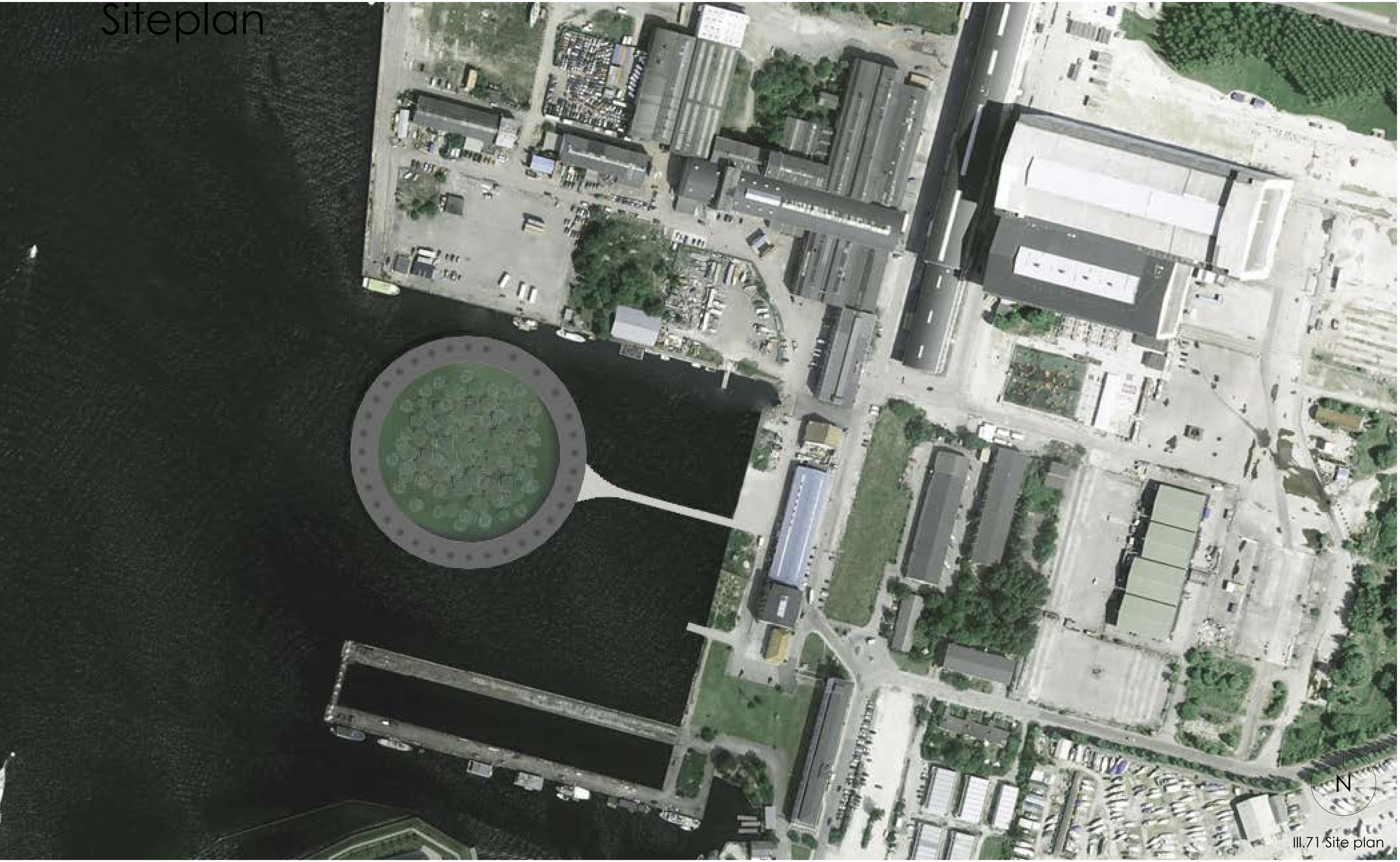
SITE PLAN

The museum rests in the water, encircling the what remains of the otherwise cut-away site, exposing the building to the water, creating a contrast between the green and the blue, in a symbiotic relationship between building and nature. The relationship between building and water amplifies the focus on water as an element in the exhibitions. By cutting away the site and isolating the building on the water, a monumentality is created, which is unique to the building, in an already monumental context. In this way, the building blends in with the monumental atmosphere of the site, while acting as a natural continuation of the linear down-scaling from the massive section halls, to the warehouses and finally the museum.

The site is accessible from land, by a single road, and from water with the harbor ferry. The existing bus stop on the site is only a hundred meters from the mouth of the bridge. In line with the sustainable and resilient theme of the museum, public transportation and biking is encouraged, and the open, paved areas close the bridge provide ample opportunity for parking bikes. Visitors arriving by car will park on the large, open and empty quay situated immediately to the north of the site, however they are forced to walk around to the mouth of the bridge, as it is the only access point to the building, this is done to ensure that every visitor experiences the narrative in its full extent, starting at the bridge.

For the same reason, the existing ferry docking station is moved to the remaining quay, rather than attaching to the new bridge, ensuring that all visitors experience the bridge. The bridge opens up in a wider space as it connects to the building, an area providing the minimum clear zone of 5 by 12.5 meters turning area, for vans delivering goods to the museum and café, and allowing for special guests and movement impaired individuals to access the building directly.

Siteplan



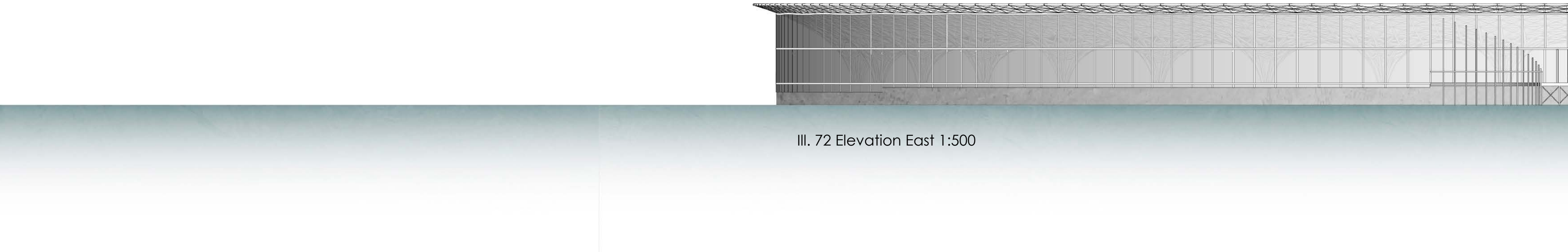
Ill.71 Site plan

ELEVATIONS

The facade drawings reveal a simple elegance in the geometric shape, which is brought to life by the complexity of the backdrop of the structural system. The railing of the bridge grows as the bridge widens out to grasp the façade, attaching itself to the regular grid of façade mullions, framing a view to the entrance and distinctly marking it.

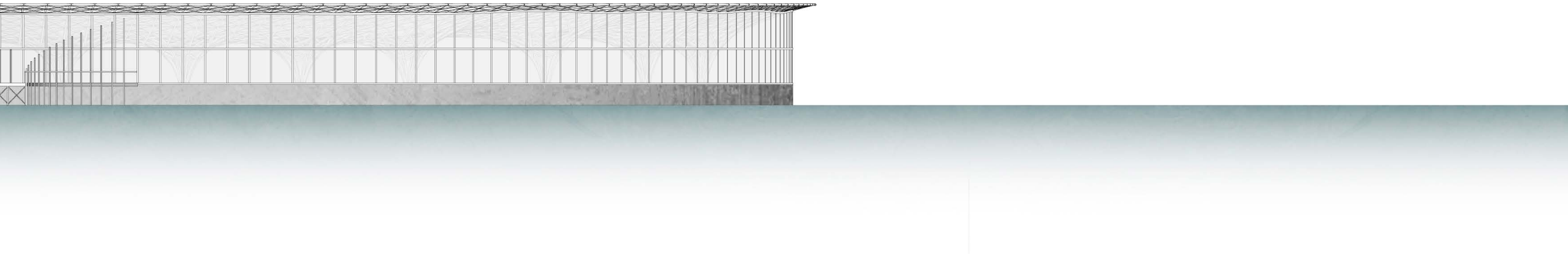
The façade becomes gradually darker, as it revolves from the entrance past the exhibitions, culminating in the darkest area in front of the contemplation room. It then becomes lighter as it passes in front of the solution exhibitions and returns to its brightest shade at the auditorium, workshops and staff area on the northern side.

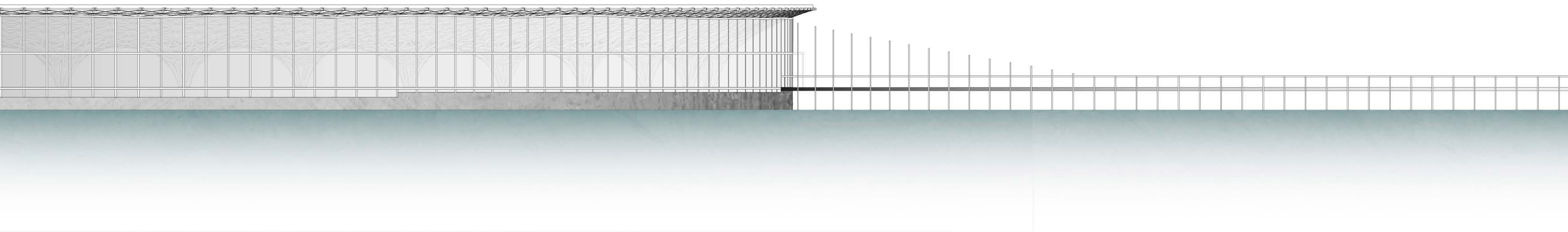
This enlightenment further emphasizes and helps shape the mood and symbolic journey of the narrative. Additionally the gradient, which is created through a gradual use of perforated metal sheets lodged in between the glazing sheets of the windows, also serves as an integrated way of drastically reducing heat gain from solar energy during the day. The density of the perforation, and thus the reduction of solar energy, increases along with the narrative, while also providing the most reduction on the south and southwest, greatly reducing heat gain from the midday and early afternoon sun.

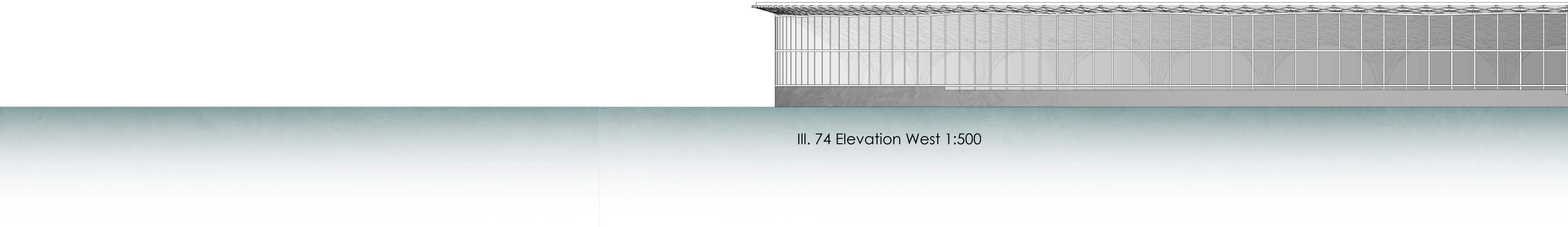


Ill. 72 Elevation East 1:500

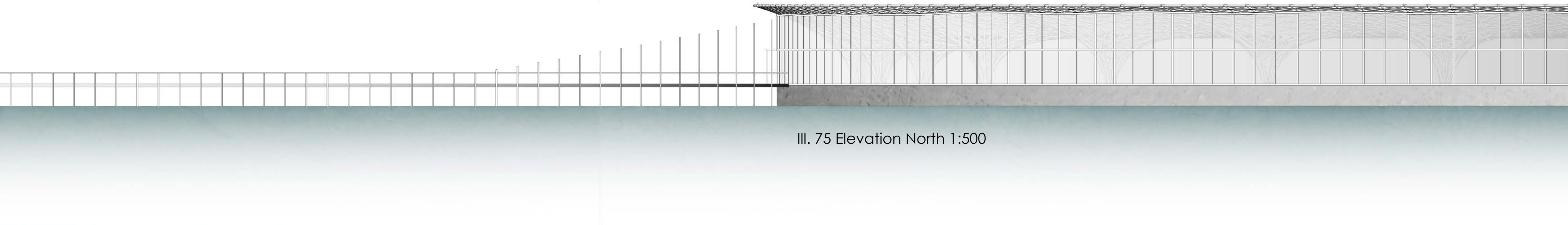
Ill. 73 Elevation South 1:500



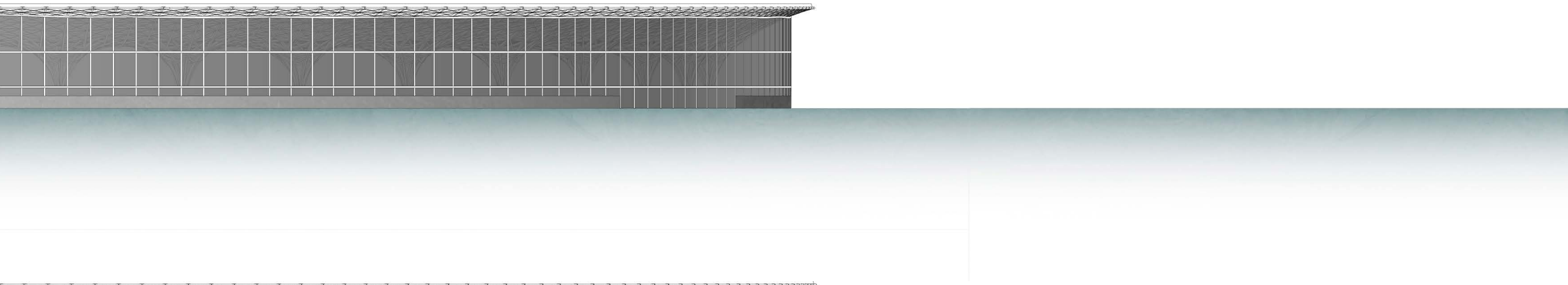


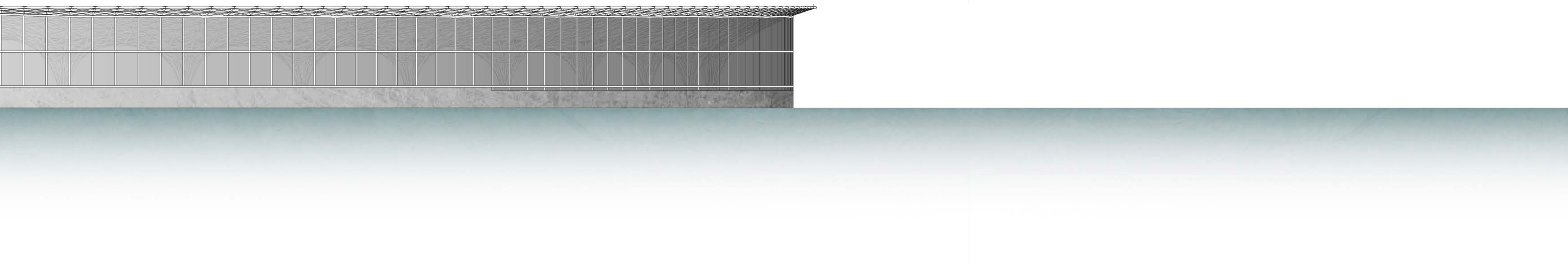


Ill. 74 Elevation West 1:500



Ill. 75 Elevation North 1:500





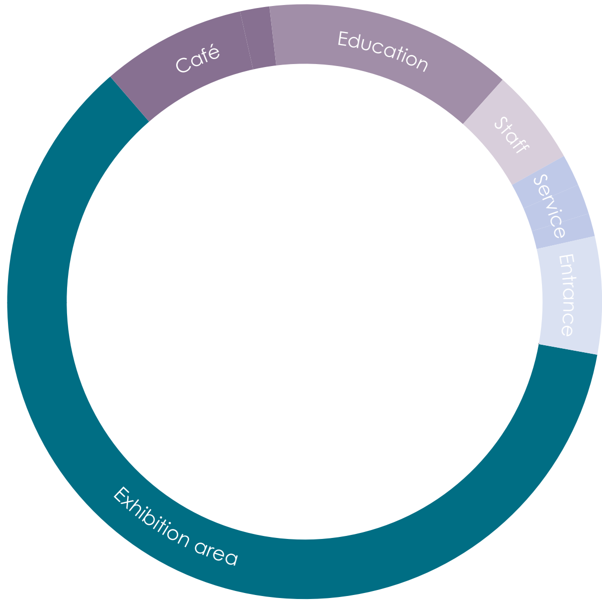
PLAN

The narrative of the museum unfolds in a clockwise movement from the entrance hall. The exhibition is split into two themes, problem and solution. The two themes are subdivided according to a linear storyline form global scale to individual households, the subdivision is marked by a small change in level, but the two themes are otherwise continuous exhibitions. In the junction between problem and solution, a room for contemplation symbolises the point of no return in an emotional journey imposed by the design of the museum, and the content of the exhibitions. The contemplation room is separated from the exhibitions through two pairs of partitioning walls, displaced to create a door-less room division, playing on a contrast of light and dark, to create an atmosphere, and a build up to the contemplation room as you enter it through the hallways composed by the walls.

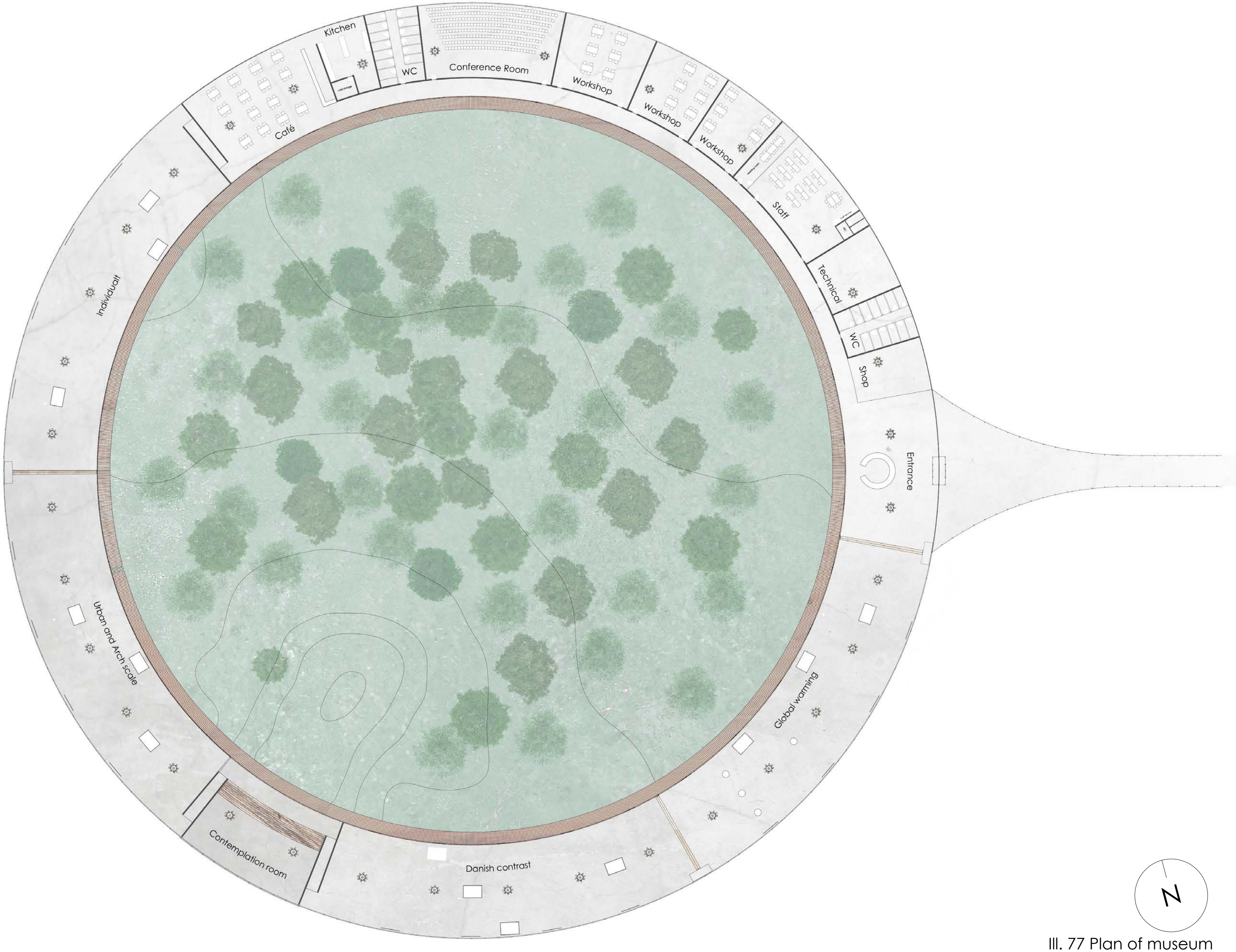
When the solution themed exhibition ends, it ends in a set of portioning walls, just like at the contemplation room. This room division helps to keep out the noise of the café from the exhibition area, and emphasizes the end of the exhibition narrative.

From all rooms, except the contemplation room, there is an almost direct connection to the courtyard, making it a communal merging place for people using the museum for all its varying functions. The courtyard is both a break out area for visitors and staff alike, as well as an important part of the experience of the building, and integrated part of the exhibitions, through exemplification.

All other functions than exhibitions are gathered towards the north, allowing for direct access through the connecting hallway, avoiding the need to move through the exhibitions, if visiting the café or attending a workshop. This also has the added quality of allowing the exhibitions to be one continuous, undisturbed journey, making the narrative as clear as possible. Situating the staff area, auditorium and workshops to the north, behind the hallway, prevents direct sunlight from overheating the working areas, that instead receive plenty of daylight from the open façade towards the north, and the opening all along the top of the partition walls.



Ill. 76 Function diagram



Ill. 77 Plan of museum

ARRIVAL

Upon arrival at the site, visitors are greeted by an isolated building volume, exposed to the environment, and in particular the water. In an otherwise large scale context, the isolation and exposure creates a unique monumental atmosphere and expression to the building, that lets it blend in with the industrial and rough context, while remaining a modern and elegant design.

This monumentality is the first step in the emotional journey and narrative of the museum experience, and is the first of many carefully orchestrated elements that shape the mood and atmosphere of the building.

When approaching the building on the long, pier-like bridge, visitors are exposed to wind and rain, and thus the building becomes a sanctuary, a lee from the wind, a shelter from the rain and an enclave of nature otherwise distant from the old industrial peninsula, a start to the journey that is very symbolic to the themes of the museum.

Ill. 78 Render of arrival from bridge

ENTRANCE HALL

After arriving at the site, and approaching the building along the bridge, visitors enter an entrance hall, facing straight on a rounded reception desk, framed by two of the columns, with a background of the trees in the courtyard.

From the entrance hall, visitors embark on a clockwise journey through the building, following a narrative of scale and a transition from cause, to consequence and to redemption.

For staff, café visitors or museum guests coming to attend events in the auditorium or workshops, a hallway along the inner façade, in the counter-clockwise direction, provides a more direct access to these facilities.

Besides a reception, the entrance hall also contains a small souvenir shop and a wardrobe.

Ill. 79 Entrance hall

GLOBAL WARMING EXHIBITION

A change in level, three steps down, marks a transition from entrance hall to the first exhibition on global warming, beginning in the largest, planet-wide scale.

Here visitors will learn about the actions, current and historic, that are affecting the global climate, as well as the impact climate change has on our planet and our way of life.

A series of colossal globes, hanging from the roof, portray the current sea levels, and the different scenarios of future rise in sea levels, based upon scenarios predicted by the UN, relating to different greenhouse gas emission levels, depending on how the world population responds in the coming years. The room balances on the contrast between the green view of the courtyard, and the blue view of the water.

The blossoming expansion of the structural system, from 8 beams combined to form a column, into a large cantilevered, forms a pavilion-like roof structure, which floats elegantly above the non-load bearing facades, allowing them to become as clean as possible, with minimal structure to interrupt the views out.

Ill. 80 Global warming exhibition

DANISH CONTEXT EXHIBITION

From the global warming exhibition, an additional three steps down signify the change into the next exhibition, the Danish context. From here, the scale shrinks to a more comprehensible scope, and the exhibition focuses on how climate change will be experienced specifically in Denmark.

The common denominator for climate change in Denmark, is water. Focus on local delay of rainwater in the courtyard, showing rainwater collection in the hollow columns, and the completely surrounding view of water, helps provide the tools for visitors to immerse themselves in the problematic scenario.

The complex and unique structural system, combined with the beautiful views on both sides, makes the atmosphere of the room an attraction in itself. However the impact, of the columns' one meter in diameter, on the room functionality is minimal

Ill. 81 Danish context exhibition

CONTEMPLATION ROOM

The end of the Danish context exhibition is also the end of the problem part of the museum. The exhibition culminates in two concrete walls that prevent any views further along the building. The walls are displaced to create a hallway that gently slopes down, becoming darker as it moves downwards.

As the hallway is at its darkest, an opening appears on the left side, revealing a massive, open space, the contemplation room. In the room, a small platform at the end of the stairs connects the entrance with the exit. The façade facing the courtyard is blacked out, blocking all light from the back of the room. In a curve deriving from the circle of the building, a series of 10 steps descend outwards, to the lowest level of the entire building. At the bottom of the stairs, a single concrete bench sits in the tranquil light reflected in and through the sea water, which floods the lower part of the façade. From the platform, two columns frame a clear, open view across the harbor. At the height of the entrance level, the columns change from glue laminated timber to concrete, visualizing the relation between the general building level and the sea level, creating an illusion of submersion as you descend the steps.

Up until this point, the narrative shapes an atmosphere that should cause concern for the environment, and how humans live within it, culminating in the contemplation room as the low point, both literally and metaphorically. The room is designed to create an awe-inspiring experience that utilizes the experienced threat of water, exemplified through a flooded aquarium like façade, to inspire a will to take action.

The exit from the contemplation room is the opposite of the entrance, here a ramp gently escalates towards a brighter room. This ascension proclaims the turn of atmosphere and mood in the narrative, as guests now enter the solution part, focusing on how to overcome the obstacles just seen. From here the floor level increases similarly to how it descended before the contemplation room, and the façade begins to brighten.

Ill.82 Contemplation room

HALLWAY

At the end of the exhibitions, past the café, a hallway begins, it connects the exhibitions back to the entrance, and provides access, and the boundary to, all the added functions, such as the auditorium and workshops. The hallway is spacious, but in a small scale compared to the large exhibitions rooms, and creates a stage for reflecting on the journey just taken, as the visit to the museum comes to an end.

The concrete partition wall allows staff and workshops to function undisturbed by museum and café visitors, while the glazed top lets in daylight and provides a visual continuation of the structural system, emphasizing that the structural roof holds itself up purely by the central columns.

Ill.83 Hallway

COURTYARD

Accessible through numerous doors all along the inner facade, the courtyard becomes a converging area for all the different functionalities in the museum, from café guests enjoying their refreshments in the sun, to workshop attendants that are using the natural reserve to study resources in nature. The doors all open up to a wooden pathway following the entire extent of the inner façade. The area is characterized by an informal expression, with no strict cultivation rules, and no distinctive designation of where guests are allowed, regardless of which function of the museum they are visiting, making it open and free-to-use area. The continuous pathway emphasizes this connection and openness between the different functionalities.

In addition to being a beautiful and tranquil area to take a break, for café guests, staff, museum visitors and workshop attendants, it also provides local delaying of rainwater, protecting the building from the otherwise trapped rainwater in the courtyard, while the building protects the courtyard from flooding due to storm surges.This serves as an example for the urban scale solutions explained in the exhibitions.

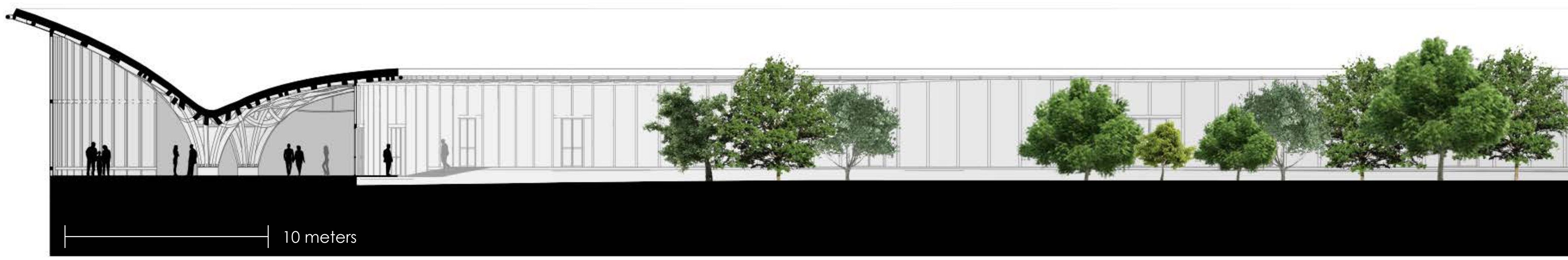
Ill. 84 Courtyard

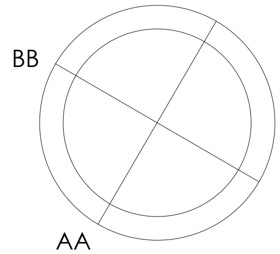
SECTIONS

The landscape in the courtyard follows the elevation of the facade, in order to maintain stepless transition from the interior to the exterior in all rooms. The pathway uses low incline ramps, rather than steps, to follow the terrain, assuring full accessibility, and a smooth transition matching the landscape. The interior levels range from +2.1 to -1.4 meters above and below current sea level, a total span of 3.5 meters from entrance to contemplation room.

The courtyard landscape follows the platform in the contemplation room, and not the lowest level. A short distance from the inner façade of the contemplation room, an indent in the elevation creates a natural rainwater basin, ensuring a controlled gathering and storage of excess rainwater.

The vegetation in the courtyard roughly follows the scale of the building, and increases in density towards the center, adding to the natural character, resembling forest more than park.

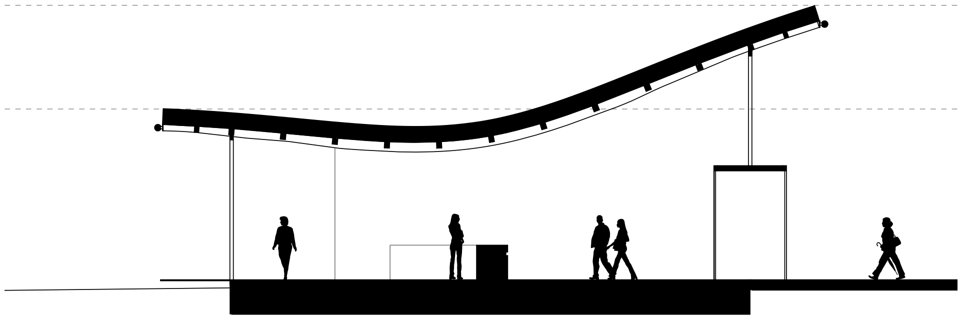




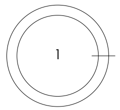
Ill.85 Section AA

Ill.86 Section BB

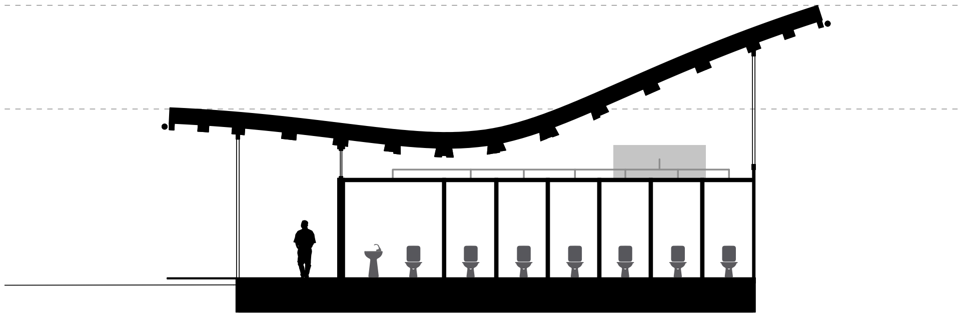
SMALL SECTIONS



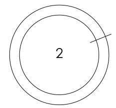
1: Entrance



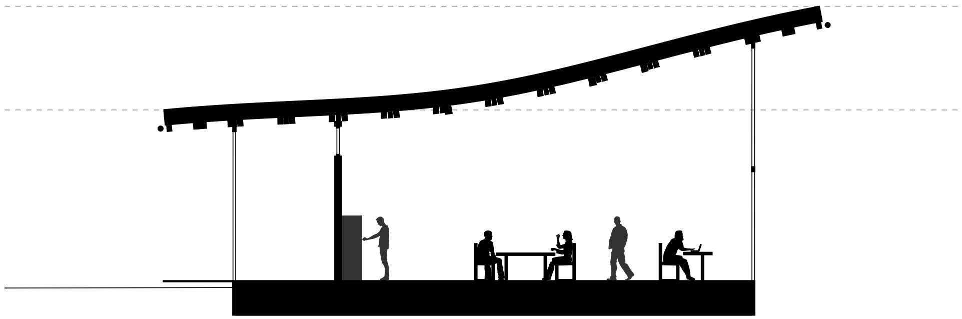
A windbreak in the facade of the entrance hall is the only break in an otherwise pristine and clean facade expression, marking the entrance along with the bridge railing.



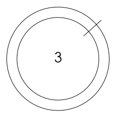
2: Toilets



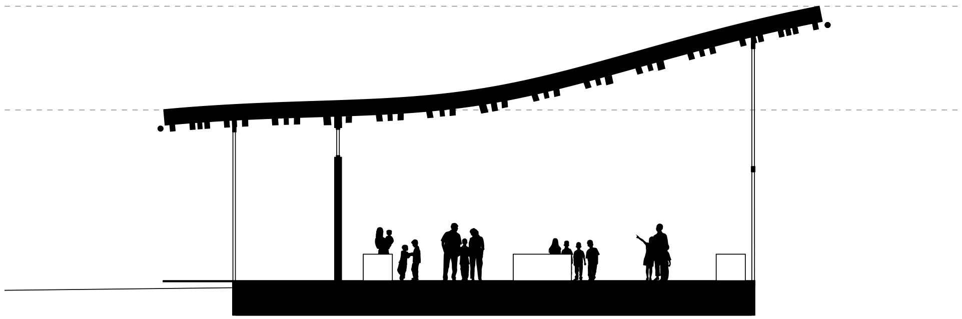
The toilets are small closed off boxes underneath the roof structure, to allow for proper ventilation, and to avoid disproportion between floor area and height. The space above is utilized for the ventilation system and other technical features from the technical room next to the toilets.



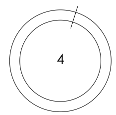
3: Staff room



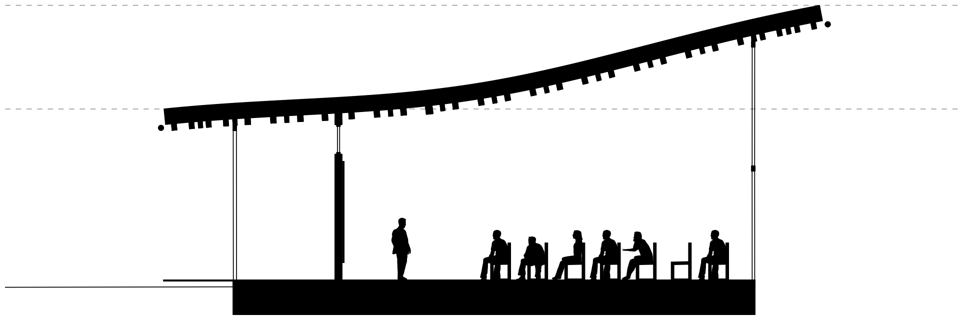
An office for the administrative employees of the museum, including a separated meeting room.



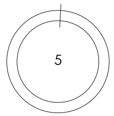
4: Workshop



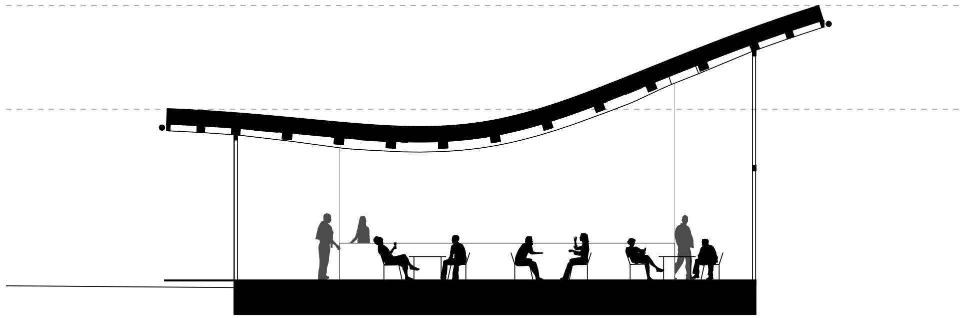
Flexible workshops areas, catering to a wide variety of events and participant.



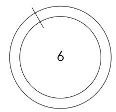
5: Auditorium



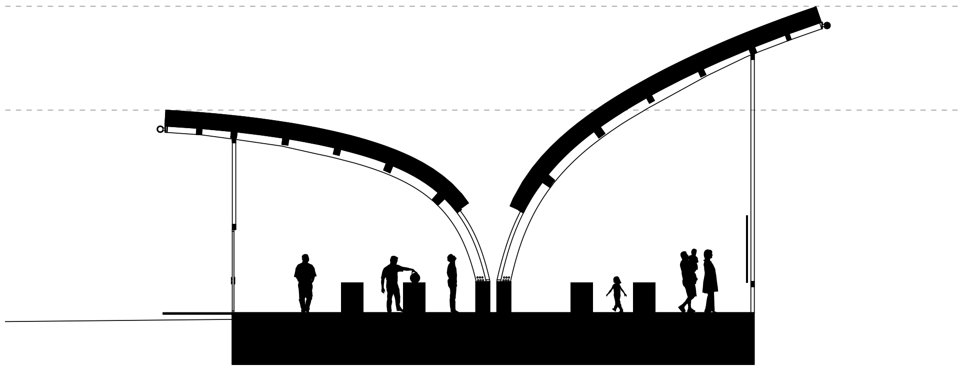
An auditorium that can be used as a conference room and lecture hall, or other similar events.



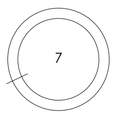
6: Café.



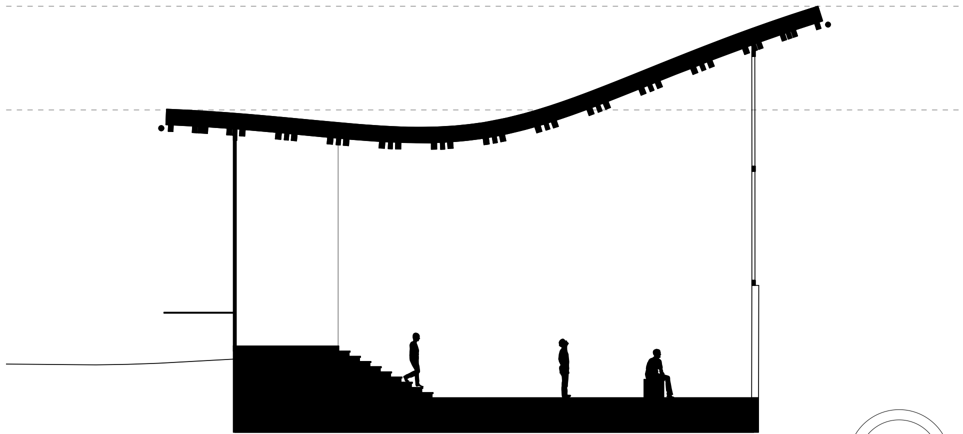
A large open area, situated in a niche between the exhibitions and the auditorium and workshops. The café has direct access to the courtyard, and guests can enjoy their refreshments in the sun.



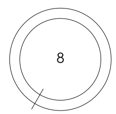
7: Exhibition



The large, open areas provide ample space for many different scales of exhibitions, and utilizes elements of the design, such as the view towards the water, the vegetation in the courtyard, and the exemplification of water collection in the columns, to create an immersive experience.



8: The contemplation room



A vast room that plays on atmospheric design aspects to create a certain emotional response in the visitors.

Ill.87-95 Small sections through functions

STRUCTURAL SYSTEM

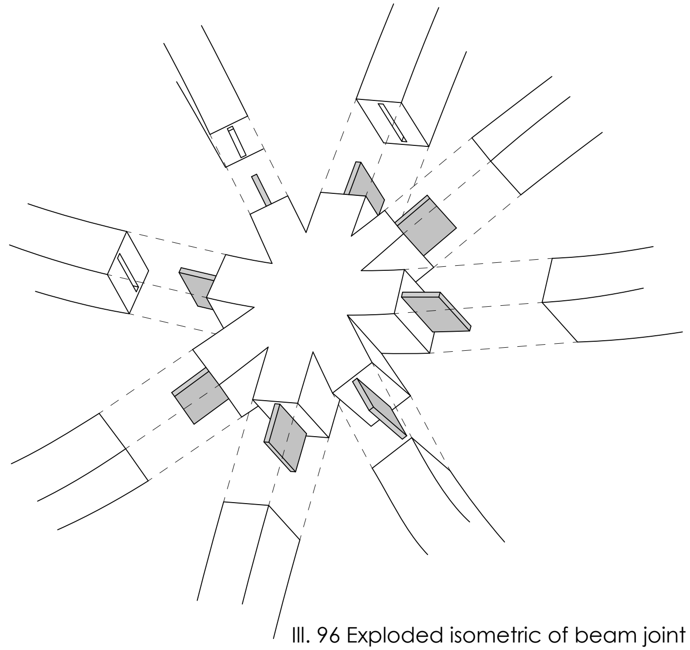
Designed on the principles of furnicular form finding, the structure utilizes the qualities of glue laminated timber to create a unique and expressive double curved shape, which compliments the simple geometrical room plan.

The system is a reversal of the, usually, vault-like structures inspired by the furnicular principles, and uses the instrinsical strength of the circular shape to create a large, cantilevered structure, only supported by a row of columns placed along the middle of the circular plan. Furnicular vaults work exclusively in compression, and to mimic this behavior in the reversed, cantilevered form, steel rings the inner and outer edge of the structure are implemented.

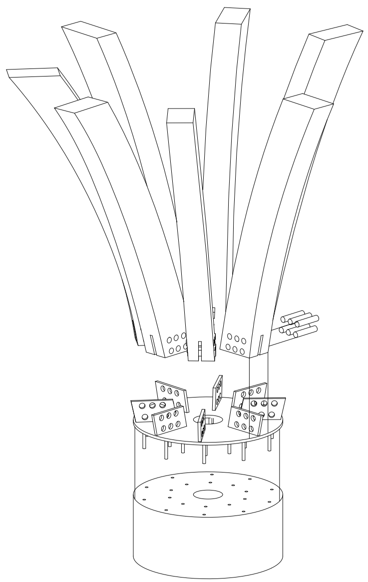
By using the furnicular principles to develop the form, the flow of forces in the structure is optimized, and the overall material usage is reduced, and a allows for a lighter expression.

The four beam intersections of the grid are constructed as a combined element, in order to retain the strength of the glue-laminated timber. The intersection is then joined with the beam elements through a hidden steel plate, creating an almost invisible joint.

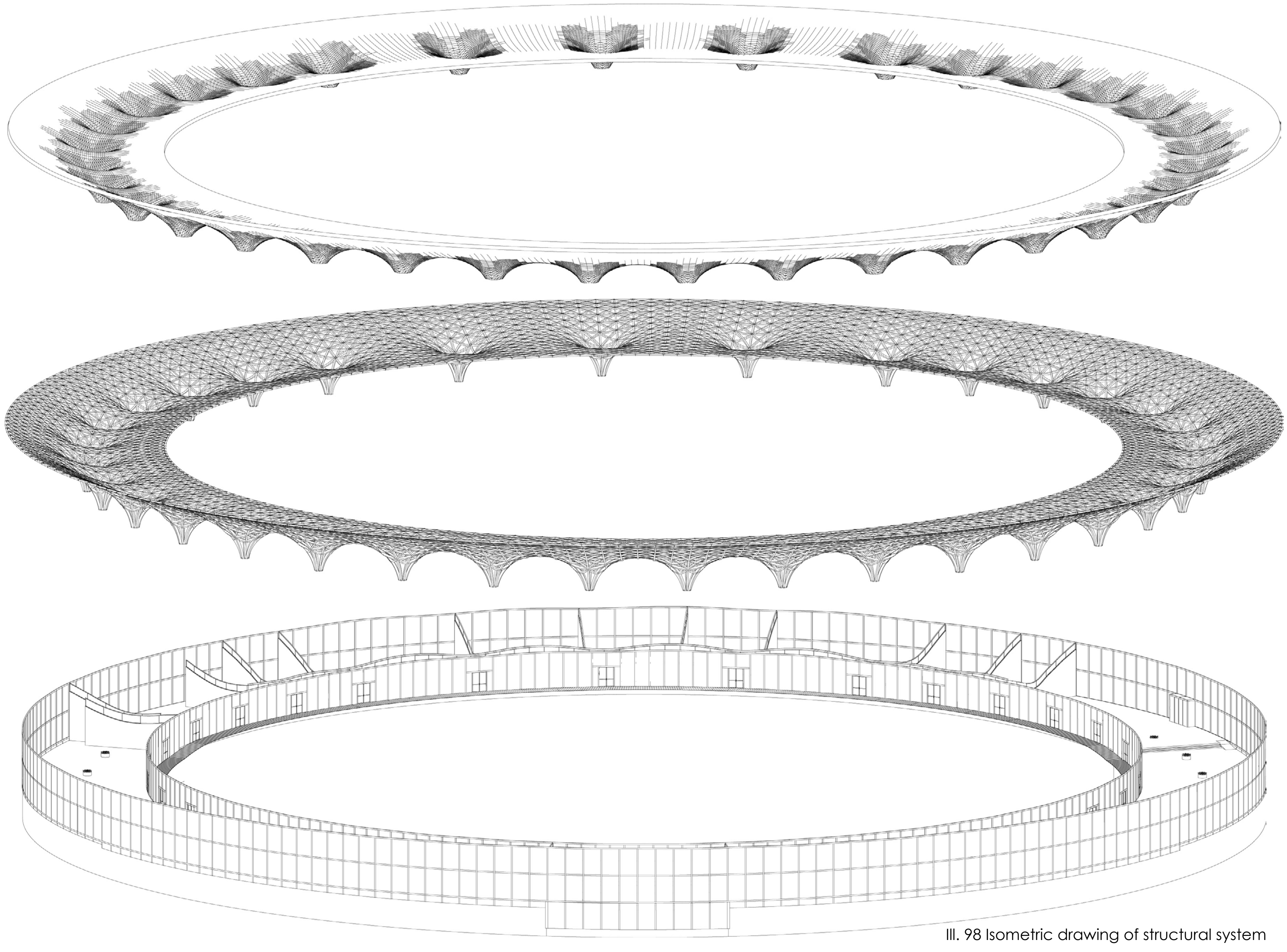
The grid of beams converges in a column for ground support, consisting of eight individual beams, all fastened to a steel plate, cast into the concrete floor and concrete column bases.



Ill. 96 Exploded isometric of beam joint

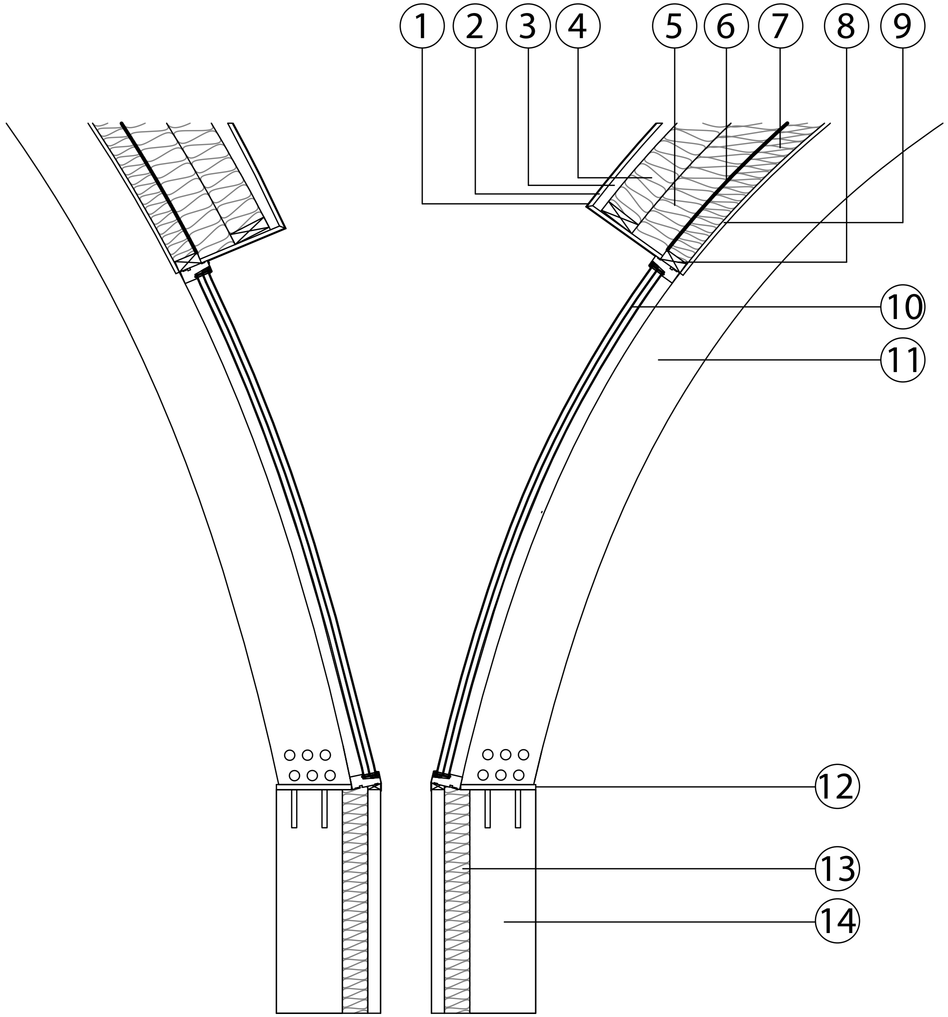


Ill. 97 Exploded isometric of column joint


Ill. 98 Isometric drawing of structural system

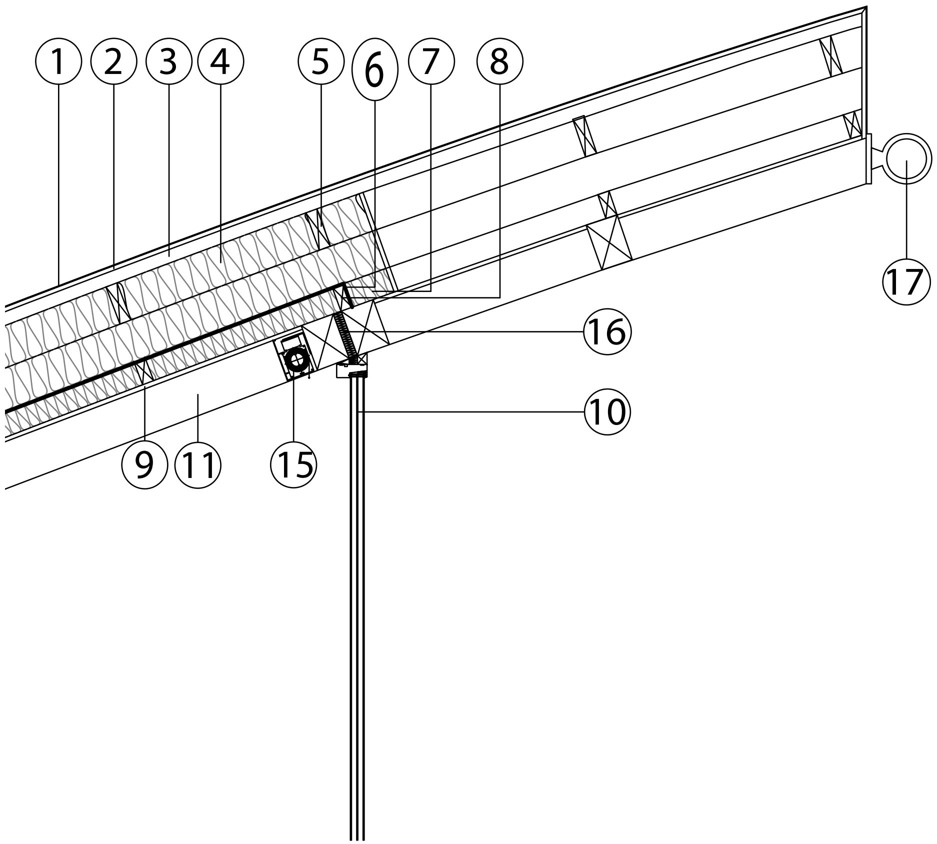
STRUCTURAL DETAIL

By turning the lower part of the roof in the columns into glazing, a clear view of the complete column is created, while also allowing for better visual conncetion through the room. The transparence of the roof inside the column also allows for the display of rainwater collection.

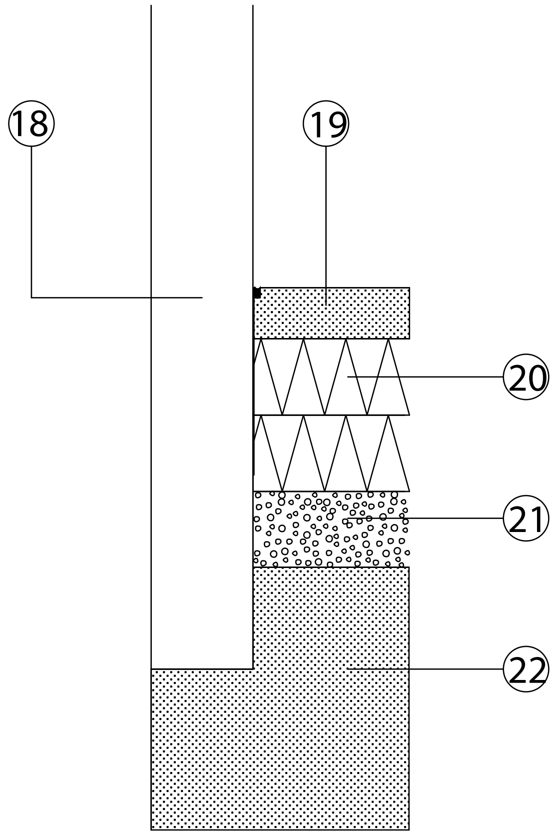


1: Asphalt roofing
2: 16mm OSB
3: 50mm Ventilated space
4: 2x 150mm Insulation
5: 2x 150x45mm Timber battens
6: Moisture shield
7: 95mm Insulation
8: 95x45mm Timber lath
9: 15mm Gypsum board
10: Triple-glazed thermal window
11: Glulam structural beam
12: 20mm Steel connection plate
13: 100mm Thermal bridge disruption
14: Cylindrical concrete column, D: 1m
15: Automatic roller blinds
16: 30mm Thermal bridge disruption
17: Steel cable, D: 150mm
18: 200mm Acrylic glass façade
19: 100mm Concrete floor
20: 2x 150mm Pressure resistant insulation
21: 150mm Damp proofing layer
22: Concrete foundation

Ill. 99 Detail of column



Ill.100 Roof detail



Ill.101 Floodable facade detail

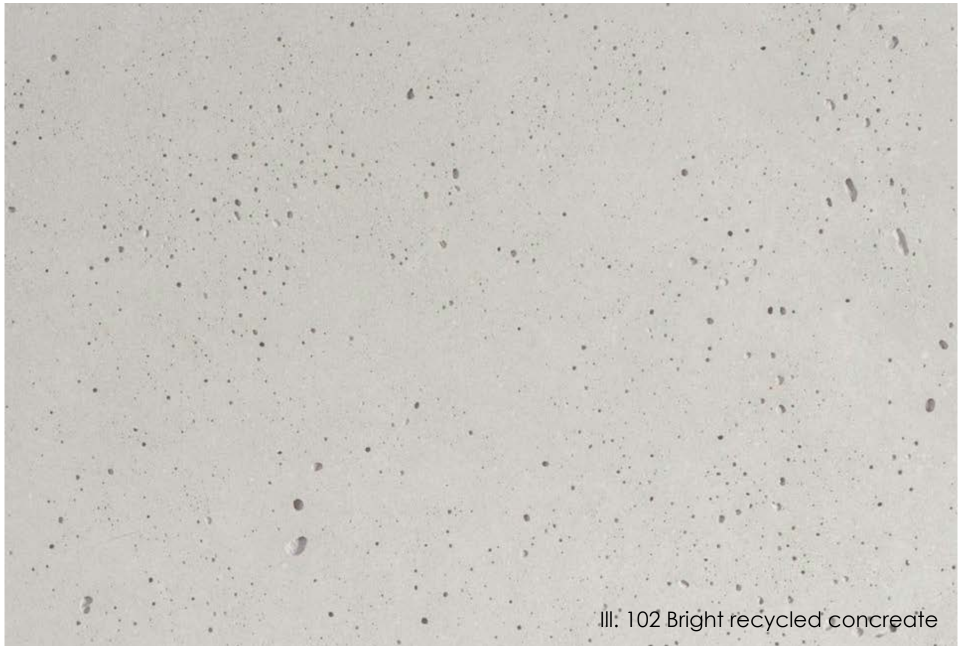
MATERIALS

Recycled concrete

The entire base of the building is constructed in recycled concrete. This upcycle concrete can incorporate up to 60% recycled material, giving the possibility to reuse the concrete that is found in abundance on Refshaleøen, in case any of the existing buildings are to be demolished (Lendager, 2016)

Glulam

The structure is constructed in glue-laminated timber. Glulam can be shaped to curved forms, and even double curved forms, during production, and therefore makes the material paramount to the realization of the form found through the furnicular principles. Although chosen for its structural abilities and qualities, the brightness of the material contributes to a perceived lightness of the roof as a whole.



Ill. 102 Bright recycled concreate

Ill. 103 Glulam beams

Oak

Oak wood is used for the façade and for the pathway around the courtyard. Oak is a local, and very durable material, particularly suitable for exterior use, and in situations where it will be exposed to moisture, as it is extremely resistant to rot. (Donsted, 2008)

Microshade

The façade is constructed with glazing units incorporating mircroshade. Microshade is microscopic lamellas imbedded within the glazing unit, shading the direct sun, comparable to exterior shading blinds in effect, while having a very limited impact upon the view out, and still letting in large amounts of daylight. The microshading reduces the solar transmittance of up to 90% in summer time, drastically reducing the heat gain on the interior, while still letting in the low, winter sun, to utilize the heatgain to reduce mechanical heating. (Microshade, 2016)

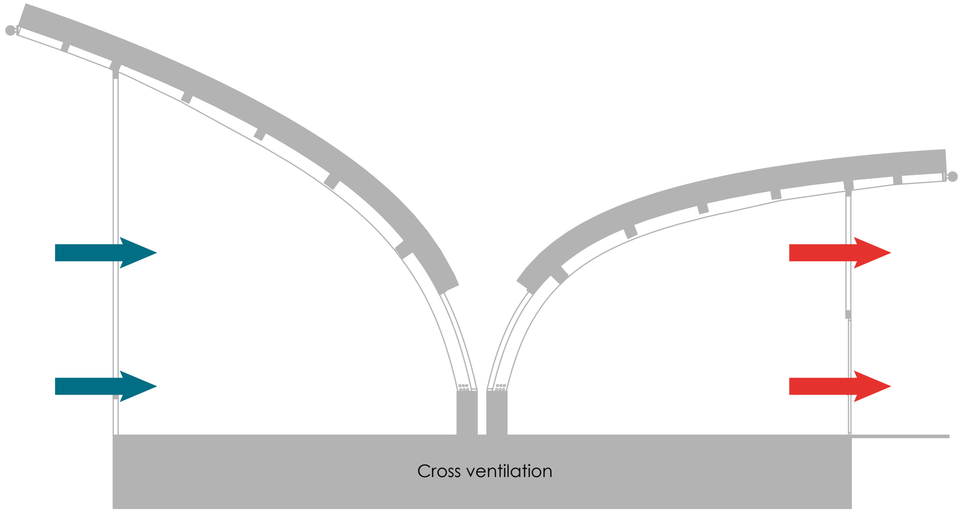
Ill. 104 Oak planks

Ill.105 Microshaded glassfaçade

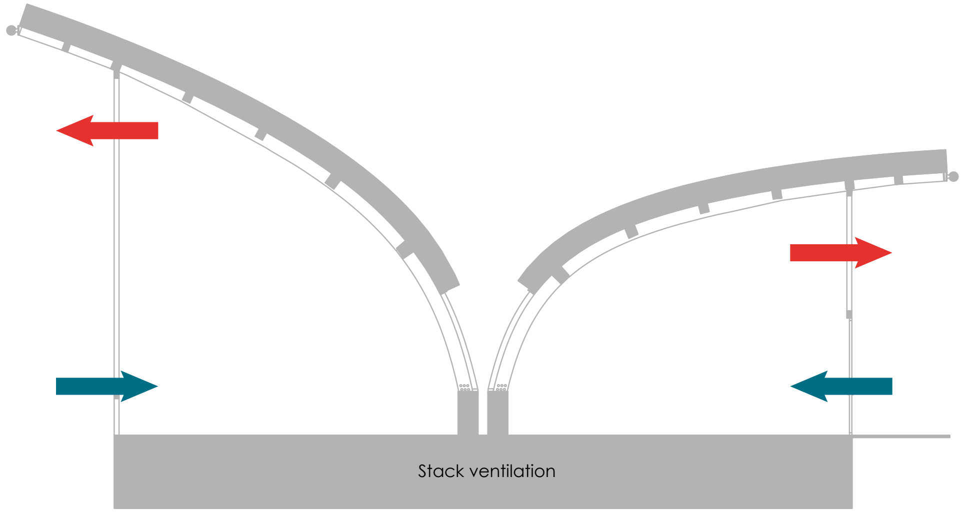
RESILIENT AND SUSTAINABLE SOLUTIONS

Natural ventilation

The small width of the elongated building provides ample opportunity to utilize cross ventilation in the summer time, and the room height of the single story allows for a combination with stack ventilation, through thermal buoyancy.



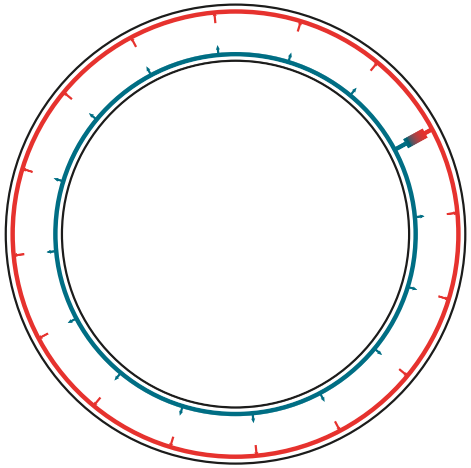
Ill.106 Cross ventilation



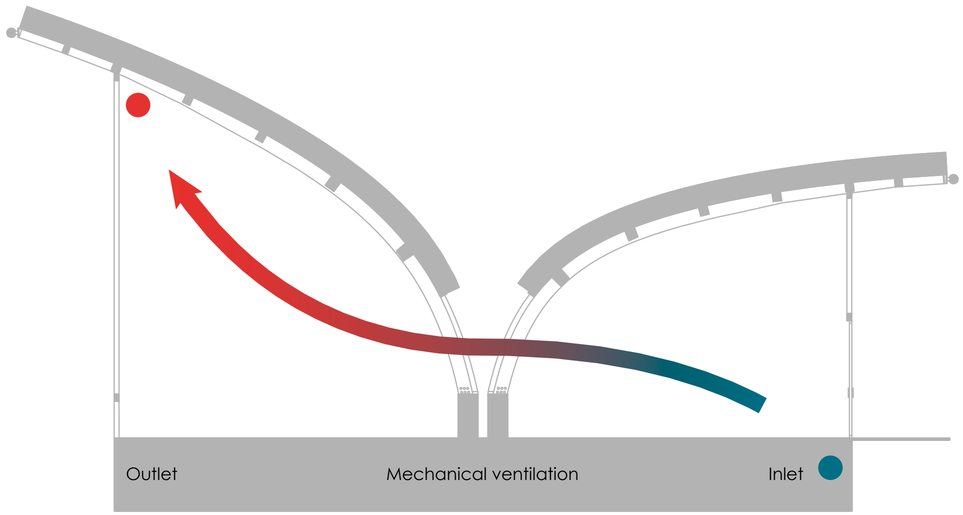
Ill. 107 Stack ventilation

Mechanical ventilation

Mechanical ventilation is using during the heating season, when outdoor temperatures prevent the use of natural ventilation, and uses heat recovery to reduce energy consumption. The ventilation is powered by a central aggregate located in the technical room, and utilizes the thermal displacement principle, by pumping in cold air in the bottom, thus forcing the heated air to exit in the top.



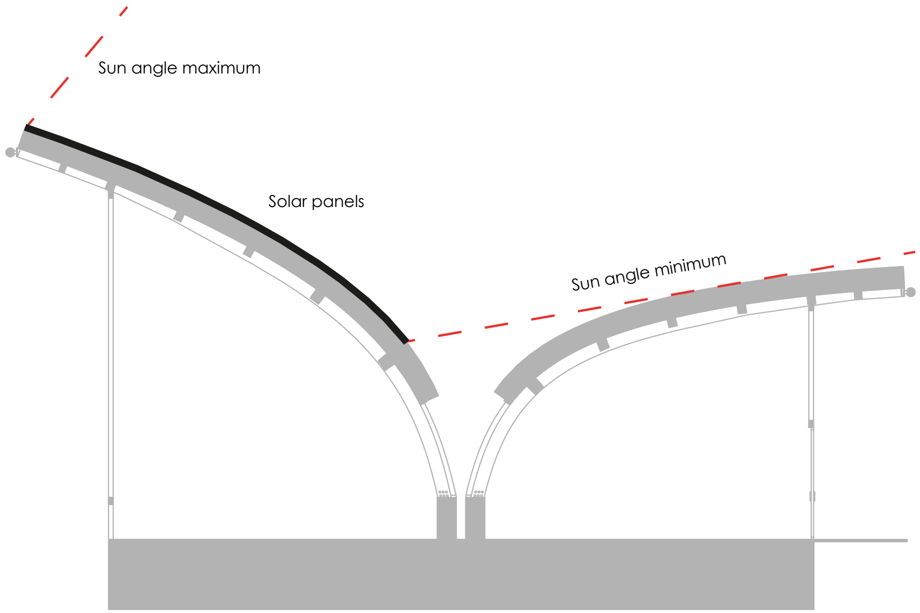
Ill.108 Mechanical ventilation ducts



Ill. 109 Mechanical ventilation principle

Photovoltaic panels

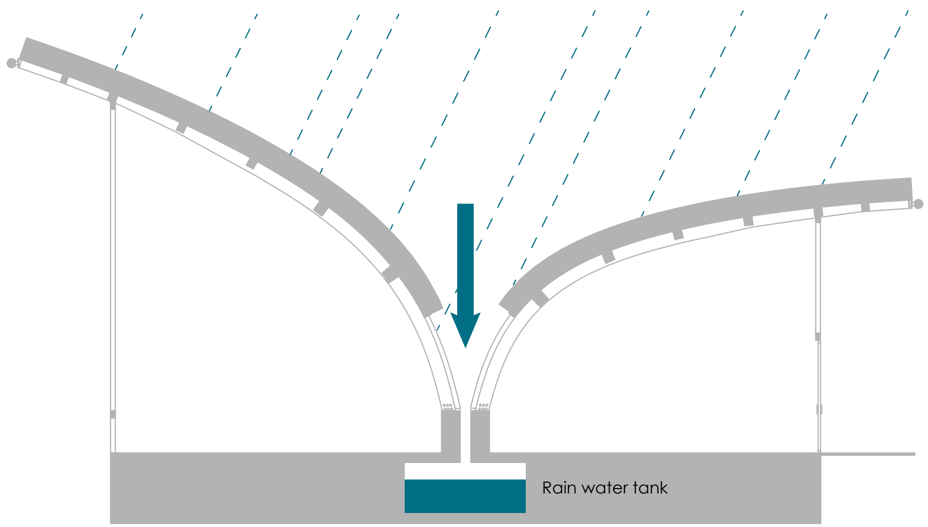
PV panels are integrated on the sloping roof, blending in with the black asphalt roofing, and the circular shape allows the museum to generate power through solar energy all throughout the day, as there will always be panels exposed to the sun in an optimal angle. The natural slope of the roof eliminates the need for additional framing to angle the panels, which would have made the panels stand out from the roof.



Ill.110 PV panels

Rainwater collection

The natural sloping of the roof is used to gather and collect rainwater from the entire surface, and as the roof always slopes towards a column, in any given point, this entirely eliminates the need for external drain pipes. The collected rainwater can be used for toilet flushing and as an element in the workshops and exhibitions. The collection of rainwater, is an exemplification of sound sustainable and resilient design, and the lower part of the column is constructed of glass, to allow the visitors to experience the unique design element, and thus integrating it into the exhibition.



Ill. 111 Rainwater collection

Local drainage of rainwater

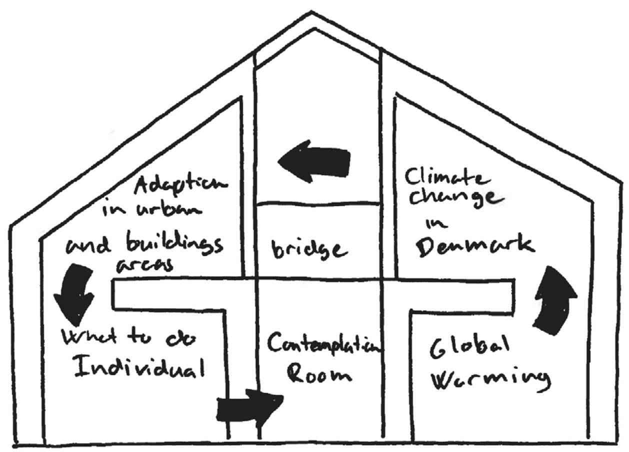
In an urban environment, such as Copenhagen, large, paved areas cause a strain on the sewage system, and maybe cause flooding during cloud bursts. The solution is to utilize permeable surfaces, and green pockets that can dissipate the rainwater, while including designed, designated rainwater basins to store excess water until the green area can percolate it. The courtyard covers the functiom of local drainage of rainwater, intended as an example for the exhibitions.

Ill.112 Local delay of rainwater

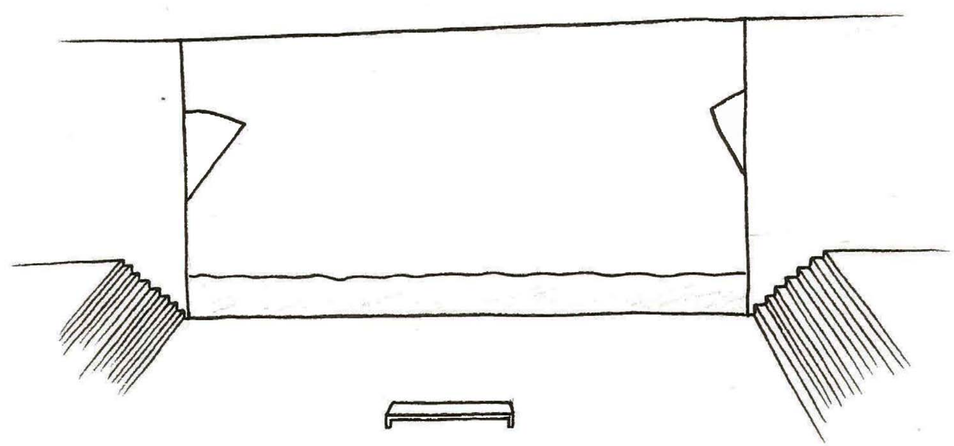
DESIGN PROCESS

INITIAL FORM STUDIES

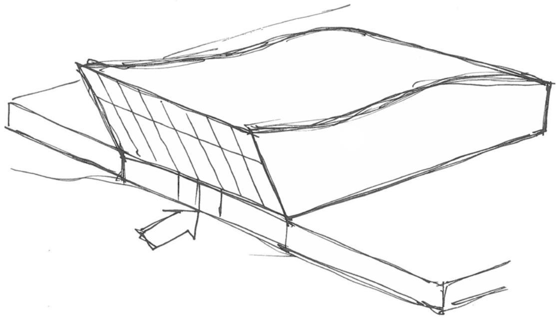
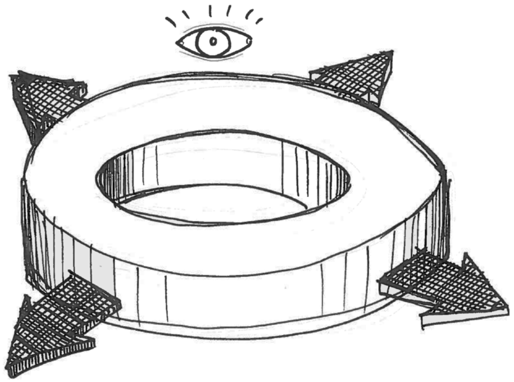
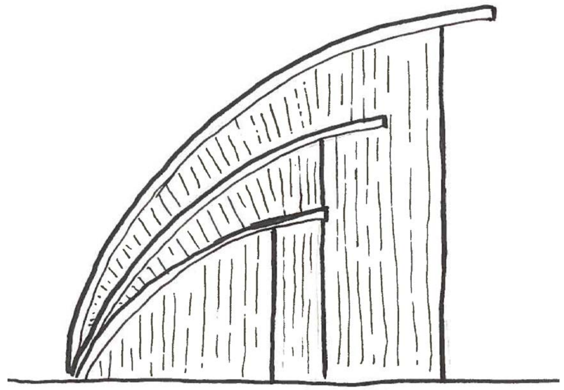
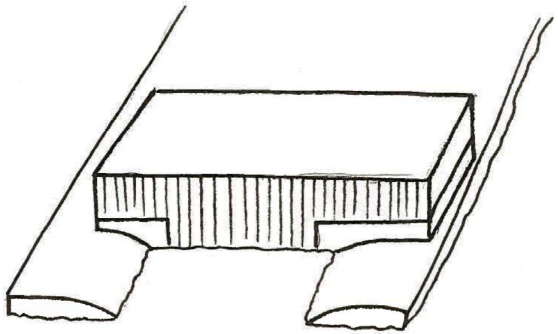
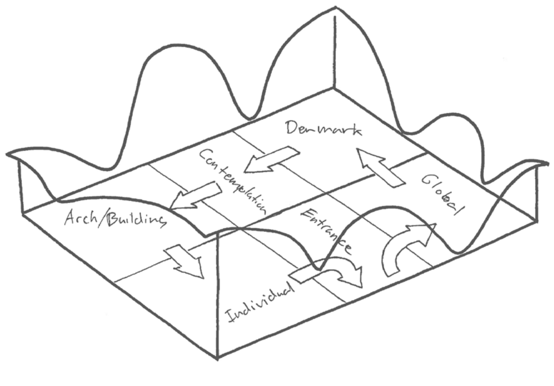
The beginning of the sketching phase ran simultaneously with the analysis phase, and as such is characterized by its explorations aiming both left and right. The investigations ranged from function based form finding, to site interaction and completely unbiased form studies, in a search for the right idea and concept, a search done through hand-sketching and model making. Through the models, an understanding of the context, scale and placement of the museum on the site was established. Although the rather unstructured beginning to the design process did not provide a strong idea and form, it did however inspire the first of a series of conceptual ideas that would eventually end up forming and staging the final form and the underlying concept of a strong narrative. Already in these very early stages of the process, the principle ideas of the contemplation room and journey through scale in the exhibition emerged, and these ideas became integral parameters for the vast majority of ideas from this point and on.

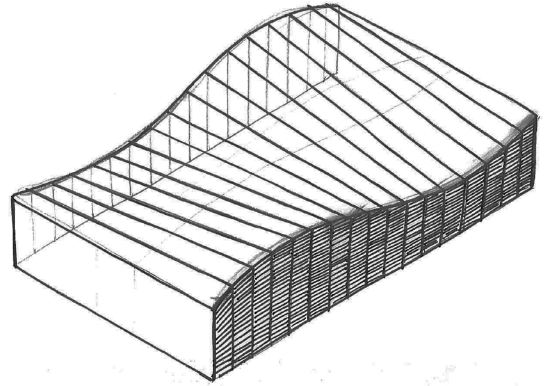
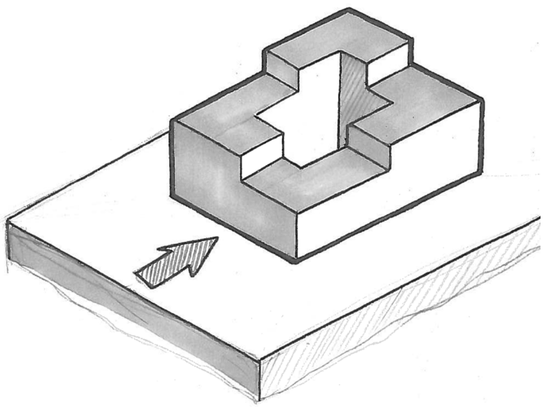
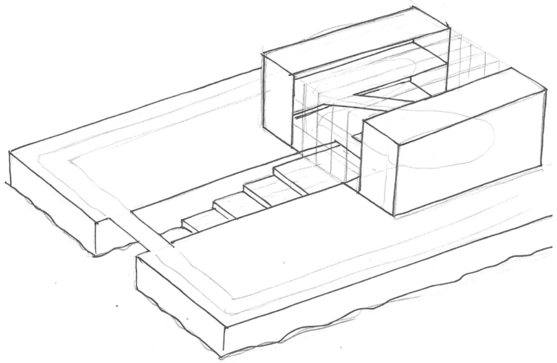
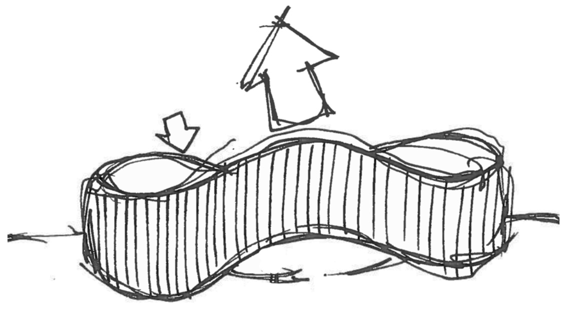


Ill. 113 Circulation



Ill. 114 Early sketch of contemplation room

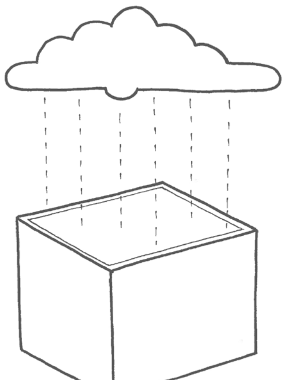






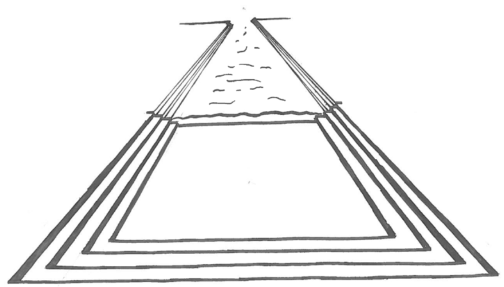
Ill.115-123 Initial form studies

The element of water

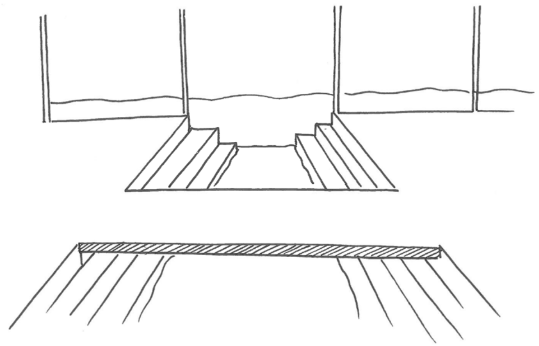
Through the analysis of climate change and adaption in a Danish context, water as a problem with potential became an inspiration for many ideas, further building upon the idea that would later become the contemplation room. Many ideas involved using water integrated in the exhibitions in the interior of the building, however this was later opted against in favor of letting water flood the façade, as it would have had a severe and negative impact on the indoor climate of the building, to have water running through the façade.



Ill.124 Rainwater collection on roof



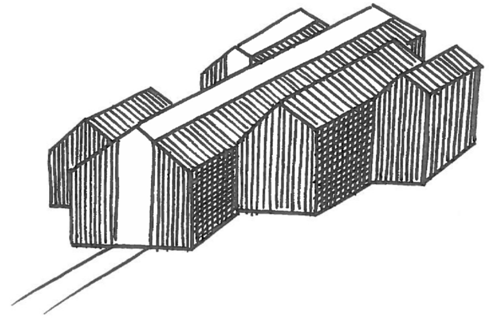
Ill.125 Connection to water

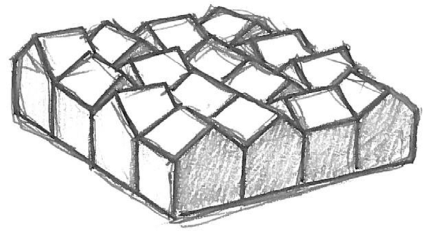


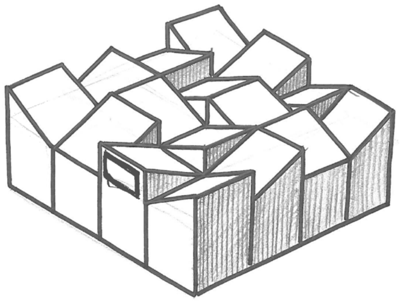
Ill.126 Water through the facade

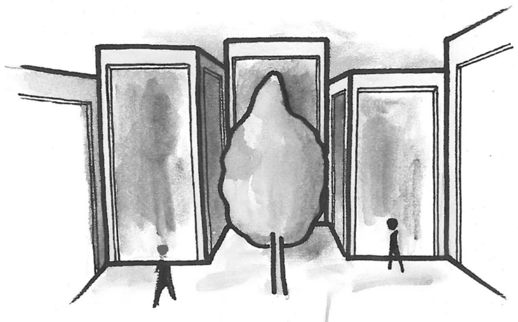
Form division by function

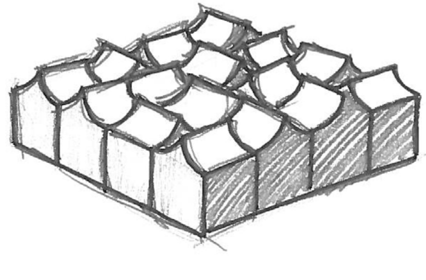
Inspired by the Utzon center that provided the frame for the work on the thesis, function as a leading design principle was investigated. The resulting ideas consisted of clusters of volumes, arranged to create a fractal form, typically arranged around a main volume or a courtyard, combining and merging all the functions in a central communal element. The resulting forms often resembled the context greatly, and thus blended entirely in, and it was in a contrast to this that the inspiration to work with monumentality first began, however it would not be until later in the process, that the final, unique manifestation of monumentality would emerge.







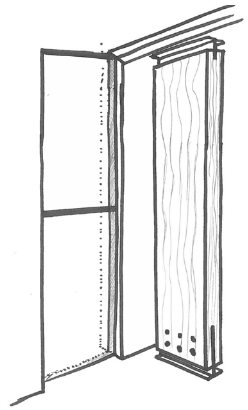


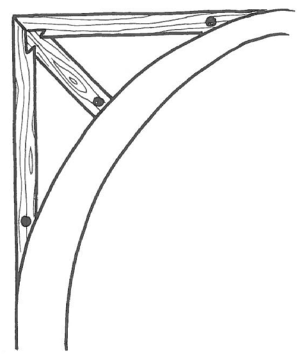


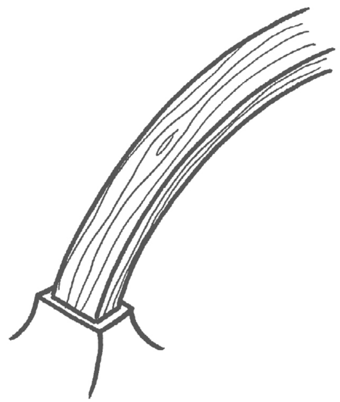
Ill. 127-131 Dividing shapes by function

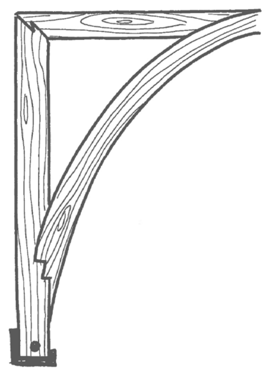
Designing from the detail

In a short workshop, the process of detailing was reversed, working from the joint and outwards, in an attempt to develop integrated structural systems that contribute extensively to the visual expression of the building. In this workshop, the idea of the joint between a wooden beam or column, and a concrete base, lodged itself within the design development, and its presence is visible in the final design.





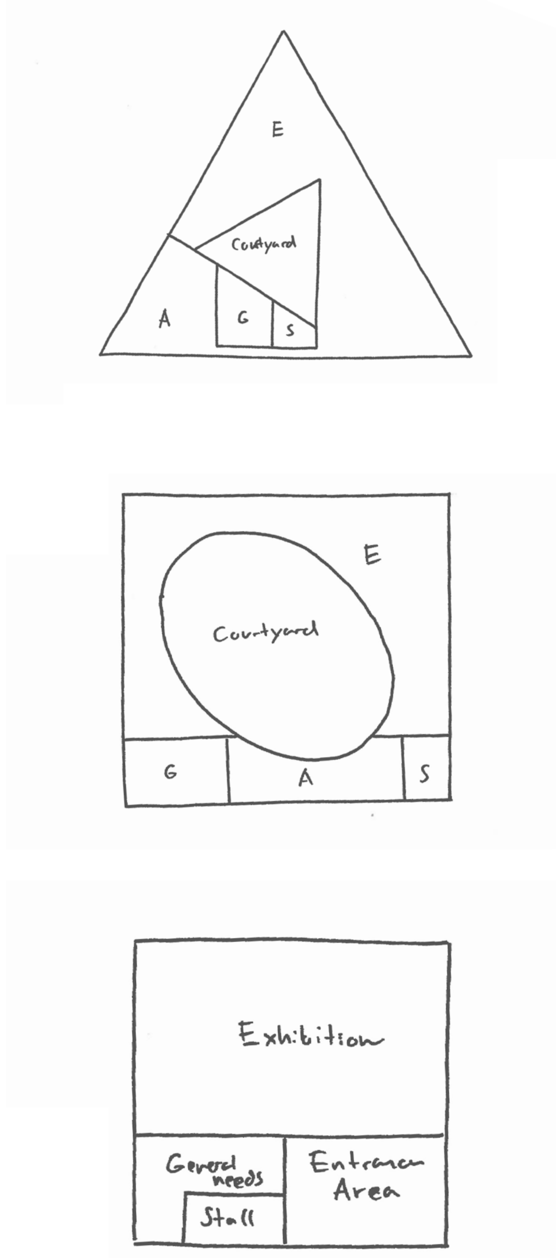




Ill.132-136 Detail sketches

Circulation and plan layout

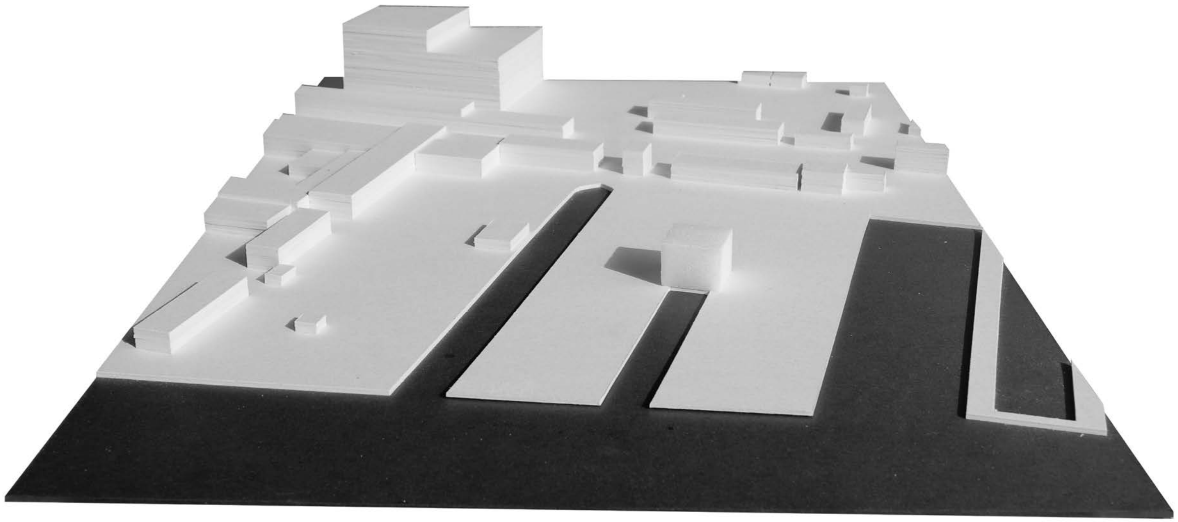
At this point in the process, the aforementioned ideas, which would eventually make their way into the final design, had not been converted into a unified narrative, and mini-workshops with different focus were continuously undertaken, in an attempt to use concentrated investigations to inspire a stronger concept. One such mini-workshop followed the mantra of 'form follows function', and sketching from plan layout and circulation were undertaken. From this mini-workshop, the idea of the exhibition unfolding along and around a courtyard was developed.



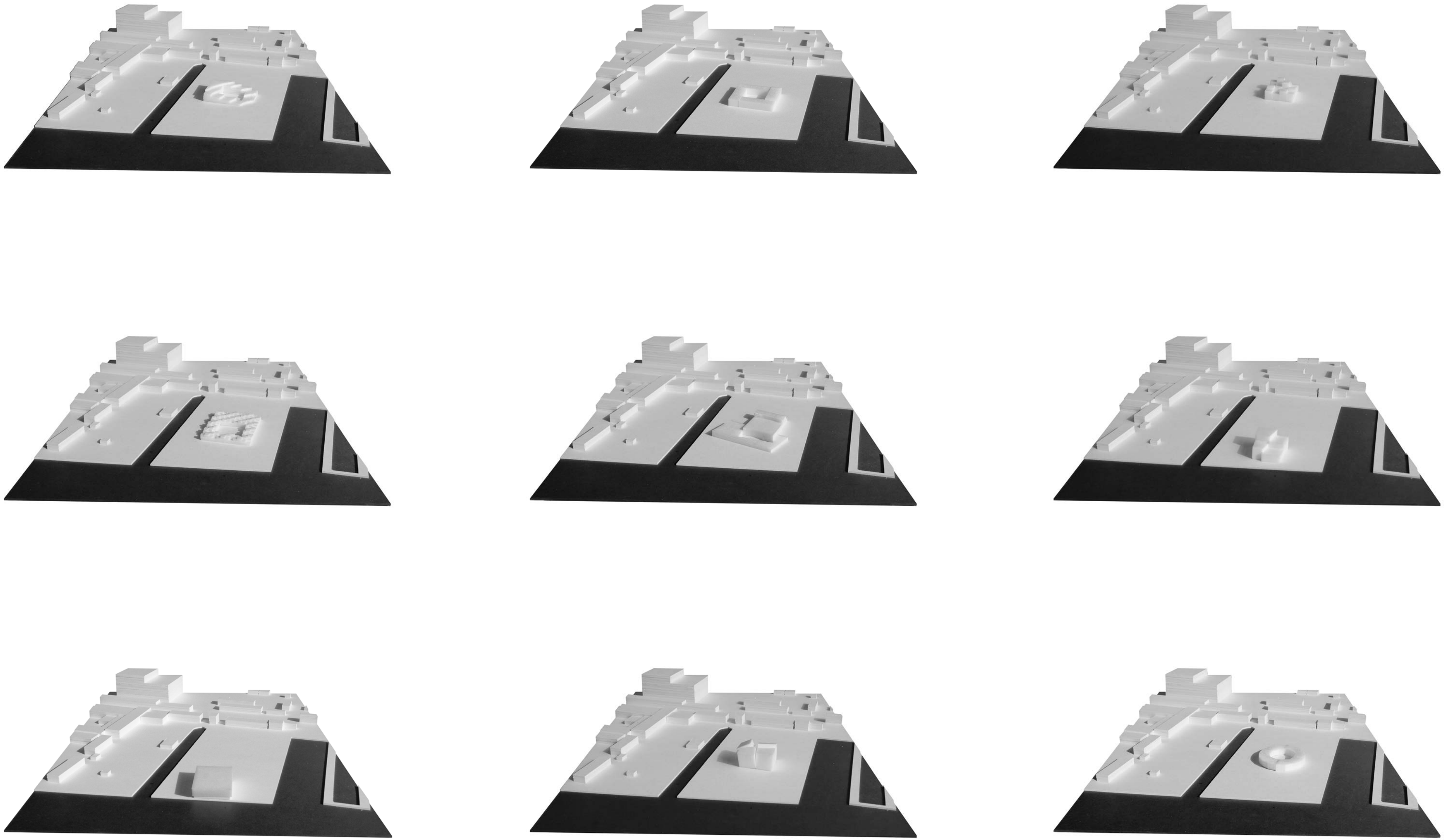
Ill.137-139 Function and plan layout

Continued form studies

With the use of a small context model, with the site as a replaceable plate, the form studies continue. It was in these general form studies, that the idea to cut away a larger part of the site first emerged. At first the idea came to be, as a combination of the desire to bring water to the façade, and using it as an important element in the design, while also maintaining public accessibility to the water through the site, by setting back the building to the middle of the site. However, on a study trip to the site, it was discovered how barren and unused the site is, even on a cloud-free, sunny day, and in combination with the idea that providing access to the water in combination with a public building could serve the sight better, by bringing more life to the area. An appealing, simple and elegant cube situated centrally on the site, cutting away a part of the site, in order to bring water all the way up to the face, became the favored design option. It was since dubbed 'the cube'.



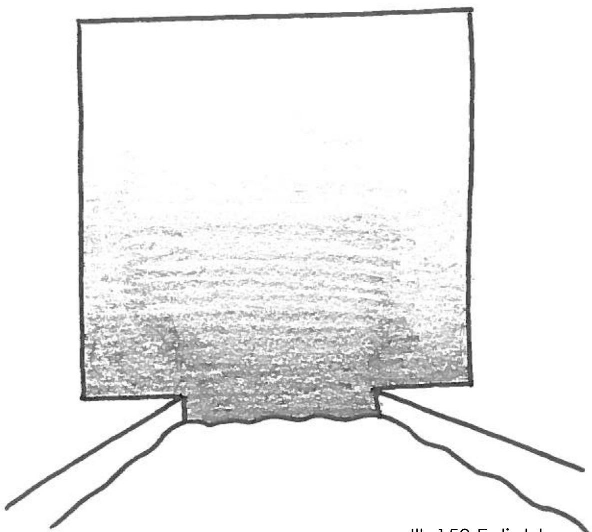
Ill.140 The cube on context model



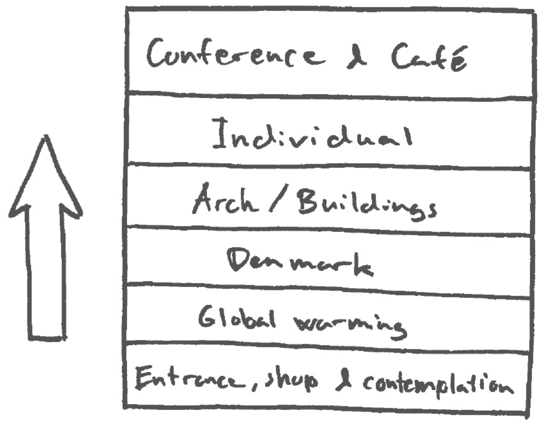
Ill.141-149 Model form studies

Integrating structure

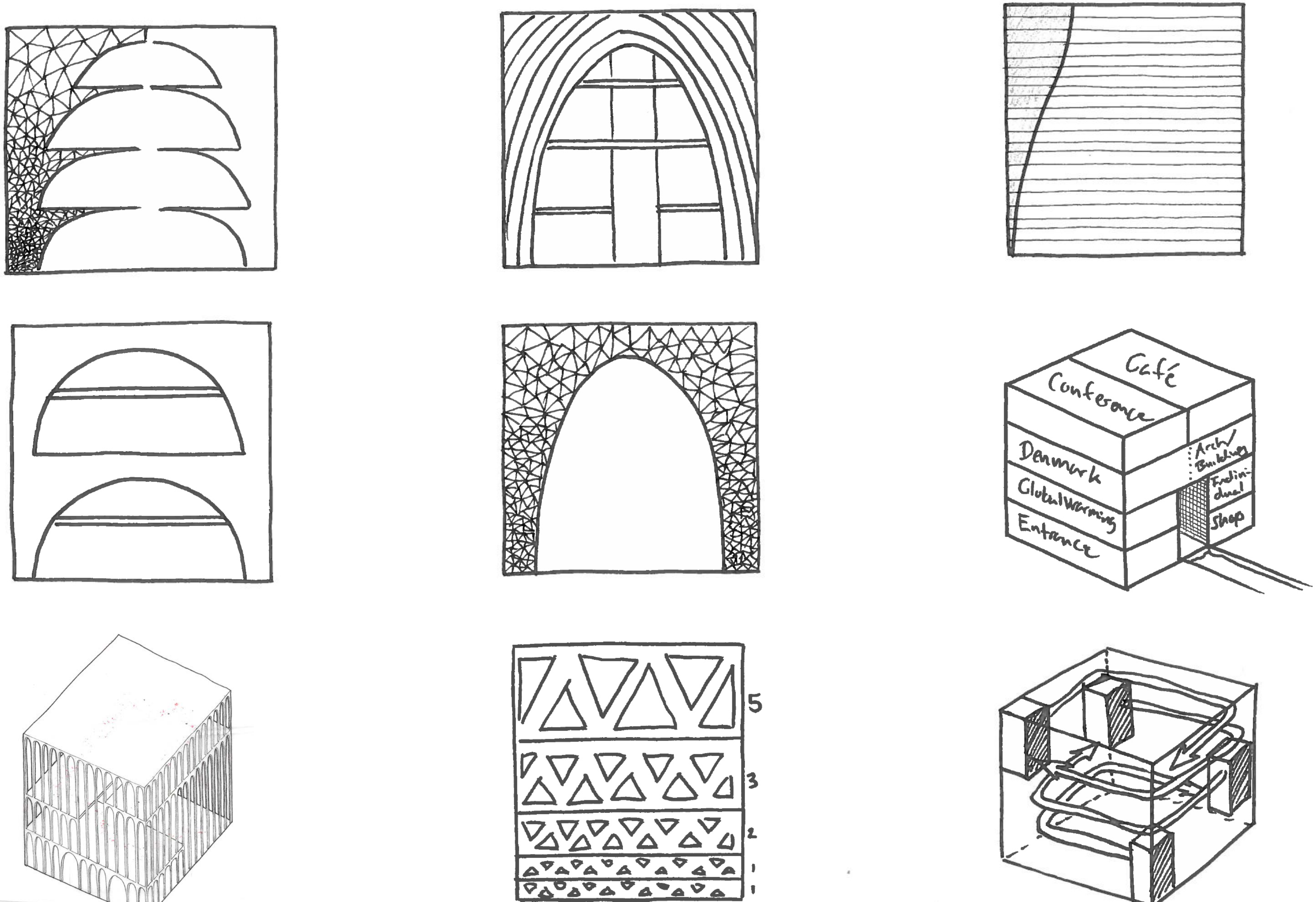
The all but chosen idea at the time, 'the cube', was a very simple geometric, yet elegant shape, however it did not, in itself, provide the uniquely expressive experience that was desired for the museum. The development of a structural system that could contribute to the aesthetic quality through a very visible structure, became a focal point for the further design process. This became the start of a very early and throughout integration of the structural system into the architectural design. A large effort was invested in developing a structural system for the cube, which could provide the form with expressive and intriguing detailing, without interfering with the clean, geometrical form, working with gradient in the density of the structural system, the idea of enlightenment through the façade expression started to grow.



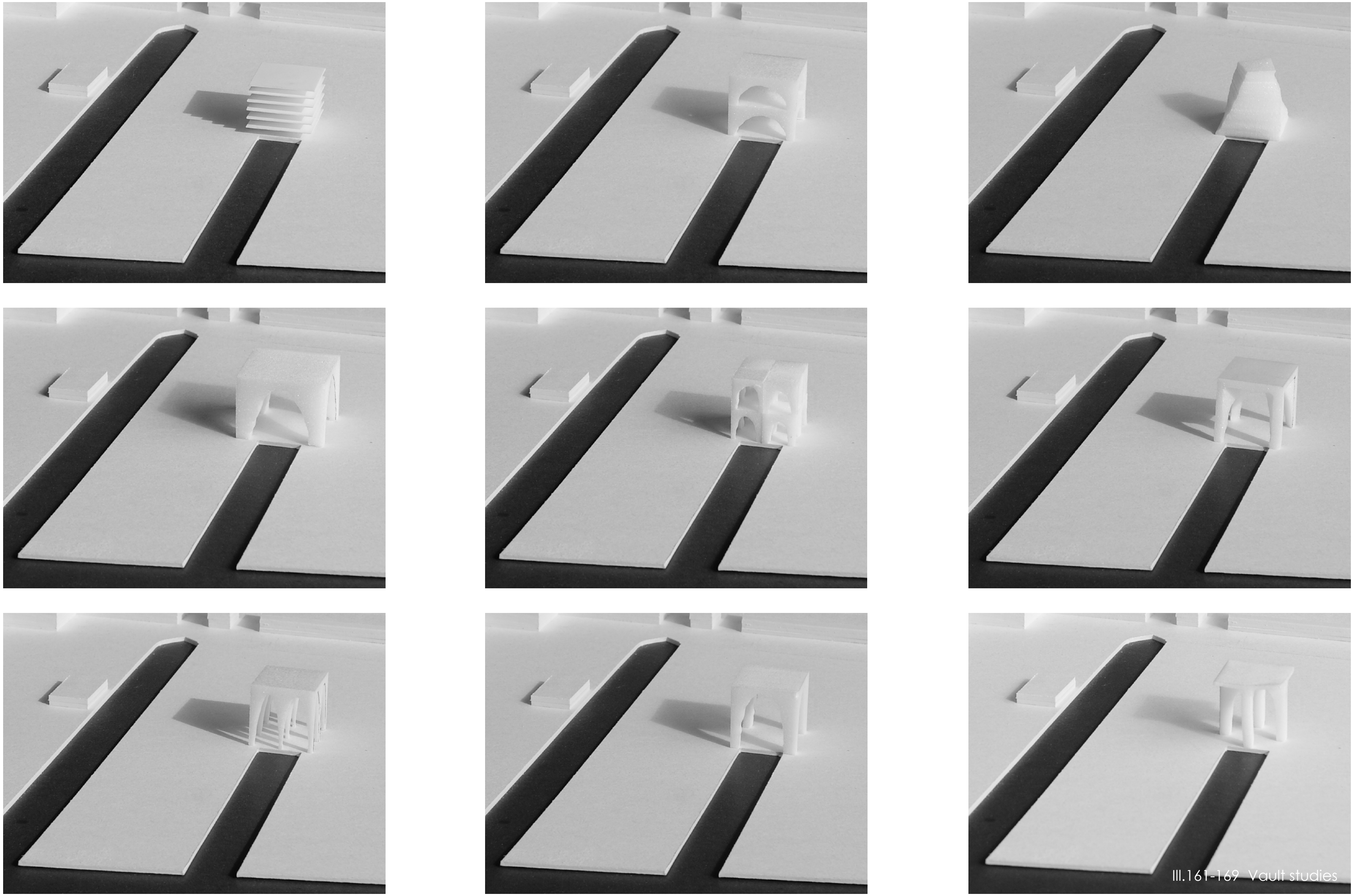
Ill. 150 Enlightenment in the facade



Ill.151 Narrative up through the building



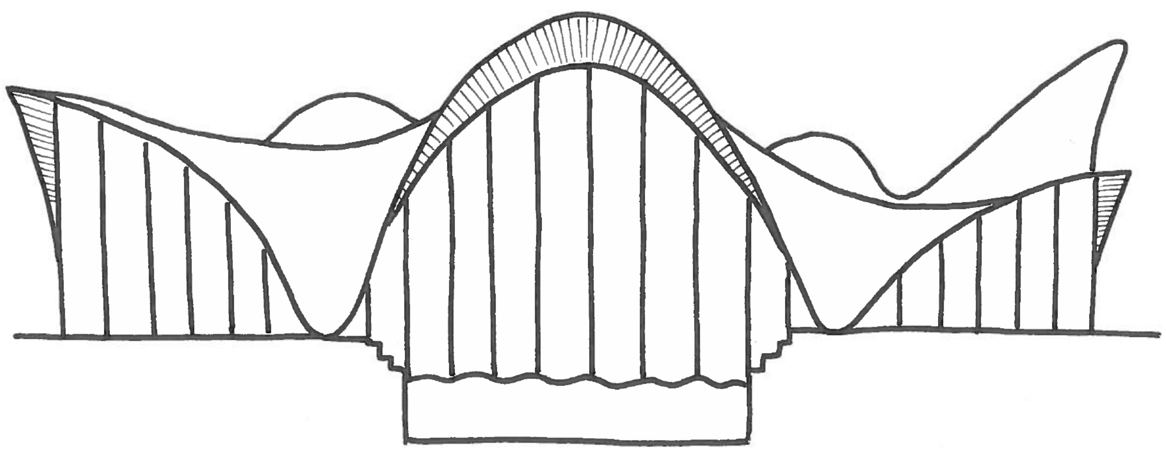
Ill.152-160 Structural systems and flow in cube



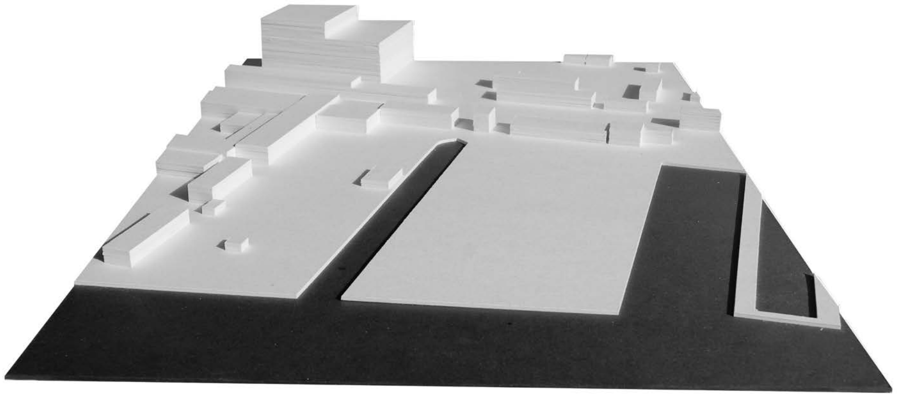
Ill.161-169 Vault studies

Vaults

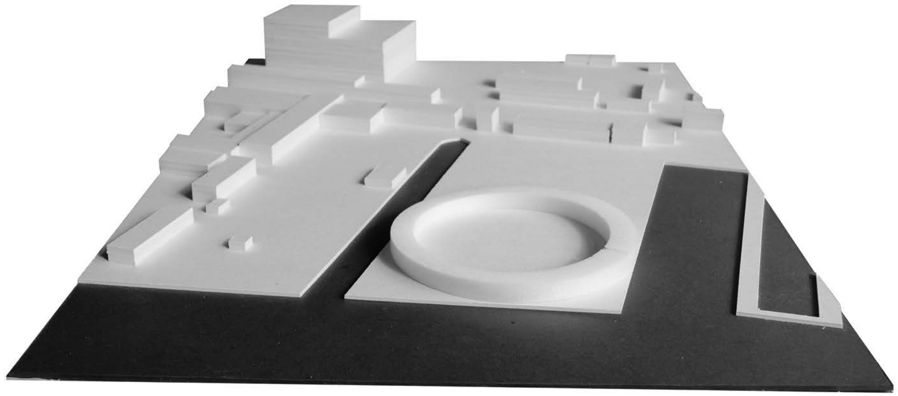
One of the main structural principles investigated for the cube, was vaults. Countless iterations were made, in an attempt to merge the principle of vaults with the scale of the cube, without achieving the desired result. The successful combination of the narrative and journey, with an expressive structural system, in a stacking, multiple floor scenario, eluded. The extensive investigations into vaults prompted a suggestion from our technical supervisor, to explore the possibilities of funicular form finding principles. The funicular form quickly inspired an interest; however, it also quickly increased the problem of stacking the structural system to create the cube. At this point, a radical decision was made to abandon the cube. The funicular principles inspired expressive shapes, fulfilling the requirement of a structural system that contributed greatly to the aesthetic quality of the building. A desire to retain the simple and geometric expression that the cube possessed, the potentials of the funicular form finding was explored and, to an extent, exploited.



Ill.170 Furnicular form roof



Ill.171 Back to square one



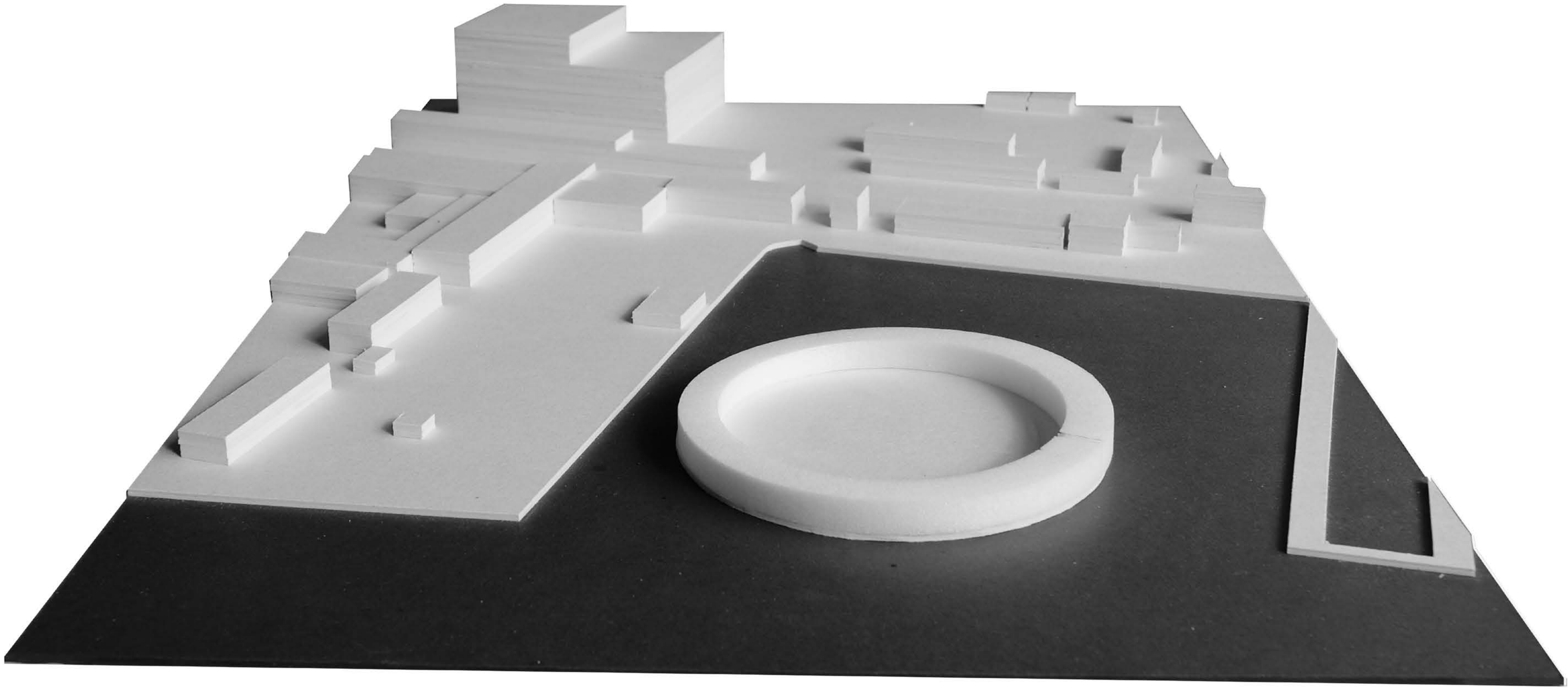
Ill.172 Circle filling the site

CIRCLE

After discarding the cube, the project was forced to take a few steps back, and was essentially back to square one, in terms of form. From this point of view, previous, pivotal ideas were evaluated, filtered and gathered. Through the simple geometrical shape of a circle, an idea that had previously appealed with its soft form providing a pleasant contrast to the rough context, a selection of the strongest ideas throughout the process could be combined to create a holistic concept. Ideas of utilizing and connecting with water, a contemplation room, monumentality, enlightenment, an emotional journey and the funicular form principles all converged in a unified concept of the narrative as a motivator and shaper.

By extending the circle to the edges of site, the possible courtyard area is maximized, and the building, which is limited to a single story by the funicular roof form, achieves a monumentality in an otherwise large scale context. The scale of the circle also neatly balances the size of the circle with the width and height of rooms.

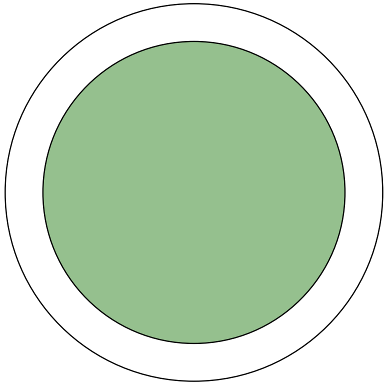
To emphasize and amplify the emotions invoked by journey, a radical choice was made, to slice away the remainder of the side surrounding the circle. In doing so, the building is entirely exposed to water, placing a focus on the relation with water. By isolating the building in the water, it allows the museum to further build upon the theme of monumentality, even though, in height, the building follows the linear decrease in scale from the section halls, through the warehouses to the flat open areas towards the water. Thus a monumentality unique to the museum is introduced.



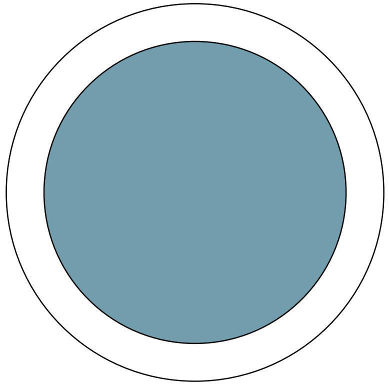
Ill.173 Cutting away the site

GREEN OR BLUE

Deciding and fine-tuning the emotional journey of the narrative throughout the museum, involved repeated choices between problem and solution, while maintaining a functionality to the design. The chosen direction attempts to find a balance between exemplifying a threat, in order to impose a will to take action, while still emphasizing that there are ways to adapt and even prevent the threat, and doing so while utilizing the design potential of these adaptations, and providing added value to the design.



Ill.174 Green courtyard



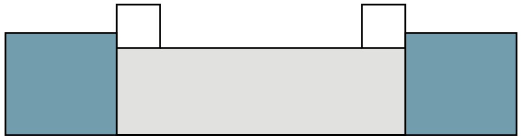
Ill.175 Water courtyard

Green

With a green area in the middle of the building, the museum gets a comfortable outdoor area, and the possibility to show-case local delay of rainwater (LAR) solutions and how it could contribute to the quality of a building. Urban farming could provide vegetables for the café and restaurant. The shading and water evaporation trees provide help regulate indoor climate. Relates to one of the most frequent issues in a Danish context, and shows how LAR can be a solution that interacts and integrates with architecture. The green approach represents a solution-oriented choice, and is heavily influenced by the added quality and functionality by a courtyard.

Blue

By having water in the center of the building, the consequences of climate change is put into focus. Usable outdoor spaces, for the café and workshops could be placed on pontoons. By choosing this solution, water becomes the clear focus of the entire exhibition and design, completely enveloping the guests from start to finish, and emphasis is put into inspiring to action, through the emotional effect of experiencing a threat of water.



Ill.176 Place on foundation

Ill.177 Floating structure

Sink

Placing the building on a fixated foundation, forces the building design to react to an exposure to flooding, once again putting a focus on the problem. By deliberately causing flooding of the façade, rather than elevating the entire building to a safe level, the threat of water is emphasized to increase awareness and to inspire action, by making a very visual experience of how severe floods can be.This option goes well with the green area solution, as the building itself becomes an exhibition/ example of how to solve a problem, although in an abstract way, and what the problem is. This creates symbiosis between the building and the courtyard landscape, protecting each other.

Float

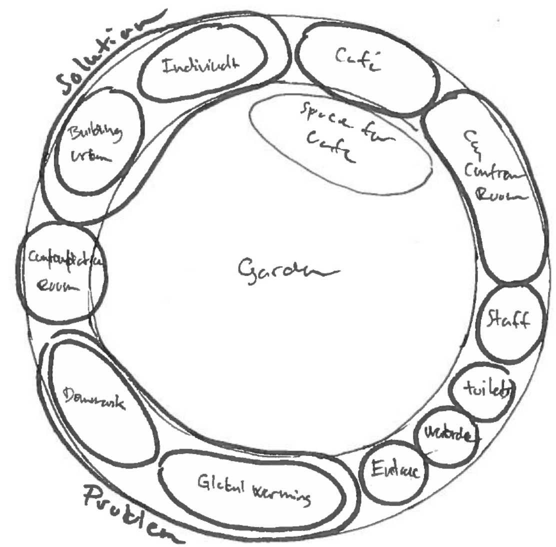
Having the building float expresses a very direct solution to the rising sea level, and goes well with the blue center, showing complete adaptation to an omnipresent element of water. The building would become indifferent to water levels, regardless of how much it rises, and acts very reassuring that the problem is surmountable, and the act of overcoming the problems can contain interesting design options.

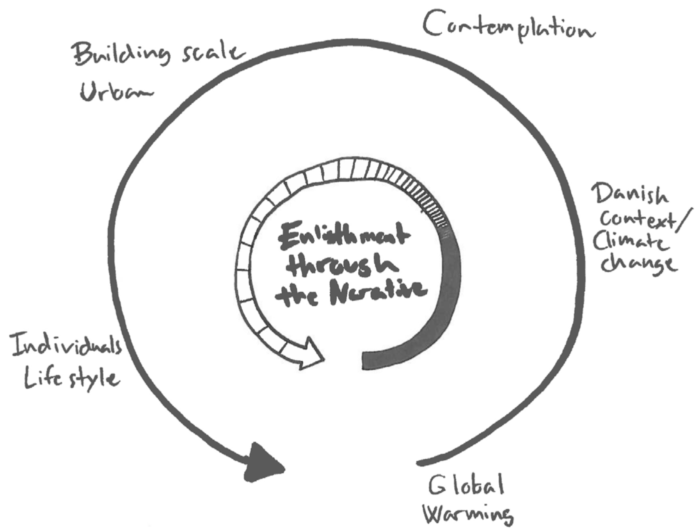
PLAN DETAILING

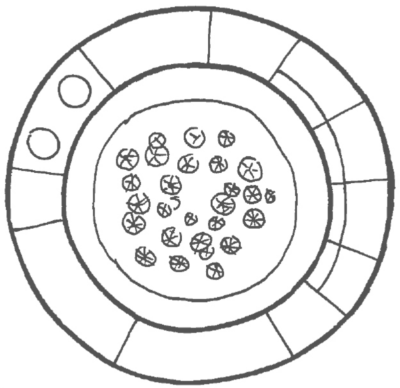
The plan was iterated upon with a strong focus on the expression and journey created with the narrative throughout the museum. Going from global warming, Danish context, urban & architectural plan, to individual household solutions and sustainable behaviour. In the middle of the narrative the contemplation acts a mental and emotional breather, allowing the impressions to sink in, and before transitioning from the problem exhibition to the solution exhibition. Special attention was given to the placement of the columns, and their interaction with the volumetric expression of the rooms, especially in the smaller workshops and staff areas, where the impact of a column was greater.

Throughout the development of the plan, the different aspects of the design, that contribute to the narrative, began to fall into place, to form a coherent and continuous emotional journey throughout the exhibition. Aspects such as the enlightenment and the decline and ascent in levels.

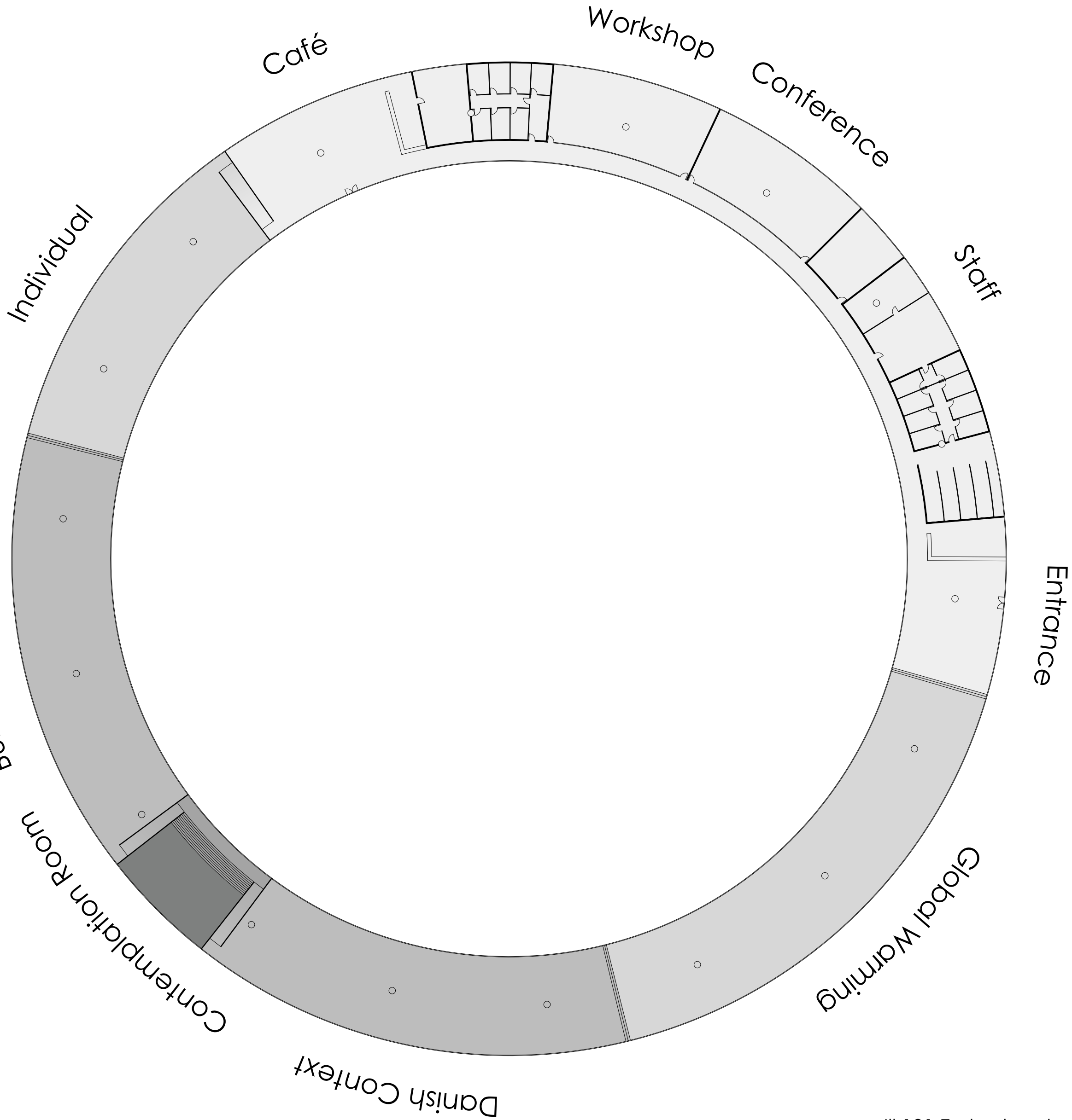
To avoid clashing with the exhibition, the additional functions of the museum were situated together. They were placed in the opposite direction of the exhibition from the entrance, to allow for direct access for guests visiting specifically for one of these functions.







Ill.178-180 Plan sketching



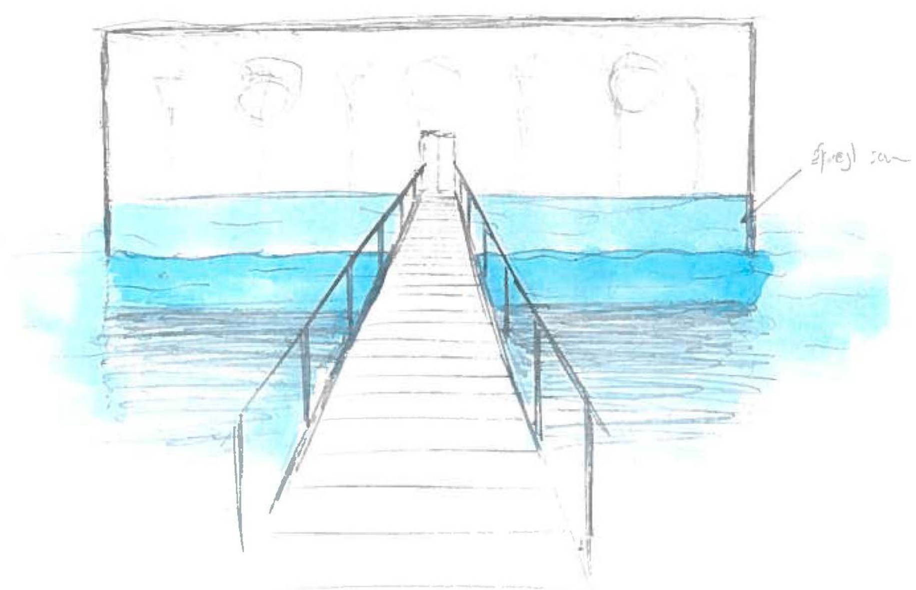
Ill.181 Early plan draft

ATMOSPHERE

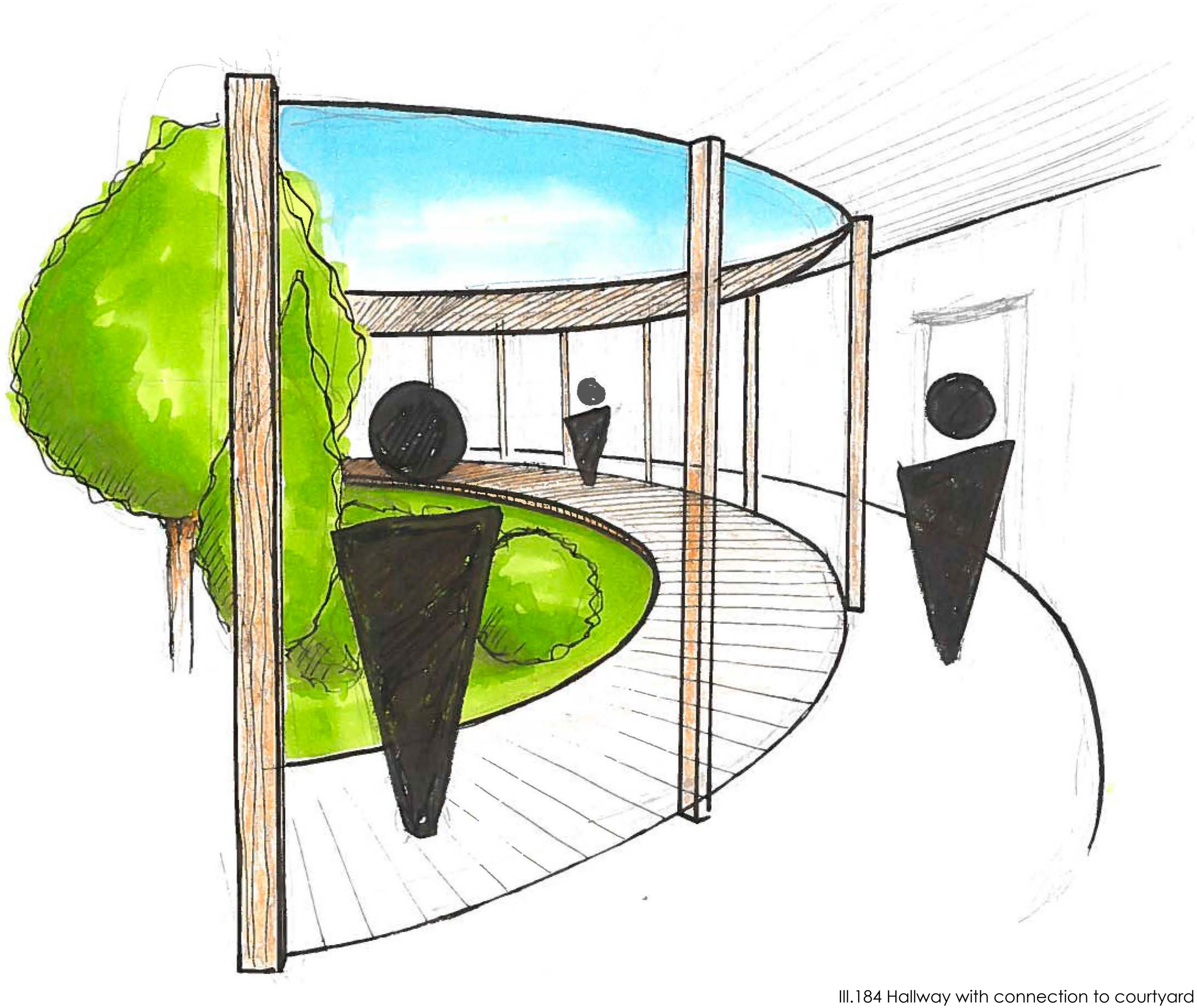
Inside the building there is a direct view to both the inner courtyard, with a lot of trees and plants, and the water through the outer façade, all the way around the exhibition. By utilizing the contrasting views of water and vegetation on the two opposite facades, an atmosphere of synergy with, and within, nature is created. From the very moment when visitors arrive on the bridge, they feel and are exposed to the elements, and the museum stands in end, and is a safe haven providing shelter from wind and water, emphasizing the symbiotic and synergetic atmosphere.

A constant proximity to water in all rooms, and a continuous direct connection to the natural reserve, along with the large amounts of natural light, create a unique and contrasting natural atmosphere, serving a constant reminder for visitor of the museum, a reminder of the beauty, power and importance of nature in our lives, and its impact on the built environment.

Ill. 182 Protected courtyard



Ill.183 Water reflected on facade

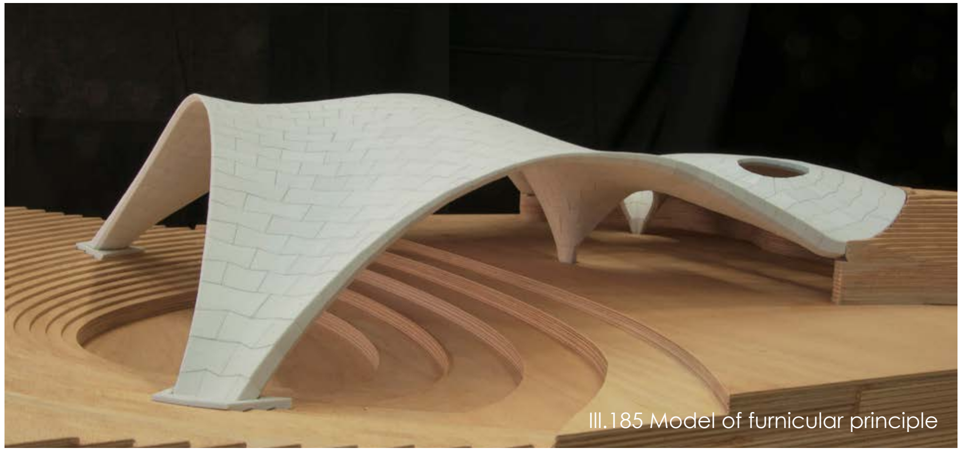


Ill.184 Hallway with connection to courtyard

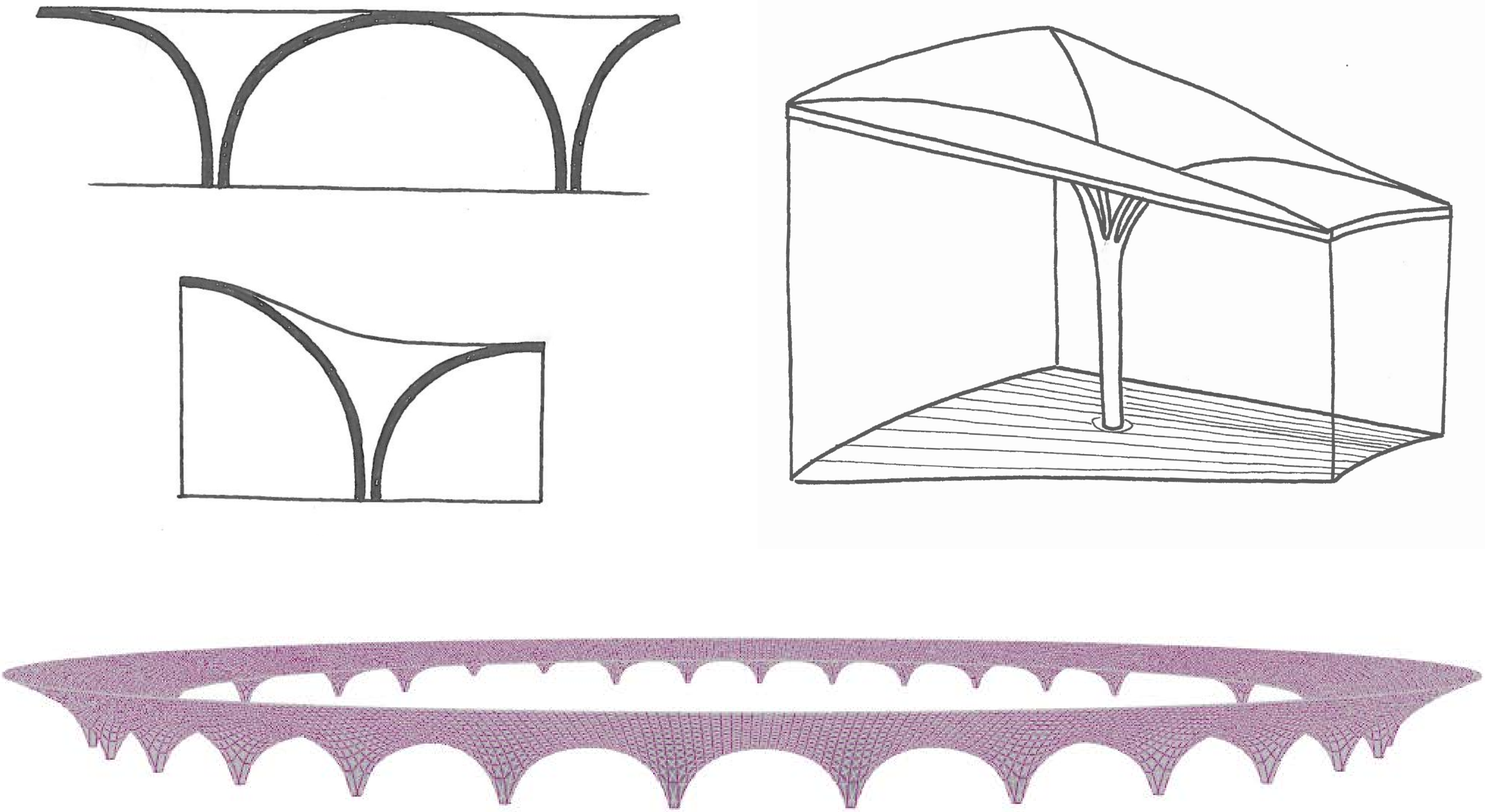
REVERSING THE FURNICULAR SYSTEM

The structural system used in the circular shape found its inspiration in the Rhinoceros plugin Rhinovault (Courtesy of Block Research Group), which is based upon the furnicular principles, usually represented by three dimensional vault structures. In order to keep the clean geometrical expression of the circle, the usual vault expression was reversed and manipulated. This resulted in a roof that unfolds from a single line of columns, giving a unique expression to the interior of the rooms, while the two facades remain clean and simple, without the necessity of structural elements.

Furnicular structures normally work entirely in compression, and at this stage a manipulation of supports in the program simulated supports in the outer rings of the structure, in order to achieve the desired form. Based on the premises that the structure would only need to 'lean' against the support in the outer ring, it would need no vertical support. It was theorized that the remaining need for horizontal support could be replaced by a ring in tension and a ring in compression, using the continuous form of the circle to support itself, eliminating the need for external support. The rings would work much like the steel bands on a wood barrel, keeping the structure in place, only if the circle is intact.


Ill.185 Model of furnicular principle


Ill.186 Furnicular form test



Ill.187-190 Reversing the furnicular system

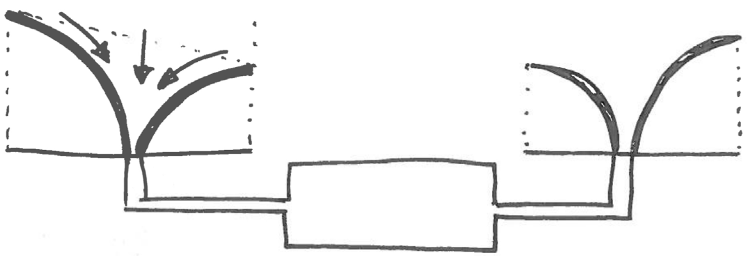
SUSTAINABLE INITIATIVES

Rainwater collection

From the early stages of the sketching phase, idea of rainwater collection was attempted integrated in the design. The natural slope of the furnicular roof allows for water collection all through the surface, as any given point is always sloping towards the center. The water collation happens through the columns, and will be visible in the exhibitions as a way to make the collection an exemplary part of the exhibition, while contributing to a unique atmosphere in the interior. The water would be stored in a water tank, in the middle of the site, and then used for toilet flushing, as a part of workshops and irrigation of the courtyard if necessary.

Photovoltaic cells

With the circular shape and the inclination of the roof on the museum, ample opportunities for placement of photovoltaic panels is provide. Majority most on the northern end of the building, where the best conditions are, but the roof on the southern side will also have sun on the part towards the courtyard



Green area

A green courtyard provides opportunity for a wide variety of sustainable and resilient initiatives. The café, and local restaurants on the island, can use an area of the courtyard to cultivate food produce for use in the kitchen, while also providing the opportunity for workshops to experiment with the edibility of alternative sources of nourishment. The green area could also function as LAR, providing an example for the exhibitions, of how to adapt to increased rainfall. In addition, the shading and evaporation form the trees helps regulate indoor temperatures.

Resilience to flooding

The building and foundation protects the courtyard from storm surge flooding, while the LAR in the courtyard prevents excess rainwater from flooding the building, creating a symbiosis between architecture and nature. Intentional flooding of parts of the exterior façade serves to put a focus on the growing problematics of rising sea levels, further adding to the emotional journey and narrative of the building.

Ill.191-194 Sustainable initiatives

STRUCAL SYSTEM

The loads and load combinations used in the optimization process are described and calculated in the structural analysis part of the appendix. Multiple grids were design and tested on the shell, some of which were discarded due to aesthetic quality compared to the selected grids, others did not obey the structural principles set for the grid. The two grid types displayed represent the most optimal variations, that both fit with alternating column distances (10 and 15 degree rotation in circle) while also providing adequate beam elements to form each column.

Grid 1 provides a very clean and minimal structure, which utilizes the natural circular movement of the building, offset to match the slightly curved radial elements, which represent the primary transfer of forces across the structure. The columns for grid 1 will consist of 6 beam elements.

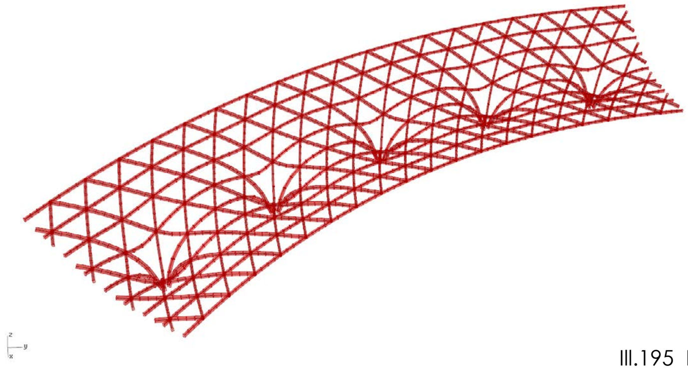
Grid 11 utilizes the same principles of force transferring and the natural circular movement, but also introduces an additional straight radial element, which, in addition to creating more direct transfer of forces, from the outer edges, to the column, also serves as a functionality tool, allowing partition walls to align exactly to this beam. In this grid the curved radial elements are defined by positioning of the longitudinal circular elements, and not vice versa, and therefore the longitudinal elements can be placed to fit with the inner partition wall of offices, auditorium and workshops, allowing for alignment similar to the case of the straight radial element. The columns of grid 11 will consist of 8 beam elements, which gives the column are more rounded look, while also providing more beam elements to take the combined loads of the cantilevered roof.

Displacement limit value is set to l/200. And the width of the roof is 19 m. As a result the displacement limit value is d=(19000 mm)/200=95 mm.

Step 1: Cross section optimization

In the preliminary tests it becomes apparent that the more rectangular a cross section, the better results in terms of overall utilization and of displacement. However, as the height (long) direction of the cross section must always be parallel to the normal vector of the original shell/mesh, the height of the cross section has a large effect on the total diameter of the columns. The resulting hollow area in the middle of it, which is to be utilized for light intake and rainwater collection, also must be considered. Therefore a balance between the structural performance of a cross section and the effect on the columns diameter must be considered for every iteration.

A ratio of around 1.6 between height and width appeared to be a nice balance, and therefore the 30x18 cm cross section is chosen. In the further iterations of other grids, optimal cross sections often landed around a ratio of 1.5, coinciding with the conclusion from the first iterations.



Ill.195 P1

Name	Max crosssection (cm)		Area	H/B ratio	Max utilzation ratio	Weight (kg)	Maz displacement (mm)	Approximate weight for full circle (tion)
	H	B						
P1	27	20	540	1,35	0,97	30611	46	220,3992
	30	18	540	1,667	0,94	30611	41	220,3992
	24	23	552	1,043	0,98	31291	52	225,2952
	33	15	495	2,2	0,97	28060	39	202,032

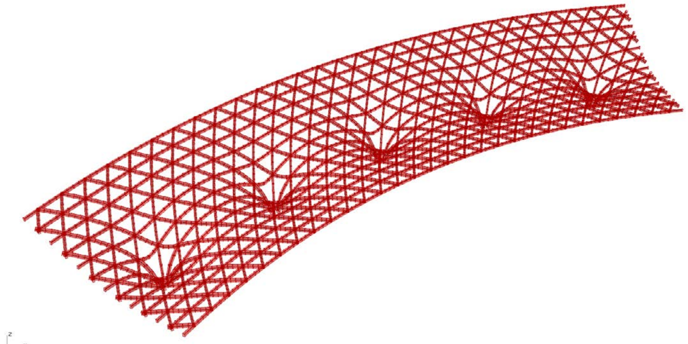
Step 2: Density of grid

Thereafter the performances of different densities of the two grids are explored, in order to determine an optimal balance between the additional self-weight a denser grid contributes, and the load carrying capability of the grid. As for the first iterations, there was a constant consideration of the maximum cross section size and how it affects the column, and it plays a large role in the choice of grid to continue optimizing upon.

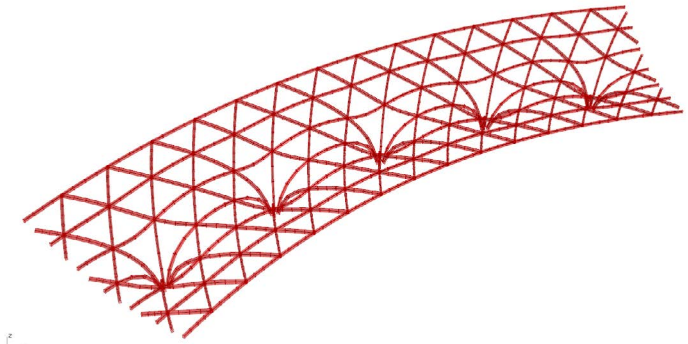
For grid 1 the normal version was chosen, as the max cross section was found acceptable, while reducing the material used in comparison with the other variations.

For grid 11 the dense variation was chosen, again due to a small max cross section size, and a vast difference in material required in comparison to the other two variations. However, for both grids, the focus was put on the material usage, while having less focus on the max displacement. This turned out to be an oversight, as the later design choice to add an overhang pushed the max displacement above acceptable values, and this procures and issue that has to (and will) be dealt with in later iterations.

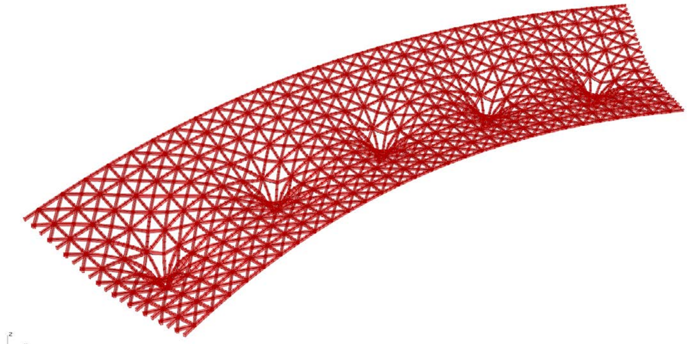
Name	Max crossection (cm)		Area	H/B ratio	Max utilzation ratio	Weight (kg)	Maz displacement (mm)	Approximate weight for full circle (tion)
	H	B						
P1 Dense	28	19	532	1,474	0,98	44289	28	318,8808
P1 Loose	35	22	770	0,591	0,96	33503	43	241,2216
P11 Dense	22	12	264	1,833	1,00	29651	48	213,4872
P11 Normal	33	22	726	1,5	0,99	71318	26	513,4896
P11 Loose	29	19	551	1,526	0,99	46624	34	335,6928



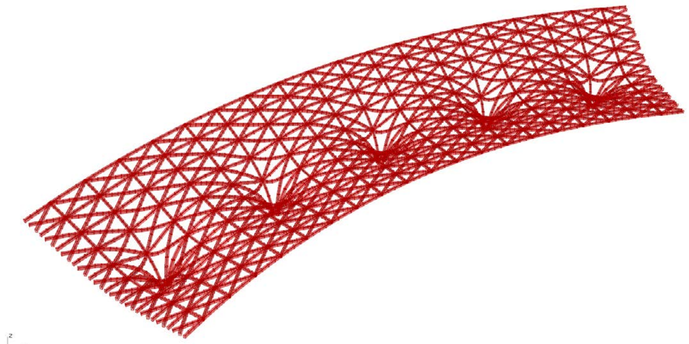
Ill.196 P1 - Dense



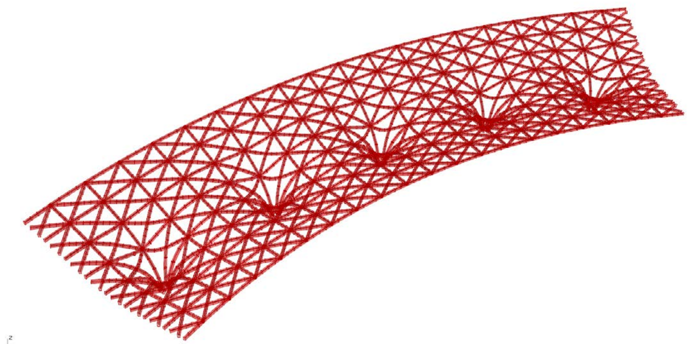
Ill.197 P1 - Loose



Ill.198 P11 - Dense



Ill.199 P11 - Normal



Ill.200 P11 - Loose

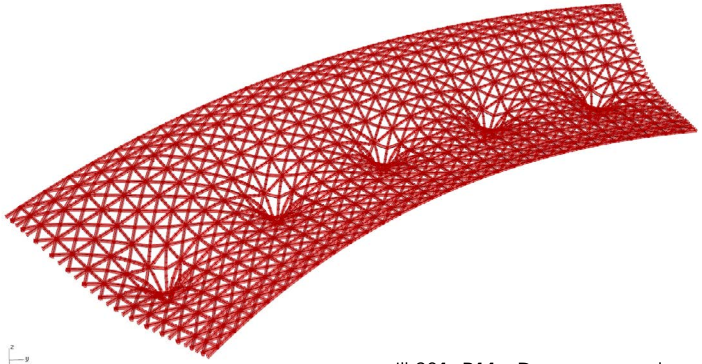
Step 3: Design variables; Overhang and 15 degree column distance.

In this stage of the optimization, an overall design choice was made to add a 2 meter overhang on both sides of the roof, and iterations were done to find the new max cross sections for both grids.

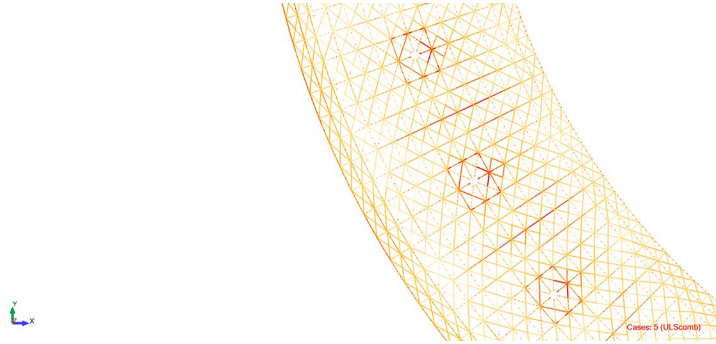
While grid 1 provides better results for displacement and weight with an overhang, the max cross section size I very unfavorable in comparison to grid 11, and for this reason grid 11 is chosen for the further development, but also because of the functionality it provides for connection with partition walls.

Grid 11 is then further tested to determine whether it can support a 15 degree rotation gap between columns. The expected increase in max cross section caused by a larger span, was also a factor in the choice of grid 11 over grid 1, as grid 1 already had a very large max cross section.

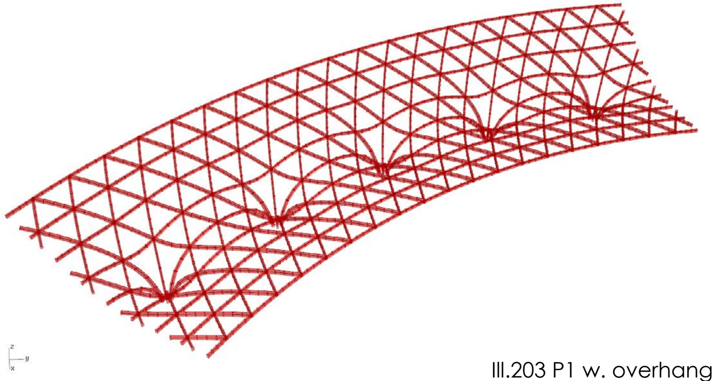
Name	Max crossection (cm)		Area	H/B ratio	Max utilzation ratio	Weight (kg)	Maz displacement (mm)	Approximate weight for full circle (tion)
	H	B						
P11 Dense w. overhang	28	18	504	1,556	0,97	75063	71	540,4536
P1 w. overhang	38	26	988	1,462	1,00	61338	62	441,6336
For 15 deg column dist	33	24	792	1,375	1,00	117339	34	844,8408



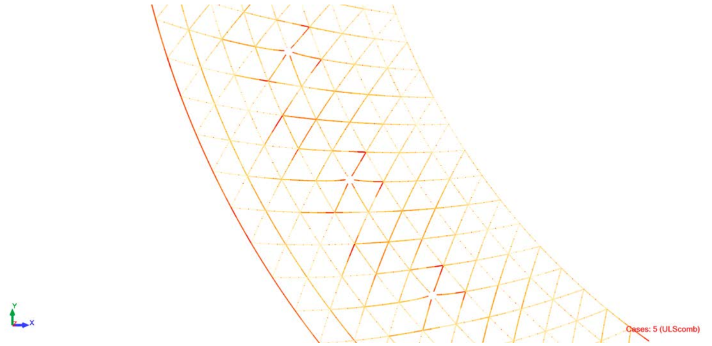
Ill.201 P11 - Dense w.overhang



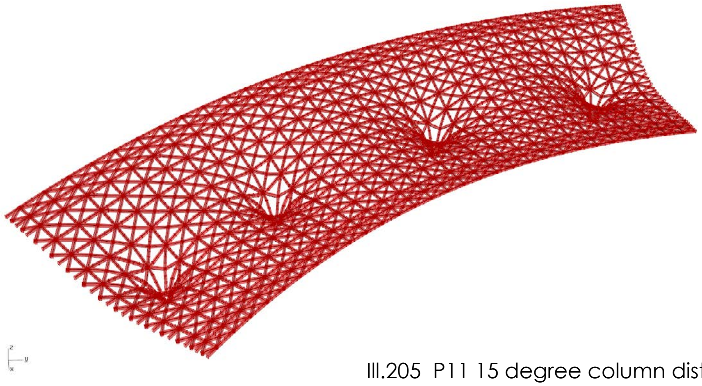
Ill.202 P11 - Dense w. overhang ratio map



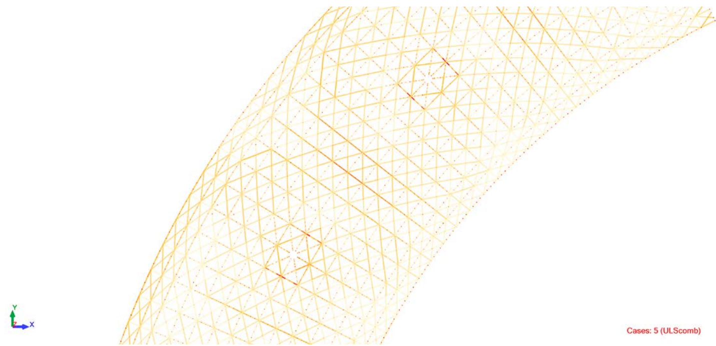
Ill.203 P1 w. overhang



Ill.204 P1 w. overhang ratio map



Ill.205 P11 15 degree column dist.



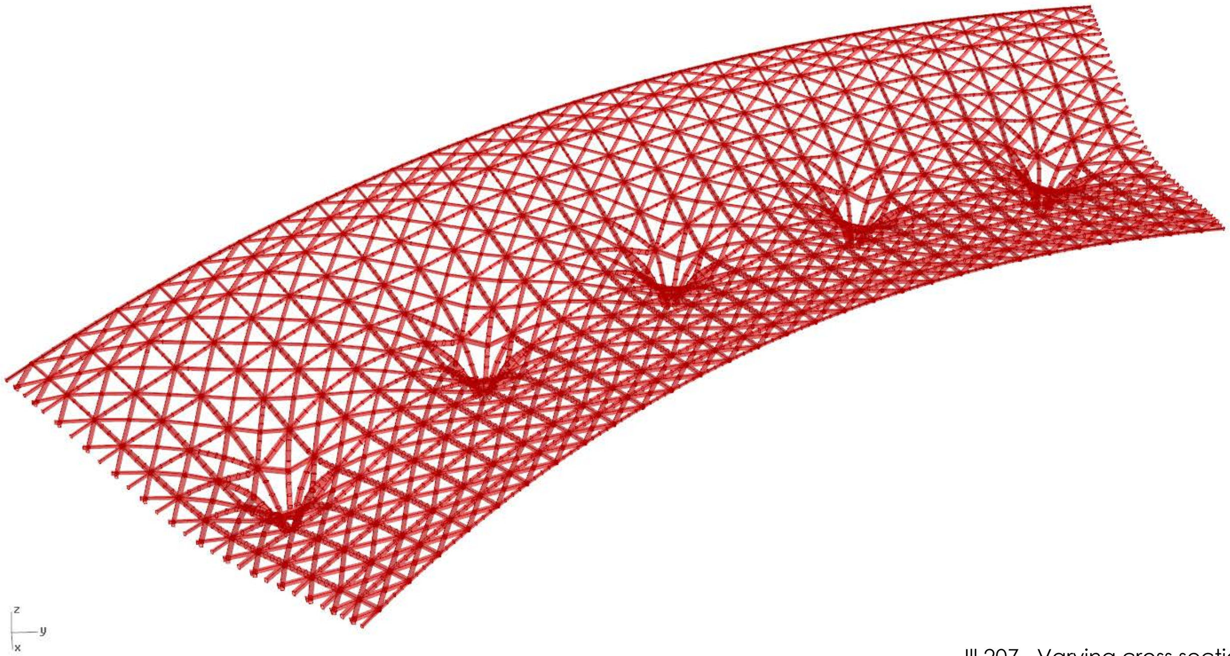
Ill.206 P11 15 degree column dist. ratio map

Step 4: Testing with varying cross sections

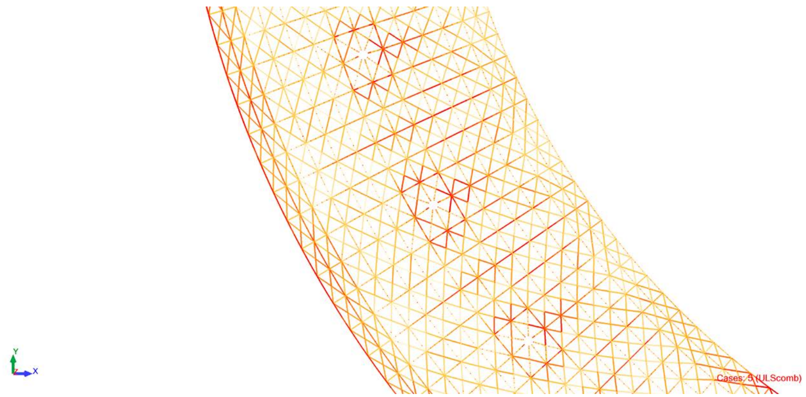
The grid (with overhang) is now tested with varying cross sections throughout the structure. This is done to emphasize the narrative in the structural system, visually displaying the flow of forces, and how the accumulation of loads increases towards the center.

The optimization through varying cross sections also greatly reduces the total material consumption, but as it was the case in the earlier steps in the process, this was prioritized, while the max displacement was out of focus, adding to the issue of the displacement exceeding the limit value.

Name	Max crossection (cm)		Area	H/B ratio	Max utilzation ratio	Weight (kg)	Maz displacement (mm)	Approximate weight for full circle (tion)
	H	B						
Varying cross sec	28	18	504	1,5556	0,97	43134	94	310,5648
	23	15	345	1,5333				
	18	12	216	1,5				



Ill.207 Varying cross section



Ill.208 Varying cross section ratio map

Step 5: Replacing the outer and inner ring with a steel ring. Allows for further reduction in the smaller cross section

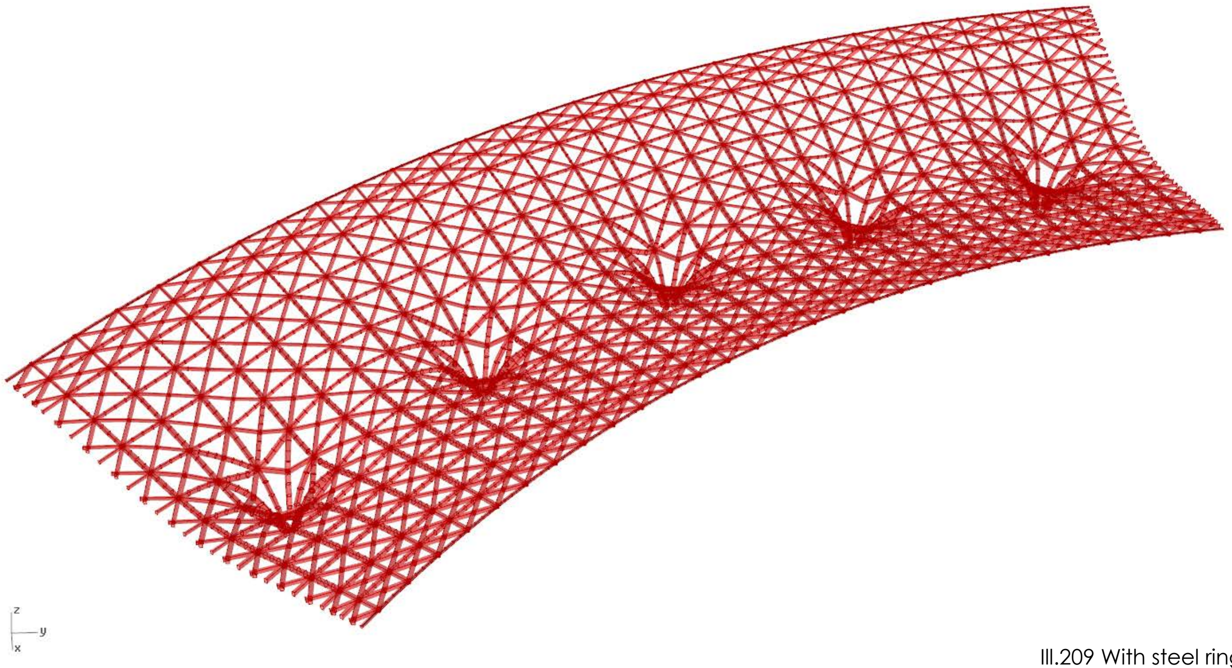
The original form designed in Rhinovault was built on the presumption of supports constraining the structure in the outer and inner ring. This presumption was made necessary due to the lack of control of individual direction constraints in Rhinovault. The principle relied on the idea that a ring in tension and a ring in compression in the inner and outer parts of the circle, could substitute the supports modelled in Rhinovault, without requiring vertical support through the façade. While the structure still provides very good results without these steel rings, iterations were made to test this initial principle.

The structure performs well, however it does not perform purely in compression, as is the idea and principle behind the form finding in Rhinovault. Yet the optimization of form and the flow of forces that Rhinovault provides is still a crucial element in creating this structure, and an important factor as to the slimness of the structure. The addition of steel rings shows that the utilization of the structure, mostly in the outer edges, is improved, and the overall displacement is reduced. This improvement is a testament to the original principle, and therefore the steel rings are added to the design, to further emphasize the narrative of the structural principle. In addition, the inner steel ring has the effect of reducing the max displacement below the limit value.

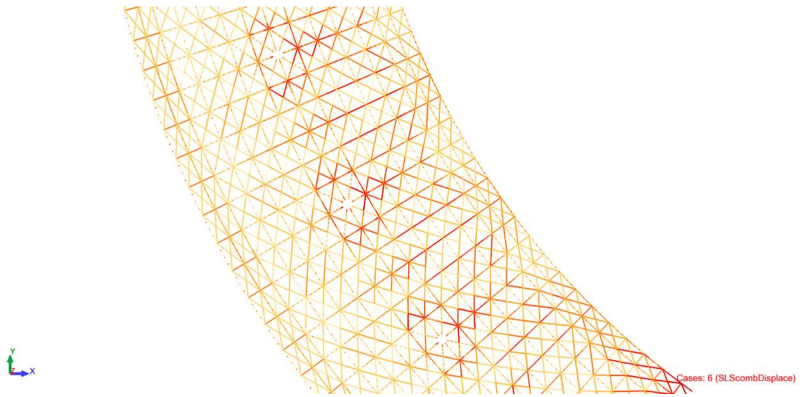
While the steel rings allows for a possible further reduction in cross section size, the reduction would increase the displacement, and possibly exceeding acceptable levels. The largest accumulation of displacement occurs in the inner circle.

In a similar way, a test has proven that pre-tensioning the steel ring shows an overall reduction (in the entire structure) to the utilization ratios of the members, and further investigation into an optimal pre-tensioning force could further help transforming the way the structural system performs, into what the original principle developed with Rhinovault is expected to. This further optimization was not performed, as the effect of the test granted very minimal reductions of 0.01 ratio, and time was running short, and very optimal results (and aesthetical expression) had already been reached for the structure.

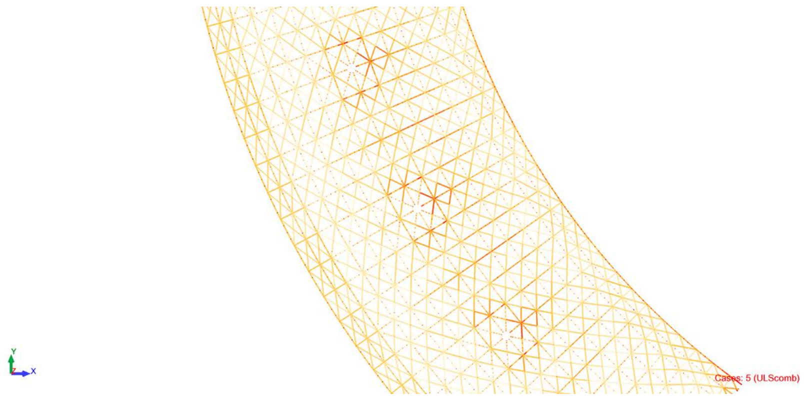
Name		Max crossection (cm)		Area	H/B ratio	Max utilzation ratio	Weight (kg)	Maz displacement (mm)	Approximate weight for full circle (tion)
		H	B						
Steel ring 15 cm	1	28	18	504	1,5556	0,96	35084	106	252,6048
(reoptimized cros sec)	2	22	14	308	1,5714				
	3	16	10	160	1,6				
Steel ring 15 cm	1	28	18	504	1,5556	0,99	47158	81	339,5376
both cicles	2	23	15	345	1,5333	steel ration 0.83			
	3	18	12	216	1,5				



Ill.209 With steel rings



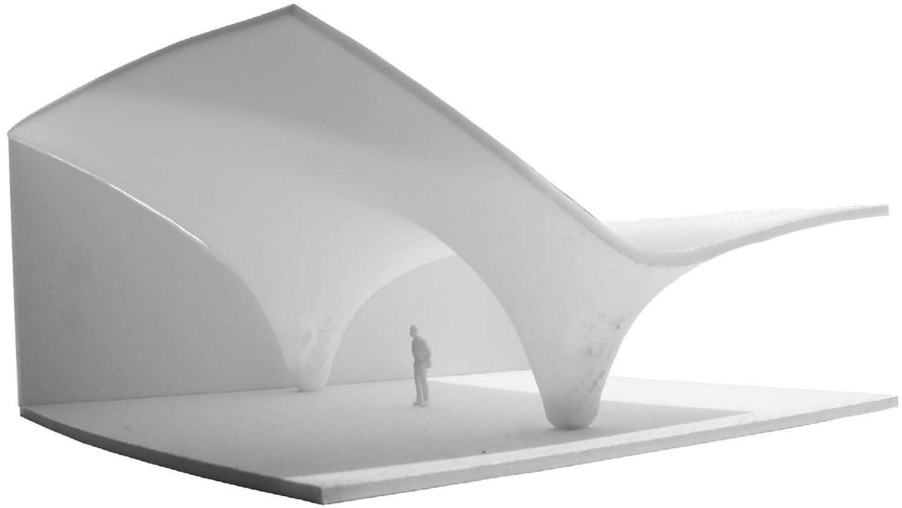
Ill.210 Steel ring outer



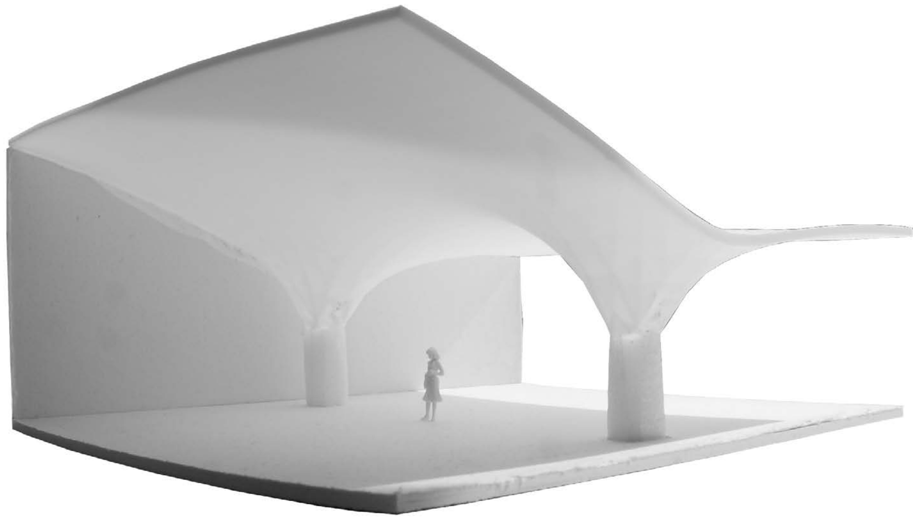
Ill.211 Steel ring both

SPATIALITY

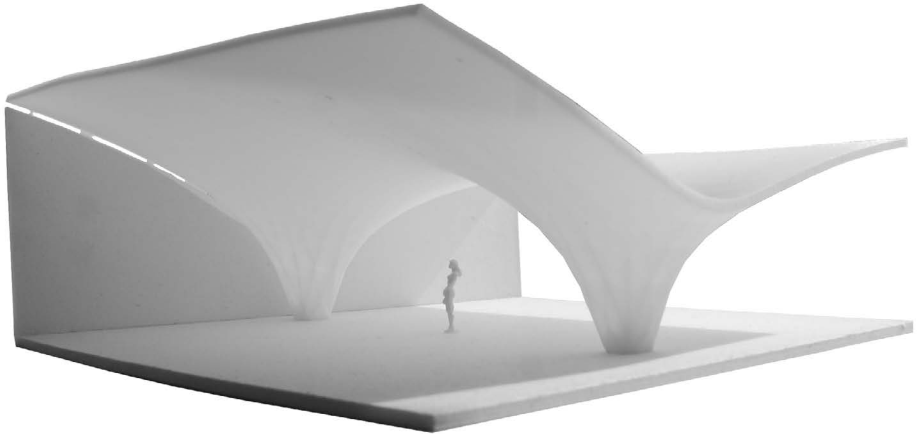
Through a series of 3D printed models, the complex, double curved structure of the roof is tested, and iterations on room height, facade height, column distance and elevation of columns helped gain an understanding of scale and impact on the spatiality of the rooms. The roof transitions into the column, and especially this transition was investigated through the models, to ensure that large amounts of unusable (due to room height) space was not created.



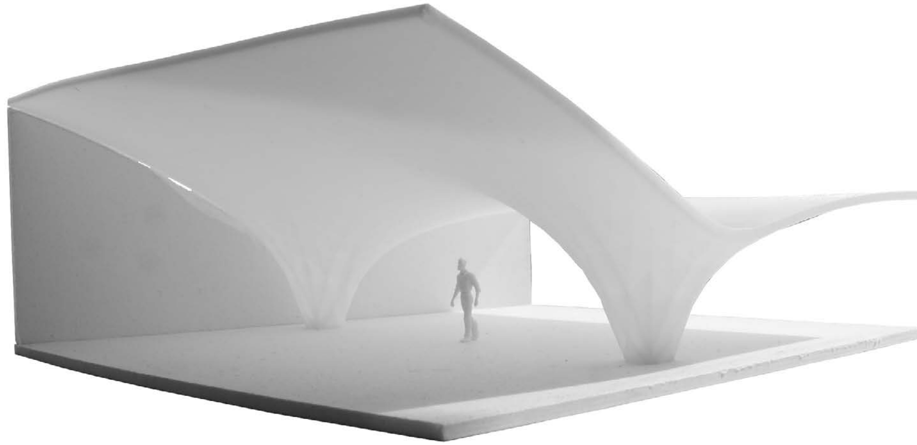
Ill.212 4 and 7 meter facade heights.



Ill.213 Roof raised on 2 meter base



Ill.214 4 and 6 meter facade heights



Ill.215 3 and 6 meter facade heights

COLUMN STUDIE

In continuation of the mini-workshop, focusing on details, in the early parts of the sketching phase, the roof-to column-to base joint was seen as an important element of the design, as it repeats itself throughout the building. Through an iterative process, the idea to constrain the wooden roof to always terminate in the same height as the entrance level emerged. Combined with a concrete base that grows downwards to follow the descending levels of the exhibitions, this further emphasized the emotional journey and narrative, and gives an visual connection to the elevation relative to the entrance.

Ill.216 Straight extension of wood beams

Ill.217 Wood beams integrated in concrete

Ill.218 Wood beams rest on concrete with steel joint

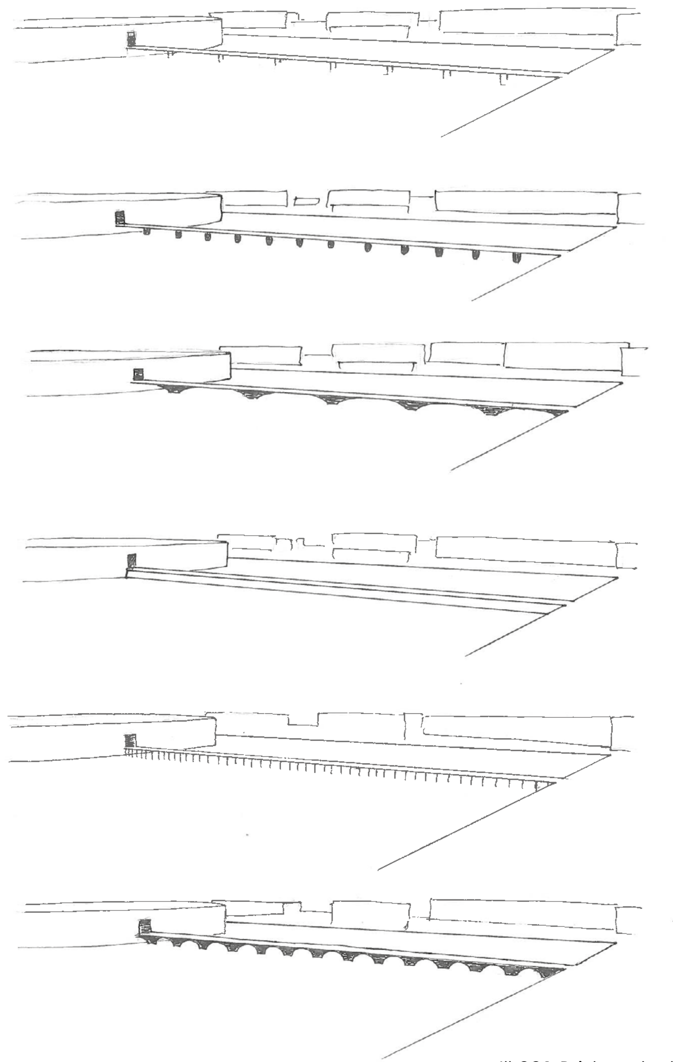
Ill.219 Wood beams rest on steel plate

BRIDGE

In order to emphasize the clear narrative and journey of the museum, and amplify the monumentality of the form, a single bridge is the only access leading out to the museum. Due to being the only access point, certain practical features must be included, in order to ensure full accessibility, and functionality for day-to-day functions. E.g. it must be possible for a truck to deliver goods, like groceries to the café kitchen. Therefore the width of the bridge is 5 meters, allowing trucks to drive through. The bridge expands towards the entrance of the museum, creating a zone large enough for a truck to turn, while also providing the possibility for movement impaired individuals to be driven straight to the door.

The bridge is key part of the first expression visitors gain of the building, and therefore the expression of the bridge is vital to the experience of the museum. Multiple designs for the bridge, and how it attaches to the façade, were made, before finally arriving on something resembling the simple elegance of the Brighton pier.

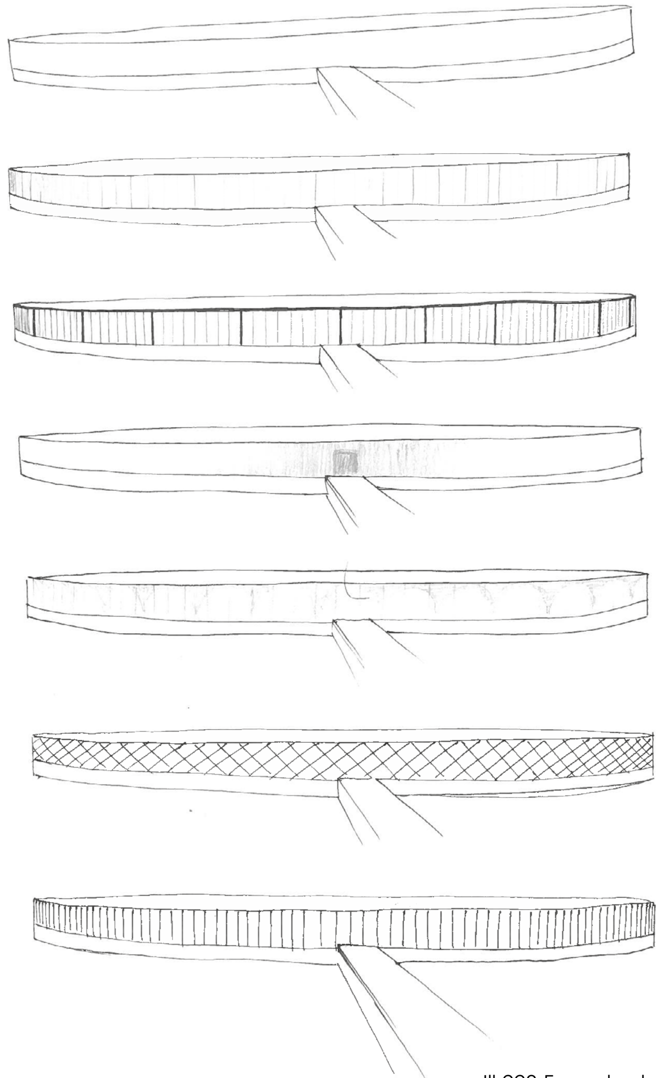
Ill.220 Brighton Pier, England


Ill.221 Bridge studies

FACADE

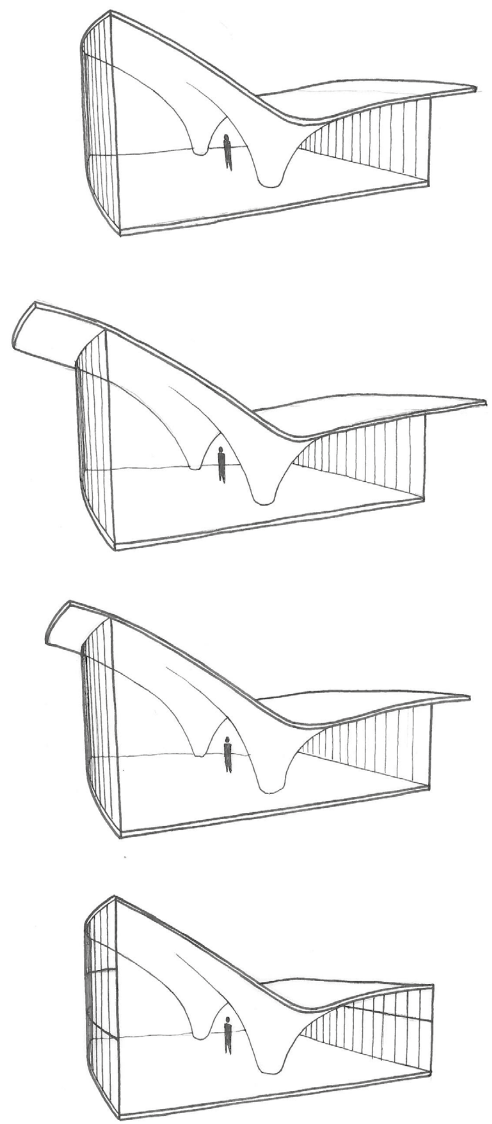
It was desired for the expression of the façade to remain as clean and simple as possible, thus emphasizing the clean, elegant and geometric circular from. A highly transparent façade would ensure great views out from the building, and connecting it with the water, while also allowing glimpses of the structure from the outside, adding a unique expression to the otherwise simple form, and creating an open atmosphere, inviting the public inside. A completely glazed façade allows for a gradual change in hue of the glass, to create the 'enlightenment' effect, in order to accentuate the journey and narrative.


Ill.222 Royal playhouse , Copenhagen

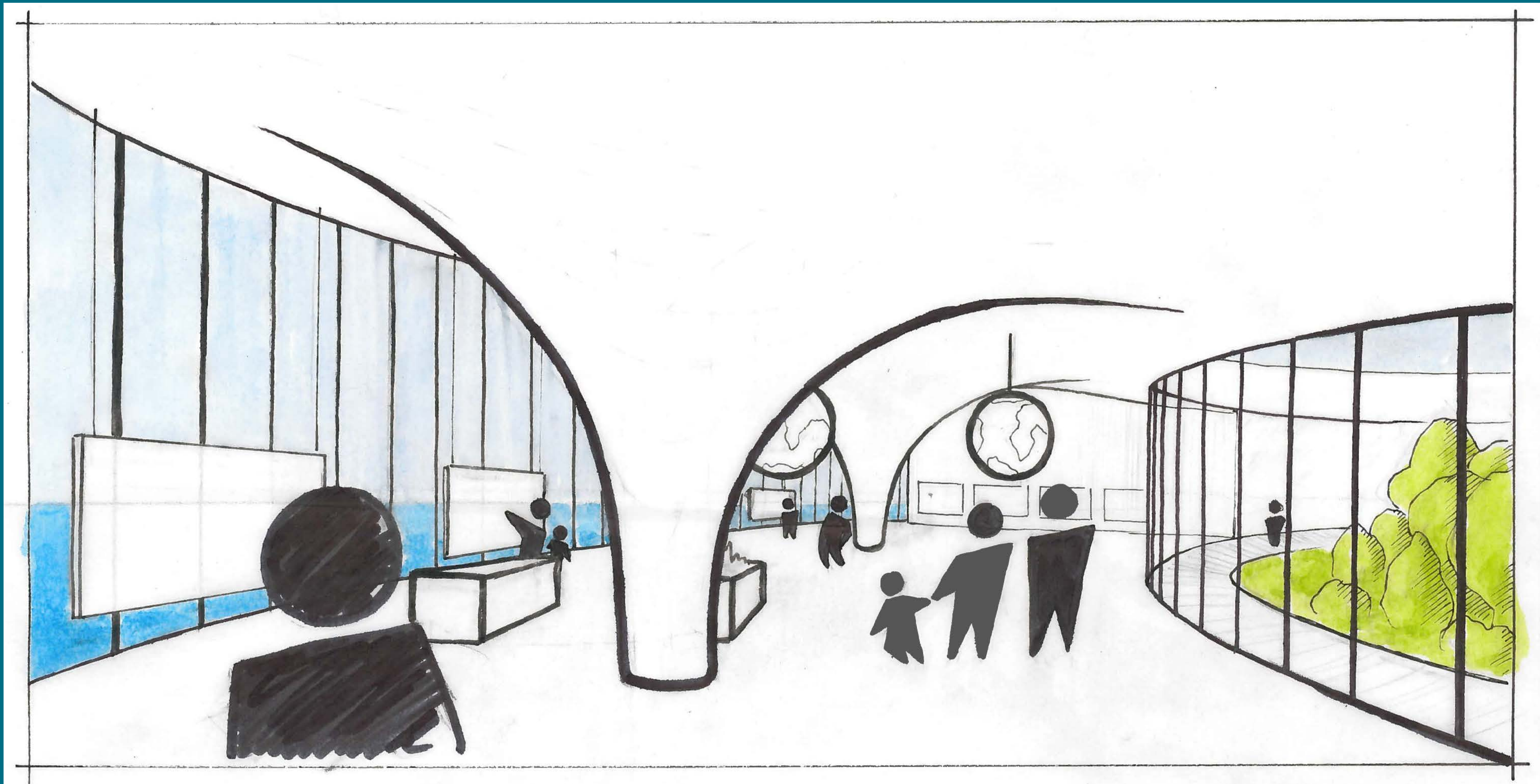

Ill.223 Facade studies

EAVES STUDY

In the synthesis phase, a choice was made to add eaves, as an extension of the roof structure. The eaves serve a functional purpose of protecting the façade from rain and adding shading against the high midday sun in the summer. The eaves are 2 meter wide, exactly covering the pathway along the inner façade, creating a sheltered space to enjoy the courtyard, even on rainy days. The 2 meters was a balancing point between adding extra stresses to the structure, creating a meaningful amount of shading, and matching the width of the pathway. The eaves extending beyond the façade, emphasizes the roof as a self-standing structure, adding to the elegance of the form, and also creates a beautiful proportion between the cantilevered surface and the size of the columns.



Ill.224 Eaves study



Ill.225 Sketch of exhibition idea

EPILOGUE

CONCLUSION

A strong narrative, materialized through architectural interaction, creates an emotional journey through the Museum of Resilience and Sustainability. Through this emotional journey, the museum seeks to create an experience that amplifies learning and the understanding of the museum's contents, and ultimately planting the seed of inspiration, encouraging visitors to embrace the knowledge available in the museum, and using it to adjust their lifestyle choices, adapting to a changing climate, while minimizing further impact upon the environment.

The purpose of the narrative reflects a strong passion of ours. A passion found in the meeting of the need for saving a climate, saving ourselves from the very same climate, and using architecture as a means to achieve this. Architecture as a means to the solution, expresses a desire to see the qualities and potential hidden within the necessary technicalities of the solutions. This passion was the guiding light for the development of the self-made programme, which the museum is based upon. The programme is inspired by the recent COP21 agreement, and its expressed ambition for member countries to inform and educate the general population on the subject, as well as a similar ambition expressed in the Copenhagen climate adaption plan. A mixture of references, including the Utzon center and Økolariet, both covered as case studies, inspires the size and mix of functions, as well as content of the building.

The form, expression and detailing of the museum all add up to amplifying the atmospheres and moods imposed by the narrative, combining with a clear, linear story through scale and problem vs solution, to create a unified and immersive experience. The immersive experience seeks to improve the impact of information gained. The design incorporates examples of solutions, and stages visual experiences of the problem, to add to the empathy of the experience.

The building uses a monumentality, created by the large, simple and geometric volume, and by cutting away the surrounding site, to merge with the huge scale context. This monumentality is the first step in setting the scene for the narrative, warning visitors of the scale and monumentality of the problems explained in the content within. The site, Refshaleøen, a former shipyard in the harbor of Copenhagen, is characterized by an industrial expression, but with a cultural atmosphere, due to its current functionality as a hub of cultural and social functionalities and events. The museum uses its monumentality to become a lighthouse for the future development of the peninsula, designated by the owners and municipality to become a culture central in Copenhagen, and a leading district of sustainability.

The building's final form and expression is a direct result of an ambition to integrate the thesis' technical aspect of tectonics into the building. However, the meaning of integration is extended beyond the usual definition of a structural system that is successfully adapted and optimized to the form throughout the process, and includes a desire to use materiality and structural principle as form-giving elements that contribute extensively to the aesthetic qualities of the unified expression of the building.

This thesis is the conclusion on an investigation in architecture as an experience. Using the narrative formed by the architecture, to create an atmosphere and a mood that encourages immersion in the exhibitions. The final form reflects an ambition to see the design potentials embedded in the technical properties of both tectonics, as well as sustainability and resilience, rather than focusing on the threat.

REFLECTION

From a one look at the building, one can quickly discern that without the focus on the tectonic approach, this project would have been an entirely different one, and much of the appeal generated through the narrative and the atmosphere would have not been the same. Effort has been put into implementing sustainable and resilient solutions, as our passion for the subject was the main reasoning behind the choice of project, and thus did not allow ourselves to forget about it, however detailing of the technicality of the sustainability of the project is limited by the overall scope of the project. The effort put into sustainability mostly revolves around the resiliency of the building, in a principal form, as this was the field within sustainability that peaked our interest, and it contributed greatly to defining the narrative and concept. Throughout the entire process, the integration of a resilient and sustainable aspect was a constant consideration, and while some choices might have fallen to the favor of architectural and tectonic quality, the consequences were continuously evaluated. In some specific cases, the integration of multiple technical aspects was a matter of two completely polar, non-combinable extremes, and in such cases the integration of tectonic structure and architecture usually prevailed.

It is an obvious cause for critical reflection, that a museum of resilience and sustainability chooses tectonic quality over sustainable quality, and similarly the technical verification of the project is entirely focused on tectonics. This scenario reflects a general struggle in the project. The attempt to balance our passion and ambition in designing a unique, tectonically integrated museum, which would stand out as an inspiring, spatial experience, not only through the material exhibited, but also as a building by itself, versus an entrenched belief that sustainable and resilient design is a critical necessity for any future project. However in this combination of passions, both of the selectable master thesis focus aspects are included, and in order to avoid grasping too wide, and thus never fully developing either, it was decided to hold on to the focus of tectonics. Limiting the focus in sustainability and resilience, to the integration and design potential of water in a principal way. Water, in multiple ways, being the primary concern for Denmark, in the field of resilience.

Through the process of working with the unique, and at times troublesome, detailing that is inherent to a shape as complex, and with as great a focus on the original expression through visible structural elements, as ours, we have learned an invaluable lesson. Firstly, it has become evident how important it is to start considering future, constructional detailing issues, even in the early stages of a design process. The further the detailing is delayed, the larger the effort required to adjust problematic detail areas becomes, when attempting to avoid interfering with the original design intent. It also became very clear that understanding the limits of construction techniques, and being up to speed with the innovative techniques and materials, allows you to push the limits of the design, while still maintaining a buildability. Our limited knowledge and experience in this area brought us dangerously close to crossing the fine line between innovative and unrealizable. Through this entire experience, we have gained an improved understanding of one of the important niches of the tectonic approach. One of which we had previously been aware, but not fully understood the scope of, that is the close relation between architecture and the construction methods and materials. The thesis was an experience of and investigation in tectonics that has shed a new light on the theme.

While the COP21 agreement and Copenhagen climate adaption plan both state intentions to educate the public on the problems and solutions of sustainability and resilience, they do not specifically describe a museum as the manifestation of these intentions, and that liberal interpretation is our own entirely. The idea of a museum is rooted in the premise that only through the united efforts of the world's population, can the disconcerting development of our climate be reversed, and thus saving the planet and ourselves. This premise also gave birth to the idea of using the narrative and emotional journey to impose an atmosphere of urgency on the visitor of the museum, inspiring them to take action. The museum becomes an attempt to use architecture as the catalyst that sparks a renewed, inspired movement to prevent sustainably and adapt resiliently.

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Illustrations:

Fig 1: Graph of increase in intense rain water events due to rising sea levels. http://www.klimatilpasning.dk/viden-om/klima/klimaaendringeridanmark/aendringer-i-havniveau.aspx

ILLUSTRATIONS

Ill. 1 - 3 Own Illustration

Ill. 4 https://maxqubit.wordpress.com/2012/05/05/guggenheim/

Ill. 5 http://architectureblog.tumblr.com/post/16183584206/subtilitas-louis-kahn-phillips-exeter-academy

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Ill. 11 http://lendager.com/p/lendager/tegnestuen/

Ill. 12 Own Illustration

Ill. 13 - 15 http://www.okolariet.dk/om-oekolariet/om-oekolariet/pressecenter

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Ill.185 - 186 http://block.arch.ethz.ch/brg/tools/rhinovault

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Ill.221 Own Illustration

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Ill.223 - 225 Own Illustration

Ill.226 DS/EN 1991-1-3:2007, Eurocode 1 – Actions and structures – Part 1-3: General actions – Snow actions, Danish Standards Foundation, Copenhagen

Ill.227 Calculation of factor for line loads

Appendix

STRUCTURAL CALCULATIONS

In order to both verify and optimize the structural system, it has been calculated upon in multiple iterations. The original structural shape, created in Rhino, using the RhinoVault (courtesy of BlockResearchGroup) plugin, is transformed to a grid of curves representing glue laminated (glulam) timber elements, and through Grasshopper3D subdivided and sorted for use in Autodesk Robot for the calculations. The information is transferred between the two programs through the use of the GH2Robot plug-in.

Self weight

The self-weight of the glulam members is automatically calculated in Robot, and varies according to the dimensioning of the members, grid shape and density.

Snow load

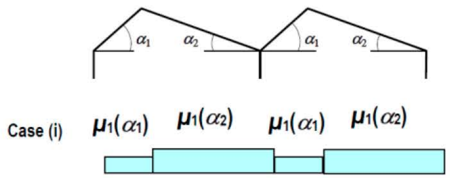
The snow load is calculated based upon the Danish standard DS/EN 1991-1-3:2007.

Snow load on the roof $[\frac{kN}{m^2}]$

$$S = \mu_i \cdot C_e \cdot C_t \cdot S_k$$

μ_i	is the snow load shape coefficient
C_e	is the exposure coefficient
C_t	is the thermal coefficient
S_k	is the characteristic value of snow load on the ground

μ_i is set to 0.8, as it is assumed that drifting of snow will occur inside the columns, and thus the weight will stack upon itself and not as an extra weight for the structure to carry, and the angle of the roof does at no point exceed 30 degrees.



Tabel 5.2 – Formfaktorer for snelast

Taghældning α	$0° \leq \alpha \leq 30°$	$30° < \alpha < 60°$	$\alpha \geq 60°$
μ_1	0,8	0,8(60 - α)/30	0,0
μ_2	0,8 + 0,8 α/30	1,6	--

Ill.226 Snow load shape coefficient

C_e is set to 0.8 for a windswept condition, as there are no immediate surroundings of any notable height, and the nearest buildings are all several hundred meters away.

C_t is set to 1.0 for a normal roof with good heat-transmission values.

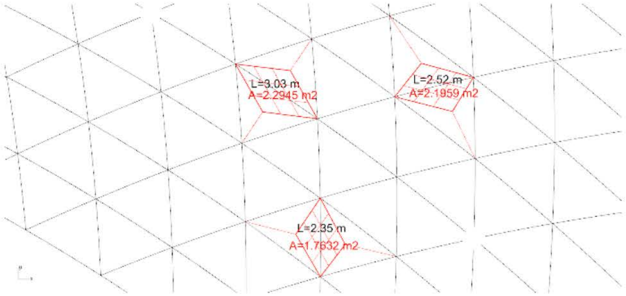
S_k is set to 0.9 kN/m^2 as is defined in DS/EN 1991 FU:2010

The snow load is calculated

$$S = 0.8 \cdot 0.8 \cdot 1.0 \cdot 0.9 = 0.576 \frac{kN}{m^2}$$

In order to translate the snow load into a uniform line load for the calculations in Robot, the area 'carried' by the elements is calculated, which is divided by the total length of the elements, in order to determine a factor to multiple with the snow load, to transform from an area load to the linear load. The factors vary slightly across the elements, and an average is used.

Example of factor calculation:



Ill.227 Calculation of factor for line loads

Factor: $\frac{2.1959m^2}{2.52m} = 0.871389m$

Average factor for this particular grid (calculated in grasshopper): 0.727

The resulting snow load, defined as a line load:

$$S = 0.576\frac{kN}{m^2} \cdot 0.727m = 0.419\frac{kN}{m}$$

Roof weight

The weight of the roof (insulation, cladding etc.) is taken from Dimensioning with Diagrams (2010) by Knud Ahler. It is a standard table value for a very light roof, excluding structural elements (includes insulation, cladding etc.)

$$Roof = 0.7\frac{kN}{m^2}$$

Multiplying this planar load with the same factor as used when transforming the snow load to a line load, the resulting line load is:

$$Roof = 0.7\frac{kN}{m^2} \cdot 0.727m = 0.5089\frac{kN}{m}$$

Wind load

The calculation of the wind load is based upon the calculation method in DS-EN 1991-1-4-2007, and calculations use table values found in the Danish standard.
The three key elements to be used in the calculations are; mean wind velocity, wind turbulence and the peak velocity pressure, and these must first be determined.

Mean wind velocity, at height Z

$$V_m(Z) = C_r(Z) \cdot C_0(Z) \cdot V_b$$

$V_m(Z)$ is the mean wind velocity at height Z.
$C_r(Z)$ is the roughness factor
$C_0(Z)$ is the orography factor, which is 1.0 unless otherwise specified.
V_b is the basic wind velocity

The roughness factor, at height Z, can be determined by the following formula, when $Z_{min} \leq Z \leq Z_{max}$;

$$C_r(Z) = K_r \cdot \ln(\frac{Z}{Z_0})$$

Z_0 is the roughness length, determined by the terrain category. For category 0, sea or coastal area exposed to open sea, it is Z_0 = 0.003 m
Z_{min} for terrain category 0 is Z_{min} = 1 m
Z_{max} is set to Z_{max} = 200 m
K_r is the terrain factor

The terrain factor can be determined using the following formula;

$$K_r = 0.19(\frac{Z_0}{Z_{0,II}})^{0.07}$$

Z_0 is the roughness length for terrain category II, area with low vegetation such as grass and isolated obstacles (trees, buildings) with separations of at least 20 obstacle heights, and is set to $Z_{0,II}$ = 0.05 m

Terrain factor:

$$K_r = 0.19(\frac{0.003m}{0.05m})^{0.07} = 0.156$$

Roughness factor:

$$C_r(Z) = 0.156 \cdot \ln\left(\frac{7.5m}{0.003m}\right) = 1.221$$

The final value needed to calculate the mean wind velocity, is the basic wind velocity, which can be determined by the following formula;

$$V_b = C_{dir} \cdot C_{season} \cdot V_{b,0}$$

V_b is the basic wind velocity
C_{dir} is the directional factor, set to 1.0 as recommended in the standard
C_{season} is the seasonal factor, set to 1.0 as recommended in the standard
$V_{b,0}$ is the fundamental value of basic wind velocity, which is set to 24 m/s according to the national annex

Basic wind velocity:

$$V_b = 1.0 \cdot 1.0 \cdot 24\frac{m}{s} = 24\frac{m}{s}$$

Mean wind velocity:

$$V_m(Z) = 1.221 \cdot 1.0 \cdot 24\frac{m}{s} = 29.304\frac{m}{s}$$

Next, the wind turbulence is calculated. The turbulence intensity $l_v(Z)$ at height z is calculated by dividing the standard deviation divided with the mean wind velocity.

$$l_v(Z) = \frac{\sigma_v}{V_m(Z)} = \frac{k_l}{C_0(Z) \cdot \ln(\frac{Z}{Z_0})}$$

σ_v is the standard deviation of turbulence
k_l is the turbulence factor, set to 1.0 as recommended in the standard

The standard deviation of turbulence can be determined by the following formula:

$$\sigma_v = k_r \cdot V_b \cdot K_l$$

Standard deviation of turbulence:

$$\sigma_v = 0.156 \cdot 24 \frac{m}{s} \cdot 1.0 = 3.744 \frac{m}{s}$$

Turbulence intensity:

$$l_v(Z) = \frac{4.571 \frac{m}{s}}{29.304 \frac{m}{s}} = 0.156$$

And finally the peak velocity pressure $q_p(Z)$, at height Z, must be determined.

$$q_p(Z) = [1 + 7 \cdot l_v(Z)] \cdot \frac{1}{2} \cdot \rho \cdot {V_m}^2(Z) = C_e(Z) \cdot q_b$$

ρ is the air density, set to 1.25 kg/m^3 as recommended in the standard
$C_e(Z)$ is the exposure factor
q_b is the basic velocity pressure

$C_e(Z)$ for flat terrain can be determined through figure 4.2 in the DS/EN 1991-1-4:2007, and is found to be 1.42

The basic velocity pressure can be determined by the following formula:

$$q_b = \frac{1}{2} \cdot \rho \cdot {V_b}^2$$

Basic velocity pressure:

$$q_b = \frac{1}{2} \cdot 1.25 \ \frac{kg}{m^3} \cdot 24 \frac{m^2}{s} = 360 \frac{N}{m^2} = 0.36 \frac{kN}{m^2}$$

Peak velocity pressure

$$q_p(Z) = [1 + 7 \cdot l_v(Z)] \cdot \frac{1}{2} \cdot \rho \cdot {V_m}^2(Z) = [1 + 7 \cdot 0.156] \cdot \frac{1}{2} \cdot 1.25 \ \frac{kg}{m^3} \cdot 29.304 \frac{m^2}{s} = 858.724 \frac{N}{m^2}$$

$$q_p(Z) = C_e(Z) \cdot q_b = 1.42 \cdot 360 \frac{N}{m^2} = 511 \frac{N}{m^2}$$

The formula is split into two variations, and the worst case is used.

$$q_p(Z) = 858.724 \frac{N}{m^2} = 0.859 \frac{kN}{m^2}$$

Due to the shape factors for a negative angled roof such as on this building, the wind load becomes favorable in combination with the snow load, and therefore the combination factor will be 0, and the wind load for the roof will not be calculated.

However, there is still a load on the façade, that is, unless countermeasures are applied, transfers horizontally into the roof.

Wind pressure on a wall

$$F_w = C_s C_d \cdot W_e$$

$C_s C_d$ is the structural factor. Set to 1 for buildings lower than 15m in height.
W_e is the the external pressure on the individual surface, at the reference height Z_e

$$W_e = q_p(Z_e) \cdot C_{pe}$$

C_{pe} is the external pressure coefficient. Set to -1.2 as per table 7.1, pp. 76, DS/EN 1991-1-4:2007

$$W_e = 0.859 \frac{kN}{m^2} \cdot (-1.2) = -1.0308 \ \frac{kN}{m^2}$$

To transfer this to a uniform line load usable in GH2Robot, it is multiplied with half the height of the façade, as half of the load with be transferred into the foundation, and thus only half will be transferred into the roof.

$$1.0308 \ \frac{kN}{m^2} \cdot 3.75m = -3.8655 \ \frac{kN}{m^2}$$

Load combinations

The structure is evaluated based on the previous loads, for both Ultimate limit state and Serviceability limit state. The load combinations for the two evaluations are defined as follows:

SLS

$$\sum_{j\geq 1} G_{k,j}\text{"}+\text{"}Q_{k,1}\text{"}+\text{"}\sum_{i>1} \psi_{0,i} Q_{k,i}$$

ULS

$$\sum_{j\geq 1} \gamma_{G,j} G_{k,j}\text{"}+\text{"}\gamma_{Q,1} Q_{k,1}\text{"}+\text{"}\sum_{i>1} \gamma_{Q,i} \psi_{0,i} Q_{k,i}$$

The ultimate limit state combination used in the structural optimization is with the snow load as the leading variable, as the wind load on the roof is favorable, and as such leading snow load is the worst case scenario.

$G_{k,j}$ is the permanent load
$Q_{k,1}$ is the leading variable load
$Q_{k,i}$ is the accompanying variable load
Partial factors
$\gamma_{G,j} = 1.35$ for permanent actions
$\gamma_{Q,1} = 1.5$ for variable actions
Combination factors
$\psi_{0,i} = 0.3$ for a wind load as an accompanying action.

Through a ULS calculation of the structure in Robot, it becomes evident that the wind load on the façade is also beneficial for the structure, as it reduces the max ratio by 0.22, drastically improving the performance of the structure. Therefore the optimization will be using an ULS load combination with only snow load, which is the worst case scenario.

Member verification

The ratios that are described in the structural optimization process, are taken from Robot, and represent a comparison between the axial and moment stresses in every member, and the design strength of that specific member, under an ultimate limit state situation. An example of this verification is done manually to exemplify the method:

Member no. 1155 (the central part of the straight radial beam that passes through the columns)

Cross section type 1:
h = 28cm
b= 18 cm
Area of cross section:
A= 280x180mm = 50,400mm^2

When calculating in ULS, the characteristic strength is transformed into a design strength, using partial factors to reduce the calculated strength of the material, as a safety measure.

Design bending strength of GL32H:

$$f_{m,d} = \frac{f_{m,k} \cdot k_h \cdot k_{mod}}{\gamma_M}$$

$f_{m,d}$	is the design strength
$f_{m,k}$	is the characteristic strength
k_h	is the height factor
k_{mod}	is the modification factor for load duration
γ_M	is the partial coefficient for the material type, and is 1.3 for glulam

The height factor k_h is calculated as

$$k_h = \begin{cases} 1{,}1 \\ (\frac{600}{h})^{0{,}1} \end{cases}$$

$$k_h = \begin{cases} 1{,}1 \\ 1.079 \end{cases}$$

The lowest value, 1.079, is used.

k_{mod} can be found in Teknisk ståbi (Jensen, B. C., 2011 pp. 315). The value is 0.8996 for glue laminated timber in an indoor environment (application class 1) in a ULS situation with snow load. The value listed in Teknisk Ståbi is a combination of k_{mod} and γ_M, and the value for γ_M is isolated:

$$k_d = \frac{k_{mod}}{\gamma_M}$$

$$k_{mod} = k_d \cdot \gamma_M = 0.692 \cdot 1.3 = 0.8996$$

The characteristic strength $f_{v,k}$ is also found in Teknisk ståbi (Jensen, B. C., 2011 pp. 314)

Now the design shear strength can be calculated

$$f_{v,d} = \frac{4\ MPa \cdot 1.079 \cdot 0.8996}{1.3} = 2.99\ MPa$$

The subject member is the part of any beam which in the construction which twists the most around its x axis, and as such expected to have a shear stress higher than the normal stress. This is verified by robot, and it is therefore the subject of the verification.

$$\frac{(\frac{V_z}{k_{cr}} + \frac{V_{t,z}}{k_s} =)}{f_{v,d}} \leq 1$$

V_z	Shear stress in z direction – gathered from robot
$V_{t,z}$	Shear stress due to torsion in z direction – gathered from robot
k_{cr}	Crack influence factor – set to 0.67
k_s	Shape factor – set to 1.23

$$\frac{\left(\frac{|-1,49\ MPa|}{0.67}+\frac{0.54}{1.23}=\right)}{2.99MPa}=0.89$$

With a ratio below 1, the member is verified. The ratio in robot is slightly higher, 0.93, which stems from the design shear strength, where robot uses a value of 2.88 MPa. The slight difference in design strength probably originates in the classification class of the k_d value used for isolating k_{mod}