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# ARCHITECTURE & SOLAR DESIGN

EXHIBITION CENTER IN THE ARCHIPELAGO OF HUNNEBOSTRAND



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Master's Thesis 2024

Building Design & Transformation

MPARC

### *Abstract*

The most common way of producing energy today is by extracting fossil fuels from the ground and burn it. This method is severely harming our planet and there are ways of producing energy that are not as harmful, so why are not those methods our primary source?

In one hour, we receive enough sunlight to provide for the world's electricity for an entire year and that makes solar energy an important step towards reaching 100% renewable energy. The first solar cell was introduced in 1954 and you could argue that, while looking at today's standard panels, the appearance has not changed that much in 70 years.

As architects, solar panels might be seen as an obstacle while trying to create beautiful design. The aim of this thesis is therefore to create a new vision and change the narrative of solar energy in the world of architecture. It focuses on and explores ways of how solar power may be integrated into buildings, with

the intention to implement the learnings in a project located on the site of Hunnebostrand. To frame this work, the research question of this thesis is the following: "How can architects design with solar panels for it to become an integrated part of the architectural concept of the building?"

To find answers for the research question, three different methods will be used. Initially, general knowledge of solar panel system needs to be studied to be able to implement it in a design, creating a framework that can be used later in the process. This phase is also where theoretical studies regarding the site will take place. This is the Research for design phase. Secondly, the Research by design phase, is where reference projects are studied, both for knowledge of solar panel integration, and inspiration for the architectural concept of the project. The third method, the Research by design phase, is where knowledge and theory are translated and gathered into design.

## *Aknowledgements*

I'd like to give a special thanks to .....

**Mikael Ekegren**, for his guidance and support throughout the course of this thesis project. His expertise, insights, and dedication have been a great help in shaping the direction of this project and making sure that it comes to term. He also assisted in times of hardships, which was crucial to the successful completion of the project. I am incredibly thankful for his commitment to my academic development and am grateful to have been able to work under his mentorship.

**Malin Unger**, for her positivity and willingness to share her knowledge regarding solar energy. Her enthusiasm and expertise made a noticeable impact, especially as this was a new field for me. Her assistance in providing valuable information and resources greatly aided my investigation of this unfamiliar subject and her recommendations for further investigation had an effect in broadening the scope of my research. I am truly grateful for her guidance.

## *Architectural background*

2021 - 2024 | CHALMERS UNIVERSITY OF TECHNOLOGY

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Master's degree in Architecture - MPARC

**2023 AUTUMN**  
Building Tectonics 2

**2022 SPRING**  
Public Buildings

**2022 SPRING**  
History, theory and method 5 - Dealing with inequalities

**2022 SPRING**  
Architectural competitions

**2021 AUTUMN**  
Healthcare architecture

2018 - 2021 | CHALMERS UNIVERSITY OF TECHNOLOGY

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Bachelor's degree in Architecture

## List of abbreviations

<b>PV</b>	Photovoltaic (also known as solar cells)
<b>BAPV</b>	Building-Added Photovoltaics
<b>BIPV</b>	Building-Integrated Photovoltaics
<b>IEA</b>	International Energy Agency
<b>kWp</b>	Kilowatt peak, standard unit used to rate performance of PV. “Peak” refers to maximum amount of power that the solar panel can produce under ideal conditions
<b>Azimuth</b>	Usually measured in degrees, and refers the orientation of the associated object (in this case building)

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Photo 1: Picture of Alan Freeman on the first documented PV powered boat

Note. From Curtis, J (1978)

## *Overview*

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FIELD OF STUDY

RESEARCH QUESTIONS

ACADEMIC FRAMEWORK

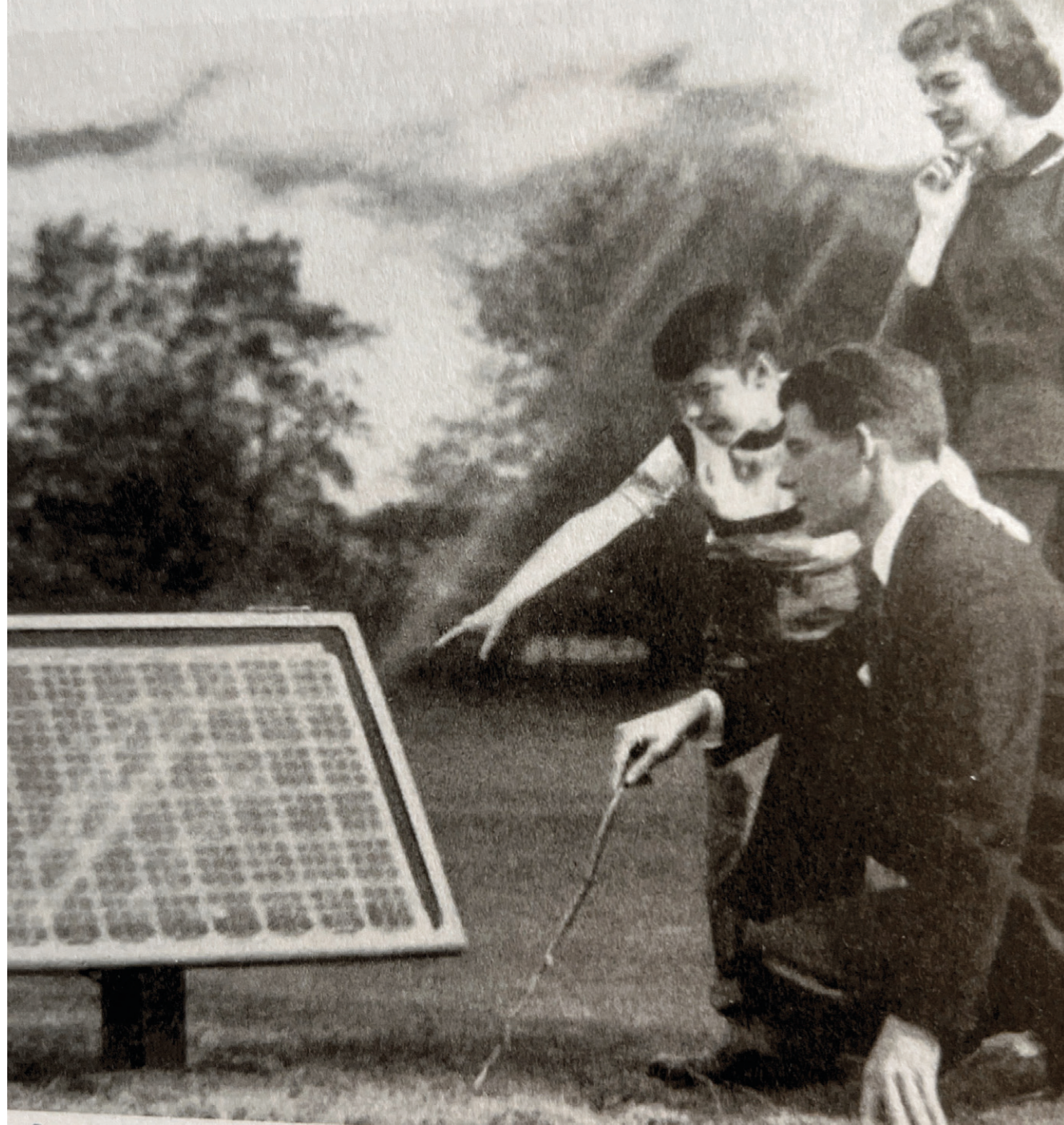


Photo 2: First photovoltaic cell

Note. From Tapetum. (2020)

## Field of study

*What do you think of when thinking about solar energy? Is it big black and ugly panels placed on roofs that turns sunlight into energy?*

There are many ways of producing energy. The most common is to extract fossil fuels from the ground and burn it, causing greenhouse gases that are heating up the planet. While using this procedure we are also emptying the earth's resources. A transition must be made into using resources that are unlimited, such as the sun.

In one hour we receive enough sunlight to provide for the world's electricity for an entire year. Solar energy is an important step on the path of reaching 100% renewable energy. The technology is there, so why are not solar energy our biggest source?

The first panel to produce energy is the photovoltaic cell, it was introduced in 1954 almost 70 years ago (Aubel, 2022). One could argue that even though the solar panel has increased in efficiency since then, the appearance of the panel is relatively the same. At least while looking at the current standard solutions.

As architects we strive to create buildings and spaces that are both functional and elegant. The appearance of a building could differ much depending on which materials are being used and the aesthetic attributes of a standard solar panel could be seen as a limita-

tion while trying to integrate it as a part of a building design. This fact is particularly relevant if the building is located on a site that has a specific context in terms of buildings, history and landscape. How can architects design beautiful buildings on places like this while also adding this technical layer of material to catch the rays of the sun?

## AIM & PURPOSE

The aim of this thesis is to create a new vision and change the narrative of solar energy in the world of architecture. It focuses on and explores ways of how solar power may appear and can be integrated into buildings, not only as effective energy-producers but also for aesthetic attributes. The aim is then to implement the learnings in a project located on the site of Hunnebostrand, to make the design more practical and contextually relevant by grounding it to a real-world location.

With this research, the hope is to overcome the gap between architects and solar design, thus shifting the focus away from efficiency and cost- and looking at it from a design perspective. Seeing the potential of solar panels and solar design, the goal is to design a project which highlights the architectural attributes and qualities that are possible to create with solar design and solar energy. Thus, spreading knowledge and inspiration to other architects.

## *Research questions*

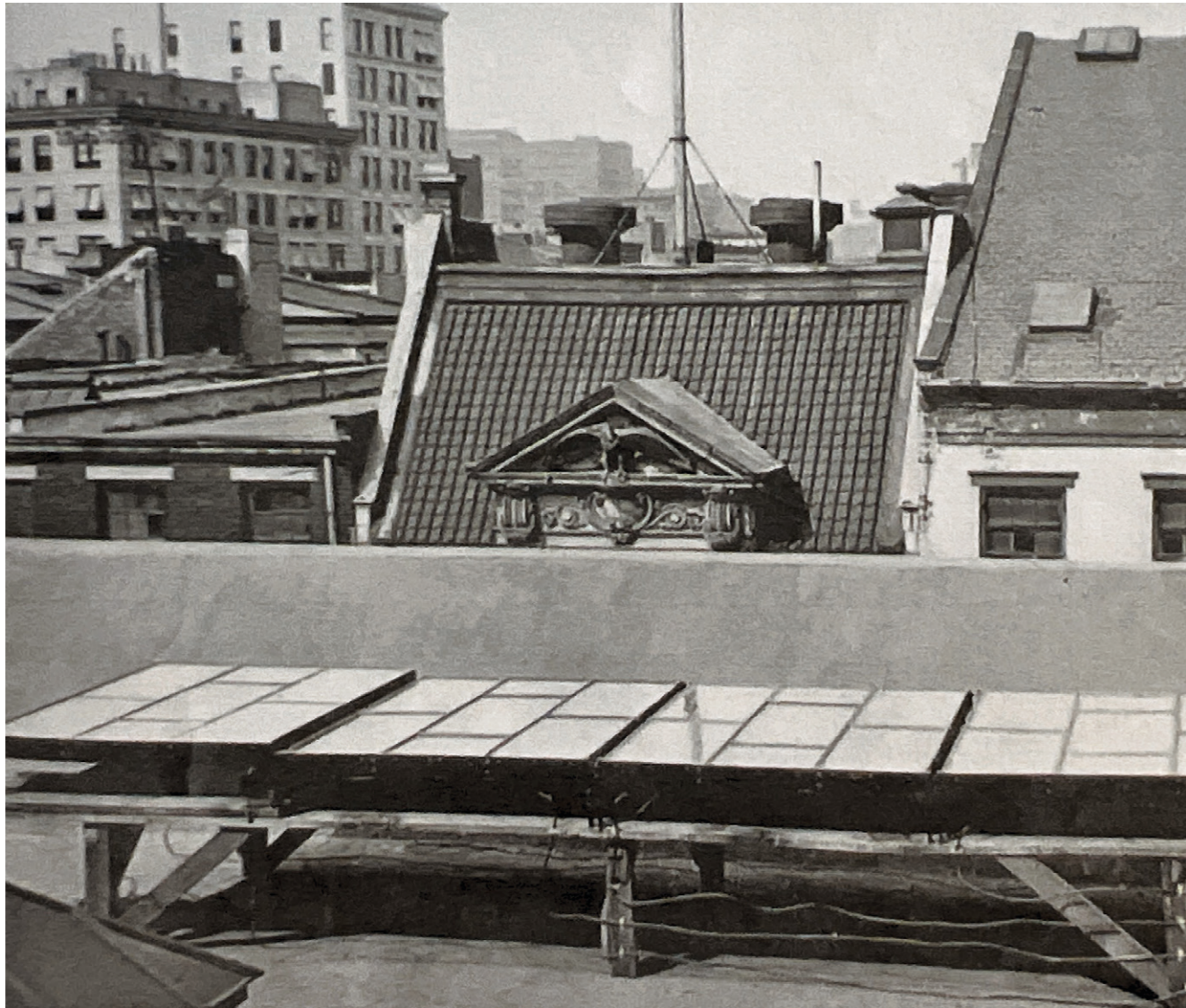


Photo 3: World's first solar array on a rooftop in New York

Note. From Perlin, J. (2013)

*How can architects design with solar panels for it to become an integrated part of the architectural concept of the building?*

*How can this practise be applied on a stone art exhibition centre in Hunnebostrand?*

## Academic framework

### DELIMITATIONS

The thesis will investigate a general question of how you can design using solar energy and will end up in one design proposal of how to do so, by following guidelines and to some extent wishes and visions from the municipality and the people living by the project location. There is also a general and a specific design principle when designing with solar panels. One can investigate different design principles, but for best energy efficiency and result, the specific location will play a big role.

This project primarily research aspects of designing with solar energy as an integrated part of the building. Energy efficiency, economical aspects and pay back is considered when making design decisions but are also balanced with aesthetics and other design choices. This project will therefore not answer to the most efficient technological solution, but as a combination of both.

This thesis does not intend to solve or focus on problems like making solar energy available for everyone and the justice perspective of who in society that are able to use it. While understanding that there may be a dark side of solar energy of how it's produced when using various raw materials, and while this is something that's being investigated in various ways of how to make better, the sustainable perspective of early production is not something that this thesis will focus on. It will also not involve participatory research of the people living in Hunnebostrand.

### RELEVANCE

The need for increasing energy efficiency and decarbonizing our energy systems is essential in the fight against global warming. In 2022, the European Council set a binding target that the member countries within the European Union would have to reduce the energy consumption by 36% before the year 2030, and that 40% of the total energy would be from renewables (European Council, 2022). These targets are even higher than from the previous year, an effect of the war in Ukraine and the need to rapidly reduce dependency on Russian fossil fuels (Climate Change News, 2022).

The building sector is a big villain in the field of energy consumption and gas emissions. In a report from the UN Environment program, it showed that they are responsible for over 34% of the energy consumption and approximately 37% of carbon emissions (United Nations Environment Programme, 2022). While being a big contributor to energy consumption, it also suggests that the building sector has a lot of potential for energy-saving and plays a big role in reaching the targets set for 2030. Architects and different project planners involved in construction should therefore be urged to contemplate on using renewable energy sources and energy efficiency methods in their work.

To be able to meet the binding target set by the European Council, buildings shouldn't need more energy over their entire lifetime than they can produce.

They should be designed and constructed in a way which transforms them from energy consumers to energy producers. Solar energy and photovoltaic is an important step towards reaching this goal, to help the environment and to reduce the carbon emissions.

### METHODS & TOOLS

To anchor this thesis in reality, a various of methods has been used in different stages of the project. It has been a process where the different phases have influenced one another and working iteratively towards finding answers for the research question.

### RESEARCH FOR DESIGN

Initially, a large amount of information regarding solar energy needed to be gathered to be able to understand the framework for the design project. This information was collected through informal discussions with different stakeholders within the field, guiding the the scope of the thesis. Theoretical studies were made that later could be implemented in the design project.

Theoretical studies on the site have been made to understand the history and context of the program and ongoing discussion regarding the future. This contributed to understand where this thesis is positioned in terms of design choices throughout the process. The site has been visited multiple times. Site analysis, sun studies, photography and mapping has been key strategies

to understand the conditions of the site.

### RESEARCH ON DESIGN

To understand what has already been produced and to get inspiration, reference projects were studied and two main categories has been explored. One focuses on earlier examples of buildings that has used solar energy systems either as an integrated or an attached system. The other category emphasizes buildings with architectural ingredients that can be translated to this project.

### RESEARCH BY DESIGN

While information and knowledge were gathered in phase one and two, phase three, the design process, is where theories have been tested on design to get new insights and learnings.

### READING INSTRUCTIONS

The thesis is divided into 5 main segments: Overview, Investigation, Project Context, Design Development and Epilogue. The Overview introduces the reader to the field of study, outlining the research questions and background. The Investigation researches theory and reference, creating a foundation for the study. Project Context analysis the chosen site and explore its characteristics and relevance. Design Development illustrates the learned concepts in a building project, while the last segment concludes with a discussion about findings and outcomes.



Photo 4: Swisstech Convention Centre, Lausanne, Switzerland

Note. From Guerra, F. (2018)

## *Investigation*

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THEORETICAL FRAMEWORK

REFERENCE PROJECTS

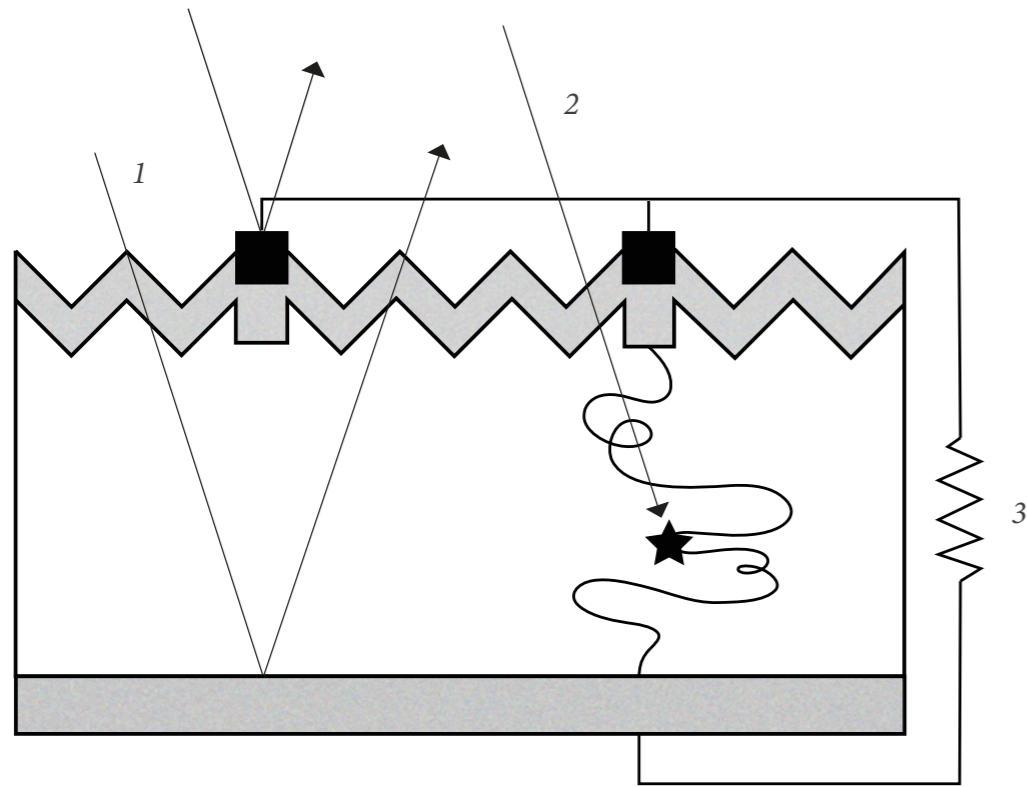


Figure 1. Principle of how a solar cell works

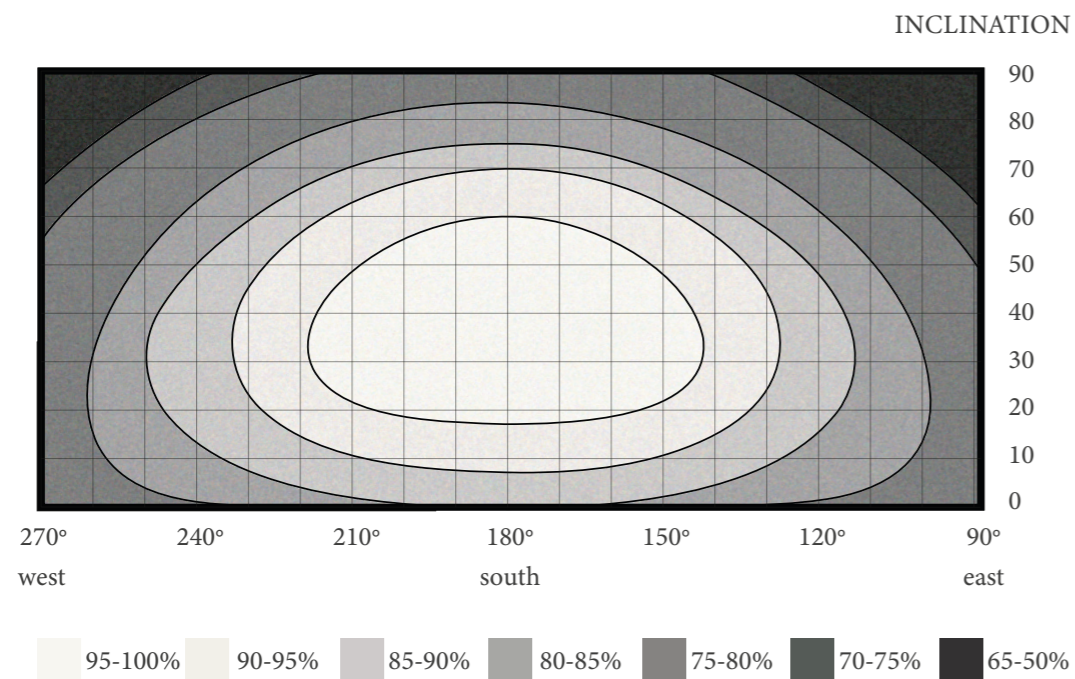


Figure 2. Change in performance due to panel orientation and inclination

## Theoretical framework

### THE MAIN PRINCIPLES

When sunlight reaches a solar cell, the radiation from the sun is absorbed and transformed into electricity. For this principle to work, the following 3 steps must be fulfilled according to Marjan van Aubel (Van Aubel, 2022) (figure 1):

1. Sunlight must reach and enter the solar cell.
2. The radiation from the sun must be absorbed in the active layer of the solar panel and converted into electric charges that are free to move.
3. Those charges must reach the metal contacts so that the power is delivered to appliances in the building, a battery, or the grid for electricity.

### SUN ELEVATION & SOLAR AZIMUTH

Integrating solar technology with architecture comes with some uncertainties. Local weather conditions may fluctuate from day to day and an accurate forecast can't always be achieved. Even with perfect conditions, buildings that have integrated solar technology won't always be exposed to sunlight (Van Aubel, 2022).

However, there are factors that contribute to its functionality. Where on earth the building is located, the season of the year, local weather conditions, time of day and orientation of solar panels all effect how much energy that may be produced. (Krippner, 2017).

To maximise the energy production, the surface of a panel should directly face the sun. For Sweden, south-facing facades receives the most sunlight and as a result are the most efficient for installing photovoltaic. At our specific latitude, the highest results are generated with an inclination of 40 degrees in a southern direction (figure 2).

As illustrated in the diagram, the further the installation is from the south, the more the production will be negatively affected. It is possible to install so-

lar cells towards east and west but will result in an energy loss around 20%. However, the production of energy in the morning increases when installing panels facing east, while panels facing west do the same for the afternoon. (Solexperter, n.d.).

Installing solar panels on different sides of the building with various orientation could lead to a more financially and energetically efficient structure. When looking at residential buildings, most energy is used during mornings and evenings. Installing solar panels on surfaces facing west and east will therefore yield a better output then focusing on surfaces with maximum performance. How the building manages and generate energy is therefore important to analyse before installing solar panels (Solarchitecture, n.d.).

While a majority of installed PV in Sweden are connected to the broader grid. and is favorable for compensating the few sunhours during darker seasons, a higher self-consumption reduces additional taxes and grid fees (Quoilin, Kavvadias, Mercier, Pappone, & Zucker, 2016). Using batteries also increase the self-consumption by being able to store the excess energy produced during the day and use it when the PV system isn't yielding (Energimyndigheten, 2024).

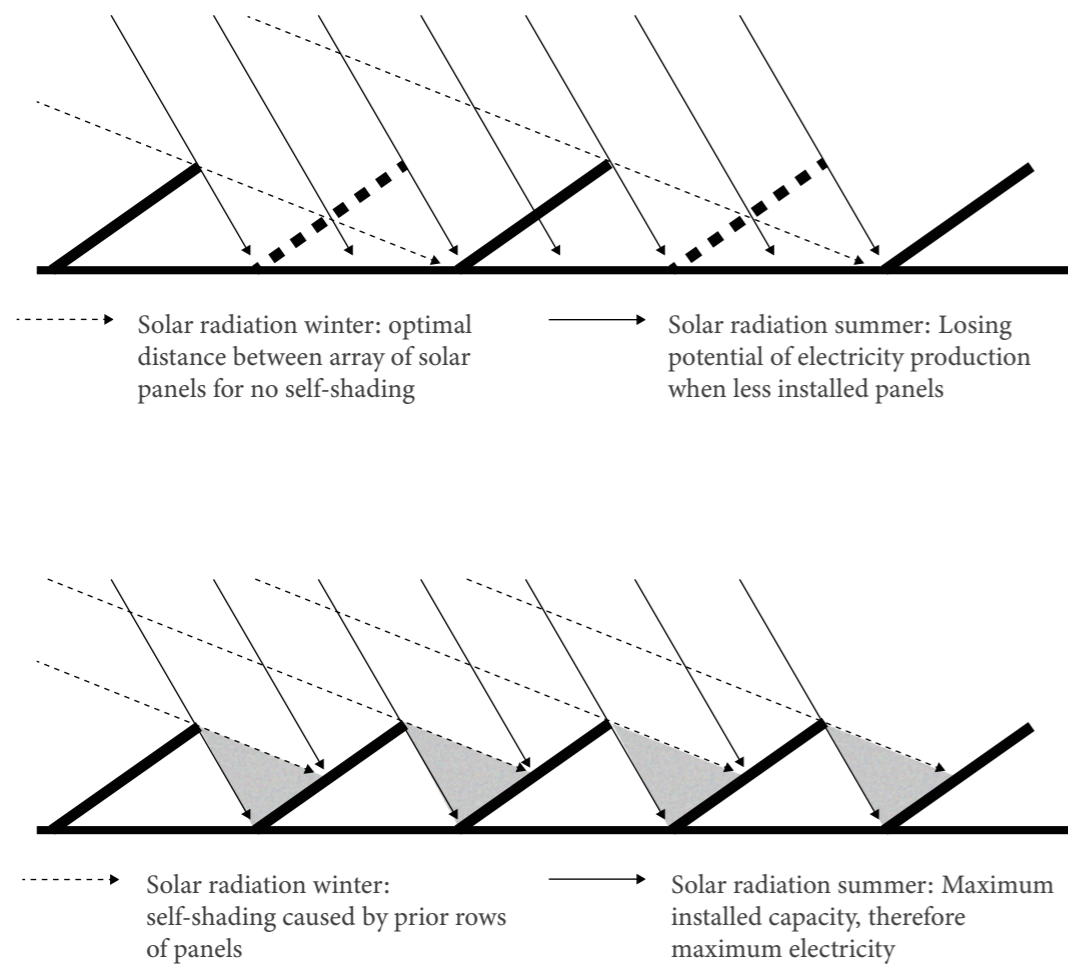


Figure 3. Different distance between rows of solar panels and the self-shading effects during winter and summer

## SHADING LOSSES

Places that are completely free of shade are difficult to find in the real world. Different obstacles such as trees, bushes, people, buildings, hills, and topography all cause shadows on surfaces that are exposed to sunlight. These shadows also change when the position of the sun changes, both affected by time of day, and which season it is. When designing a building, it is important to minimize these shadows as well as optimize the angle of the solar PV system so that it is functional for both summer and wintertime (Krippner, 2017).

For PV modules that are installed towards the south, an effect of self-shading occurs due to prior rows of modules. This applies to all rows except for the first one. To minimize the shade that is caused, the modules are placed further away from one another. However, during summertime, the sun is higher in the sky and therefore doesn't require as high of an inter-row distance. Compared to winter, when the sun is relatively low, and the distance for no self-shading is needed to be longer. (Yang, Campana, Stridh, & Yan, 2020)

## INTEGRATION OF BIPV

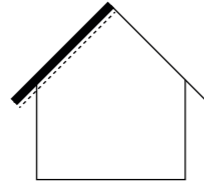
When photovoltaic are installed on roofs or facades, the system becomes a part of the aesthetical features for the entire building. For this reason, it cannot conflict with the building's architectural concept, but must either work as a complement with the elements that creates the building's surfaces, or an intentional contrast to these (Krippner, 2017).

There are different methods to work with to achieve this. Some cases work to minimize the visibility of the modules (often installed on roofs). Other cases work with different colors and materials of PV to instead adapt to the building context or the overall architectural vision (Hirschl, 2005).

One important aspect, which has a great impact on the integration result of solar panels, are the dimensions and scale of these panels according to the size of the related surface. There is often an aim to cover the entire surface for a consistent appearance and must therefore be planned in accordance with the structural principles of the different surfaces (Krippner, 2017).

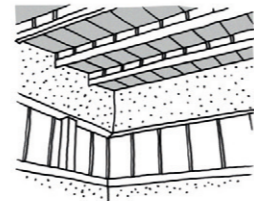
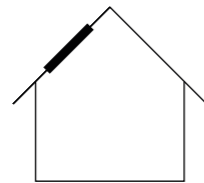
**A. Sloping, roof-integrated, not accessible from within the building**

Discontinuous roofing, continuous roofing



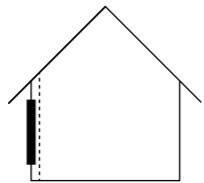
**B. Sloping, roof-integrated, accessible from within the building**

Atrium, skylight



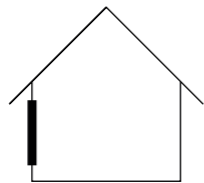
**C. Non-sloping (vertically), envelope-integrated, not accessible from within the building**

Rainscreen facade, masonry wall



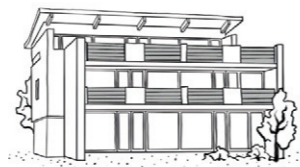
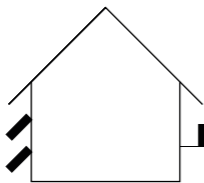
**D. Non-sloping (vertically), envelope-integrated, accessible from within the building**

Double skin facade, curtain wall, window



**E. Externally-integrated, accessible or not accessible from within the building**

Balcony balustrades, shutters, awnings, louvers, brise soleil



## DESIGN INTEGRATION

PV installations that are mounted as add-ons after the building is constructed, are often viewed as disruptive elements for the aesthetics when it comes to roof and facades. The biggest reason for this, is till today seen as when the installed panels are elevated from the building shell and therefore becomes more prominent. On the other hand, Integrated PV are often viewed to be more subtle and sometimes even sophisticated (Krippner, 2017).

When first designing with PV modules, it's important to clarify what building typology and the characteristics that are set for roof and facades. The defining elements of a building's form, style, and function are all attributes that influence the design work when implementing PV. Installing solar panels on roofs are the most common application form. However, it is important to coordinate the building component dimensions with the mainly small-scale roofing material (Krippner, 2017). In addition to this, when photovoltaic systems are installed on roofs or facades with the ambition of full coverage, incompatibility of standard modules and surfaces may be an obstacle.

You can either manufacture a solar panel with a different shape, or work with so called *dummy* modules. These do not yield energy and are only implemented as place holders to not disrupt the aesthetic (Krippner, 2017). However, custom made are more expensive and may require it's own parallel connection when installed (Solpaneler och batterilager, n.d.).

## STRUCTURAL INTEGRATION

There are many ways to integrate PV in building. According to a report made by the International Energy Agency (IEA) they can be divided into 5 categories, where each has a specific characteristics and potential benefits of how to integrate the systems.

A. It is important that the BIPV connect fully to the roof material to ensure protection from rain and snow. Exposure to high temperature makes it important that BIPV can handle thermal expansion as well.

B. With its vertical envelope it gives a sleek architectural appearance and is still an important factor when it comes to weather protection.

C. Although not accessible from within the building, these systems contribute to the building's weather protection and energy generation while maintaining an elegant architectural appearance.

D. With these systems is is important to balance the generated electricity with the daylight transmission. It is also important to think about the sight lines to the outside.

E. This form gives a lot of possibilities on where and how to place the systems.

The complexity in the building's orientations, the energy outcome and the architectural vision are all necessary to consider when deciding between the different application forms (Bonomo, 2021).

Figure 4. Application categories based on type of building integration

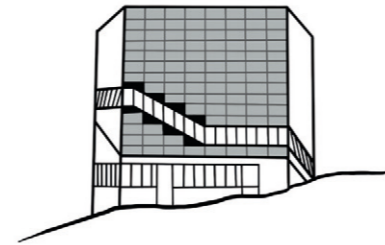
## Reference projects

### MONTE ROSA HUT

Bearth & Deplazes Architects and

Solar technology: Monocrystalline PV panels, manufactured by 3S Swiss Solar Solutions AG

 Jenins, Switzerland



The Monte Rosa Hut, located in the Swiss Alps, is an example of innovative sustainable design through the use of BIPV. The hut's design integrated PV panels into its facade and roof seamlessly, which shows how renewable energy solutions can be both functional and aesthetically pleasing.

The building's exterior integrates PV panels on its south-facing facade, blending active energy-generating modules with dummy modules to maintain a consistent appearance while maximizing energy production. This design approach highlights the potential for BIPV to contribute to both energy effi-

ciency and architectural coherence.

The facade's use of aluminium complements the PV panels, offering durability, light weight, and a reflective quality that aligns with the building's modern, high-tech aesthetic. This material choice enhances the building's flexibility in harsh conditions and supports its sustainable energy goals.

The Hut is filled with timber on the inside, creating a warm and inviting contrast to the sleek, industrial exterior. This combination of materials shows how sustainable design can achieve both functional and visual harmony.

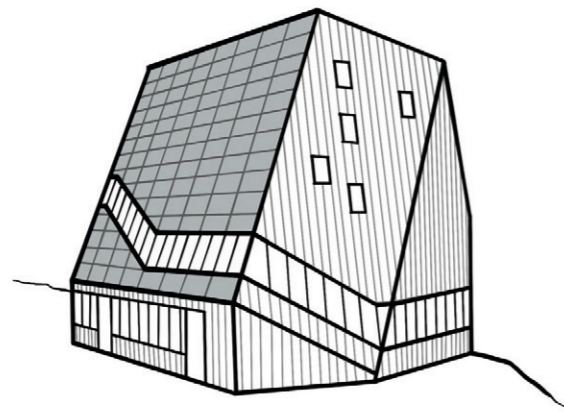

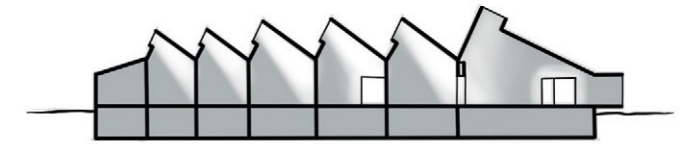


Figure 5 Illustrated volume of Monte Rosa Hut.

### KUNSTMUSEUM APPENZELL

Gigon Guyer Architects

 Appenzell, Schweiz



The art museum Appenzell showcases an innovative approach to natural lighting through its carefully designed window placements. The museum's combination of north-facing roof windows and strategically positioned side windows creates an ideal environment for displaying art.

The north-facing roof windows provide consistent, diffused daylight that enhances the visibility of artwork without exposing them to harmful UV rays.

The side windows create a dynamic

play of light and shadow, creating more beautiful exhibition spaces and offering scenic views of the surrounding landscape.

This thoughtful arrangement not only provides lighting but also contributes to the museum's architectural rhythm and aesthetic appeal.

The art museum Appenzell serves as a valuable reference for balancing natural light with the preservation of interior elements, offering inspiration for innovative and sustainable architectural design.

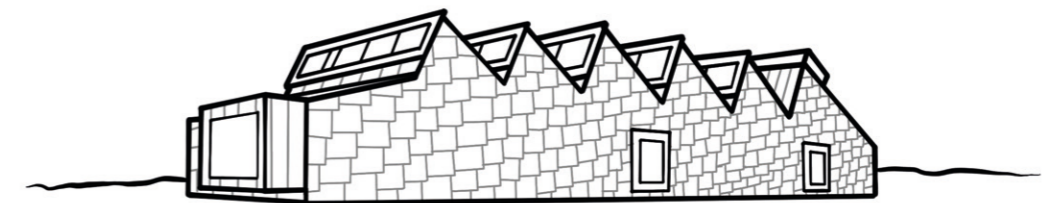


Figure 6 Illustrated volume of Kunstmuseum Appenzell



Photo 5: Solar panels added on numerous roof structures in Hunnebostrand, indicating a feasibility to integrate solar technology on the site

## *Project context*

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SITE

SCOPE



Photo 5-6: Historic pictures from Hunnebostrand and Udden, with prevalence of stone masonry

Note. Hunnebostrands bildarkiv (1910)

## Site

### INTRODUCTION TO SITE

The selected project site is located on Udden in Hunnebostrand, a historically rich site on Sweden's west coast. Only 2,5 driving hours from the capital of Norway, Oslo, and 1,5 driving hours from Gothenburg. In the late 1800s and early 1900s Udden was the key place from where the stone masonry was shipped. This has made Udden and Hunnebostrand a key influence for the identity of the place (Lindberg, 2011). Today Udden is part of a project to expand the already existing outdoor sculpture park with an exhibition center. This project offers a unique opportunity to imple-

ment building-integrated photovoltaic and create an intriguing synergy where history and future meet.

By working with BIPV systems, this project not only pays attention to the rich geological heritage of Hunnebostrand and its stone masonry history, as showcased in the stone exhibition, but also merges these elements with modern sustainable technology. This duality forms a space that is both practical and symbolical, linking the craftsmanship of the past with modern technology from today.

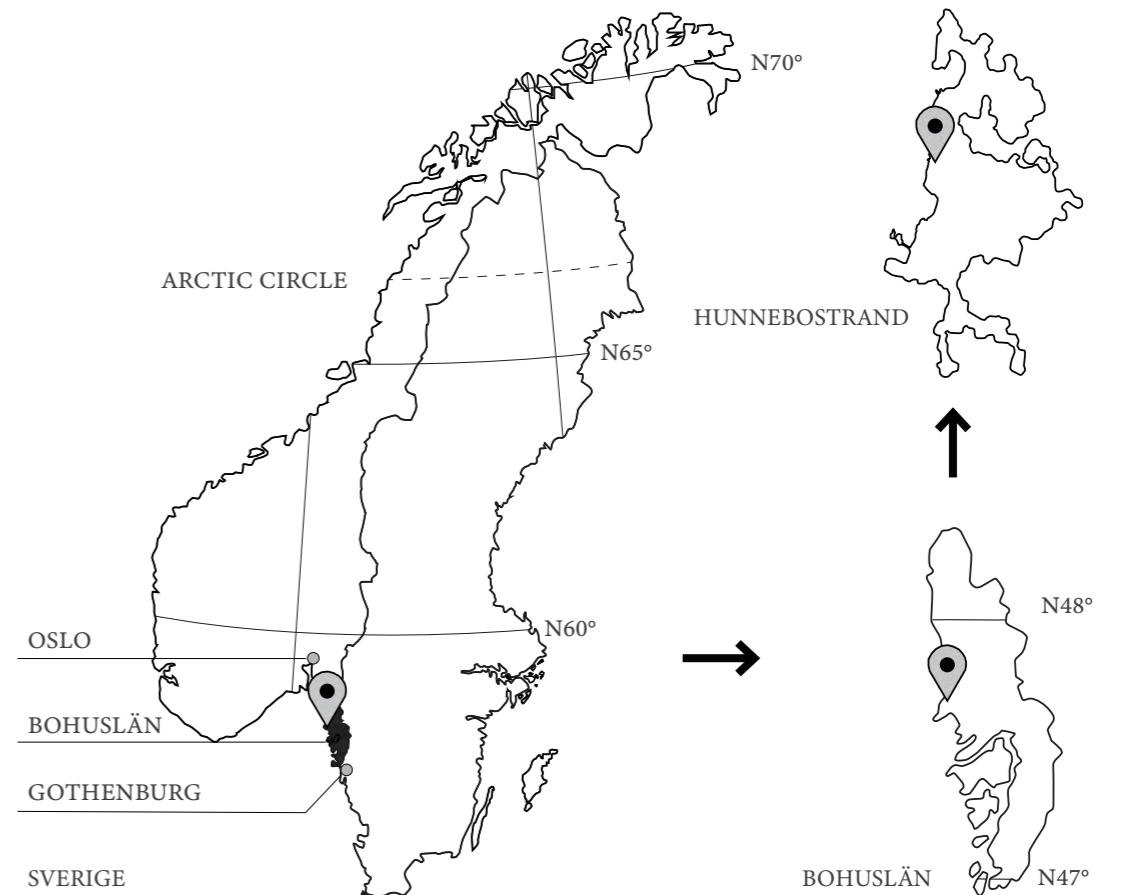


Figure 7 Geographical position of project location

## UDDEN SITE OVERVIEW

Udden is a popular destination and is well visited both by tourists and local residents. It features a scenic walkway that connects Hunnebostrand and Ullebergshamn, a swimming area and a lot of space for outdoor activities. With its west-facing position with view over the water, Udden is ideal for watching sunsets over the horizon (Lindberg, 2011).

The chosen project location is consciously located to serve as either the starting or finishing point of the outdoor sculpture park. Positioned right on the water's edge, between the mountain Nordre Höge Berg and the ocean, the exhibition center helps to frame the sculptures and enhance the overall experience of the park.

## BUILT ENVIRONMENT

Building typology that can be found in the adjacent area of the site, such as residential houses and boat sheds, generally have a modest scale which blends well with the terrain. Observations from the site indicate that most buildings had a tendency to harmonize with the surrounding landscape instead of trying to dominate it. This suggests a need for a design strategy that has a modest impact, respecting the site's natural topography with a low-profile volume.



Photo 7-8: Adjacent buildings



Figure 8: Analysis of site and its surrounding functions

## SUN CONDITIONS ON SITE

The preconditions of the Nordic climate present specific challenges when trying to implement building-integrated photovoltaic systems due to the shadowing effect. This is particularly true during the darker seasons when the sun is at its

lowest angle. The site's proximity to the mountain to the south further amplify this effect. Positioning the building as far from the mountain as possible is therefore of importance to achieve the maximum energy yield for a day.

The placement of the building along the waters edge is therefore consciously made to create favorable sun conditions, and placing parts of the building over the water further distance the building from the mountain. Additionally, this

placement also creates a possibility for outdoor space closer to the water, while considering views for residential villas located behind the building, the coastal walk and maintaining areas for various activities.

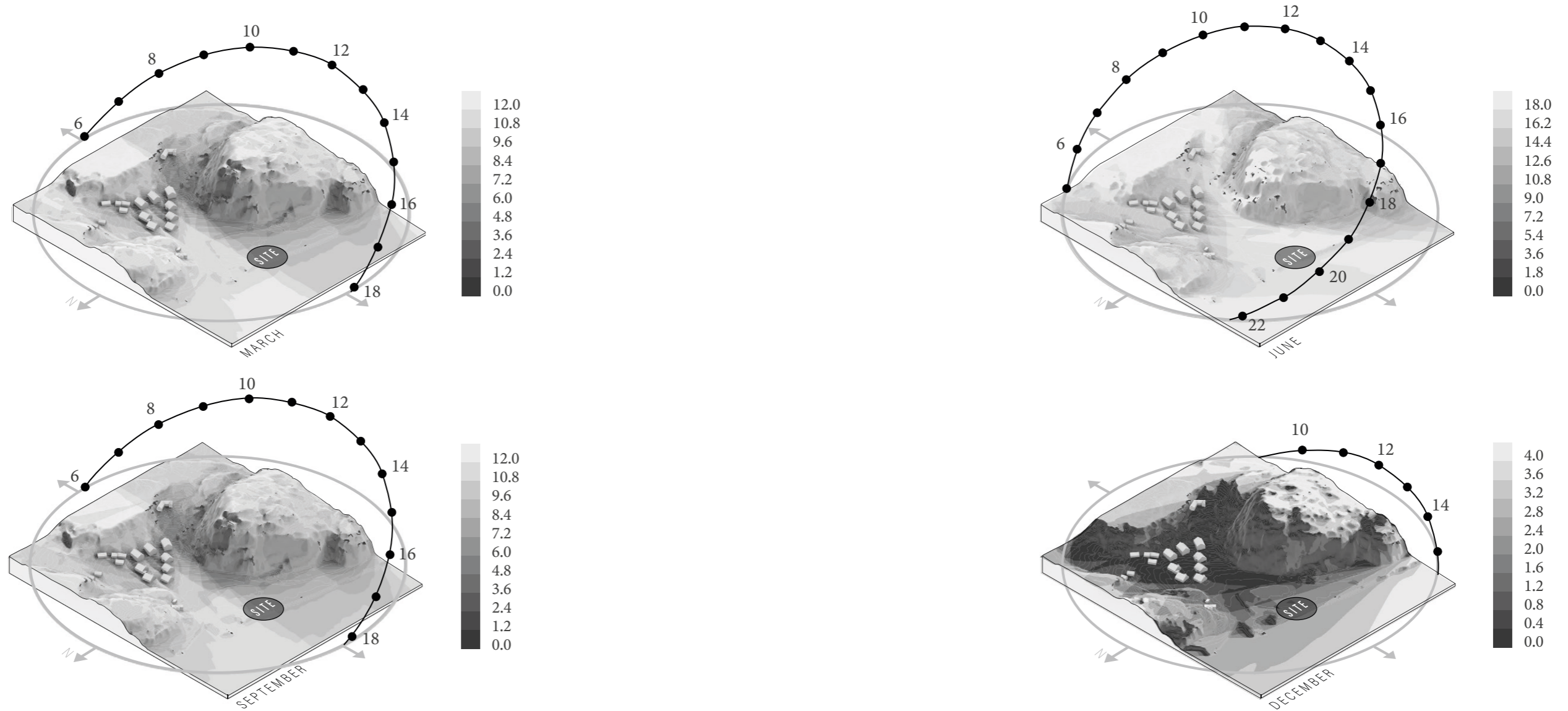


Figure 9: Direct sun hours on the site of Udden

## Scope

### SPATIAL ORGANIZATION

The program has grown from the knowledge that was gathered while reading the earlier reports and concept studies of the site. Their vision has inspired this take of the program. However, additions and alterations has been made to fit the interpretation of the task.

The central reception hall serves as the heart of the building, ensuring intuitive navigation and easy access. It leads visitors fluently towards the exhibition and museum space, to engage and assure interaction with the stone and art display. The event room, adjacent to the exhibition space, allows for flexible use, either expanding the exhibi-

tion for more space, or functioning as a separate area for community events and workshops.

The inclusion of a restaurant and event room serves to give back to the community by offering spaces for gatherings and special occasions. Furthermore, the workshop is designed to engage the community by involving them in the craft of stone art.

Supportive functions like restrooms, cloakroom and technical rooms, are positioned to ensure there is a smooth functional flow without disruptive elements for the visitor experience.

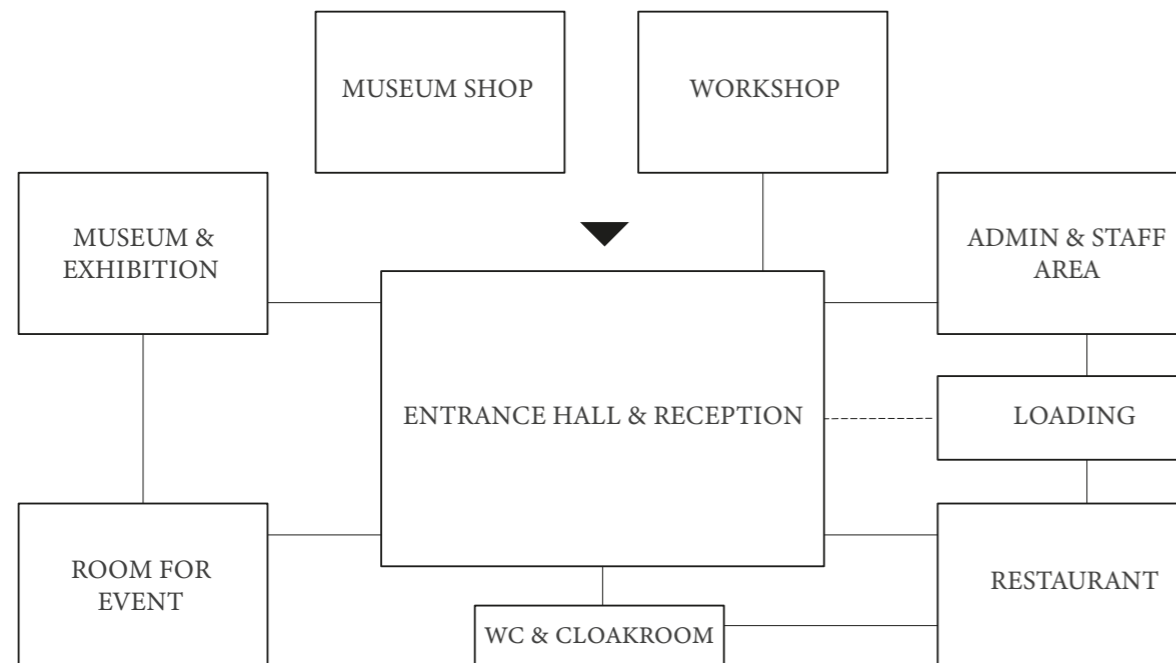


Figure 10: Illustration of spatial organization and connections in building

### SPACE PROGRAM

PUBLIC FUNCTIONS		SUPPORTIVE FUNCTIONS	
Entrance hall	110 m <sup>2</sup>	Storage	38 m <sup>2</sup>
Reception	14 m <sup>2</sup>	Restrooms	23 m <sup>2</sup>
Museum shop	33 m <sup>2</sup>	Cloakroom	8 m <sup>2</sup>
Museum & Exhibition	250 m <sup>2</sup>	Kitchen	45 m <sup>2</sup>
Room for event	96 m <sup>2</sup>	Waste	11 m <sup>2</sup>
Workshop	44 m <sup>2</sup>	Technical room	30 m <sup>2</sup>
Restaurant	100 m <sup>2</sup>	Battery room	10 m <sup>2</sup>
		Dressing rooms	20 m <sup>2</sup>
		Administration	44 m <sup>2</sup>
<b>TOTAL</b>	<b>1004 m<sup>2</sup></b>		

## *Design development*

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FORM & FUNCTION

BUILDING PROPOSAL

STRUCTURE & DETAIL



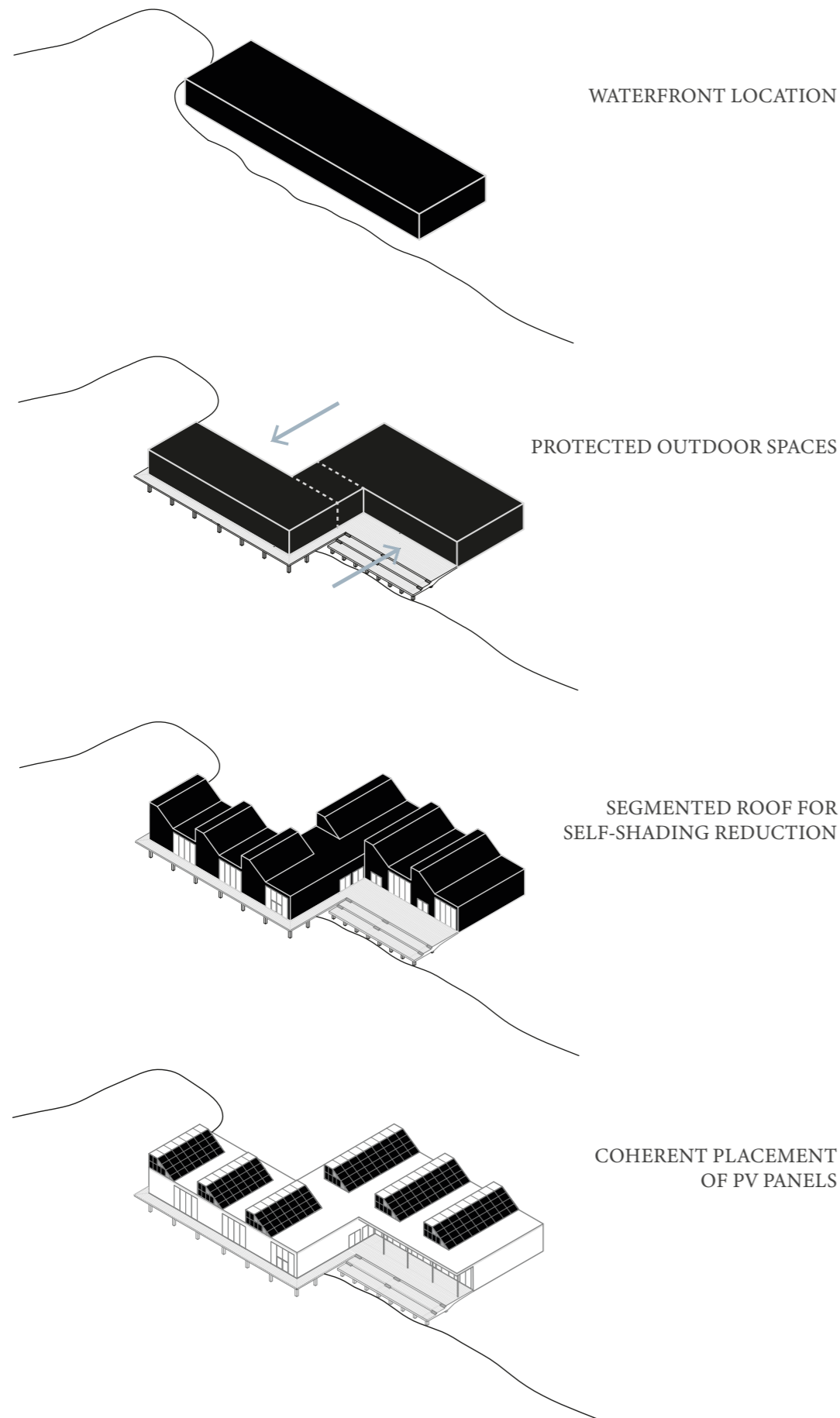


Figure 11: Design strategies for volume development

## Form and function

### VOLUME TREATMENT

The developed volume proposal is a result from theoretical framework, the chosen reference projects and consideration of the specific conditions for the site.

The placement of the building form is influenced by the shading generated by Nordre Høge Berg on the site, which asks for an orientation out towards the water, and also makes the buildings connection to the coastal walk more prominent.

The segmentation of the building roof structure is designed to minimize

self-shading, ensuring an even distribution of light across the structure. It also supports the strategic placement of photovoltaic panels, optimizing their efficiency while minimizing the perceived mass of the building.

Careful placement of visible elements, including photovoltaic modules, enhances the overall aesthetic consistency of the structure. To maintain this visual harmony, dummy modules are strategically placed in areas where the standard modules cannot fit, ensuring a cohesive look throughout the design

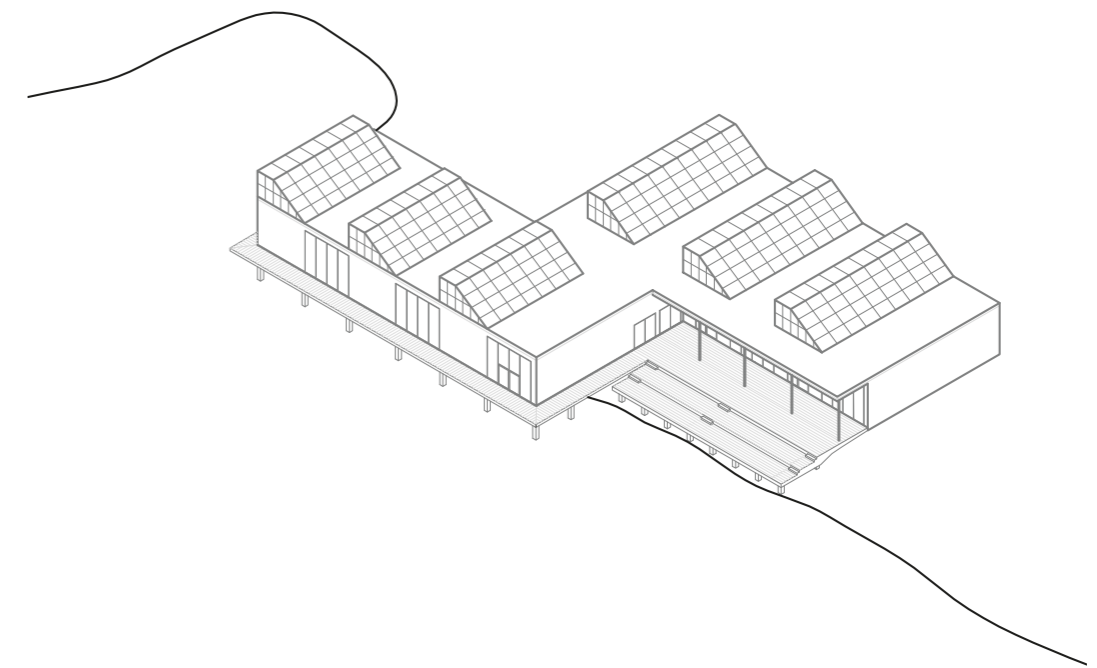


Figure 12: Volumetric illustration of design proposal

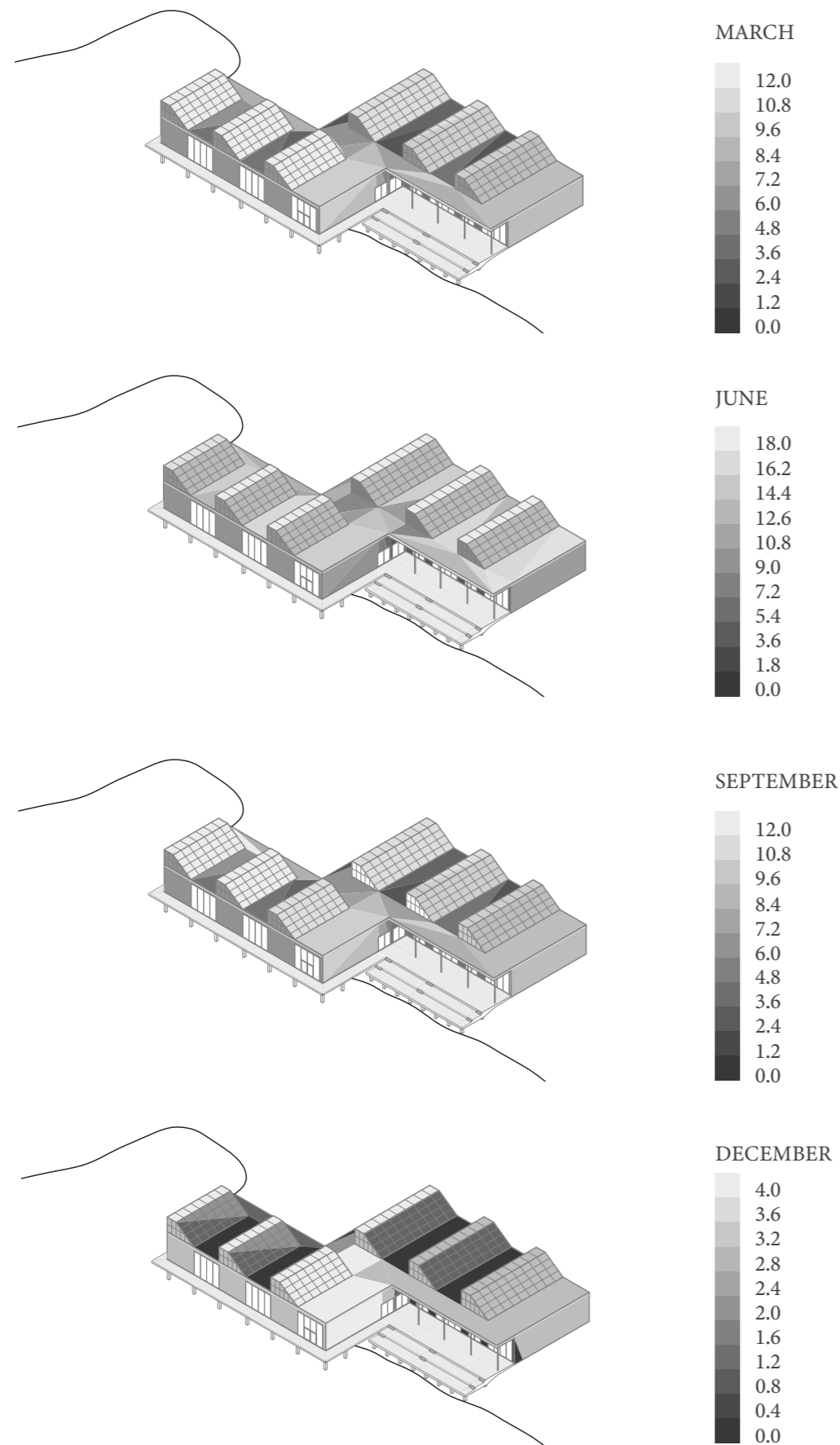


Figure 13: Number of direct sunlight hours received by different part of the building during a day

## ENERGY CONSUMPTION

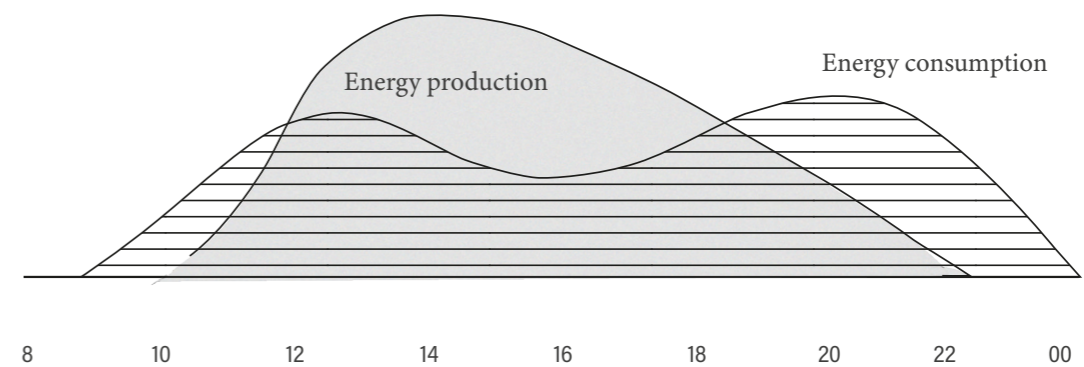
The building is primarily used during the day for exhibitions and the restaurant is open for lunch and dinners, along with events in the evening. The PV system is optimized for high energy production during these times.

South facing PV panels captures the maximum sunlight during the middle of the day, which aligns well with the peak usage hours of the exhibition spaces. West-facing PV panels are beneficial for capturing sunlight in the late afternoon and early evening, which

corresponds with opening hours of the restaurant and event room.

Given this pattern, the combination of south and west-facing PV panels would maximize energy production during the building's most active hours, ensuring a more sustainable energy profile.

Batteries store the generated electricity and compensate for days or times with less sun transmission, while excess energy is sold to the grid.



**Morning (8 am - 10 am):** Low to moderate energy production with south-facing panels.

**Midday (10 am - 2 pm):** High energy production, primarily south-facing, matching with the exhibition and museum's peak operational hours.

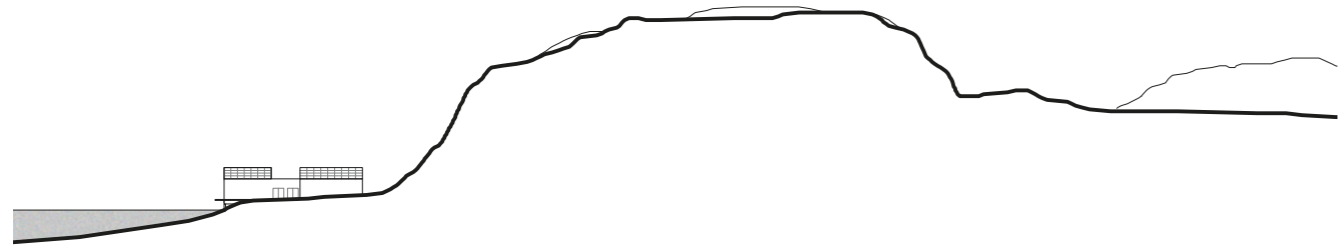
**Afternoon (2 pm - 6 pm):** Continued high energy production with a slight shift to the west-facing panels to extend the peak as the sun moves

**Evening (6 pm - 9 pm):** West-facing panels become more effective as the sun sets, supporting energy needs for the restaurant and event spaces.

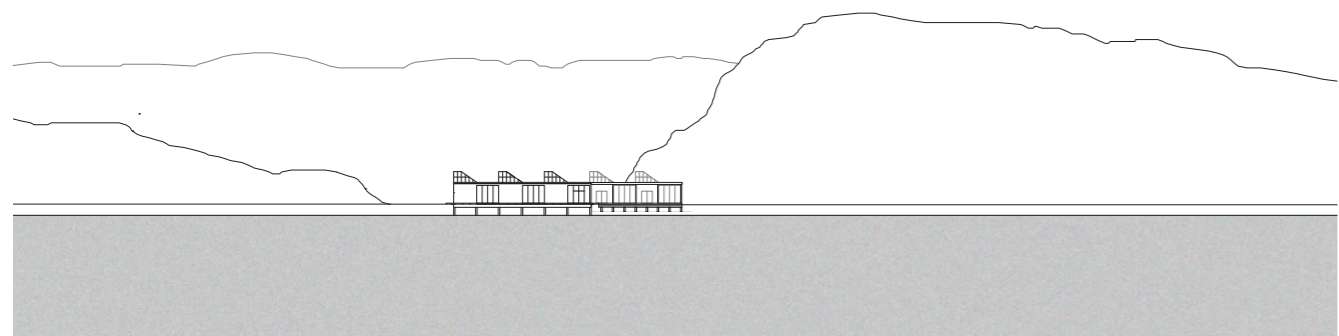


Figure 14: View from water

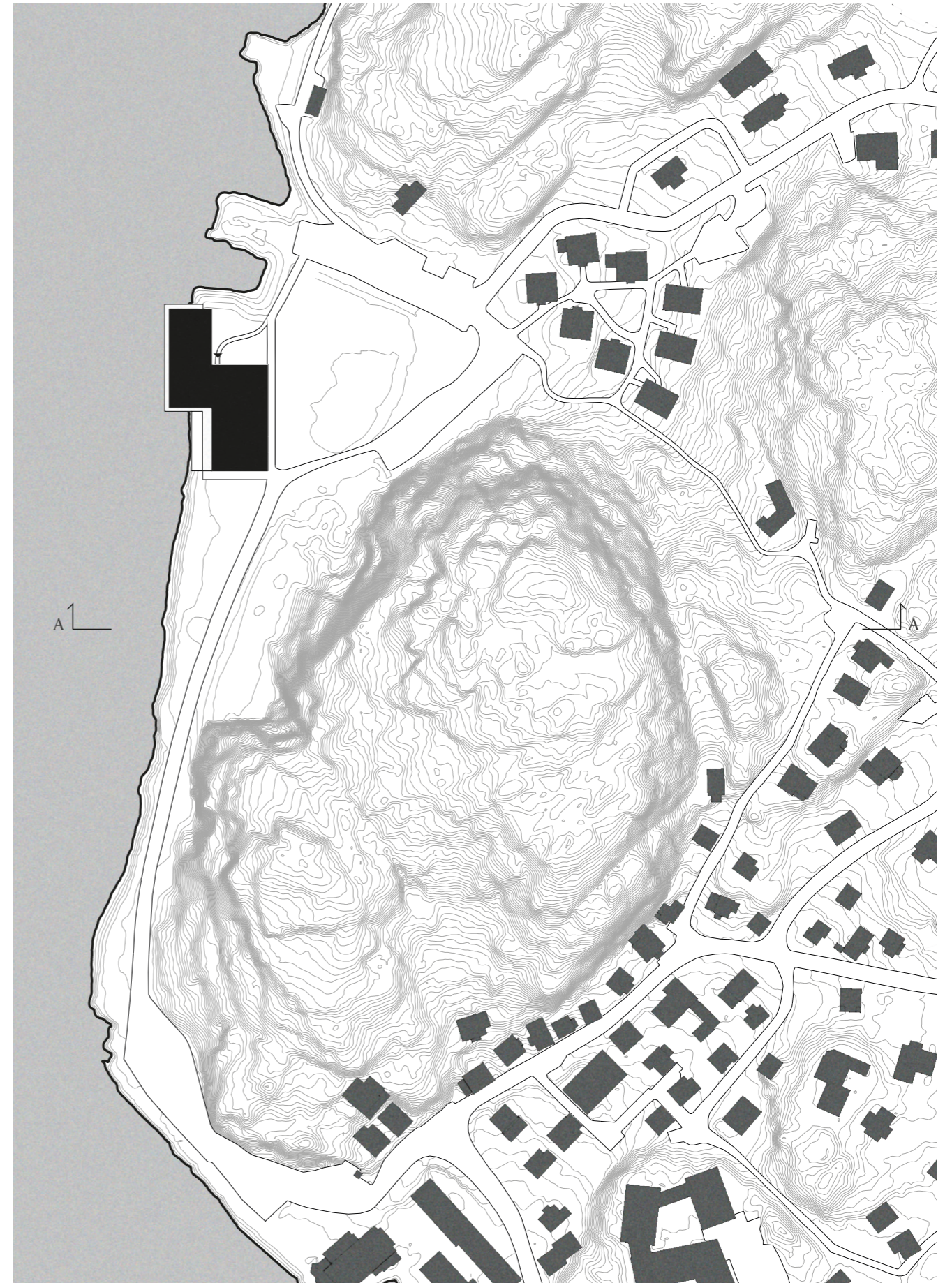
BUILDING PROPOSAL



SITE SECTION A-A 1:2000



SITE ELEVATION (WEST VIEW) 1:2000



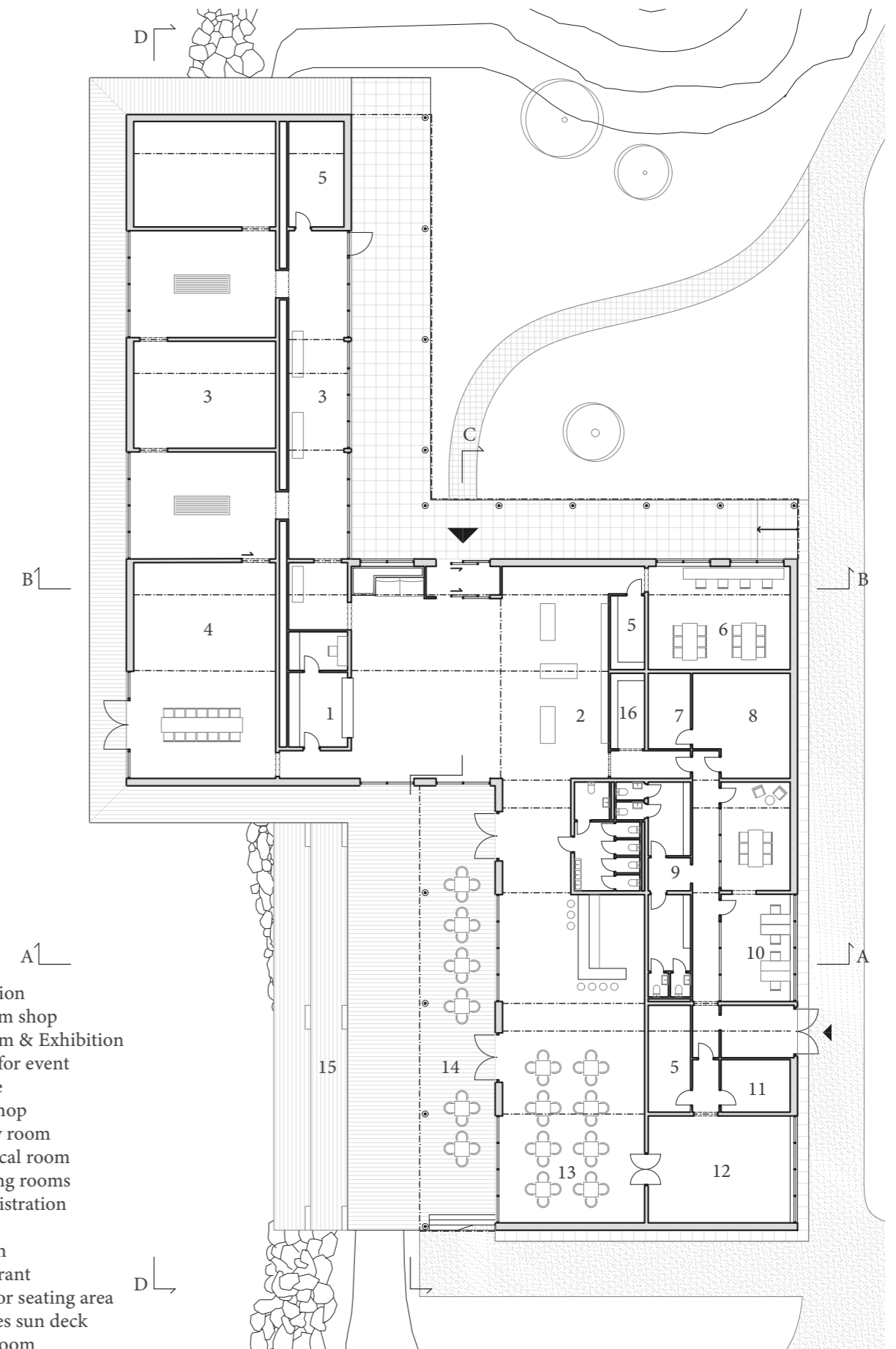
⊕ SITEPLAN 1:2000



Figure 15: Main entrance to building



Figure 16: Outdoor seating area with sun deck



1. Reception
2. Musuem shop
3. Museum & Exhibition
4. Room for event
5. Storage
6. Workshop
7. Battery room
8. Technical room
9. Dressing rooms
10. Administration
11. Waste
12. Kitchen
13. Restaurant
14. Outdoor seating area
15. Terraces sun deck
16. Cloakroom

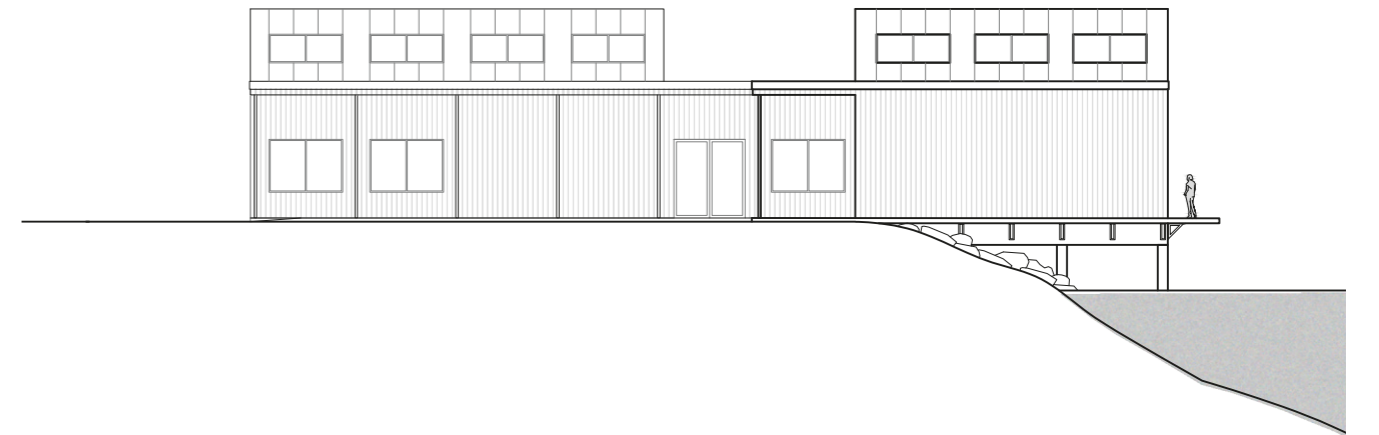
FLOOR PLAN 1:300  
 0 5 10m



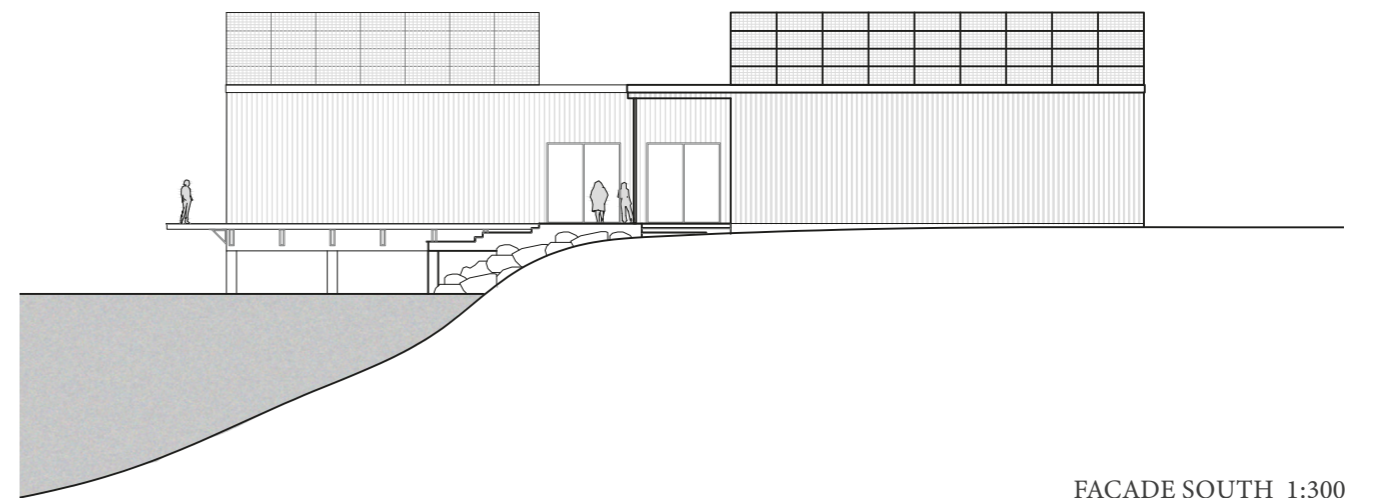
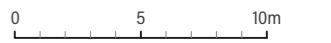
Figure 17: Entrance hall with reception



Figure 18: Exhibition room with ocean view

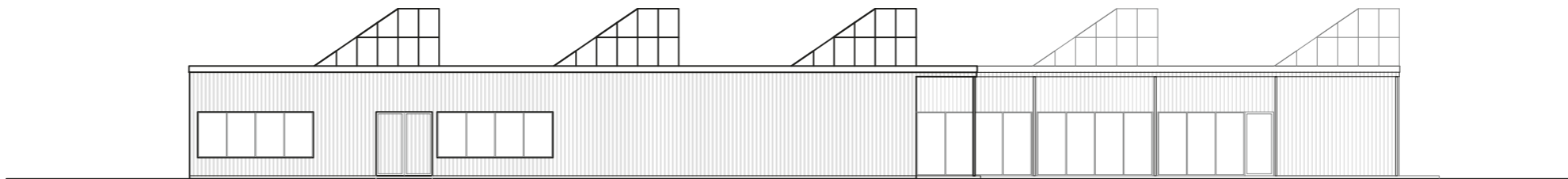


FACADE NORTH 1:300

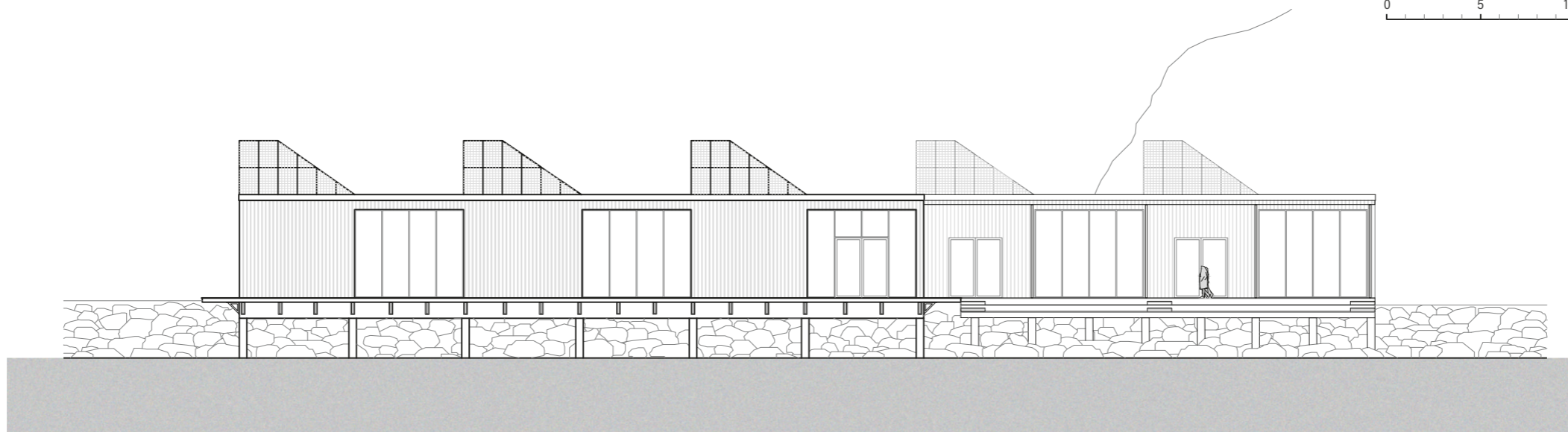


FACADE SOUTH 1:300





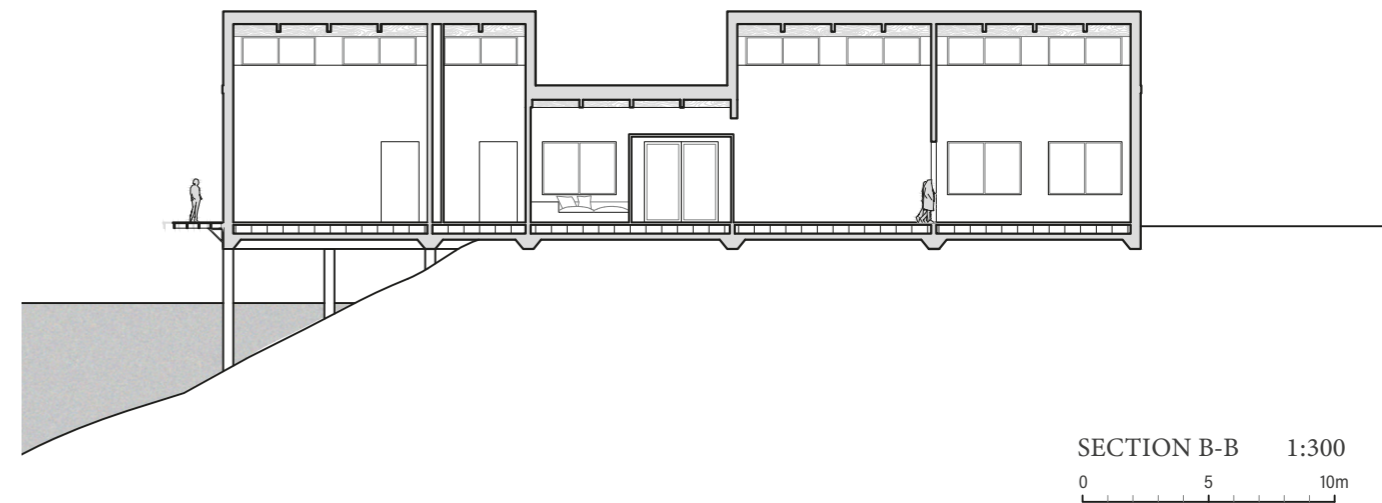
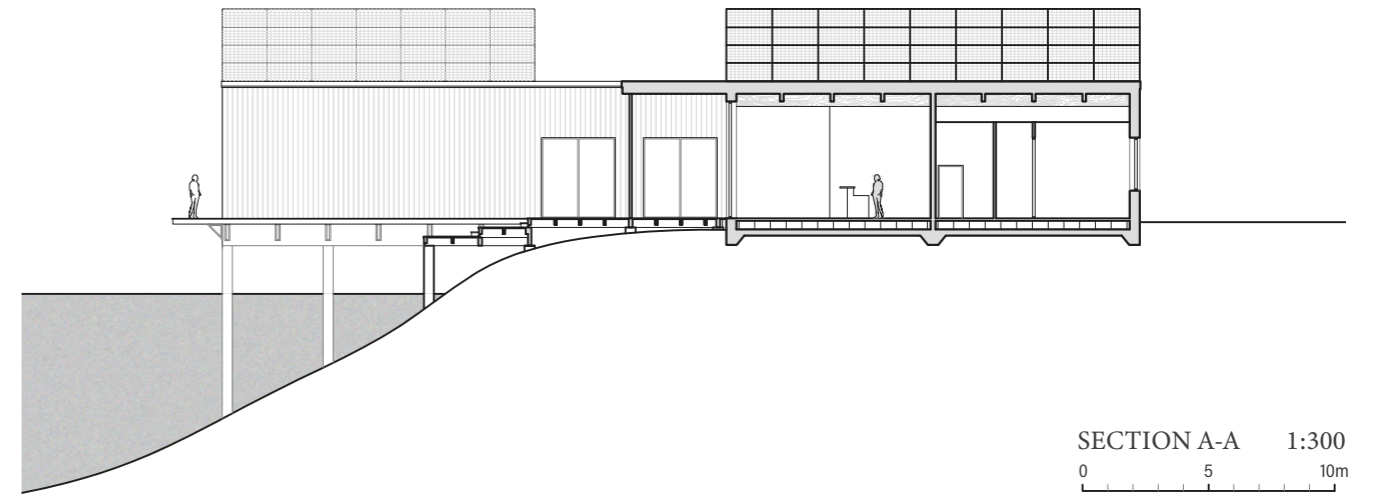
EAST FACADE 1:300  
0 5 10m

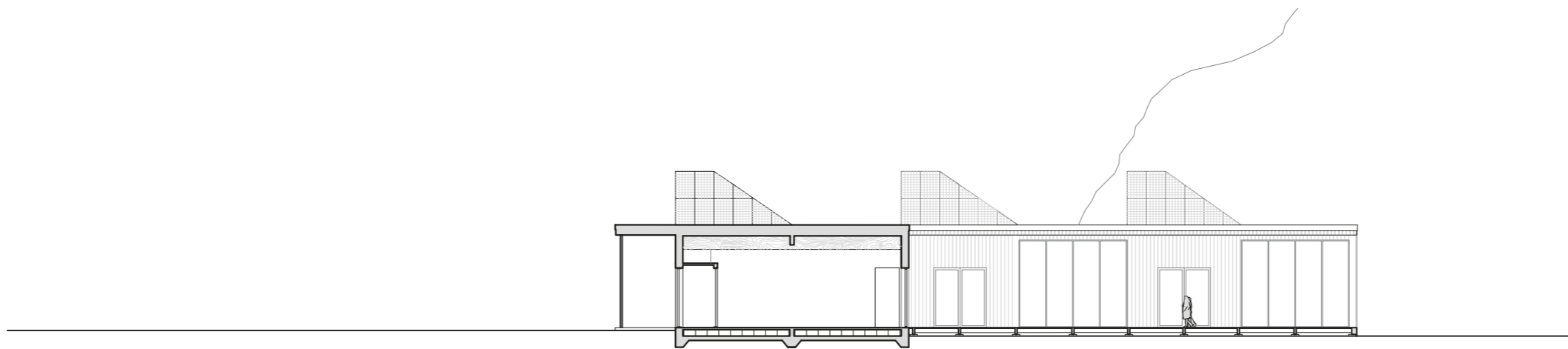


WEST FACADE 1:300  
0 5 10m

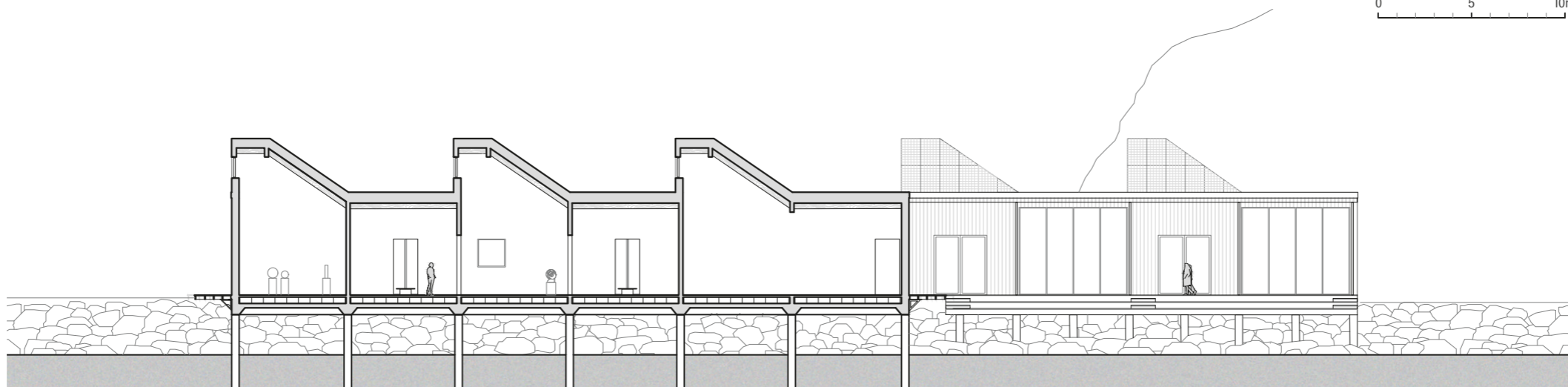


Figure 19: Exhibition room with raised ceiling





SECTION C-C 1:300



SECTION D-D 1:300

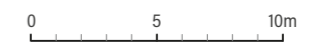




Figure 20: Restaurant

## EXTERIOR



CORRUGATED  
ALUMINIUM SHEET



BLACK PV PANEL,  
WITH BLACK FRAME



BLACK COLOURED  
GLASS

## INTERIOR



GIPSYM BOARD



CONCRETE &  
GRANITE TILES



LIGHT PIGMENTED  
GLULAM

## Structure and detail

### PV INTEGRATION

The PV panels used for both west facade and the roof towards the south are standard monocrystalline solar panels, but in two different sizes. A more commonly used larger size and a smaller variant, chosen to better function with the dimensions for the facade. The panels facing the south are installed horizontally to minimize the effect of self-shading, as partial shading can greatly impact the energy yield for the entire system. The panels are also incorporated with bypass diodes, further reducing the effects of partial shading.

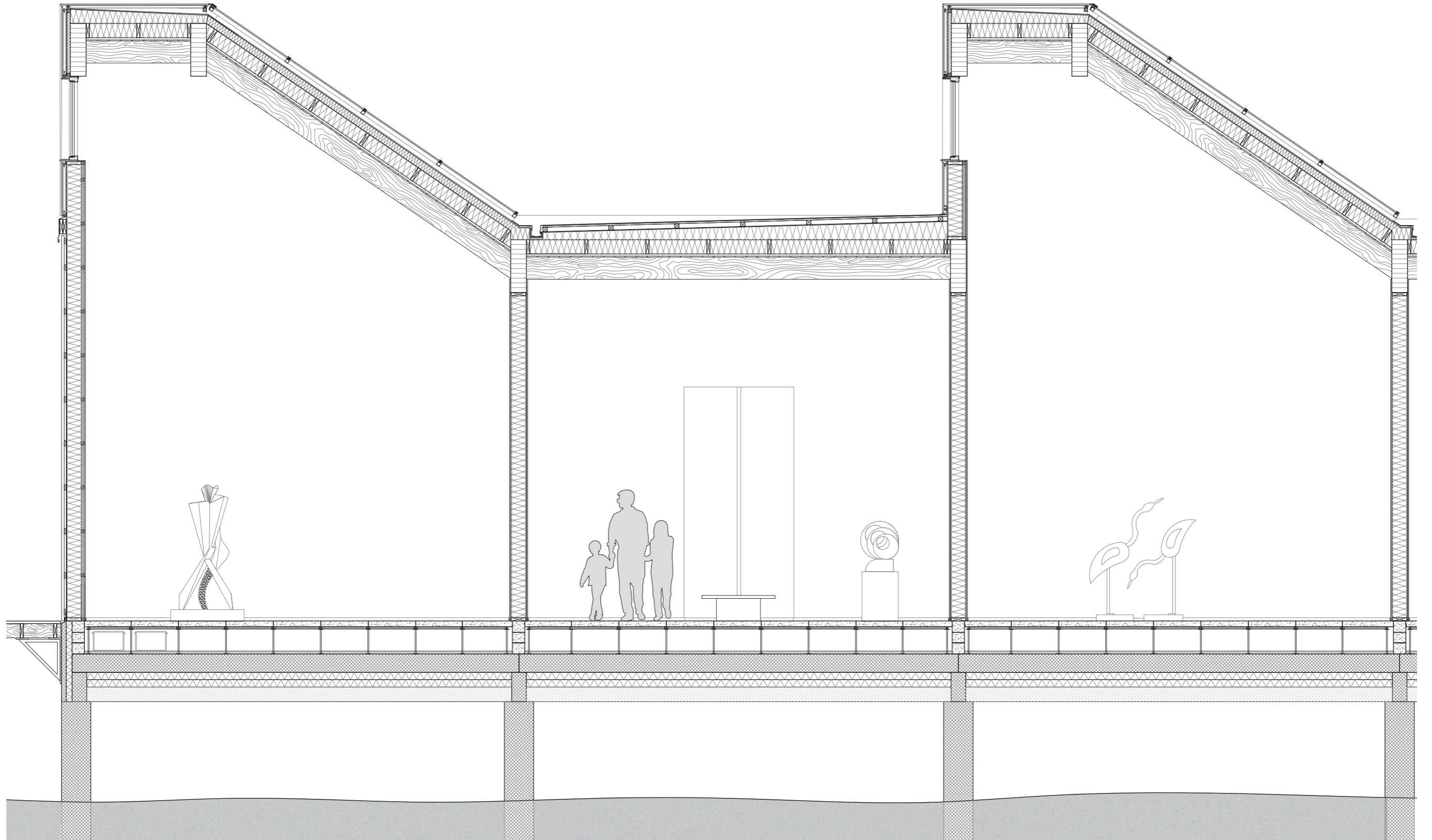
The structural grid was carefully adapted to ensure a seamless integration of the PV system. Instead of strictly following a 4-meter grid, minor adjustments were made to align with the panel dimensions, 3.9 meters for the smaller volume expanding over the water and 4.05 meter for the water volume.

### MATERIALS

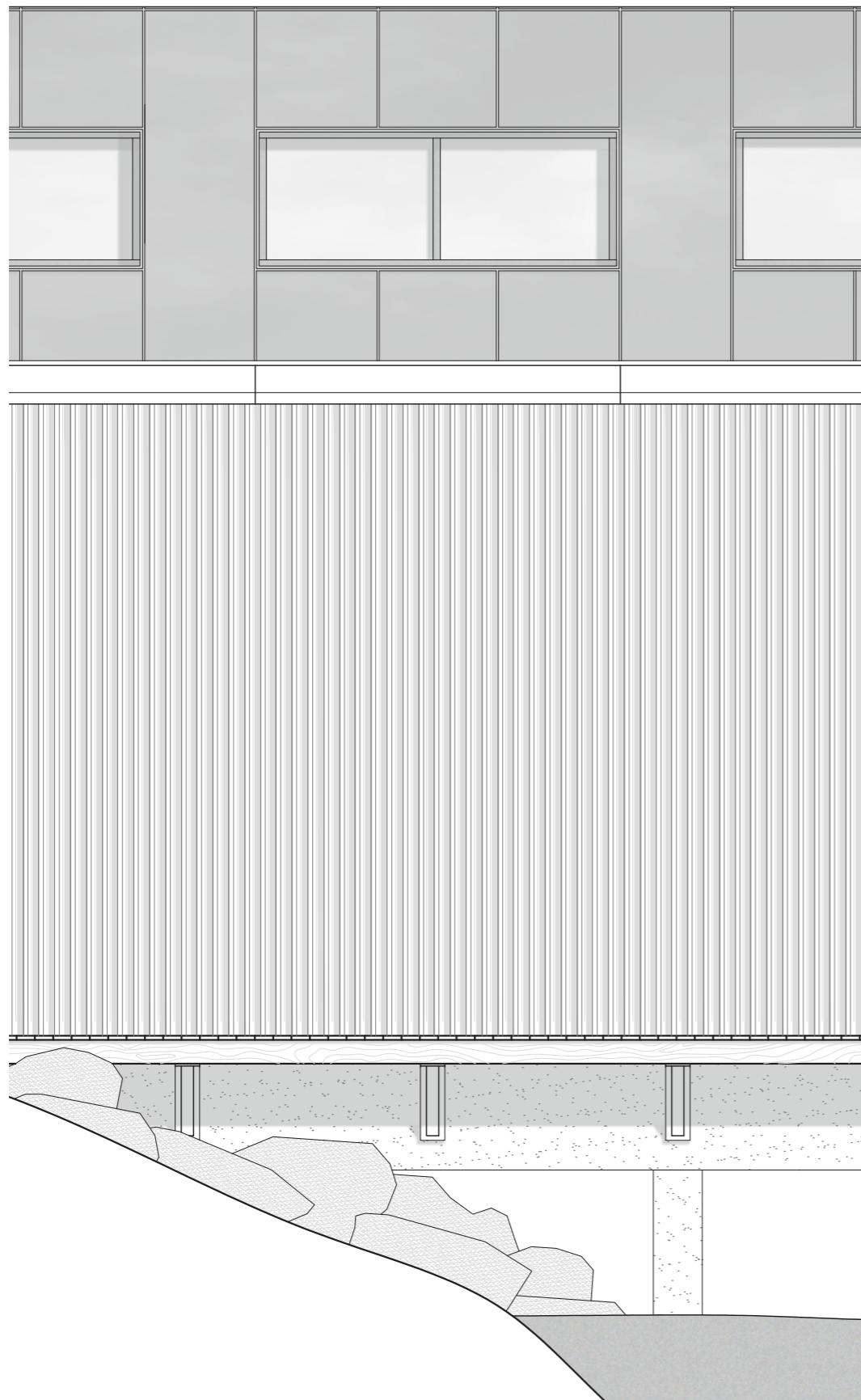
The materials chosen for this project has been deliberately selected to create a facade that visually resonates with the aesthetic attributes of photovoltaic panels.

The exterior uses corrugated aluminium sheets on the lower sections and black enamel laminated safety glass on the upper sections to mirror the reflective and colored characteristics of the solar panels. This industrial material palette, which includes aluminium, glass, and glulam timber, reflects the site's heritage while also embracing modern construction techniques.

The interior space is designed to provide a warmer, more inviting atmosphere, in contrast to the harsher exterior, which establishes a intentional contrast between the exterior and the interior.

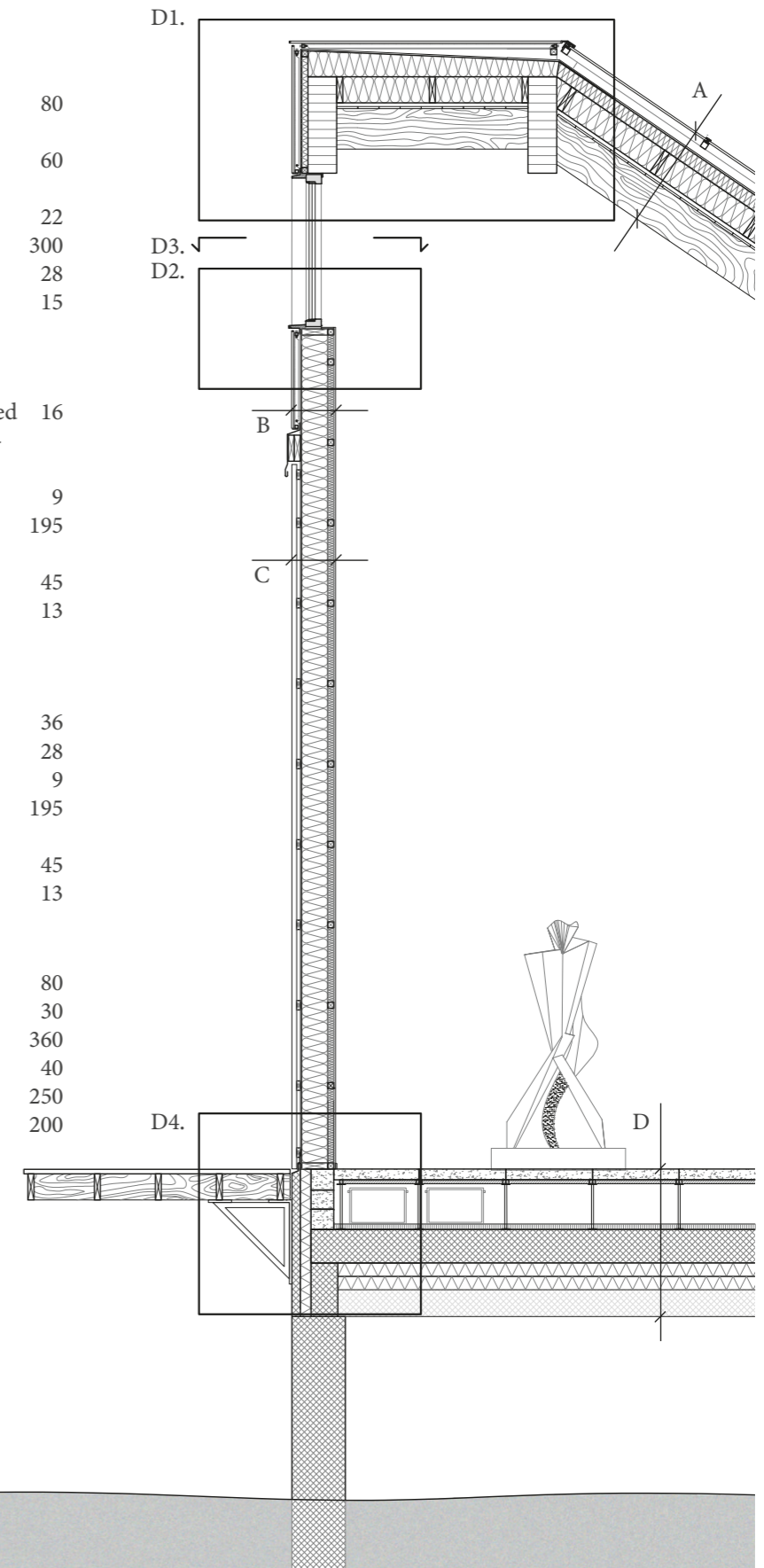


CONSTRUCTION SECTION 1 : 50

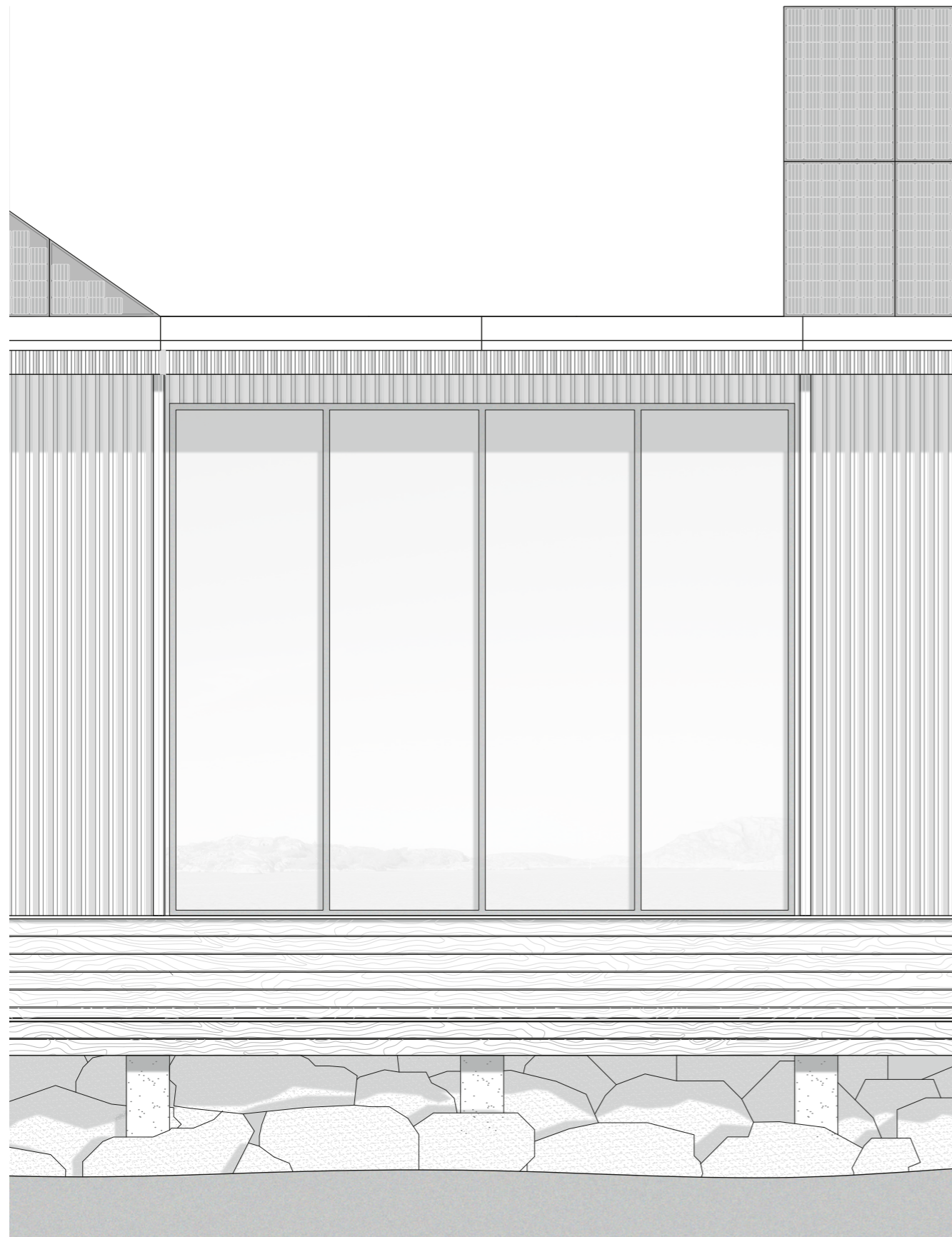


FACADE ELEVATION 1 : 50

<b>A. ROOF</b>	
1724 x 1134 Solar roof / Monocrystallina solar cells	80
Battens / Air gap	60
Waterproofing membrane	
OSB panel	22
Glulam Beams / Insulation	300
Battens	28
Wooden panels	15
<b>B. WALL</b>	
Laminated safety glass enamelled black adhesive fixed to aluminium section	16
Fibre-cement sheeting	9
Insulation	195
Vapor barrier	
Insulation / Installations	45
Plasterboard	13
<b>C. WALL</b>	
Corrugated aluminium sheet	36
Battens	28
Fibre-cement sheeting	9
Mineral-wool insulation	195
Vapor barrier	
Insulation / Installations	45
Plasterboard	13
<b>D. FOUNDATION</b>	
Reinforced concrete tiles	80
Galvanized steel stringers	30
Installation space / pedestals	360
Sound insulation (XPS)	40
Precast concrete slabs	250
Insulation	200
Waterproofing membrane	



DETAIL SECTION 1 : 50



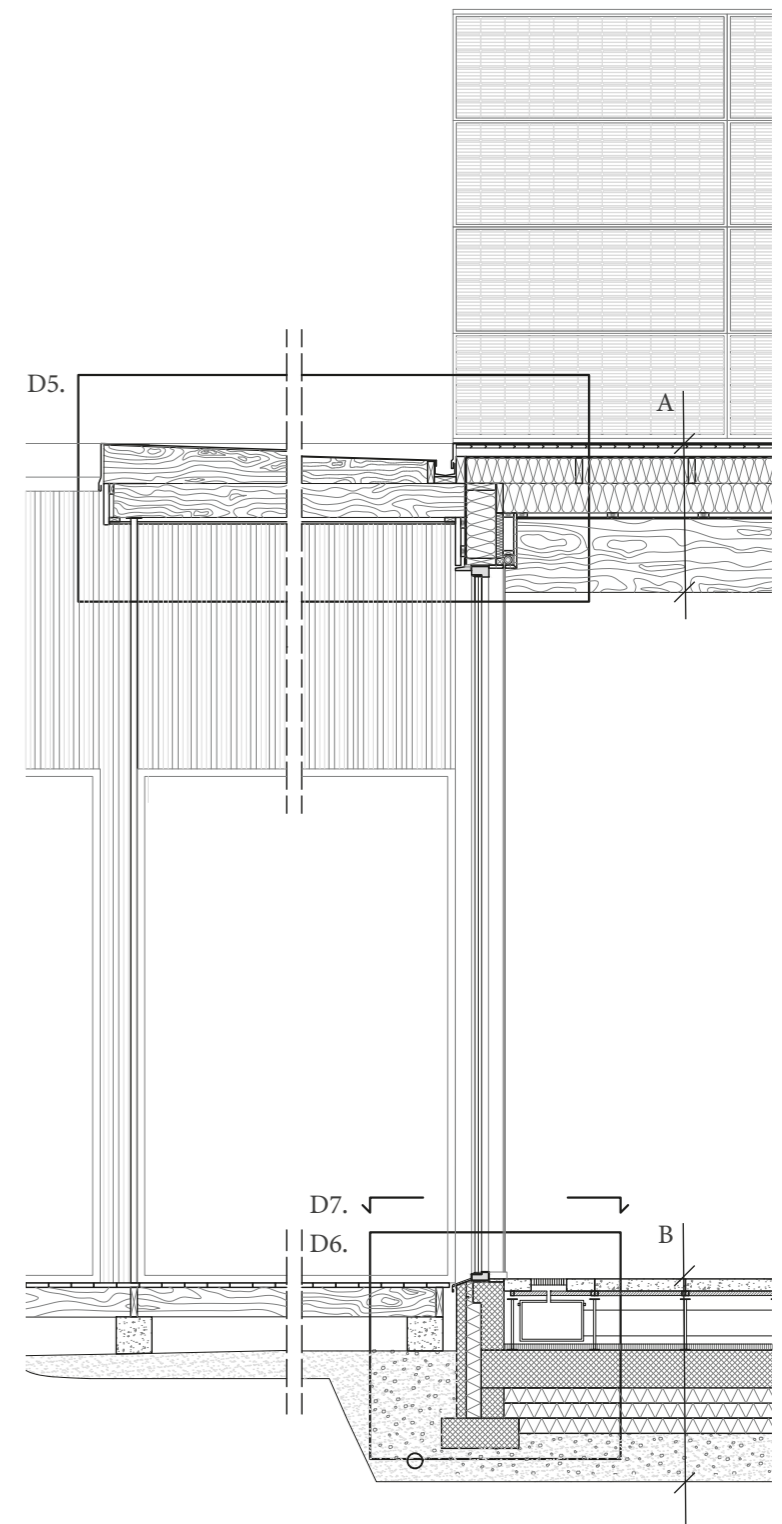
FACADE ELEVATION 1 : 50

**A. ROOF**

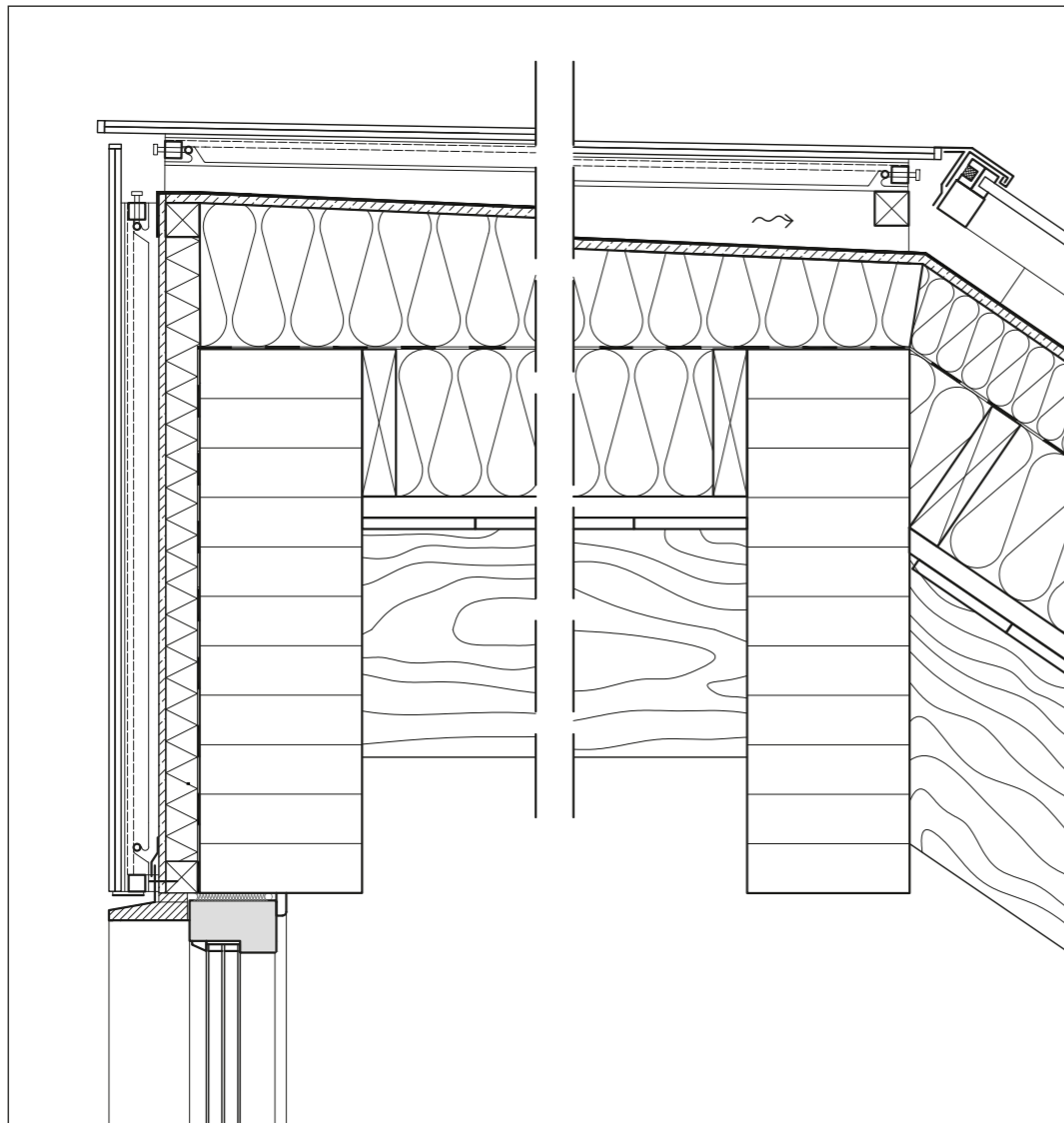
Sheet metal roof	10
Tar paper	
Tounged grooved timber	20
Air gap	60
Wind protection layer	
Glulam beams / Insulation	400
Battens	28
Wooden panels	15

**B. FOUNDATION**

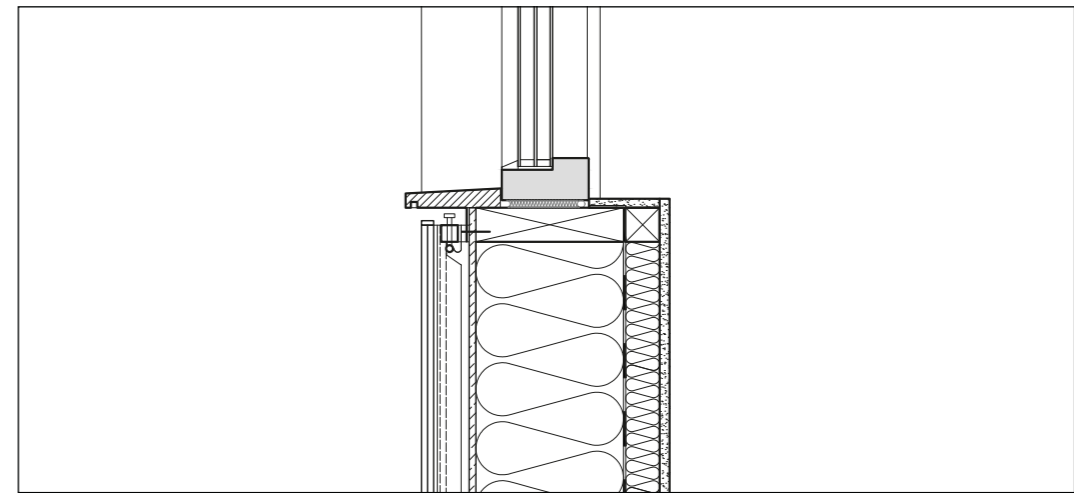
Reinforced concrete tiles	80
Galvanized steel stringers	30
Installation space / pedestals	360
Sound insulation (XPS)	40
Precast concrete slabs	250
Insulation	300
Macadam	320
Woven fabric	



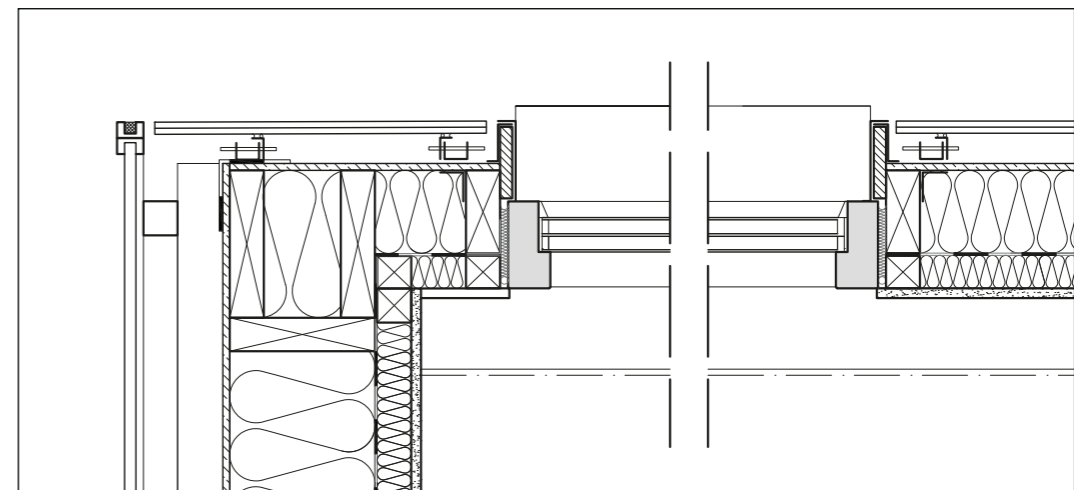
DETAIL SECTION 1 : 50



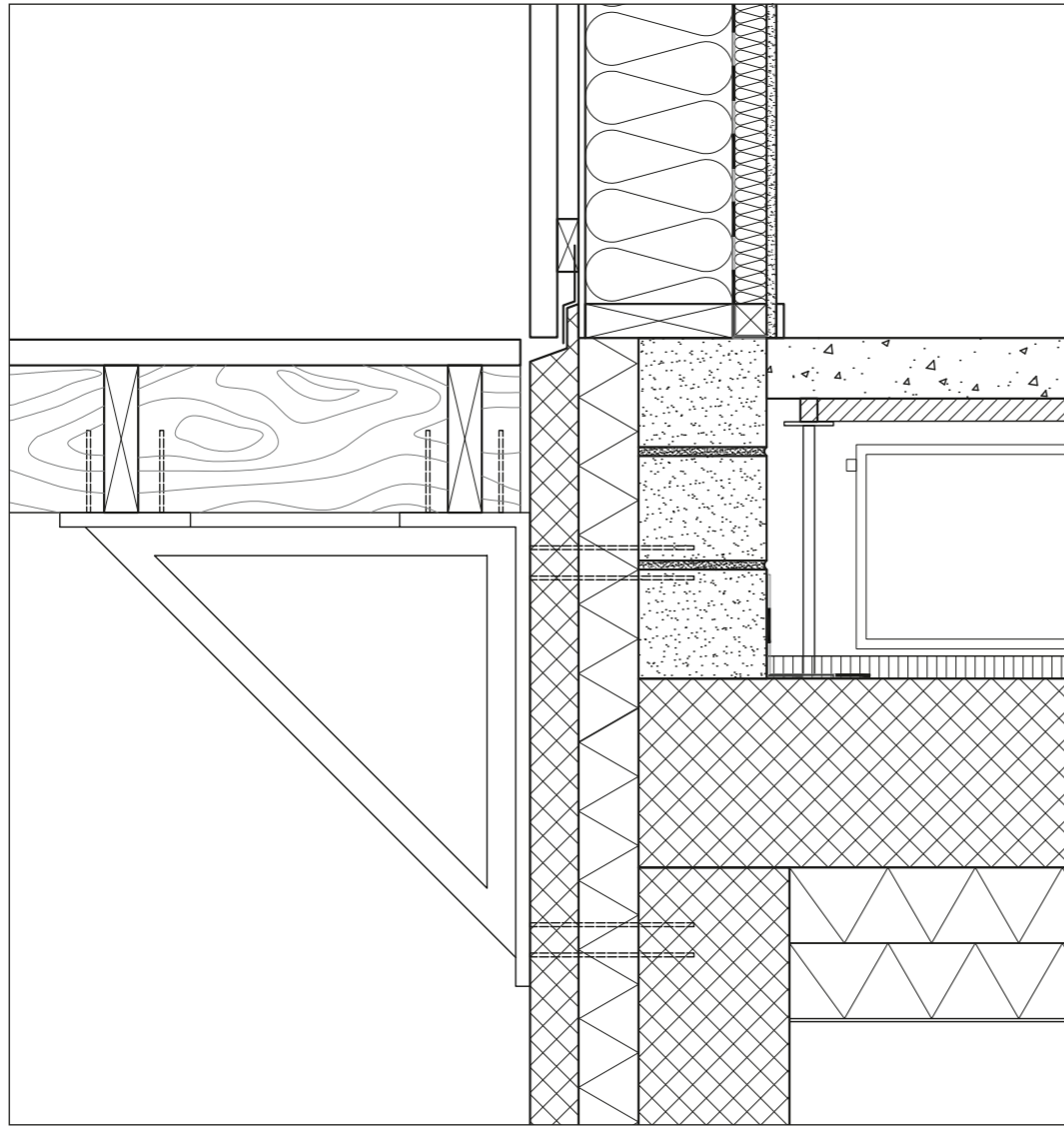
DETAIL 1 1 : 10



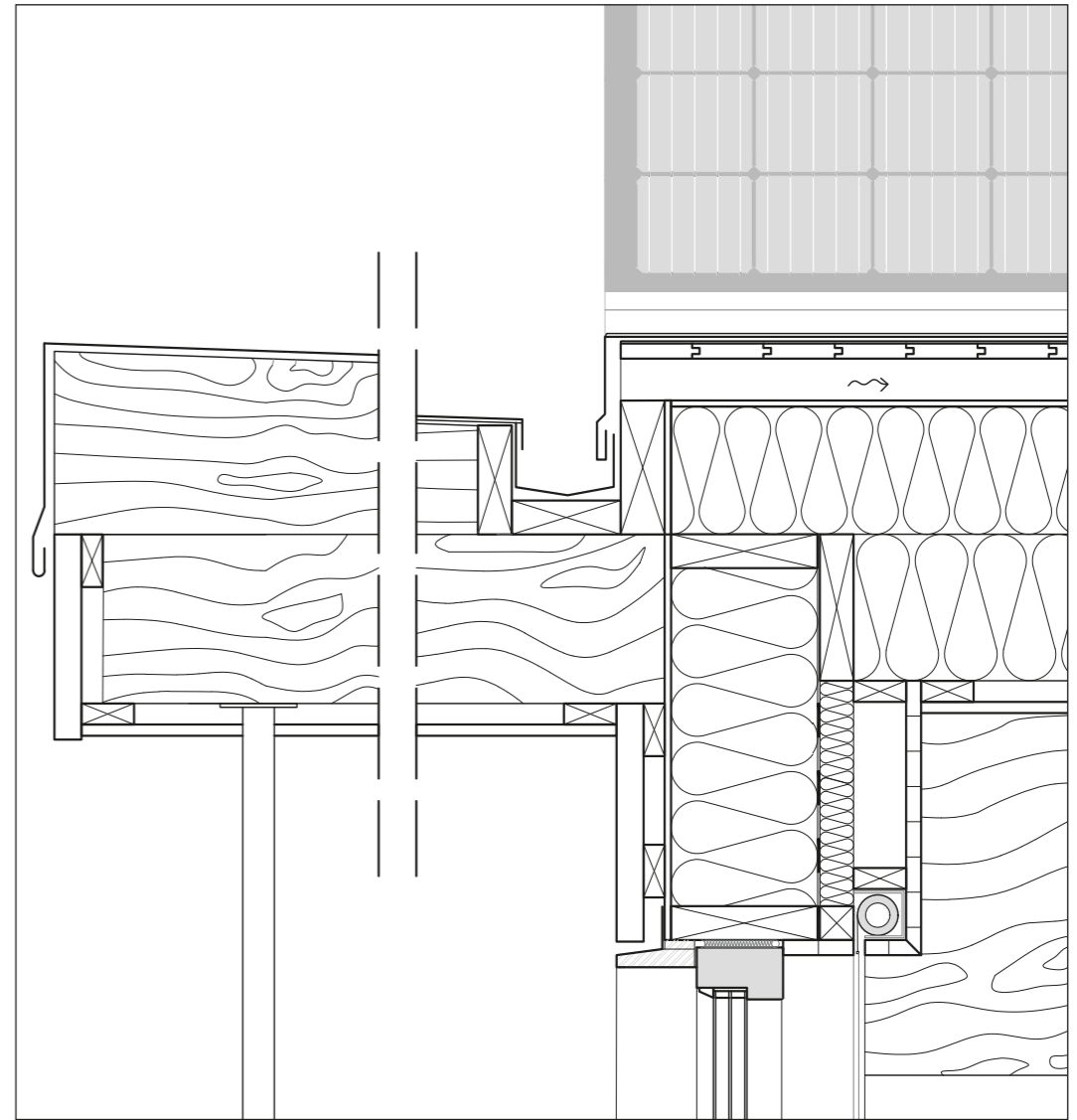
DETAIL 2 1 : 10



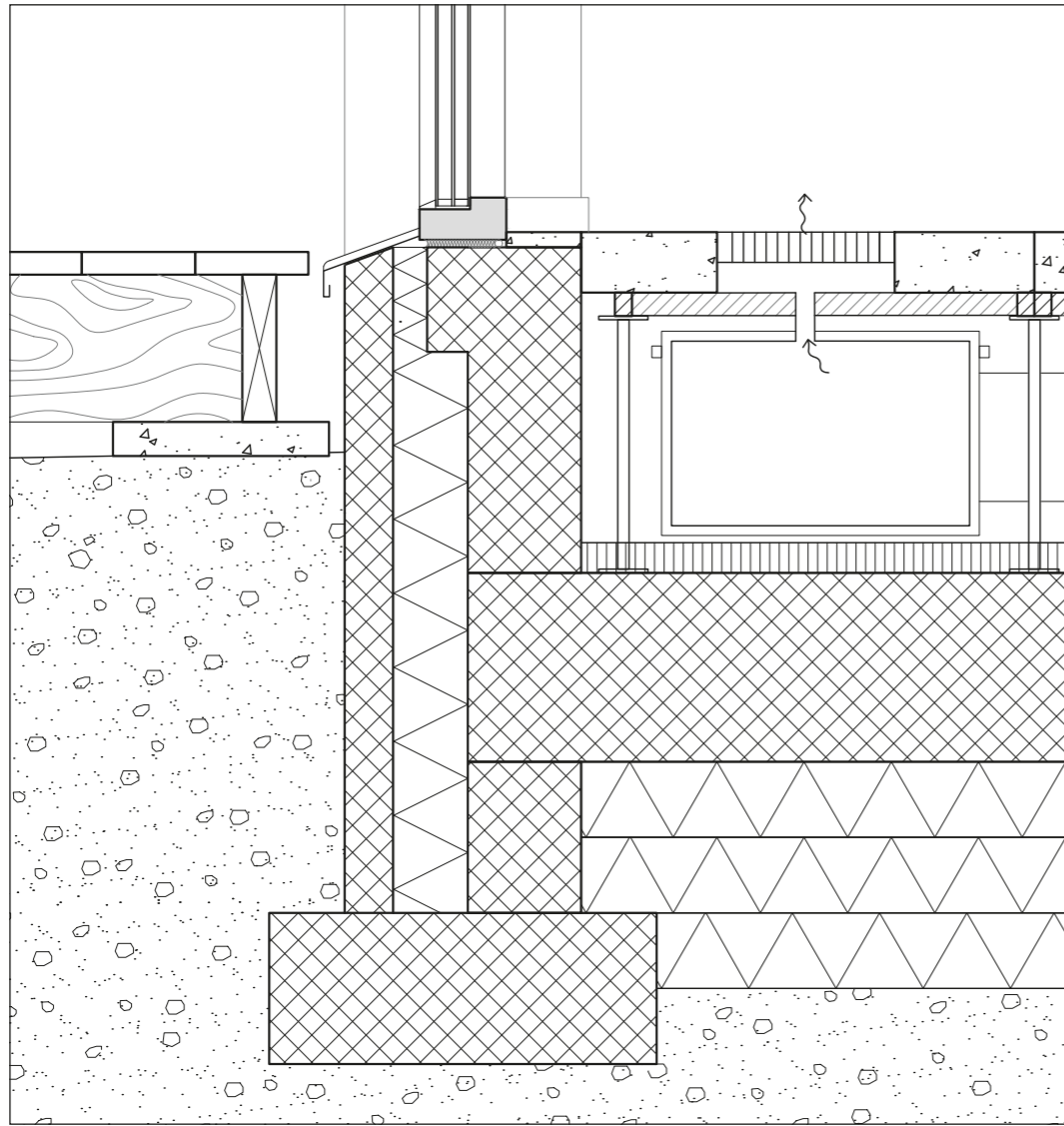
DETAIL 3 1 : 10



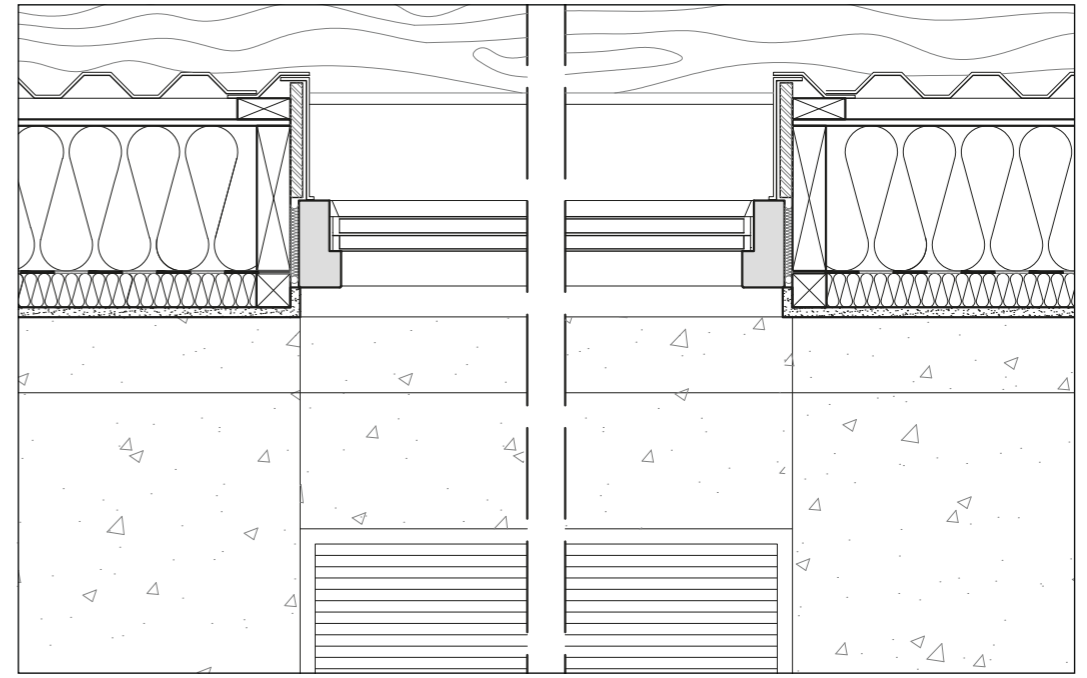
DETAIL 4 1 : 10



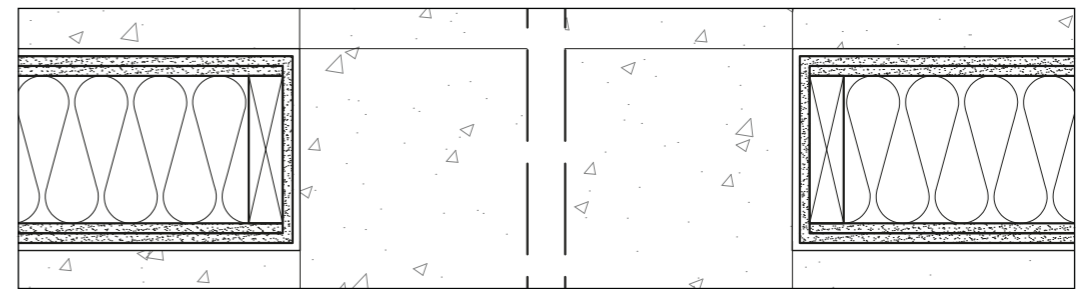
DETAIL 5 1 : 10



DETAIL 6 1 : 10



DETAIL 7 1 : 10



DETAIL 8 1 : 10

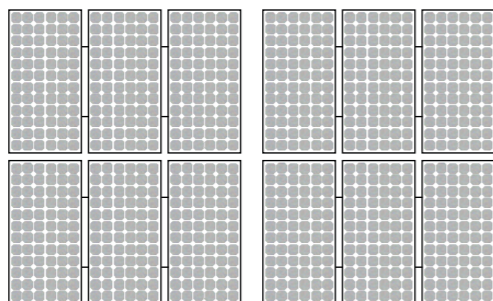
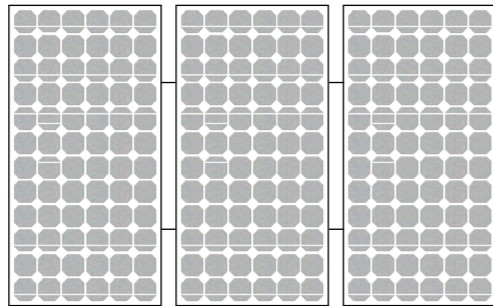
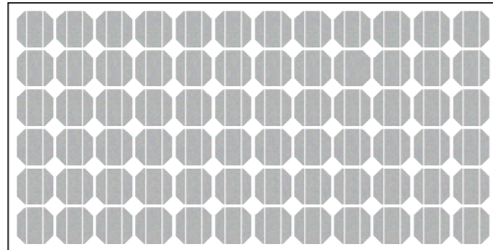
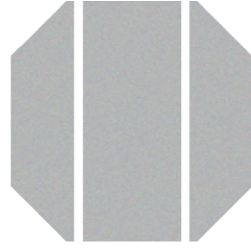


## *Epilogue*

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DISCUSSION

BIBLIOAGRAPHY



## Discussion

This thesis has explored the relationship between technique and architectural design. It has investigated how PV panels can be incorporated into the building, replacing other conventional materials, by using building integrated principles of Photovoltaic.

Addressing the challenges of building integrated photovoltaic requires a multidisciplinary approach, involving collaboration with experts to ensure that both the aesthetic and functional goals are met effectively. During this semester, conversations with stakeholders have therefore been part of the investigation and extra tutorials with a solar energy consultant have helped to anchor this project into reality while maintaining architectural ambitions.

The choice of working with traditional PV panels was made deliberately at the project's outset. This decision was influenced by the prevalence of these panels in the market, which facilitates broader relevance and comparability, and also allowed for the project's scope to be confined to a limited range of PV products. Given the importance of accommodating the constraints of these panels, including size, shape and color, this early decision proved to be crucial for the rest of the project. While its dark, large and rigid nature created some obstacles that needed to be addressed, it also helped to streamline certain decision-making by providing

clear parameters and limitations to the construction.

To apply the theory in a practical example, the exhibition center was selected as a function based on its varying spatial requirements. This was beneficial in the work as it allowed a maintained focus on the experience of the rooms rather than in the program of the building. Implementing the theory in a design project provided a deeper understanding for the subject. Integrating PV panels in a project is highly context oriented, and different obstacles raised as a result of the chosen site.

As a conclusion, when working with PV panels as a part of the architectural design, accepting that some level of compromise is inevitable and leads to more pragmatic solutions for the project. The resulting building aims to find a balance where the PV integration is visually acceptable, even if not entirely seamless, while still providing energy benefits for the users.

In continued work of this project, the wish would be to further investigate how the chosen PV panels and their dimensions can be further implemented in the rest of the building. By working with the dimensions for the facade as a continued grid pattern, and how the window openings could be affected by this as well.

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Yang, R., Campana, P. E., Stridh, B., & Yan, J. (2020). Potential analysis of roof-mounted solar photovoltaics in Sweden.

### PICTURES

All pictures without references are photographed or produced by the authors.

Photo 1: From Curtis, J (1978). Alan Freeman, Inventor of Solar Powered Craft [Online image] Retrieved from <https://www.shutterstock.com/sv/editorial/image-editorial/alan-freeman-inventor-solar-powered-craft-rugby-956485ri> (2024-06-15)

Photo 2: From Tapetum. (2020). First modern photovoltaic cell. [Online image] Retrieved from: <https://tapetum.in/blogs/solar/evolution-of-solar-energy> (2023-10-19).

Photo 3: From Perlin, J. (2013). Charles's Fritts installed the first solar panels on New York rooftop in 1884. [Online image] Retrieved from <https://www.smithsonianmag.com/sponsored/brief-history-solar-panels-180972006/> (2024-07-01)

Photo 4: From Guerra, F. (2018). Swisstech Convention Center [Online image] Retrieved from <https://archello.com/story/48105/attachments/photos-videos/13> (2024-07-01)

Photo 5: Unknown photographer (1910). Udden 1910 [Online image] Retrieved from <http://digitaltmuseum.se/011014487306/vy-hastedalen-92/media?slide=0> (2024-09-05)

Photo 6: Unknown photographer (1910). Hunnebostrand 1910 [Online image] Retrieved from <http://digitaltmuseum.se/011014421383/hunnebostrand-1896/media?slide=0> (2024-09-05)