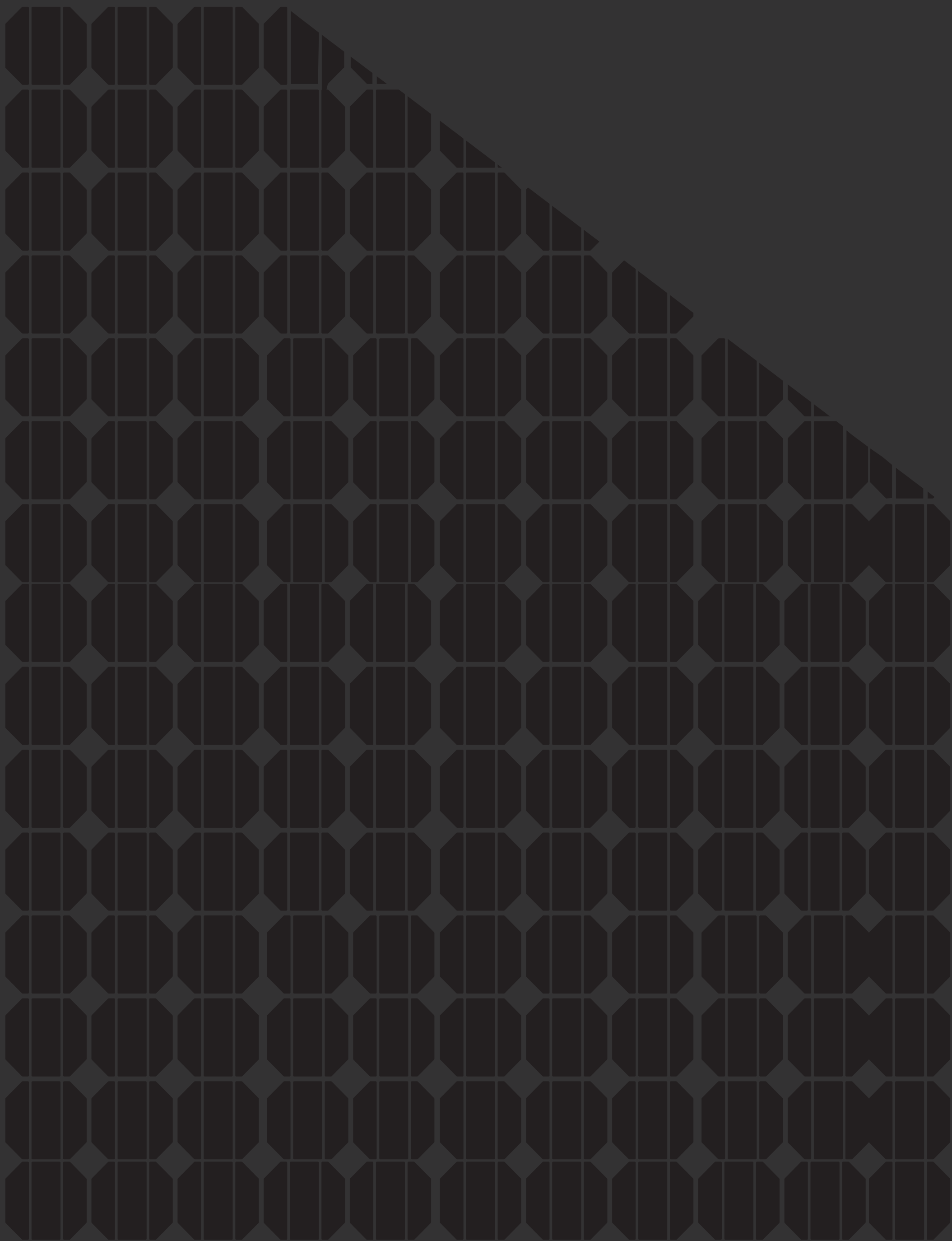

ARCHITECTURE & SOLAR DESIGN

Exhibition centre in the archipelago of Hunnebostrand

Ebba Nordberg

Examiner Björn Gross / Supervisor Mikael Ekegren

Building Design & Transformation

Chalmers School of Architecture

Department of Architecture and Civil Engineering

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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. 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 add to the narrative of solar energy in the world of architecture. It focuses on and explores different ways of how solar power may be integrated into buildings, with the intention to implement the learnings in a project located on the sensitive site of Hunnebostrand. To frame this thesis, we will work with the research questions: "How can architects design with solar panels for it to become an integrated part of the architectural concept of the building?" and "How can this practice be applied on a stone art exhibition center in Hunnebostrand?".

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. This phase is also where theoretical studies regarding the site will take place. The second phase is where we investigate reference projects, both for knowledge of solar panel integration, and inspiration for the architectural concept of the project. The third method is where we translate the knowledge and theory gathered into design.

The findings highlight the importance of involving multiple stakeholders and thorough planning to ensure the integration aligns with both practical demands and creative visions. The approach taken by this project to address the issue provided one method on how to answer the thesis question. However, there are additional methods to successfully integrate the panels into the architectural design.

Keywords: Solar Architecture, Photovoltaic, Building-Integrated Photovoltaic

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Joakim Lundin, for sharing his knowledge regarding the site and its conditions, his helpfulness and assistance with photographs and for providing lodgings during site visits.

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List of abbrevations & Definitions

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

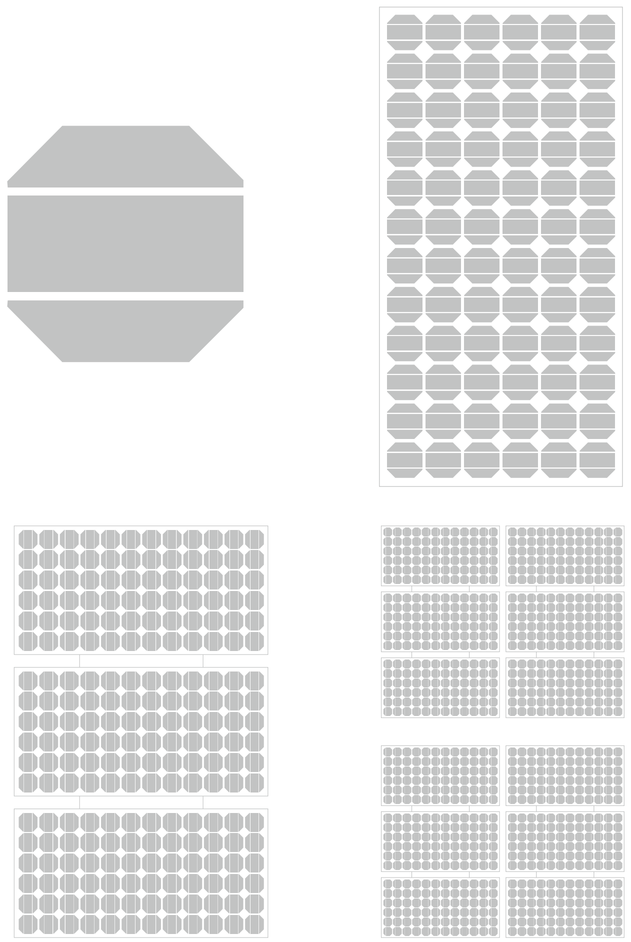


Figure 1. Illustration of a solar cell, module, panel and array

Table of content

Introduction 8

Field of study 10
Major subject 10
Aim and purpose 10
Research questions 10
Academic framework 11
Delimitations 11
Relevance 11
Methods and tools 12
Reading instructions 12

Investigation 14

Theoretic framework 16
The main principles 16
Sun elevation & Solar Azimuth 16
Shading losses 18
Integration of BIPV 18
Design integration 20
Structural integration 20
Lifetime expectancy and maintenance 20
Case studies 22
+Energiehaus Kasel 22
Kunstmuseum Appenzell 24

Project context 26

Site 28
Introduction 28
Sun conditions 31
Dialogue 34

Design proposal 36

Scope 38
Brief 38
Space program 38
Volume treatment 40
Building proposal 41
Direct sun hours on building 55
Photovoltaic integration 56
Structure & Detail 58
Materials 58

Conclusion 70

Discussion 72
Bibliography 73

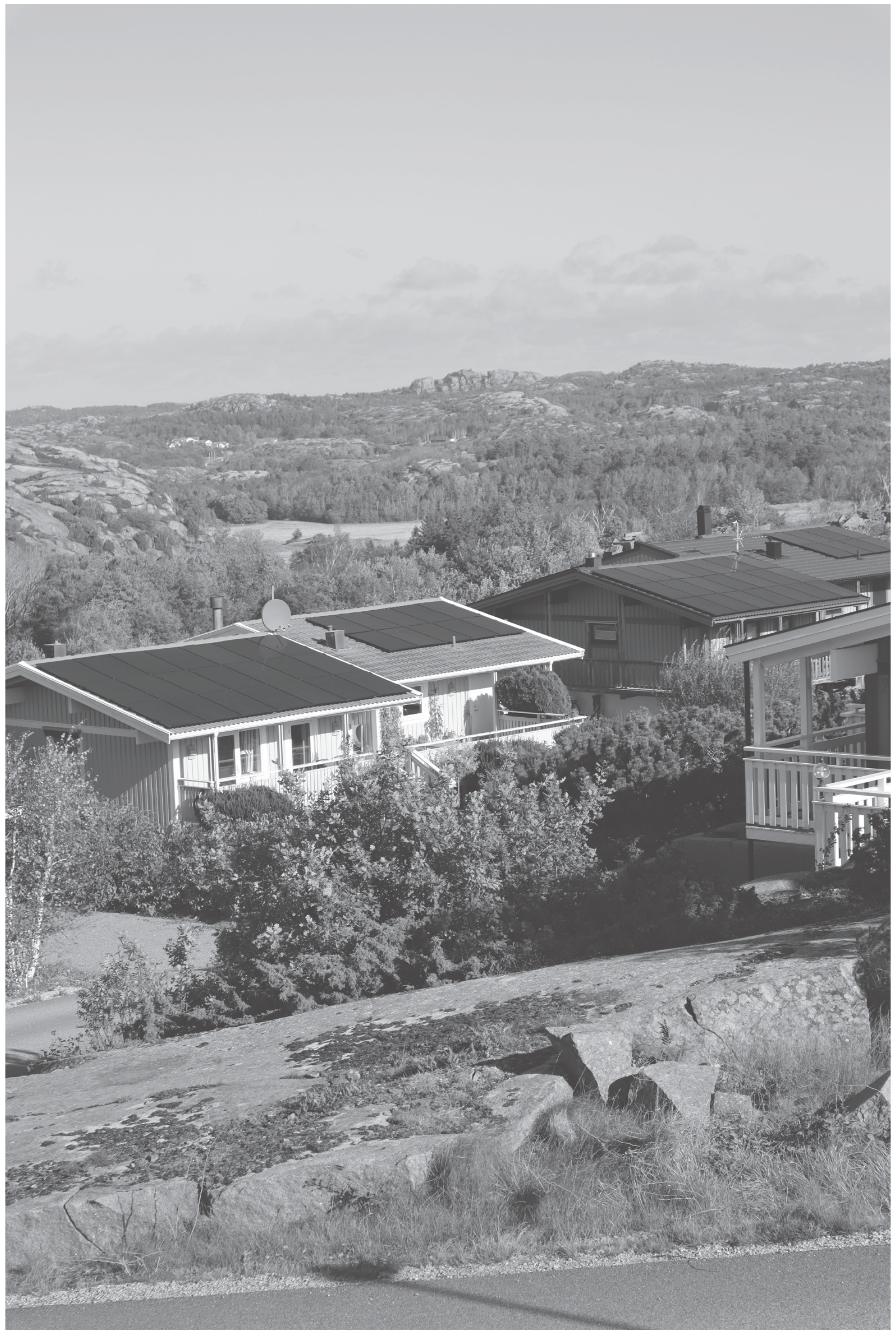


Photo 1. Solarpanels added on numerous building in Hunnebostrand

Introduction

Field of study
Research questions
Academic framework

Photo 2. Solarpanels on existing roof in Ulebergshamn

FIELD OF STUDY

Major Subject

What do you think of when thinking about solar energy? Is it large 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 worlds 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. One could argue that even though the solar panel has increased in efficiency since then, the appearance is relatively the same. At least while looking at the current standard solutions (Aubel, 2022).

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 limitation 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 contribute to a new narrative of solar energy in the world of architecture. It focuses on and explores different ways of how solar power may appear and can be integrated into buildings, not only as effective energy-producers but also for aesthetics attributes. The aim is then to implement the learnings in a project located on the sensitive site of Hunnebostrand, with the presumption that if PV can be implemented well on a site like this, it can be implemented anywhere.

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

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 on a cultural and historic location and will end up in one proposal of how to do so, by following guidelines and to some extent wishes and visions from the municipality and the people living there. 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 Counsil 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 Counsil, 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 / PHASE 1

To start this thesis of, 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, pointing us in the right direction. 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 during different seasons. Site analysis, mapping of material and texture, sun studies, photography and so on has been key strategies to understand the conditions of the site.

RESEARCH ON DESIGN / PHASE 2

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 emphases buildings with architectural ingredients that can be translated to this project.

RESEARCH BY DESIGN / PHASE 3

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

Reading instructions

This thesis consists of five segments, Introduction, Investigation, Project context, Design proposal and Conclusion. The first segment provides background information on the subject and outlines the purpose of the thesis. The investigation section includes both theoretical studies and case studies on built references. The next chapter analyses the site and its context and together with the investigation section the findings will be tested in the design proposal segment. The outcome will then be further discussed in the concluding chapter.

Photo 3. Solarpanels on existing roof in Ulebergshamn

Investigation

Theoretic framework
Casestudies

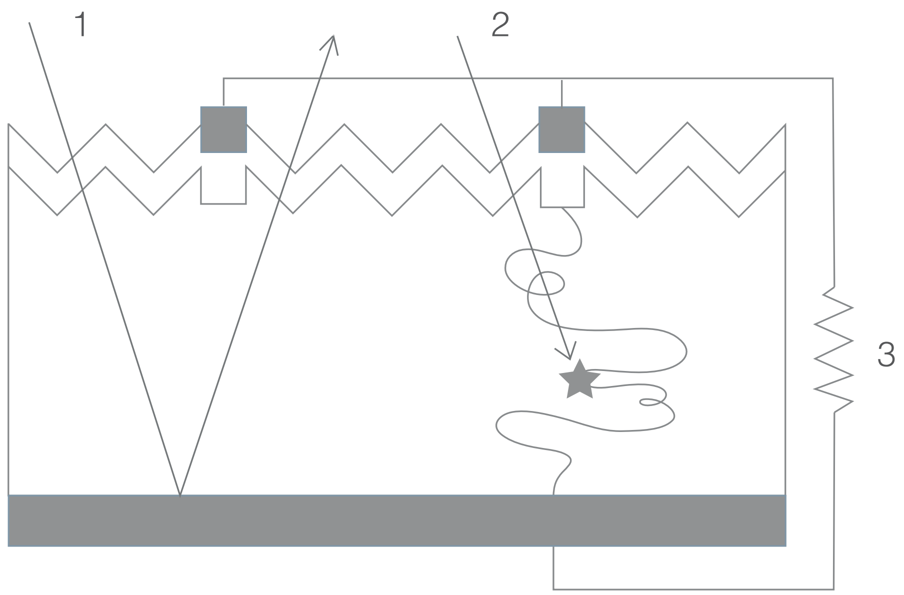


Figure 2. Principle of how a solar cell works

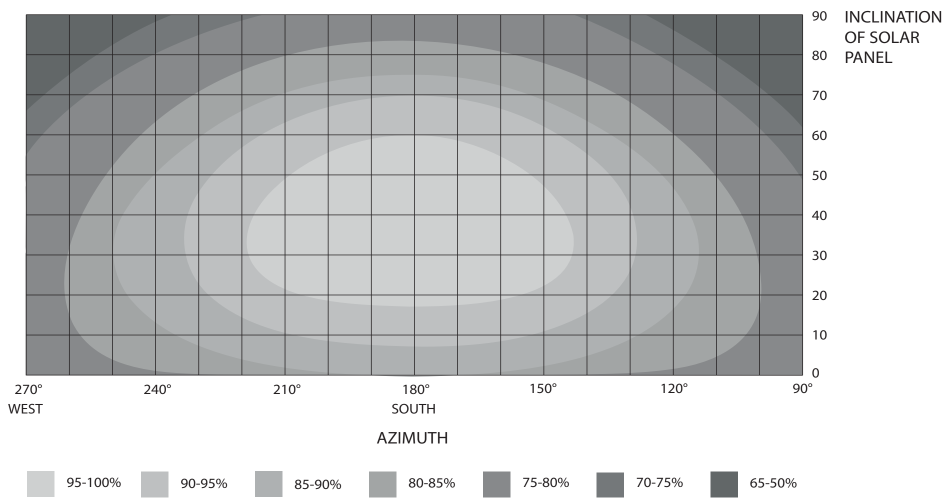


Figure 3. Change in performance due to panel orientation and inclination

THEORETIC FRAMEWORK

The main principles

Sunlight is made up of electromagnetic radiation across a wide spectrum of wavelengths. 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 (figure 1):

1. Solar radiation, or 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 (Van Aubel, 2022).

Sun elevation & Solar azimuth

To integrate 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. For example, the amount of sunlight able to reach a solar cell can generate 25 times more energy on a clear day in summer than during a cloudy winter day (Krippner, 2017).

To optimize 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 best results are generated when solar panels have 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 affected. It is possible to install solar 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, u.d.).

To install photovoltaic on elements of the building with different orientation, may result in a more cost and energetically effective building. Instead of focusing on a partial approach aimed at pre-selecting the most favorable surfaces, an analysis of the energy self- generation and of the building energy management system is essential to make the most of the solar potential (Solarchitecture, u.d.). For example, mornings and evenings are times when most electricity is consumed in residential buildings, which means that in this context, one gets better output from their solar panel system with installing east- and west-facing panels (Solexperter, u.d.).

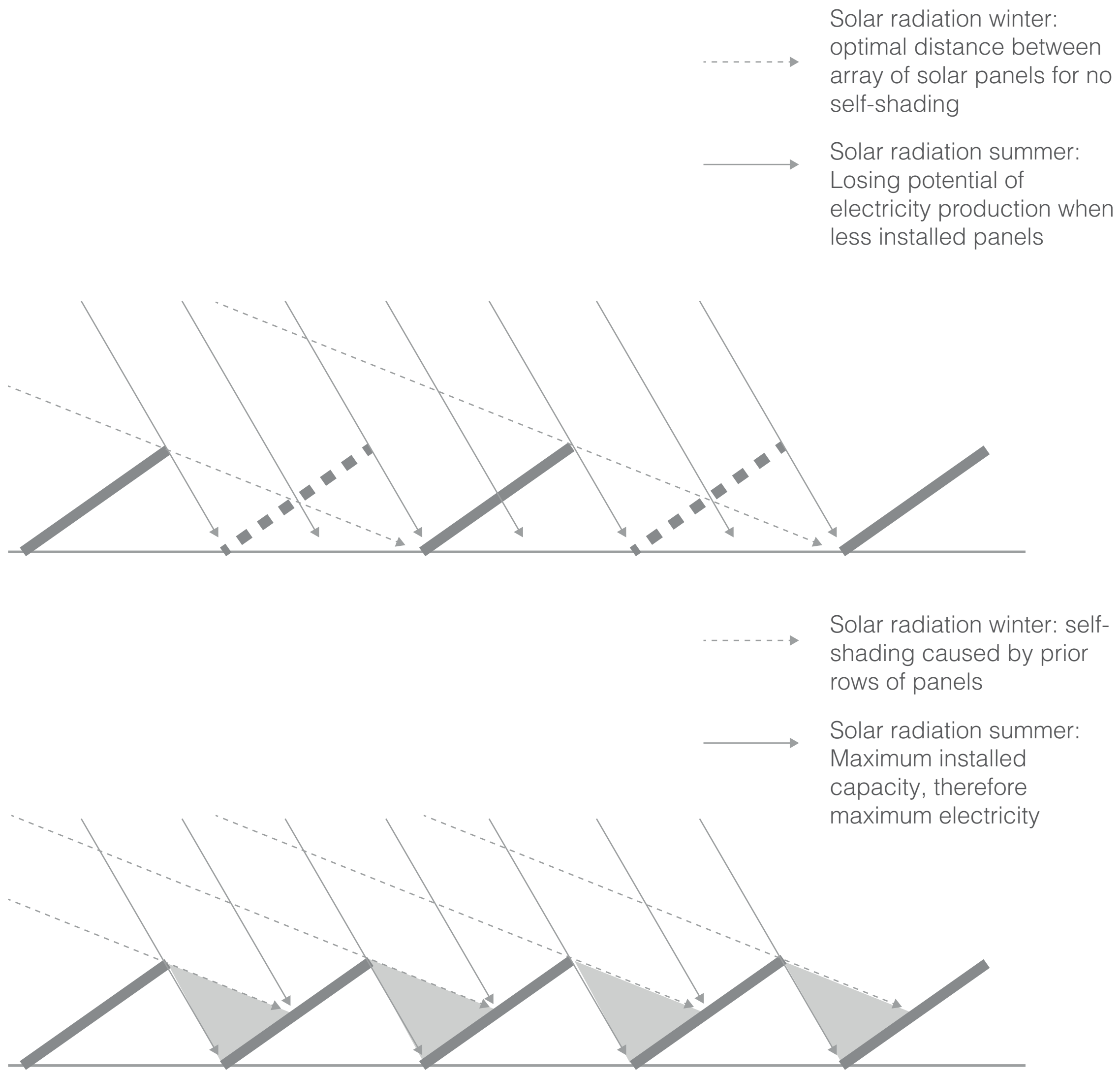


Figure 4. Different distance between rows of solar panels and the self-shading effects during winter and summer

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 typography 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 angel of the solar PV system so that it is functional for both summer- and wintertime (Krippner, 2017).

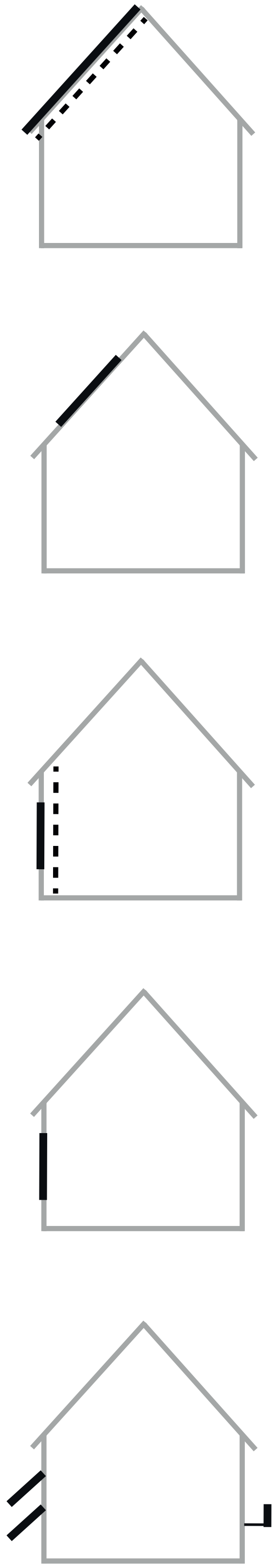
For PV modules that are installed towards the south, an effect of self-shading occurs due to prior rows of modules. This applies to all rows except for the first one. To minimize the shade that is caused, the modules are placed further away from one another. However, during summertime, the sun is higher in the sky and therefor 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. Continuous roofing, discontinuous roofing

B. Atrium/Skylight

C. Rainscreen facade, masonry wall

D. Double skin facade, curtain wall, window

E. Balcony balustrade, shutters etc.

Figure 5. Different application categories

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). When the intention is to install photovoltaic systems over an entire surface, the standard modules might not have the suited measurements.

You can manufacture solar panels with different shapes and measurements than the standard module or you can work with dummy modules that does not produce energy. The dummy module can complement the PV system in terms of aesthetic attributes (Krippner, 2017). However, solar panels that are not standard modules needs their own connection when installed due to the amount of voltage produced, and are often more expensive. (Solpaneler och batterilager, n.d.).

Structural integration

According to a report from the International Energy Agency (IEA, 2021) there are five different application categories when it comes to mounting building integrated photovoltaics.
A. Sloping, roof-integrated, not accessible from within the building
The modules are installed between a tilt angle of 0° and 75° from the horizontal plane.
B. Sloping, roof-integrated, accessible from within the building
The modules are installed between a tilt angle of 0° and 75° from the horizontal plane.
C. Non-sloping, envelope-integrated, not accessible from within the building
The modules are installed between a tilt angle of 75° and 90° from the horizontal plane.
D. Non-sloping, envelope-integrated, accessible from within the building
The modules are installed between a tilt angle of 75° and 90° from the horizontal plane.
E. Externally integrated, accessible or not accessible from within the building
The modules are installed on an external integrated device.

Lifetime expectancy & Maintenance

The average guarantee period for a standard PV: s electrical performance is around 20-30 years. In reality, they can last between 25 to 40 years. Optimally, the BIPV systems should function both as a building component and an electricity generator throughout the lifetime of the building.
Building integrated photovoltaics needs continuous maintenance. The needs differ depending on the climate on site and it can involve cleaning the panels from dirt, snow or ice, or repairing or replacing one or more panels etc. The maintenance should be considered by the planners in terms of accessibility to the system and such during the design phase (Boddaert et. al, 2019).

CASE STUDIES

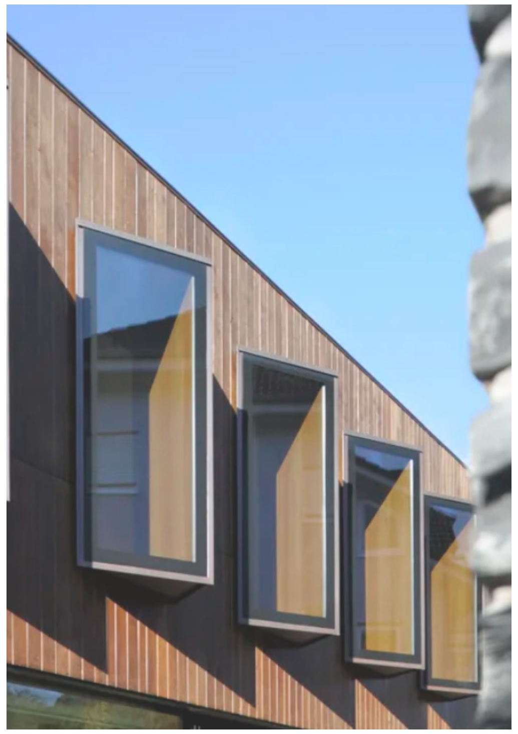


Photo 4-6. + Enegiehaus Kasel

Note. From L. Blatzek, W. Becker. *+Energiehaus*

+ Energiehaus Kasel

Architect: Stein Hemmes Wirtz

Kasel, Germany

+Energiehaus was constructed in 2009 and is a two-story office building that accommodates the bureau responsible for its design. The house is planned so it can be transferred into a residential home if it is needed. The structure consists of a solid wood construction on a concrete floor slab, with the wooden elements visible in the interior design. The entire building has a 30-40 cm thick layer of insulation and is thermal-bridge free. Additionally, the house has a heat recovery ventilation system. The materials used on the facades are sourced regionally, integrating the building with its surroundings. The entire part of the roof that faces south has integrated solar panels while the north-facing roof has elements of copper.

The interior is defined by its wood and slate materials, as well as the open floor plan that connects the two floors in the open entrance area. The wood windows on the ground floor are large, triple glazed with a design that makes them seem almost frameless, connecting the inside spaces with the outside. (Archdaily, 2013).

This building is beautifully composed with high-tech sustainable components and great architecture and is therefore valuable for the investigation in this thesis. The integration of the solar panels is particularly interesting because they are not only added to the roof structure but are incorporated into the roof, being the top layer mounted above the water bearing layer. To enhance the integration of PV even more a void is created where the panels are. This results in an understated roof appearance that seamlessly connects to the rest of the building. The approach of creating a void is advantageous for future modifications, particularly if there are changes in the dimensions of the standard modules.

Photo 7. Kunstmuseum Appenzell
Note. From S. Bagutti *Kunstmuseum Appenzell*

Kunstmuseum Appenzell

Architect: Gigon Guyer Architects

Appenzell, Schweiz

The Appenzell Kunstmuseum was built in 1998 and is dedicated to the local artist Carl August Liner and his son Carl Walter Liner. The rooms are not, however, designed to exhibit specific paintings by the two artists but rather are dimensioned to house various presentations of the two but also showcase exhibitions of contemporary art.

The rooms are more general than specific and are relatively small. They have a low level of detail, bright walls and concrete floors. The light comes from windows set in in the gabled roof. They are designed not to exaggerate or compete with the art.

The Appenzell Kunstmuseum is a valuable source of inspiration for how the architects have created an interesting sequence of rooms that have the optimal attributes for showcasing different exhibitions. With its carefully placed windows, two on the facades for offering view over the landscape and contributes to orientation within the building, and the rest set overhead in the gabled roof facing north, giving the exhibition an equal set of lightning throughout the day without exposing the art to harmful sunlight. The exhibition rooms with their design and level of detail is enhancing the display in a way that is innovative and aesthetically inspirational.

Photo 8. Kunstmuseum Appenzell
Note. From S. Bagutti *Kunstmuseum Appenzell*

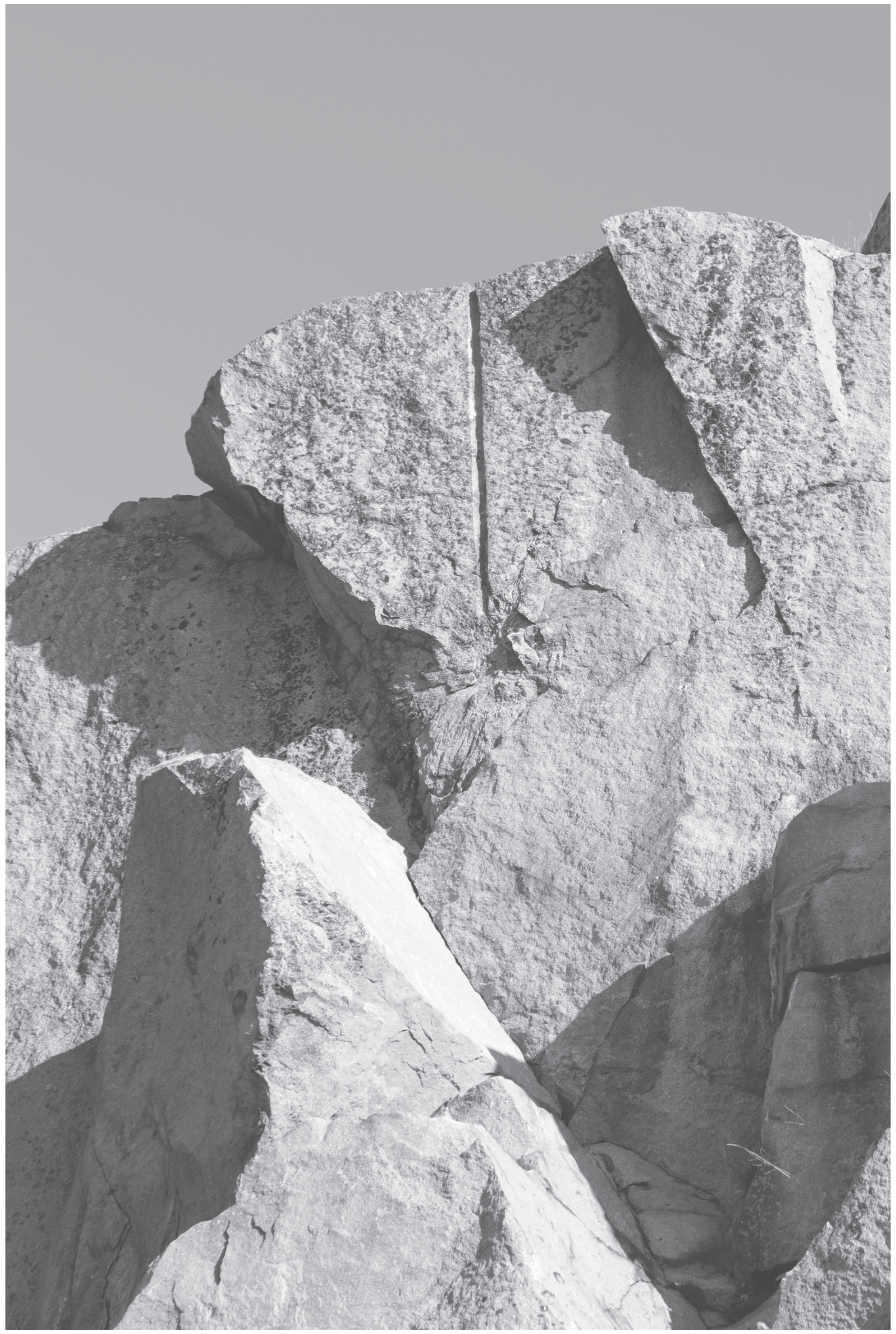


Photo 9. Cliffs at the site

Project context

Site
Dialogue

Photo 10. Buildings in Hunnebostrand

SITE

Introduction

In Bohuslän county on the west coast, 2,5 hours from Oslo and 1,5 hours from Göteborg, lies Hunnebostrand. It is a small village with a low number of inhabitants. During summers that number increases significantly. There are restaurants and shops and most of them are only open during summertime when the village has a lot of tourists. The main tourist attraction is the landscape with its unique archipelago, creating the most outstanding sunsets.

During the late 1800 and early 1900, Hunnebostrand grew from being a small fishing village to become an important stone industry village. There were different companies on different locations all around the town, with workers coming from all over the country. This era has shaped Hunnebostrand to what it is today and there are a lot of traces to be found from this time. (Lindberg, 2011)

One of them is a place called Udden, located between Nordre Hogeberg and the ocean. Udden was used as a shipping dock for the stone industry, and in 1920 the stone masonry also initiated on Nordre Hogeberg. It kept going there for almost 50 years and since then, Udden has been relatively untouched. (Lindberg, 2011)

The area today is well visited both by tourist and people living close for different reasons. It holds a popular walkway between Hunnebostrand and Ulebergshamn, it has a place for people who wants to go swimming and it has lots of area for outdoor activities. It also has the most amazing views out towards the horizon, making it a great place for recreation.

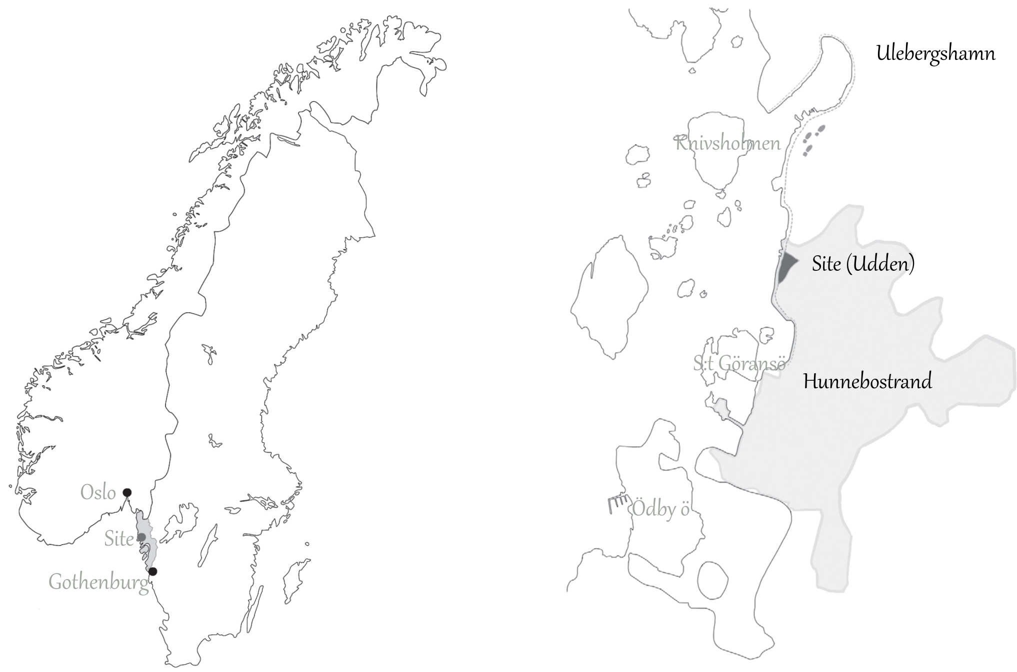
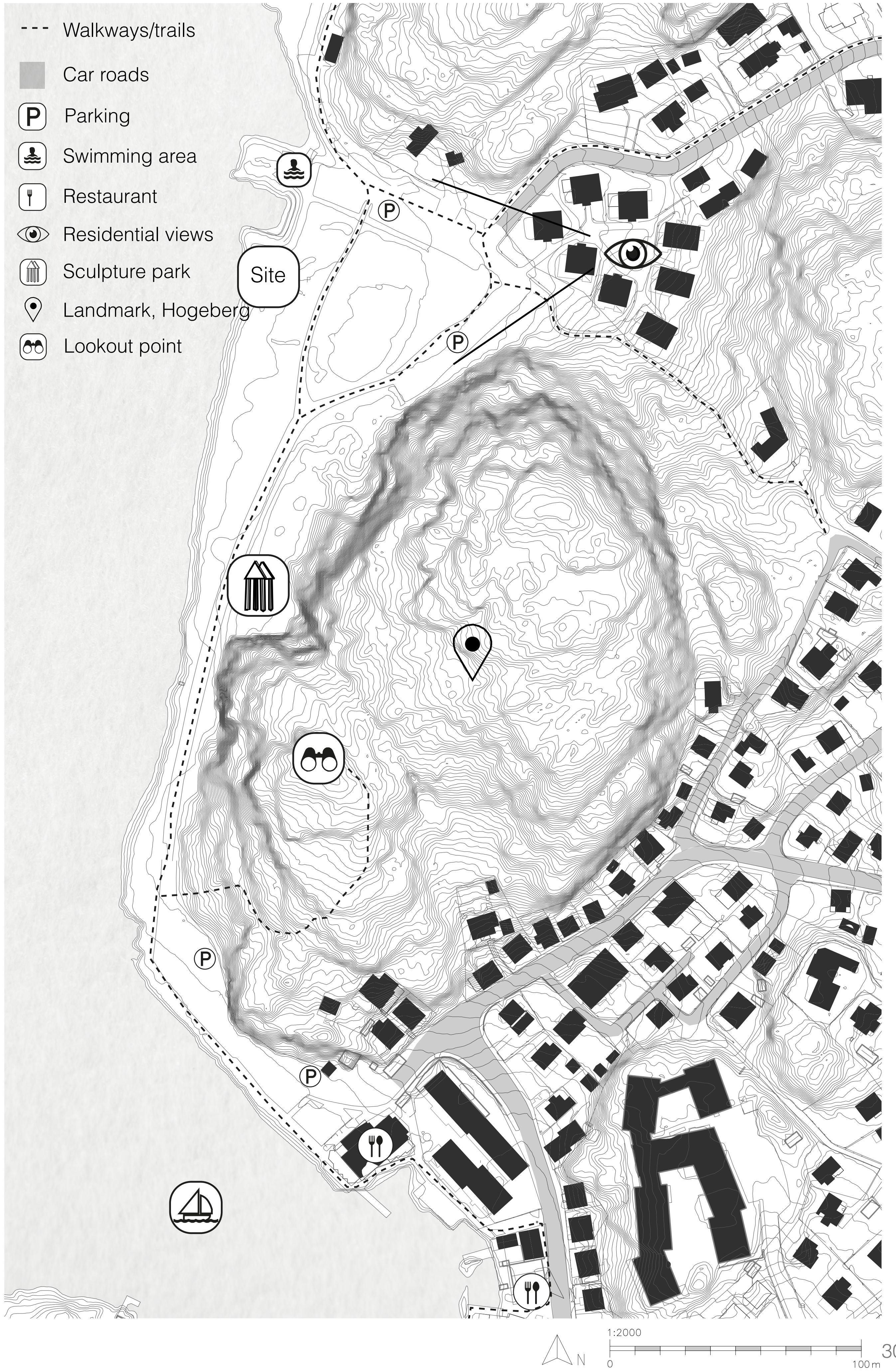


Figure 6. Geografic location of the project

Photo 11-12. Pictuers of Udden



Sun conditions

Nordic climate conditions pose certain challenges when designing a building with integrated photovoltaic systems. Due to the sun's position in the sky, objects on the ground cast significant shadows, particularly during winter when the sun is at its lowest point. The figures below illustrate how the area's sunlight conditions are greatly affected by shadows from the mountain to the south. Therefore, positioning the building to the northwest, as far away from the mountain as possible, would provide the best opportunities for the PV system to receive sunlight and generate energy. The building is therefore placed along the coastline with parts of it built over the water to create even more distance towards the mountain. Additionally, the placement fulfills the ambition of maintaining the area for activities, adding events to the coastal walk and retains most of the views for the residents in the area.

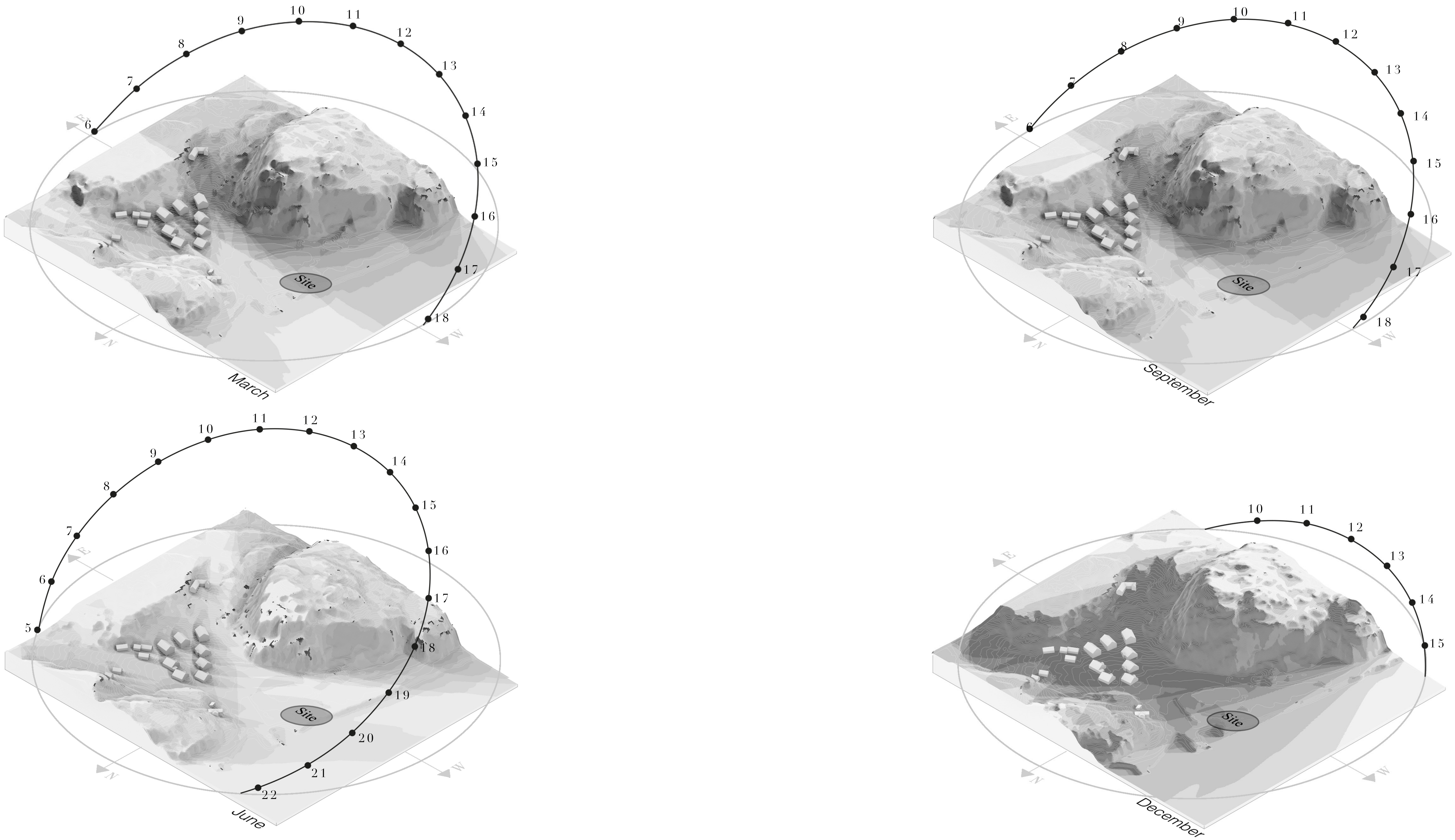


Figure 7. Direct sun hours at Udden



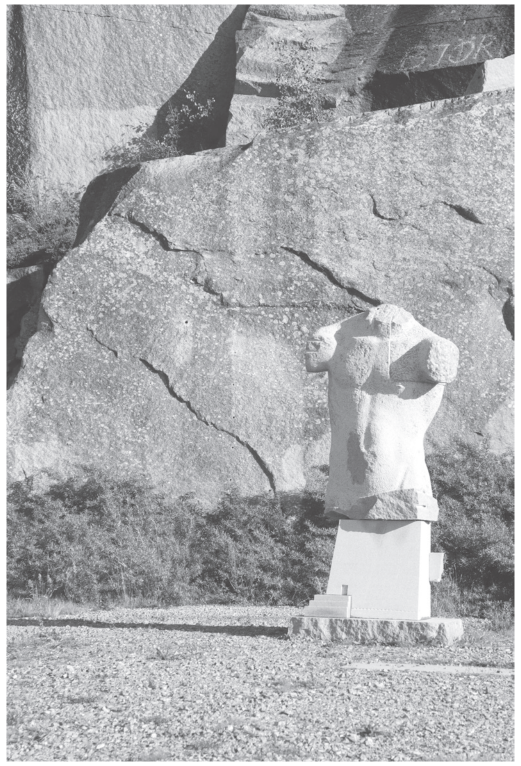
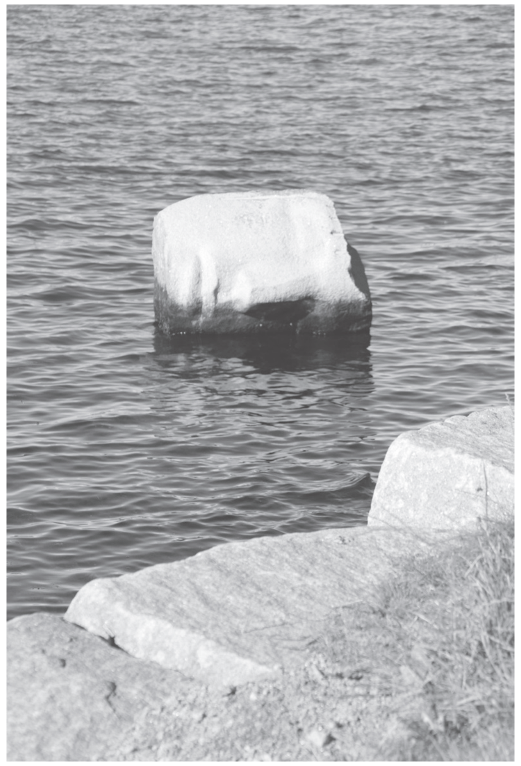



Photo 13-16. Various stone sculptures on site

DIALOGUE

In 2010 there were plans on building residentials on Udden. However, due to public opinion, the project was cancelled. A lot of people questioned the decision to build upon land that has such a great value for the tourism because of its untouched nature and access to the coastline. From this opinion grew a group of people who continued to discuss and develop ideas for the future usage of Udden.

In 2011 they completed a pilot study with the aim of developing an idea for continued discussion of establishing a park with sculptures and a connecting center for stone art. The group wanted to showcase a proposal that would be sustainable regarding the recreational aspect in terms of exploitation on the site.
In collaboration with Bohusläns stone scholarship the group hosted an exhibition with stone sculptures on Udden in 2011. They wanted to investigate the public interest of Udden and see if a new program of the site would be accepted. A survey was handed out during the exhibition, and it got a rate of 8,6 out of 10. Other reactions were gratitude for the site not being a new home for residentials and generally positive feedback. Further on they held working seminars with different stakeholders, investigated the possibilities for Udden, did research on different reference projects and asked Gert Wingårdh for a vision. They end the pilot study by saying that they hand over the study to the municipality and the public to discuss and react upon (Lindberg, 2011).

The exhibition is still running today (2023) and in 2017 a new project regarding Udden started called Udden Skulpturcenter. It was an initiative from the group Udden Skulptur and Kulturhuset Hav och Land. A new steering committee was formed with different members. There were representatives from Hav och Land, the municipality of Sotenäs (both politicians and officials) and private stakeholders. They also had a project manager and an artistic director on a consultant contract (Stenens Hus, 2023).

The steering committee hired the architect Todd Saunders to create a concept with sketches to use as a material for discussion. The result was presented in 2018 on different locations, one of them at Udden. The discussion has engaged a lot of people and citizens were invited to participate in public meetings regarding Saunders concept. The conclusion of the concept study is that there is a public support regarding a Stenens Hus on Udden however, there is a difference in opinions regarding the execution and location of the building.

” Udden shall develop in to a first class destination with international status, where culture and tourism cooperates, where history and the future meets, where the unique value of the place enhances the experience of the granites significance and greatness in the landscape. We see before us an architectonic creation where all the elements can be accommodated. Stenen hus shall mediate a strong belief for the future, where the tale of the village history can be told”
- Steering committee

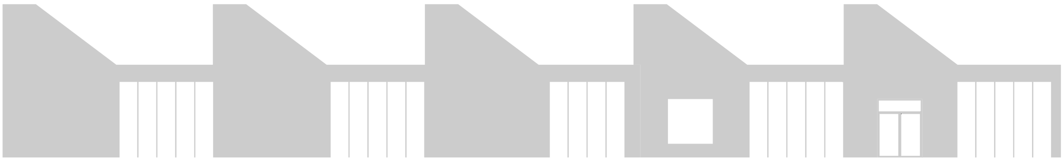


Figure 8. Illustrative building facade

Design proposal

Scope
Volume treatment
Building proposal
Structure & Detail

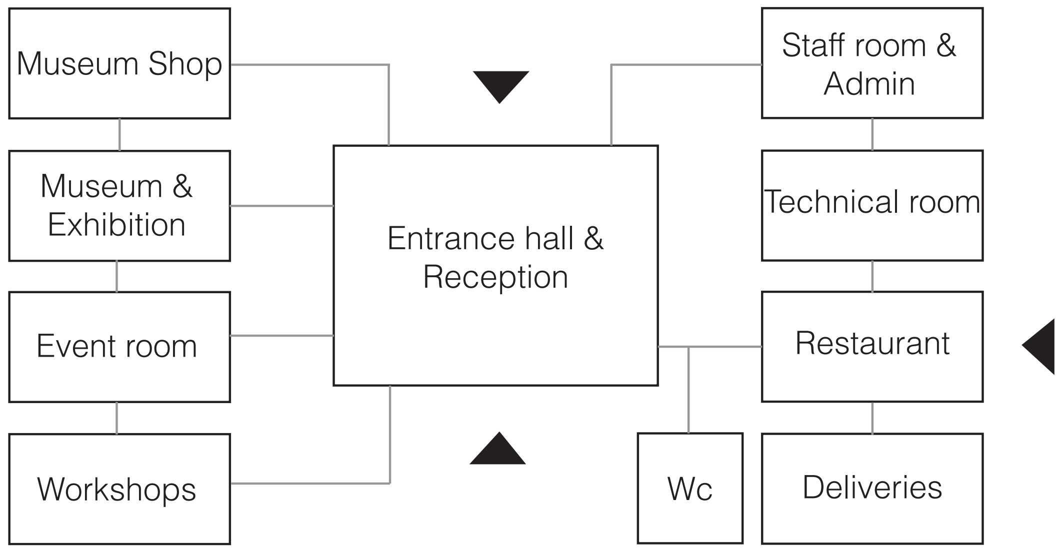


Figure 9. Connections within the building

SCOPE

Brief

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 have been made to fit our interpretation of the task.

The building can be seen as a destination or be experienced by people who are walking by, therefore it was an important decision to have two main entrances leading into the entrance hall which serves as the heart of the building.
From the entrance hall, guests can easily navigate further to the exhibition area or to the restaurant. The exhibition area consists of a sequence of rooms offering various display options for the art and sculptures. It is designed with a straightforward flow that guides guests seamlessly through the exhibition, allowing them to interact with the stone and art display.
Adjacent to this space, the event room functions as an additional area for the exhibition and museum when required. Otherwise, this space can serve as a community locale.

The south wing of the building houses the restaurant and the admin areas. The admin areas are facing the east while the bigger restaurant space is facing the west, and together with its outdoor dining offers the guest the views out towards the ocean.

Space program

PUBLIC FUNCTIONS	
Entrance Cloakroom Reception Shop	303 sqm
Restaurant	190 sqm
Event room	109 sqm
Work shops	(25 x 2) 50 sqm
Museum / Exhibition	340 sqm

SUPPORTING FUNCTIONS	
Staff room	40 sqm
Restrooms	23 sqm
Changing rooms	23 sqm
Technical room	30 sqm
Kitchen	63 sqm
Storage	25 sqm
Goods delivery	13 sqm
Waste	13 sqm

TOTAL 1277 sqm

Figure 10. Reception

VOLUME TREATMENT

The buildings' volume, placement and orientation are a result of the conditions from the site, the theoretical framework and inspired by the reference projects.

Udden gives several opportunities in terms of interesting building locations. The specific project site was chosen in consideration of the shading from Höge berg and the already existing program of the location.

The building's footprint is designed to create protected outdoor spaces that enhance the exhibition and program within the building. It is also shaped to either invite passersby's into the foyer or let them experience parts of the exhibit while outside, creating a curiosity for the inside.

The volumes segmented roof is designed to minimize self-shading as it is strategically a placeholder for the integrated photovoltaic panels. The volume also creates interesting sequences of rooms within, and together with window openings offers various of possibilities for the exhibition.

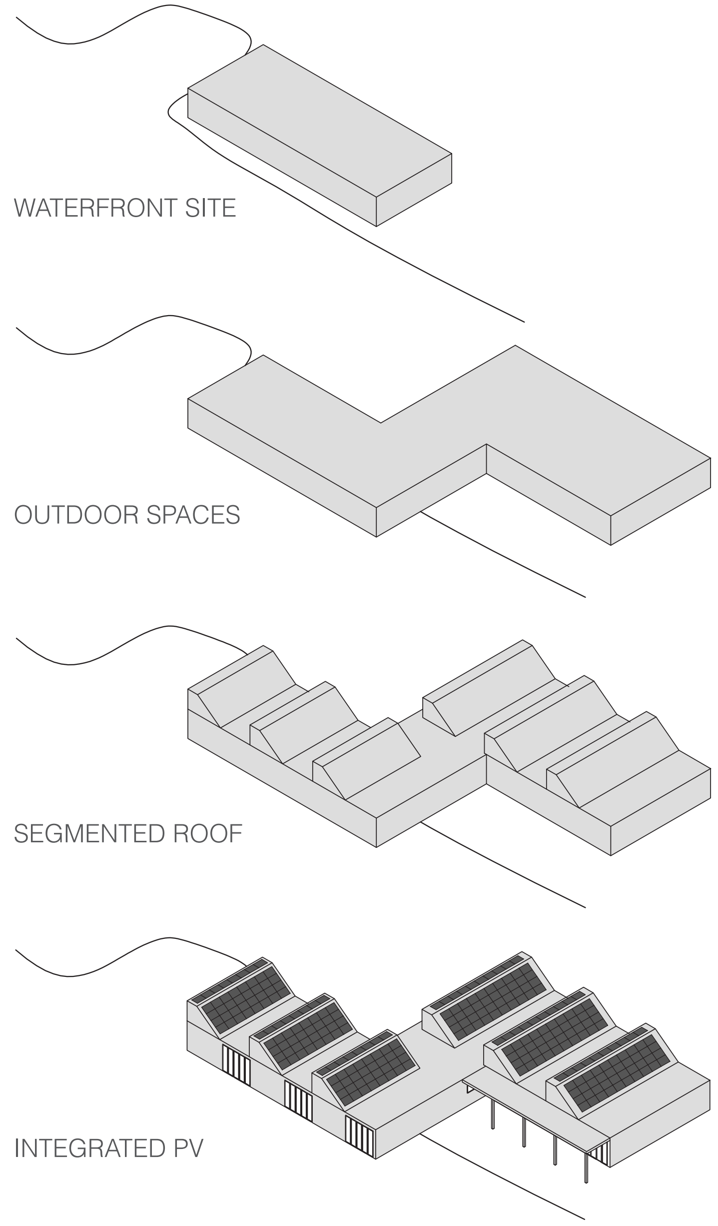
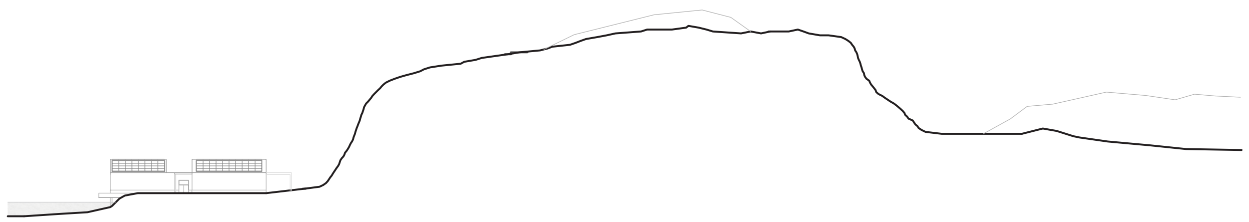
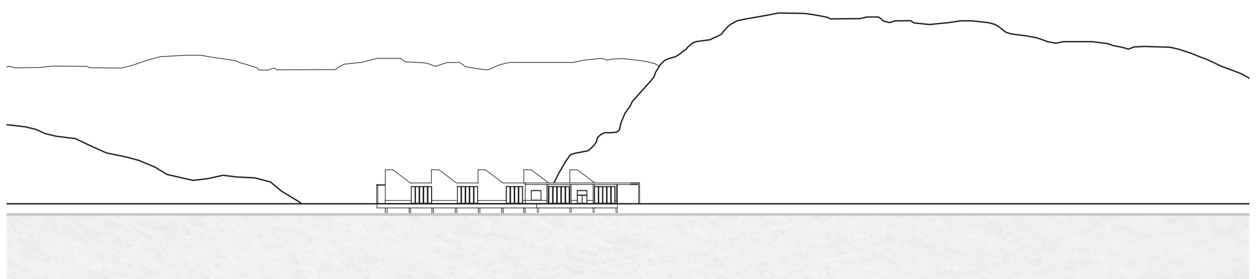


Figure 11. Design strategies

BUILDING PROPOSAL



LANDSCAPE SECTION 1:2000



WEST LANDSCAPE ELEVATION 1:2000

SITE PLAN 1:2000

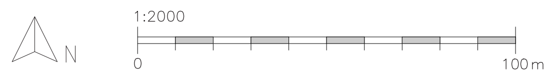
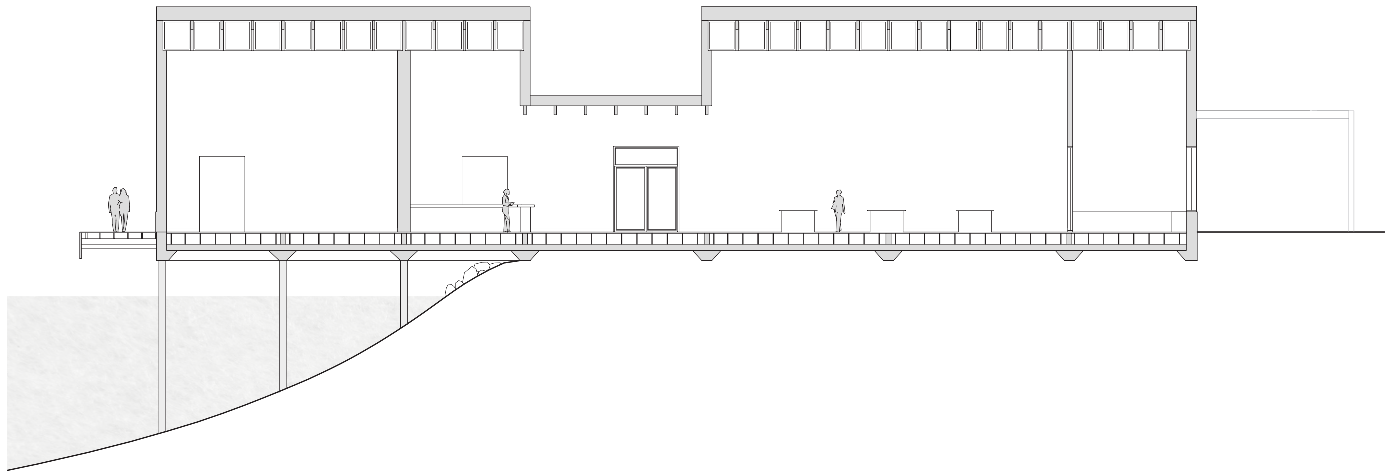
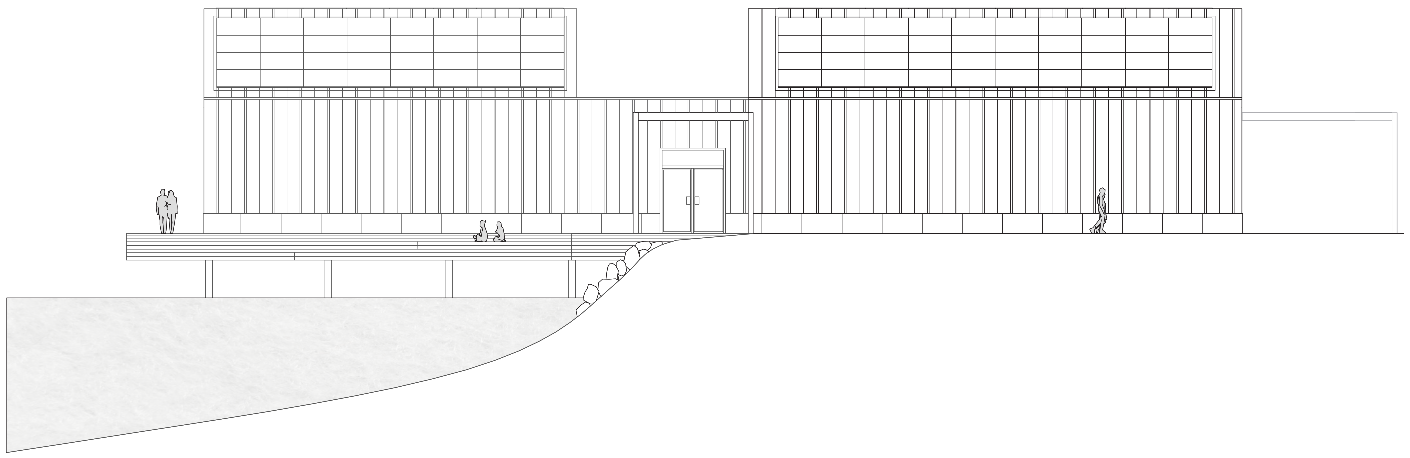


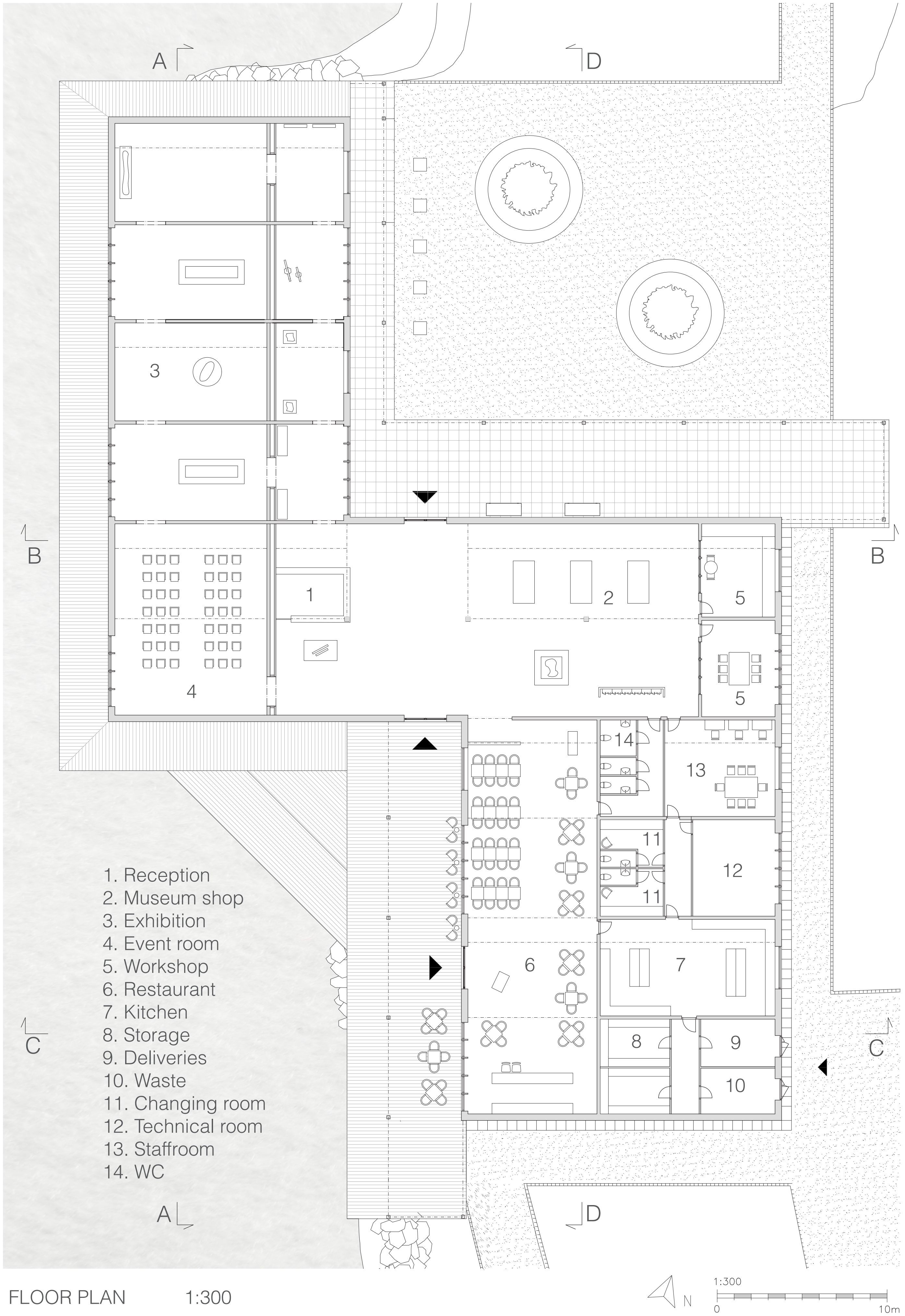
Figure 12. North entrance



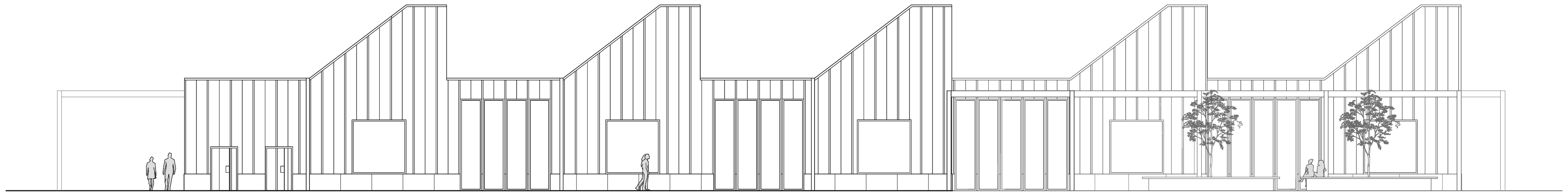
SECTION B-B 1:300



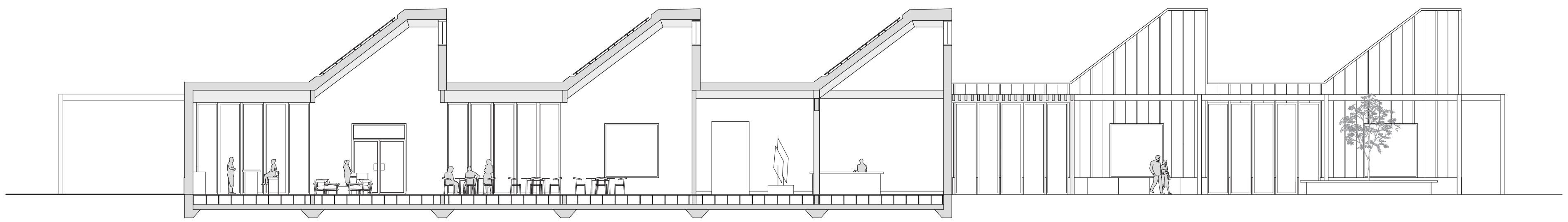
SOUTH FACADE 1:300



FLOOR PLAN 1:300



EAST FACADE 1:300



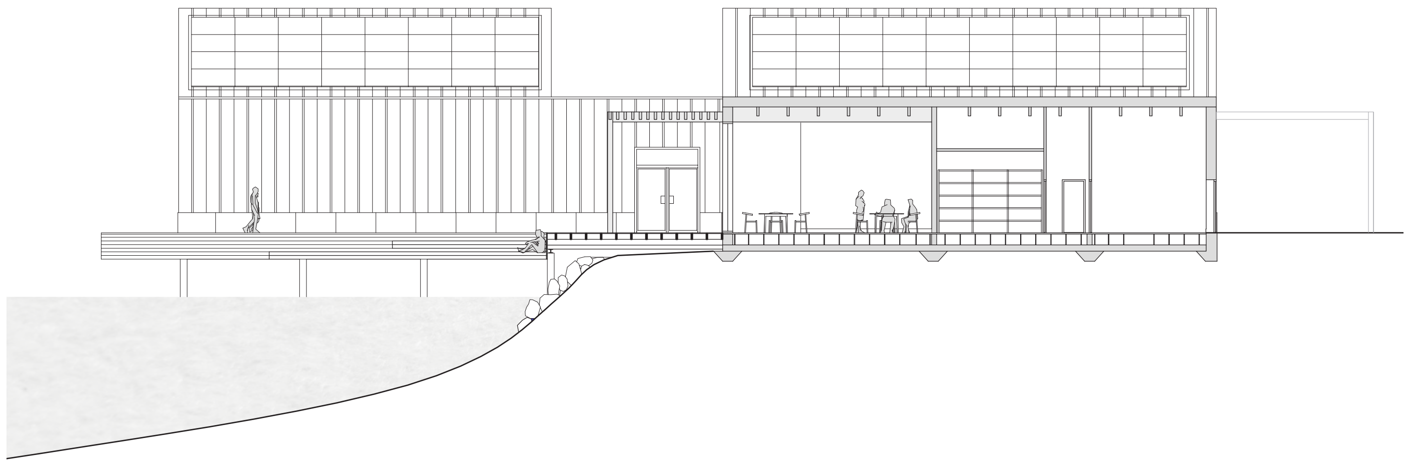
SECTION D-D 1:300

1:300

0 10m

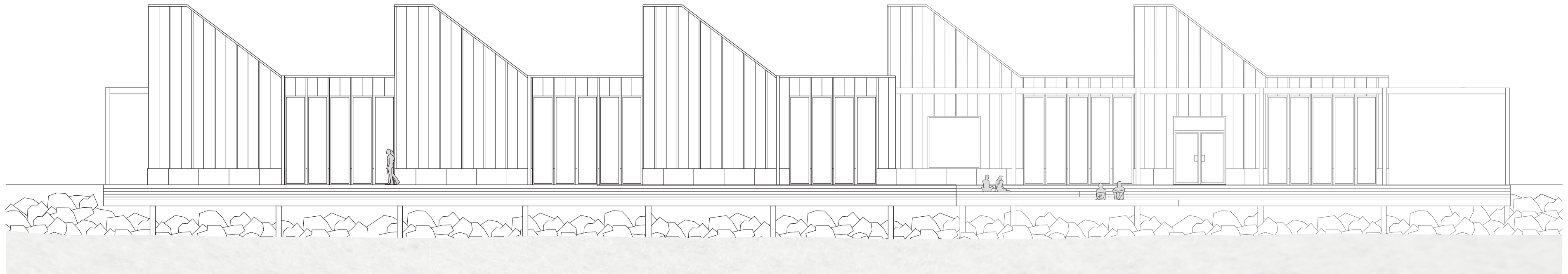
Figure 13. Restaurant

NORTH FACADE 1:300

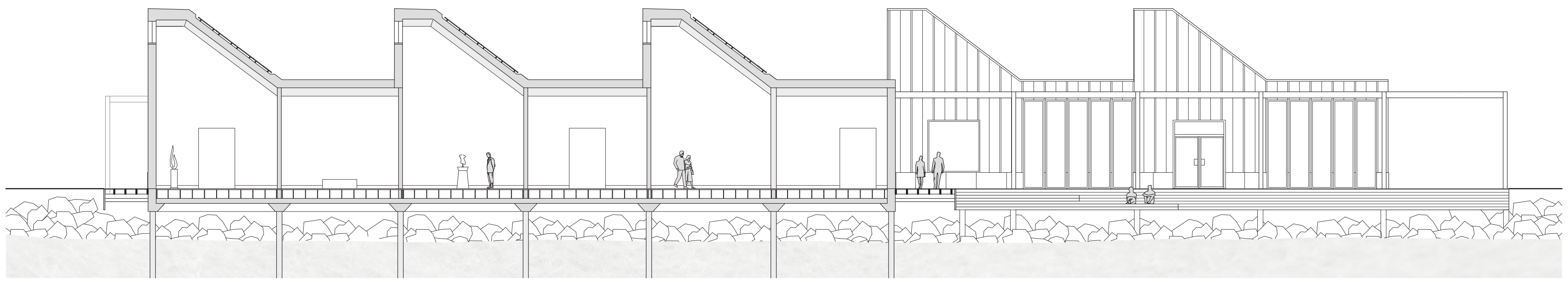


SECTION C-C 1:300

1:300
0 10m



WEST FACADE 1:300



SECTION A-A 1:300

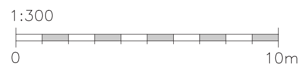


Figure 14. View from water

Direct sun hours on building

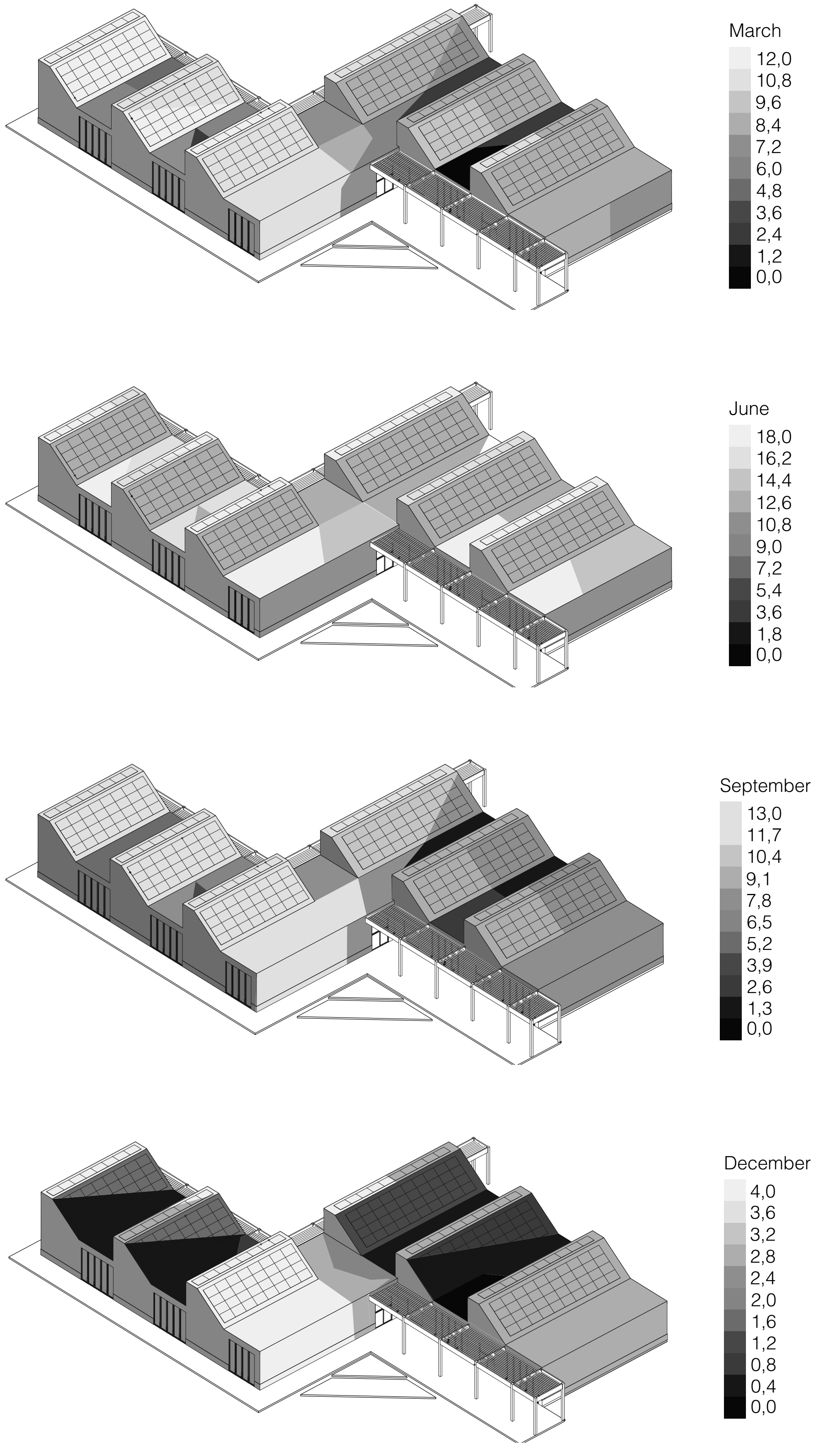


Figure 15. Amaount of direct sunlight hours recieved by different parts of the building in a day

Photovoltaic integration

The volume of the building is determined by the site's programmatic requirements, as well as its capacity to integrate solar panels. For optimal performance, the panels require a 40% inclination and a south-facing surface, and the intention was to design this building with as many surfaces with those requirements as possible. However, since the usage of the building is from morning to evening, with more energy requirements in the evening, the building is tilted slightly so that the panels catch rays a little longer in the afternoon, generating energy to the restaurant.

The decision to incorporate solar panels exclusively on the roof rather than the facade was driven by mostly practical considerations. Since the building's entire shape is a result of sun studies, the absolute best surfaces for panels were created as the roof, reducing the need for panels on the facade. Also, due to the fact that panels may vary in sizes in the future, designing a facade based on the current standard modules could be an obstacle when they need to be replaced. Furthermore, this design ensures easy access to all panels for maintenance and minimizes the risk of public sabotage.

270 pieces of monocrystalline solar panels with one of the standard measurements 1724x 1134 mm are incorporated into this building. All panels are installed horizontally to reduce the impact of self-shading as partial shading can significantly affect the energy yield for the entire system. The components are integrated into the roof, not merely attached, but rather recessed into a lower section which can be seen in the details further on. This creates a more subtle roof appearance and a seamless and more aesthetically pleasing integration of the photovoltaics. Furthermore, since the lowered sections are designed to be slightly bigger than the PV systems, this accommodates the possible size alterations of the panels in the future.

Figure 16. View from the exhibition area

STRUCTURE & DETAIL

Composition

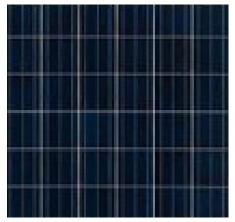
The structure is supported by partly a solid concrete foundation and partly with concrete reinforced steel pillars where the volume extends over the water. The floor consists of 600x600mm granite tiles that are elevated from the foundation on a steel support system. This approach makes it possible for various installations in the building to be installed beneath the tiles. The building stands with a post and beam construction which enables large, unobstructed spaces within its design. Most of the roofs gluelam beams and some of the pillars are exposed, which gives an honest expression of the structure and a sturdy appearance. Also, it highlights the significance of the shape of the roof. All the wood is darkly pigmented and in contrast, the walls are cladded with white plaster to be flexible for various exhibition materials.

The facade is clad in sheet metal with vertical rims to give the building a more vertical appearance. The pattern of the rims is created by the placement of windows. Each window has two rims directly connected to its side and then one that breaks in the middle. This pattern then repeats itself across the building. To ensure the durability of the sheet metal and prevent damage, a granite stone is securely affixed as a base for the facade. To enhance the entrances and to protect some of the windows from the sun, a wooden pergola is constructed on both sides of the building. The pergola's color resembles the interior wood pigmentation.

Materials

Sheet metal

Dark pigmented wood

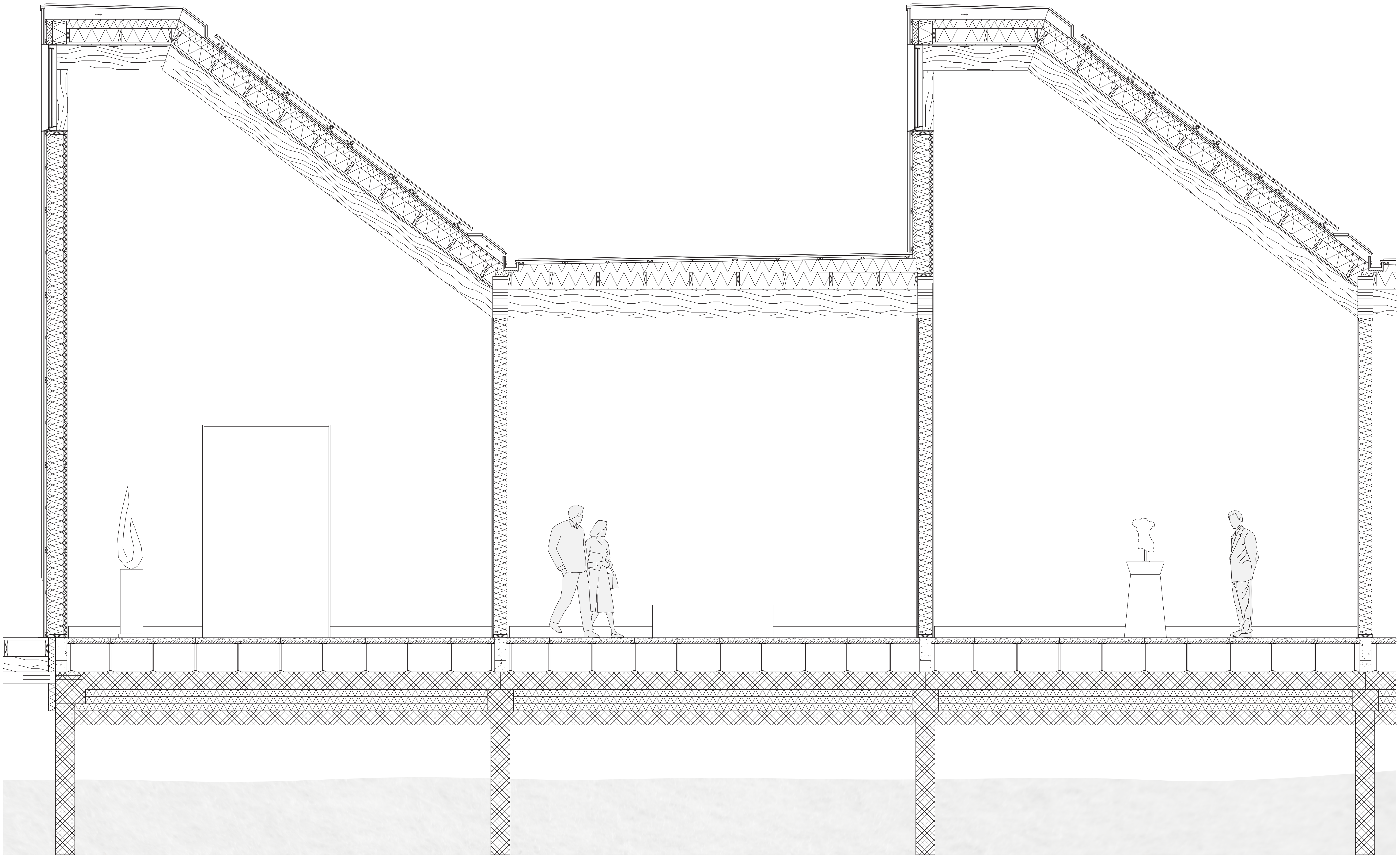


Solar panel

Gypsum board

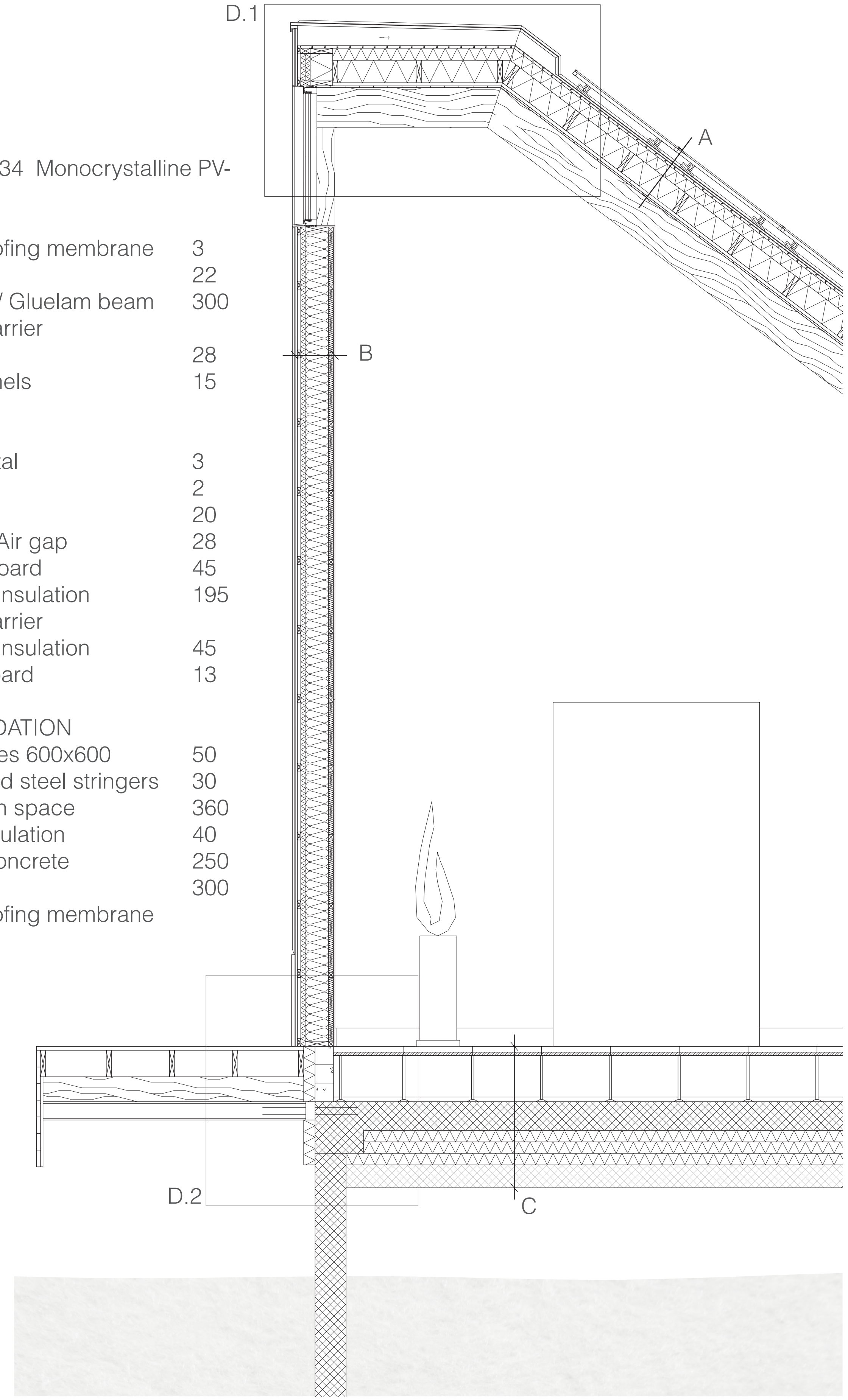
Dark pigmented wood panels

Granite stone tiles



CONSTRUCTION SECTION 1:50

FACADE ELEVATION A 1:50

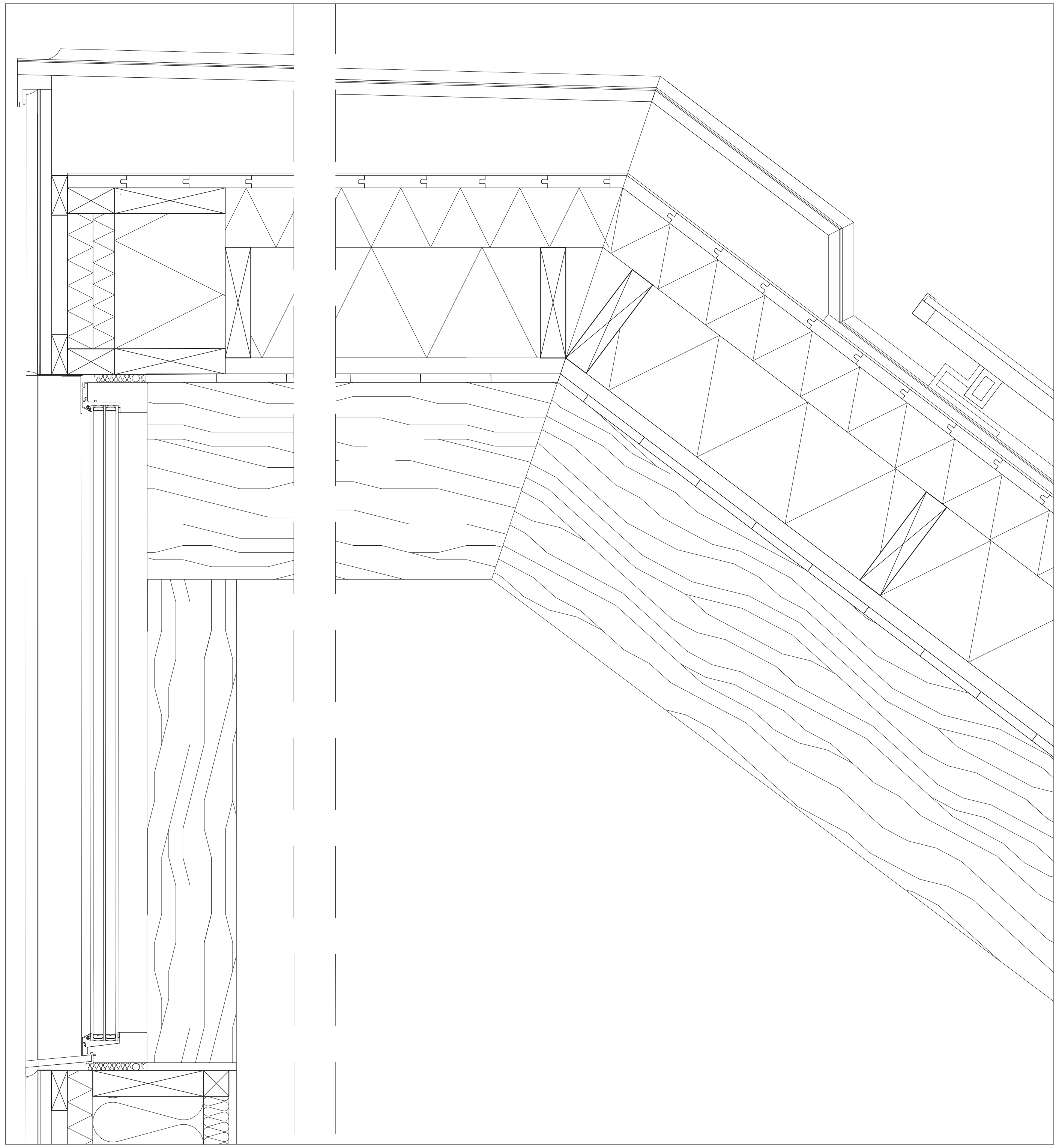


A. ROOF
1722 x 1134 Monocrystalline PV-modules
Air gap
Waterproofing membrane 3
Formwork 22
Insulation/ Gluelam beam 300
Vapour barrier
Battens 28
Wood panels 15

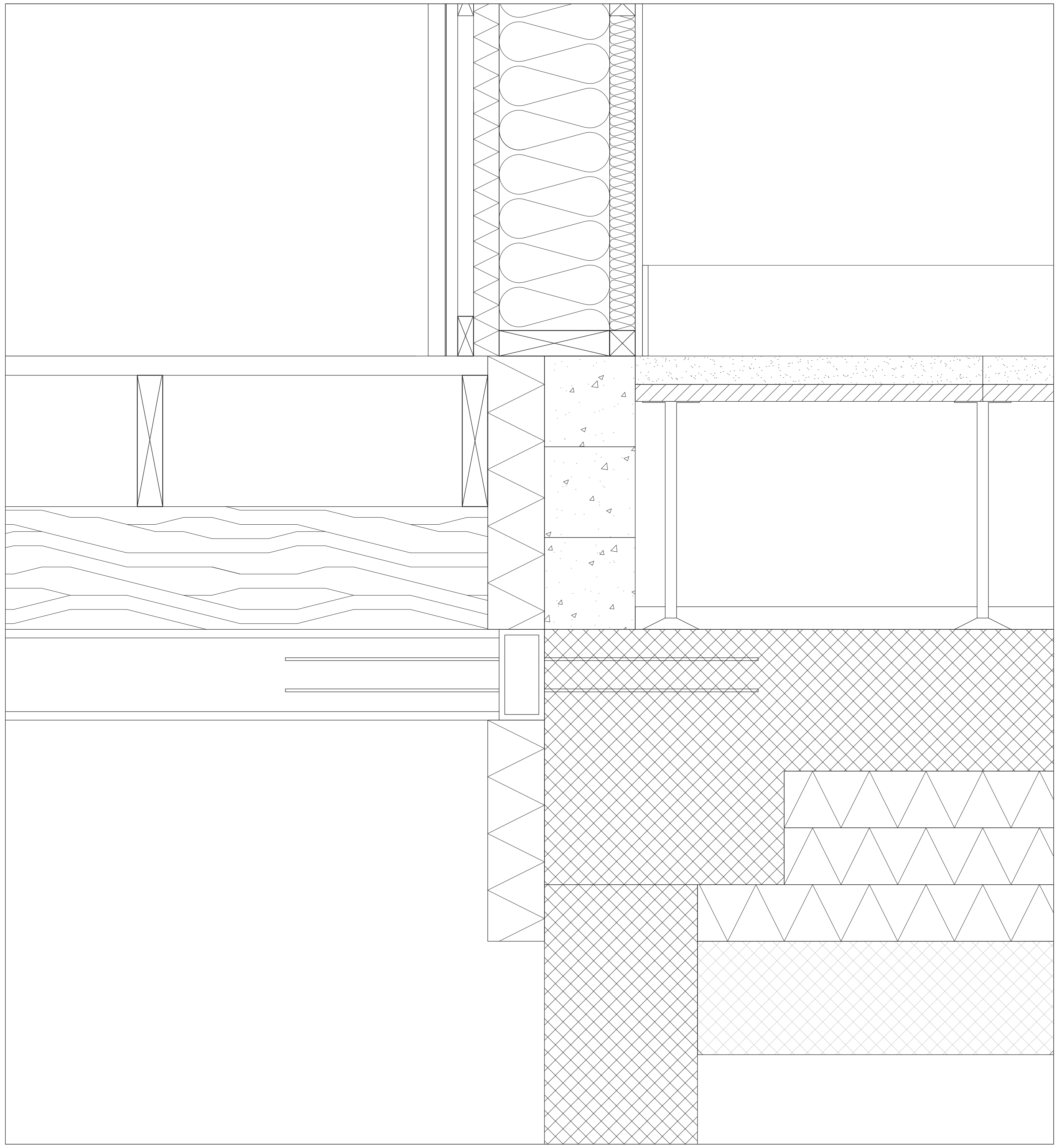
B. WALL
Sheet metal 3
Tar paper 2
Plywood 20
Battens / Air gap 28
Weatherboard 45
Battens / Insulation 195
Vapour barrier
Battens / Insulation 45
Plaster board 13

C. FOUNDATION
Granite tiles 600x600 50
Galvanized steel stringers 30
Installation space 360
Sound insulation 40
Precast concrete 250
Insulation 300
Waterproofing membrane

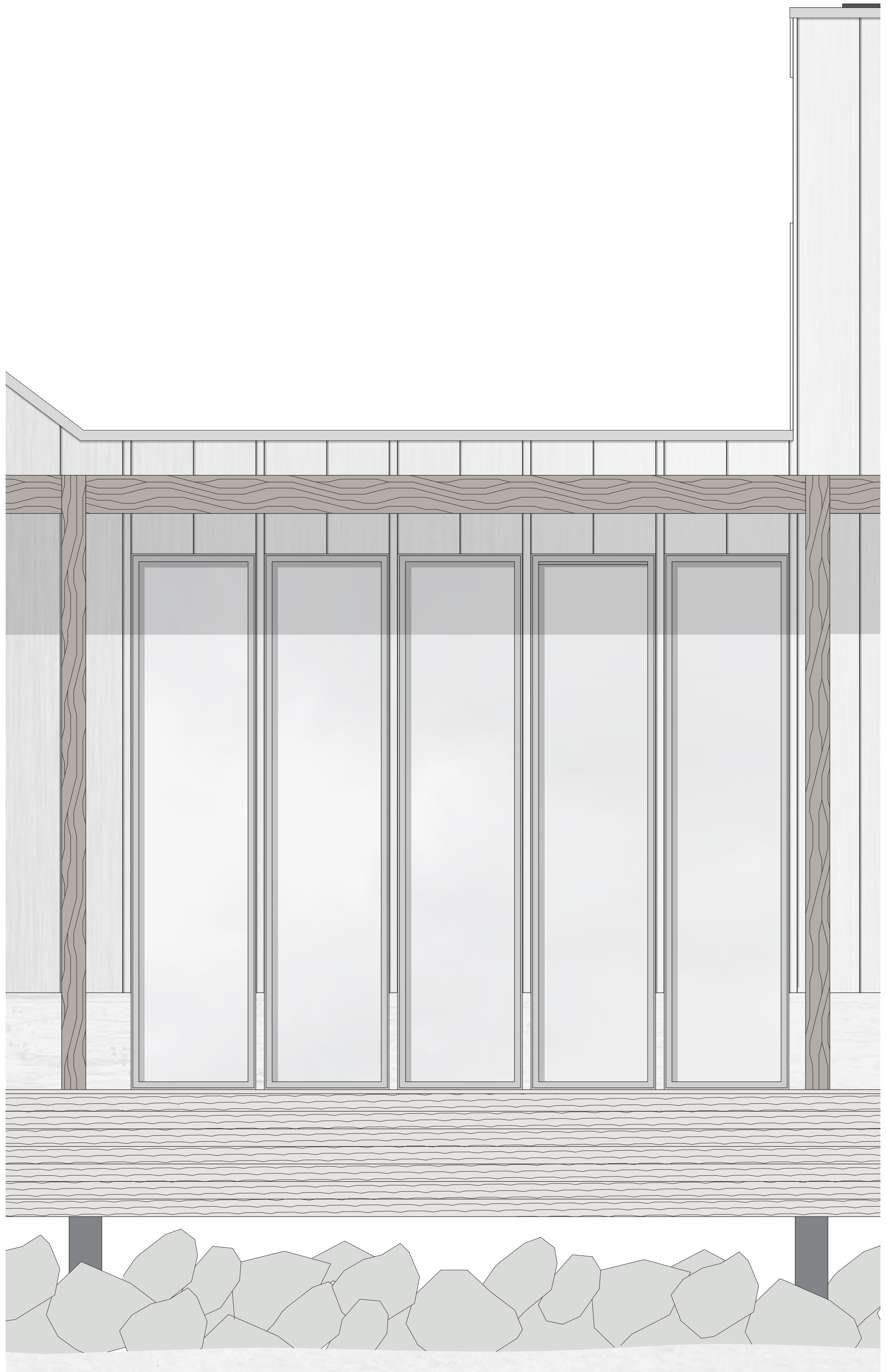
CONSTRUCTION SECTION A-A 1:50



DETAIL 1 1:10

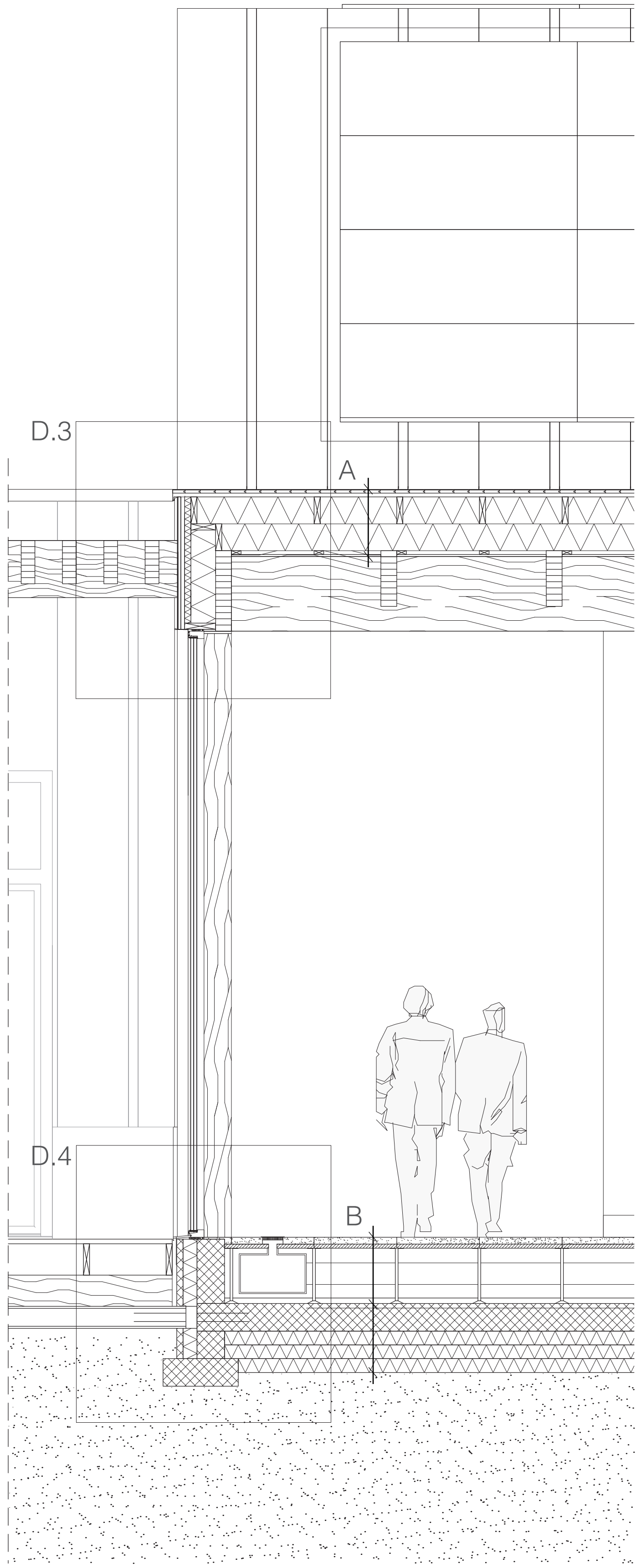


DETAIL 2 1:10



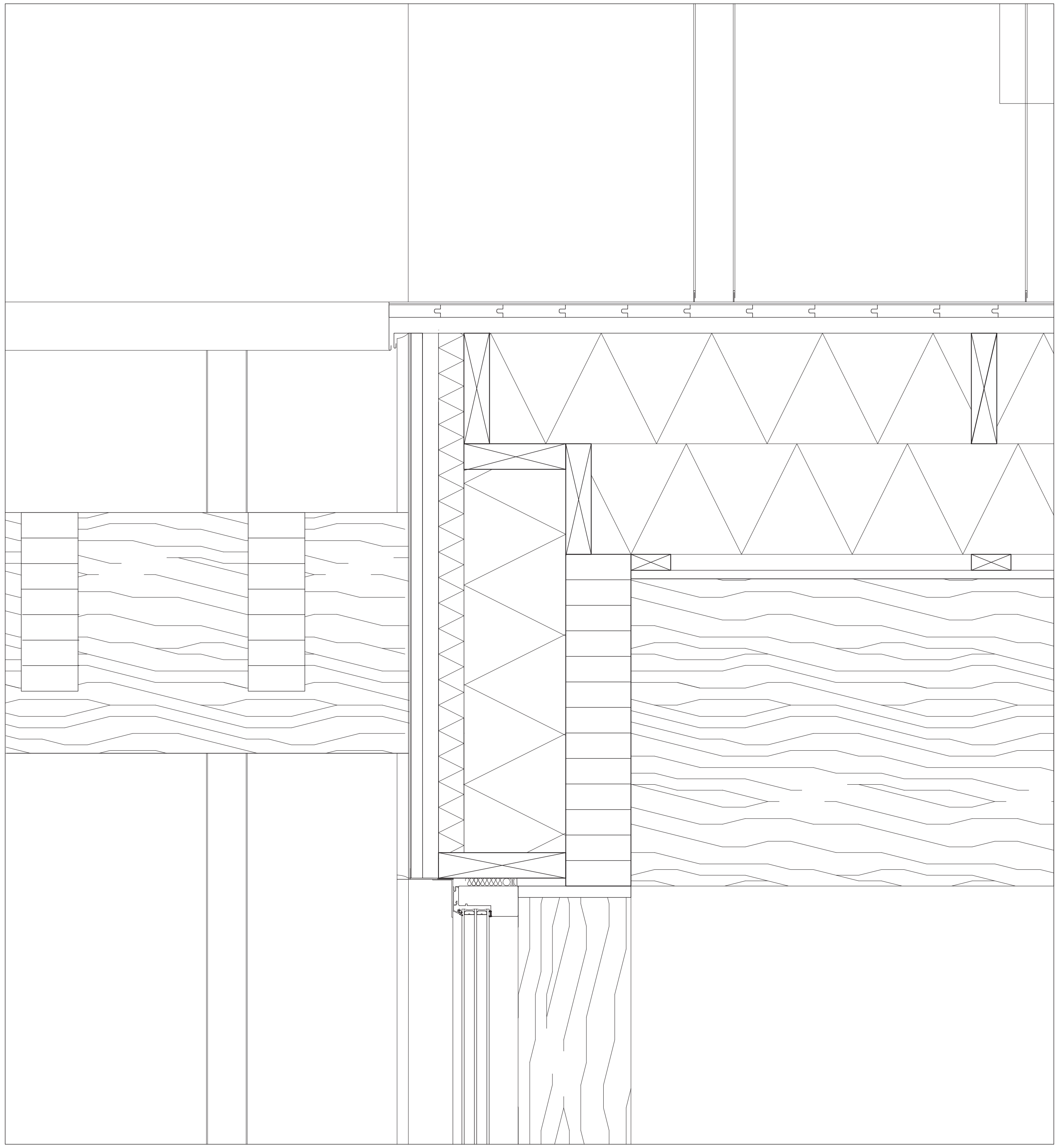
A. ROOF
Sheet metal 3
Paper tar 2
Formwork 22
Battens / Air gap 28
Insulation/ Gluelam beam 390
Vapour barrier
Battens
28
Wood panels 15

B. FOUNDATION
Granite tiles 600x600 50
Galvanized steel stringers 30
Installation space 360
Sound insulation 40
Precast concrete 250
Macadam
Woven fabric

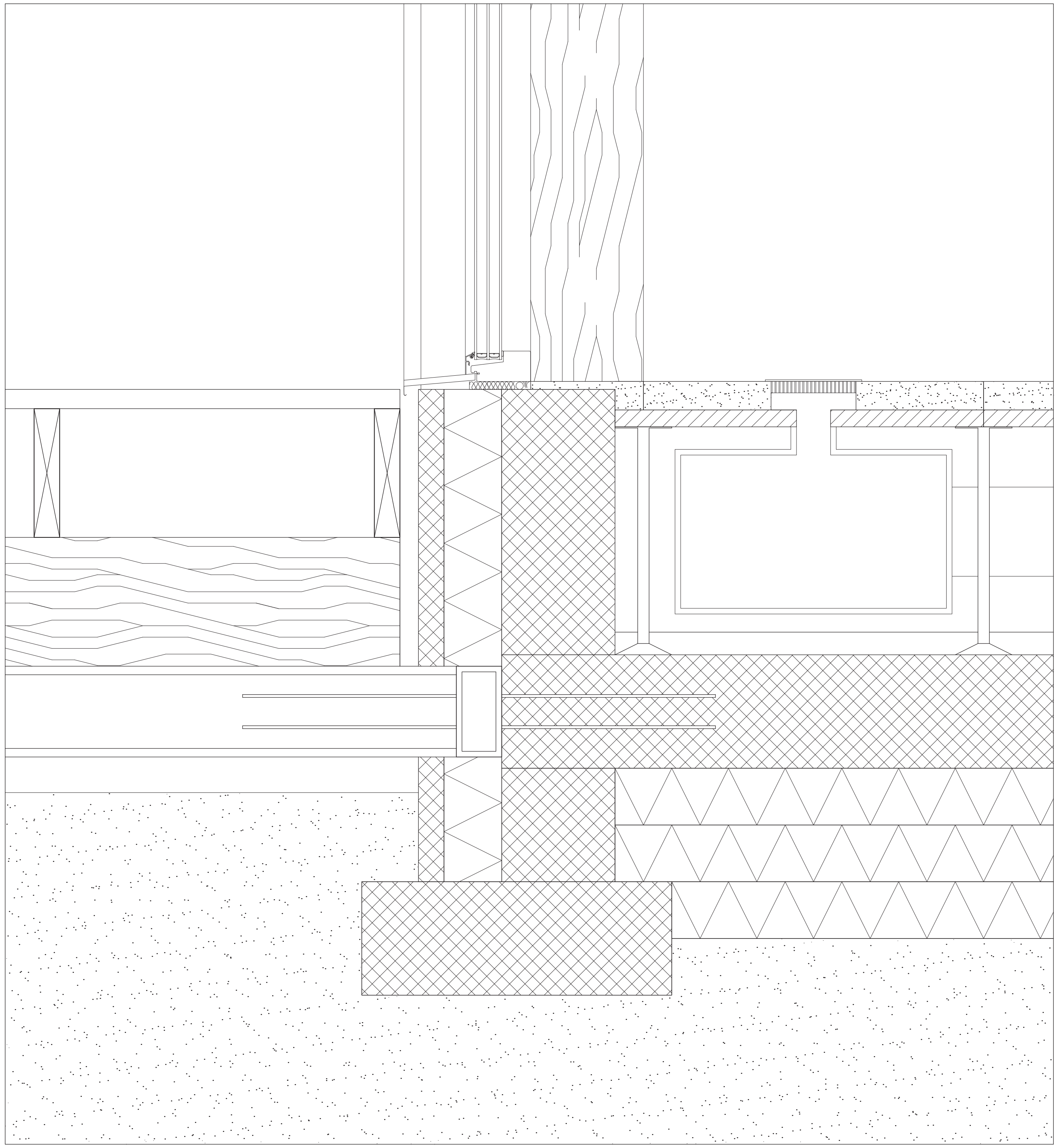


FACADE ELEVATION B 1:50

CONSTRUCTION SECTION B 1:50



DETAIL 3 1:10



DETAIL 4 1:10

Figure 17. South entrance

Conclusion

Discussion
Bibliography

Figure 18. View over the bar

DISCUSSION

The idea for this thesis originated when I visited a building slated for solar panel installation. This particular installation was part of an educational endeavor, bringing together everyone from the planners to those physically mounting the panels. This was a typical installation intended to be placed on an existing roof, so naturally, no architect was involved. By observing the process and especially the programs being used for planning and visualization, I was inspired to explore the possibilities of integrating photovoltaic systems more deeply into architectural design.

In a webinar held by project manager Malin Unger at RISE, I learned that 92% of Sweden's solar cell output is installed on buildings, however, only 2% of them were designed together with the building. As I started to investigate the subject more, I realized that there was much to learn, and that the topic motivated further exploration, particularly from an architectural perspective.

This thesis has explored how architects can design with and integrate photovoltaic systems into architectural design to achieve a cohesive and successful outcome. By examining various approaches and assessing how these can be applied to a stone art exhibition center in Hunnebostrand, the research delves into the potential of combining functionality and aesthetics.

The findings highlight the importance of involving multiple stakeholders and thorough planning to ensure the integration aligns with both practical demands and creative visions. The approach taken by this project to address the issue, by designing the entire building's volume based on the sun's orientation, seamlessly integrating the technology for panel installation, and carefully selecting materials that complemented the industrial character of the solar panels, provided one method to answer the thesis question. However, there are additional methods to successfully integrate the panels into the architectural design.

One question that consistently followed me throughout the process was whether it is sufficient to place panels only on the roof and still consider it a successful project. I would argue that the answer is yes. Over time, I came to realize that a successful project does not necessarily require covering every surface of the building with solar panels. Instead, it is equally important to highlight the architectural qualities of the building and ensure that the overall design is aesthetically pleasing. And in this project that meant placing all panels on the roof and rather letting them influence the volume and the materials.

The site in Hunnebostrand was carefully chosen because of its preconditions. It proved to be a challenging yet inspiring choice. As mentioned in the aim and purpose chapter, the aim is to implement the learnings from the theory into a project on a sensitive site, with the presumption that if PV can be integrated well on a site like this, it can be implemented anywhere. The small scale and coastal location contributed to a more careful approach that respects the site. I imagine that the outcome would be very different if an urban site was chosen for the project.

In conclusion, working with the integration of PV panels has been an enlightening process. Designing with solar panels means accepting the distinctive aesthetics they bring and strategically using it to enhance the architectural qualities of the building. For further exploration, I would be interested in examining how solar panels could make a greater impact in interior design and how solutions beyond the traditional black standard panels could be implemented.

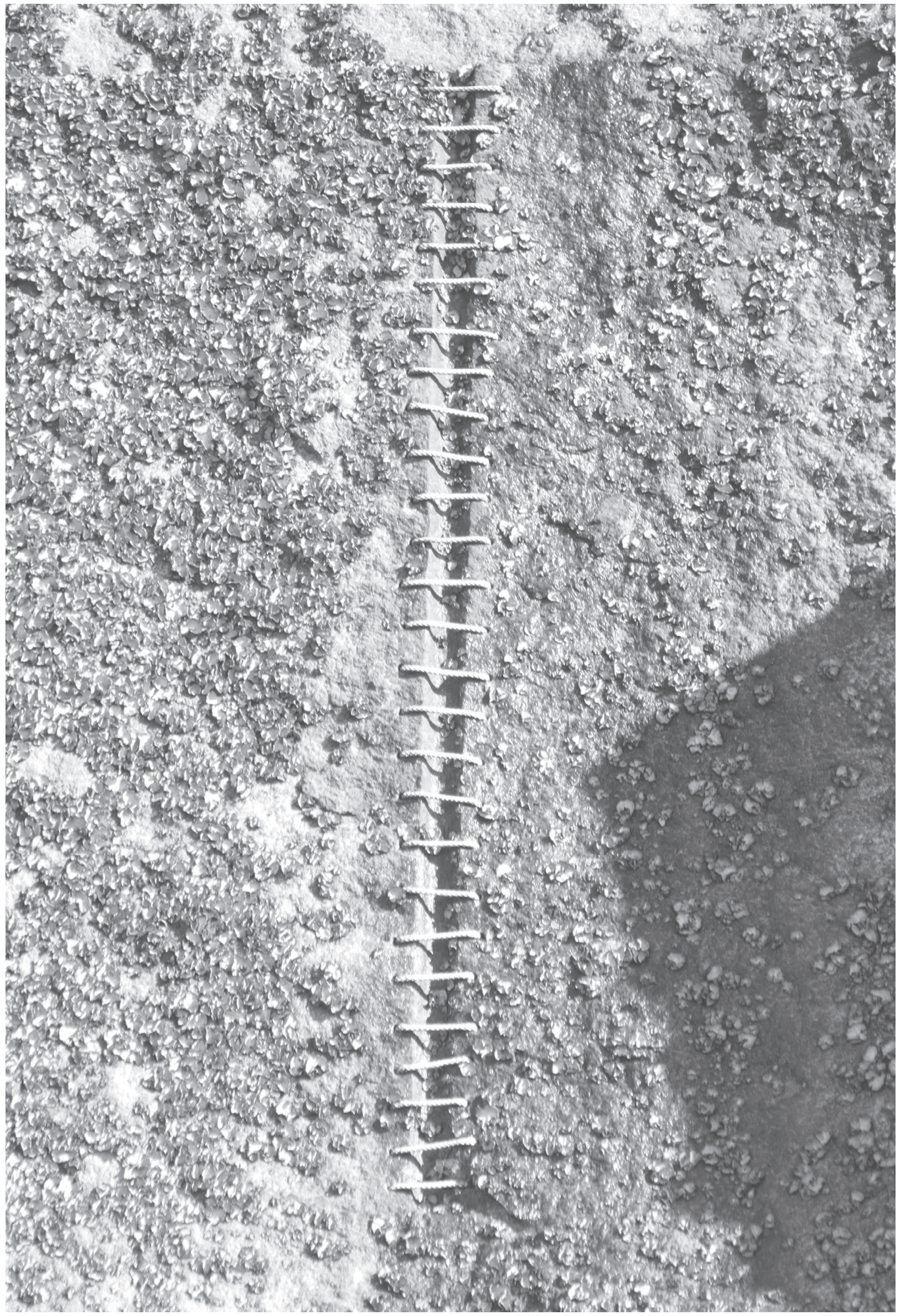


Photo 19. Detail on the mountain Höge berg

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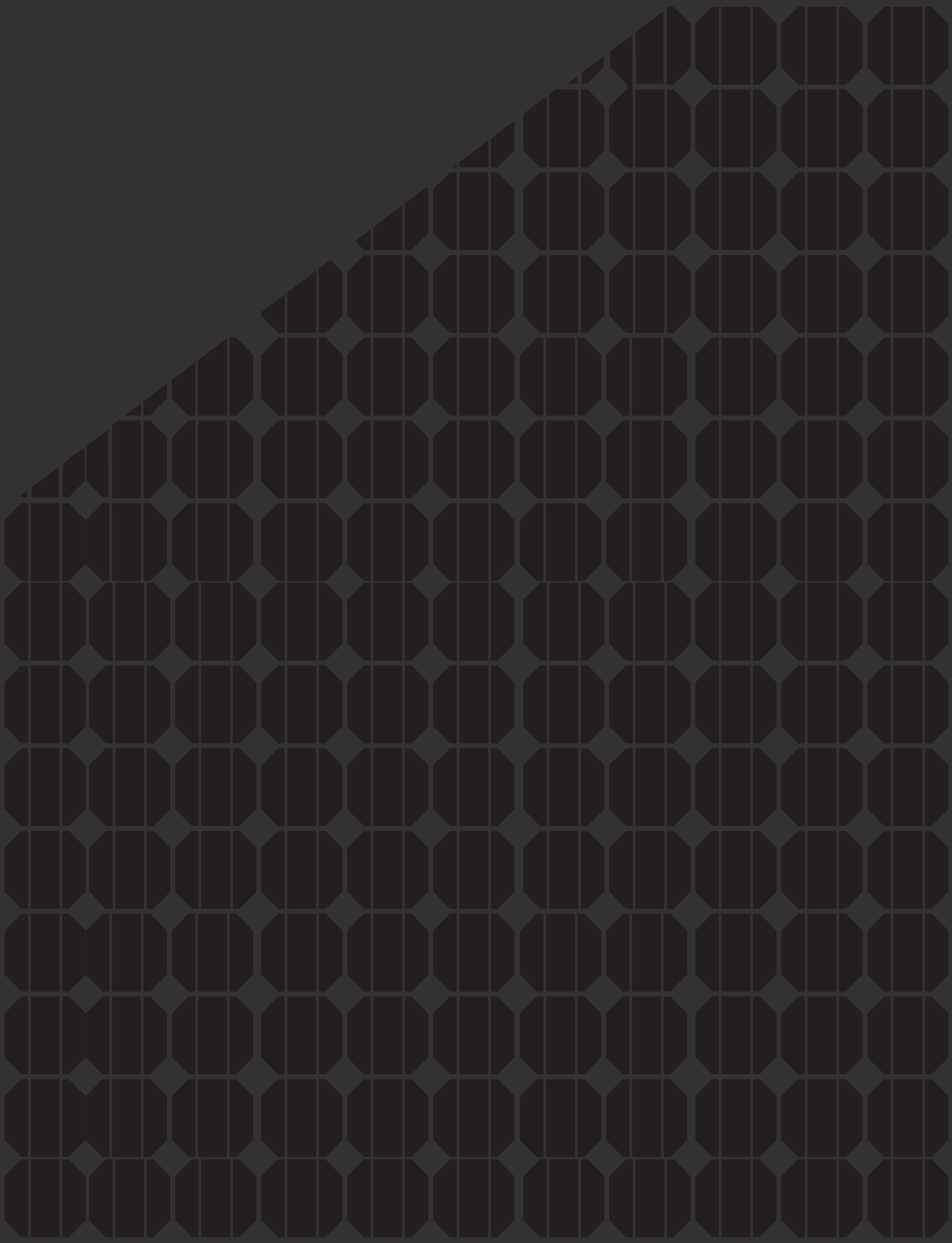
Photos

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

Photo 4-6. + Enegiehaus Kasel
Note. From L. Blatzek, W. Becker. +Energiehaus [Photograph] Retrieved from: https://www.purplus.team/projekte/energiehaus-kasel. (2025-04-12)

Photo 7-8. Kunstmuseum Appenzell
Note. From S. Bagutti. Kunstmuseum Appenzell [Photograph]
Permission to use photographs given by Gigon and Guyer Architects who send me the photos. (2025-02-27)



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MT 2025