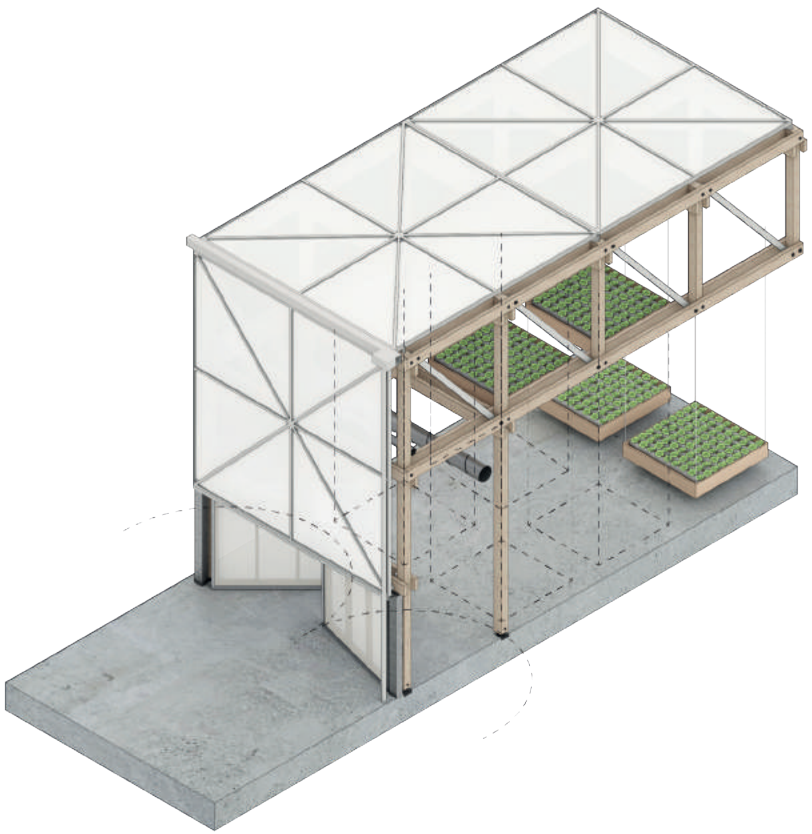
# Copenhagen Community Greenhouse

## Responsive Architecture



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# Abstract

This thesis investigates integrated design in architecture. It does so through a project case of a new community greenhouse for Copenhagen. A meeting place for different scales of agriculture, as well as a place where agriculture and people can meet.

The design approach explores design in correlation to dynamic climate and structural simulations, as well as social and spatial qualities. This is done on the basis of tectonic theory and architecture as a performance, with a methodological focus on co-evolution and system thinking.

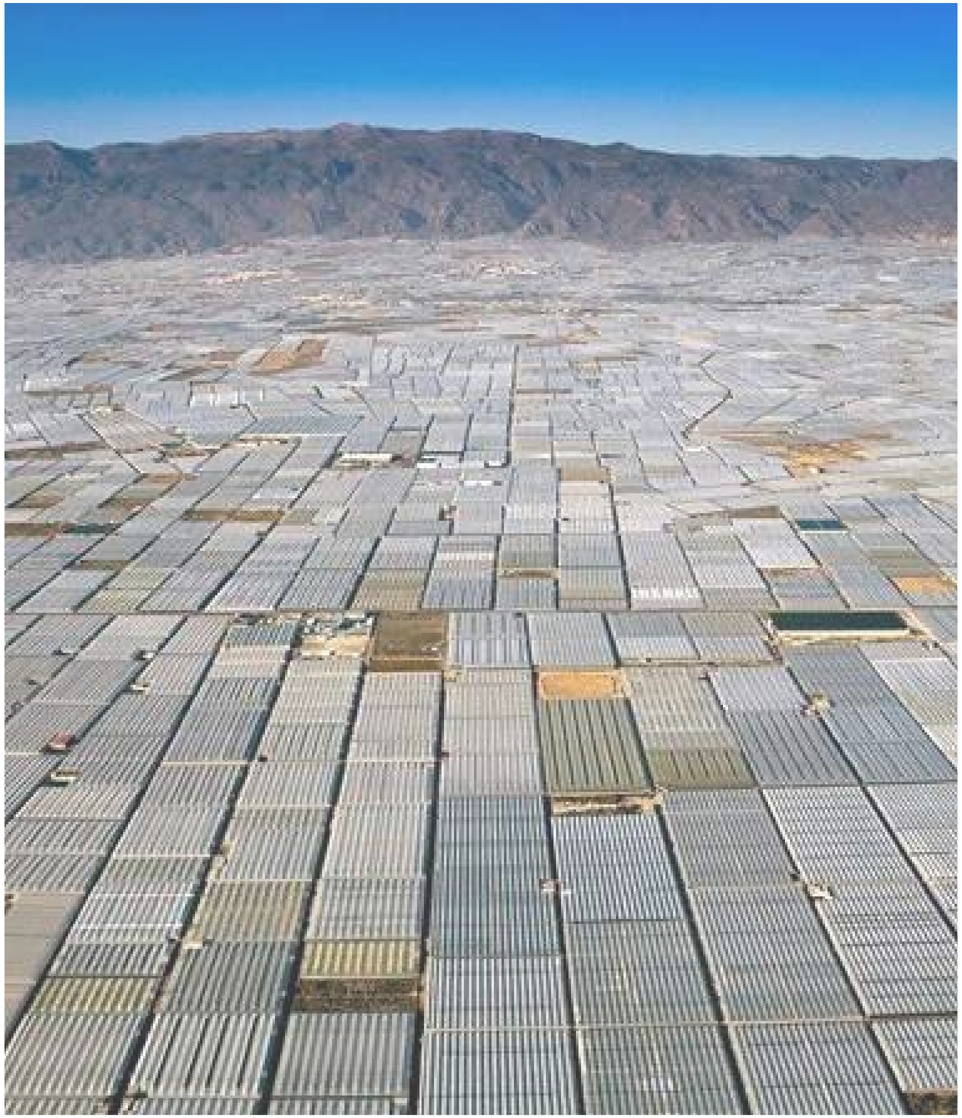
The project presents a new typology for people and agriculture and the design approach behind it.

## Reader’s guide

This report will present the overall strategy and concept, a design presentation and selected parts of the process.
The first part will present the framework of the vision, strategy, methodology and tectonic theory.
The second part will present the design of the Greenhouse Community Center. First with a broad overview of the design and afterwards go more in depth with the different aspects of the design.
The third part is a design log that shows selected parts of the design process and ends with a conclusion and reflection.

# Table of content

ill. 1 - *Traditional farming, This image was originally posted to Flickr by Tiomax80*



ill. 2 - *Modern farming, greenhouses, Almeria, Spain, property of Yann Arthus-Bertrand*

*Traditional farming*

*Modern farming*

# Motivation

Food is essential for our lives not only for nutrition, but also as the center of social interaction. However, modernization of agriculture has made society increasingly detached from the production processes. Recent tendencies point towards a greater concern for food quality and local food production. So, how can modern technology and food production become an integral part of our social life, and promote a community and culture around food?

# Strategy

**Past and present food production**

Agricultural production was in the past tightly coupled to the place it was consumed. Farmers would come to the city to sell their products, which created social and commercial exchange. Nineteenth- and twentieth-century industrialization and modernisation created a shift in this relationship. Technological advancement in agriculture made the need for manual work obsolete and industrialization meant urbanisation by depopulating the countryside (Despommier, 2010). To keep the city clean meant physically separating production and trade. A sanitization of the urban environment together with global trade and export of produce causing segregation, where agriculture has become an abstraction in our lives (Franck, 2005a). What used to be a physical presence of working the land is lost. An uncritical acceptance of a distant production on a gigantic scale has become normal.

**Contemporary reaction**

Recent developments show a movement towards localizing food production. More consumers are seeking high-quality food products from local farmers. In addition, new forms of food production are developing in the urban environments in many different scales. Private consumers supplement their own consumption with growing herbs in a windowsill or a small garden. Also, large scale urban agriculture is enabled by new technology making it less space demanding and more efficient (Despommier, 2010).

The main goal in this project will be to facilitate this development through architecture. We will examine a new typology rethinking and reforming our food production infrastructure.

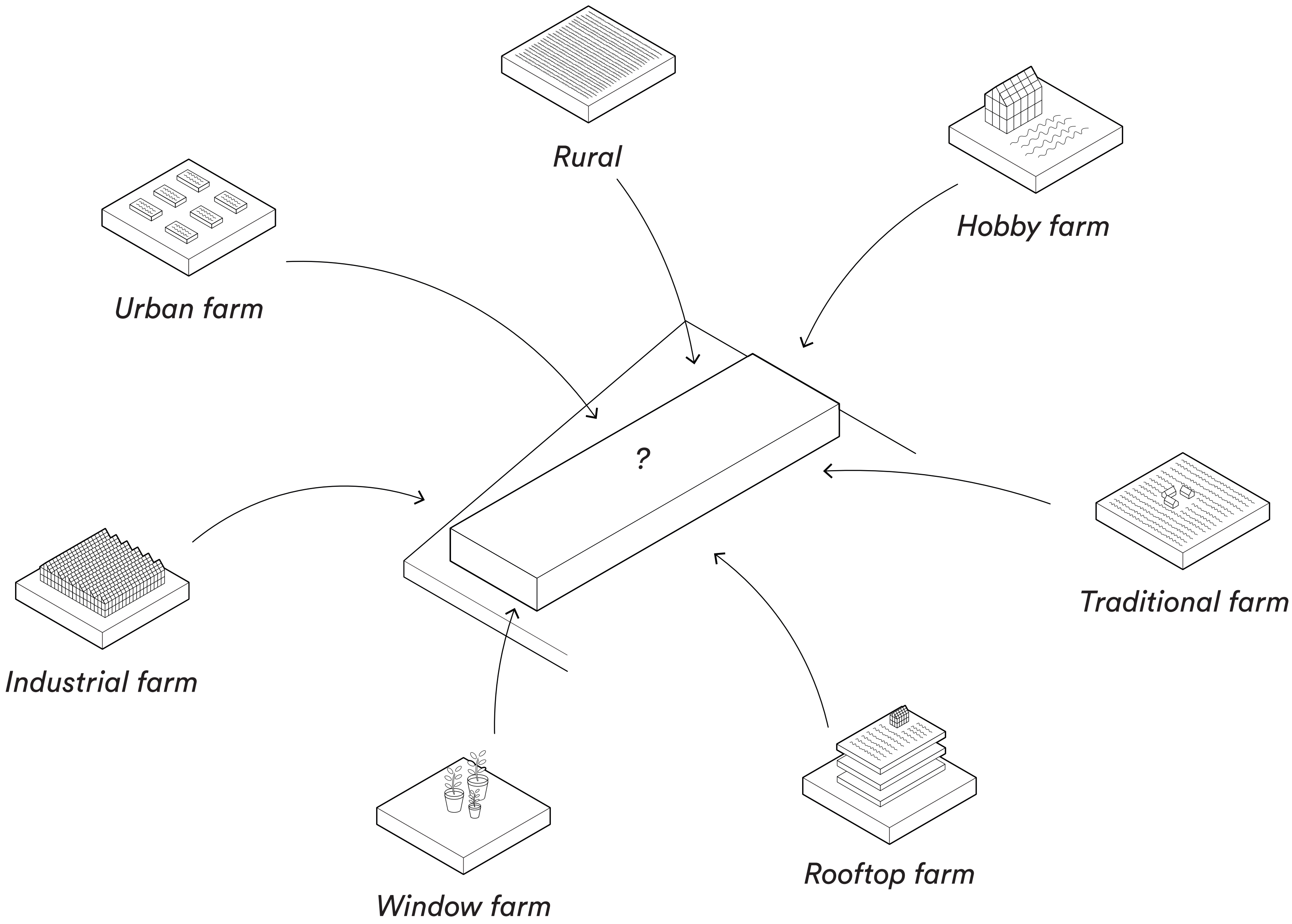
**Strategy**

This project will create a new typology combining the greenhouse with the community center creating a greater connection between producer and consumer. This will be a modern reflection of the traditional farmers market, where producers have social and commercial interaction with the consumer.

In a modern context, the building will have to be a meeting place for great variation in scales of agricultural production. This will be a place where production, retail, and consumption of food is united to complement each other and combined into cultural experiences.

Modern technology for greenhouses and farming enables the creation of new architectural environments for greater efficiency in agricultural production. This project will investigate how to use these environments as a human experience as well.

This will require a building that can house many different purposes in scale and function, that will create a compound of agriculture and culture, creating a symbiosis between plants and humans.




ill. 3 - *Strategy diagram*

# Methodology

We have consciously chosen a subject area, that requires a multitude of themes, applications of disciplines and modes of working. Working with integrated design can pose a challenge in the creative process, but it is a necessity to have a broad perspective to achieve a design that answers the many challenges posed when creating architecture.

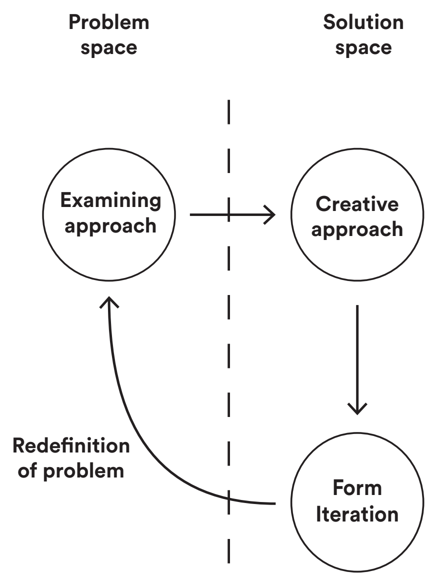
We will describe our understanding of an integrated design process and outline a structure of how we will approach this in practice. Our process will be organized around *system-thinking*, *primary generators* and *co-evolution*. We will give an overview of the entire process, by considering how the design process changes throughout a project. The text will describe the different design tools and how they affect the iterative design process.

**Process**

The integrated process is often approached as a problem-oriented, which can be hindrance in the creative process. The integrated process is better described through the concept of *co-evolution*. The designer works in a *problem-space* and *a solution-space*. *The problem-space* is used for understanding and examining information, while *the solution-space* is used when combining this information into a design (Lawson, 2005 pp. 274-275). The problem-oriented approach improves the understanding of a subject but does not result in a more creative process.

The important exercise is therefore to connect the problems and apply them in creative solutions. This is described in ill. 4 as a cyclical process where the *problem-space* is used to examine a subject, which is then used in the *solution-space* to design. This design iteration will create a greater understanding and redefine the original problem. The connection between *problem-space* and *solution-space* can be further understood through *system-thinking*.

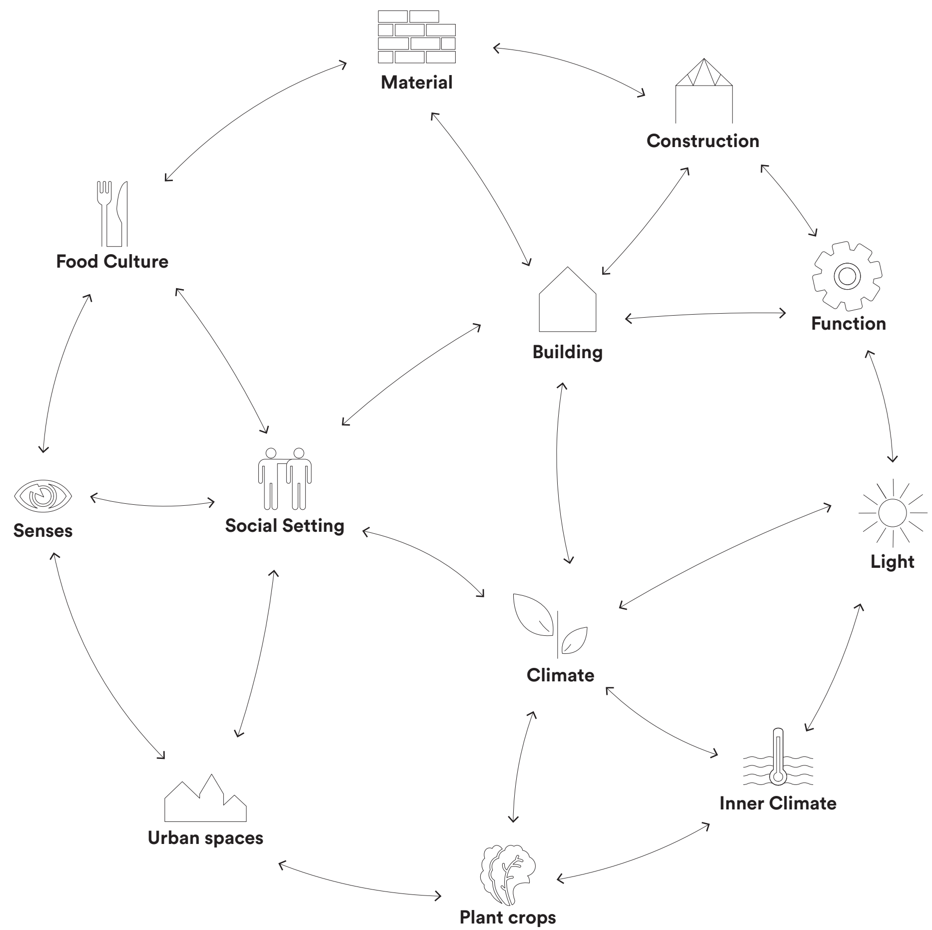
System-thinking methods can be used to capture the complexity of the integrated process (Foged,



ill. 4 - *Co-evolution process diagram*

2018b). ill. 5 is a system-thinking mapping of the different subjects in our project. A few central themes branch out into sub-subjects, creating a complex net of connections requiring a cross-disciplinary approach, and an exchange between problem and solution finding. The separate elements can be understood thematically (differentiation), parallel to that, the interconnectedness as a system is understood (Integration)(Foged, 2018b).

The overall design process should not be seen as a never-ending cyclical process, but a chronological progress, with a start and a final goal. The final goal is already somewhat defined at the outset, since a certain level of detail is required to present the project. ill. 6 shows a mapping of our overall process. The x-axis shows the “perfect” progression from initiation of the project to the final product. The design process will in practice be more sporadic illustrated with the line on the graph going away from



ill. 5 - *Co-evolution process diagram*

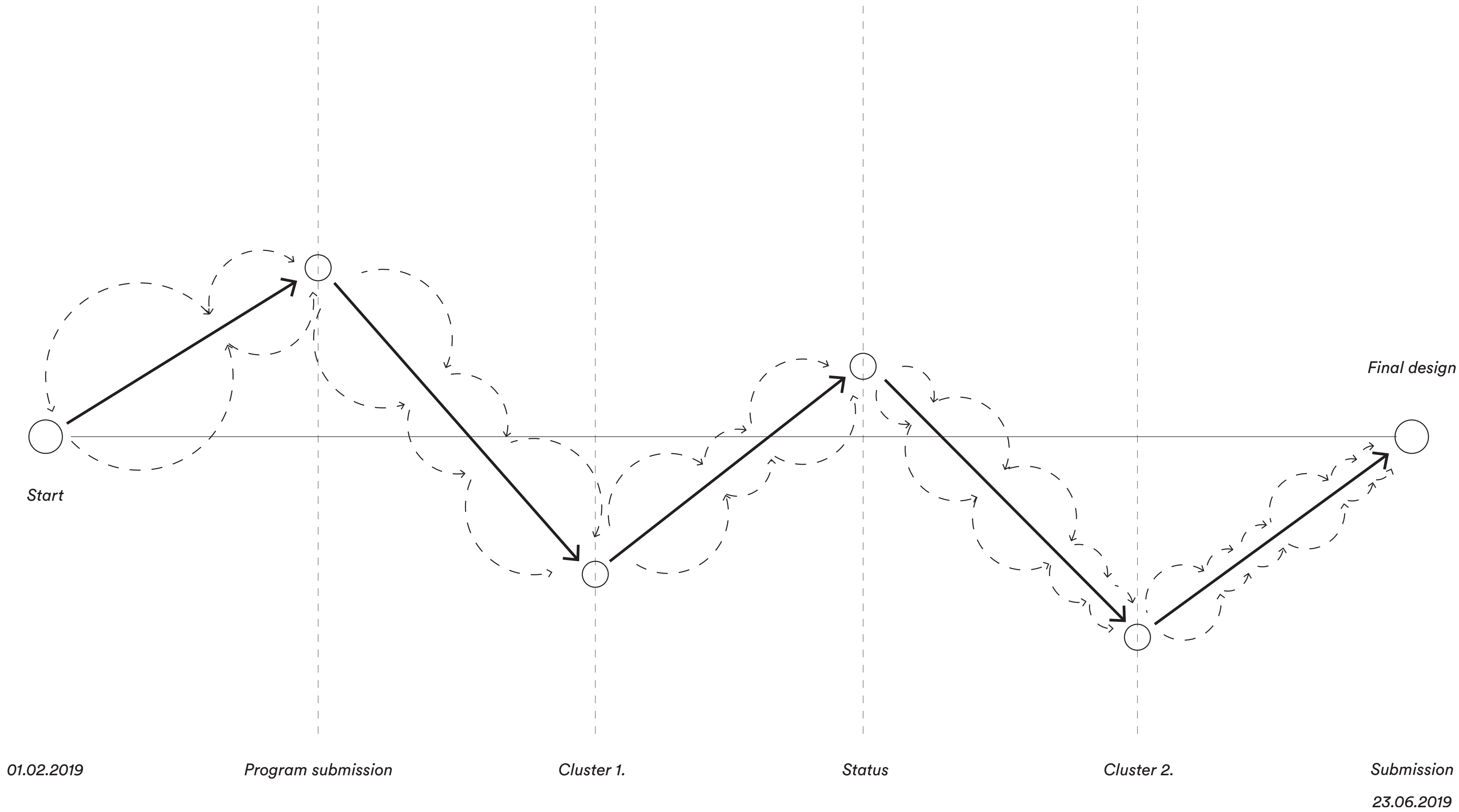
the axis. This is required in a design process where the design is constantly developed by the production of iterations, and therefore important also to regularly evaluate where the process is going. The diagram plots important points as milestones marked by specific dates for clusters, seminars and supervisions. The design progress was presented, to evaluate the direction based on the external feedback. The project can also be seen, as in ill. 6 a switching between converging (creating the solution) and diverging (finding the correct solution). This is illustrated by the dashed lines, showing how the early stages are characterized by greater diverging than in later stages.

The *primary generators* are used to organize and steer the complexity of the process. By developing a simple idea, the possible solutions are narrowed down, and simplifies the process of taking decisions (Dark, 1979). This would mean that many decisions during the iterative design process are taken from an intuitive basis, through *primary generators*. In practice this is done through a number of different representations of the design, which can be done with different characteristics and for different purposes (Lawson, 2004, 31-51). Computer models, physical models and analog sketches will each have their own characteristics and will explore the design in different manners and should therefore be used for different purposes. Our project has a broad approach to the design and will need several different tools and methods to understand the entirety. Some of these tools will have to be founded in a more problem-based approach, so how can this be implemented in a creative design process?

The Performance-oriented design process which focuses on the performance of the building, and changing our view of the process, by blurring the boundary between analysis and form (Kolarevic and Malkavi, 2004). The Performance-oriented design process will create a stronger connection between the problem and solution space. The analysis gives us an understanding of the potential performance of the building, which should be reflected in its form. This notion requires tools that can easily simulate such performances and implement information in early design stages, i.e. creating *feedback loops* between form and analysis (Parigi, 2014). This should not be a tool to further implement technical knowledge into a design, but to create complementarity between the different aspects.

**Methods**

Using these theories, we will choose a number of methods or tools to develop our design. As described earlier from Lawson's theory on the characteristics of different design representations, the different methods will give different outcomes. The specific design method should therefore be picked carefully to achieve the right outcome. This is especially important when developing a project with a wide integrated scope. The design should be represented in the




ill. 6 - *Process time diagram*

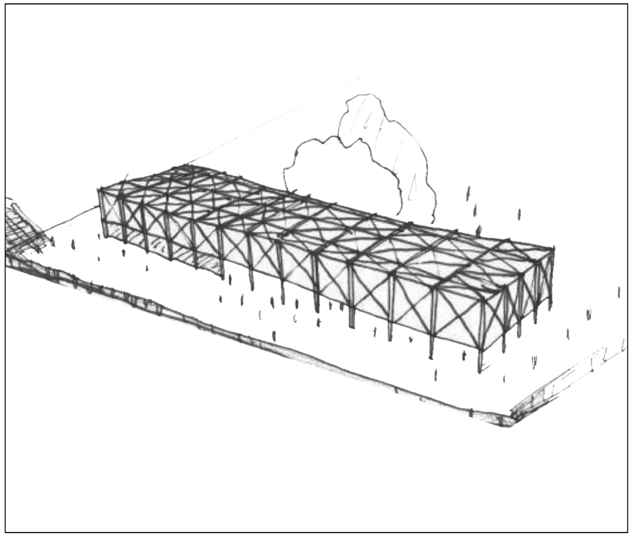
correct ways to answer the design from several perspectives. We try to include a wide array of different methods to explore the design in a comprehensive manner.

Our subject matter will first be explored and expanded through literary reviews. We will combine knowledge of several themes reading and analyzing theory. We will also collect technical data on inner climate, structure and plants, and do phenomenological studies of the site and case-studies. This information will be used for technical, experiential, and theoretical parameters for the design process. All these different explorations will then be combined using system thinking, combining technical knowledge with theoretical and phenomenological.

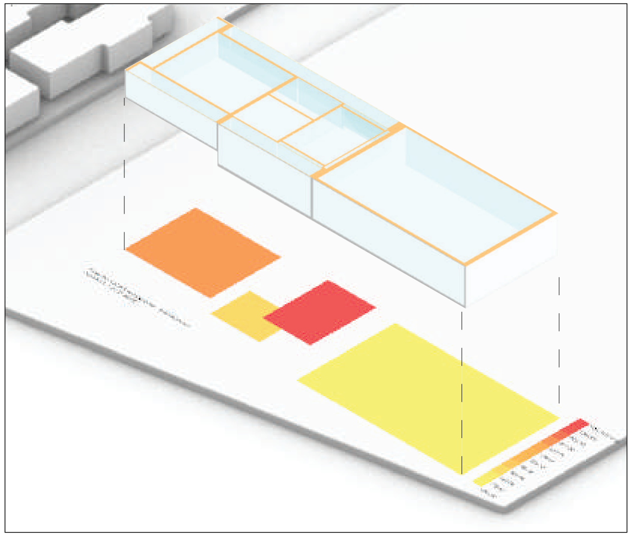
In the iterative process, design representations will be made through analog drawing and models to create an impulsive and intuitive versioning process. Digital drawings and models will be used to create more precise proposals, but also as a way to implement technical simulation in the early design stages. In ill. 7 we have a chosen a number of different design iterations, created using different methods. All these individual representation inform the design in completely different ways.

**Conclusion**

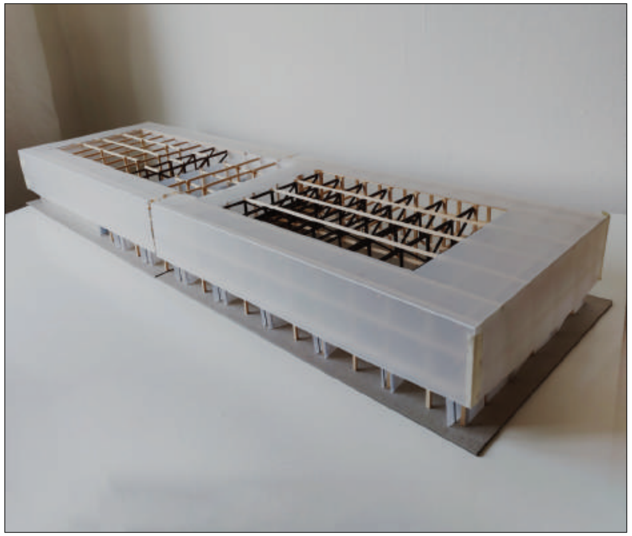
The integrated approach is defined as focusing on a number of building performances, which result in creating the character of the building. The integrated design process must therefore incorporate and make these performances complement each other. This will be done through differentiating the problem field and examining it, to combine them in creative solutions. Examining the complexity of the project through *system-thinking*, and then steering an iterative process of diverging and converging through the use of *primary generators*. The focus on many different subjects should also be reflected in the way that we examine them and implement them in the design. Numerous methods will be used to cover the themes relevant to the design. The iterative design process will be supplemented by simulations allowing to asses designs from several perspectives. This will create an, overall, very divergent design process in terms of method and subject, converging themes using simulation and *system thinking*.



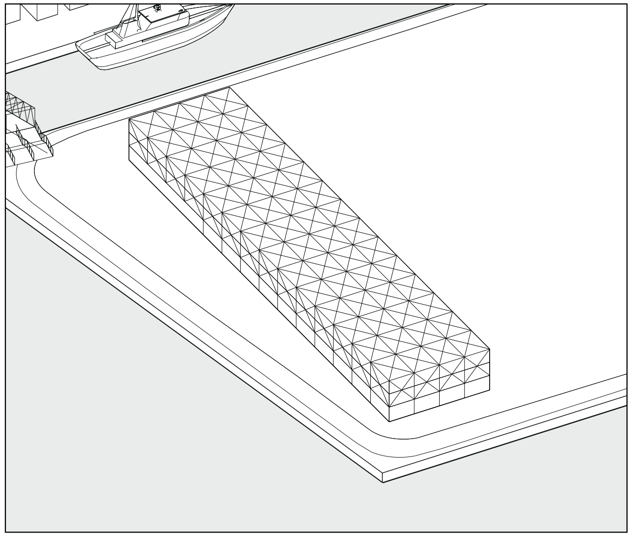
*Analog sketch*



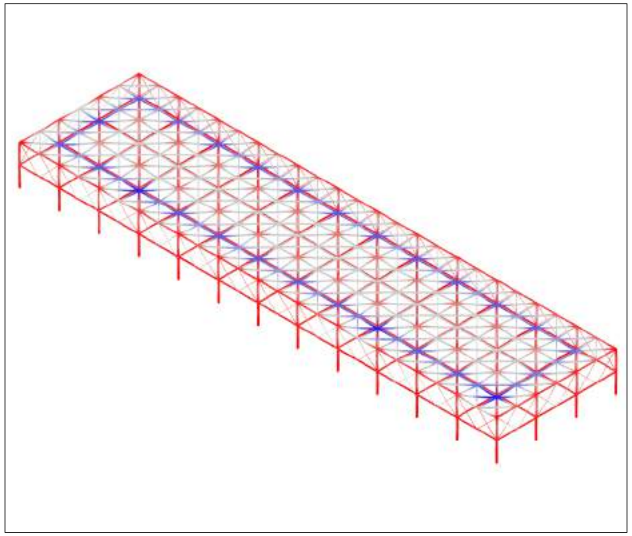
*Climate simulation model*



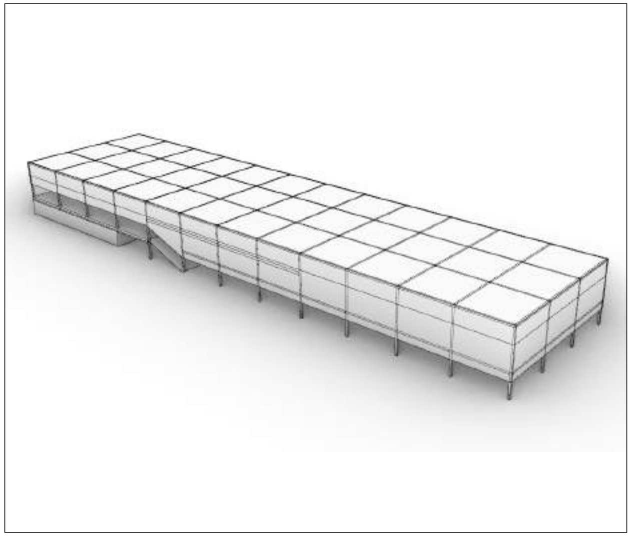
*Physical model*



*Diagrammatic sketch*



*Structural simulation model*



*Digital model*

ill. 7 - *Different design representations*

# Tectonics

This section discusses how the integrated process can be used in an architectural expression through the theory of tectonics. This will be done as a literary review, discussing several views on tectonics, giving a comprehensive understanding of concepts relevant to the project. The starting point of this discussion will be Sekler's tectonic theory. This will then be discussed in relation to temporality and environment, through texts of Leatherbarrow, Foged and Kolarevic, together giving an overall theory and direction for the project. These theories are not directly comparable since they describe two different fields in architecture tectonics and performative architecture. This will be an attempt to expand the subject of tectonics looking at performative architecture through a tectonic understanding.

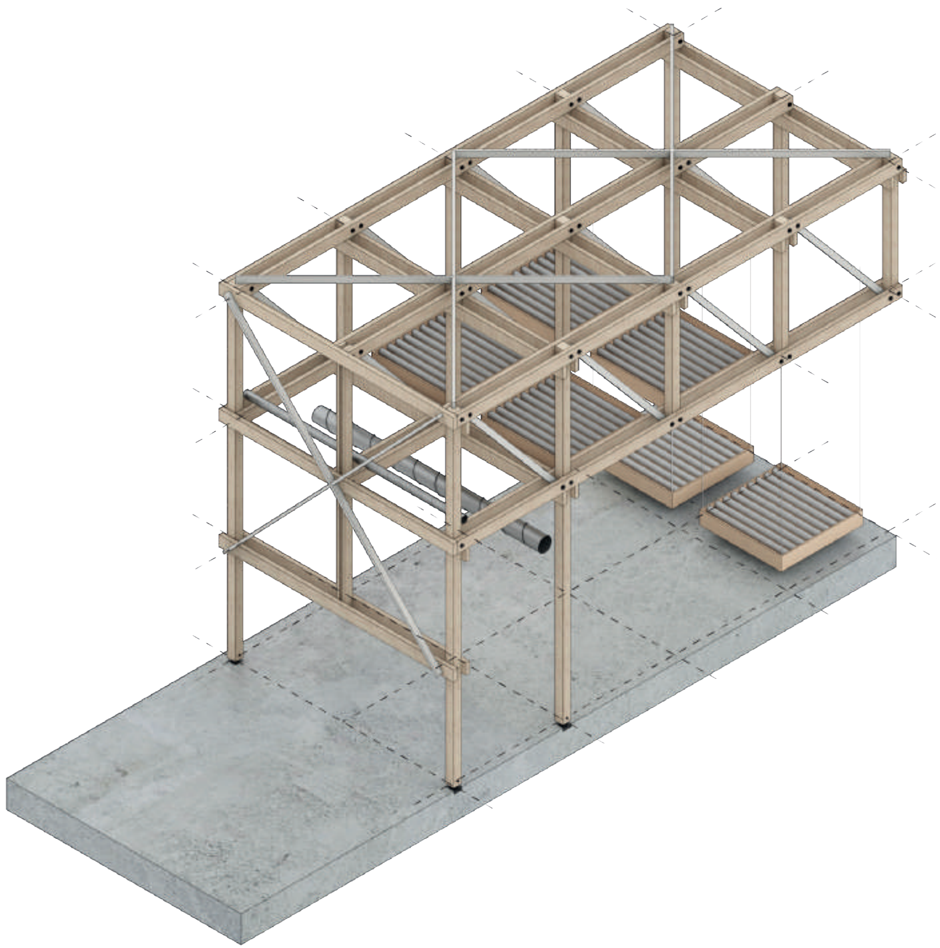
**Forces to form**

In Sekler's essay *Structure, Construction, Tectonics* architecture is defined as both consisting of a structure and a construction. This distinction is important when expressing tectonic qualities. The structure describing the buildings ability to distribute the natural forces, and construction describing how the building is assembled. The relationship between these two concepts can be described as tectonic (Sekler, 2018). These qualities can together create a conceptual expression of form to force. Frampton would later describe architecture as an interdependent construction of both tangible and intangible elements such as location, history, culture, functions, physical constraints and bodily perception (Frampton, 2018). This would mean that a tectonic architecture cannot only be created through the expression of form to forces, but must also incorporate external factors. This is still only describing the external factors as shaping the physical environment. The next section will focus on how these external factors can be seen as the architectural environment, and therefore be a greater asset in creating architectural expression.

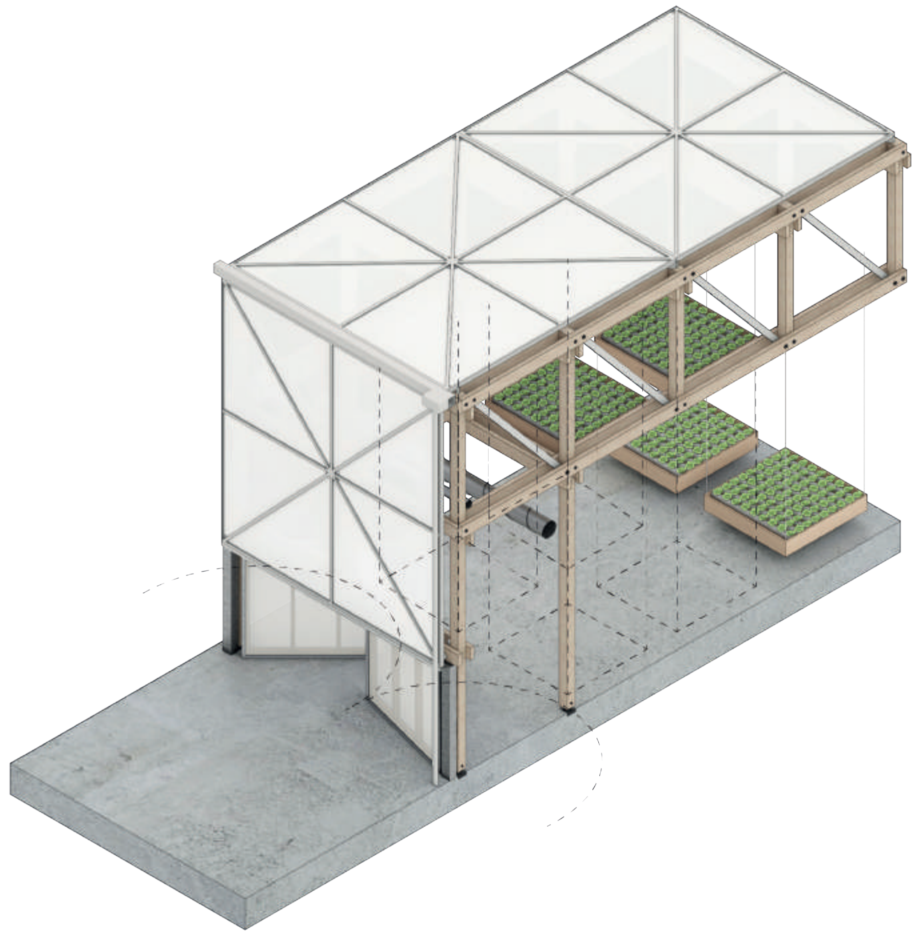
**Temporality in architecture**

Leatherbarrow discusses, in his essay *Architecture's Unscripted Performance*, how architecture can be described as performances rather than objects. Sekler and Frampton describes architecture as a static collection of physical elements understood through cultural, and sensuous perspectives. Leatherbarrow posits that the buildings do not simply consist of the physical elements themselves. Buildings have a temporal and unpredictable character, being an event, rather than a quantifiable object. By the interaction between the physical building and external influences of wind, rain, gravity, sun and people, a performance is created. The building is therefore defined through its performance against and with its temporal and environmental influences. (Leatherbarrow, 2004).

Further elaborating on time, in his text *Making*



*Tectonic architecture*



*Responsive architecture*

ill. 8 - *Tectonic architecture*

ill. 9 - *Responsive architecture*

*space for time*, he discusses buildings from a temporal dimension. Describing buildings as, by definition, aimed at achieving a permanence. Simultaneously, the "finished" building cannot be prohibited from exposure to change. Continuance without change is impossible, the facades will become weathered, functions change and sensuous perception of the building change. Change is a fundamental contextual condition, and time should therefore be a fundamental design dimension. (Leatherbarrow, 2015).

The physical construction elements are in a constant performance against its external environment. The environment and therefore the building is under constant change, which should be a dimension integrated into the architecture. So how do we create an architecture accommodating external influences? And how do we accommodate that these external influences are under constant change? This will be discussed in the next two sections, first how architectural environments are created, and secondly how this can be adapted to over time.

**Environment and human perception**

*" [the building] must wait on the environment to give it what it lacks — light, air, human events and so on." (Leatherbarrow, 2004, p. 16).*

As described by Leatherbarrow in this quote, the building does not exist until it is filled with an environment. The building manipulates the natural environment changing temperatures and lighting conditions by filtering and obstructing radiation and sheltering from or opening up to wind and rain. The building itself will additionally create these environments with heating and cooling installations, ventilation and illumination from light fixtures. Leatherbarrow describes the natural environment as following *the time of the world* (Leatherbarrow, 2015). *The time of the world* relates to the seasonal change of the calendar and the schedules of daily life. The building should be responsive to the different conditions, of the natural environment, happening over a year and in daily schedules. During winter the building should play the role of an insulator by keeping heat inside it, while in the summer it plays the opposite role of cooling the interior down. Human interaction will also change over a year and in daily schedules, some easy to predict, such as clothing, other harder such as mood and activity

Foged describes in his text on *environmental tectonics* how the conditions of the interior environment create different experiences of buildings through human perception. Materials are understood differently depending on temperature, illumination or individual perception. The collaboration of the senses measures and perceives the architectural environment creating an intensification of the experience stimulating the sensing of space, place and the environment itself (Foged, 2018a). This can be related to time in what Leatherbarrow calls *the time of experience*, which relates to the sequential spatial movement through buildings. Different accelerations, delays and lingering happens through the building's obstructions, materiality and spatiality, experiencing the building environment through sensing and moving. (Leatherbarrow, 2015).

Since buildings must live under this ever-present change and environmental exposure, it should be facilitated and accommodated for in the building. By integrating responsiveness into it, the architecture creates a two-way relationship between space, environment and user. The space allows the user or the environment to generate spatial reconfiguration. By allowing the movement of physical building elements the user can create new space, connections or separations. Allowing the user control over the building's programming both according to patterns of use, and to manipulate how the building changes the environment. (Kolarevic, 2015).

**Conclusions**

This text has gone through several theories on tectonics and made comparisons between them and theories of performative architecture, aiming to develop an architectural expression for the integrated process, articulating technical elements aesthetically. Discussing architecture first as the expression of the physical environment. Then in relation to architecture as performance, and how the permanence of buildings is under constant change and performance against the natural forces. This placed an importance of integrating elements that can accommodate constant change of environment.

The building should therefore not be seen as an environment consisting of physical building elements alone, climates and humans have an unavoidable effect in defining the architecture. All these elements should be used, as Sekler described, to create architectural expression.

# Site location

ill. 10 - *View from opposite side, property of Lars Fabricius*

The project site is located at an old dry dock on the western side of *Refshaleøen*, an old industrial area in Copenhagen, Denmark.

The area of *Refshaleøen* has a prominent placement towards the harbor of Copenhagen. This places the building in the presence of many of other important cultural institutions. It is also placed in an area that is undergoing a rapid transition where a prominent food scene and diverse cultural initiatives are emerging. The building's placement is chosen to tap into this development as well as giving the production of food a prominent position in the city.

ill. 11 - site location in Copenhagen

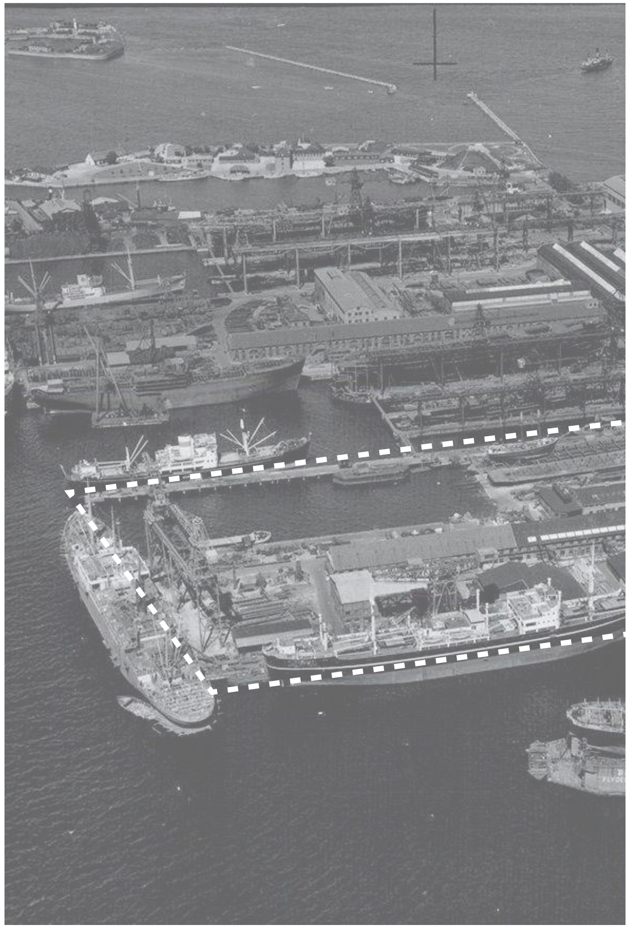
# Past, present and future

*Refshaleøen* has since the nineteenth-century been an industrial area of Copenhagen. housing the *Burmeister & Wain* shipyard company from 1872 to 1996. In this period, the company grew to one of Denmark's biggest workplaces, where they produced containerships. The remnants of the company have given the area a strong industrial presence. Significant are the old production buildings known has *B&W hallerne*. The area is regarded important industrial heritage of Copenhagen.

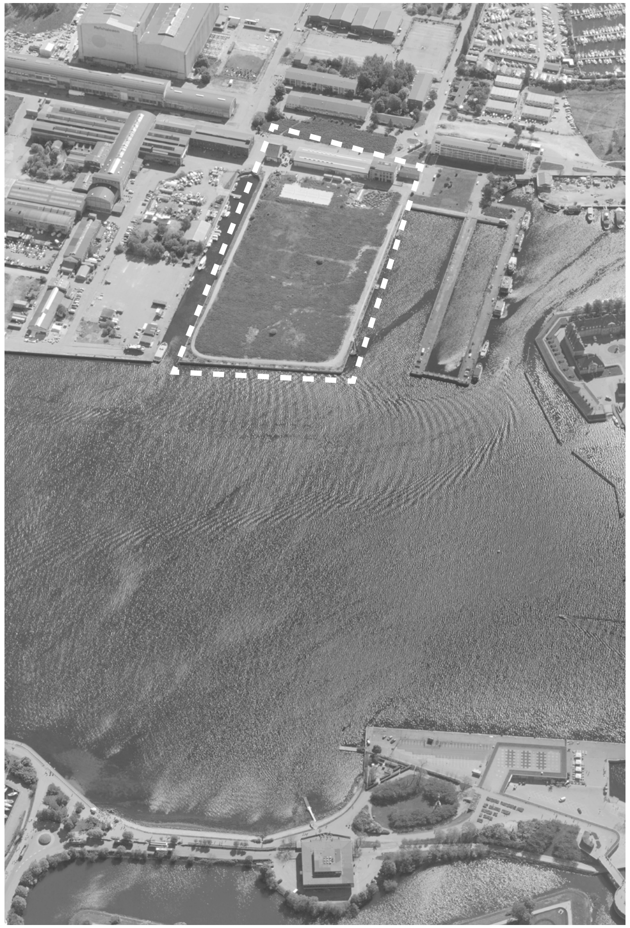
In recent years it has become an area of temporary functions. E.g. festivals, sport, food venues, recreation, small business and creative developments. Many of which has inhabited the former industrial buildings and given them a new life. This has made the area a more integrated part of Copenhagen and has started a social and cultural infrastructure (Københavns Kommune, 2015).
The future development consists of an expansion of the peninsula to the north called *Lynetteholmen*. Leftover dirt from the area will be used to create more land. 35.000 people are estimated to live there when the development is finished, and new infrastructural investments will make it an integral part of Copenhagen.

The general area has for many years been industrial, but the municipality has in recent years started converting the area into an integrated part of the city. Temporary events such as exhibitions, festivals, food markets and small businesses have flourished and helped popularise the area. (Transport-, Bygnings og Boligministeriet, 2018)

*Refshaleøen* will in the future undergo a big transformation from culturally aspiring industrial area into a dense urban environment. There is a wish to build upon the already established culture, as the area will transit from temporary experimental into a permanent urban environment.

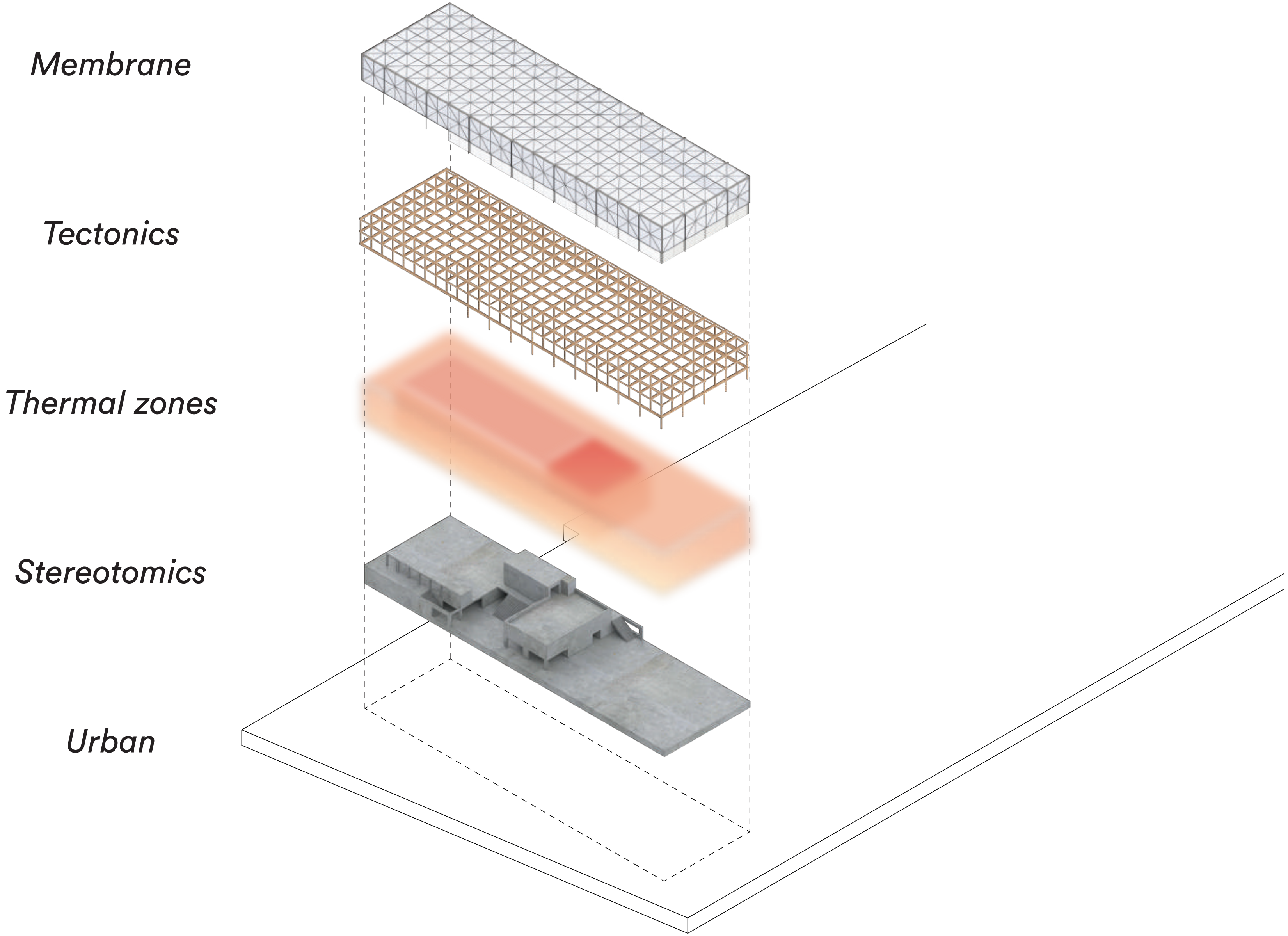


ill. 12 - *Historic aerial picture of site, Taken from Stadsing-iniørens samling. Property of Kaj Lund Hansen*



ill. 14 - *Picture of site today , Property of Styrelsen for Data-forsyning og Effektivisering*

ill. 13 - *Visualisation of Lynetteholmen, Property of By og Havn*



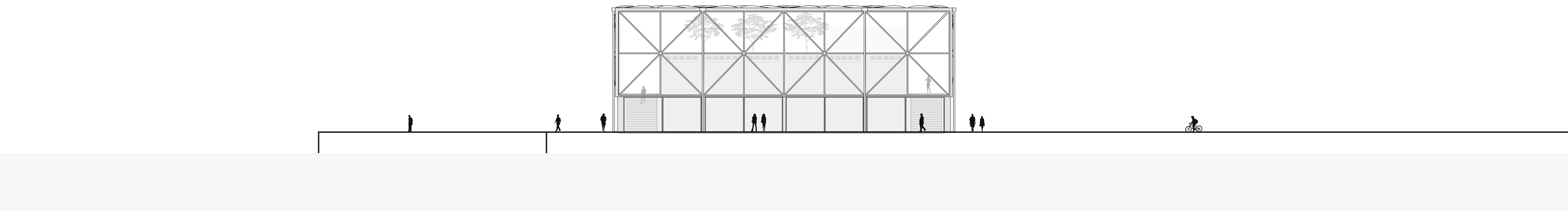

ill. 15 - *Exploded drawing design overview*

# The design

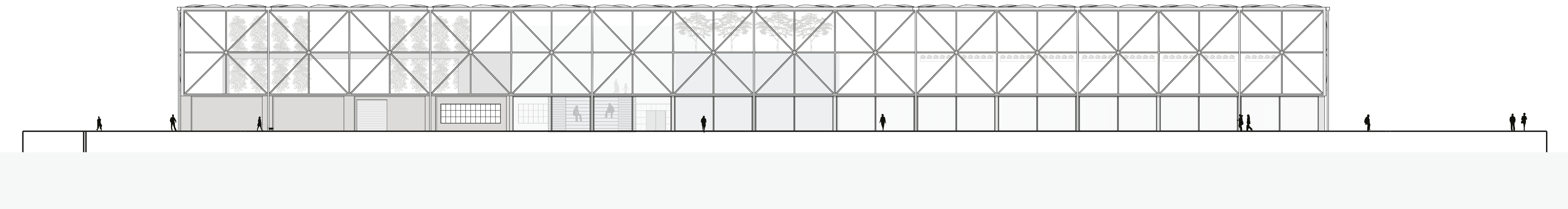
This first part of the report will present the final design in plans and sections to start out by giving an overview of the building. This section is meant to be revisited throughout the reading of the report to again understand the individual design elements in the buildings entirety.

# Elevations

Elevation south, 1:500

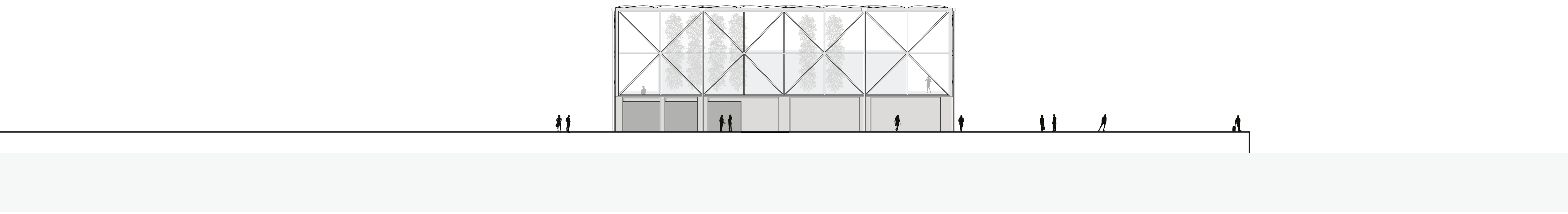


Elevation west. 1:500

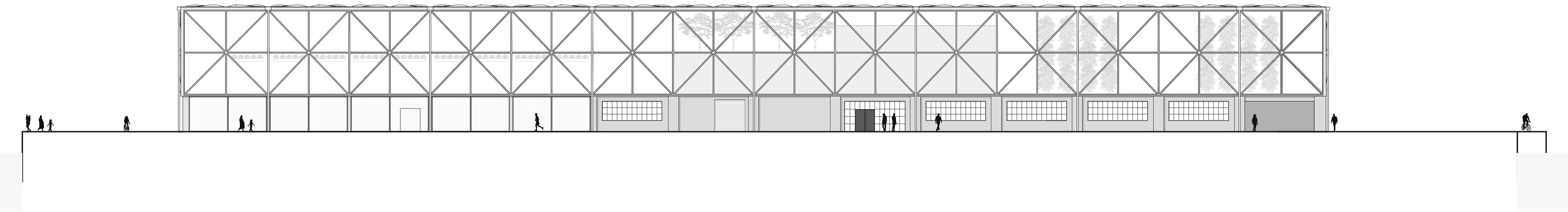


ill. 16 - *1:500 South & west elevation*

**Elevation north, 1:500**



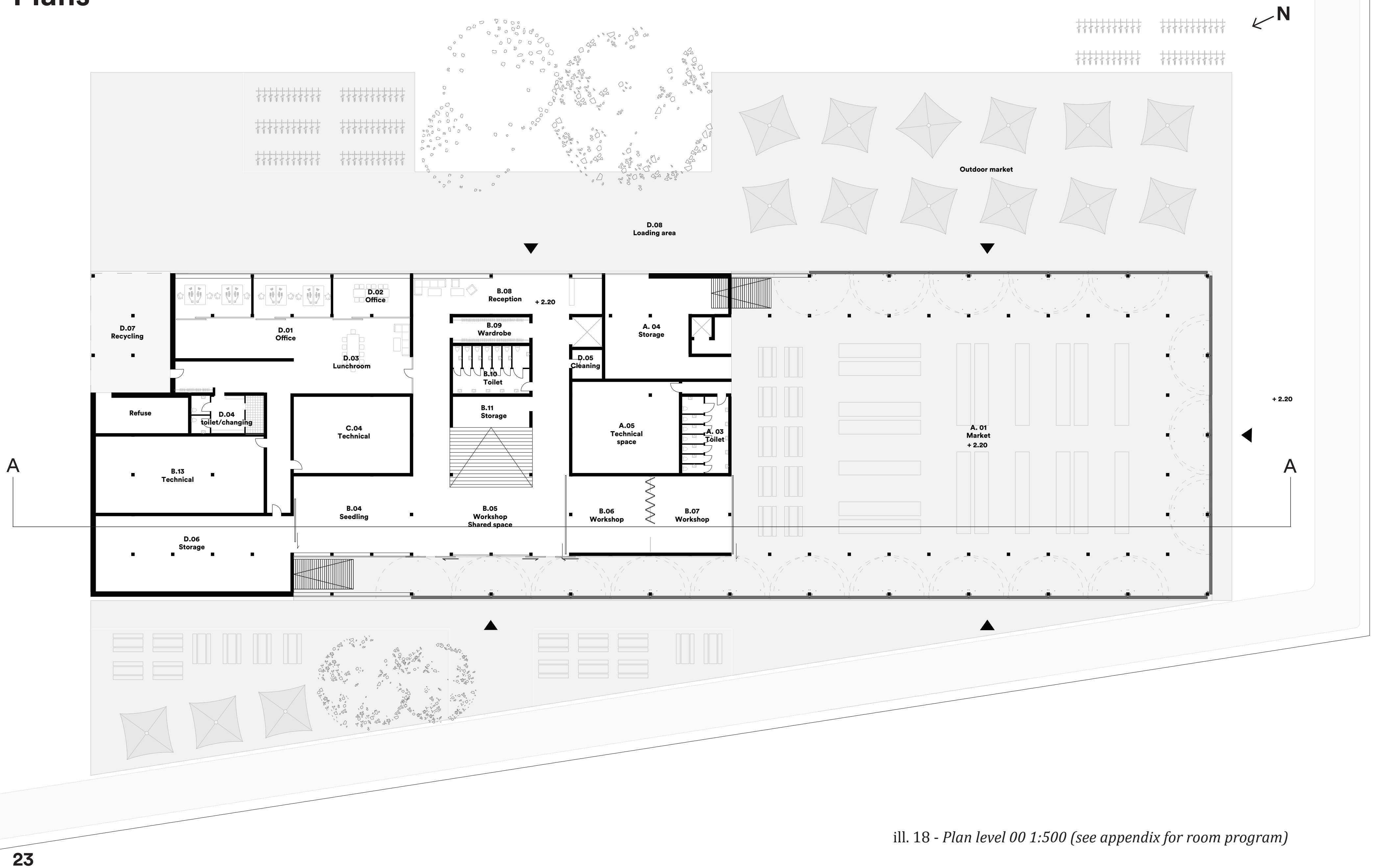
**Elevation east, 1:500**



ill. 17 - *1:500 North & east elevation*

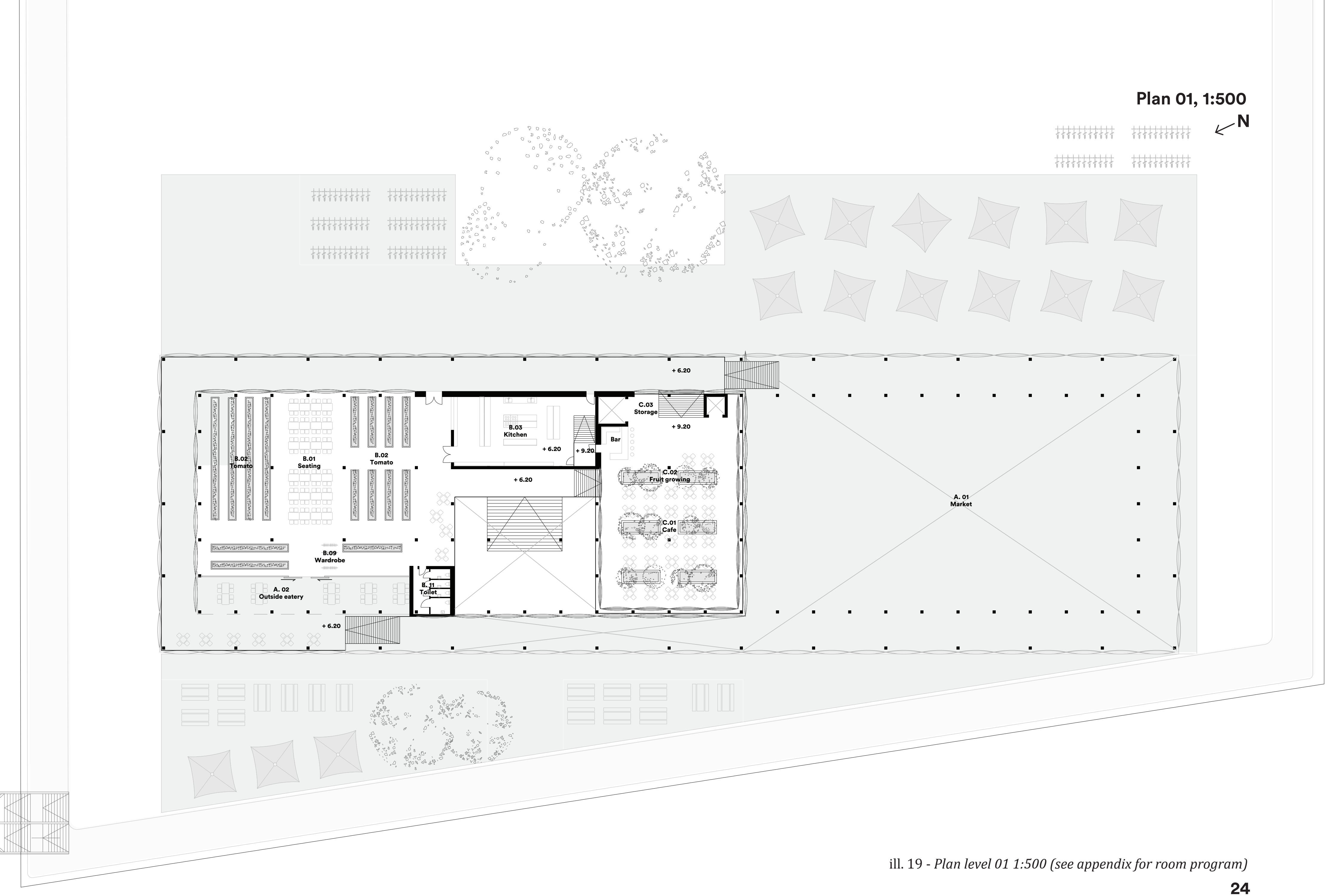
# Plans

Plan 00, 1:500



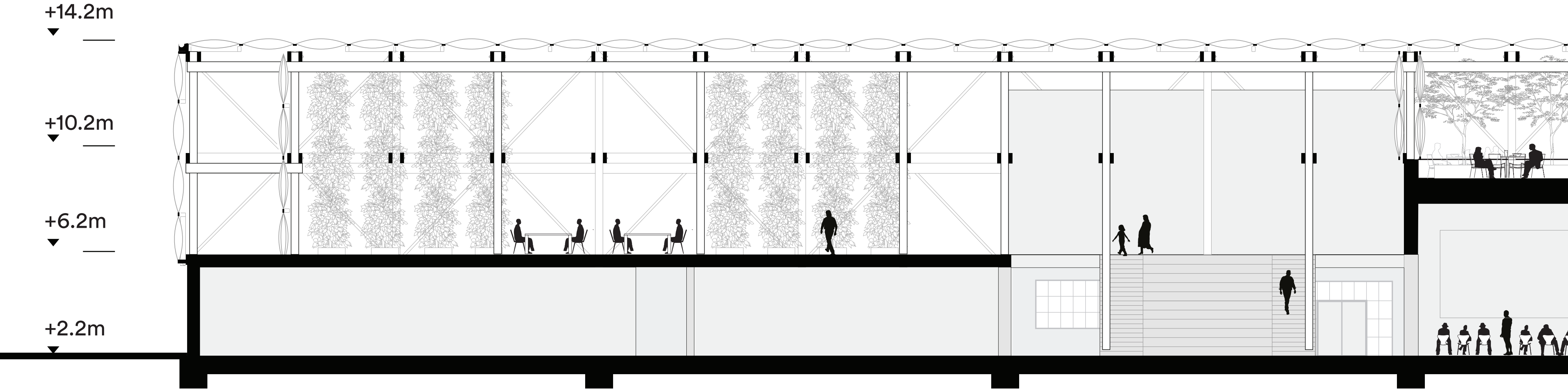

ill. 18 - *Plan level 00 1:500 (see appendix for room program)*

## Plan 01, 1:500



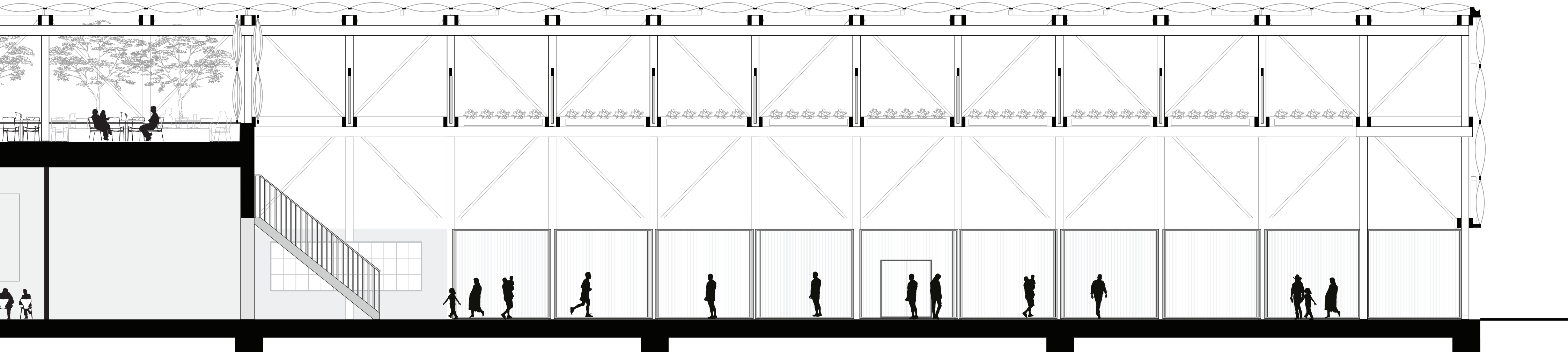

ill. 19 - *Plan level 01 1:500 (see appendix for room program)*

# Longitudinal section




ill. 20 - *Longitudinal section 1:200*

**Section AA , 1:200**



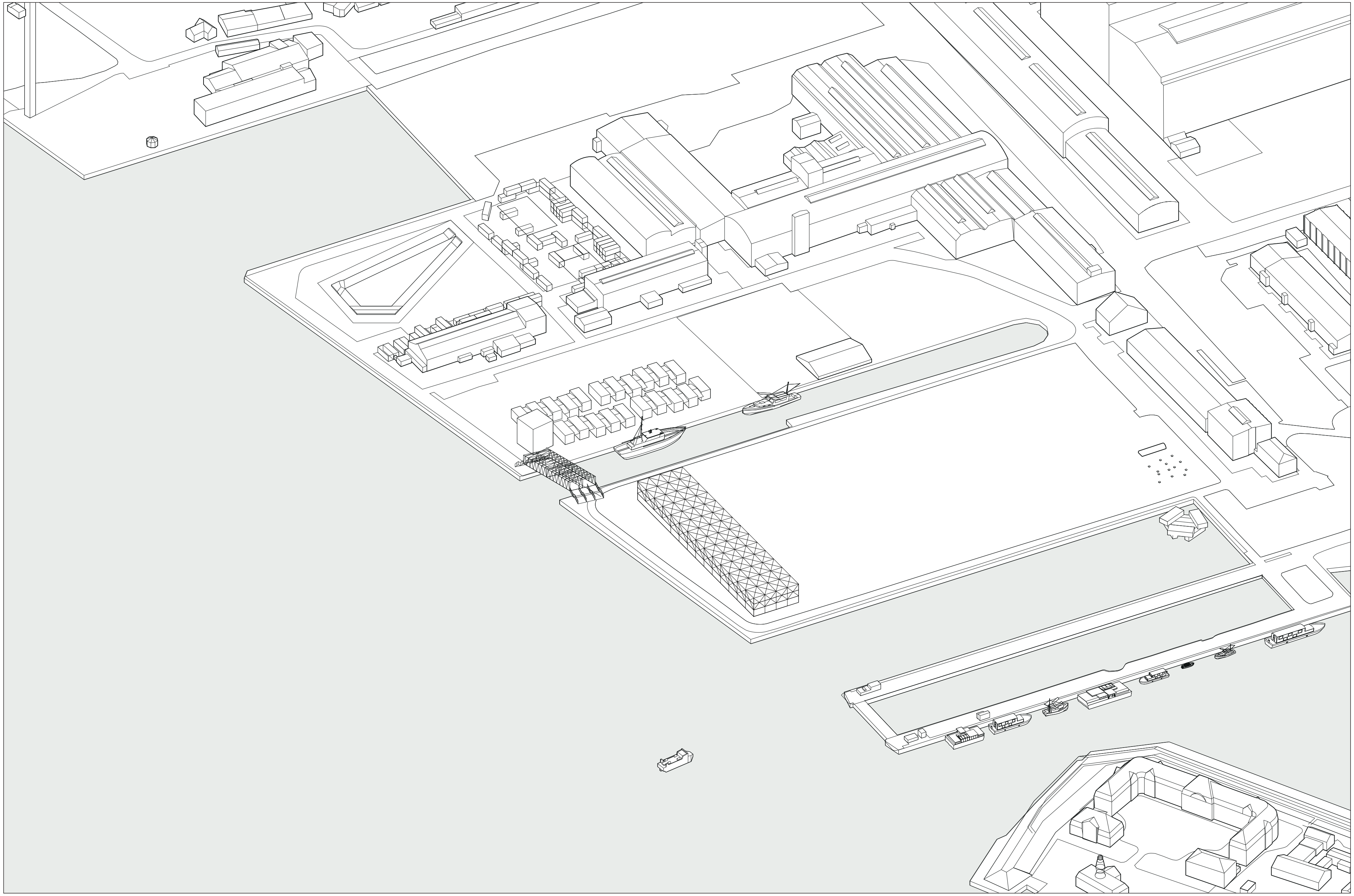
ill. 21 - *Render of approach*

# Urban role

The building has a central position in the city and will communicate its purpose of both being a cultural destination, a center for agriculture. The illustration shows a scenario, where people have left the building, only leaving the plants. The lights in the building is therefore switched to a lower spectrum of light only focusing on frequencies necessary for plants, while at same time function as an urban landmark on the harbour front despite its isolated position in the city.
This segment of the report will elaborate on the relation to the context and how the building is approached depending on the use and season.

# Placement in the context

The site poses several challenges, how it relates to its industrial context, how it positions itself on such a large undefined site. The site consist of a long oblong piece of land with channels on both sides and the harbour water to the west.
This leaves a huge undefined plane to be filled out. The most prominent position on this site is at the end of the site situating the building on the harbour front. The building mainly have to relate to the strong border of the water.
Another challenge of the site is that its future is very undefined, no concrete plans has been made for the site, but it will in all probability be developed in the future. This is also why the building is placed on the border of the site in an confined manner. The building takes a generic appearance giving room for character of area to develop in many directions. The building relates to the old industrial buildings in its vicinity, using modularity in the construction and facade expression, and a simple rectangular shape.
The building can be accessed by bike or public transport via *Refshalevej,* which connects to the city. Visitors will enter from the southeastern corner walking along the wharf to the building. The site is also connected by the harbour bus station placed on the southwestern corner, and a bridge leading north along the harbour front.

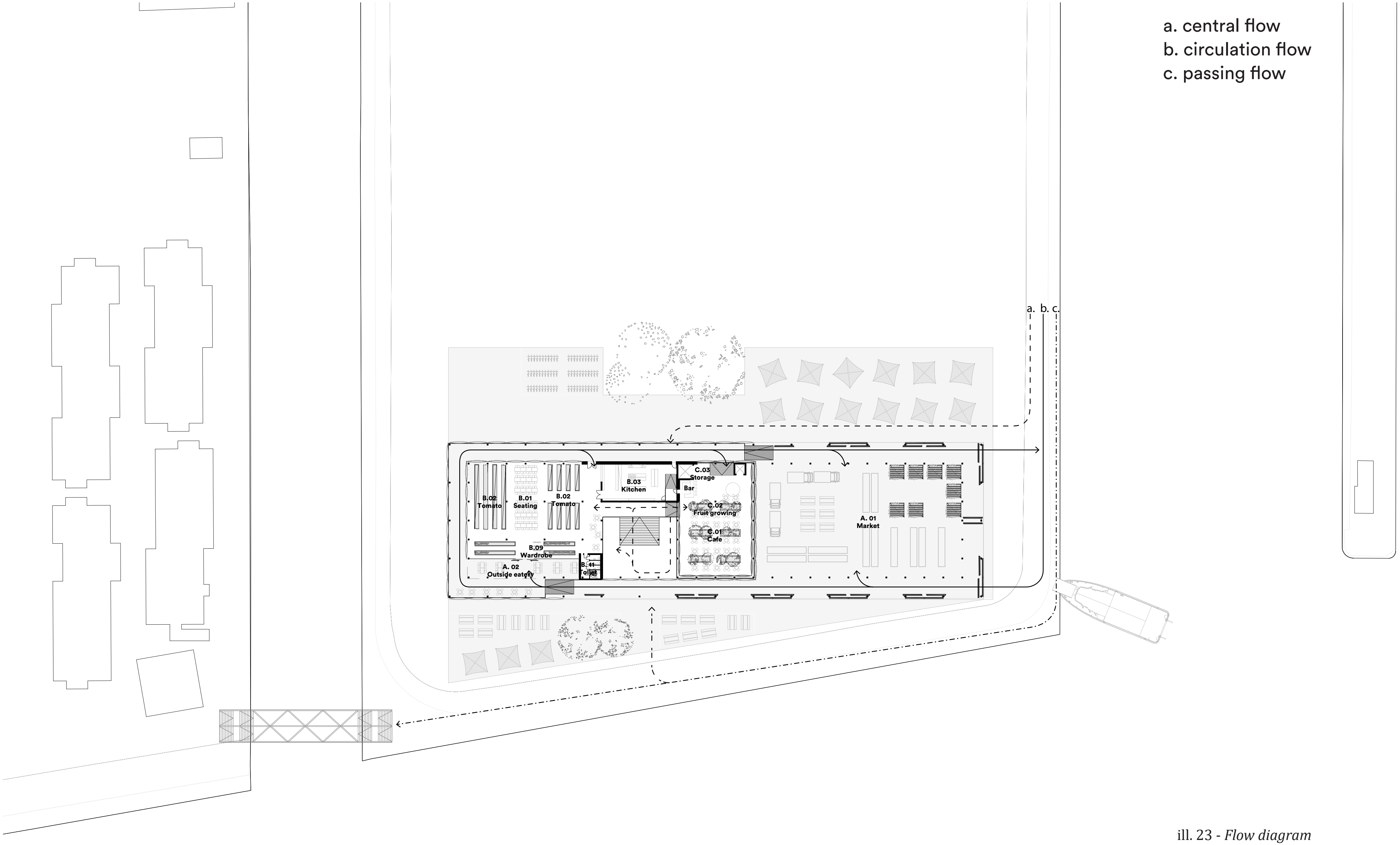


ill. 22 - *Placement in context axo*

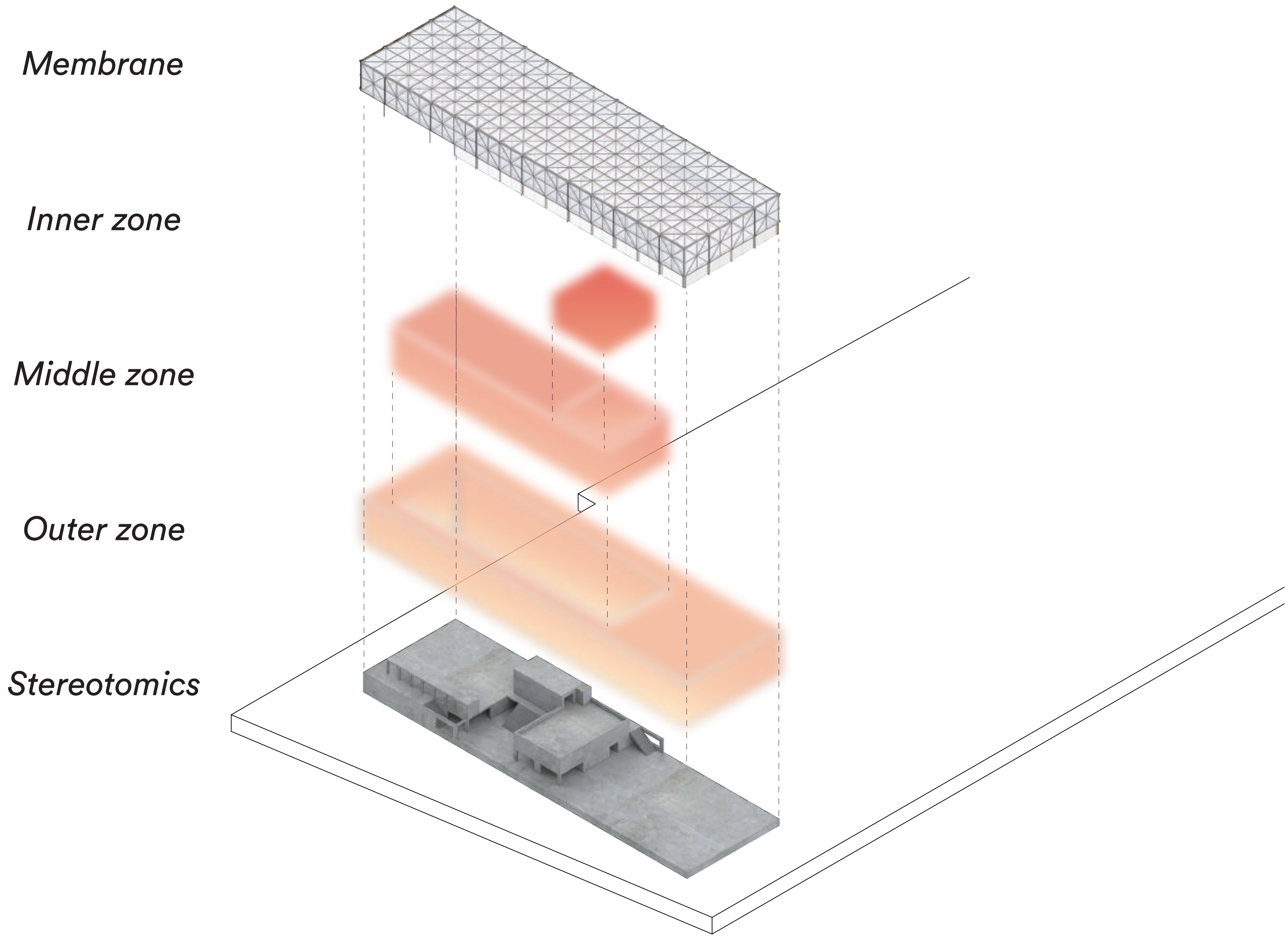
## Flow in and around the building

The main flow of the city will come from the southern wharf. Here we have three ways the flow will interact with the building. Flow c. passes the building by going along the wharf and passes the harbour bus station. This will create urban activity in front of the building and create life on the triangular plaza.

Flow b. will be the most apparent way of accessing the building. First time or occasional visitors will experience the building in this way. The building is designed with a colonnade along its periphery, which functions as a transition zone between inside and outside. The circulation flow will go along this periphery letting the visitor access the building functions as a serial experience. The flow will, in the end, go back where it started creating circulation activity throughout the building. Flow a. is the central flow, being less apparent by placing its entrance away from the main flow. It will be used by regular visitors and staff, directly taking part in the community created in the building. Here the visitor will enter the reception and can from there enter the offices or go directly in to the central workshop area. This central atrium will connect directly to the other functions, creating a shortcut, for regular visitors with a distinct purpose of avoiding going through the busy market.



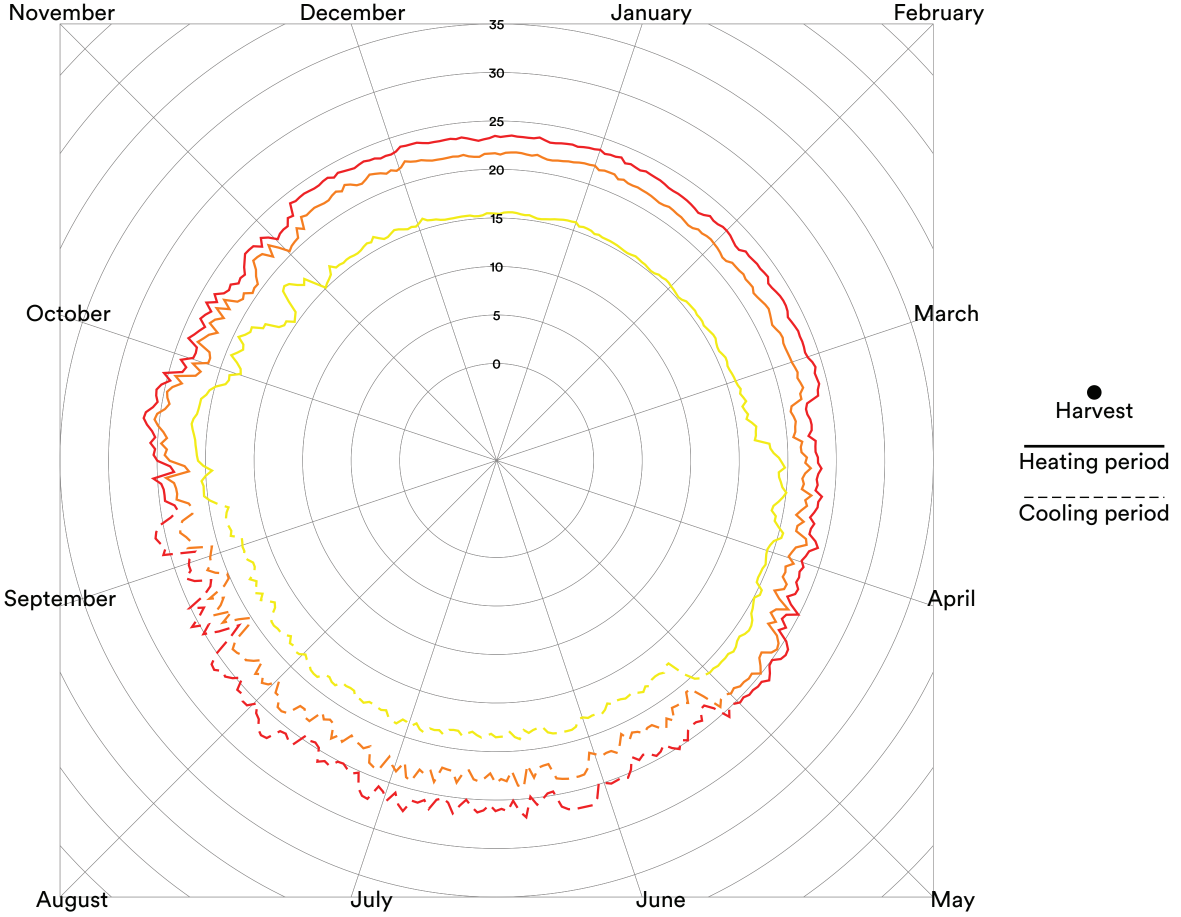

ill. 23 - *Flow diagram*




ill. 24 - *Exploded thermal overview*

# A Greenhouse for humans

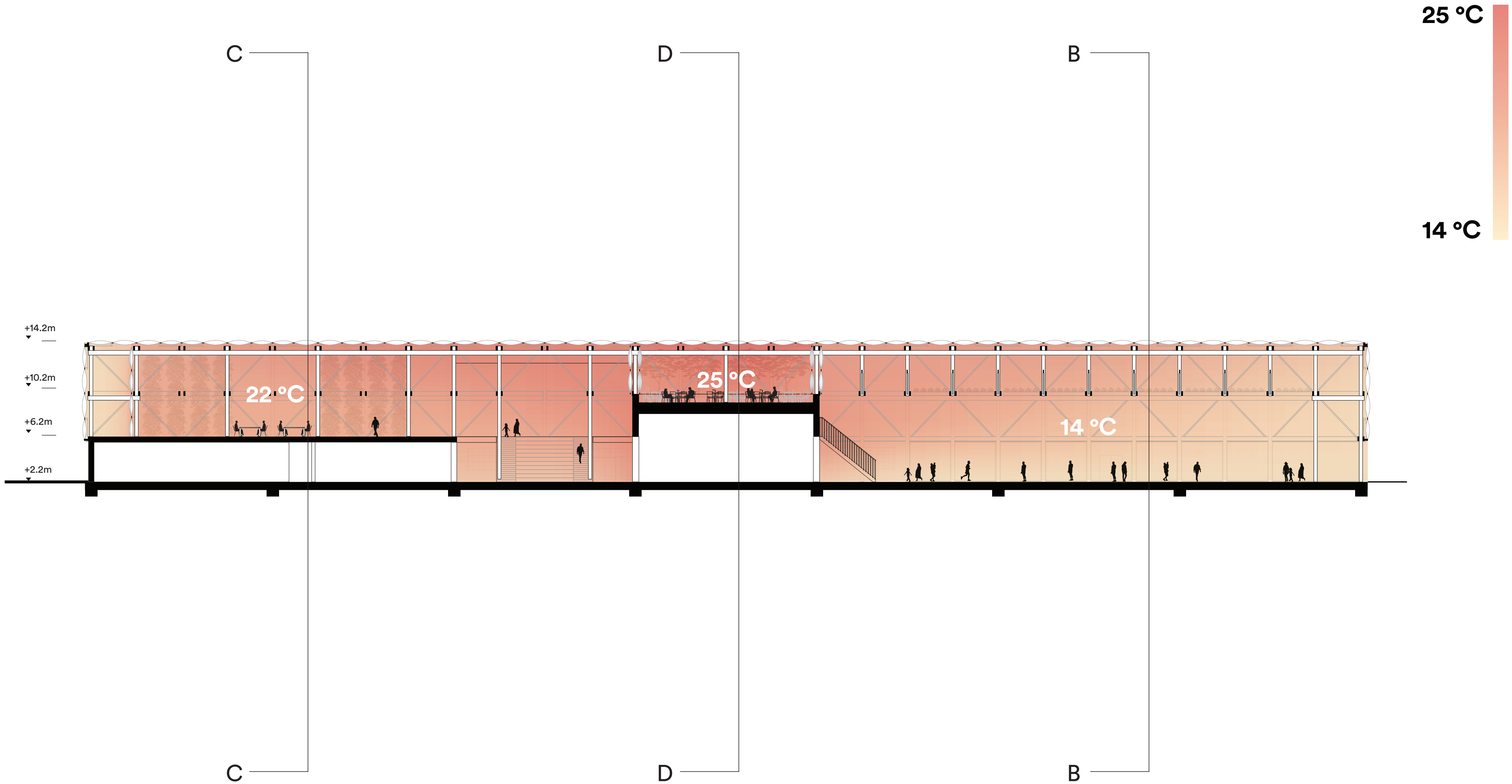
The visitor will experience different thermal environments in the building, used for different crops, but also create different human experiences. Three distinct climate zones are created by layering the building. Placing the zones closest to the local environment in the outer layer and the warmest zone at the buildings core.
This section will go through the different environments, how they are created and experienced. It will also showcase the different variations in how the building is used through numerous scenarios. The design has been created by working in parallel with architectural design and climate simulation, creating a synergy between technical performance and human experience.




ill. 25 - *Simulation diagram of temperatures in the zones*

## Thermal climates

The building relies on the passive heating and natural light it receives, which is also used for the plants to grow. This is supplemented with artificial heating and lighting to keep a stable temperature and lighting condition throughout the year. The building is split into three different zones each with their type of crops, temperature requirements and functions. The zones are placed at different heights placing the warmest zone highest where hot air will flow. Placing the thermal environments together will inevitably result in an exchange of energy between zones. This has been strategically utilized to conserve energy usage of the building. By placing the zones with the lowest thermal requirements in the outer layer it serves as a protective membrane for the inner layers. The layers are split up by ETFE walls with different thermal properties, with a descending U-value towards the core achieving a greater thermal performance in zones that require the most energy usage.



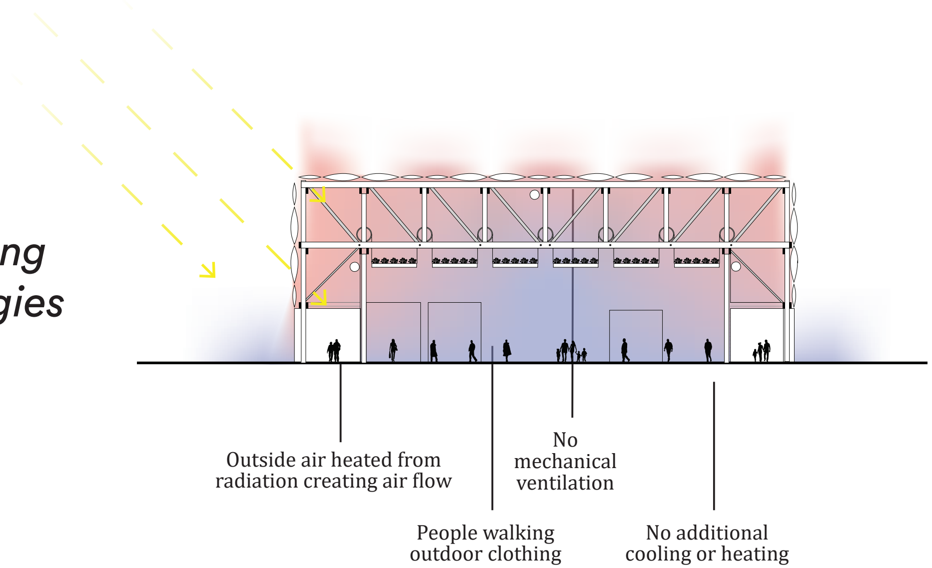
25 °C
14 °C
C
D
B
+14.2m
+10.2m
+6.2m
+2.2m
22 °C
25 °C
14 °C
C
D
B

# Heating and cooling strategies

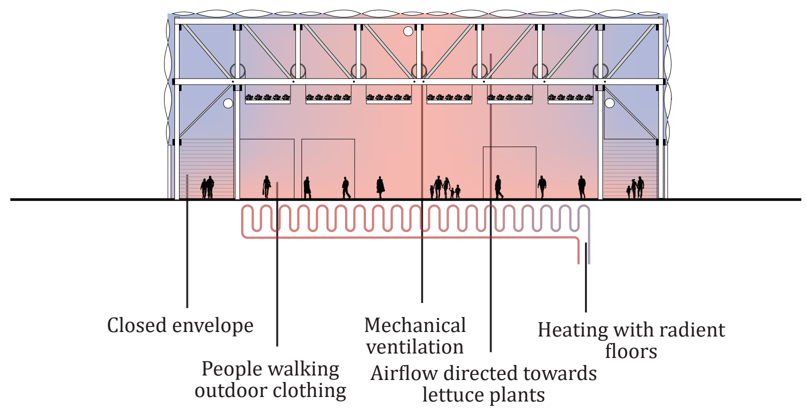
To respond to the changing natural environment each zone will respond differently depending on its temperature requirements. The graph in ill. 26 shows the need for a cooling and heating strategy. The building uses mechanical and natural ventilation, and radiant floors, for cooling and heating. Tubes will be cast into the concrete floors, where it will use heating and cooling from the harbor and geothermal energy. The outer zone will, during the summer, cool down using natural ventilation by opening the outer walls. During the winter the envelope will be closed, and rely on heating from thermal floors and mechanical ventilation. The middle zone will rely on natural ventilation, during the cooling period, and use mechanical ventilation and radiant floors during the heating period. The inner zone will use mechanical ventilation through the year, heating during winter and cooling in summer, preventing its enclosed position from causing overheating

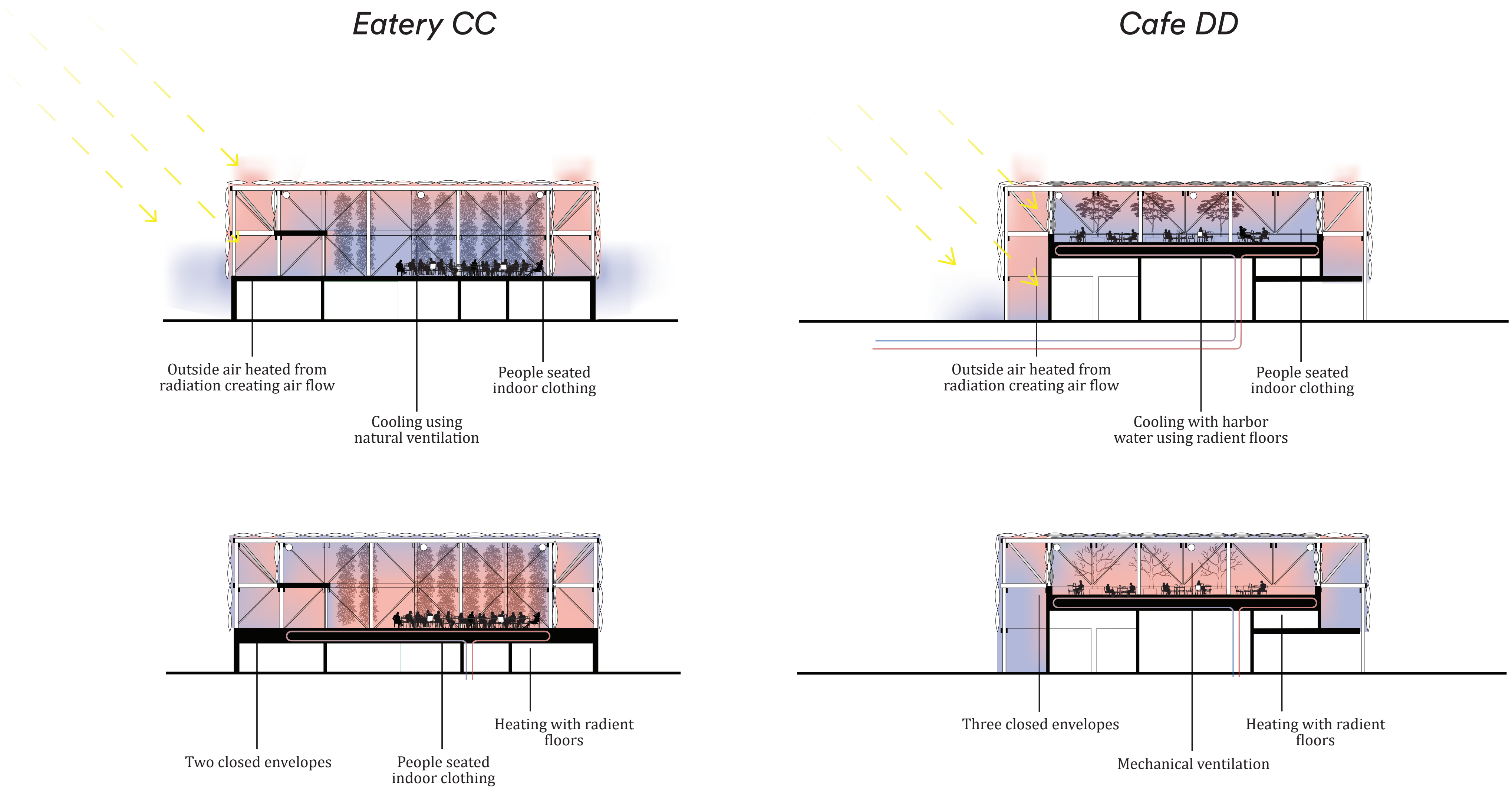
*Market BB*

*Heating strategies*



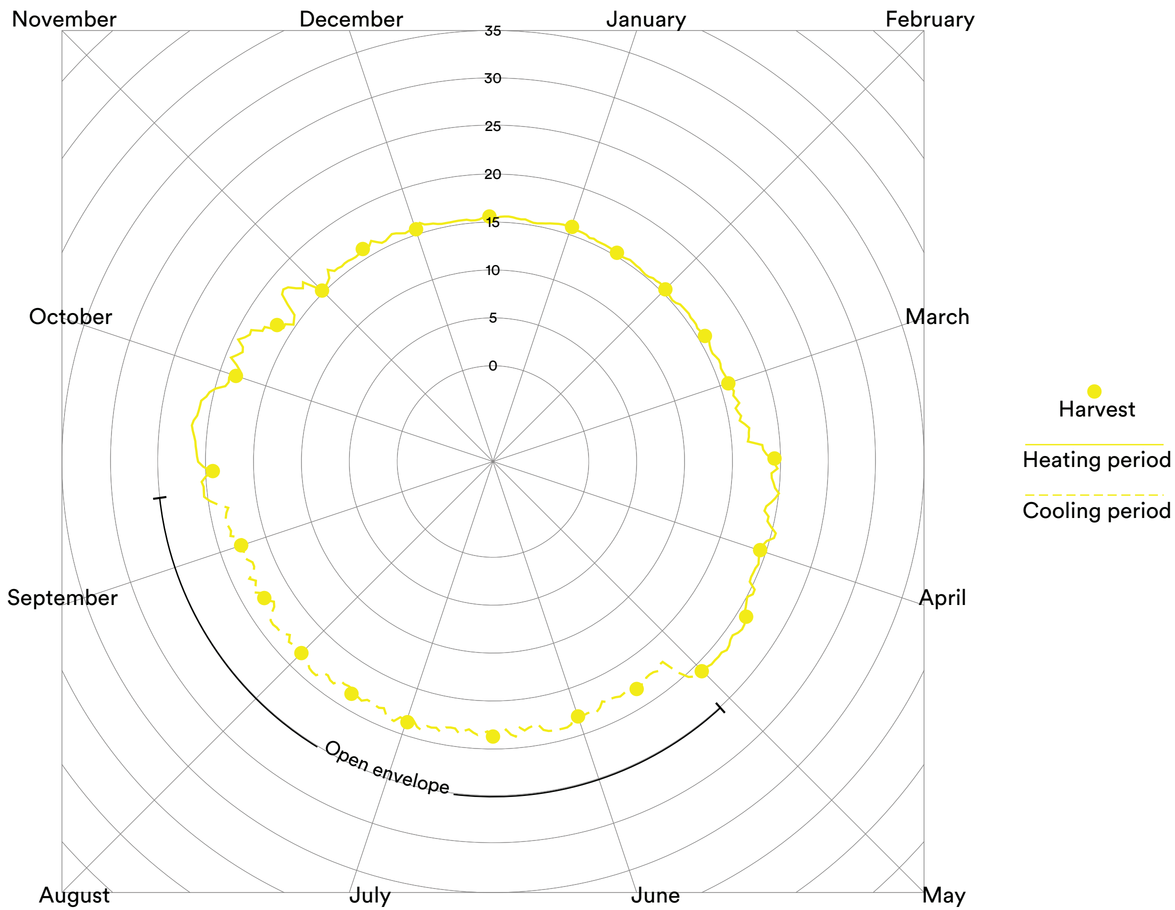

*Cooling strategies*






ill. 26 - *Sections showing strategies for cooling (Top) and heating(bottom) strategies*

# The Market square

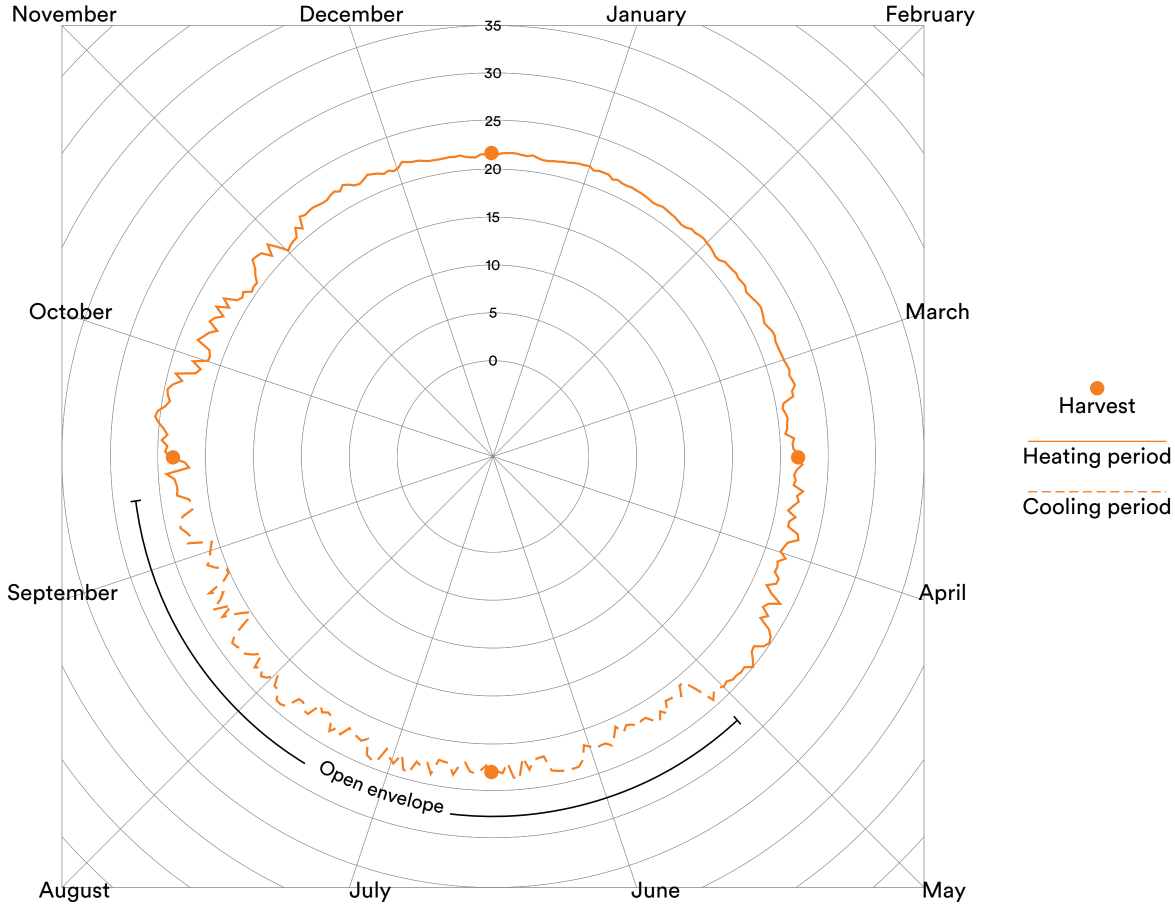



ill. 27 - *Simulation diagram of temperatures in market*

The market is the most exposed space in the building, and it will be the room drawing most visitors, being the building's main entrance. The market will be used for growing lettuce in hydroponic trays suspended from the ceiling, allowing the trays to be lifted down to be plucked by visitors. As seen on the graph in ill. 27, the harvest will be regularly placed throughout the year. This is possible since the greenhouse creates optimal conditions even in winter. The lettuce grows at a relatively fast pace and by planting the lettuce at different intervals it will be possible to continually harvest.
The market will also be the most flexible room, being a large open space. This means that it can be used by many different retailers: one day it can be filled with stalls selling produce from larger local farms, while the other day it can be filled with small time vendors who grow plants in their backyard. The market will be surrounded by movable walls allowing the building to be opened during summer.

ill. 28 - *Visualisation of a summer day at the market square*

# The Community eatery

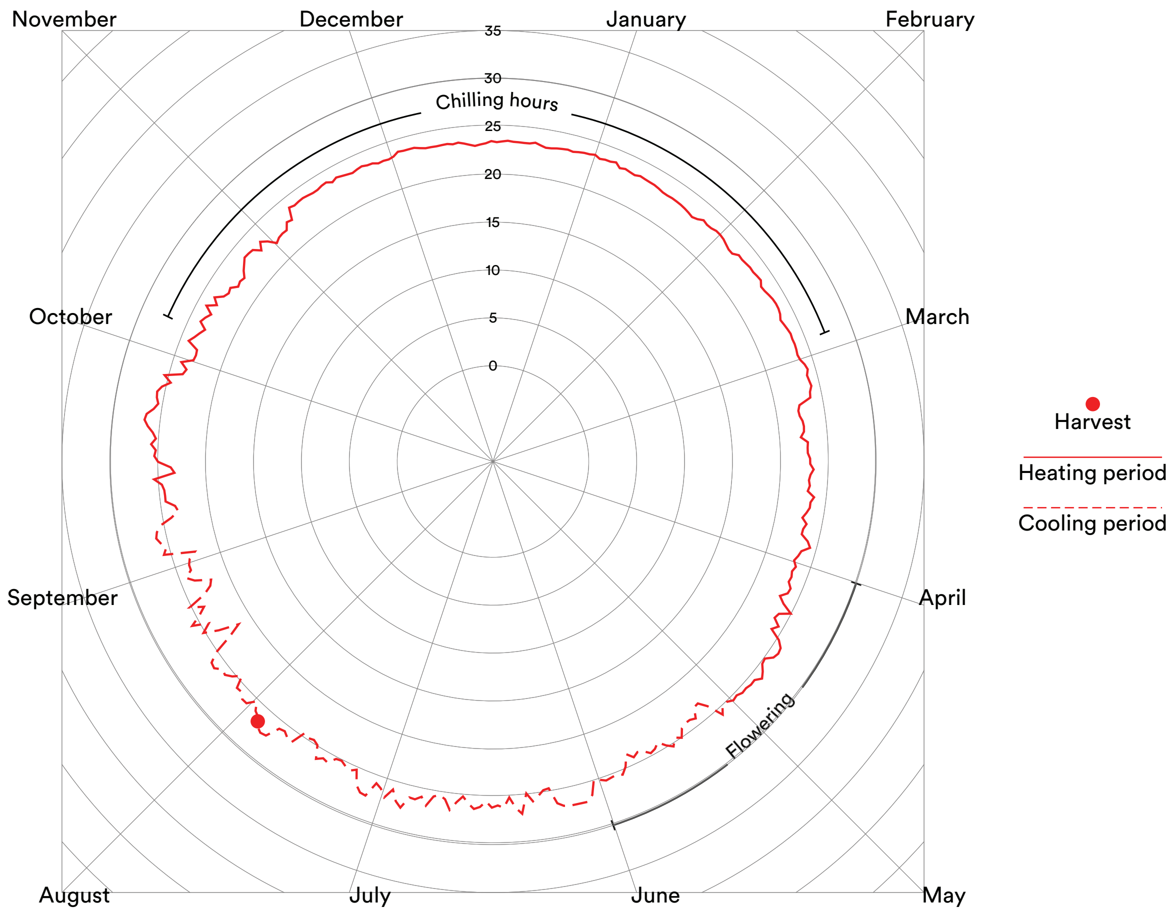



ill. 29 - *Simulation diagram of temperatures in eatery*

The eatery will be a meeting space in the building where people can come to eat together with friends or strangers. The eatery will be used for growing tomatoes, since they require a regular temperature of 22 °C, which is also an optimal indoor temperature for humans. The plants have their initial seedling phase which require higher temperatures, in a separate room. This means that the tomatoes also can harvested at a regular intervals throughout the year.

The eatery will be used for community dining directly connected to a kitchen. The eatery also has a room placed in the outer zone creating a winter garden environment used for quicker meals or simply having a seat while passing through the building. The Eatery is also directly connected to the workshop space located in the central atrium room.

ill. 30 - *Visualisation of a winter afternoon in the community eatery*



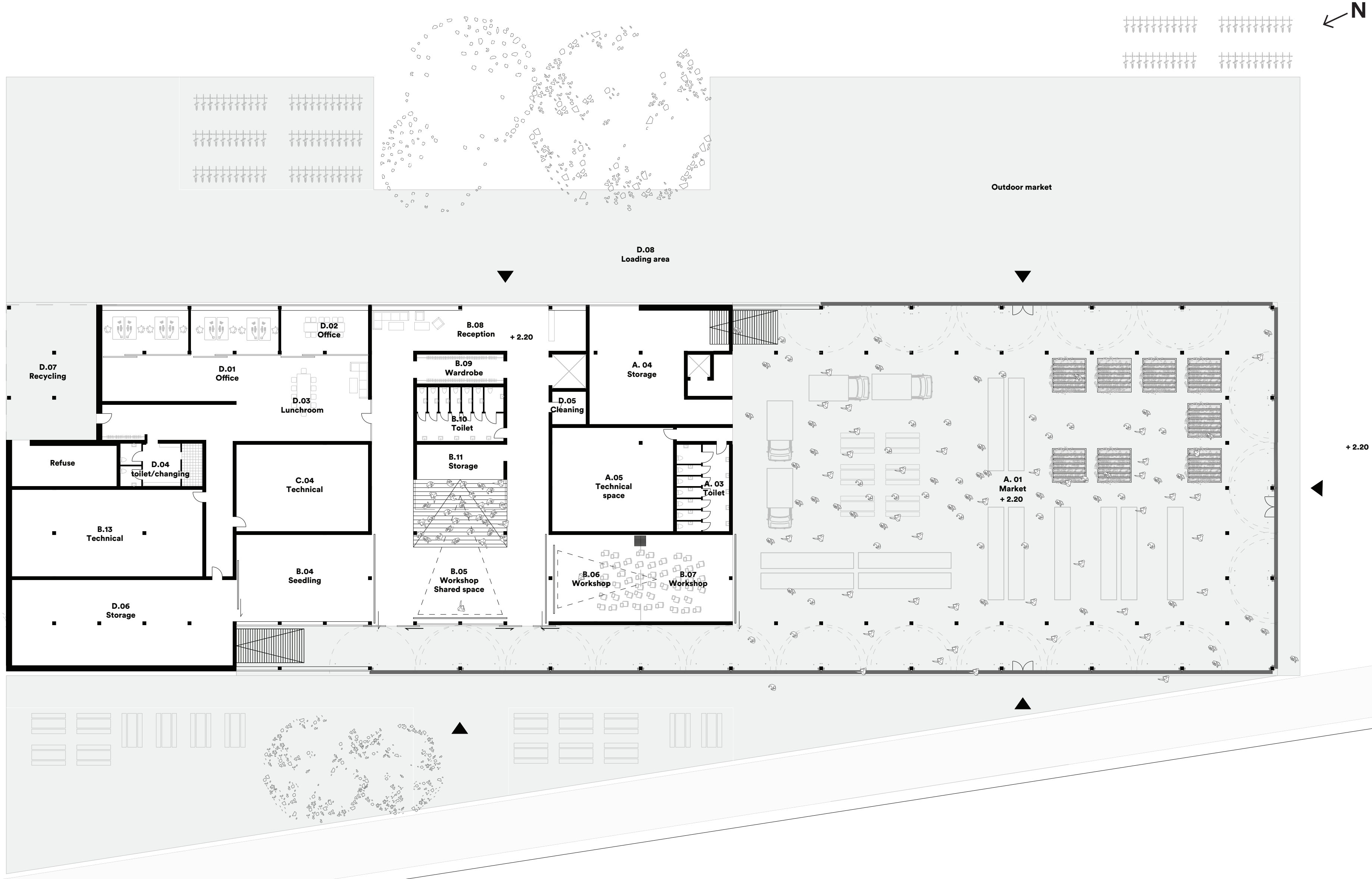

ill. 31 - *Simulation diagram of temperatures in café*

## The Intimate café

The cafe will be the warmest of all the zones keeping a high temperature throughout the year. This room will facilitate the growth of apricot trees requiring a temperature of 25 °C. The apricot trees are perennial and are therefore also seasonal, meaning they will only have harvest once a year. This also means that the visitor will be able to have different experiences throughout the year. In winter the trees will be bare from leaves. During this season's the trees require around 600 chilling hours, which means they will require a temperature below 10 °C to release hormones required for flowering. Low temperature hours will be placed during the night where excess heat can be allotted to other zones through the system of radiant floors. Between April and June, the trees will start to flowering with a pinkish hue as depicted in ill. 31. The cafe is placed at the highest level giving a view of the other zones, but it also creates a distinct location to have intimate interaction in warmer climate.

ill. 32 - *Visualisation of a spring afternoon in the intimate café*

## Plan 00, 1:500

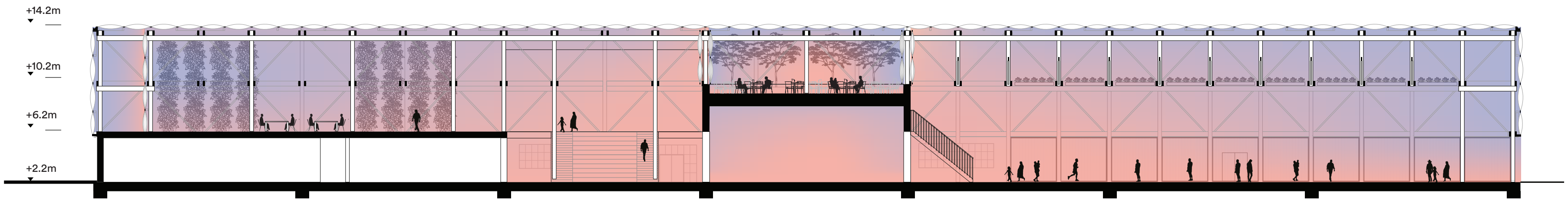



ill. 33 - *Winter scenario plan level 00 1:500*

# Winter scenario

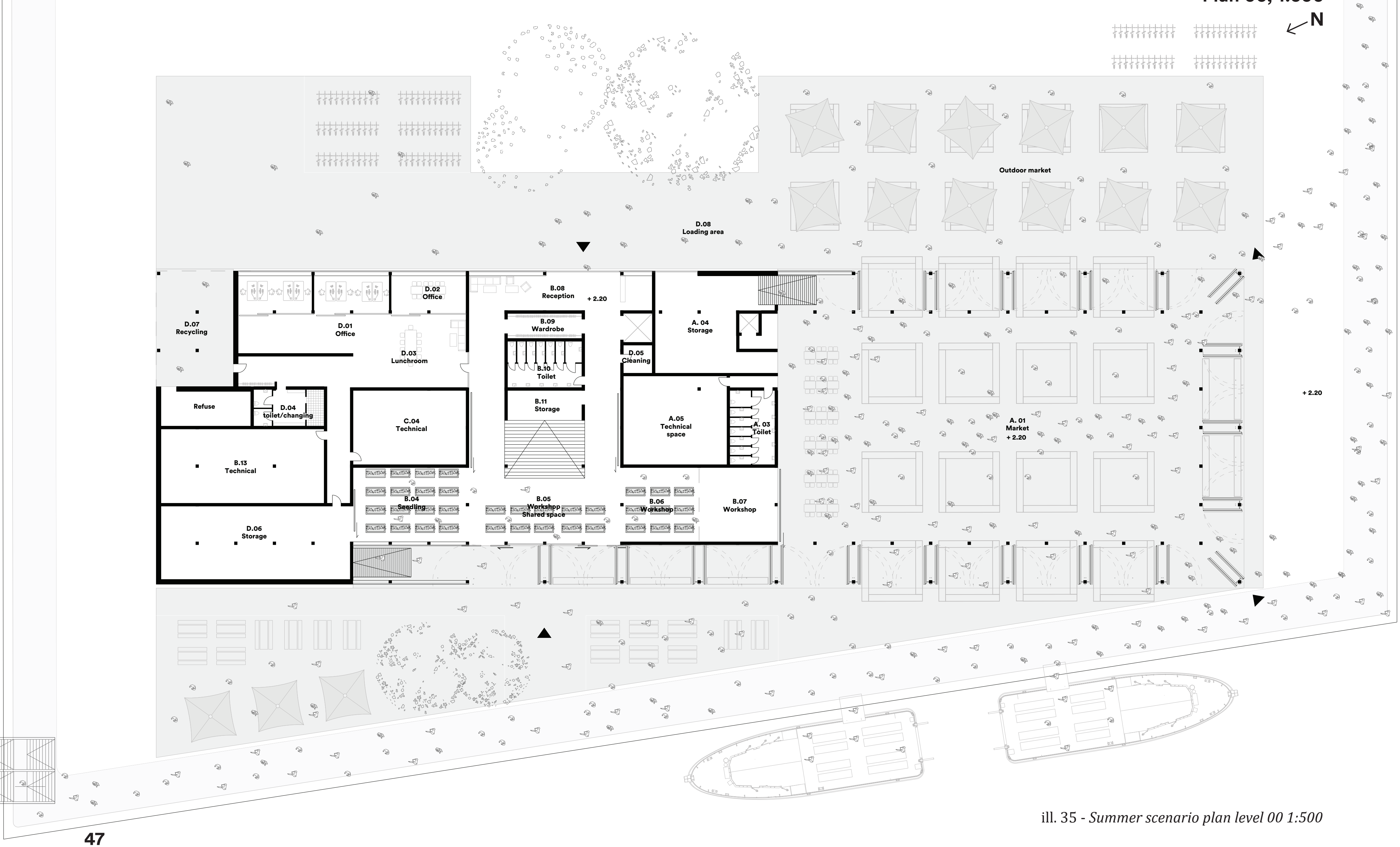
During winter the building will have to withstand the lower temperatures of the outside and be sheltered the interior from wind, rain and snow. The buildings envelope will be closed off and the building will be entered through an entrance in middle of the building or from the three doors on the movable walls in the market. In this specific scenario the building will be separated from the outside, as well as creating separations within the building. Two large sliding doors can close off between the market and the workshop. The workshop is additionally partitioned into two spaces. In this case, the workshop is used to have two separate lectures. The large stair in the central atrium room is as a grandstand used by audience for lectures or projecting films on the opposing wall. The market in this scenario is housing the everyday market activity of the building. The general flexibility of the market is showcased. The hydroponic lettuce platforms are lowered down in a quarter of the market allowing visitors to pick the harvest. The market is also filled up by movable aisles filled with fresh vegetables from local farms. Another quarter of the market has food trucks parked with benches used for quick meals while shopping. The space has low heating requirements, still requiring visitors to keep their outside clothing on, but sheltering from wind and rain.

Since all the rooms are separated in this scenario they require individual temperature regulation. All the rooms will be heated by radiant floors, leading used air up to the roof where the mechanical ventilation system is placed. The inner and middle layer zones will still be able to maintain a higher temperature by insulating using two or three layers of the building.




ill. 34 - *Flow of energy relative to zones, winter*

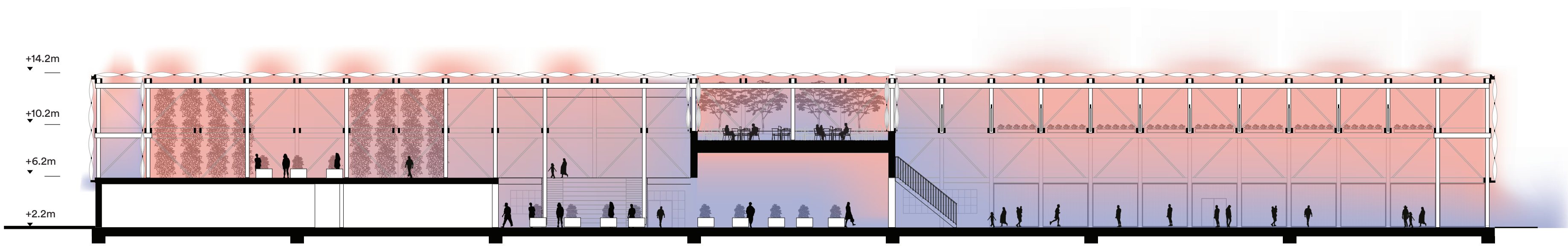
# Plan 00, 1:500




ill. 35 - *Summer scenario plan level 00 1:500*

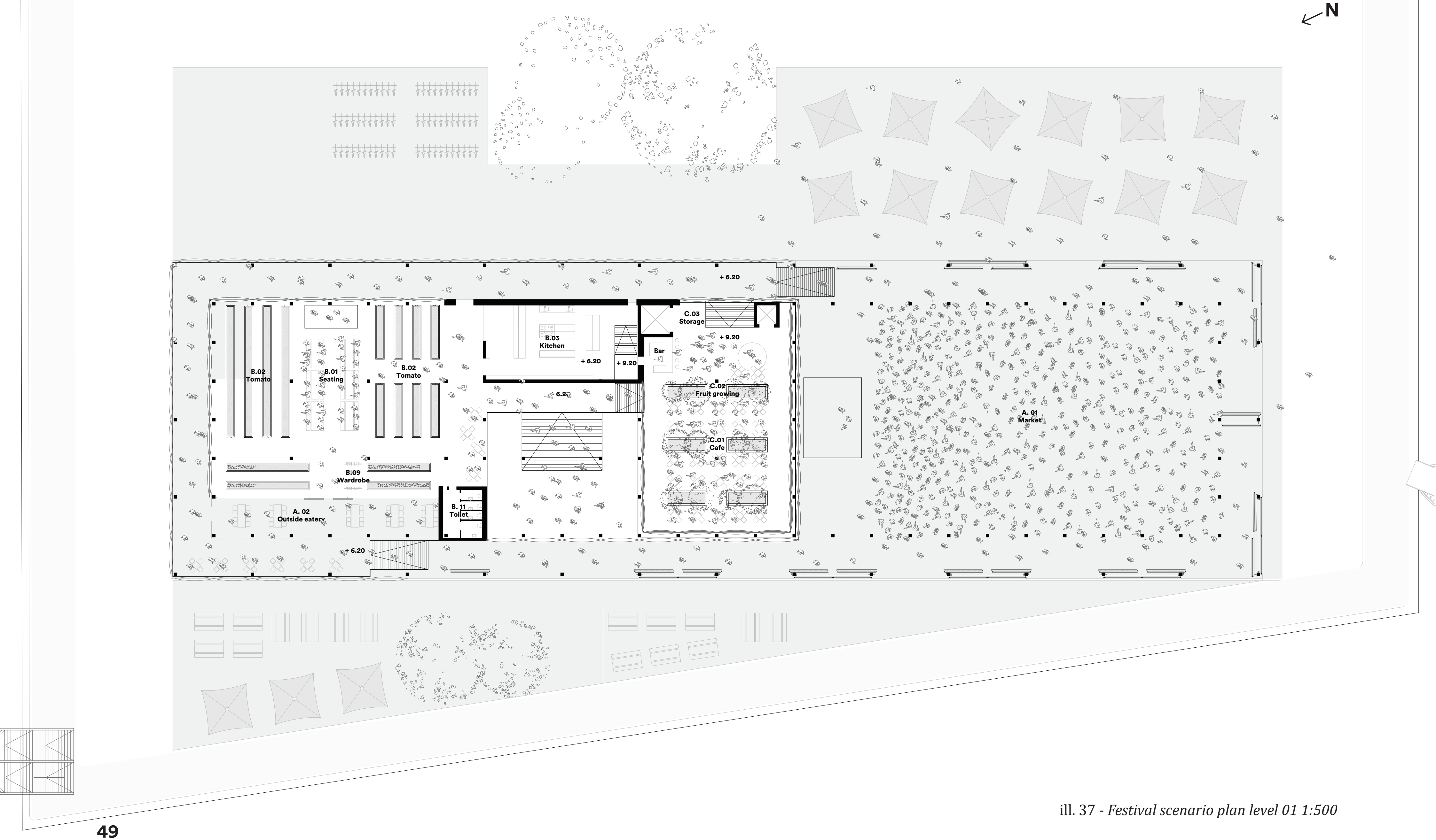
# Summer scenario

in the summer season the temperature rises, potentially creating overheating issues with the transparent envelope.
To prevent this, the building will open its envelope allowing the outside air to permeate the building. The market can be considered an outside space entered from all directions. The walls are in this scenario opened to stand perpendicular to the facade. This creates a number of niches used for different purposes. In this scenario the market is filled with market stalls and the niches are used as market stalls as well. The corners of the market are used as entrances. The niches created in the hallway zone on the other side of the workshop are used for temporary outside serving. Since the walls are interactive, they can be adjusted according to changing environment. A strong wind from the west can be sheltered by closing off a side of the building
The inside and outside flows together by letting the market stalls continue out to eastern plaza. On the western side, two boats are docked selling fish. The workshop is used for an urban farming class, where Tomato seedlings are taken out of the seedling room to be replanted in the eatery.
In this scenario natural ventilation is used to cool down the entire building, letting outside air flow through the building. To let air into the middle zone, the walls to the atrium room will be opened as well as vents in the facade. The cafe will be closed off and relies on cooling from harbour water.




ill. 36 - *Flow of energy relative to zones, summer*

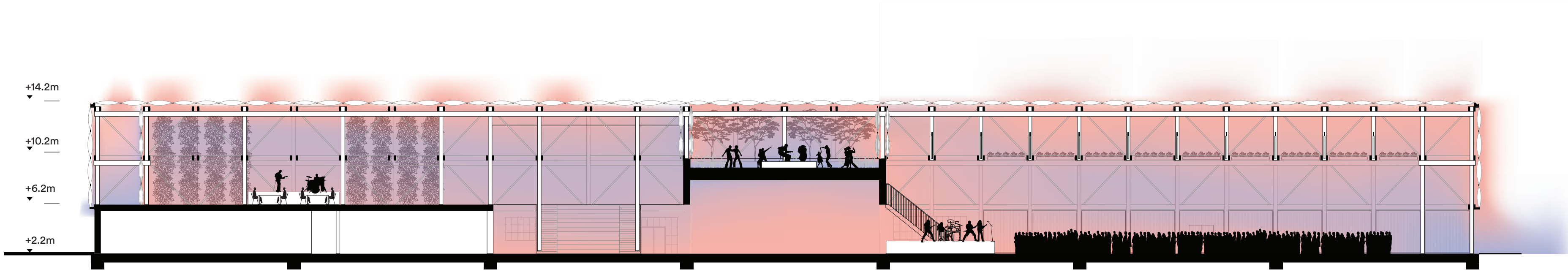
## Plan 01, 1:500



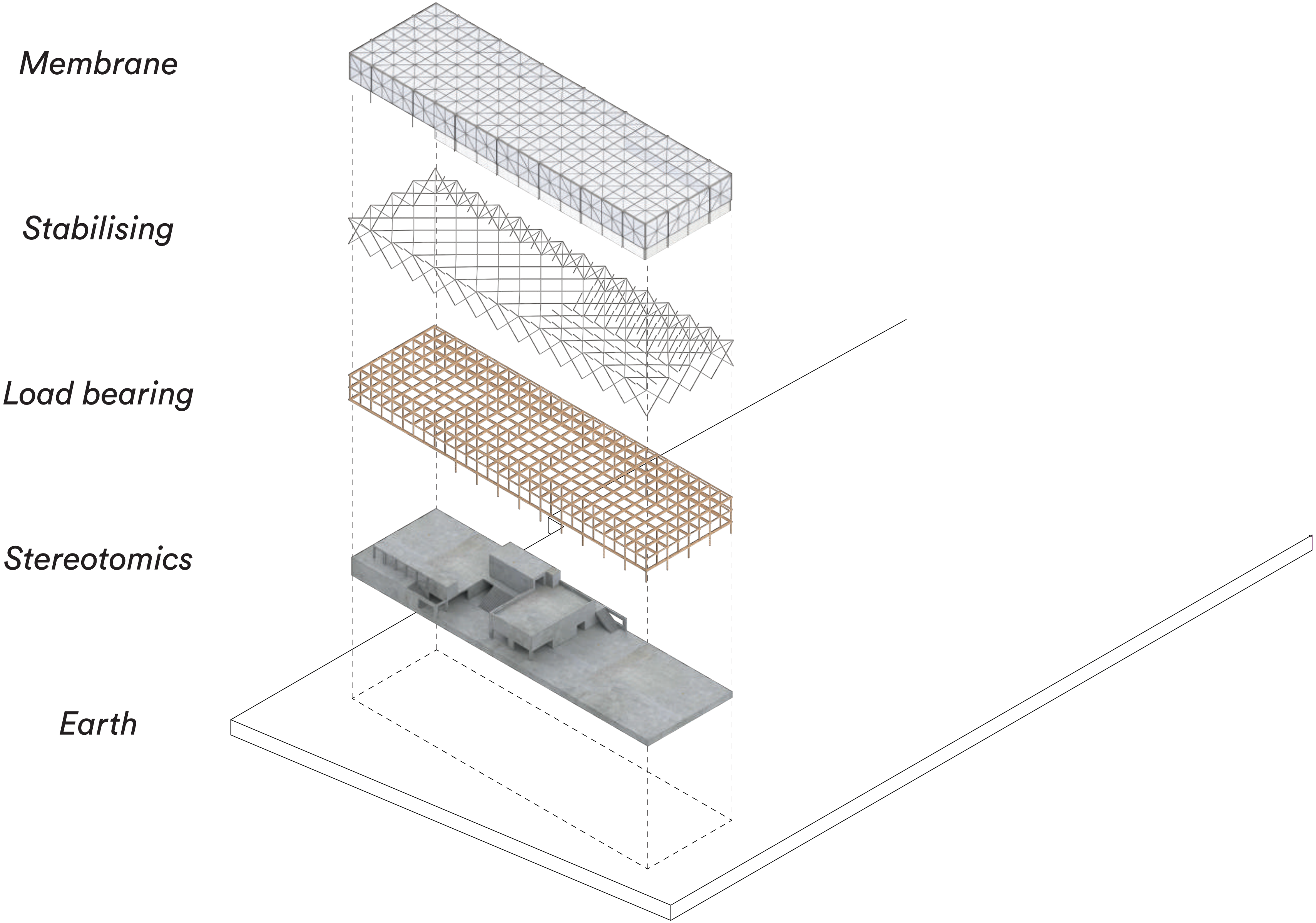

ill. 37 - *Festival scenario plan level 01 1:500*

# Festival scenario

In this scenario the building will host a musical festival having to withstand a large people load, both creating heat and polluted air.
The doors to the market will be opened allowing fresh air to permeate the space, but additional mechanical ventilation might be needed in case of larger concerts. Half of the doors in the market has been opened 180 degrees to create a facade with larger openings allowing people to go between inside and outside but still creating a define concert space. The outside market is used to sell beverages and food for the festival guests. The workshop room could be used for additional circulation space or supplement the storage room, to keep concert equipment, or to create a backstage area. In this scenario the entire wall between market and eatery will be opened to create a free flow between the different spaces each with a stage. The eatery can be used for seated concerts, while the cafe will be used for small intimate concerts. The north western plaza can also be used for outside concerts or as lounge space. The Central atrium will be used for a lounge space for people to be seated in between going to concerts. The seedling space can be used for selling beverages and food.
The people load will create the most difficulties. The inner climate is supplied with fresh air that will be heated from solar radiation entering the envelope as well as a significant people load.



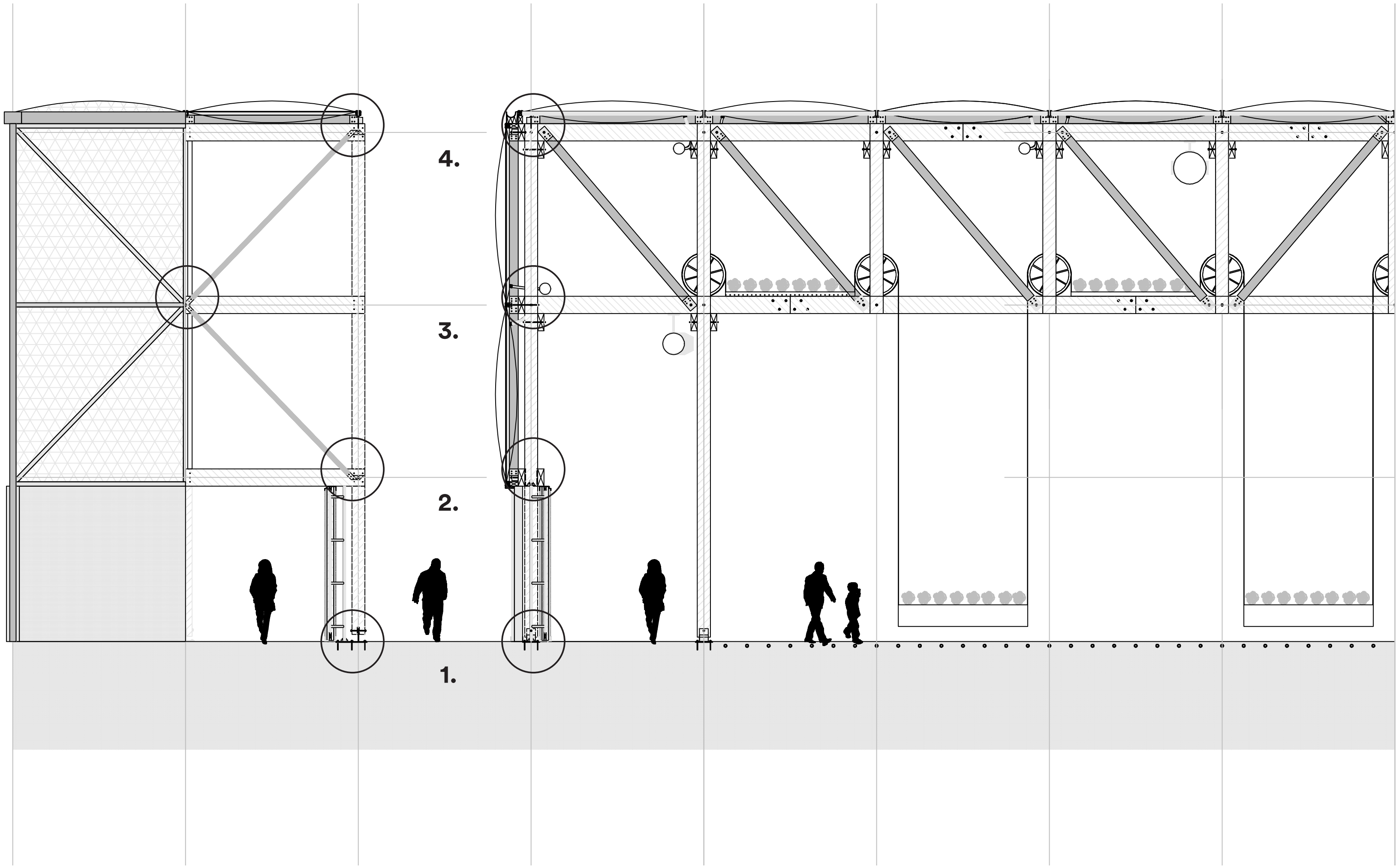

ill. 38 - *Flow of energy relative to zones, festival*




ill. 39 - *Exploded structure overview*

# Structure, construction & tectonics

The building is designed with a simple structure clearly showcasing how forces are transmitted through columns and beams of the building. The building is constructed from plastic, steel, timber and concrete, that each holds their own aesthetical and performative properties. The detailing is based on simple joints in a repetitive system clearly showing how the building is put together. The entire building rests on a heavy concrete base. In the following section the structure and construction will be explained in detail, how the elements of the building physically comes together and how this creates a tectonic expression.

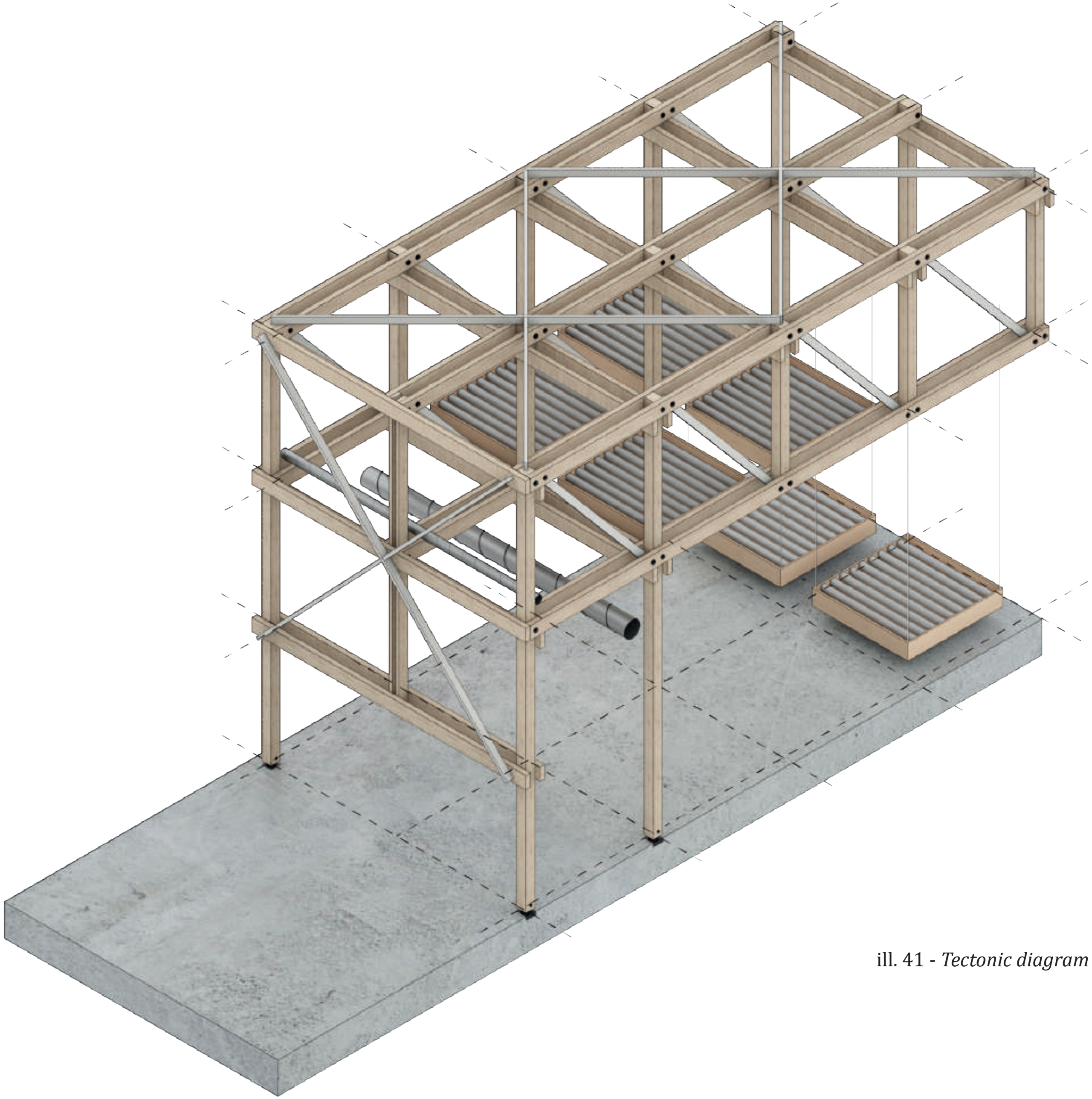



ill. 40 - *1:150 principal construction section of the market square, connection*

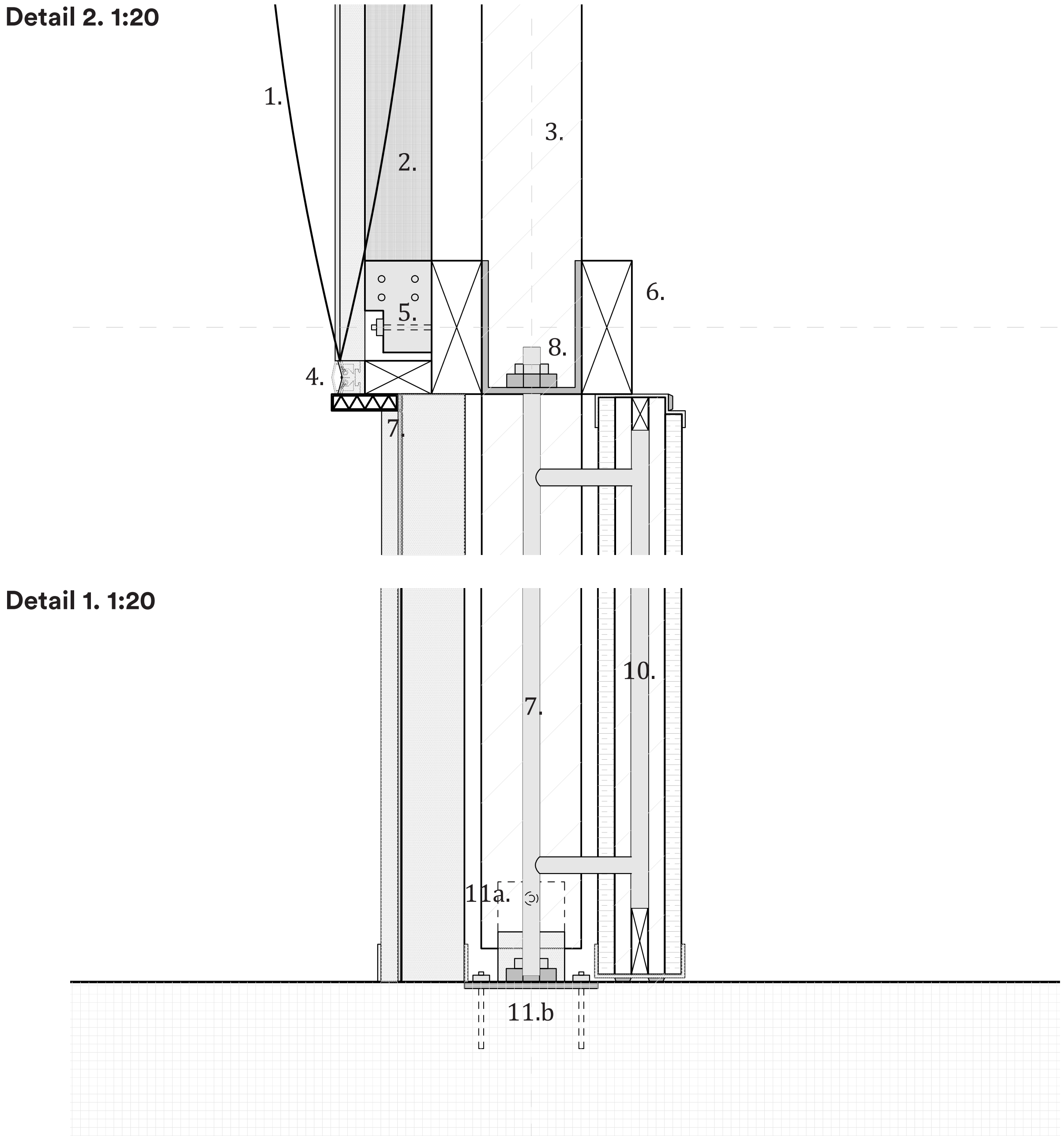
# Tectonic assembly

The building's structure is composed of layers. The concrete base creates a foundation for the timber structure to stand on. The timber structure translates the external and internal loads down and binds the buildings together. The steel acts as the stabilising system, as the structure is constructed with hinged joints. The structural pattern of triangles gives the building geometric stability, but also shapes the contours for the attachment of the skin.

The flexibility of the design is thought into the structure, so the mechanical systems can work. The column spacing in the facade fits with a double door, and the truss over the market square is designed to hold a hydroponic system. The dimensioning of the elements is based on simulations of the loads imposed by physical constraints of gravity, wind and snow, and from the hydroponic system suspended from the roof.



ill. 41 - *Tectonic diagram*




ill. 42 - *1:20 principal construction details, connection with base & swing door to ETFE transition*

# Ground, facade detail

1. 2 layerd ETFE
2. 200mm x 50mm, t 5mm, S275 steel tube
3. 300mmm x 300mm C30 column
4. ETFE seal
5. Pinned steel cross bracing joint
6. 2 x150mm x 400mm C30 beam (II)
7. Galvanised steel door frame
8. Steel U-bracket, door spinner bearing
9. Rotating steel tube with offset to door
10. Door: 2 x 50mm polycarbonate, 150mm timber frame, offset steel hinge

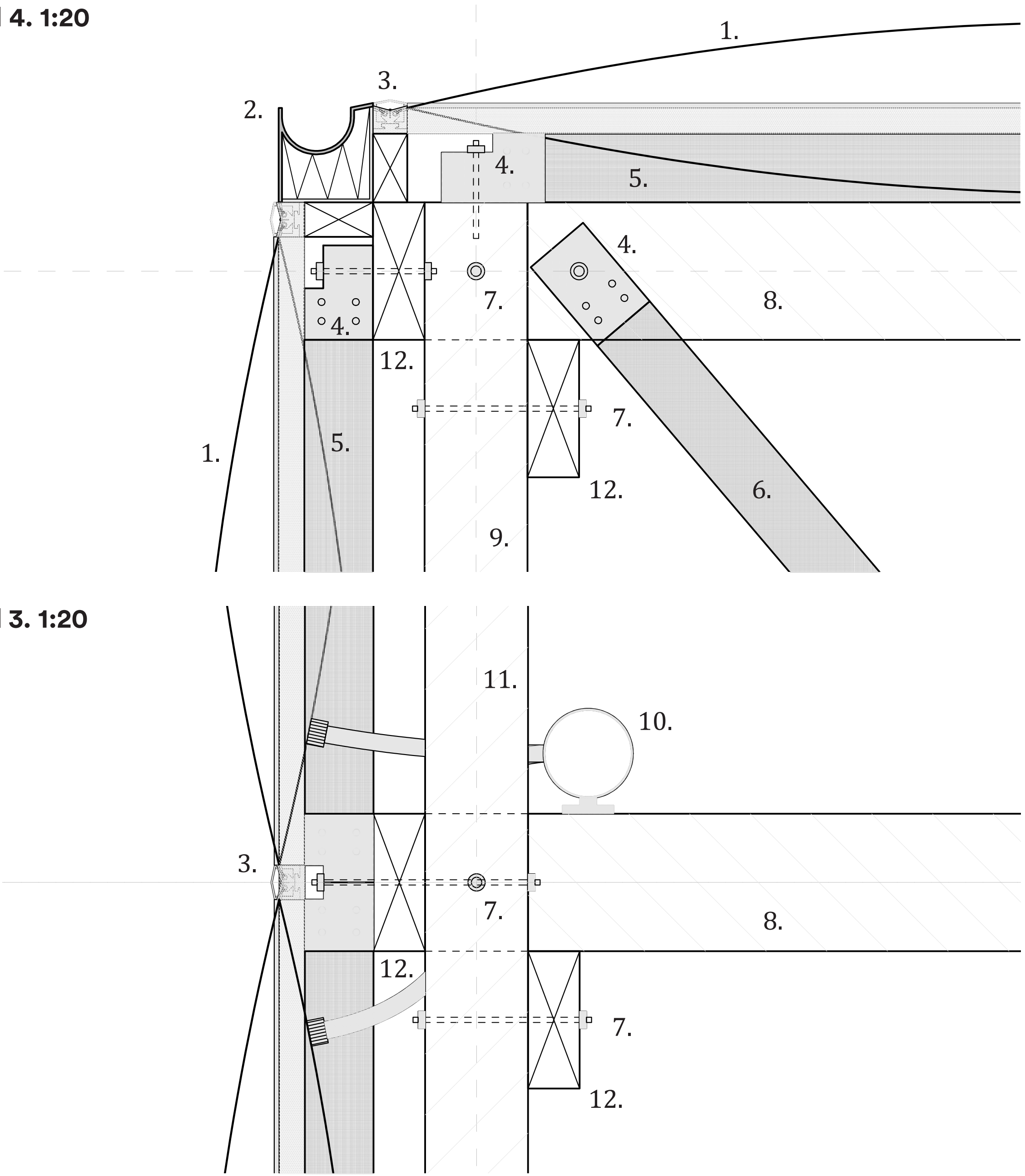
11a. Hinged steel joint, door spinner bearing

11b. Lowered steel joint fixed to concrete

This detail is of the construction from the ground to the first ETFE membrane. The door mechanism is designed to be able to fold 180 degrees for the different building modes. A steel foot creates a lifted transition from the concrete to the column. The membrane and the carrying structure is split with a small gap. Separating the stereotomic, tectonic and skin.

**Detail 4. 1:20**

**Detail 3. 1:20**

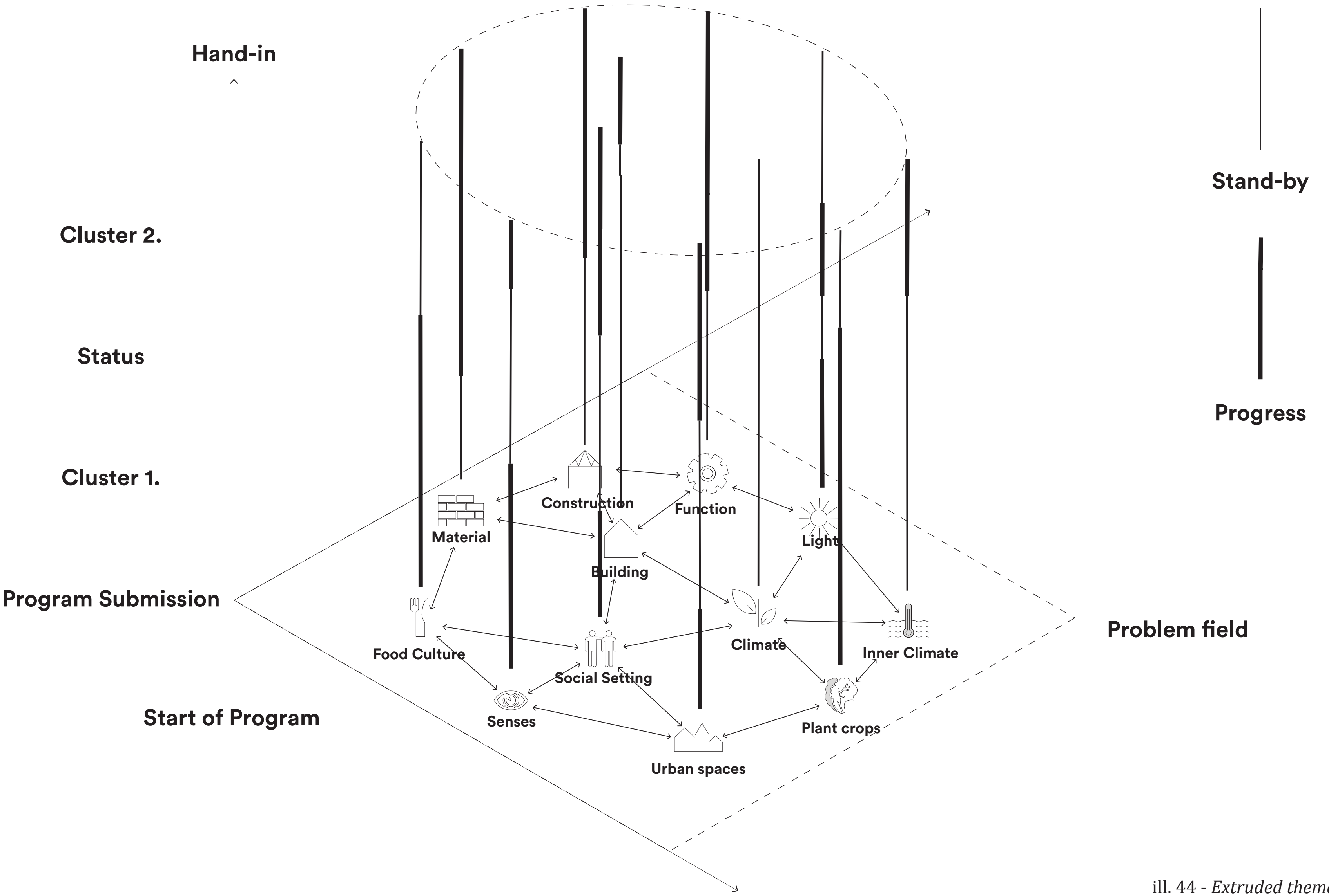



ill. 43 - *1:20 principal construction details, construction to facade skin & roof corner*

# Facade, roof detail

1. 2 layer ETFE
2. Gutter
3. ETFE seal
4. Pinned steel cross bracing joint
5. 200mm x 50mm, t5mm, S275 steel tube
6. 200mm x 100mm, t5mm,S275 steel tube
7. Pinned/bolt timber beam/column joint
8. 2 x 150mm x 400mm C30 beam (II)
9. 300mmm x 300mm C30 column
10. ETFE pressure system
11. 2 x 100mm x 300mm C30 laths (II)
12. 150 x 400mm C30 beam

This detail is a continuation of the previous detail up to the roof corner. The timber columns and beams are the load carrying system and the stabilises from lateral forces. The pinned joints are placed on the central axis of the beam and column. This keeps them uninterrupted and makes for simpler joints.




ill. 44 - *Extruded thematic diagram*

# Curated design log

The graph in ill. 44 shows our system thinking diagram in a 3-dimensional graph with time as the z-axis. This shows the complexity of the design process where individual themes are explored in periods parallel to each other. These individual subjects are constantly cross connected at any point on the z-axis.

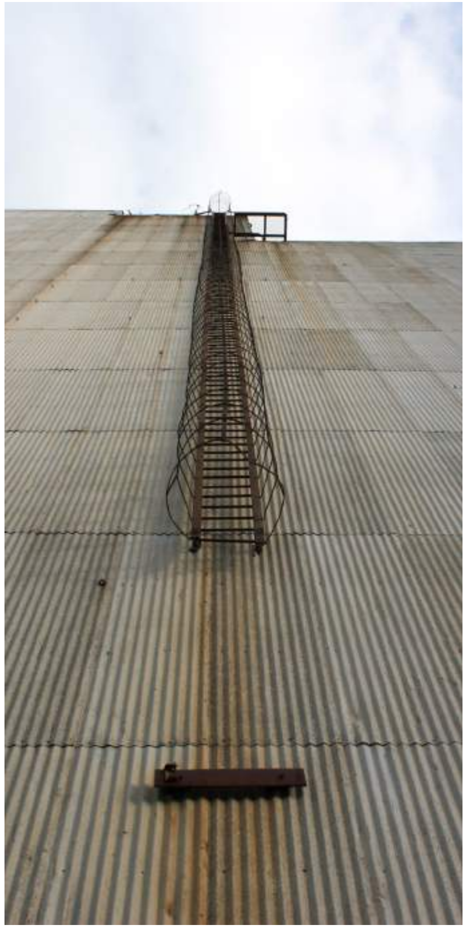
In this section we will go through how the individual themes have been explored and developed simultaneously with influencing each other. We will first go through our process regarding the urban context working in different scales, then our climatic studies with a focus on simulation, and finally our construction process.

# Character of the area

We initially visited the site in order to pin down the atmosphere and the site related principles that would influence the design.
When visiting the area of *Refshaleøen* it is quick to realize it was not intended for recreational purposes, quite the opposite. Massive remnants of shipyard buildings and big empty fields reveals the intended industrial purpose that once were. These buildings look abandoned, with trees and bushes growing in them. It seems like cultivation has stopped and merged nature and the warehouse buildings into a very distinct topography of heavily patinated concrete, steel, wood and bricks structures.
New functions are emerging in and around the buildings creating pockets of new use and transforming the old building mass. The landscapes in between is being inhabited by new temporary construction, some reflecting new and fine materiality and others as conversions of containers and scrap.
The area clearly shows its former industrial purpose, with its angular structure, large scale of the buildings and long linear spaces, designed mainly with practicality and effectiveness in mind. The new developments attempt to break down the very open and monumental scale and introduce a human scale.
The space is a patchwork of old pragmatic industrial systems as well as new opportunistic wonderland of culture and entrepreneurship. The unique identity is clearly used by the new inhabitants, as they seem to be inspired by the abandoned industrial topography. These new developments add to the industrial patchwork of *Refshaleøen* revealing contrast everywhere; new and old, human and monuments, industry and culture, temporary and permanent, nature and urbanity.
The area now has a diverse character, thus differentiating from once being very singular in its function. The monumental structures engage in conflict with the human scale. Breaking down the industrial lines with smaller articulated formations of concrete blocks, containers and other industrial leftovers, with a strong human perspective between the industrial lines. We derived four form principles from visits to the site

1. Permanent monumental scale and temporary human scale.
2. Angularity and linearity that define spaces, with grid structures.
3. Diversity of materials of tactility, color and mass.
4. Contrast of artificial industry and natural landscape merges.


ill. 48 - *Natural landscape meets artificial*

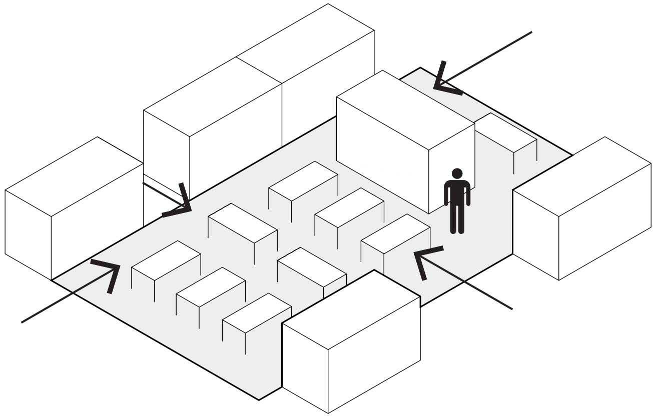


ill. 46 - *Monumental scale*

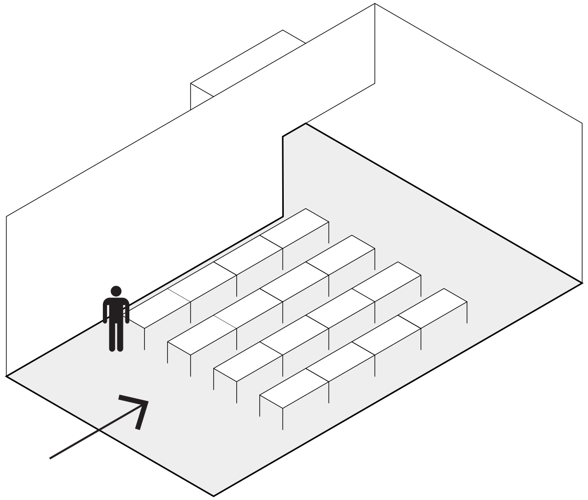
ill. 47 - *Diversity of materials*

ill. 45 - *Angularity and linearity*

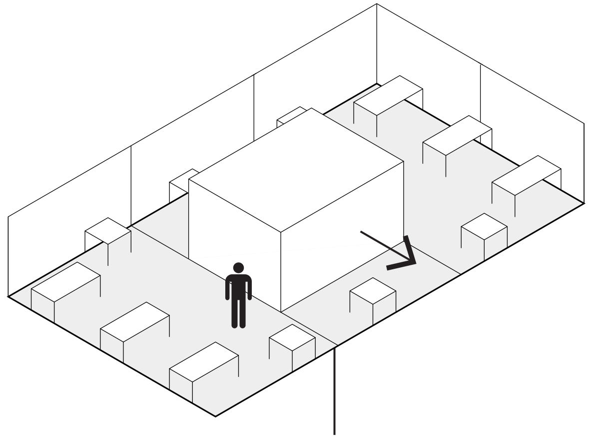
# Case studies of eating places



ill. 51 - *Spatial principles Reffen*



ill. 50 - *Spatial principles Absalon*



ill. 49 - *Spatial principles Silo*

Early in the process we visited different eating places to get a greater understanding of their architectural qualities. The places where chosen for their different spatial and food experiences.

*Reffen* is an outdoor food market built of containers and shacks. Containers are stacked on top of each other, centering on a covered space with seating and a bar area, creating a human scale in the urban landscape. The architectural intention is to create a structure from the industrial context, with a "do-it-yourself" aesthetic, to showcase how this is created from a diverse community stall of owners that evokes an explorative experience.

*Absalon* is a community house, transformed from an old church. The main space is the old church aisle, a high ceiling room connecting all functions. The tables are placed in rows and the guests are sharing tables with other groups encouraging informal meetings. The intention of the space is to reference the old community of the church, but also renewing it into a modern context. The place is a vibrant and informal meeting space, giving the impression of being a second living room.

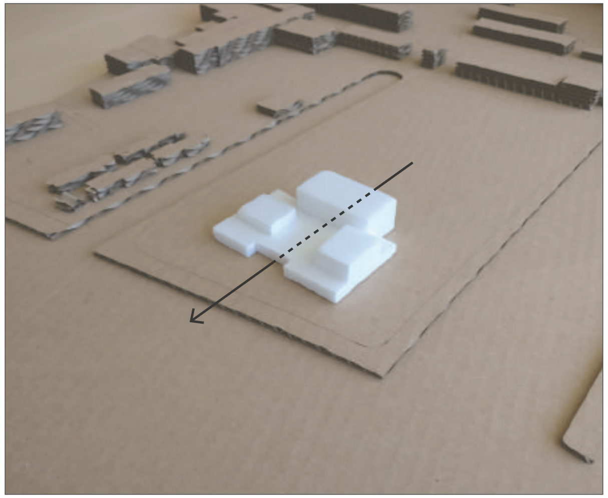
*Silo* is a restaurant situated on top of an old silo. It uses concrete, referencing the original material. The concrete is combined with softer and warmer materials like wood. The space has a lower ceiling than at Absalon and is split into three sections with two cores at each end. The tables are placed in sections, for smaller groups, creating more intimate spaces. The restaurant's high placement detaches it from the local street context.


ill. 54 - *Picture of Reffen*

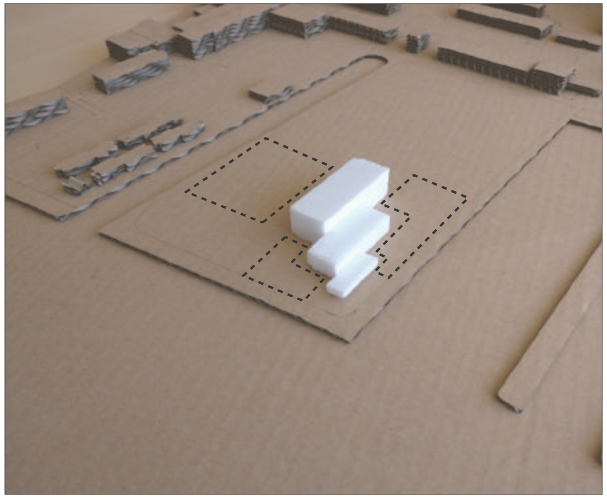
ill. 53 - *Picture of Absalon*

ill. 52 - *Picture of Silo*

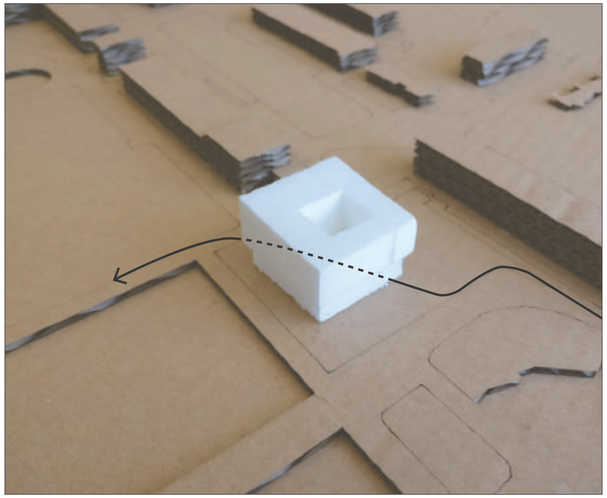
# Analytical design



ill. 55 - *site description diagrams 1*



ill. 56 - *site description diagrams 2*

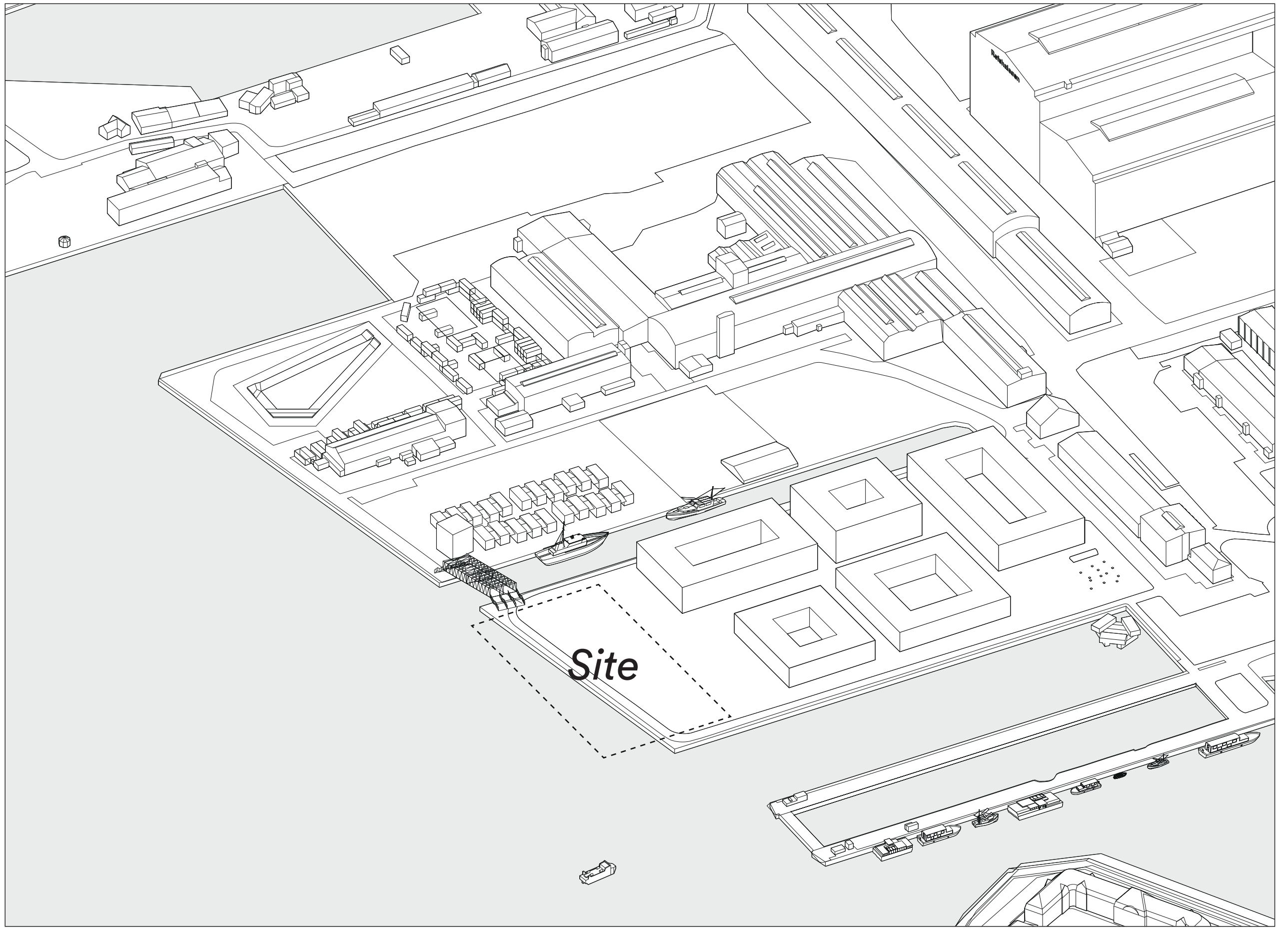


ill. 57 - *site description diagrams 3*

In the start of the process we designed these three design iterations to get a greater understanding of the site. We explored how the site would respond to different shapes, and to understand where we could place the building.
From the beginning of this study we had picked out three placement we deemed significant. The first being the tip, the second oriented towards the southern channel and the third by the main entrance to the site. The different placements all had their challenges, the two first ones had difficulties with spaces around itself in their very open and undefined context. The first iteration attempted to directly relate itself to the quay. The second tried to define spaces around the building by creating niches, in the building form. The third study where placed away from the harbor situated into a more defined space. Here The building would be more integrated into an urban like context and would here serve as a gate to the larger site. Through these iterations we concluded that the building would be placed on the tip of the site, and use the surrounding water to attach itself to the site.

# Defining an urban strategy

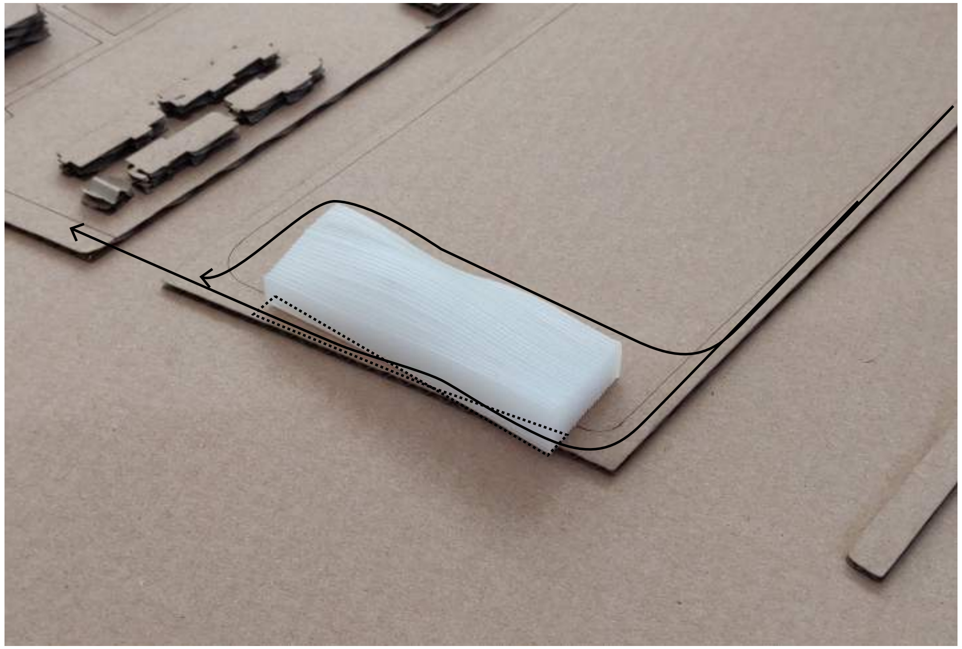
The overall conclusion of our urban analysis was to place the building on the tip of the site. This was done to make room for future development as seen in ill. 58. We had also concluded on some major descriptors for the character of the area that would be considered in the design process. Mainly relating to the industrial context. We had in the analysis phase been inspired by the long rectangular composition of the building topography and the modular appearance of the site. Although broken up by the temporary development of *Reffen* and some student housing. Another conclusion was that we would not necessarily consider fitting the building into the local industrial the context. The building could also be seen as fitting into the greater context of the harbour, which consist of a patchwork of different architecture developed over a long time spanning from *The Masting Crane* built in the 18th century to the future development of *Papirøen*.



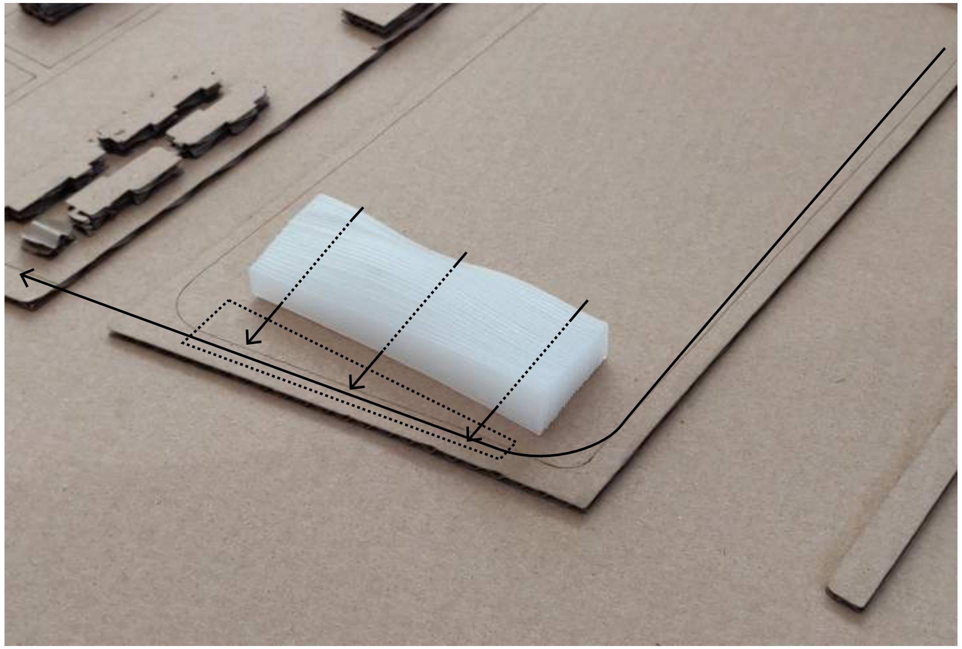

ill. 58 - *Site with future context scenario*

# Analysis of immediate context

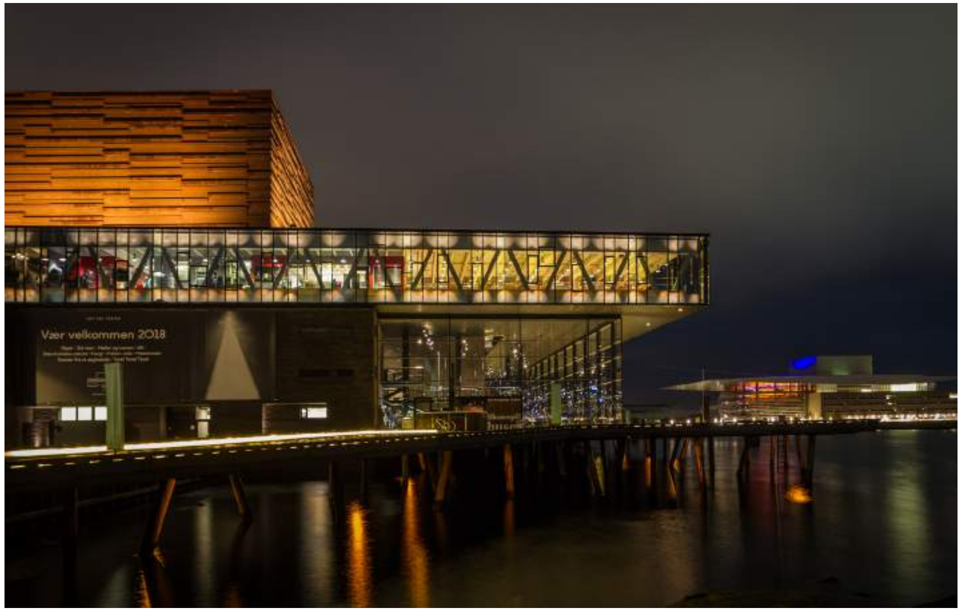
Further into the design process we started considering how the building would relate to its immediate context. We especially focused on how the building would relate to the water. Before these considerations we had decided to place the building as a long rectangular shape placed centrally near the wharf.
We mainly discussed two approaches of relating to the water, discussing these on the basis of two case studies: *The Royal Playhouse* and *Copenhagen Street Food* on *Papirøen*. Both situated on the Copenhagen harbor-front, but *Copenhagen Street Food* having been moved and renamed to *Reffen*. For these studies we worked with a physical context model, exploring the different spaces created. As well as working in plan both digitally and through analogue sketches to examine how the function of the building could define the urban context
One of our main strategies was to focus on the slight angle of the wharf. By placing the building in relation of the grid of the other buildings of the area.
The two main discussions related to whether the building should be placed going out over the water. Like in *The Royal Playhouse*, were pedestrians are brought over the water, by walking on a wooden bridge. In our iteration this would result in the rectangular shape partly positioned over the water creating two triangular spaces, one being on land the other being inside the building suspended over the water. This would mean that visitors would have to go through the building or go behind the building in order to go past it.
The other approach was inspired by the old *Copenhagen Street Food* market, placed in old industrial buildings drawn away from the wharf, creating a long relatively narrow plaza in front of the buildings. We decided on the second approach since we deemed it more important to define the place as a destination, where visitors would enjoy vicinity to the water rather than programming it with a building.



ill. 59 - *model photo over edge*



ill. 60 - *model photo  away from edge*



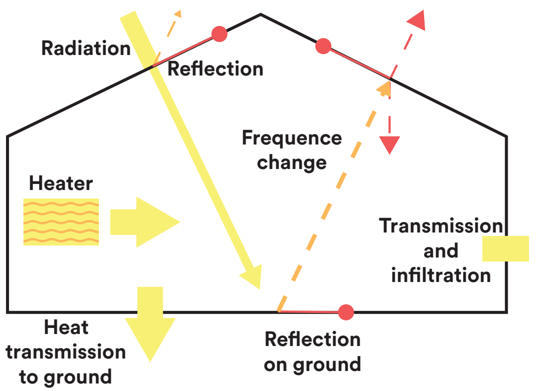

ill. 61 - *Skuespilshuset, property of Lars Fabricius*

ill. 62 - *Papirøen, Jonas Juodišius*

# Greenhouses and crops

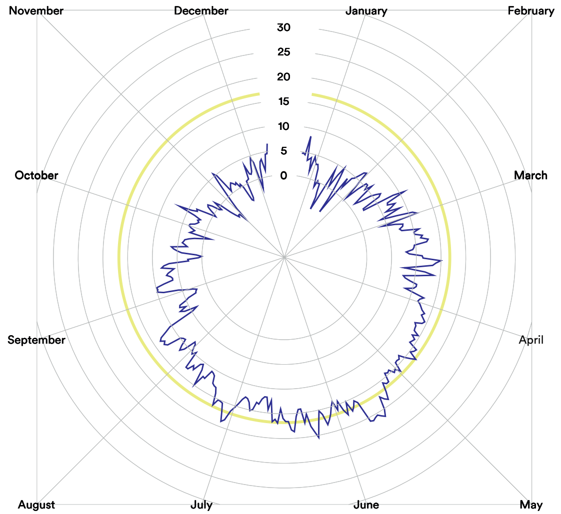
The initial process of designing a greenhouse started with research and gaining general knowledge on greenhouses and greenhouse crops. We collected some general information on crops from books on practical operation of smaller greenhouses (Petersen, 1994). These sources are not peer-reviewed, but we deemed a rudimentary knowledge of the subject as sufficient for the project. .

We did additional research for simulation of greenhouses. The basis for this was a mathematical model (Fitz-Rodríguez et al., 2010), Parameters derived from this study were later taken into account when simulating with Honeybee. The research process ended with an excursion to Greenhouses used by *University of Copenhagen*. Here we got a general introduction to the greenhouses and how they are operated in practice. This gave us an opportunity to confirm knowledge previously gained, and gave us a general understanding of important parameters of greenhouse operation. Through this knowledge on greenhouses and crops we defined three different climates, described through graphs showing the daily outdoor temperatures for an entire year in Copenhagen, compared to the optimal temperature conditions of each crop, see ill. 65 to ill. 67. This was also supplemented with knowledge of other parameters such radiation and humidity requirements. This described how we would have to change the environment through the architecture.

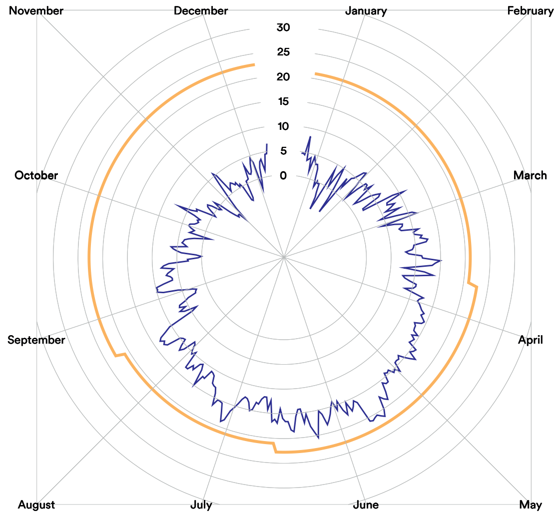


ill. 63 - *Diagram - Greenhouse parameters, intellectual property of Fitz-Rodríguez, E. et al. (2010)*

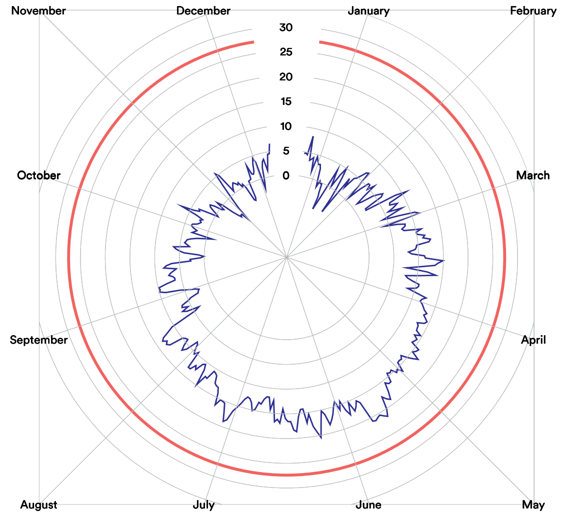

ill. 64 - *Excursion Høje Taastrup væksthuse*




ill. 65 - *Temperature diagram Lettuce*




ill. 66 - *Temperature diagram Tomato*




ill. 67 - *Temperature diagram Fruit*

**Cold**

A colder climate is optimal for producing lettuce, which thrives in lower temperatures. They require at least a temperature of 10 °C, but can handle up to 20 °C. The diagrams shows the high risk of overheating during the summer months.

**Temperate**

A temperate climate will be suitable for producing tomatoes. They require very specific and variable temperature conditions depending on the phase in plant's growth. Creating a temperature of around 23 °C, and for the seedling phase up to 30 °C.

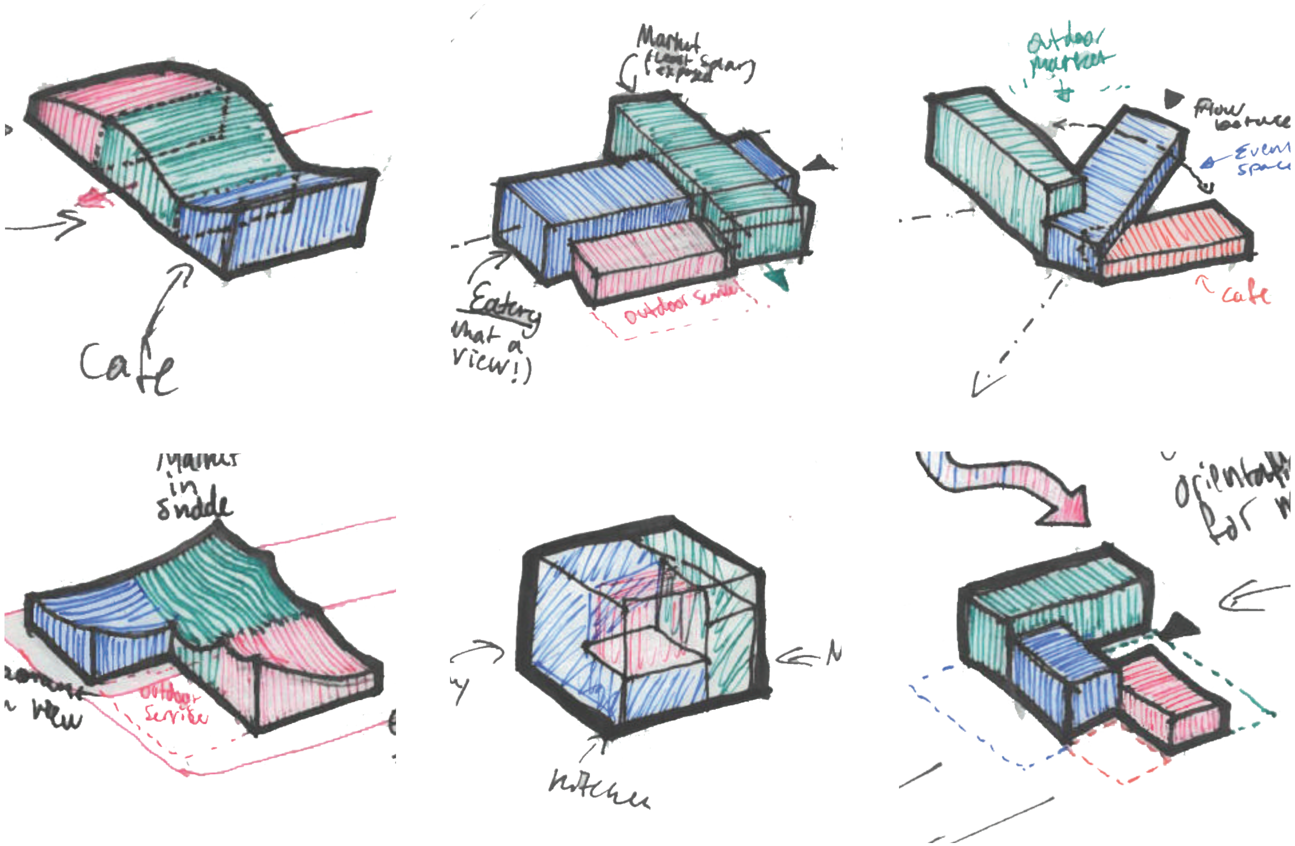
**Warm**

Figs, peaches, apricots and kiwis are grown in warmer climates and require temperatures greater than 10 °C. Since the plants grow natively in very warm climates, the upper temperature limit should therefore be set by the people using the space.

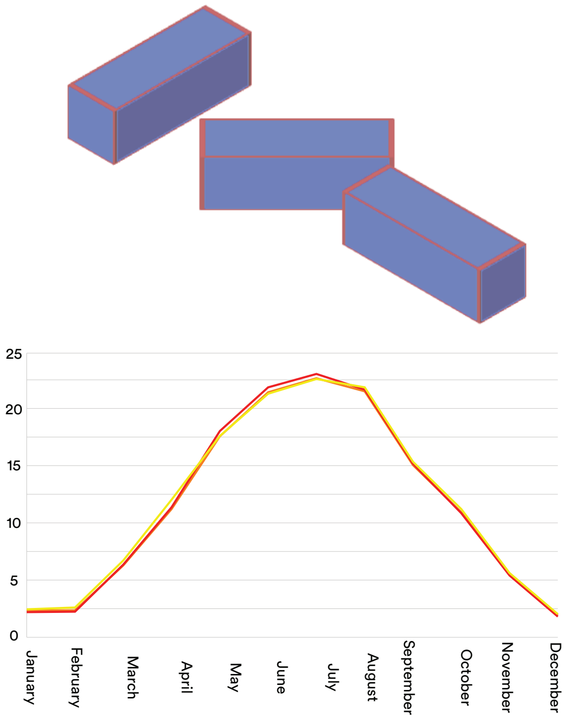
# Climate

The results of the research described in the previous section was then used in a design process, which was combined with climate simulations done in Honeybee. The design was first explored through diagrammatic sketches (see ill. 68), which examined how the three different climates would relate to each other, and be experienced by the visitor. We made simulations parallel to these sketches, using simplified volumes and as few parameters as possible (see ill. 69 to ill. 71) to explore the effect of different shapes. We concluded that we could manipulate inner climate through architectural shape alone

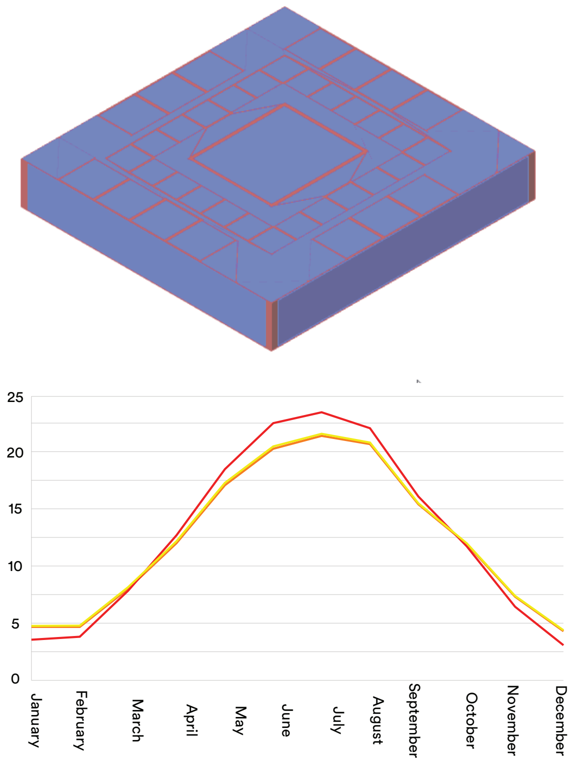
These design explorations also resulted in very simplified design iterations, both related to overall shape and to the performance. The results of the simulations gave us the possibility to rate the different designs, but it did not help develop the design itself.



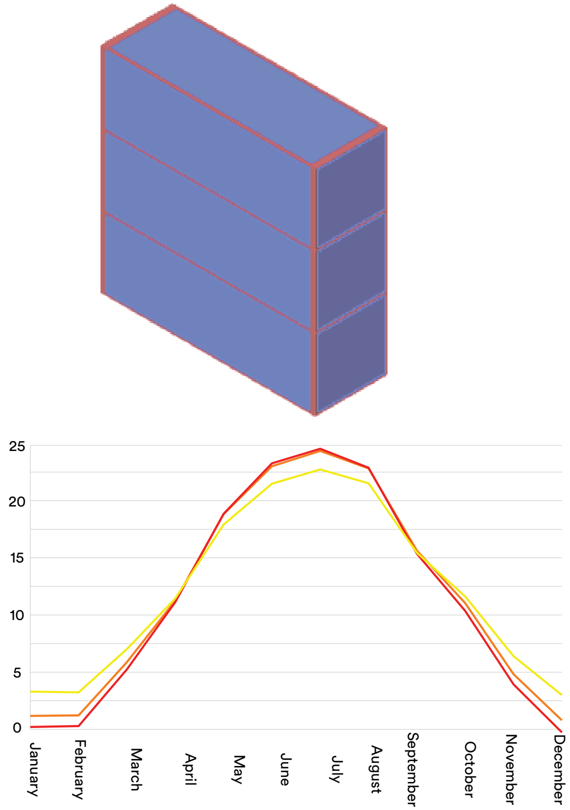

ill. 68 - *Diagrammatic sketches*




ill. 69 - *Simulation model of rotated volumes*



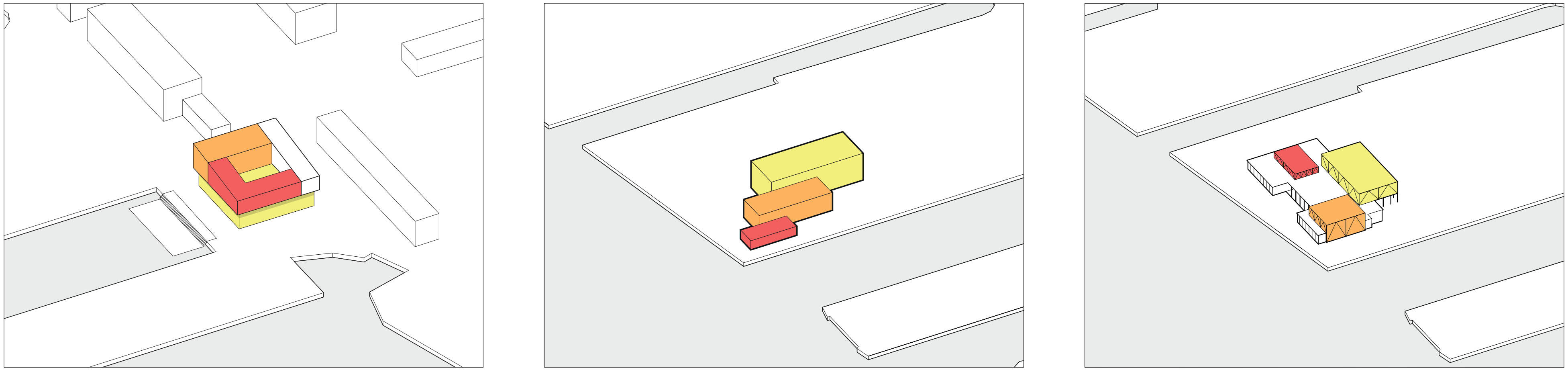

ill. 70 - *Simulation model of layered volumes*



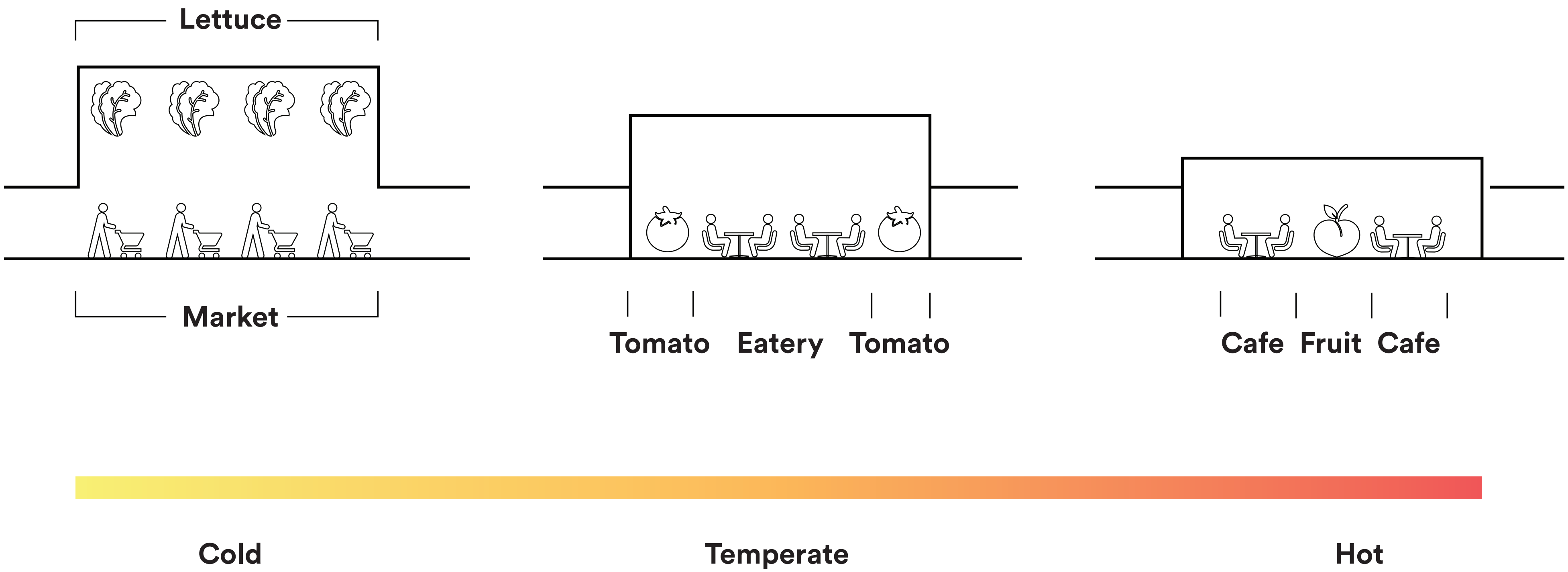

ill. 71 - *Simulation model stacked volumes*

# Climatic design

In this next phase we focused on combining our climatic analyses into a concrete design. We did this in parallel to our urban analyses. In the previous analysis we explored how the architectural shape would affect the inner climate, and we applied these principles to design iterations. We also did this in relation to how the building would be experienced to the different climate zones
The design also raised a number of questions. How should the visitor go through the building and experience the different climates. One principle was to separate the climates, as in the top iteration, having an undefined base to connect the different climates. The middle proposal explored placing the climate together in a sequence raising the question of how the zones would be physically connected and still be able to keep separate climates.
This design process resulted in the definition of a general concept for the project. Having three distinct climates would also create different functions in the building, and would additionally create a sequence of different environments. The visitor would then be able to experience going from cold to warm climates in zones that grows lettuce, tomatoes and fruit. This was also the start of defining how the plants could be part of the architecture and be shaping volume in each space.



ill. 72 - *Design iterations combining climate and shape*




ill. 73 - *Principle for combining function and climate*

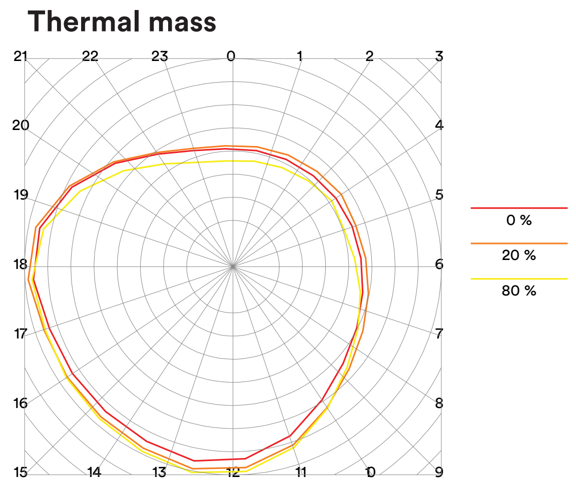
# Final climate model

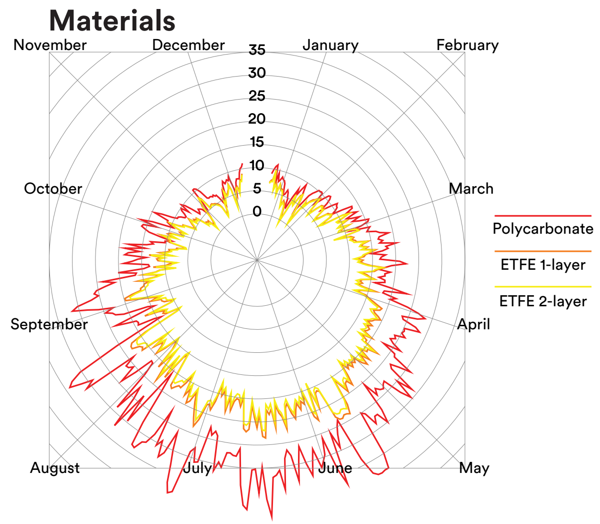
To further the simulation model we started making more complex and detailed simulations. We continued exploring the concept of layering the building. The main goal of this model was to take as many aspects into account as possible. We experimented with people load, heating, cooling, natural and mechanical ventilation, context, material, and shading. Creating the climatic model required simplifying while still reflecting reality, both to reduce required computing power, but also to minimize the risk of making errors. A simple model will often be closer to reality than a complex one.

However, it is important to note possible sources of error in the climate simulation. This simulation was done using Honeybee, a plug-in for grasshopper, which has certain limitations. Honeybee is a program designed for simulating office or residential buildings, this project is closer to a greenhouse, which would perform differently. Honeybee also calculates an equal distribution of temperature in a zone, which can cause imprecisions in a building having large open spaces with difference in the height of rooms.

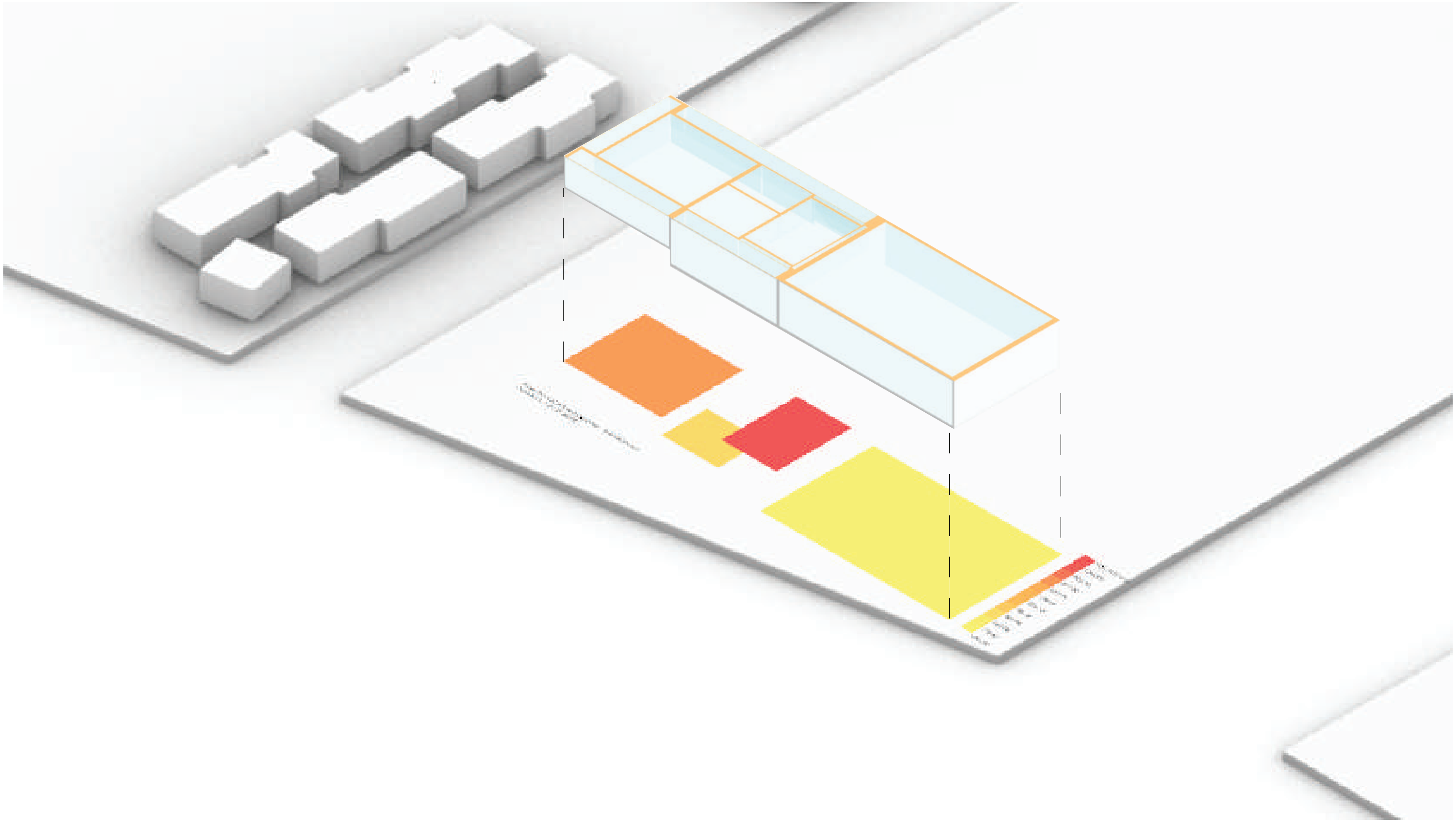
Honeybee does not support the calculation of air pollution from CO2 or other pollutants. This could have been relevant to explore the relationship between plants and humans.

Another major factor of miscalculation is the ETFE- material. ETFE is very untested in simulation since it is a newer material (Poirazis, Kragh, Hogg, 2009)Despite these factors for miscalculation, the simulation can still be valuable in a design process to validate and experiment. The simulation should however be supplemented with other knowledge, in this project we also tried to find other projects for reference of the effect of different interventions. We have particularly used the descriptions of the *National Aquatics Center* in Beijing from the book *ETFE - technology and design* by Anette LeCuyer and *Thermally Active Surfaces in Architecture* by Kiel Moe.

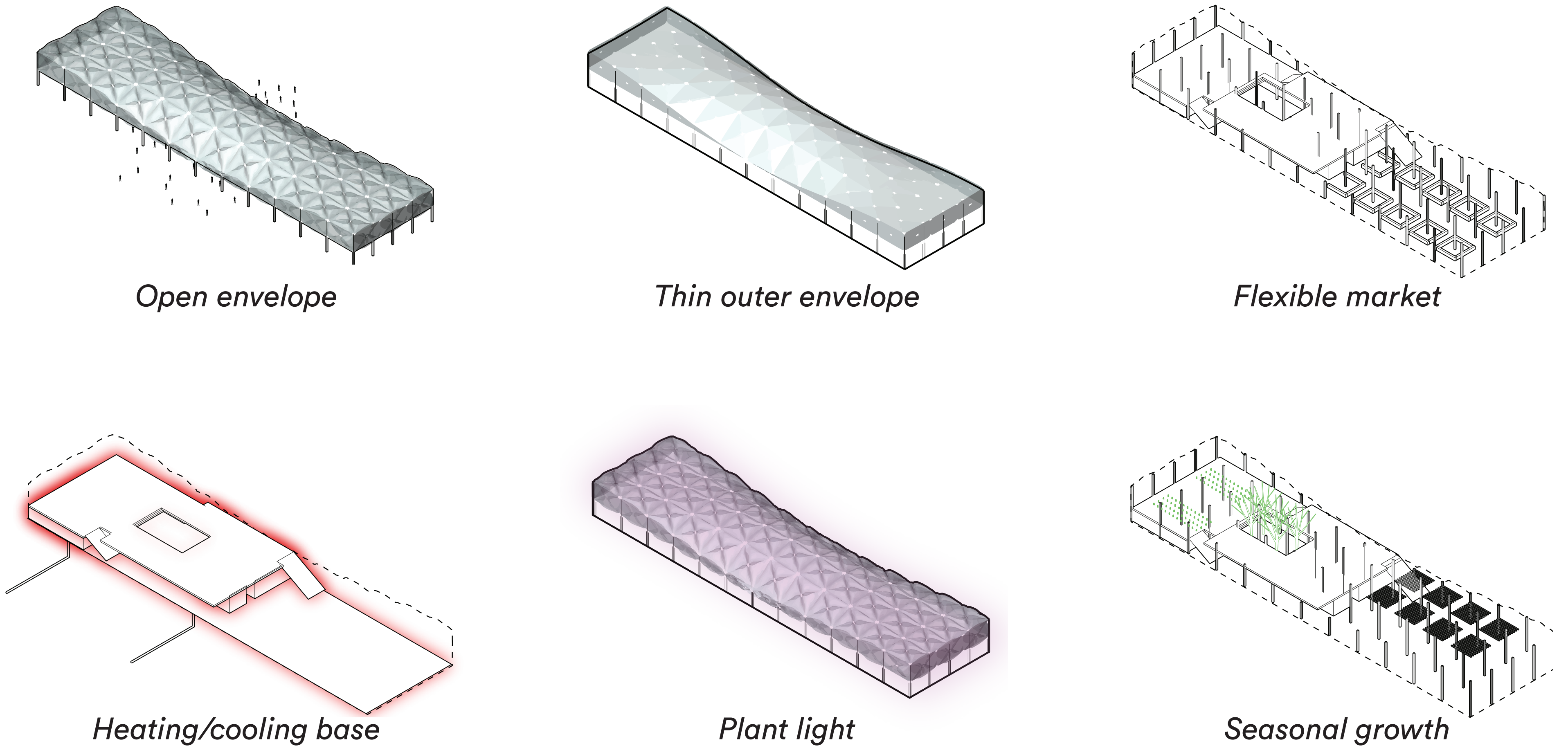



ill. 74 - *Adding more parameters to the design*



ill. 75 - *Final simulation model and final result from simulation*



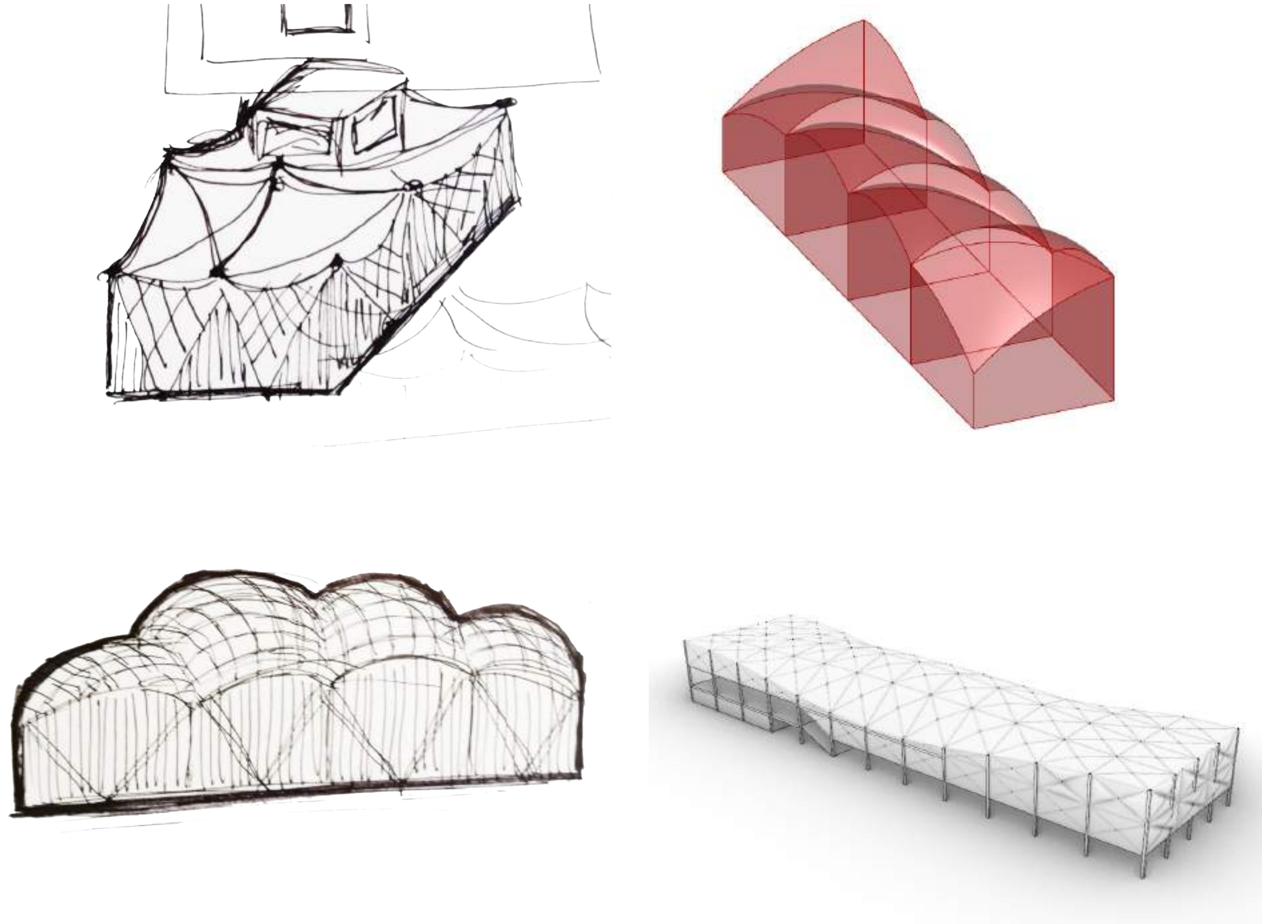

ill. 76 - *Diagrams showing multiple ways of adaptation in the architecture*

# Responsive architecture

Later in the project we realized our design was very influenced by time and change. From reading texts by Leatherbarrow on architecture and time, we started to develop a concept incorporating time. The building is influenced by many different factors over time. One that  was apparent from the start was weather conditions, especially when designing a greenhouse. This resulted in diagrams exploring how the building could change its appearance throughout the year, in order to adapt to changing temperature and angle of solar radiation. We expanded this to also include changing temperatures of the building's thermal mass by using radiant surfaces, but also focusing on how plants could influence the architecture at different growth phases see ill. 76. We also considered  the market having the ability to physically open up during summer. This become a more central feature. We  explored this through models to get an understanding of the effects of movable walls in the facade, and how these walls would work.

ill. 77 - *Model exploring moveable walls*

# Investigation of structures

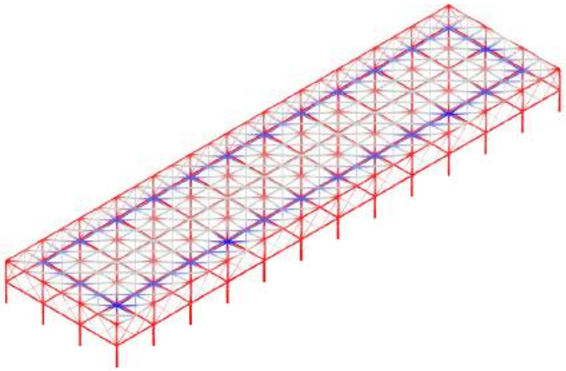


ill. 78 - *Strucurtal investigations*

The initial investigations of structural system were investigated through sketching. Creating simple concepts for the structure and how it would withstands its loads. This was a very broad investigation in order to find an overall direction.

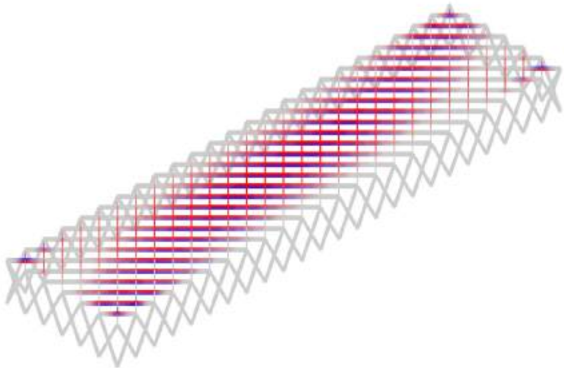
We had initially decided on working with wooden structures, since it fit well into our overall concept together with the lightweight plastic facade.

After having a more clear design concept for the building, we tested structural. We did this in Karamba, where different systems for the same building was compared. This was done alongside working digital 3D drawings. The investigations was not about getting any specific design output, but was more about exploring different possibilities. Different design iterations were designed together with testing different structural systems.



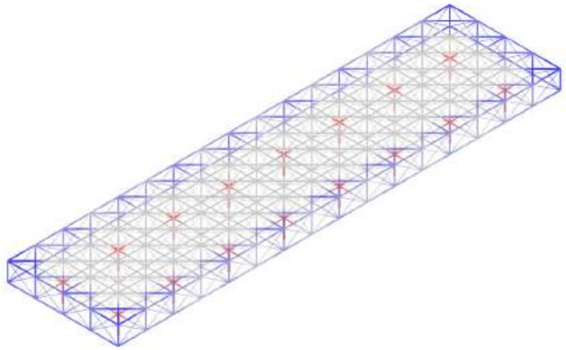
*column structure*

Columns in 10m x 10m grid,
Lateral stability from cross bracing



*Large span*

30 meter span
Lateral stability in facade and roof



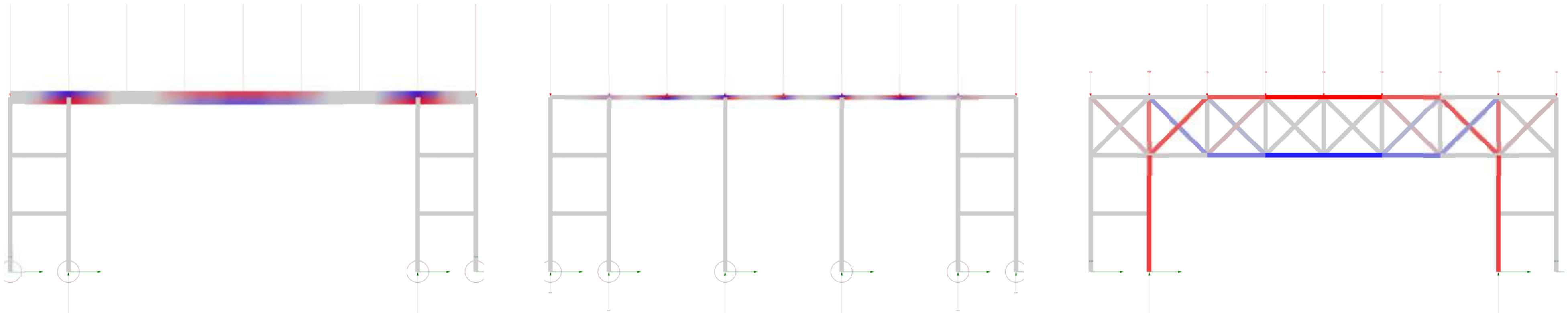
*Floating truss*

Free facade with 10m eave
20m central span
Lateral stability from cross bracing

ill. 79 - *Karamba models exploring different structures*

# Designing the structure

After having a basic idea of the overall building concept and structural system, we made physical models. The structural system was tested by first testing sections of the building in model using pinned joints, using the facade as stabilizing planes
And afterwards a 1:100 model of the entire building. Simultaneously, simple structural simulations were tested in 2D. This was in order to figure out how to overcome the spans of the market, eatery and cafe. Simple vertical loads were applied simulating snow and, the skin and self weight.
The span was found to be too wide for just a beam to go across. Columns could make the span work, but did not result in a satisfying expression, as the columns were too defining for the room.
The Truss was found to be satisfactory performing with the span, as well as being able to carry point loads simulating a hanging hydroponic system.
The columns was found to be a suitable system for the rest of the building, where it was better suited for the lower roof height and the defining character of the columns was more suitable.

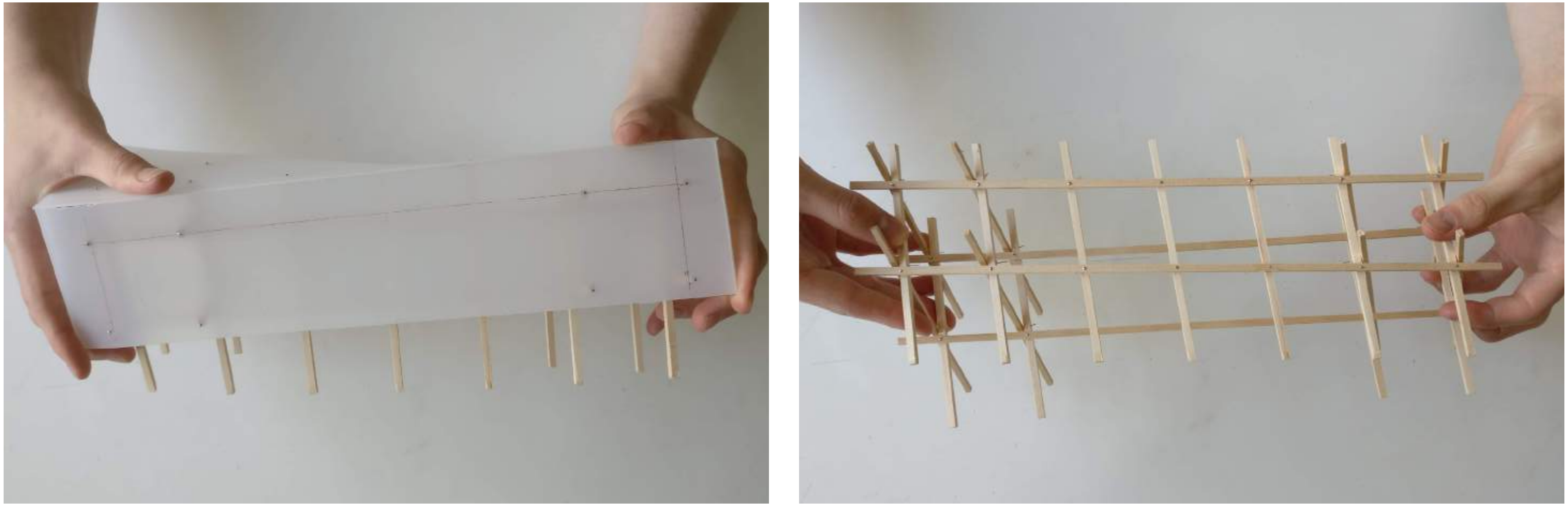


**Beam (control)**
Spans 22m
Max.Dis. 26mm
Max.Normal 0kN
Max.Moment 75kNm

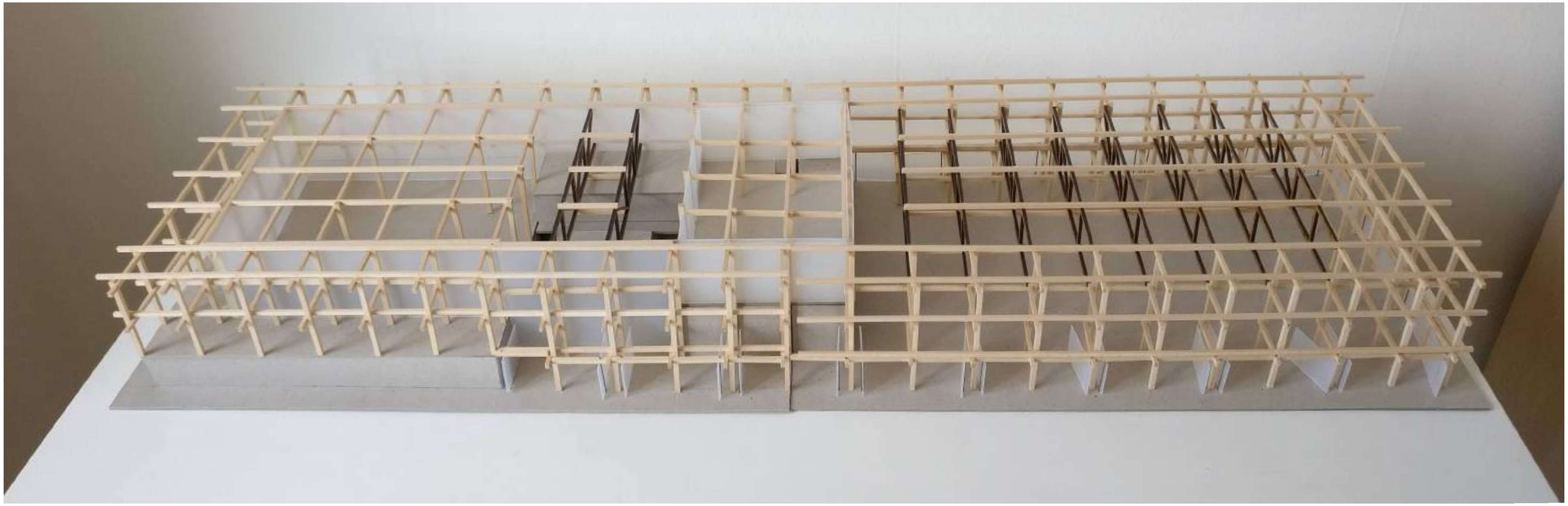
**Columns (no hydroponic system)**
Span 22m/3
Max.Dis. 7mm
Max.Normal 0,5kN
Max.Moment 7kNm

**Truss (with hydropoic system)**
Span 22m
Max.Dis. 22mm
Max.Normal 157/-164 kN
Max.Moment 0kNm

ill. 80 - *Structural 2D simulations from Karamba*



ill. 81 - *Structural model investigation*



ill. 82 - *Structural model investigation*

# Detailing the construction

The dimensioning of the elements was carried out between sketching detail drawings investigating how to join the elements and building a simulation model in Grasshopper and Robot Structural Analysis. The aim of the simulation was to find the dimensions of the timber elements of the system and investigate the structural stability of the system. The simulation tested for wind case dominant from the west, snow and self weight that included the hydroponic system hanging over the market.

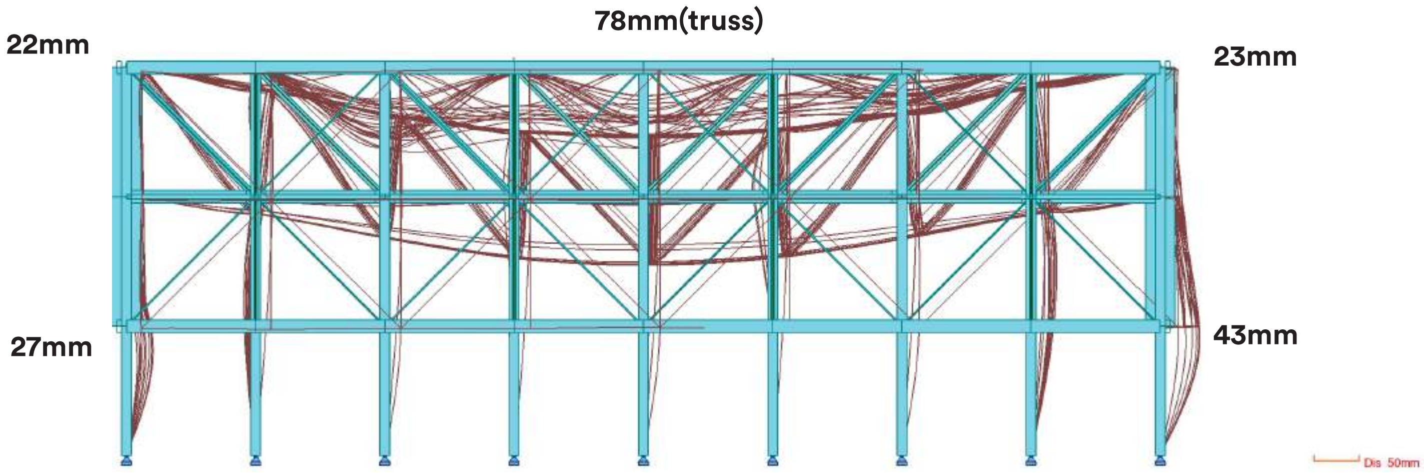
Initial testing showed that the steel diagonals of the facade and over the roof was enough to stabilise the system, which meant simple pinned joints of the wood was possible.

The building initially had too large deformations from the west wind being the dominant load case. Further testing showed additional steel diagonals solved this in an acceptable way.

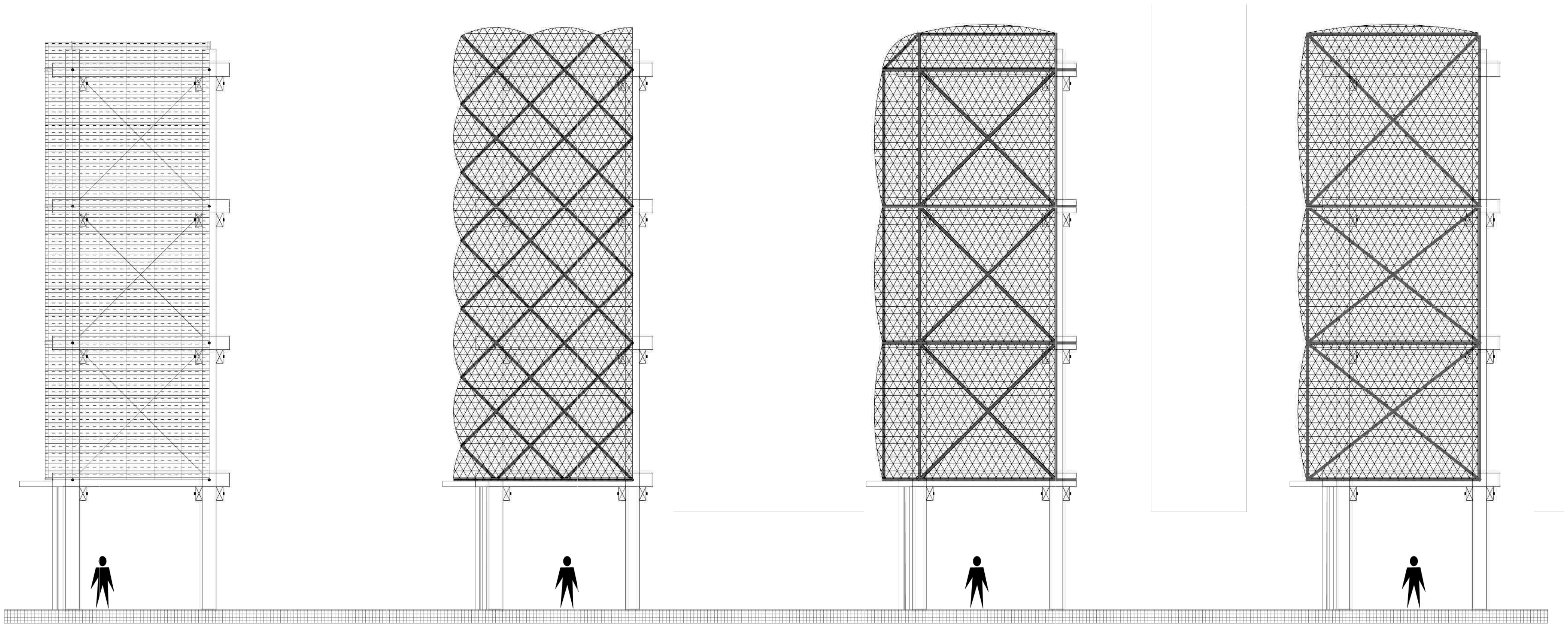
The point loads from the hydroponic system transferred moment forces longitudinal in the building, which created problems in certain elements. This was solved by removing unnecessary elements, that was connecting them.

From sketching detail drawings, we investigated how the beams could meet the columns, when the joint had to be pinned. From building the model it was tested with single beams on the side of the column, which proved difficult to realize in the entire building. The split beams had an advantage of making the system more parallel. Simulations of both single and double beams showed that the double beam resulted in less deformation.

The results of the simulation gave dimensions presented in the detail drawings in the presentation. The results were gave satisfactory results for ULS and SLS conditions for all the tested load cases.




ill. 83 - *Robot displacement, Dom. Wind SLS*



ill. 84 - *Facade investigation drawings*

# Conclusion

The Community Greenhouse is situated on a prominent location just across from the Little Mermaid. This places the building alongside important institutions of culture, making a strong statement that a house devoted to food should have a central placement. Refshaleøen is a place with a strong industrial heritage with great development potential, but also a blossoming cultural and commercial scene. The building will be an active part in this transition, being a catalyst for the future, but doing so by incorporating the heritage and cultural tendencies into a permanent presence and being adaptive in its layout in order to respond to the unpredictable change of its environment.
The end design is a greenhouse that mixes different types of crops with programming according to the temperature of the space. The functions can act as separate rooms, that each relate to different scales. The market square, community eating and the intimate cafe each has a different approach to the layout of the agriculture, thus creating different spatial and environmental experiences. The two main flows of the building give different possibilities of interaction. The regular visitors using direct passages to functions, or irregular visitors who just us it like an urban space. An atrium room binds the central three rooms to the secondary functions with an adaptable layout. It can open to the surrounding rooms and reconfigure the layout according to the event,this means it can facilitate both everyday use and large events.

The project has from an early stage revolved around the idea that food, as well as agriculture,2 has a forgotten potential in our daily and cultural life. That something of great social value is hidden away in our contemporary society is a waste. Thus, the project is developed on some basic principles of bringing together what already exists across different scales. Plants and people, producer and consumer, hobbyists and professionals, technology and tradition, artificial and natural. The exchange is where the culture can thrive and develop, and the inclusion of food creates a culture around something everyone can relate to. Together with a structure that focuses on performance and responsiveness. Movable walls make it possible for changeable spatial compositions depending on the event, season and time of day. The simple mechanical systems behind are intended for the users themselves to be in control, and makes it possible for the community to be actively involved, instead of having complex regulatory systems. With inspiration from the traditional farmer's markets, social interaction is created between consumer and producer. With different places of eating, framing social meetings and interactions. The Community greenhouse is a place where modern agriculture and culture meets and through an experiential and responsive architecture results in a more inclusive experience.

ill. 85 - *Visualisation from across the harbor*

# Reflection

As this project has developed the field of exploration has expanded, several decisions where taken which now can be reflected on. The project was done using a broad perspective, and the reflection will therefore pose questions, that covers a wide field. We would like to reflect on the impact the building would have on the city and society, and how our use of method on theory has influenced our design.

This project creates a new typology, first of all by merging a greenhouse with a community house, and secondly by placing it into the city. If our goal is to bring food production closer to the consumer, have we chosen the right solution? The combination of the two aspects of culture and agriculture allows urban dwellers to interact and possibly take part in in the production of food, which would not happen had this only been a greenhouse. By placing other functions within the greenhouse, the normal cultural activities of the city is made into a learning experience for the visitor.

The design is additionally intended to be a social performance, using food as a catalyst for urban life, and creating a scene for social interactions. The project presents different scenarios, where the building function and layout changes. As a result of working with responsiveness in architecture, the creation of the architecture is placed in the hands of the user. The design of simple flexible solutions offers an endless number of combinations and uses that we as designers did not specifically design. This allows the building to adapt to unforeseen changes but also lets the user community define how the building should be used.

Throughout the process we have taken many different perspectives, attempting to combine technical knowledge with aesthetical considerations. How has this influenced the design? And has it negatively influenced the design process to have too wide a scope instead of concentrating on fewer aspects? Also, the combination of the theory of tectonics raises questions on our use of the method. We have primarily used digital modeling and simulation, but since our project is heavily reliant on human sensing, it can be limiting to understand that design through a computer model, and it could have been questioning whether other aspects should have been explored further in model and maybe relying more on experiential analysis of case studies. But looking on the general approach of widening the scope of design, we believe it has had a positive impact on the design, since it incorporates and shapes the design, to perform better in relation to these aspects. We started climate simulation at an early stage and this became very influential in shaping the concept. The structural simulations came later after the contours of a concept were already in place and had less influence on the overall concept. This means that integrating these aspects in the early design phases helps shape the overall direction of the project, while focusing on them at later stages, results in a problem-oriented approach of solving an already defined concept.

Our broad focus from the beginning has been a good way of making the project a case of exploration the possibilities of integrated design in architecture. Therefore, the final design was influenced and controlled by this approach, but it has also been part of expanding the perspective that has led to the final design concept.

# Literature


Dark, Jane. (1979) The Primary Generator and the Design Proces, in Design Studies Volumne, first edition,  Elsevier Ltd, pp. 36-44

Despommier, D. (2010) The Vertical Farm. first edit, HortScience. first edit. New York city: Thomas Dunne Books.

Sekler, Eduard Franz (2018) 'Structure, Construction, Tectonics', in Foged, I. W. and Hvejsel, M. F. (eds) Reader on Tectonics in Architecture. first edit. Aalborg: Aalborg University Press, pp. 71–82.

Foged, I. W. (2018a) 'Environmental Tectonics: Convergences Between Six Causalities', in Foged, I. W. and Hvejsel, M. F. (eds) Reader on Tectonics in Architecture. first edition. Aalborg: Aalborg University Press, pp. 379–393.

Foged, I. W. (2018b) 'Integrated Design Process by Sequential Primary Generators', problem based learning in higher education, 6(1).

Frampton, K. (2018) 'Studies in Tectonic Culture: Reflections on the Scope of the tectonic', in Foged, I. W. and Hvejsel, M. F. (eds) Reader on Tectonics in Architecture. first edit. Aalborg: Aalborg University Press, pp. 145–176.

Franck, K. A. (2005a) 'Food for the city, food in the city', Architectural design, 75(3), pp. 35–42.

Franck, K. A. (2005b) 'The City as Dining Room, Market and Farm', Architectural Design, 75(3), pp. 5–10.

Fitz-Rodríguez, E. et al. (2010) 'Dynamic modeling and simulation of greenhouse environments under several scenarios: A web-based application', Computers and Electronics in Agriculture. doi: 10.1016/j.compag.2009.09.010.

Heidegger, M. (2018) 'The Question Concerning Technology', in Foged, I. W. and Hvejsel, M. F. (eds) Reader on Tectonics in Architecture. first edition. Aalborg: Aalborg University Press, pp. 49–68.

Kolarevic, Branko, (2015) Towards architecture of change, in Kolarevic, Branko and Parlac, Vera (eds) Building Dynamics: Exploring Architecture of Change, first edition, Routledge, pp. 1 - 17

Københavns Kommune (2015) 'Lokalplan nr. 209 med tillæg nr. 1'. Available at: https://www.kk.dk/nyheder/lokalplan-refshaleøen-tillæg-1-vedtaget

Lawson, B. (2004) What designers know. first edit. Oxford: Architectural

Press.

Lawson, B. (2005) How Designers Think. Fourth edi. Oxford: Architectural Press.
Leatherbarrow, D. (2004) 'Architecture's Unscripted Performance', in Kolarevic, B. and Malkavi, A. (2004) Performative Architecture. first edit. Edited by B. Kolarevic and A. Malkavi. New York city: Spon Press.

Leatherbarrow, D. (2015) Making space for time, in Kolarevic, Branko and Parlac, Vera (eds) Building Dynamics: Exploring Architecture of Change, first edition, Routledge, pp. 17 - 29

Lecuyer, Anette W. (2008) ETFE: technology and design, Birkhäuser

Moe, Kiel (2010) Thermally Active Surfaces in Architecture, first edition, Princeton Architectural Press;

Parigi, D. (2014) 'Performance Aided Design : tradition and development of tectonic design process', (September).

Pallasmaa, J. (2012) The Eyes of the Skin. Third edition. West Sussex: John Wiley and Sons, Ltd.

Petersen, H. (1994) Drivhuset. fifth edition. Copenhagen: Politikens Forlag.

Poirazis ,Harris; Kragh, Mikkel, and Hogg, Charlie (2009) Energy modelig of ETFE membranes in building applications, Available at: https: http://www.ibpsa.org/proceedings/BS2009/BS09_0696_703.pdf (Accessed: 21. May 2019).

Transport-, B. og B. (2018) Regeringen og Københavns Kommune vil bygge en helt ny bydel. Available at: https://www.trm.dk/da/nyheder/2018/regeringen-og-koebenhavns-kommune-vil-bygge-en-helt-ny-bydel?fbclid=IwAR2o-I6XxpCa9jM85mRSlaUHzqTt-UH1kfk9zOZaZ6Jkf0xsYA8_Dse_pTc (Accessed: 27 February 2019).

# Illustrations

All illustrations are our own except for:

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ill. 2 - Modern farming, Spain. http://www.yannarthusbertrand2.org/, property of Yann Arthus-Bertrand
ill. 10 - View from opposite side, property of Lars Fabricius
ill. 12 - Historic aerial picture of site, Taken from Stadsinginiørens samling, Property of Kaj Lund Hansen
ill. 13 - Visualisation of Lynetteholmen, https://www.trm.dk/da/ministeriet/lynetteholmen, Property of By og Havn.
ill. 14 - Picture of site today, Property of Styrelsen for Dataforsyning og Effektivisering
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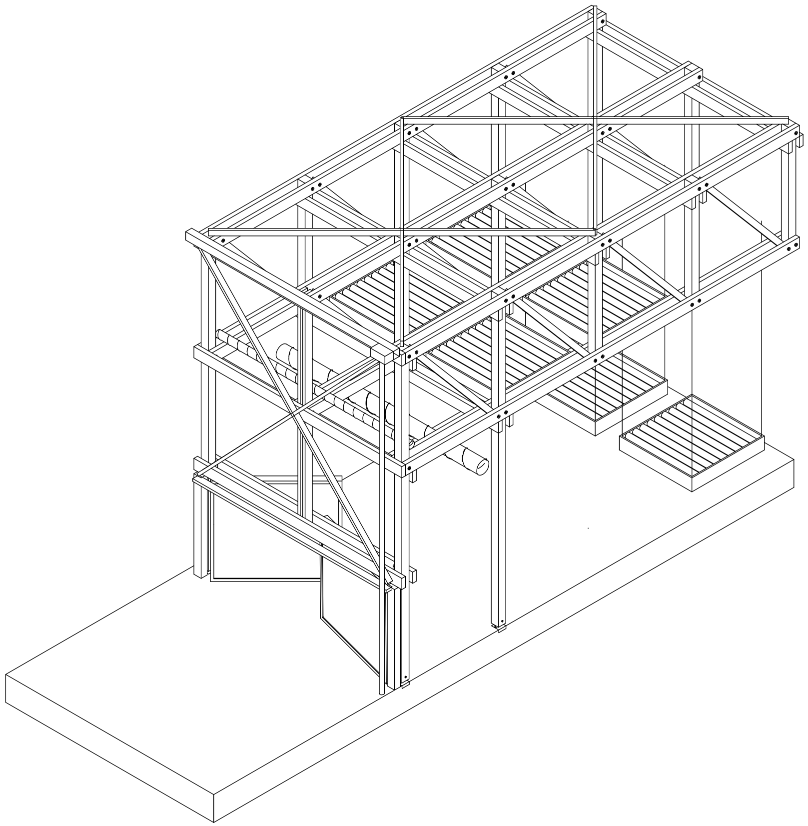
ill. 62 - Papirøen, https://www.flickr.com/photos/32332238@N02, property of Jonas Juodišius
ill. 63 - Diagram - greenhouse parameters, based on a diagram from: Fitz-Rodríguez, E. et al. (2010) 'Dynamic modeling and simulation of greenhouse environments under several scenarios: A web-based application', Computers and Electronics in Agriculture. doi: 10.1016/j.compag.2009.09.010.

# Copenhagen Community Greenhouse

## Appendix



M.Sc. Arch04 - May 2019 - Group 16 - Jeppe Fabricius Svansø - Mads Bue Jensen

# Room program

| Code | Functions | Number | m2 |
|---|---|---|---|
| **A.** | **Market** | | |
| A.01 | Market | 10 | 1552 |
| A.02 | Outside eatery | | 198 |
| A.03 | Toilets(guest) | 1 | 36 |
| A.04 | Storage | 1 | 102 |
| A.05 | Technical space | | 105 |
| | **Total** | | 1993 |

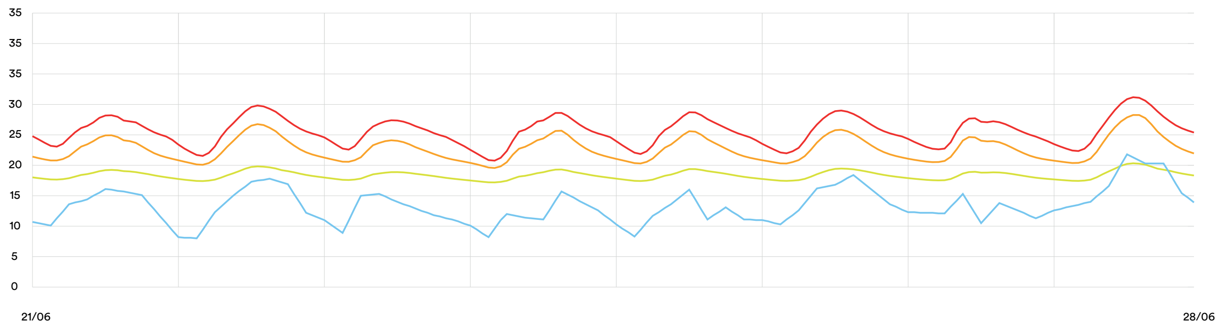
| | | | |
|---|---|---|---|
| **B.** | **Eatery** | | |
| B.01 | Seating area | 1 | 111 |
| B.02 | Tomato | 1 | 371 |
| B.03 | Kitchen | 1 | 121 |
| B.04 | Seedling | 1 | 92 |
| B.05 | Workshop | 1 | 155 |
| B.06 | Workshop 2 | 1 | 62 |
| B.07 | Workshop 3 | 1 | 62 |
| B.08 | Reception | 1 | 76 |
| B.09 | Wardrobe | 1 | 20 |
| B.10 | Toilets(level00) | 1 | 37 |
| B.11 | Toilets(level 01) | 1 | 18 |
| B.12 | Storage | 1 | 45 |
| B.13 | Technical space | | 130 |
| | **Total** | | 1300 |

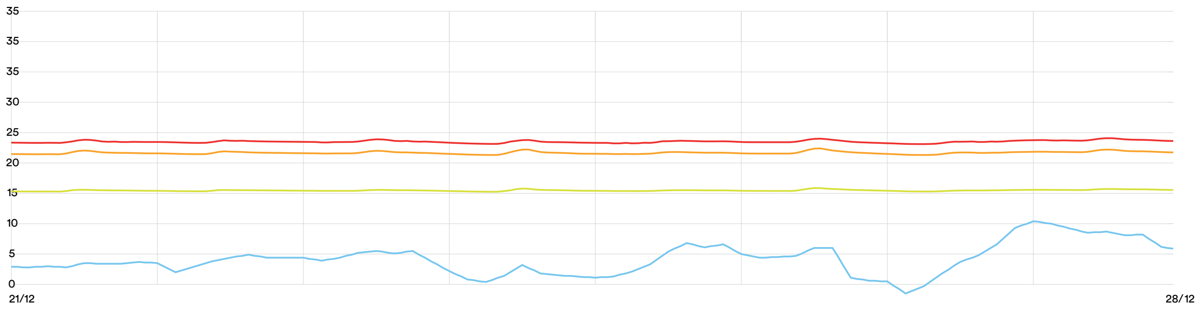
| | | | |
|---|---|---|---|
| **C.** | **Cafe** | | |
| C. 01 | Seating area | 1 | 250 |
| C. 02 | Fruit | | 47 |
| C. 03 | Storage/staff | 1 | 47 |
| C. 04 | Technical space | 1 | 90 |
| | **Total** | | 434 |

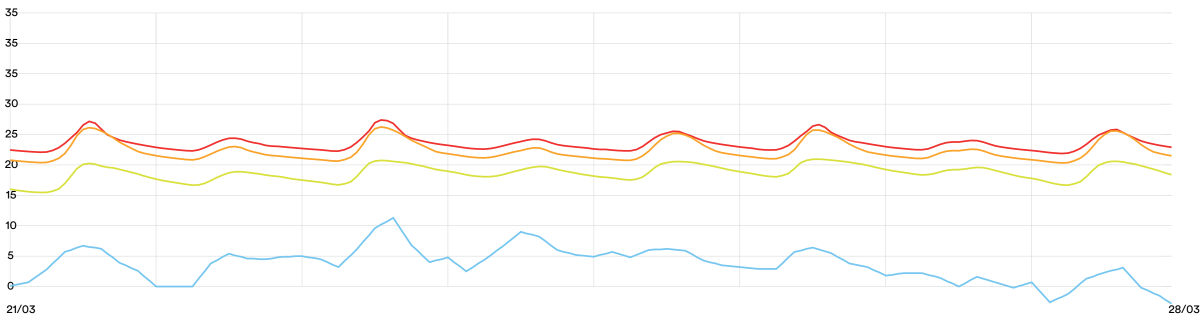
| Code | Functions | Number | m2 |
|---|---|---|---|
| **D.** | **Other** | | |
| D. 01 | Office | 2 | 126 |
| D. 02 | Meeting room | 1 | 29 |
| D. 03 | Lunchroom | | 58 |
| D. 04 | Toilet/Changing | | 58 |
| D. 05 | Cleaning | 1 | 7 |
| D. 06 | Storage | | 151 |
| D. 07 | Trash/recycle center | | 129 |
| D. 08 | Un- offloading area | | |
| | **Total** | | 558 |

| | |
|---|---|
| Total building area | 4285 |

# Hourly temperatures of three times a year

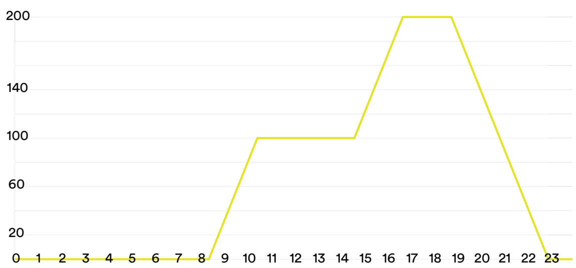


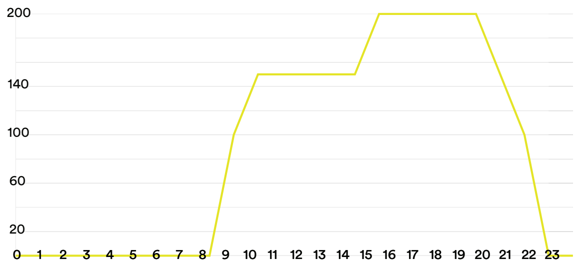




# Occupancy schedules in Honeybee model

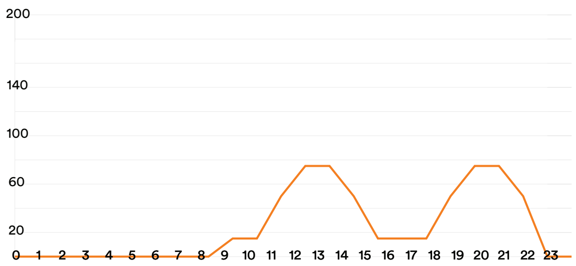
Occupancy schedule - Market, weekdays



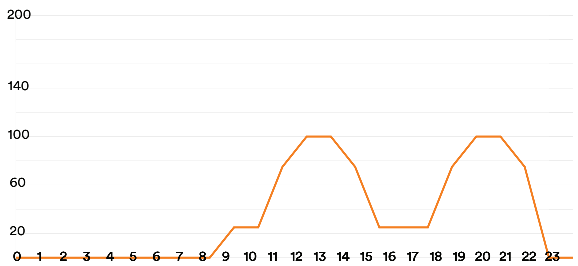
Occupancy schedule - Market, weekends



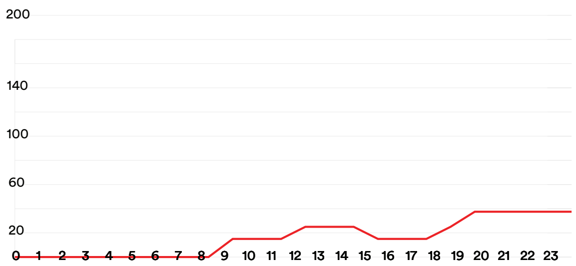
Occupancy schedule - Eatery, weekdays



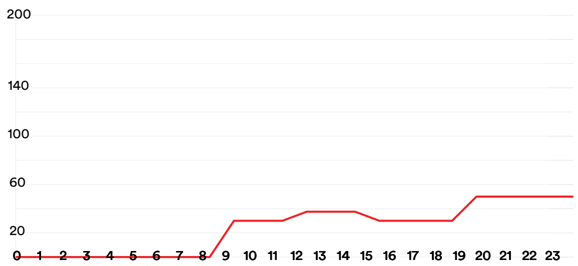
Occupancy schedule - Eatery, weekends



Occupancy schedule - Cafe, weekdays



Occupancy schedule - Cafe, weekends



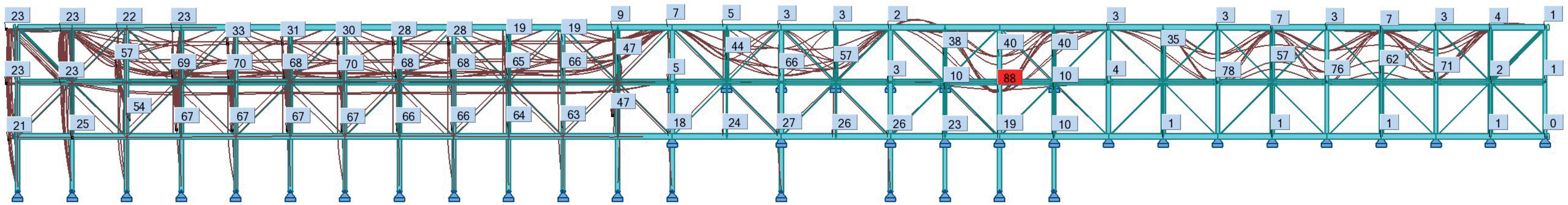
# Simulation inputs in Honeybee model

| Code | Max peopl | Envelope r | MET value | Natural ventilation |
|---|---|---|---|---|
| **A.** | | | | |
| A.01 | 200 | ETFE 2-laye | 2 | Winddriven cross ventilation |
| A.02 | 50 | ETFE 2-laye | 2 | Winddriven cross ventilation |
| A.03 | | ETFE 2-laye | 2 | Winddriven cross ventilation |
| A.04 | | ETFE 2-laye | 2 | Winddriven cross ventilation |
| A.05 | | ETFE 2-laye | 2 | Winddriven cross ventilation |
| | | | | Winddriven cross ventilation |
| **B.** | | | | |
| B.01 | 100 | ETFE 3-laye | 1.2 | N/A |
| B.02 | | ETFE 3-laye | 1.2 | N/A |
| B.03 | | ETFE 3-laye | 1.2 | N/A |
| B.04 | | ETFE 3-laye | 1.2 | N/A |
| B.05 | 100 | ETFE 3-laye | 1.2 | N/A |
| B.06 | 100 | ETFE 3-laye | 1.2 | N/A |
| B.07 | 100 | ETFE 3-laye | 1.2 | N/A |
| B.08 | | ETFE 3-laye | 1.2 | N/A |
| B.09 | | ETFE 3-laye | 1.2 | N/A |
| B.10 | | ETFE 3-laye | 1.2 | N/A |
| B.11 | | ETFE 3-laye | 1.2 | N/A |
| B.12 | | ETFE 3-laye | 1.2 | N/A |
| B.13 | | ETFE 3-laye | 1.2 | N/A |
| **C.** | | | | |
| C. 01 | 50 | ETFE 5-laye | 1 | N/A |
| C. 02 | | ETFE 5-laye | 1 | N/A |
| C. 03 | | ETFE 5-laye | 1 | N/A |
| C. 04 | | ETFE 5-laye | 1 | N/A |

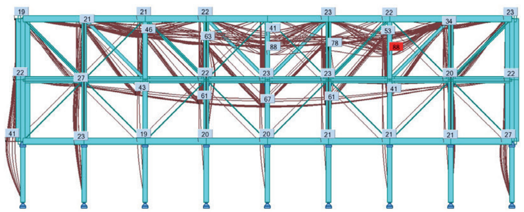
| Material name | U-value(W/m2-k) | Solar heat gain coefficient | Visual transmittance |
|---|---|---|---|
| ETFE 2-layer | 2.6 | 0.71 | 0.82 |
| ETFE 3-layer | 1.7 | 0.62 | 0.75 |
| ETFE 5-layer | 1.18 | 0.53 | 0.62 |

| Thermal mass material | Conductivity(W/m-K) | Density | Thermal Absorptance |
|---|---|---|---|
| Concrete wall 200mm | 1.95 | 2240 | 0.7 |

# Deformation of elements

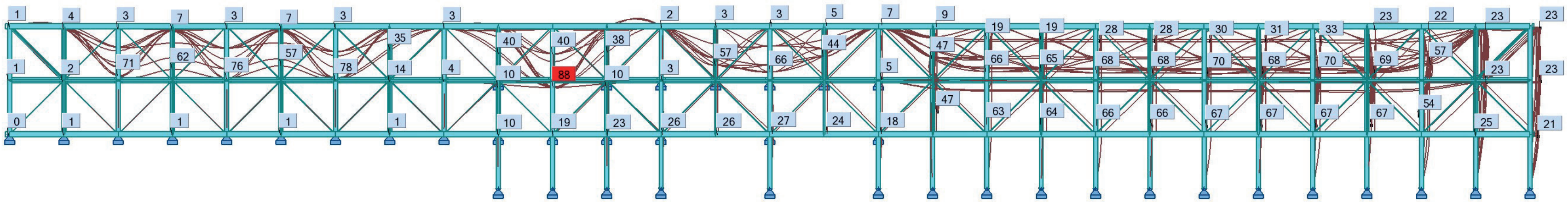


*East deformation, SLS, dominant wind*

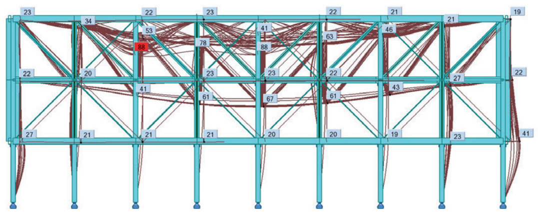


*North deformation, SLS, dominant wind*

## Deformation of elements




*West deformation, SLS, dominant wind*



*South deformation, SLS, dominant wind*

# Robot simulation results, Timber design

| Truss beams of the market square | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Material | Ratio ULS | Case | Ratio | Case vx | Ratio | Case vy |
| Lower truss beam | C30 | 0.14 | 12 ULS. Dominant wind | 0.11 | SLS. Dominant wind | 0.49 | SLS. Dominant wind |
| | C30 | 0.16 | 12 ULS. Dominant wind | 0.02 | SLS. Dominant wind | 0.63 | SLS. Dominant wind |
| | C30 | 0.15 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.64 | SLS. Dominant wind |
| | C30 | 0.15 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.65 | SLS. Dominant wind |
| | C30 | 0.14 | 12 ULS. Dominant wind | 0.00 | SLS. Dominant wind | 0.65 | SLS. Dominant wind |
| | C30 | 0.15 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.65 | SLS. Dominant wind |
| | C30 | 0.14 | 12 ULS. Dominant wind | 0.00 | SLS. Dominant wind | 0.63 | SLS. Dominant wind |
| | C30 | 0.15 | 12 ULS. Dominant wind | 0.02 | SLS. Dominant wind | 0.62 | SLS. Dominant wind |
| | C30 | 0.16 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.61 | SLS. Dominant wind |
| | C30 | 0.13 | 12 ULS. Dominant wind | 0.08 | SLS. Dominant wind | 0.44 | SLS. Dominant wind |
| Upper truss beam | C30 | 0.09 | 12 ULS. Dominant wind | 0.06 | SLS. Dominant wind | 0.45 | SLS. Dominant wind |
| | C30 | 0.06 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant wind | 0.57 | SLS. Dominant wind |
| | C30 | 0.06 | 12 ULS. Dominant wind | 0.03 | SLS. Dominant wind | 0.60 | SLS. Dominant wind |
| | C30 | 0.05 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.59 | SLS. Dominant wind |
| | C30 | 0.06 | 12 ULS. Dominant wind | 0.00 | SLS. Dominant wind | 0.60 | SLS. Dominant wind |
| | C30 | 0.05 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.59 | SLS. Dominant wind |
| | C30 | 0.06 | 12 ULS. Dominant wind | 0.02 | SLS. Dominant wind | 0.59 | SLS. Dominant wind |
| | C30 | 0.05 | 12 ULS. Dominant wind | 0.03 | SLS. Dominant wind | 0.56 | SLS. Dominant wind |
| | C30 | 0.06 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant wind | 0.57 | SLS. Dominant wind |
| | C30 | 0.09 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant wind | 0.39 | SLS. Dominant wind |

| Columns of the market square | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Material | Ratio ULS | Case | Ratio | Case vx | Ratio | Case vy |
| Outer columns cc 8m | C30 | 0.08 | 12 ULS. Dominant wind | 0.07 | SLS. Dominant wind | 0.04 | SLS. Dominant wind |
| | C30 | 0.17 | 12 ULS. Dominant wind | 0.09 | SLS. Dominant wind | 0.13 | SLS. Dominant wind |
| | C30 | 0.21 | 12 ULS. Dominant wind | 0.11 | SLS. Dominant wind | 0.19 | SLS. Dominant wind |
| | C30 | 0.26 | 12 ULS. Dominant wind | 0.13 | SLS. Dominant wind | 0.22 | SLS. Dominant wind |
| | C30 | 0.40 | 12 ULS. Dominant wind | 0.15 | SLS. Dominant wind | 0.25 | SLS. Dominant wind |
| | C30 | 0.47 | 12 ULS. Dominant wind | 0.15 | SLS. Dominant wind | 0.24 | SLS. Dominant wind |
| | C30 | 0.33 | 12 ULS. Dominant wind | 0.18 | SLS. Dominant wind | 0.20 | SLS. Dominant wind |
| | C30 | 0.22 | 12 ULS. Dominant wind | 0.17 | SLS. Dominant wind | 0.22 | SLS. Dominant wind |
| | C30 | 0.18 | 12 ULS. Dominant wind | 0.12 | SLS. Dominant snow | 0.23 | SLS. Dominant snow |
| | C30 | 0.17 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant snow | 0.23 | SLS. Dominant snow |
| | C30 | 0.17 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant snow | 0.13 | SLS. Dominant snow |
| | C30 | 0.14 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant snow | 0.05 | SLS. Dominant snow |
| | C30 | 0.16 | 12 ULS. Dominant wind | 0.03 | SLS. Dominant snow | 0.07 | SLS. Dominant snow |
| | C30 | 0.14 | 12 ULS. Dominant wind | 0.02 | SLS. Dominant snow | 0.07 | SLS. Dominant snow |
| | C30 | 0.12 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant snow | 0.05 | SLS. Dominant snow |
| Inner columns cc 4m | C30 | 0.67 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant wind | 0.08 | SLS. Dominant wind |
| | C30 | 0.88 | 12 ULS. Dominant wind | 0.06 | SLS. Dominant wind | 0.14 | SLS. Dominant wind |
| | C30 | 0.88 | 12 ULS. Dominant wind | 0.07 | SLS. Dominant wind | 0.15 | SLS. Dominant wind |
| | C30 | 0.92 | 12 ULS. Dominant wind | 0.09 | SLS. Dominant wind | 0.19 | SLS. Dominant wind |
| | C30 | 0.90 | 12 ULS. Dominant wind | 0.10 | SLS. Dominant wind | 0.19 | SLS. Dominant wind |
| | C30 | 0.93 | 12 ULS. Dominant wind | 0.12 | SLS. Dominant wind | 0.23 | SLS. Dominant wind |
| | C30 | 0.90 | 12 ULS. Dominant wind | 0.13 | SLS. Dominant wind | 0.23 | SLS. Dominant wind |
| | C30 | 0.94 | 12 ULS. Dominant wind | 0.14 | SLS. Dominant wind | 0.26 | SLS. Dominant wind |
| | C30 | 1.00 | 12 ULS. Dominant wind | 0.16 | SLS. Dominant wind | 0.24 | SLS. Dominant wind |
| | C30 | 0.79 | 12 ULS. Dominant wind | 0.16 | SLS. Dominant wind | 0.25 | SLS. Dominant wind |
| | C30 | 0.24 | 12 ULS. Dominant wind | 0.16 | SLS. Dominant wind | 0.21 | SLS. Dominant wind |
| | C30 | 0.18 | 12 ULS. Dominant wind | 0.19 | SLS. Dominant wind | 0.21 | SLS. Dominant wind |
| | C30 | 0.23 | 12 ULS. Dominant wind | 0.17 | SLS. Dominant wind | 0.20 | SLS. Dominant wind |
| | C30 | 0.14 | 12 ULS. Dominant wind | 0.15 | SLS. Dominant snow | 0.19 | SLS. Dominant snow |
| | C30 | 0.10 | 12 ULS. Dominant wind | 0.12 | SLS. Dominant snow | 0.19 | SLS. Dominant snow |
| | C30 | 0.07 | 12 ULS. Dominant wind | 0.08 | SLS. Dominant snow | 0.19 | SLS. Dominant snow |
| | C30 | 0.64 | 12 ULS. Dominant wind | 0.08 | SLS. Dominant snow | 0.12 | SLS. Dominant snow |
| | C30 | 0.78 | 12 ULS. Dominant wind | 0.07 | SLS. Dominant snow | 0.09 | SLS. Dominant snow |
| | C30 | 0.78 | 12 ULS. Dominant wind | 0.06 | SLS. Dominant snow | 0.05 | SLS. Dominant snow |
| | C30 | 0.75 | 12 ULS. Dominant wind | 0.05 | SLS. Dominant snow | 0.05 | SLS. Dominant snow |
| | C30 | 0.78 | 12 ULS. Dominant wind | 0.04 | SLS. Dominant snow | 0.08 | SLS. Dominant snow |
| | C30 | 0.75 | 12 ULS. Dominant wind | 0.03 | SLS. Dominant snow | 0.06 | SLS. Dominant snow |
| | C30 | 0.76 | 12 ULS. Dominant wind | 0.02 | SLS. Dominant snow | 0.08 | SLS. Dominant snow |
| | C30 | 0.74 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant snow | 0.06 | SLS. Dominant snow |
| | C30 | 0.74 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.07 | SLS. Dominant wind |
| | C30 | 0.58 | 12 ULS. Dominant wind | 0.01 | SLS. Dominant wind | 0.03 | SLS. Dominant wind |

# Loads and load combinations

**Load combinations**

**ULS**

The ULS combination will be based on:

$\sum_{j\geq 1}\gamma_{G,J}G_{k,J}$"+"$\gamma_p P+\gamma_{Q,1}Q_{k,1}$" + " $\sum_{i>1}\gamma_q\Psi_{0,i}Q_{k,i}$ (EC0, 2015, 6.10)

| | | |
|---|---|---|
| $K_{FI}=1.1$ | Consequence classification 3 (CC3) | (EC0,2015, A1.2(A)) |
| $\Psi_0=0.3$ | For wind when snow is dominant | (EC0, 2015, A1.1) |
| $\Psi_0=0.0$ | For snow load when wind is dominant | |

Dominant snow:

$1.0\cdot 1.1\cdot \textit{Permanent load}$ "+" $1.5\cdot 1.1\cdot \textit{snow load}_{dom}$ "+" $1.5\cdot 0.3\cdot 1.1\cdot \textit{wind load}$

Dominant wind:

$1.0\cdot 1.1\cdot \textit{Permanent load}$ "+" $1.5\cdot 1.1\cdot \textit{wind load}_{dom}$ "+" $1.5\cdot 0.0\cdot 1.1\cdot \textit{snow load}$

**SLS**

The SLS combination will be based on:

$\sum_{j\geq 1}G_{k,J}$"+"P"+" $Q_{k,1}$" + "$\sum_{i>1}\Psi_{0,i}\,Q_{k,i}$ (EC0, 2015, 6.14b)

$\textit{Permanent load}$ "+" $\textit{snow load}_{dom}$ "+" $0.3\cdot \textit{wind load}$

$\textit{Permanent load}$ "+" $\textit{wind load}_{dom}$ "+" $0.0\cdot \textit{snow load}$

# Loads and load combinations

**Snow load**

Applied to the 3582 $sqm$ $(32m \cdot 112m)$ of the entire rood

| | | |
|---|---|---|
| $S_k = 1{,}0\ kN/m^2$ | | (EC1, 2015, pp. 50) |
| $C_{top} = 0.8$ | $windblown, open\ area$ | (EC1, 2015, t.5.1.a) |
| $C_s = 1.0$ | $l_2 \leq 10h \qquad 32m \leq 120m$ | (EC1, 2015, pp. 52) |
| $C_e = C_{top}\ C_s = 0.8$ | $S_k = 0.8 \cdot 1.0$ | (EC1, 2015, pp. 50) |
| $c_t = 1.0$ | $roof\ transmittance > 1\ W/m^2K$ | (EC1, 2015, pp. 52) |
| $\mu_i = 0.8$ | $roof\ inclination = 0°$ | (EC1, 2015, t.5.2) |
| $S = \mu_i\ C_e\ C_t\ S_k = 0.64\ kN/m^2$ | $0.8 \cdot 0.8 \cdot 1.0 \cdot 1.0\ kN/m^2$ | (EC1, 2015, 5.1) |

**Live loads**

Not applicable

**Dead load**

Self-weight of timber elements from Robot structural analysis

Estimate of ETFE membrane, applied as line load to the beams, columns and steel cross bracing in both roof and façade.

$$1.05 \frac{kg}{m^2} \approx 0.01kN/m^2$$

Point load for truss over market area $(includes\ whinch, water, plants\ and\ hydroponic\ system)$

$$(9m^2\ per\ load\ point)$$

$$F_{z,truss} = 30\ kN$$

# Loads and load combinations

**Wind**

| | | |
|---|---|---|
| $C_{dir} = 1{,}0$ | Standard value | (EC1, 2015, t.1a) |
| $C_{season} = 1.0$ | Standard value | (EC1, 2015, t.1b) |
| $V_{b,0} = 24.0\ m/s$ | Standard value | (EC1, 2015 |
| $V_b = C_{dir}\ C_{season}\ V_{b,0} = 24.0\ m/s$ | $1.0 \cdot 1.0 \cdot 24\ m/s$ | (EC1, 2015, 4.1) |
| Terrain category I | flat land open to water | (Teksnisk Ståbi, 2013, t.4.9) |
| $q_p(12) = 1.0\ kN/m^2$ | reference of table | (Teknisk Ståbi, 2013, Fig.4.2) |
| $C_{pe,10}$ | $\frac{h}{d} = 1\ \&\ sharp\ roof\ edge$ | (EC1, 2015, t.7.1 & 7.2) |
| | $A = -1{,}2$ | |
| | $D = +0.8$ | |
| | $E = -0{,}5$ | |
| | $F = -1.8$ | |
| | $G = -1.2$ | |
| | $H = -0.7$ | |
| | $I = -0{,}2/+0{,}2$ | |

# Loads and load combinations

$W_e = q_p(z_e) \cdot c_{pe}$ Roof and facade zone load (EC1, 2015, 5.1)

$$W_{e,A} = 1.0\frac{kN}{m^2} \cdot -1.2 = -1.2\ kN/m^2$$

$$W_{e,D} = 1.0\frac{kN}{m^2} \cdot +0.8 = +0.8\ kN/m^2$$

$$W_{e,E} = 1.0\frac{kN}{m^2} \cdot -0.5 = -0.5\ kN/m^2$$

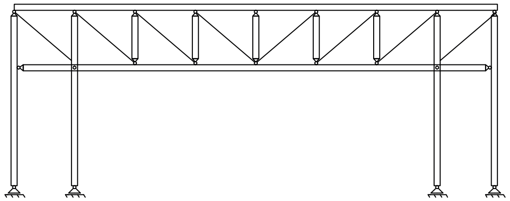
$$W_{e,F} = 1.0\frac{kN}{m^2} \cdot -1.8 = -1.8\ kN/m^2$$

$$W_{e,G} = 1.0\frac{kN}{m^2} \cdot -1.2 = -1.2\ kN/m^2$$

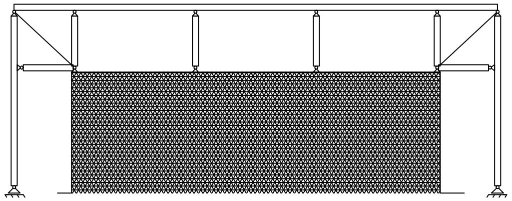
$$W_{e,H} = 1.0\frac{kN}{m^2} \cdot -0.7 = -0.7\ kN/m^2$$

$$W_{e,I} = 1.0\frac{kN}{m^2} \cdot +/-0.2 = +/-0.2\ kN/m^2$$

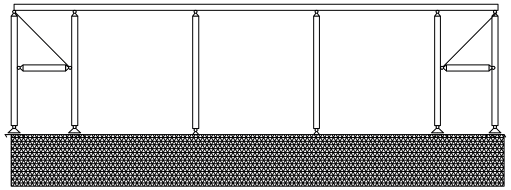
# Robot simulation structural basis diagrams



*Market*

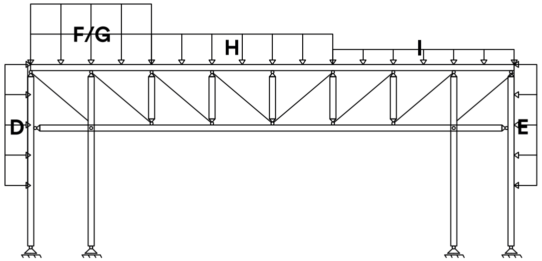


*Café*

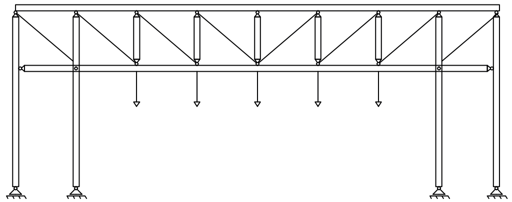


*Eatery*

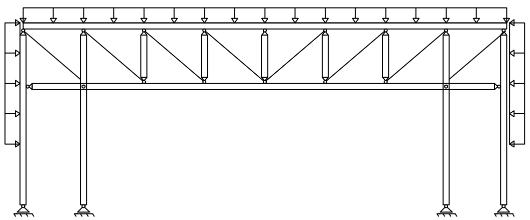
# Force diagram principles, Market



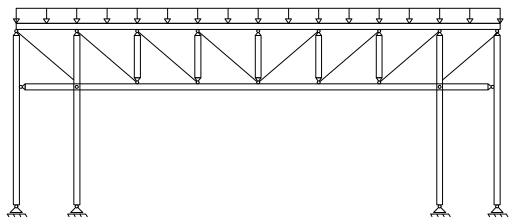

*Wind loads*



*Hydroponic system*

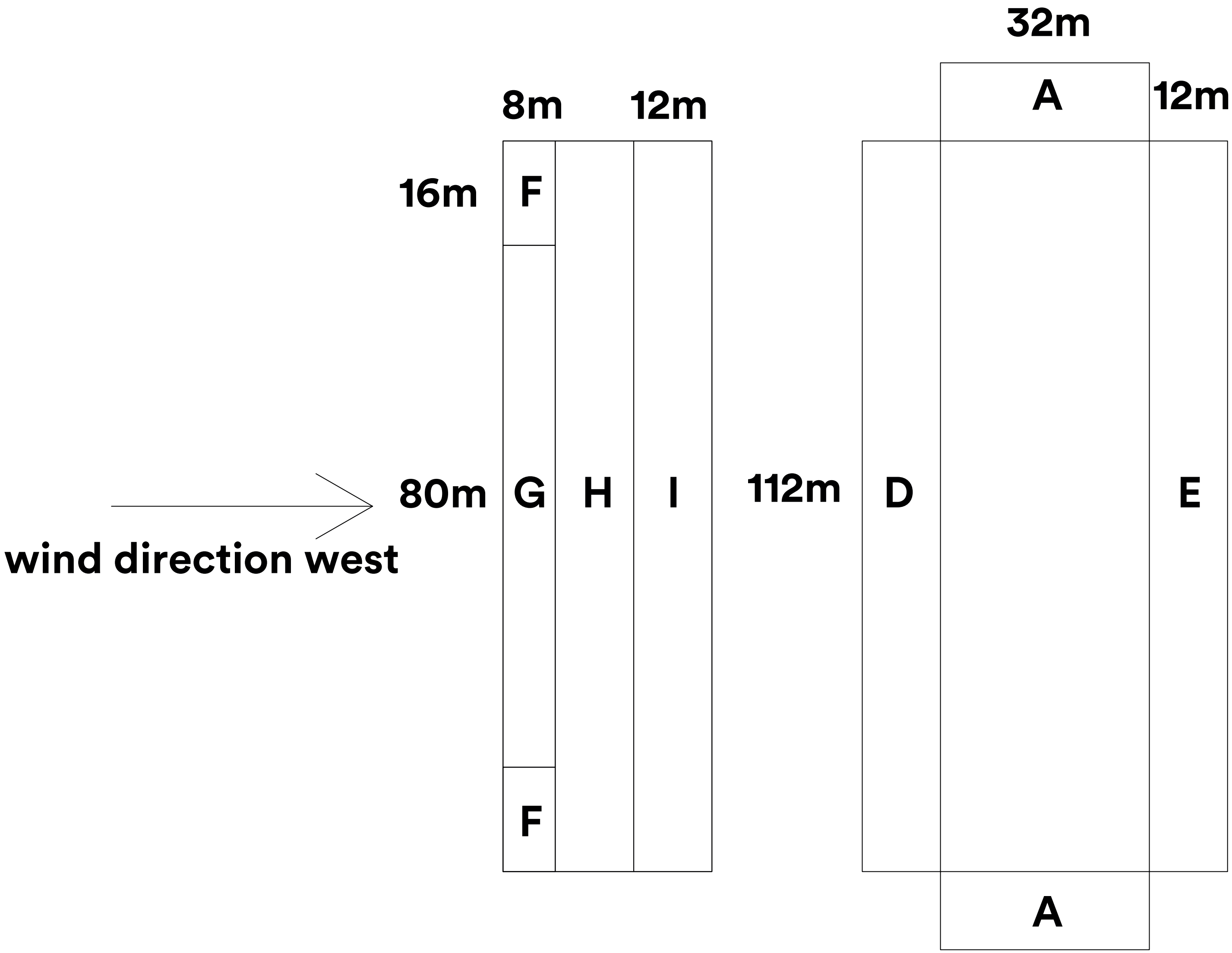


*Membrane self weight*



*Snow load*

# Building surfaces for wind load



# Literature

Eurocode 1 (2015) Forkortet udgave af Eurocode 1 – Last på bærende konstruktioner, 3. edition, Dansk Standard

Eurocode 0 (2013) Forkortet udgave af Eurocode 0 – Projekteringsgrundlag for bærende konstruktioner, 2. edition, Dansk Standard

Jensen, Bjarne C. (2013) Teknisk Ståbi, 22. edition, Nyt Teknisk Forlag