MASTER

The Oasis retreat

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The Oasis Retreat

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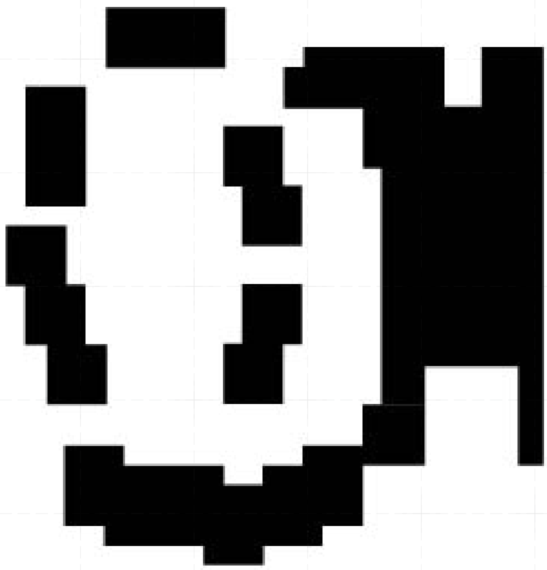

The Oasis Retreat

Xtra Big House Graduation project

Eshuis, L.A. (Laura)

2020-2021

Contents

Abstract

Xtra Big House - Living in a green retreat in the port of Rotterdam

This project provides an answer to the question: How can the current industrial port area of Merwe Vierhaven in Rotterdam be transformed into a resilient green retreat with a mixed-use community cluster?

The design features flexible, grid-based plans and buildings with sustainable resources that provide spaces for the individual, community and public, and local flora and fauna. A resilient co-existense of all these factors is designed to evolve and last through time. By using a grid- and component-based structure, the design is able to adapt and to grow to accommodate shifting needs. Wellbeing and wellness are strongly integrated in the project by its program and by creating retreat spots and lush oases on a range from public to private spaces throughout the plan.

The research covers (affordable) housing, biobased materials, biomimicry, biophilic design, co-housing, Open Building, port architecture and the local ecology of Rotterdam, parametric design and digital manufacturing techniques such as CNC milling and 3D printing. The knowledge from this research has been applied to develop the design. Digital manufacturing is applied in the structure and in the parametric skin and pavilion designs.

The Oasis Retreat houses a community cluster, food court and spa. It offers a retreat in the green to the cluster and people of Rotterdam and beyond. It invites to relax, interact, and explore a new way of living, immersed in a green oasis in a revitalised part of the urban Port of Rotterdam.

Introduction

Xtra Big House - Living in a green oasis retreat in the port of Rotterdam

The brief for this project was to design a resilient, and self-sufficient community cluster in the port of Rotterdam.

Well-being

When looking far back in history, people were part of nature. Throughout time, people have found shelter and protection from the elements and dangers of nature. By modifying our environment, the life of humans improved. However, one can argue that from the moment that technological advancements entered our lives, we have gradually become more detached from what we are originally part of: Nature. Our current environment is largely indoors and online, which does not engage all of our being, our senses and our instincts. We are always connected and processing information through technology. Especially since working from home has become part of many people's daily lives, it has become more difficult to 'switch off'.

This has implications for us as individuals, but also as a society. Psychological issues and negative feelings like stress, anxiety, loneliness and isolation have increased during the current COVID-19 pandemic. A survey amongst people in Rotterdam points out people move less, have little contacts with others and this affects their (mental) health. People working from home for a longer period are at a higher risk of burnout and mental issues. Our health depends on a healthy lifestyle and good healthcare, but also on the quality of our environment. Having qualitative green- and shared spaces for retreat and recreation would invite to go out, move, interact and switch off.

Co-housing

Due to the increasing costs and a shortage of housing, initiatives of Co-living and Co-housing have seen a rise again in recent times. It is however not a recent trend, but has been around for decades. By sharing facilities, one has access to a wider range of amenities for the same budget.
Besides this it also offers a possible solution to feelings of loneliness, as one is part of a community. As a designer, one cannot design people and their relations to one another, but one can create architectural opportunities that invite community forming.

Environmental effects

The societal detachment from nature does not merely affect people, but also our environment in the widest sense, which is now largely influenced and controlled by human action. The artificial modifications we have made, the disproportional amount of space and resources we have allocated to ourselves and our needs, has caused a problematic dis-balance in the world. In order to have a sustainable way of life for ourselves as well as our environment, we need to change our approach.

Climate change in Rotterdam

Climate change is happening and poses real potential threats to a country like the Netherlands. This in particular for the Port of Rotterdam due to its position along the water, but also as it is a densely built and paved area with little green. It has to deal with rising water levels that could cause flooding. Also, it will increasingly have to deal with urban heat islands, water drainage and polluted air.

Research question

This project provides an answer to the question: How can the current industrial port area of Merwe Vierhaven in Rotterdam be transformed into a resilient green retreat, housing a mixed-use community cluster?

Design approach

Within our power to alter our environment also lies the answer to mitigate or even reverse some of the problems the world currently faces. By creating flexible, resilient plans and buildings with sustainable resources that provide spaces for the individual, flora, fauna, community and public use, a resilient co-existence of all these factors is created to evolve and last through time. Well-being and wellness are strongly integrated in the project by its program and by creating retreat spaces and lush oases on large, public and intimate, private spots throughout the plan. Biophilic design and blurred boundaries make for a strong integration of nature and natural elements in all levels of the resident's daily lives.

Parametric design and Digital fabrication

The newest technological developments will be implemented to shape and manufacture design elements. Digital manufacturing allows for mass customisation, and parametric design enables generative design based on desired conditions, creating options that can be optimised for many factors.
The project is partially parametrically designed using Rhino and Grasshopper software. For the manufacturing, digital fabrication methods such as 3D printing, CNC milling and laser cutting are applied.

The first part of this booklet is comprised of the research, location analysis and case studies. After this follows the design, and the third part of the booklet treats the parametric design and digital fabrication.

Acknowledgements

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I want to take this opportunity to express my gratitude to everyone who has played a part in my completion of my graduation project, and thereby the conclusion of my period as an architecture student.

A Heartfelt thanks to my two main tutors Juliette Bekkering and Cristina Nan for their inspiring, challenging and motivating tutoring throughout this year. I have learned so much and they have helped me further develop into a confident designer. I am grateful to have spent time with you and that you got us all through this unprecedented Corona-graduation year.

I want to thank Cristina in particular for teaching us parametric design through many tutorials. It has surprised me and definitely caught my interest, which I will take into my career as an architect. Thank you for your admirable dedication.

My sincere thanks also go to my third tutor, Hajo Schilperoort for his motivating words, for helping develop my construction system and for pointing out the right things of my previous work at the right time. Thank you for keeping me sharp on my key concepts throughout the process.

This year would not have been as great without my fellow Xtra Big graduates with whom we have been able to spend many online and offline meetings and later long days on campus to help and motivate each other and have a good laugh. Thank you Andrea, Alex, Bas, Bas, Christina, David, Erik, Jesper, Matteo, Nick, Sem, Sjoerd and Tadeusz!

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Mom & Dad, thank you for giving me the opportunity to study Architecture and helping me out whenever I needed it. Daniël, thank you for always keeping me sharp on detecting nonsense and occasionally being a very sweet brother. Finally, Rudie thank you for being my best friend and partner that got me through it all.

THANK YOU!

Research

Co-housing

Collective research conducted by Sjoerd Harrems

Big cities are getting overcrowded and buying or renting a living space is getting increasingly more difficult. Co-housing could be a solution to this problem. Living in a co-living community is not easy, and it requires sacrifice, patience and flexibility. Co-housing could be a resilient and sustainable solution for traditional housing. Co-living and working have many variations depending on the residents and their demands.

C.0 (embassynetwork, n.d.)


C.1 Villa overgooi (Baan, n.d.)

Co-housing

Buying and renting a property nowadays is getting increasingly more difficult in big cities. The recent decades show a migration from the urban land towards the cities, which creates this high demand for property in those cities. There is a division between who can afford the property and those who live in uncertain conditions for the social labour which a city provides. (Bhatia & Steinmuller, 2018, p. 122) Due to these circumstances, a new typology is emerging to offer a cheaper way of living. Co-living is not something that has recently been invented but, co-living has already a rich history in America, for example. In 1960 the free-love and anti-establishment movement produced a series of communes. These communes defined their own way of living, politics and set of rules. They often were not bound by the system of a country. (Bhatia & Steinmuller, 2018, p. 127) The reason that these communes could not persist is uncertain. The struggles of living together or the legal issues surrounding building occupation and the habits of residents might have been the problem. (Bhatia & Steinmuller, 2018, p. 127)

Becoming a community with each other is one of the critical aspects of co-living. Geographic boundaries can define communities to a loose network of associations. (Fisher and Sonn 2007) Nowadays, since we communicate more through the internet, communities can also be formed without any physical interaction. If we talk about communities, we speak of neighbourhoods, small towns, metropolitan areas, professional societies, universities, organizations, internet forums, Facebook and many more digital groups based on shared interests. (Hovmand, 2013, pp. 7) Being part of a community gives certain privileges and obligations. One of these is to determine who can join the community and who does not. Some types of communities this privilege is determined by a person or institution outside of the community. The boundaries of a community are something that can be seen as a fluid process; the members of a community are constantly

C.2 Co-working space Barcelona (Nieve/Productora Audiovisual., 2015)

changing boundaries. (Hovmand, 2013, pp. 8) There are some attempts to model these communities and their behaviour, but it is a difficult process to map all factors that are being involved. Hovmand explain this by the following phrase: "The sum of the whole is greater than the sum of the parts," it means that a system behaves in ways that could not be predicted or reduced to properties of the individual components." This makes it very difficult to design a community as an architect. We cannot predict these communities and the behaviour of its inhabitants. Also, there are no universal rules for a community which can be applied to every newly produced community.

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A system behaves in ways that could not be predicted or reduced to properties of the individual components.

- Hovmand, 2013-

"

Within the scope of this research, we discuss Co-housing, co-living and co-working. All of these topics are strongly related to each other. The Cambridge Dictionary describes the definition for co-housing as "a group of homes that include some shared facilities (= areas, rooms, equipment, or services for particular activities" (Cambridge Dictionary, 2020a) The difference with co-living is that this is the practice of co-housing.(Cambridge Dictionary, 2020b). Co-working often is integrated into the co-housing concept. These communities offer luxurious facilities and working spaces for start-ups and entrepreneurs (Davies, 2015, p. 12). The craze of co-working partly inspires the craze of co-living. Young professionals who started up a small business and decided to do this within shared office space with other small businesses in order to reduce rent for office space and to increase their professional network. Co-living and working might be something only reserved for students or pepole with an alternative lifestyle. However, it could be an attractive solution and opportunity for the young professional whose lives are suited for this lifestyle. (Davies, 2015, p. 12) Co-housing can take various forms and can differ in many different ways. For example picture C.1 shows a project Villa Overgooi which is a form of co-housing where five private clients built a house together. This Villa has five separate houses with their own living space. They only share the same building. (nextarchitects, n.d.) At the other end of the scope, we have a simple co-working space where an architecture firm shares their building with a local company shown in picture C.2 (Mairs, 2016) In this research, the different types of co-housing will be explained, and some examples will be given and explained more thoroughly.

C.3 Co-working space Barcelona (Mairs, 2016)

Project
Shared office space

Company
Nook Architects

Location
Barcelona | Spain

Program
Co-working

Zamness

The shared office space made by Nook Architect in Barcelona is the more traditional well-known co-working typology. It is located in a building which in the past was a warehouse and workshop. They started with a blank canvas and divided the space through three light volumes in the centre axe of the building. One of the design intentions was to dilute the limits between work, rest and leisure time. (Nook architects, 2018) This idea derives from a flexible workspace concept in which employees can choose where to work at the office. (Mache et al., 2020, p. 1) It is proven that there is a significant difference in working conditions, reduced mental demands and an increased workload. Besides that, the levels of occupational stress decreased significantly over time. (Mache et al., 2020, p. 1) We could argue if it is healthy to have an office where private life is getting intertwined with work life.

The Collective

An example of a combination of co-living and a co-working space is 'The Collective' in Londen. Which is an 11-floor building with 550 rooms, a co-working area and 10.000 square foot of shared space. (Davies, 2015, p. 12) There is still some uncertainty about the sustainability of these models; for instance, the rent is comparable to local studios or rooms, but in return, the co-living building offers different luxurious facilities. Another problem is that some companies have an explicit selection process and this raises questions about the inclusivity of co-living. (Davies, 2015, p. 12) We could argue that this explicit selection procedure is a bad thing for the diversity and accessibility of co-living communities. On the other hand, creating a sustainable community is a delicate process. If there is no selection procedure, there is a particular risk there will be no community at all because there is no coherency between the members of the community. We could place a question mark with 'The Collective' project if the community is this big and frequently changes, is it a community at all?

C.5 Elevation share house (nhdm, n.d.)

C.4 Exploded view of share house concept (nhdm, n.d.)

Co-living

We can recognize two significant ways of organizing a community. The first one is run and organized by big companies who create these enormous co-housing communities. The second is more a small scale community where the residents are responsible for their own community.

Share House

Sharehouse is a definition in Asia which represents a house of 5-15 young people in a co-living situation. This type of housing known in Korea, Taiwan and Japan because of the increased tuition fees and housing cost. Co-living is a solution for young people who cannot afford to rent or buy a house. (Bhatia & Steinmuller, 2018, p. 123) Share housing is mainly developed by private or public entities who struggle to have a connection with their residents and provide continual programming and support. In Seoul, 23% of the people between 20-34 years are living in poor housing conditions such as a basement, rooftop additions or modified study rooms. Share housing offers these people humane living conditions and a social community. In order to properly scale up the share housing concept, Habitat for Humanity and the Seongbuk District local government work together on a big share housing project in Seoul. The municipality offered a piece of land, functioned as a co-client and partnered up with Habit for Humanity. The combination of a non-profit organization, government and individuals created a tight community on different levels. (Bhatia & Steinmuller, 2018, p. 123) The WYP project offers a space to live, work and socialize. Much public space has been created to offer this type of community living, shared spaces function as the central nodes for social interaction in the building. Spaces for youth work and learning are combined with community functions such as a library and meeting rooms. (nhdm,

C.6 R50 outside facade (Alberts, 2013)

Project
R50 – Cohousing

Architects
Heide & von Beckerath, ifau und Jesko Fezer

Location
BERLIN | GERMANY

Year
2013

Program
Cohousing

n.d.) This project is creating a solution for young people who live in poor conditions.

Baugruppen

An example of a co-living space is the 'Baugruppen' or 'building groups'. This is a different type of model where people collectively self-initiated a co-housing project. This results in the possibility of not needing a project developer. They could save up to 10 to 20 per cent per square foot. (Bhatia & Steinmuller, 2018, p. 123) In this type of model, the future homeowner decides where they want to invest in and where they could save money. (Kroth, 2016) Unfortunately, peoplle are competing in a market where big project developers could easily outbid these co-housing initiatives. Arranging a loan together for a co-housing project in time to buy a piece of land is almost impossible. Policies should make it possible for these initiatives to gather a loan in time for a piece of land so they can compete fairly with other investors. (Kroth, 2016) A problem that might occur is that the Baugruppe cannot support the needs of its habitants over time. For this problem, the Baugruppe introduces 'blank units'. These units can be changed and built over time to adapt to the needs of its inhabitants. (Bhatia & Steinmuller, 2018, p. 122) This adaptability enables different interpretations of living space.

Embassy

Another type of co-living is the more international-based community living. The Embassy is a combination of smaller communities but has many other communes across the globe. (Bhatia & Steinmuller, 2018, p. 127) The international Embassy network is based in Berlin, The Netherlands, Greece, Costa Rica and Haiti. Creating a

C.7 R50 shared living room(Kroth, 2016)

C.15 The embassy living room (embassynetwork, n.d.)

C.8 The embassy dining together (embassynetwork, n.d.)

fast network where residents could easily move between locations. There are multiple Embassies in San Francisco, and they host between 17 and 23 residents. The Embassy network supports a more nomadic lifestyle which is used by people who travel a lot for business or people who enjoy this lifestyle. The difference between other co-living projects is that the Embassy network is created and controlled by the residents themselves but also locally. (Bhatia & Steinmuller, 2018, p. 127)

Conclusion

Without the interference of big companies, these communities are able to acquire properties and last. They can then have a more simple organization structure where the resident is responsible for their own community, instead of the more hotel-like co-living where every possible service is included in the price.

Co-HOUSING

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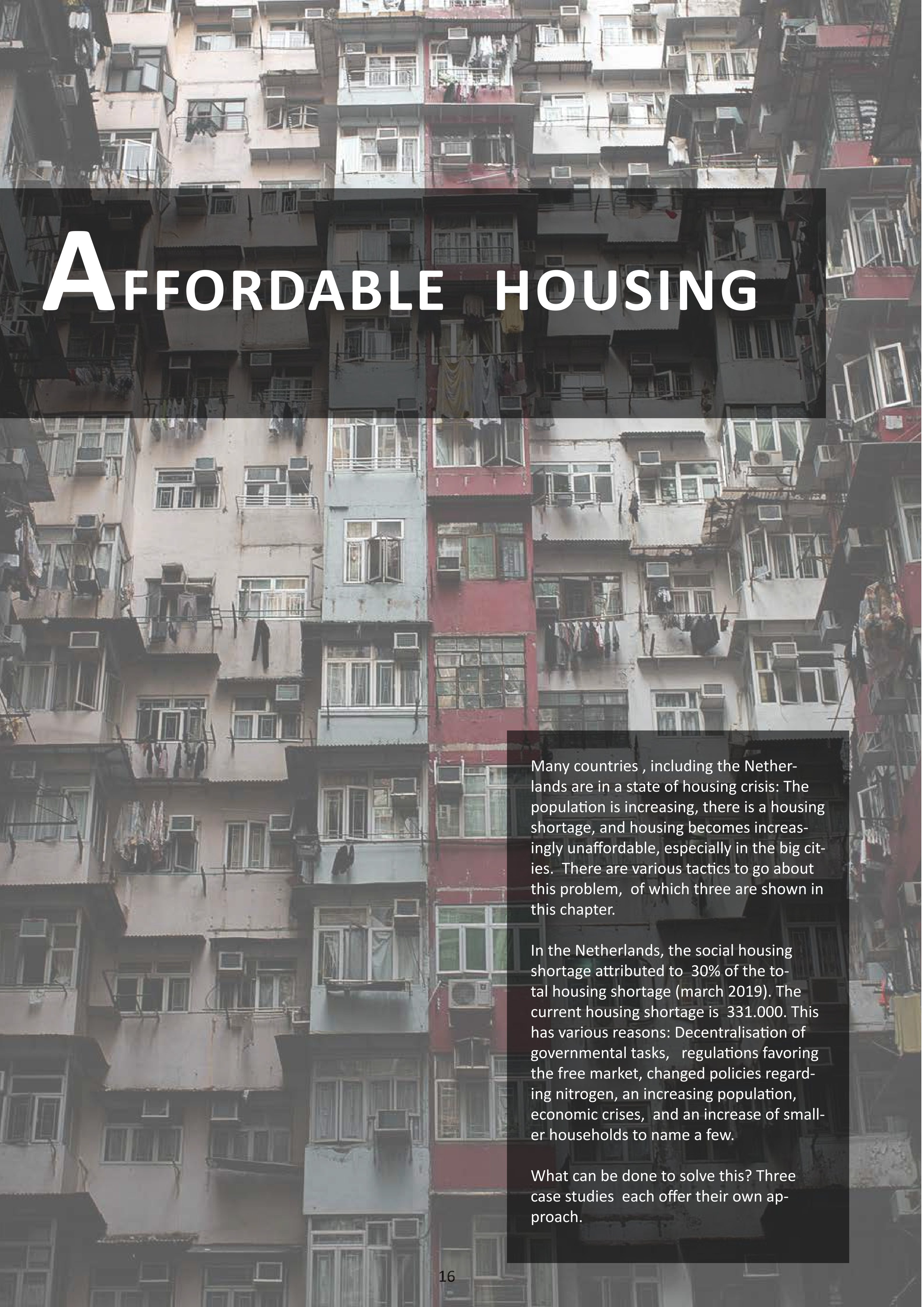


Affordable housing

Many countries , including the Netherlands are in a state of housing crisis: The population is increasing, there is a housing shortage, and housing becomes increasingly unaffordable, especially in the big cities. There are various tactics to go about this problem, of which three are shown in this chapter.

In the Netherlands, the social housing shortage attributed to 30% of the total housing shortage (march 2019). The current housing shortage is 331.000. This has various reasons: Decentralisation of governmental tasks, regulations favoring the free market, changed policies regarding nitrogen, an increasing population, economic crises, and an increase of smaller households to name a few.

What can be done to solve this? Three case studies each offer their own approach.


A.2 NEMAUSUS exterior (Jean Nouvel, n.d.)


A.3 NEMAUSUS, the façade can be opened completely (Jean Nouvel, n.d.)

When Jean Nouvel designed NEMAUSUS in the eighties, he had a clear vision of what it should offer its tenants: Good housing, which in his opinion was larger housing, for the same price. He created open plan apartments ranging from 90 to 160 square meters spread over one, two or three floors. By separating the building services from the apartments, the construction became less complex, apartment sizes could be maximised and the apartments would have natural light and ventilation from two sides.

Project
NEMAUSUS

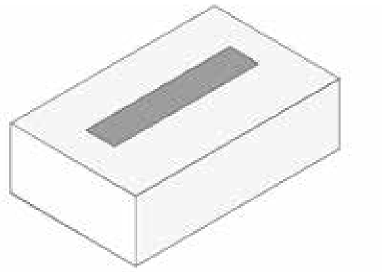
Architect
Jean Nouvel

Location
Nîmes | France

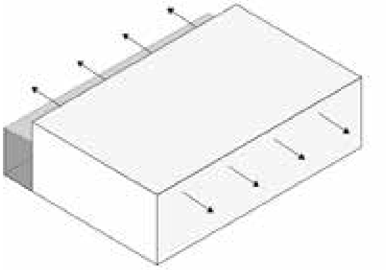
Year
1985-1987

Program
Experimental housing

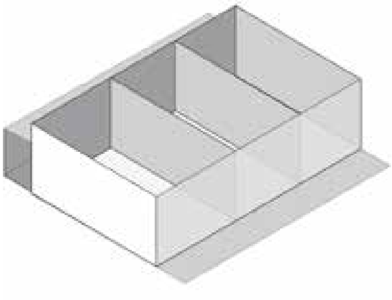

A.4 NEMAUSUS, interior of an apartment (Jean Nouvel, n.d.)



Many buildings place their services and infrastructure in the core of the building.

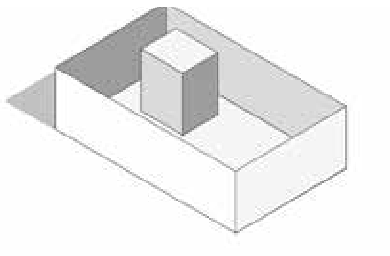


By putting these on the (north) side, the construction is simplified and apartments stretch to both sides, allowing better natural ventilation and more daylight.



The construction consists of prefabricated concrete slabs and walls.

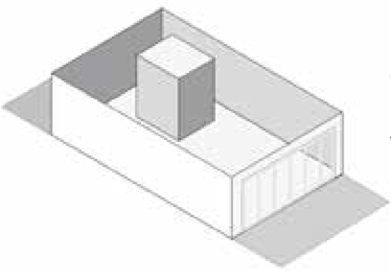
A.5 people sitting on the horizontal part of the balustrade (Richard Copans and Stan Neumann, 1995)



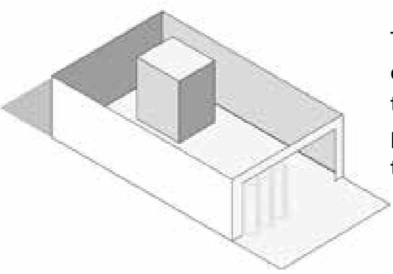
A closed core in the apartment houses the ‘wet’ services and storage space, dividing the apartment in different areas

The construction consists of prefabricated concrete slabs and walls. For the façade and interior finishing, Nouvel took inspiration from industrial sites. The cladding is made with thin concrete covered by corrugated steel plates. The concertina doors that fold away completely are inspired by firestations. The balconies are enclosed by slanted perforated steel panels, inspired by scaffolding during the construction phase of a building. Due to regulation these were not allowed to be placed with only the slanted part, so a horizontal plate was added , which ended up enhancing the outside area, as it could be used for seating, placing plants etcetera. By using these low cost construction methods and by using materials that are often used for more industrial products, more of the budget can be spent on the size of the building and its apartments. The interior is deliberately unfinished; the rough concrete walls are exposed, and the annotations of the contractor are drawn back on. The architect wished for the building to keep this bare appearance and set up rules prohibiting to add finishes to the walls. However, tenants did cover up the walls with their own wallpapers, posters etcetera to make it their own.

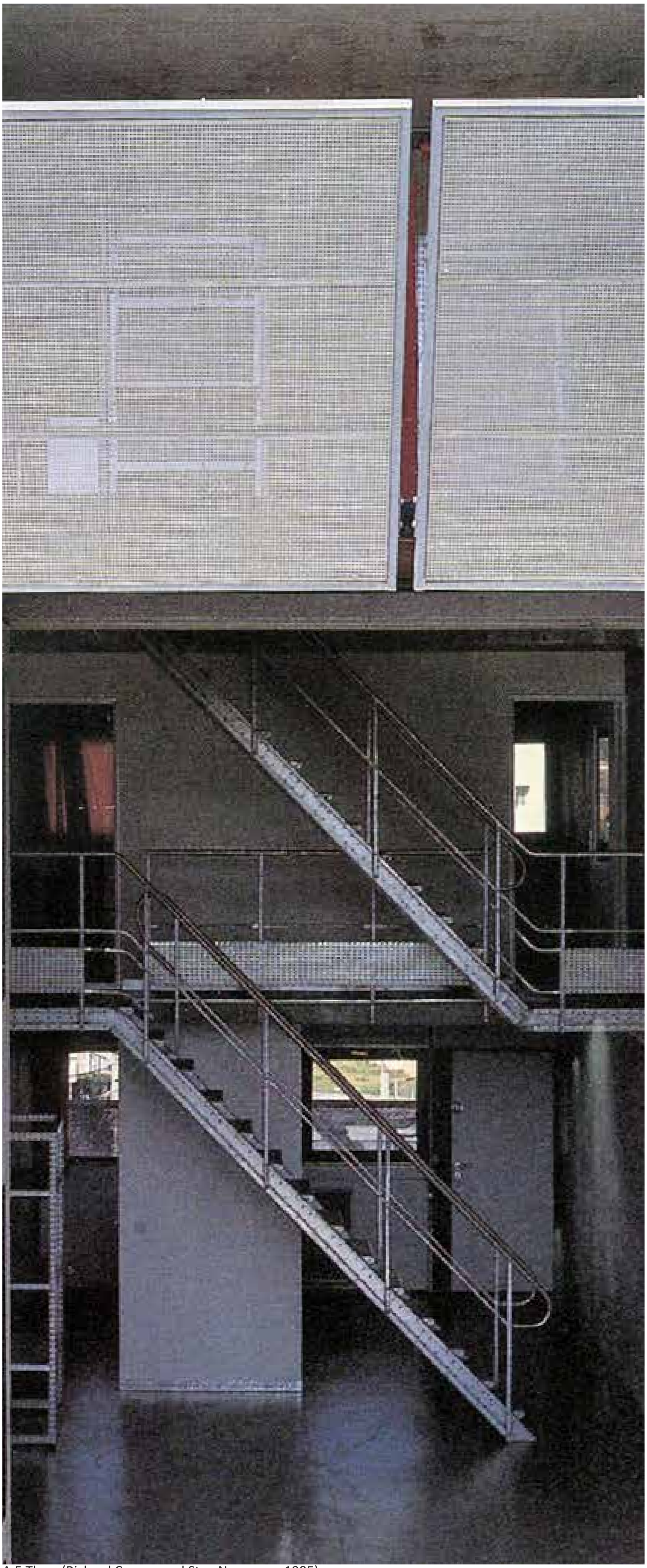
> “
> **A good room, for just about everybody, means a big room. A good apartment, above all else, means a big apartment.**
> ”
>
> - Jean Nouvel-



On the south side a large balcony is added, which can be used for leisure but also storage



The concertina doors open up all the way to seamlessly expand the living space towards the outside


A.5 The v (Richard Copans and Stan Neumann, 1995)

The project managed to create 30 to 50 percent bigger apartments for the same price. Unfortunately, the regulations for social housing calculate rental prices based on the amount of square meters, so residents also had to pay 30 to 50 percent more.

The NEMAUSUS project failed to meet its main goal; larger, better social housing for the same price. Despite saving costs, the regulations did not allow for such projects. This teaches a lesson about the importance of awareness of the constraints of the context in which one is working. But nevertheless, by using simple constructions, changing layout, having minimal infill of the plan, providing minimal finishing and using industrial materials, costs are lower and the tenant has freedom to tailor it to their wishes.

A.7 WikiHouse framework Ahad, n.d.)

A.8 A WikiHouse with cladding and infill under construction (Woningbouw atelier, n.d.)

Project
WikiHouse

Creator
Alastair Parvin - Open Systems Lab

Year
from 2011

Program
Housing

Unprecedented connection
When the internet came into existence, it was the start of an unprecedented platform to share knowledge and ideas with everyone from everywhere. this open source software also sparked new possibilities in the democratisation of architecture. This is at the point where open source hardware, such as 3D-printers and CNC machines emerged, which is where WikiHouse comes in. It is an open source platform that uses digital manufacturing techniques to let people create customized building packages to build your own home.

The Goal
Alastair Parvin is the co-founder of Wikihouse. In a TED talk he raises the question why it is that architecture serves the richest one percent of the population, whereas it could be a great tool to apply to solve societal issues and design for the other 99%. He raised the question what it would mean for cities if they are not designed 'by the few with a lot, but by the lot with a little'; a city developed by its citizens. People building their own houses is nothing new, but is a principle that got lost in industrialized communities, but now this concepts opens up this possibility again.

Wikihouse aims to democratise architecture by providing a platform which makes it possible for anybody to not just design, but also to manufacture and assemble customised, low cost, high performance homes. If someone improves a certain design, they share this on the platform, creating a constantly evolving catalogue of designs.

“

Our mission is to put the tools & knowledge to design, manufacture and assemble beautiful, low-cost, low-carbon buildings into the hands of every citizen, community and business.

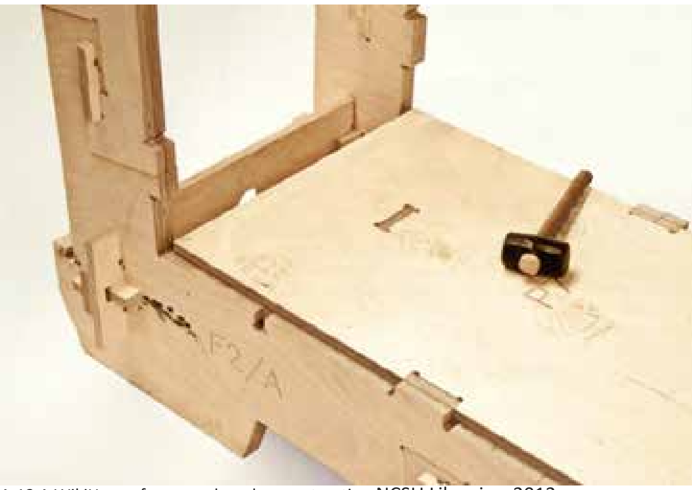
”

A.11 a two storey WikiHouse (WikiHouse Foundation, n.d.)

The package

On the WikiHouse platform, one can find standardised house packages, which can be adapted for each unique project. This then provides a set of building elements that are designed in such a way that they can not be misassembled. the parts are numbered and there is one way to put the elements together. Possible mistakes are anticipated and designed ‘away’.

A.10 a closeup of a numbered interlocking connection (Ahad, n.d.)



A.12 A WikiHouse framework under construction NCSU Libraries, 2012

Assembly
The elements are modular and assembled using dry connections. Almost all parts are connected by interlocking parts or by wedges, that can also be printed. With limited tools and basic skills the framework can be assembled.

By using digital fabrication tools, the elements are designed with much precision. The building parts are build up out of flat elements, which makes for easy fabrication and efficient transportation.

Local Fabrication
The separate elements do not exceed a certain size, and are composed out of flat elements, to enable smaller factories to produce the necessary elements, and hereby making local, small scale production possible.

Build your own home
Each client can determine which parts are built by themselves and which parts of the construction they outsource to professionals, thereby giving the client more control over construction costs.

The wooden OSB elements are assembled to create the framework of the home, which is then to be fitted with windows, insulation, internal and external covering and cladding and the infrastructure for electricity, water and heating.

A shift for society
The Wikihouse can be altered over time, adding extra parts or even building an entire neighborhood. These possibilities could instigate a citizen led urban development across the globe.

WikiHouses are designs based on standard, modular elements that can be adjusted according to one's wishes. It is cost-effective due to a quick building process, low tech assembly that can be done by the clients themselves, because it can be locally produced, and because one can fill in the framework with what is locally available.

The components are up to 90% reusable. The carbon footprint of a WikiHouse is up to 3.3 times lower than for conventional concrete or brick housing construction.

A.13 a finished WikiHouse in Almere, the Netherlands (Keratop, n.d.)

A.14 The Half Houses in Chile, Iquique (99 Percent Invisible, n.d.)

A.15 The Half Houses in a later stage, expanded by the owners. (Cristóbal Palma, n.d.)

A.16 the interior before resident's occupancy, and during, after alterations. (Tadeuz Jalocha, n.d.)

Project
Quinta Monroy ('Half House')

Creator
Alejandro Aravena, Elemental

Location
Iquique, Chile | Monterrey, Mexico |

Year
from 2010

Program
Housing

Pritzker price 2016
Aravena received the Pritzker prize for his work in social housing.
"His work gives economic opportunity to the less privileged, mitigates the effects of natural disasters, reduces energy consumption, and provides welcoming public space.He shows how architecture at its best can improve people's lives." - Tom Pritzker

A.17 Half Houses project, Villa Verde in ConstitucIón, Chile (99 Percent Invisible)

A.18 The Half Houses in Monterrey, Mexico (Ramiro Ramirez, 2010)

History

In the seventies, professor John F.C. Turner came up with an idea about the fact that people can build their own homes. He felt that housing should be seen as an ongoing project.

Alejandro Aravena founded his firm Elemental in Chile with the goal of alleviating social deprivation. What he saw happening in social housing is that it was not affordable to built a full size home, so instead people were offered smaller homes. In the line of thought of John F.C. Turner, he figured, why not provide half of a full-sized house?

The Half House

In Chile, the challenge was to provide housing to 100 families for about 10.000 dollars per family, which usually resulted in apartments of 40 square meters at most, as land use would take up most of the budget. These families refused the idea of high rise buildings, as they would be unable to expand the small apartments.
The idea was therefore not to build a small house, but half a good house, using public money to built what families would not be able to build themselves. The principle of this is called incremental housing, which takes inspiration from slums and favelas. “Incremental housing can be defined as a gradual step-by-step process whereby building components are improved by owner-builders as funding, time, or materials become available.”
The half house meets minimal requirements and provides a basis equal for all families, but is part of a framework that allows residents to create expansions over time. In this way, families can create their own unique houses tailored to their personal wishes over time. This results in a hybrid form of designed/planned housing and the self-building potential of the people.

Challenges

The half houses have made scarcity into a tool and have a noble cause. Despite this, the approach comes with its own challenges, as the initial construction and building of the half houses has to be financed, and also that the completion of a house might take a long time, as it depends on when the financial means become available.
Nevertheless, by providing good quality basics, a framework and trusting the self building capacities of families, this approach is, over time, able to provide social housing of an up to standards size, and tailored to the individual.

AFFORDABLE HOUSING

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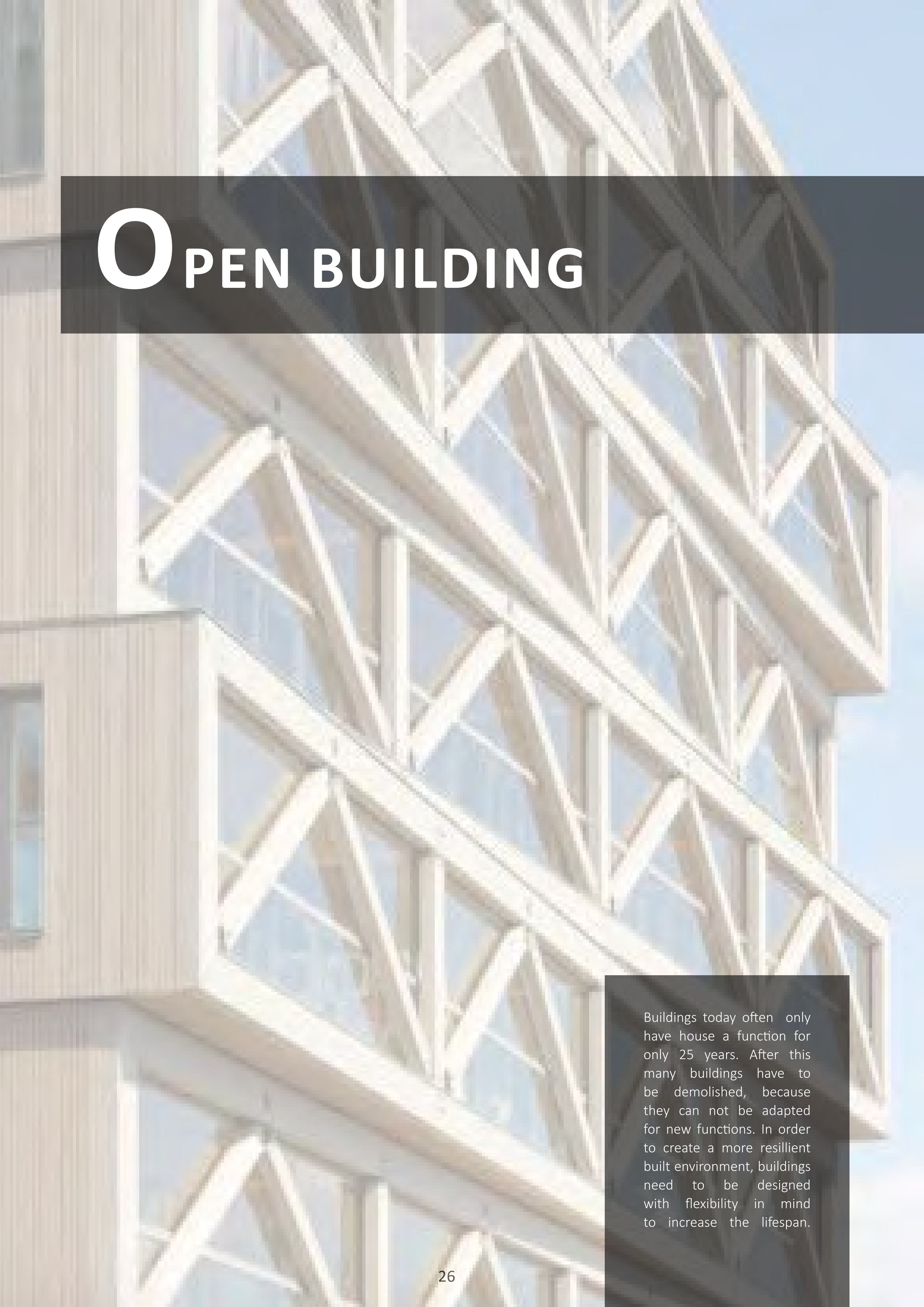


OPEN BUILDING

Buildings today often only have house a function for only 25 years. After this many buildings have to be demolished, because they can not be adapted for new functions. In order to create a more resillient built environment, buildings need to be designed with flexibility in mind to increase the lifespan.

OPEN BUILDING


F.1 John Habraken, the man behind Open Building

State of the art

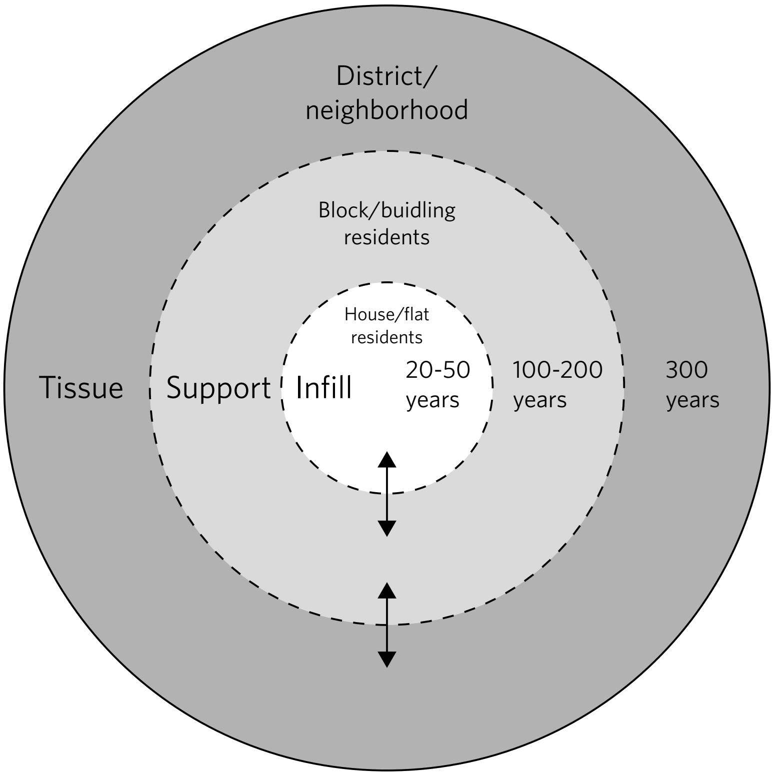
"In terms of project finance, the rate of investment in refurbishing and maintaining existing building stock is sharply rising. Renovation now accounts for more than half of the construction market in many developed nations. Yet the relative capacity of buildings to adapt to changes in infill systems, use or user preferences has greatly diminished. The average life span of new buildings has plummeted, from 100 years to as few as 20 or 30. [1] To increase the lifespan of buildings, they need to be designed with flexibility and adaptability in mind. On of the most practical and still applied ideas to fulfil this, is N.J. Habrabken's "Open Building." [2]

The origins of Open building

Open building is a concept for adaptable buildings which has been around for quite some decades. "Developments are widespread and accelerating. "They accompany change: in environmental structure, in production and construction methods, in the market for services and products, in product technology, and in the demand for suitable housing. However, unlike many new products or methods, Open Building was not invented." [1]
"Open Building had emerged more gradually in response to many different forces, from social to political, prevailing conditions and trends in residential construction and manufacturing, and to many other factors that demand more effective and responsive practices." [1]

Like mentioned earlier, the idea originates from 1961, when a young Dutch architect, N.J. Habraken, published his book De Dragers en de Mensem het einde van de massawoningbouw, a slender volume subsequently translated as Supports: An Alternative to Mass Housing (1972). In Supports, Habraken observed that mass housing (MH) had begun to disrupt an age-old natural relation between human beings and their built environment. [1]
"Traditionally, each household acted directly to take charge of the act of dwelling. When you look at the Amsterdam canal houses, for example, there was a clear and common typology. However, each inhabitant or owner is free to adapt their own dwelling. Every stoop, every facade, every window and every plan was therefore different, which created variation in a broadly shared environmental theme. However, when mass housing started to occur such participation and responsibility of individual households was suddenly excluded, entirely eliminating owners from participating in the housing process." [1]
According to Habraken it was possible to rebuild this natural relationship or process within built environment. To restore healthy environmental structure to residential areas in the face of new and rapidly changing environmental conditions would require some form of support. Residents needed to be able to make dwelling decisions on their own behalf, rather than to be provided with standardized housing units. [1]

Habraken goal was however not to reinvent housing types. He proposed to construct a base in full recognition of and in harmony with local culture, including traditional architectural character. He focussed on the use of local technology, although questions of technology were not the focus. In addition, Habraken wanted to directly connect with contemporary professional architecture and, in so doing, to transform it. [1]
After a decade of applied research and publications followed by pioneering prototype 'Supports' projects built by municipalities and housing associations, the groundwork for Open Building had been laid. [1]



F.2 Diagram showing the different levels in Open Building

Levels

"An urban planner isn't concerned with the architecture of the buildings that are realised within the city; He produces a context in which architects can work. That insight led Habraken to the concept of levels, which became guiding for Open Building: wherever you are working you are always busy working within something that has already been made by someone else, and what you make becomes a context for someone else. If that's not the inhabitant, then an interior architect. And if you concentrate on your own level then you can also be much more open towards unexpected changes, you can improvise more. " [1]

"Tissue (urban level) decisions are made for the wider public realm and includes establishing urban patterns of built form and space, placement of streets, parking and utility networks, setbacks and 'street furniture.' Furthermore, they might be like a masterplan and address the character of building facades, the location of public buildings, and the land uses within the urban tissue." [1] Within that urban structure, you have the Support level. Independent decisions on the Support (base building) level involve the common areas of the building, those parts which may endure for a century or more. To use multi-family housing as an illustration: the base building may be comprised of the load bearing structure, plus the building's common mechanical and conveyance systems and public areas, as well as all or most of its outer skin. Individual tenant changes can - and should - leave the Support unaffected.

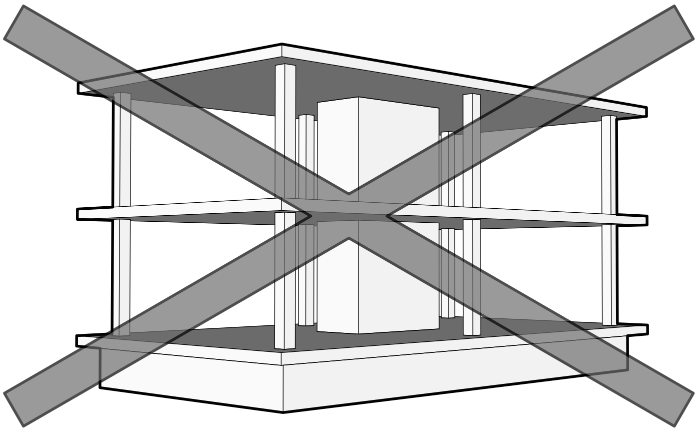
Systems and parts associated with the infill (fit-out) level tend to change at cycles of 10-20 years. This can be systems, separating walls, furniture etc. Transformation may be occasioned by occupants' changing requirements or preferences, by cyclical need for technical upgrade or by changes in the base building. [1]

From the 3 levels the support and infill are the most relevant to us architects and will be explained more in depth. [1]

Key concepts in Open building: Supports

"The Support concept can be compared to a highway as a finished product whose lanes are intended to be occupied by many kinds and sizes of vehicles, while a Support is a finished building, ready to be occupied by variable infill. In this layout the size of individual occupancies - dwellings, offices, etc. - are not pre-determined, they are open to be filled in as desired. Like explained earlier, the Support is the permanent part of a building with the shared functions which provides serviced space for occupancy. The multi-family base building functions as vertical real estate, to be developed and subdivided just as any real estate project. It will include public ways (stairs, elevators and corridors or galleries), commons (laundry rooms, community rooms, public foyers, etc.)." [1] Supports also contain all shared building services, delivering them to the front door or separation wall of each occupant. Next to the structure and the earlier mentioned elements, the Support also includes trunk (main) lines for electricity, communications, water, gas, and drainage. However, individual dwelling unit heating and air conditioning equipment is not generally part of the Support, but rather part of the infill. [1]

"The design of the Support is determined by the local market, architectural styles, climate, building codes and land use rules, investment requirements and other local conditions. This means that the support is not a general design that can be copied to any place. Within its specific social and technical setting, the Support is built using locally appropriate means of design and construction. Transformations in building may result



F.3 A support is not a mere skeleton

from social, technological, demographic and market changes during the useful life of a building. Even when residential use remains, the original unit sizes and configurations can become outmoded as incomes, household composition and space needs change on a dwelling-by-dwelling basis. The Support is intended outlast infill changes, independent of the individual occupants' choices, while accommodating change. Once erected, the form of the Support is closed in. The common services are all installed, the site is cleared, and any disruption to local traffic is at an end. From the perspective of the community, the Support appears complete. But to be occupied, it requires infill." [1]

Key concepts in Open building: Infill

In Open Building, most technical and organizational elements of the building are part of the infill layer. This means that the architects role changes, just as the role of the occupant. Architects will focus more on the architecture itself, which you could call the durable shared part of the building, while the occupants fill in their own dwelling. However the architect should in designing the building take many different infills into account. Infill can be produced off-site and then brought to the building site as a full package. However, elements that are built on site can also be part of the infill. A separating wall can be an infill element as long as the resident has control over its position, and if they can be changed without changing the support. If this not the case, the wall is part of the Support, rather than the infill. Therefore, infill elements are defined by social as well as technical criteria.

"

A Support is not a mere skeleton. It is not neutral, but is rather enabling architecture. It is more like a serviced, environmentally protected site within a built landscape: a Support is a physical setting that offers space and possibility to make dwellings with as few constraints as possible, while requiring as little work as possible [1]

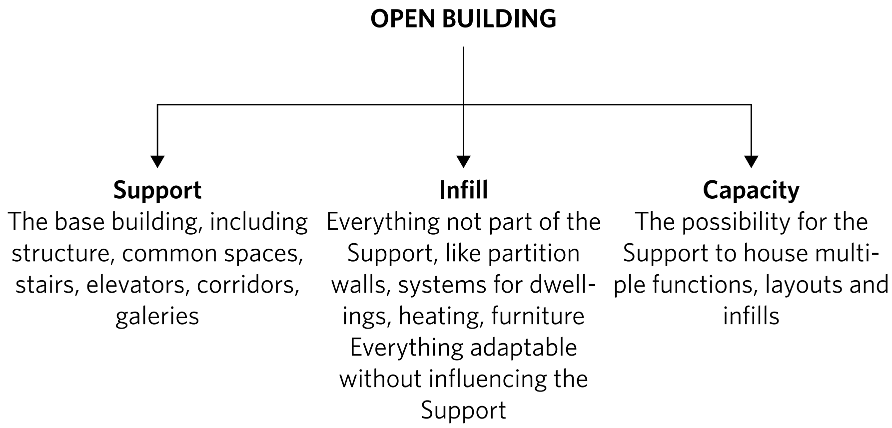
"

"The infill typically comprises all components specific to the dwelling unit: partitioning; kitchen and bathroom equipment and cabinets; unit heating, ventilating and air conditioning systems; outlets for power, communications and security; and all ducts, pipes and cables which individually service facilities in each unit." [1]

Capacity

"Next to those concepts there is another things that separates Open Building from conventional building design. In conventional architecture the design starts with 'defining the problem.? 'Getting the program right,' which leads to a 'design solution.' In Open Building, the concept of capacity replaces the set program and its function during the design process. Capacity analysis is at the core of Open Building. It works with 2 main ideas: 1) designing form to be open-ended and dynamic; and 2) designing space or form (at multiple scales) with built-in capacity to accommodate more than one 'program of functions' over time. Form is considered in terms of possibilities rather than in terms of a single, rigid and predetermined function." [1]

Design of the Support has to include capacity according to three principles:



F.4 Open building and its 3 key concepts

First, each dwelling in a Support must allow a variety of layouts. Second, it must be possible to alter the floor area by changing the boundaries of units within the base building or expanding it. Third, the Support or its parts must be adaptable to varying functions, some of which may be non-residential in character, like offices, leisure or commerce.

"In designing Supports, such evaluation of capacity must be approached systematically. First comes the evaluation of possible uses. Here a series of possible layouts are compared, from a schematic design all the way through the technical workout. The interplay between base building and infill must also be explored. Since adaptability is an essential characteristic of Supports, change must be easily achieved. Supports must be designed without knowing infill or systems will be used by the occupant. Nonetheless, the form doesn't have be neutral to optimize useful capacity. Totally 'flexible' multi-purpose space, as we often see nowadays - space devoid of columns, walls, changes in section or qualities of light - offers no architectural definition for dwelling." [1]

Capacity is also visible on the Tissue level. In urban neighbourhoods, individual buildings on lots can change or be replaced without forcing an adjustment in overall neighbourhood spatial and formal order. This insures the stability and continuity of the urban fabric.

Openbuilding.co

Recently the Open Building has been widely used by the group OpenBuilding.co. A group of Dutch architects under the International Open Building Council work with the ideas of Habraken, translated to the current Built Environment. They work with a few core principles.

Open building principles

"Open Buildings are a much-needed concept to lower the ecological footprint for which the global building industry is responsible; in particular to reduce its production of waste and CO_2-emissions by extending the lifespan of buildings and engaging in circular economies. At the same time, Open Buildings support the transition from the consumer society to one based on participation, involvement and inclusion.

New development models and co-makership

Open Buildings are buildings open for appropriation and co-creation. They form the "infrastructure" for home-owners and users to inhabit and co-produce their environment. In terms of Habraken the "infrastructure" is the Support, which is filled in by the home-owners. They offer possibilities for new real estate development models and forms of co-ownership and co-making. They involve future users and residents in the early stages of a project, which create a strong sense of ownership and belonging and are a powerful tool in community development. Open Building is a process open for ideas, for interpretation, for participation.

Resilient and adaptive open cities

Open Buildings make Open Cities. Open Cities accommodate a dynamic, differentiated, mixed and intense use of space. The principles of Open Building form a resilient and flexible building model for real estate that help creating an open and diverse city that is adaptable to social tendencies and climate change. Open Buildings accommodate the social, economic and technological complexity of our time and the future, add value and are timeless.
In terms of sustainability OpenBuilding.co goes further than the original ideas by Habraken." [3]

“

“Supports are part of the public domain and are permanent, while the infill belongs to the individual and is changeable. Public participation and freedom of choice of the user is the key objective. [4]

- John Habraken, 1961-

Open building and sustainability

Extending the lifespan of buildings

“Open Buildings are buildings open for change. They are designed to adapt to many ways of use for the purpose of extending their lifespan. They combine a robust and resilient structural framework (“carrier” or “support”) with re-usable (renewable or recycled) infill systems that are designed for disassembly, such as facades, interior walls, fixed furniture and technical facilities. With the concept of Open Building, the environmental costs of maintenance, renovation and even transformation - during the total lifespan of the building - are significantly reduced.” [3]

Where Habraken only used the interior of buildings as infill, OpenBuilding.co goes even further, talking even about facades, fixed furniture and technical facilities which can be changed over time. This could increase the lifespan of the buildings even more.
However, the idea of linking Open Building with sustainability is also something that also Kendall mentioned in this book discussing the ideas of Habraken.

Sustainability in Open Building, and architecture as a whole, leads to two principles. First: Build environments need to be created that can change, and thereby remain viable. Second: Subsystems, or the infill, should be disentagled, so that the change or removal of one doesn’t require the destruction of another — at the very least, design and build to reduce collateral damage. [1]

Because the Open Buildings are designed with change in mind, they decrease the need for demolishing existing building which have outgrown their initial function, which have to be replaced by new buildings. This is the thing that makes Open Buildings so sustainable, and which can create a more resillient architecture.

F.5 PATCH 22 in Amsterdam

Project
PATCH 22

Architect / Company / Whatever
Frantzen et al.

Location
Amsterdam | The Netherlands

Year
2016

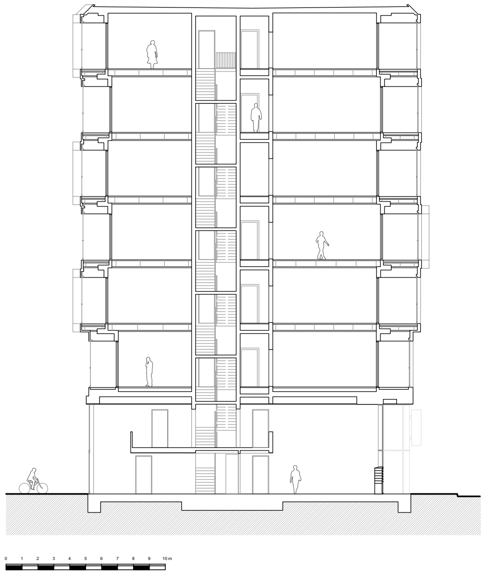
Program
Housing

Patch22 is one of the successful plans in the Buiksloterham Sustainability Tender of 2009. The building is more than 30 meters high, which makes it a high-rise building in wood. When it was realized it became the highest wooden building in the Netherlands. Thinking about the program, they decided that they wanted to do something that had never been possible with previous clients. The aim was to create an outsized wooden building with a great degree of flexibility, striking architecture and a high level of sustainability. [5]

F.7 Facade of PATCH 22

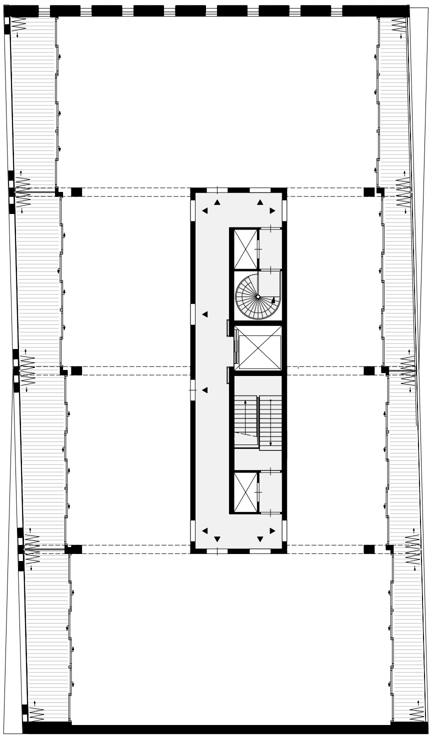
PATCH 22 by Tom Frantzen, who is also part of OPENBUILDING.CO, is a clear example which shows what Open Building can offer and how it works in the real world. For the project Frantzen et al. tried to attract owners who wanted to think themselves about what they wanted in their apartment, and how they want it. The floorplans remain open, except of the central core in the middle of the building and the commercial plinth and can be used as a large loft apartments of up to 540m2 with huge balconies, as up to eight smaller apartments. The building can be converted from residential space to open office space covering the entire floor thanks to the lack of structural dividing walls the generous storey height of 4m and the high floor load of 4kN, or transformed into commercial space, all without changing the structure. Apartments can be subdivided or merged, and the division into apartments will remain flexible in the future. The apartments themselves offer complete layout flexibility because the occupants are able to install the pipework and wiring to their own need and demands in the Slimline flooring system, a hollow floor with a removable top layer. Because of this the adaptation of the building can de done quite easily.

“To achieve flexibility during the (hopefully extended over and over) lifecycle of the building we designed the sections not only to accommodate apartments in every imaginable way but thanks to the gross floor heights of 4m lots of other scenarios are possible as well. By applying escape route regulations for housing as well as those for office buildings PATCH22 can even be used to house offices. To make sure there will be no objections by the government against an alternative use in the future we drew up a new kind of land-lease contract in cooperation with the city of Amsterdam.” [6]

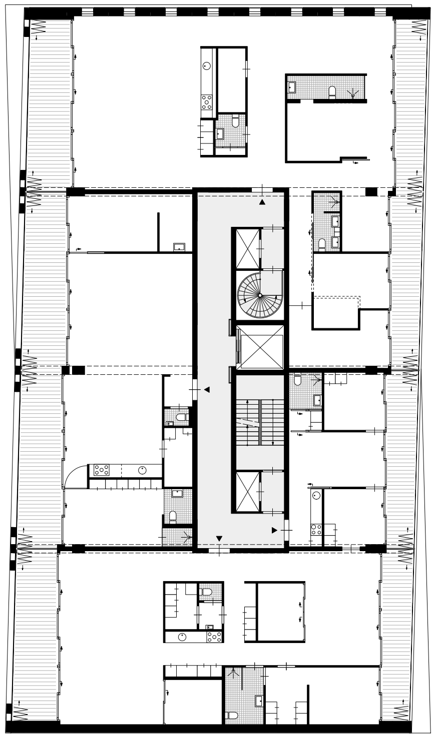


F.8 Section, showing the support of the building

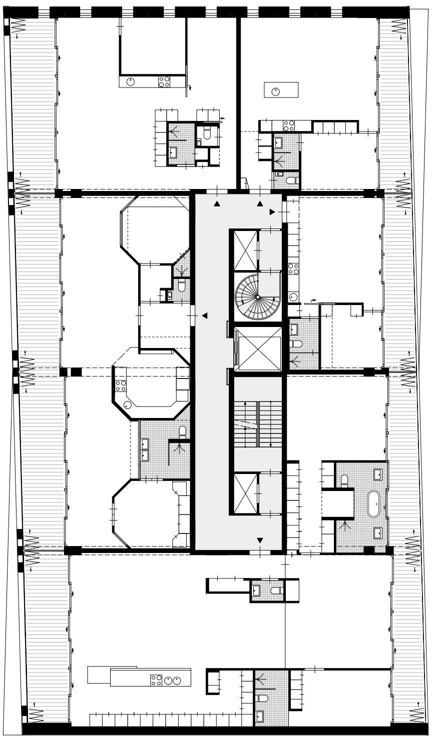
F.10 Interior of one of the apartments



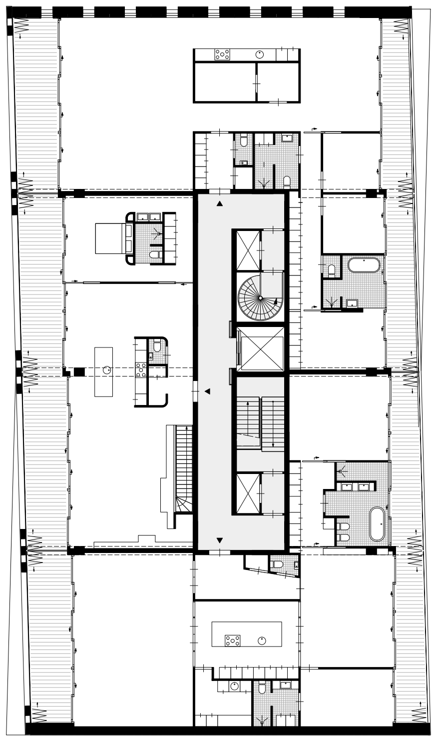
F.11 Empty floorplan of Patch 22



F.13 Possible floorplan of Patch 22



F.12 Possible floorplan of Patch 22



F.14 Possible floorplan of Patch 22

The flexibility is mainly visible when looking to the floorplans. Frantzen started by designing the floorplans empty, with just the structure and central core fixed. After this he made many different alterations for the building, and together with the future owners the designs of the apartments were made. Since the owners could decide themselves how much space of on of the floors they wanted, this resulted into very diverse floorplans, with all kinds of different apartment sizes, all with different layouts. This becomes very clear in the floorplans above, when you can really see the diversity in the layouts. [6]

F.15 Atlas Exterior

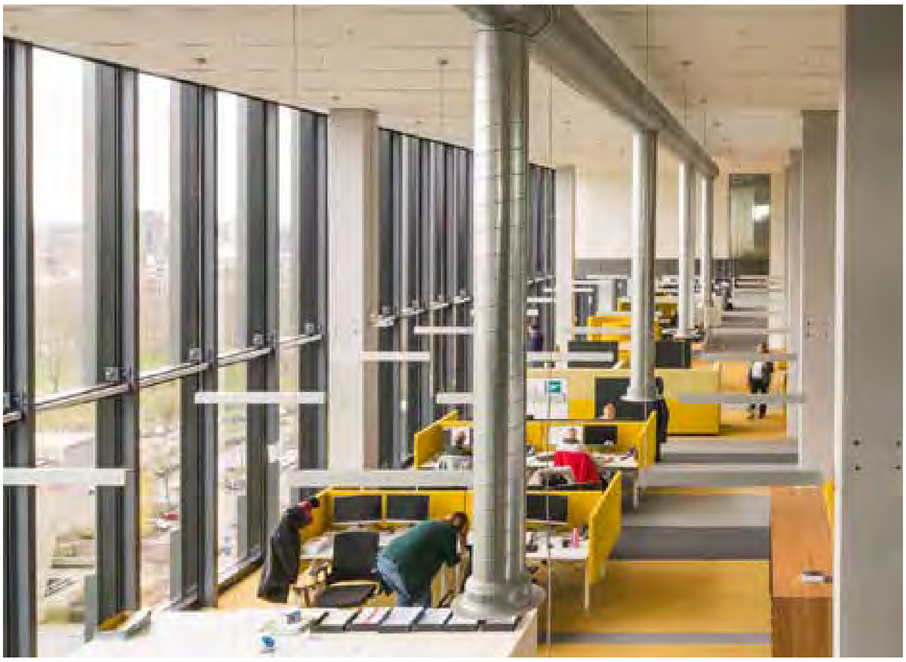
Project
Atlas

Architect
S.J. van Embden
Renovation by Team V architects

Location
Eindhoven | The Netherlands

Year
2019

Program
Education



F.16 Atlas Interior

Even though Atlas was not designed according to Habraken's Open building design, which came after the building was built over 60 years ago, Atlas is still a good example of why architects should design with flexibitiy in mind. Van Embden designed the building to grow, making every second floor using a steel construction instead of a concrete slab, an designing the whole building to be stripped and to be renovated. During the renovation by Team V architects, a lot of the original building was reused, like the floors and the steel structure of the curtain wall facade system. Due to the facts that some floors were removable, the design became more open again, and fitted it todays context. This was all possible, becasue van Embden designed the building with those things in mind. Because of this the lifespan of the building has increased again, and van be used for many years to come. It even became the world's most sustainable Educational building by BREEAM![7][8]

So even though it is not designed with Open Building in mind, Atlas is a prime example for why designing with felxibility and adaptability in mind offers resillience in the built environment.

OPEN BUILDING

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Biophilic design

One of the ways to improve people's well-being is to introduce biophilic aspects into their environment. As mentioned in the introduction, people have become quite detached from their natural habitat: nature. We are experiencing our life largely inside, in office buildings and online through a device. During the current COVID-19 pandemic, (mental) health issues have increased among the population, including the inhabitants of Rotterdam.

The book 'Zo Kan Het Ook' by Jaco Appelman, Mireille Langendijk and Anouk van der Leest has been used to compile an overview of different aspects and relevant applications of biophilic aspects into the design.

A.1 Shell showing origins of Fibonnaci proportions. (Zo kan het dus ook, n.d.)

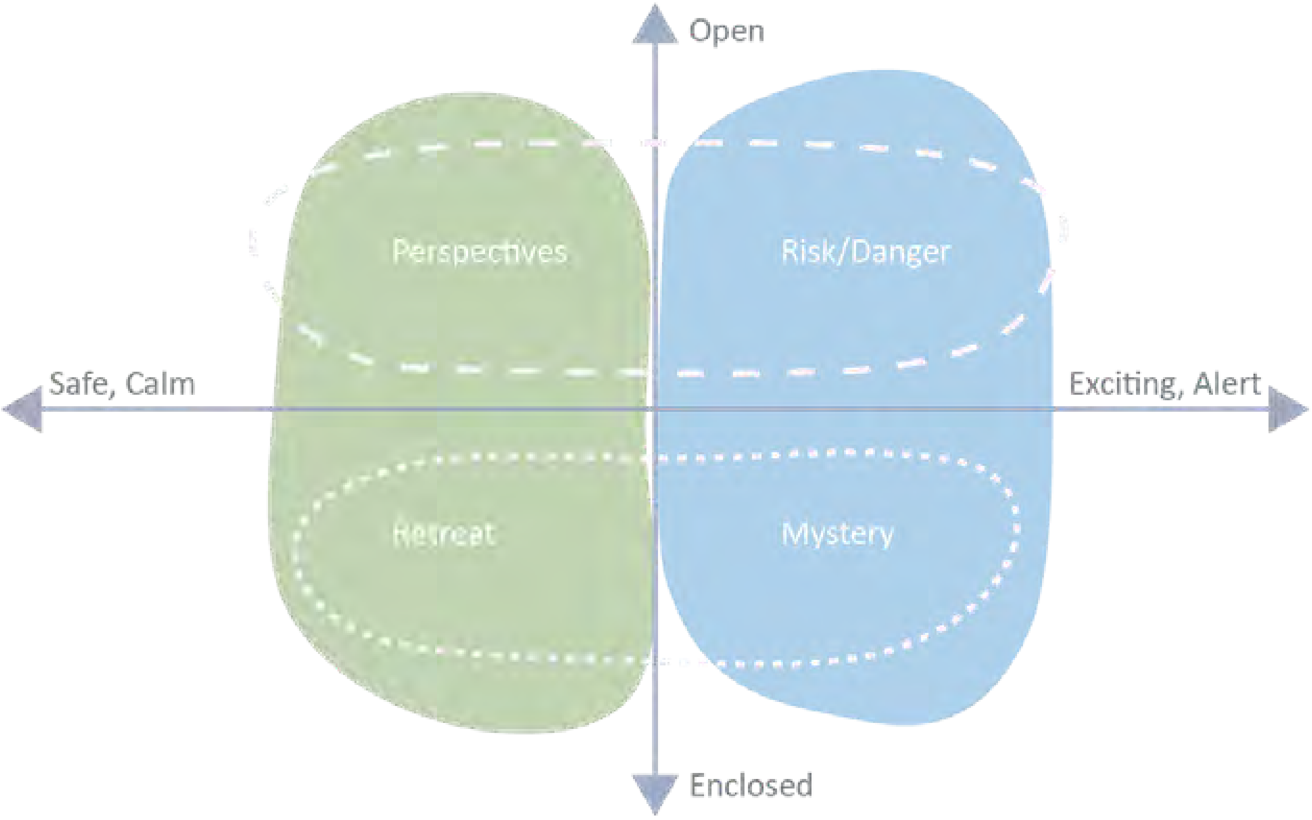
A.2 Conceptual visualisations of biophilic design aspects

Love for life
The term Biophilia means ‘love for life’, and refers to mankind’s natural inclination to connect to nature. While we have gradually been moving away from nature with our industrial developments and technological advancements, there is growing interest in how to reintroduce nature in our lives. Biophilia has been proven to benefit people’s well-being. This is not necessarily as literal as planting trees, but the effect can also be achieved by incorporating more indirect or abstract references to nature.

Natural Environment
One can create a visual connection to nature, for example to a body of water, trees and plants or a landscape. An indirect connection to nature can be achieved by incorporating sounds, scents or imagery referring to nature.
One can incorporate arrhythmical sensory stimuli, such as waves or wind, and temperature and airflow fluctuations. One can also use a combination of direct and diffuse light.

Natural analogies
Designing or decorating with biomorphic patterns and shapes , or by using natural materials also improves the connection to nature. Examples of natural materials are wood, flax, linen but also 3D printing with material of ground mussel shells and algae offers an innovative, compostable and cyclical option for 3D printing.
One can also incorporate biophilic design by working with the complexity and order found in nature, for example the proportions of the golden ratio, the Fibonacci sequence or fractals. These approaches can also be incorporated very well in methods of parametric design, as goes for an increasing amount of other biological principles as our technological understanding and design software is more and more developed.
Nature offers a valuable source for design inspiration, not only to increase our well-being, but also from a constructional and economical perspective. This is elaborated in the Biomimicy chapter.

Image source
a.1 KNNV Uitgevers, available on https://knnvuitgeverij.nl/artikel/zo-kan-het-ook.html



A.3 Conceptual matrix of four biophilic design principles

Nature of the space

A less obvious method is to mimic our natural environment and how we experience it. These options are contrasting each other, but one can pick the best approach fitting for each function or desired effect. One can work with perspective by creating wide streets, vistas, vides, balconies, terraces and by working with glass.
One can design a place of refuge where one can retreat, recharge in nature and be in contact with natural elements.
As opposed to the perspective and refuge, one can also design related to mystery or a sense of danger or risk to put the user in an alert, focused state.
Incorporating mystery can be done by doing the opposite of the wide perspectives providing a total overview, so working with the principle of denial and reward, meandering pathways and a sequence of spaces. Two examples of how the sense of danger can be used is by working with high walkways or glass floors.
Incorporating these biophilic aspects will increase the initial costs, but well-being and productivity of the users will increase, so it should be considered as a long term investment. This goes as well for investors and project developers, as the property value will increase up to 15%, and in the case of housing with gardens adjacent to recreational water even up to 30%, according to research by the Economic Research department of the University of Wageningen.

Biobased materials

Biobased materials are from natural origin or partly composed with natural materials. Some examples are: Wood, bamboo, flax, hemp, straw, wool, cellulose, clay, sand and bioplastics. An advantage of most biobased materials is that they are self-cleaning, anti-bacterial, vapour permeable, self-regulating and often possess favourable acoustic and thermal qualities. More on this in the chapter on Biobased materials.

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BIOBASED MATERIALS

As the world population keeps growing and resources are becoming more and more limited, this requires new ways of thinking. This is no different in the field of the built environment, where biobased materials are developed and used in all building elements to replace established, less sustainable materials.

B.0 a rammed earth façade with openings (Material District, 2013)

B.1 The Sustainable development goals of the United Nations, formulated in 2015 (European commission, n.d.)

Definition
Biobased materials are defined as follows: Biobased means 'derived from biomass', or 'composed in whole or in part of biological products issued from the biomass (including plant, animal, and marine or forestry materials). [Annex 4, the Expert group for the review of the bioeconomy strategy and its action plan]

Biobased and sustainability
"Biobased products can make the economy more sustainable and lower its dependency on fossil fuels. therefore the EU has declared the biobased products sector to be a priority area for future growth, reindustrialisation and adressing societal challenges."

Some biobased materials are also incorporating circularity, as they contain material that is otherwise considered to be a waste stream. In the development of most biobased materials and designs, the aspect of reusability and recyclability is also taken in to account, for example by using dry connections and by using natural, biodegradable binding material. There is much innovation involved in this research field, as modern day technology opens up possibilities that were not there even just a few years ago. But in some cases it is also a matter of (re)discovering of old or local principles or materials, or by translating the principles from another field into that of the built environment. For example, Hempcrete is thought to have been used in ancient pyramids, and is re-emerging as a biobased material during the last years.

Biobased materials can play an important role in reaching 2030 sustainability goals. Especially those about 'sustainable cities & 'communities' and 'climate action' but it could also positively affect other goals of the list.

Properties
There is a large variety in biobased materials and therefore also in the level of their circularity, biodegradability, availability, structural properties and costs.

In most cases, the material is comprised of two or more elements, making it a biocomposite. A biocomposite is made up of a reinforcing phase and a matrix phase: The reinforcing phase can be in the form of fibres, sheets or particles, and provides strength and stiffness. The matrix phase is what holds them together , transfers applied loads and protects them. The biocomposites can be divided into structural and non-structural biocomposites.

Working with these (partly) natural and innovative materials means influences of the environment, fire behavior, fibre direction, quality, consistency , application of regulations and the necessary experience from the constructors are matters that need to be investigated.

This chapter investigates three of these materials and case studies with this material: The Biocomposite NABASCO, Hempcrete and Mycelium.

B.2 Reed (Mark Altrogge, n.d.)

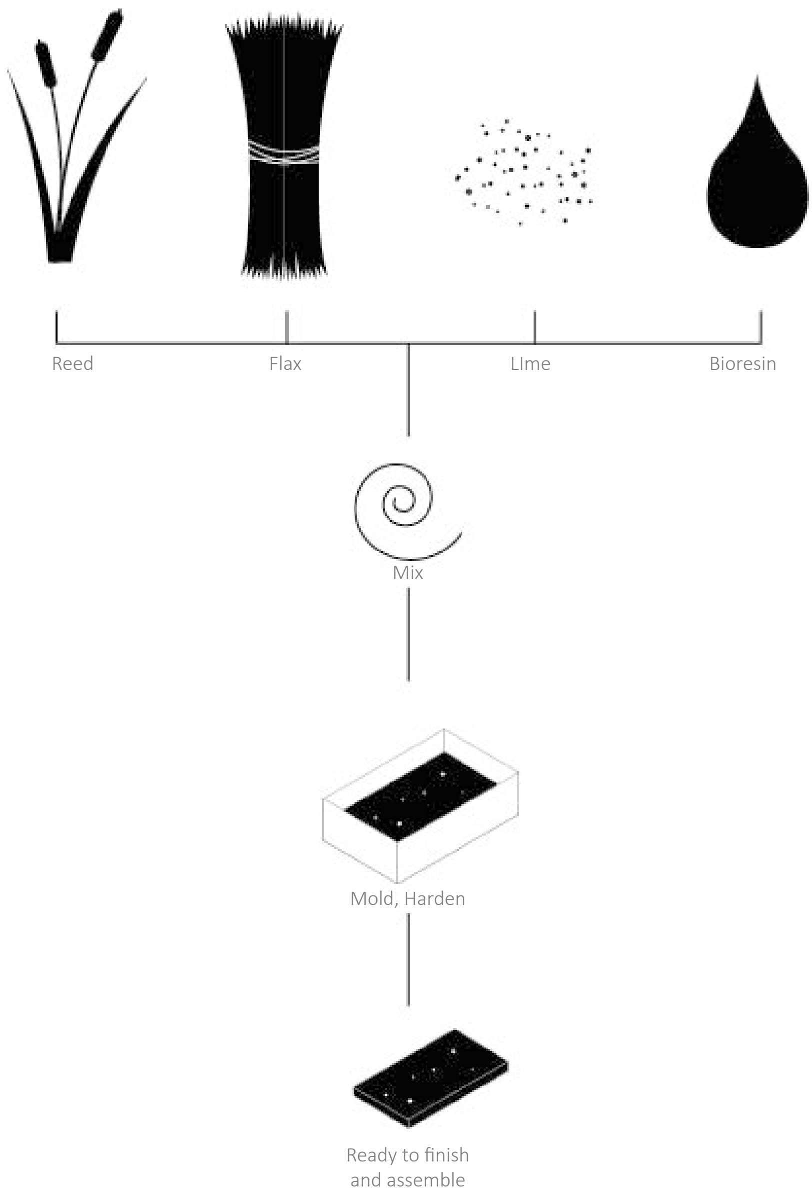
B.3 Biocomposite panels of the TU/e Virtue Solar Decathlon 2018 design (Hans de Wit, n.d)

Biocomposite Nabasco panels
As the term biocomposite is very broad and can mean whatever panel material. In this case the biocomposite panels of Nabasco are reviewed. Nabasco stands for Nature Based Composites. It is a biobased and circular material, which is composed out of reed or flax together with lime and a bioresin [image B.4]. Other compositions and using for example cloth or hemp fiber is also possible, but this will result in a panel material with slightly different properties.

Acquiring of components
The reed is acquired from waste streams of nature areas. The lime is substracted during the proces of water softening. The bioresin is based on wastestreams of biofuels. The resulting product is 82% circular.

Material properties
The finished product is a plate material that has a smooth matte finish, which can be made into any shape a mold can create, and can be manipulated with engraving, milling, laser- or water cutting. If desired, color pigments can be added to the mixture, but the chosen materials affect the color first hand. The composition in reed will result in a light edition as seen on the image above, and the flax results in a darker panel. The resulting panel is solid, with a specific weight of 1.71g/cm3. To compare, CLT wood is 0.45 g/cm3 , so it is relatively heavy. Also, the material is brittle and sharp edges can break off if not handled properly. The material can be applied as a cladding material for furniture but also for façades.

Biocomposite panels are circular materials with a low carbon footprint, but are relatively expensive. partly due to the costs of bioresin.



B.4 The fabrication process of a type of biocomposite panel, using Reed, Flax, Lime and a bioresin.

B.5 The World's first biobased façade (Ronald Tilleman, n.d.)

Project
Gasontvangststation

Company
Studio Marco Vermeulen
Location
Geraardsbergen, Belgium
Year
2013

Program
Gas receival station

The Agro Food Cluster of Nieuw Prinsenland, the location of the project, wants to exemplify sustainable development that aims to close loops in the field of energy, water and waste streams. The goal was to develop a façade panel that was as sustainable as possible while remaining technically feasible. The letters in the design represent the chemical elelements hydrogen, carbon and nitrogen in the correct proportions. The façade is cladded with 80 panels made of natural hemp fibers and bioresin. The panels were produced in double enclosed molds, which makes the emissions of the soluble material during hardening ip to 95% less than normal. Once hardened, the molds are removed and the panels are assembled onto the building with screws.

B.6 The making of the panels, representing chemical elements (Ronald Tilleman, n.d.)

B.8 The Nabasco Façade with letters protruding at various depths (Ronald Tilleman, n.d.)

Hempcrete

Hemp is a plant that does not have to be treated with chemicals, needs little waterand helps regenerate the soil. The stalks are used to create hempcrete. Hempcrete is a biocomposite of hemp hurd and lime combined with water. The lime functions as a binder for the hemp by coating it and glueing it together once mixed with water. This results in an organic, biodegradable and reusable building material.

Unique Material

The difference with other composites is that the lime binder only coats the particles to glue them together, without filling the voids between them. The advantage of this is that the hempcrete is lightweight and breathable. Its specific weight is 240-260 kg/m3 By varying the proportions of the components, the hempcrete can acquire varying structural, thermal and moisture absorbent capacities.

Application

Hempcrete got its name as it is an entirely organic biobased, very lightweight concrete, that can be used in construction in some cases, but also as insulation and finishing. It is also suitable to be used in renovation projects. It can be used in various ways. It can be cast directly on existing walls to create insulation, avoiding thermal bridges. It can also be cast in molds, to create bricks or other shapes.

Properties

Like the hemp during its life span, the hempcrete is low maintenance. Hempcrete is very suitable for thermal regulation, due to its thermal mass, and especially because of its ability to diffuse accumulated heat, reducing the heat transfer between interior and exterior. Because of its porous composition, it can store large amounts of moisture without causing problems, and is also able to release the moisture when the conditions change. Because of this, it is suitable for hot, cold and humid climates. The thermal and ventilation performance of hempcrete makes it suitable to reduce heating costs , eliminate the need for mechanical airconditioning and can be used in passive house designs. It cannot be used as a self supporting structure yet, but will support the construction and can be used to create separation walls.

Hempcrete is highly fire- and fungus resistant material that is also well suited for acoustic insulation. Because of its composition out of organic elements it is a non-toxic material, which makes it safe for the inhabitants. As it also provides a surface that is suitable to be finished with plaster, Hempcrete can be integrated into existing buildings as well.

B.9 Hempcrete wall (a10studio, n.d.)


B.10 The renovated house in its green surroundings (Cedric Verhulst, 2015)

Project
House renovation

Company
Martens van Caimere Architecten
Location
Geraardsbergen, Belgium
Year
2015

Program
House

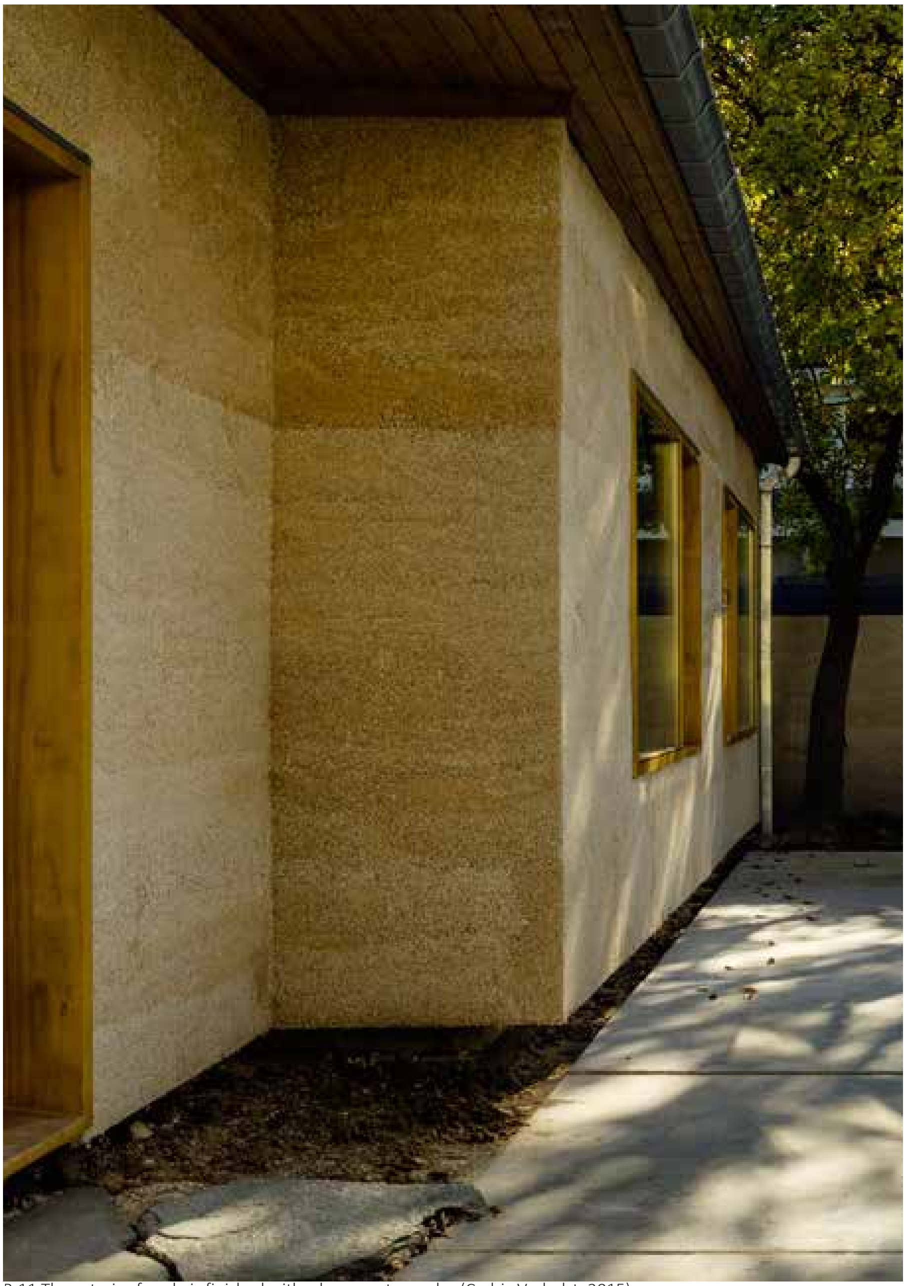
Hempcrete rendering

While hempcrete can be used in the form of bricks and added inside a building structure, it can also be used on exposed façades. It can also be used in renovation projects, to upgrade the energy efficiency and sustainability of a building. A way to do this is to create a hemp-based render, which is done by putting up wooden boards around the building to create a formwork in which the hemp, lime and water mixture is poored into. This is done layer by layer, and thereby creates a similar appearance as that of rammed earth. By pouring directly against the walls, there is much less of an issue of heat loss often caused by thermal bridges in traditional insulation methods. The thermal mass of the hempcrete helps retain heat and makes the structure more weather resistant due to its ability to store and let go of moisture.

"

Hempcrete combines the insulation and finishing in one layer, reducing building costs.

"



B.11 The exterior façade is finished with a hempcrete render (Cedric Verhulst, 2015)

While in some cases using hempcrete can be more expensive, the architects claim that in this case it is a more economical solution than concrete would have been. As the hempcrete is applied both as insulation and finishing in one go, this saves building costs. It is also more sustainable, as it is a material that stores CO2 instead of producing it, and as it is made from hemp stalks, which is a waste product, this greatly reduces the need for new raw materials in projects.

Since the existing house was renovated rather than demolished, this also reduces the impact of this project, and also saves costs as taxes for renovation are lower than for new projects.

The client for this project wanted a self-sufficient, low tech house. This is achieved by using the hempcrete, adding a stove, solar panels and a rainwater filtration system.

B.12 The hempcrete rendered finish provides a comfortable indoor climate (Cedric Verhulst, 2015)

B.13 the exterior hemp render façade (Cedric Verhulst, 2015)


B.14 Mycelium interlocking bricks (Korey Rosenbaum, 2016)

Mycelium

Mycelium in nature
Mycelium is a three-dimensional network of fungal threads that often grows underground, but can also grow on other places, like rotting tree trunks. Mushrooms can sprout from mycelium. Mycelia are organisms that break down organic material, and a large part of all plants interact with fungi. On top of this, mycelium is an important food source for insects and other invertebrates.
A mycelium network can grow to occupy several square kilometers, and is therefore not limited to small dimensions.

Mycelium as a building material
Mycelium is a material that is created from a mixture of materials. The main ingredient are traces of the Ganderma mushroom. This is mixed with plant remains, for example hemp, cattail or mace. This can be retrieved from waste streams of the local agricultural sector. The natural process of the spores breaking down organic material by forming networks is used in the creating of a desired element.

The production process
As mycelium is based on spores growing between loose remains, this means it can be made in any shape. This can be done by using a mold. In the first stage, which takes four to five days, the molds are covered to keep out oxygen and are placed in a dark, closed space. The plant remains function as nutrition for the spores, which break them down. In this process, the spores create a natural network of connections through the remains, thereby glueing it all together.

After this, the mycelium is taken out of the molds and baked for a few hours at 80 degrees Celsius to stop the growing process. If this step is skipped, actual mushrooms will start to sprout. After baking the production process is done and the mycelium element is ready for use.

Durability of the material
In terms of the life span of mycelium, this is very dependent on the application. Packaging stays good for months, furniture for several years, but building elements can last several decades.

Mycelium is a lightweight, biodegradable composite material that uses a waste stream as a resource. It has diverse possible applications within the built environment.


B.15 Mycelium origins: bags with cellulose and mycelium from which mushrooms grow (Case Western Reserve University, n.d.)

B.16 Mycelium pavilion (Stichting Nieuwe Helden, 2019)

Project
The Growing Pavilion

Company
Company New Heroes (Pascal Leboucq)
Location
Eindhoven, Netherlands on Dutch Design Week 2019
Year
2019

Program
Pavilion

Designed for and exhibited on Dutch Design Week 2019, The Growing Pavilion drew attention for the potential of biobased building methods. The goal of the design team was to create an iconic biobased pavilion that shows the outstanding beauty of biobased construction and design. It is made of a large amount of biobased materials such as wood, hemp, cattail, cotton and of course mycelium. Inside the pavilion was an exhibition of grown design objects.


B.20 The interior of the pavilion. (Oscar Vinck, 2019)


B.18 interior frame withdress from growing material
(Stichting Nieuwe Helden, 2019)

Disclaimer

The use of mycelium is not yet applicable in terms of buildings other than structures like this temporary pavilion, as the current building code does not yet include biobased materials like mycelium. With more research, testing and experience in working with this material, this could become incorporatedin in the future building code.

The pavilion is the result of two years of material research. The mycelium panels are covered with an Impershield coating, which is made from tree barks and grasses from Mexico. The coating is produced by Impershield in the Netherlands. The trees shed their bark automatically, from which the resin can be extracted. The resin and the grass then go through a process of fermentation, and end up being a coating that protects against moisture, dirt and UV-radiation.

For the transparant panels it was researched if it could be made out of PLA. PLA is a biopolymer, extracted from a natural source. It is possible to create transparent PLA panels, but not in the desired size without a large investment of time and money. Therefore in the end, glass panels were used. Glass can be recycled very well, so this is also an environmentally friendly choice.

B.19 Close up of façade (Stichting Nieuwe Helden, 2019)

BIOBASED MATERIALS

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B. 08. Ronald Tilleman, n.d. [online] Available at: https://www.biobasedbouwen.nl/projecten/biobased-gevel-voor-gasontvangststation/ [retrieved on 27 sept 2020]

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Biomimicry

Biomimicry or rather biomimetics, derives from the Greek word "bio" (βίος) and "mimetic" (μίμησις) which means to mimic biological elements of nature. In other words, biomimicry is defined by finding properties in living organisms and systems which can be integrated into the sciences.

The Research on biomimicry is conducted by Christina Poliviou and the author.

Figure 1 (ICD / ITKE University of Stuttgart)
Exterior view of Research Pavilion 2012.

WHAT IS BIOMIMICRY?

Biomimetics is the technical term used in biochemistry, biology, pharmaceuticals, and by material scientists, to find properties in living organisms and natural systems which can be recreated and applied for industrial, medical and biological products.[1]

Nature as inspiration

Throughout history, architects have perceived nature as a main inspiration for their designs and used it in a superficial way to realize their forms and functions.

During the classical era, Greek Philosophers observed organisms and considered harmony and proportion as the important parts deriving from nature.[2]

However, during the course of the last decades, a new way to understand nature has been discovered. This time, nature was recognized for its methods and analogies of growth during the last 3.85 billion years of evolution. Hence, it was vital to identify that nature had to be understood in a deeper sense than just the mimicking of beauty and direct formations. [2]

Knowledge translation

An important aspect to understand, is that biomimicry is based on a strategy of abstracting properties from nature. The approach of translating knowledge on a systemic and performative level, is similar to the way that problems are solved in engineering and biology, through recognizing patterns. The aim is to implement both the design principles of nature and the fabrication ones, in order to have a successfully informed biological and material system.[3]

Way of design thinking

What also defines biomimicry, is that it is a way of design thinking. It stems from the fact that it uses biology's analogies as a foundation core for creative problem solving in architecture and design. Since it is considered as a different design thinking approach, it consequently incorporates a particular approach for obscuring the required information from nature. The strategy for this design thinking, falls under two categories.

Design looking to biology (Top-Down approach)

This approach is defined by finding a

1. Benyus, J. M. (2002). Biomimicry (1ste editie). Harper Collins UK.
2. Aziz, M. S., & El sherif, A. Y. (2016). Biomimicry as an approach for bio-inspired structure with the aid of computation. Alexandria Engineering Journal, 55(1), 707–714. https://doi.org/10.1016/j.aej.2015.10.015
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4. Lebedev, J. S. (1983): Architektur und Bionik. Verlag für Bauwesen, Berlin. – Nachtigall, W. (2003): Bau-Bionik. Springer, Berlin.
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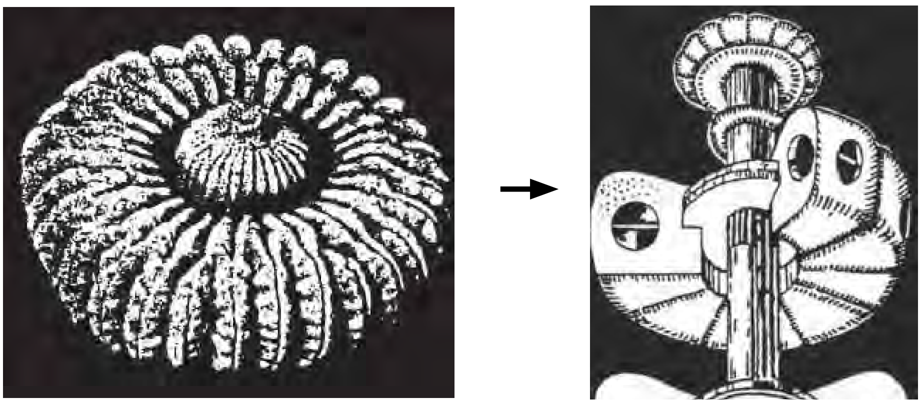

Figure 2 (Lebedev, 1983)
The hollyhock-fruit in this instance does not have a biobased relationship with the outcome, instead only a biomorphic one because it does not refer to the functions of the fruit.

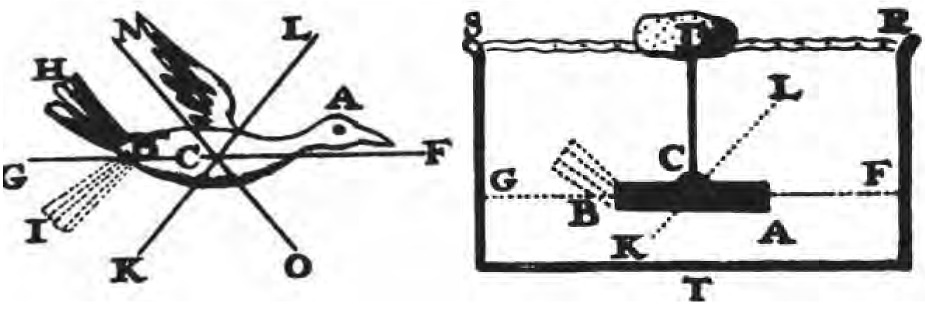

Figure 3 (Borelli, J.M. 1685)
This set of diagrams demonstrate the process of analysing the morphology of the bird, while abstracting its properties and applying them into a model experiment.

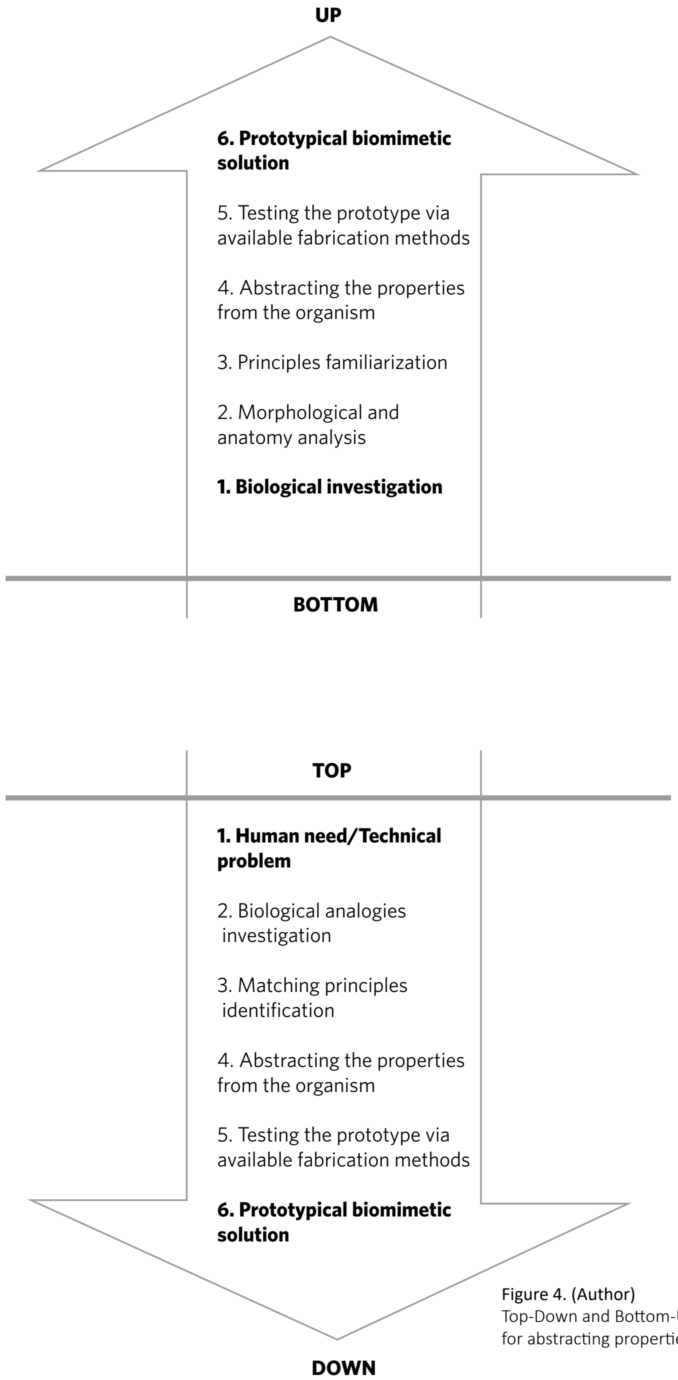

Figure 4. (Author)
Top-Down and Bottom-Up approaches for abstracting properties from nature.

human need or a design problem and utilizing natural organisms or ecosystems as a means to an appropriate solution. [2] (Figure 2)
This approach highlights that it is essential that designers need to be aware of their design needs or problems, so they can appropriately match them with organisms which have solved or found similar solutions to something analogous.

Biology influencing design (Bottom-Up approach)

This method focuses on a selected characteristic, behaviour or function which an organism or ecosystem possesses, which can be interpreted into the needs or problems. [2] (Figure 2)
With this approach, it is more about the existing knowledge of candidate solutions that biology provides. In this instance, one can translate the existing knowledge in a specific problem they are already against with.

Bioinspired and Biobased

In biomimicry, there is an important difference between bioinspired and biobased design. The first one characterizes designs which abstractedly imitate elements of nature, purely based on their form, and not on their function.

Many examples in architecture are based on a form similarity and some of them include the Russian architecture of the 20's which happens to be described by Lebedev in his book as "Forms of the nature, like ocean mussels, petals, turtle-tanks, bended and pleated plant-leaves became converted into forms of the built environment". [4 5] He then continues with the comparison of the hollyhock-fruit's shape, (Figure 3) as the bioinspired model for a hollyhock-high-rise (Figure 3). However, if one was to compare the system of the hollyhock-fruit, then those systematic properties would have a rather different impact on the outcome of the architectural design and would be then called biobased design. [2]

First biomimetic example

The first known bionic experiment was conducted by J.A. Borelli, after his book "De motu animalium" was released in 1685, where he explores the effect of a bird's tail. From that example, he made an experiment to understand how a bird uses its tail to ascend. Therefore, in his experiment he abstracted the "natural principles" deriving from the bird. (Figure 4) (Exploration – abstraction – transformation)[5]

Figure 5 (ICD, Aggregate Pavilion, 2018)
This image demonstrates the extensive data control, based on new prototypical fabrication methods.

WHY BIOMIMICRY?

After discovering the many benefits which natural properties might offer us, it is important to distinguish why they are essential in our evolution.

An obvious reason to why they might be more important now, is due to the climate change, since our built environment does not adapt to the natural disturbances, but instead creates an even worse environmental impact.[1] Our traditional methodology only focuses on mitigating the negative effects, however it is necessary to alter this towards a different approach, where it instead benefits the environment, and one option is via biomimicry.[1]

Minimum energy used

In addition to the climate change mitigation, nature can be seen as an advantage towards energy and material efficiency, the economy as well as time saving on projects' process. The reason is because of its ability to intelligently plan to use the minimum energy to produce an organism, which must be perceived as an example into our material world.

Nature's evolution has found ways to apply qualities which are more efficient and effective than ours. This is indicated in nature's availability of various mechanisms which range from nano particles to ecosystems. At the moment, our technology fails to implement such qualities, as it firstly has to understand them. [2] Furthermore, our material resources, are treated as if they were infinite, however that is not the case regarding materials which are non-renewable. We tend to leave the design process as an after-thought, whereas nature operates simultaneously on the design system and materiality. It treats materials as expensive and designs with particular attention to detail.[3]

As a result, it offers durable materials and cheap structures, which are resilient under the appropriate conditions. It is therefore evident that biology does not have restraints like we do. The only beneficial restraint nature has, is that it is driven by "the survival of the cheapest." [3]

"It is not the strongest of the species that survives, nor the most intelligent that survives, it is the one that is the most adaptable to change."

- C. Darwin, 1859-82-

Computational based design

One of the main reasons to assign biomimicry as a new vital design thinking process, is due to the concept of computation as a design tool. Through the last decades, a theory has been developed which strived for a deeper meaning into the biological analogies, instead of pure form mimicking. The way to achieve that was through computational control. As Kostas Terzidis explains "Computation is the procedure of calculating, i.e. determining something by mathematical or logical methods...". [4] He continues "Computation is about the exploration of indeterminate, vague, unclear and often ill-defined processes; because of its exploratory nature, computation aims at emulating or extending the human intellect.It is about rationalization, reasoning, logic, algorithm, deduction, induction, extrapolation, exploration, and estimation". [4] With the help of computation then, the exploration towards imitating evolution and natural selection became easier when scientists in 1960, have explored ways to create genetic algorithms. Following that, in 1990 these algorithms were introduced into architectural softwares, which can now process real time data, and translate it with precise control, into various fabrication methods. [4] (Figure 4) Due to the evolving computational technologies, it is becoming more frequent to implement the complex systems of biology into architecture and design.

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2. Vincent, J. F. V. (2014). Biomimetics in architectural design. Intelligent Buildings International, 8(2), 138–149. https://doi.org/10.1080/17508975.2014.911716
3. Vincent, J. F. V. (2002). Survival of the cheapest. Materials Today, 5(12), 28–41. https://doi.org/10.1016/s1369-7021(02)01237-3
4. Aziz, M. S., & El sherif, A. Y. (2016). Biomimicry as an approach for bio-inspired structure with the aid of computation. Alexandria Engineering Journal, 55(1), 707–714. https://doi.org/10.1016/j.aej.2015.10.015

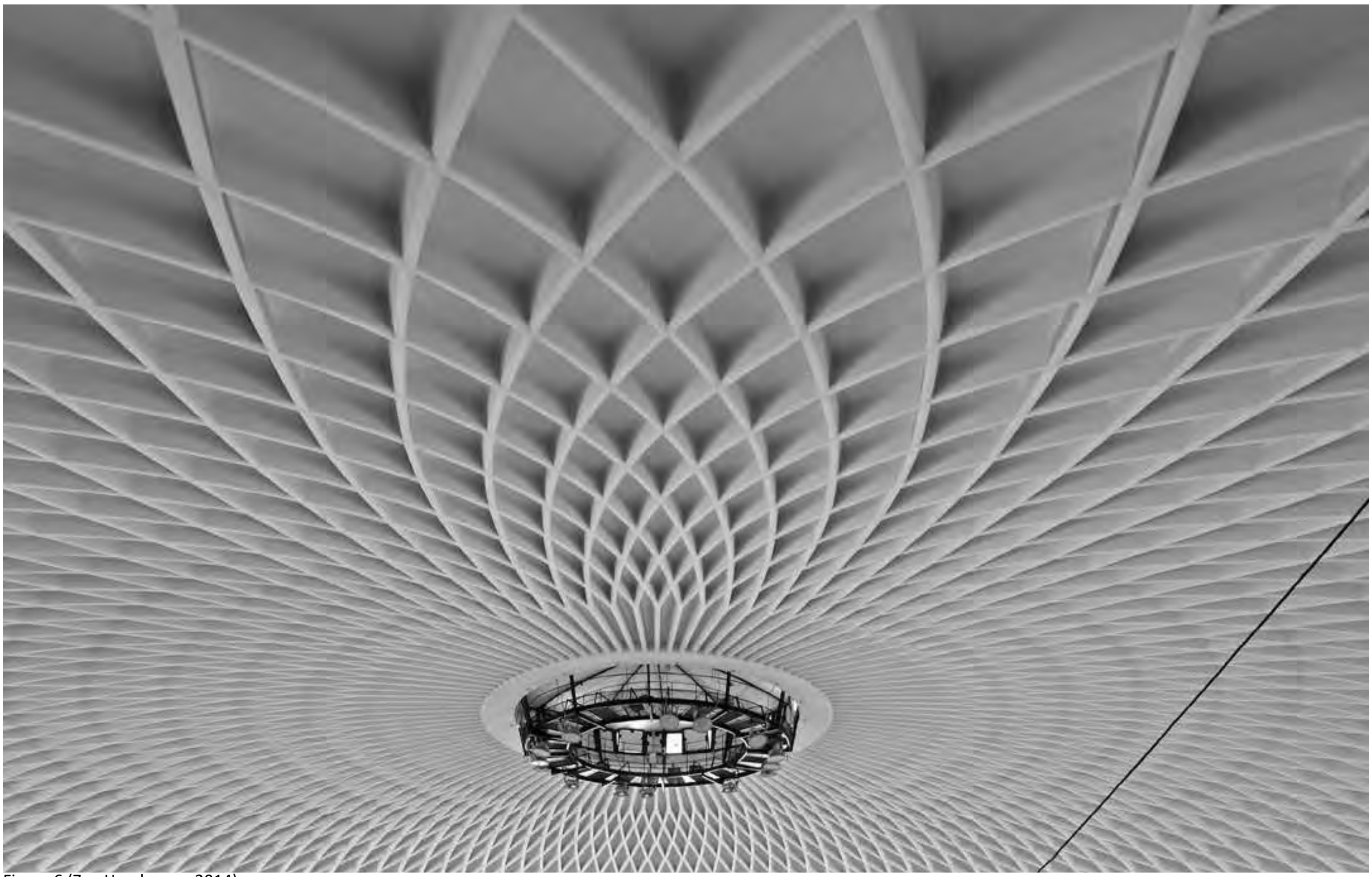
Figure 6 (Zoe Henderson, 2014)
The interior of the dome roof structure of the Palazzetto dello Sport

PALAZZETTO DELLO SPORT

The Palazzetto Dello Sport was built in 1957 for the Olympics in Rome, Itlay. The Indoor Arean is designed by Pier Luigi Nervi and Annibale Vitelozzi. With its structural organisation inspired by cancellous bone growth, it resulted in a materially highly efficient design.

Pier Luigi Nervi

Pier Luigi Nervi (1891-1979) was an engineer, architect, builder and professor. In his writings one finds his concept of architectural resilience, which is an ever-evolving relationship between building forms, techniques and materials.

Architectural resilience is an important theme in his work. One of his fundamental principles is the connection between aesthetics and technology, which he thought could be best understood through analyzing both ancient and modern architectures. Nervi set up three features for a correct architectural result: Statica, funzionalita, economia (statics, functionality, economic efficiency) (Nervi, 1945). He did not explicitly include beauty, like Vitruvius did, as he saw this as a result of the combination of the three features.[1] He investigated the underlying building principles related to geometry and statics, which eventually resulted in his designs with ribbed domes such as the Palazzetto Dello Sport.

Italy's reinforcement ban

Italy has experienced shortages of steel for several years during the twentieth century. The country was subject to international trade sanctions as a response to their invasion of Ethiopia in 1935. This resulted in a big rationing of steel in construction, and in 1939 reinforcing bars were completely banned.[2] Another reason for this was the Italian Fascist political athmosphere that shifted towards self-sufficiency. Most metal reinforcement was imported, and therefore making it an anti-autarchic material which was banned from use.

This forced engineers to either use existing traditional construction systems, or to experiment with non-standard reinforcement materials produced within the kingdom of Italy. As cement was a mass-produced material in Italy, research was based around cement-based floor systems with nominal, no or new types of reinforcement material such as bamboo or aluminum.[3]

Ferrocement

Amongst others, Nervi was practicing in this period of the reinforcement ban which forced him to be innovative. He was working on a series of hangars which at that moment could only be made with an expensive and time-consuming construction of timber formwork and on-site poured concrete. This resulted in Nervi's patented efficient and economical construction procedure. He developed new methods of prefabrication, including a reinvention of ferrocement.

Ferrocement is built up out of layers of thin flexible wire mesh encased in cement, which reduces the needed thickness. He later combined this method

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2. Henderson, Z. (2017) 'Nervi: the Master of Parametric Design and construction' https://medium.com/@ZoeHenderson92 retrieved on 10-10-20

3. Adriaenssens, Sigrid & Billington, D.. (2016). The ribbed floor systems of Pier Luigi Nervi'

Figure 7 (ASBMR Bone Curriculum 2004)
Cancellous Bone growth

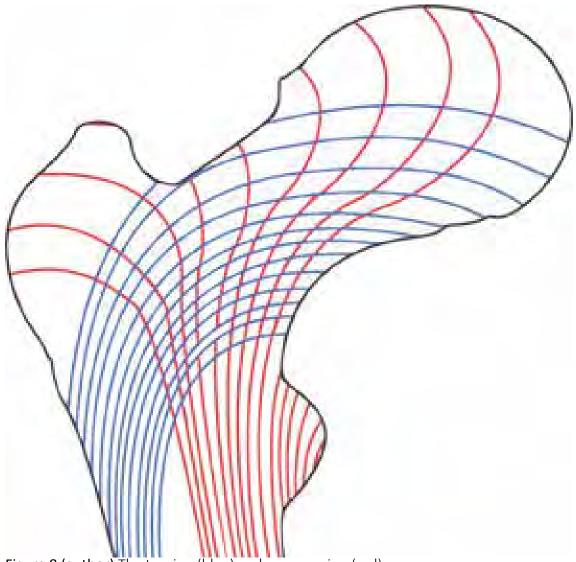

Figure 8 (author) The tension (blue) and compression (red) lines along which the bown growth is concentrated

with his patented construction procedure, which provided the opportunity for mass-produced reusable ferrocement forms on moveable scaffolding. This enabled a more cost effective construction of large floors supported by evenly spaced columns. This development formed an important step in from the traditional beam and joist system towards his constructions with isostatic rib patterns.[3]

Isostatic lines

More than a century earlier, Karl Culmann (1821-1881), professor of engineering science, and Julius Wolff (1836-1902), anatomist and surgeon, shared insight into each other's work. Culmann developed 'graphical statics', a method of visual structural analysis based on vector scaling, used in the engineering field to calculate forces. By using this visual analysis, the hypothesis for Wolff's law was formulated about the trabecular force trajectories within cancellous bone and bone loading.[4] Isostatic lines define main directions of tension and are tangent to the trajectories of the bending moments on which the torques are zero. By applying this knowledge from the engineering field to the medical field, Wolff was able to interpret the material distribution in cancellous bone. The bone growth follows along principal stress trajectories. By doing so, material grows where it has to withstand forces, and is left out where it is not needed, making for an efficient and relatively lightweight element.

Translation to the built environment

Aldo Arcangeli, an engineer who worked for Nervi & Bartoli, translated this knowledge to be applied into the built environment to be used in the design of floors. He developed a concept in which the floor ribs are designed along the isostatics of the principal bending moments. This principle could also be used in domes and other applications by organizing the ribs along the isostatics of the bending moment or normal stresses.

Culmann and Wolff understood how the function and performance relate to material patterning. In the same way, Nervi's work finds its basis in the broad understanding of material properties and their visual and structural patterning.[4] It visualizes the structural patterns that result from the flow of forces.

"… If my conclusions are right, we are witnessing the birth of a style based on the truth, inspired by natural forms, characterized by purity of lines, by functional clarity common to all human endeavours and which being anchored to physical laws will evermore evolve towards a more complete final truth. Isn't it a marvellous promise? (Nervi 1963: 47)"[1]

Fabrication and Assembly

For the Palazzetto Dello Sport, Nervi uses ferroconcrete with the principles of the isostatic lines. The dome structure spans a diameter of 60 meters and is comprised out of 1620 rhomboidal hollow blocks.[5] There are just thirteen different block shapes, which are repeated around the

“

it was amazing to find that by limiting our task to the interpretation of a purely physical phenomenon, we were able to discover unexpected and expressive new forms

”

- Pier Luigi Nervi, 1956-[5]

Figure 9 (Zoe Henderson, 2014)
The assembly of the dome roof structure of the Palazzetto dello Sport

center of the dome. The dome is supported by 36 Y-shaped flying buttresses, each supporting a width of 10 degrees of the dome circle.
The dimensions of the rhomboid elements are limited, so they can be made by hand and two workers can handle each piece.[1] By doing this, there was no need for an often costly wooden support, which greatly reduced construction costs.[6] The pieces are laid out to form a vast mosaic, and the connections between the pieces form the isostatic rib structure that provides the structural strength, and gives the interior its aesthetic quality.

Conclusion

This project is the result of a bottom up approach, as the research was not specifically done to apply in architecture. The research was conducted by Wolff (anatomist and surgeon) by using Cullmans (professor of engineering science) principle of visual analysis for force calculation, which was applied to investigate cancellous bone growth. Later, this biological phenomenon that was now documented, was put to use for architectural design, like in Pier Luigi Nervi's Palazzetto dello Sport.
In Nervi's work, economics and fast assembly are key factors. By taking inspiration from natural growth processes Nervi took inspiration not only from modern technological possibilities, but also from the old architecture of for example cathedrals, which uses flying buttresses, to convey the lateral forces of the dome structure.
By looking at nature the material deposition along the lines of load distribution results in a more efficient use and placing of material.

The construction and fabrication is simple and straightforward, and the human scale is taken into account when determining the sizes of each component. the construction process is thereby relatively simple and shows Nervi's skill to integrate design and construction with eachother.

As a point of critique that Zoe Henderson points out, is that the construction feasibility of these kind of free-form structures often relies on rigid frameworks that are time and labour-intensive to construct. Current designers and engineers should look into ways how to further improve mankinds construction possibilities to achieve the true efficiency of bio-inspired designs over the whole design process.

Figure 10 (ICD / ITKE University of Stuttgart, Roland Halbe,2011) Research Pavilion 2011
Photo of the actualized pavilion.

Research pavilion 2011

Design Strategy

What do robots do to help with the process, and how are they implemented into the design process in biomimicry?

The role of the robot has been advanced from a rather "repetitive specific robotic manipulation", to an industrial robot which represents the output device, that is connected via a digital chain of data processing steps, which connect the final robotic output, to the digital information model. Robotic fabrication, in the context of architecture, is thus concerned with the production of diversity. This means that, in order to manufacture original building elements, the numerical control of the robot must be applied via generative computational methods. [1] Due to the kinematic freedom of robotic fabrication, there are new opportunities introduced, which involve geometric complexity in construction systems. Thus, it enables us to be more structure efficient in architecture, which can be described in a few words as better form, and less materiality. [2]

Fittest landscape

There is a clear analogy between the survival of evolution of nature, with the evolution of manufactured outcomes based on the robotic tools, which have been evolved. The analogy of the biological morphospace and the robotic morphospace, is that it's a fitness landscape (survival of the fittest) and that means that not all subjects will be meaningfully populated, thus only the most useful at the time will evolve and remain in the actualized space. [2] An example of application in this robotic morphospace of architectural evolution, is the Research Pavilion 2011.

The Pavilion

The project focuses on the biomimetic design methodologies applied in architecture, which seek to explore integral material, structural, as well as spatial systems. This would test specific fabrication possibilities within the morphospace of architectural evolution, by conducting a morphological analysis of a specific property derived from nature. [2] Instead of only translating biomorphic patterns from biology to architecture, the biomimetic knowledge is transferred on a systemic and performative level, through understanding patterns which help solve problems in biology and engineering at the same time. [9]

Instead of only translating biomorphic patterns from biology to architecture, the biomimetic knowledge is transferred on a systemic and performative level, through understanding patterns which help solve problems in biology and engineering at the same time. [2]

1. Menges, A., & Schwinn, T. (2012). Manufacturing Reciprocities. Architectural Design, 82(2), 118–125. https://doi.org/10.1002/ad.1388
2. Universität Stuttgart. (2015). Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design. Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design, 4. https://doi.org/10.1007/978-3-319-11418-7
3. BAGGER, A. 2010. Plate Shell Structures of Glass Studies Leading to Guidelines for Structural Design. In Civil Engineering. Technical University of Denmark.

Figure 11 (ICD / ITKE University of Stuttgart, Roland Halbe,2011)
Close image of the plate structures inspired by the sea urchin.

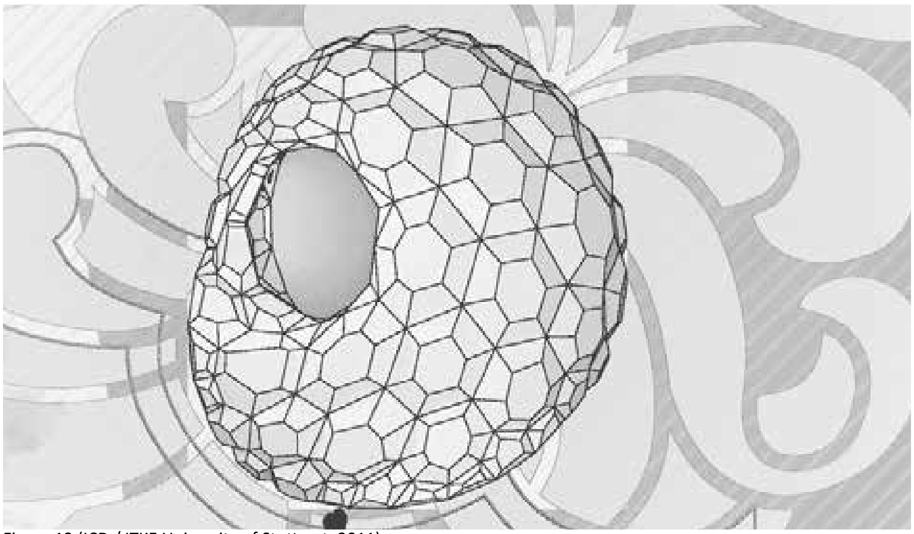

Figure 12 (ICD / ITKE University of Stuttgart, 2011)
Plan view of the pavilion.

Plate structures

Plate structures in nature are a very efficient resource, due to their performance efficiency. Their geometric complexity defines the foundation for material efficiency because this is necessary for surviving in nature. As Bagger also stated, plate structures are a popular choice to mimic, because of their performative construction system, shaped by individual, planar elements. Unlike the grid shells' joints, which carry the primary load bearing structure, the geometry of the plates, allows them to be organized in a way, to individually carry the primary load bearing structure. [3] Therefore, the system of plate skeletons, specifically the sea urchins, offers possibilities for adaptable, prefabricated building systems. (Figure 9) [2]

The sand dollar, which is a sub-species of the sea urchin (Echinoidea) was an interesting morphological study to conduct and abstract the basic principles from. The reason is because the skeleton of the sand dollar incorporates a modular system of polygonal plates (plate structure), which are connected at the ends by finger joints of calcite protrusions. [1] (Figure 10) As a consequence, to this geometric formation, they individually carry the primary load bearing structure and can be perfectly translated into the built environment as prefabricated elements, and at the same time offer energy and economical efficiency.

Therefore, the optimal drivers for this project are the plate structure system and the finger-like jointing system which resist shear forces acting across the edges of the plate structure.

Material Strategy

It is important to understand that the aim of this research, was to appreciate how the technology, combined with the biologically inspired plate and finger joinery arrangement, would be transferred into a pavilion, which also has its own requirements and limits. [2] Thus, it is necessary to comprehend how the technology pull and biology push approaches were implemented into the process of designing and fabricating the pavilion.

Technology pull: (Top-Down)

Human needs looking into particular characteristics into nature in order to solve a problem.

Wood, as a locally available and renewable resource has been chosen as the fabrication material of the pavilion. The reason is due to the high structural capacity it beholds and its resistance to shear forces, without the need of extra supports. For this project, the robotic fabrication process enables additional design flexibility in terms of the wood processing, which can expand thepossibilities of wood usage and form placement. [3] For this reason, it is clear that for the Research Pavilion, the wood joinery has been efficiently and uniquely fabricated using variable angle arrangements. [2] [4]

Biological push: (Bottom-Up)

Particular characteristics in nature, translated into human needs.

The exoskeleton plates of the sand dollar and the sea urchin were chosen for investigation due to their special geometric organization. The principle is based on three plates strictly meeting on one point. Due to this organization, the organism can resist external forces, and by doing that it also allows for its growth process to take place. [5] Therefore this means that any plate structure which is made of just plates and attachments at the points of connection, will have stability. In regard to real life fabrication, this arrangement provides stability by resisting any internal forces which may lie in the plate. Therefore, every face of a pure plate structure only carries plate forces. (not bending moments or torsion for stability) [5]

1. Universität Stuttgart. (2015). Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design. Biomimetic Lightweight Timber Plate Shells: Computational Integration of Robotic Fabrication, Architectural Geometry and Structural Design, 4. https://doi.org/10.1007/978-3-319-11418-7
2. KRIEG, O. D., DIERICHS, K., REICHERT, S., SCHWINN, T., AND MENGES, A. 2011. Performative Architectural Morphology. Respecting Fragile Places- 29th eCAADe Conference Proceedings, 573–580.
3. Zari, M. P. (2010). Biomimetic design for climate change adaptation and mitigation. Architectural Science Review, 53(2), 172–183. https://doi.org/10.3763/asre.2008.0065
4. MENGES, A. 2011. Integrative Design Computation: Integrating Material Behaviour and Robotic Manufacturing Processes in Computational Design for Performative Wood Constructions, Proceedings of the 31th Conference of the Association For Computer Aided Design In Architecture (ACADIA), pp. 72–81.
5. Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27

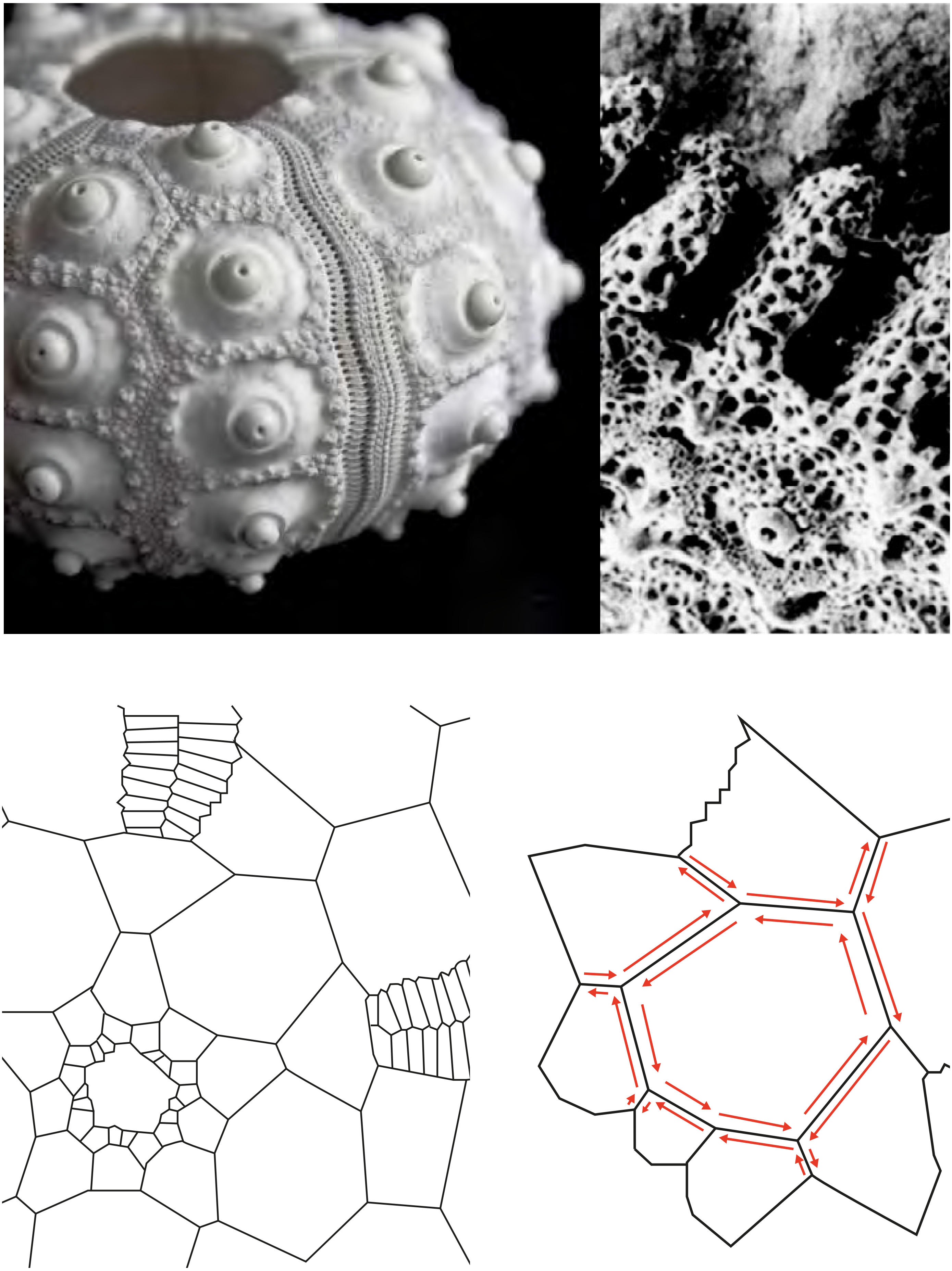

Figure 13 (ICD Stuttgart,2011 and Author)
Sea urchin exoskeleton , consisting of plate structures, preventing any bending or shear forces, and is connected via finger calcite protrusions.

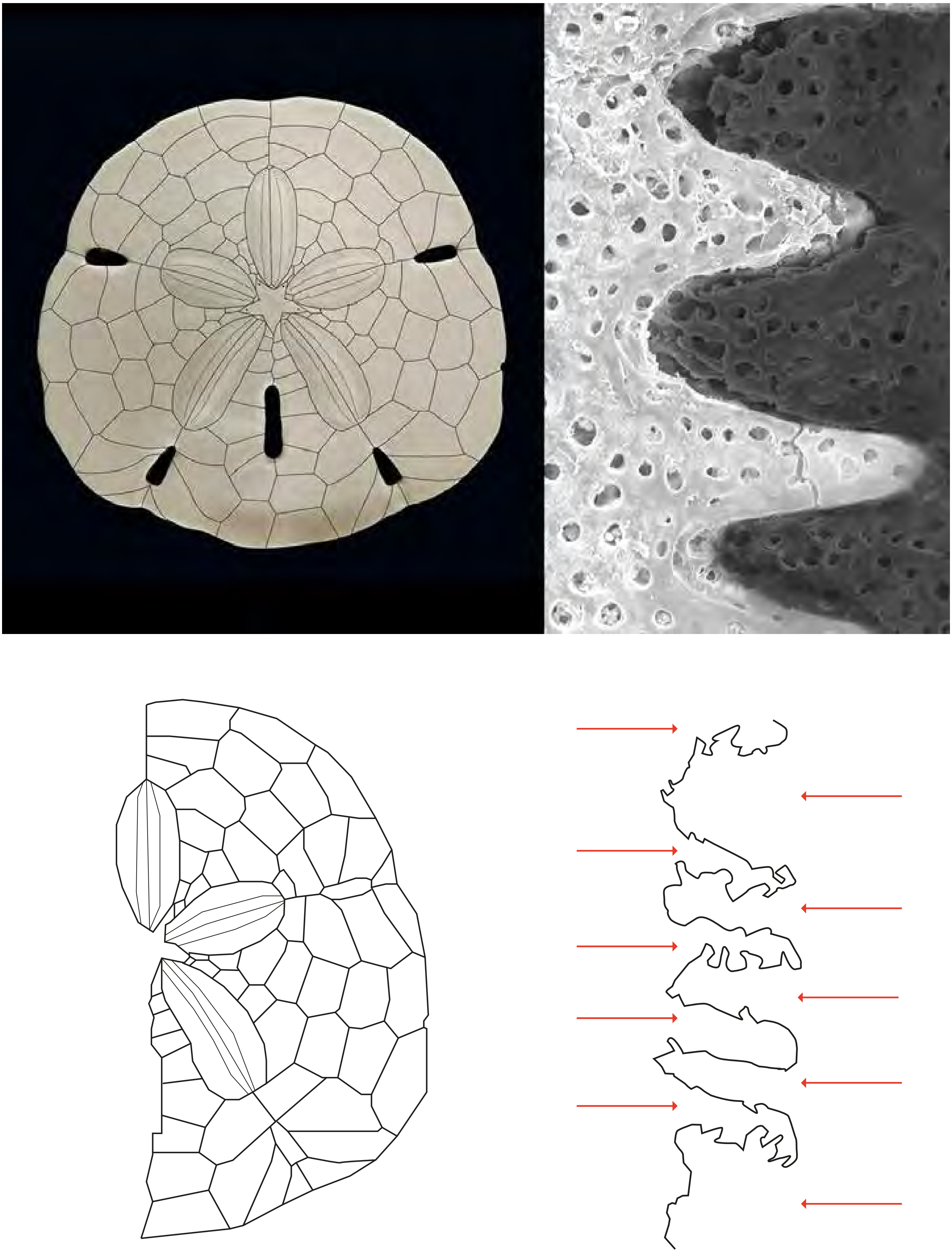

Figure 14 (ICD Stuttgart,2019 and Author)
The sand dollar (subspecies of the sea urchin) also consists of a plate skeleton structure, and is similarly connected with the finger like calcite protrusions.

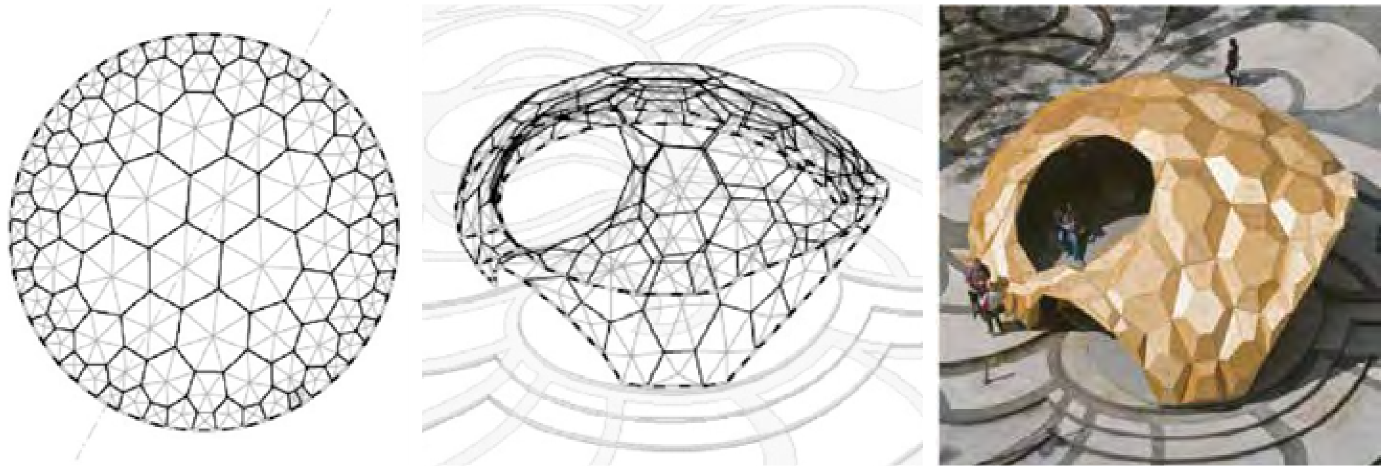

Figure 15 (Magna, R. , 2013)
The plate skeleton of the sea urchin is translated into a voronoi cell and is applied into the 3D geometry.

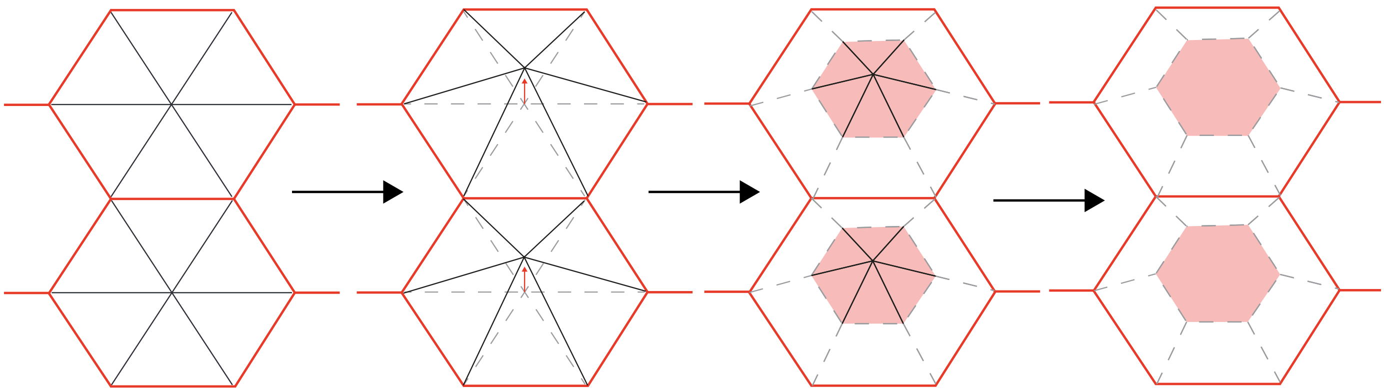

Figure 16 (author, 2020)
Method ensuring convex and flat plates for anticlastic geometries. 3-plate rule achieved by hexagonal planar polygons, translated from the centre up, with cut frustrum.

Geometric morphologies transfer:

As a strategy to implement the sand dollar's cellular morphology and its three connecting plates rule into the generative computational design tool, a Voronoi diagram has been applied.

It proposes that each Voronoi cell represents the polygonal boundary of a cellular plate. [1] Via the Voronoi diagram, there is a precise control of the size and the stretching of these cellular plates, which constitute the global partitioning.

A flat 2-dimensional regular hexagonal mesh (topological map) was the basis for the panelization process, with a 3D geometry based on it. The cellular plates from the topological map therefore relax on the surface of this 3D geometry without being distorted, due to the parametric control. (Figure 11) Global stress, support reactions as well as the inner force distribution amongst the joints were mostly taking into account while setting up the parametres. [1 2]

Other biological principles:

Heterogeneity can be found applied in this project. That is visible due to the different sizes of cells, which adapt to local curvature and discontinuities. When there isn't enough curvature, the cells can take up to 2m height, however when not, they can only be 0.5 m high.

Apart from heterogeneity, the pavilion also takes after the anisotropy property of biology. Since the pavilion is a directional structure, there is obvious stretching and orientation of the cells, according to mechanical stress. Lastly, hierarchy is one of the most fundamental biological principles. Hierarchy can be found in the two-level structure. For the first level, the finger protrusions of plywood are put together as a cell, whereas on the second level, the cells are connected, with a simple joinery. There is a clear benefit with this prototype, and that starts from the fact that this is a very lightweight customized structure. This type of optimization can be applied to other custom geometries too. [2] For this reason, it is clear that for the Research Pavilion, the wood joinery has been efficiently and uniquely fabricated using variable angle arrangements. [3 4]

Abstraction for biomechanics

The most important part abstracted from the sea urchin is the plate exoskeleton morphology due to the 3-plate rule. The morphology was abstracted to CAD models and analyzed with FE simulations. After evaluating its structural system, it was realized that the plates could be only united by normal, lateral and shear forces. Regarding the geometrical influence of the biological organism towards the mechanical abilities, concave plates were avoided due to their high stress concentrations in the corners.

1. Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27
2. Waimer, F., Magna, R., & Knippers, J. (2013). Nature-inspired structural optimization of freeform shells. Structures and Architecture, 1177–1182. https://doi.org/10.1201/b15267-163
3.KRIEG, O. D., DIERICHS, K., REICHERT, S., SCHWINN, T., AND MENGES, A. 2011. Performative Architectural Morphology. Respecting Fragile Places- 29th eCAADe Conference Proceedings, 573–580.
4. MENGES, A. 2011. Integrative Design Computation: Integrating Material Behaviour and Robotic Manufacturing Processes in Computational Design for Performative Wood Constructions, Proceedings of the 31th Conference of the Association For Computer Aided Design In Architecture (ACADIA), pp. 72-81.

As a result, it is the reason why these particular geometries cannot be found in nature, especially in the morphology of the sea urchins. The hexagonal planar surfaces principle can only operate for geometries with positive Gaussian curvature. Hence, the design freedom was achieved by raising the level of each cell. (Figure 12)

Fabrication method

For the finger joinery, a custom fabrication tool was made which allows the finger cut to happen with the front of the tool, which can have as an outcome a form-fitting finger joint connection. To be able to produce convex and concave connective forms, there must be an external axis which could continuously reposition the object, so that there can be access to the whole perimeter of the plate, by the industrial robot. (Figure 13) The biomimicry derived object requires an increasing amount of freedom, which suggests the expansion of solutions in CNC milling, as well as the expansion of the biological concepts in morphospaces. [1]

Apart from the biomimetic principles translated into the design process, there are specific parametres for the robotic fabrication which need to be applied into the computational design tool as part of the process too.

One of the main factors which is important for this process, is the way mathematics is used to describe the relation of the object being milled, with the milling, by algebra and trigonometry. The fabrication tool paths, can achieve different structural and geometric properties between the plates, in order to produce the correct angles of joinery. These parametres are embedded into the computational design tool, which inform the design process. [1]

The custom process of the robotic fabrication programming includes the topological analysis of how the plates are joined with each other. This is, as stated above, the automated tool path generation which is gathered into a point cloud, and also converts the tool path code from a machine code, into an ISO-based CNC format for the milling process. [1]

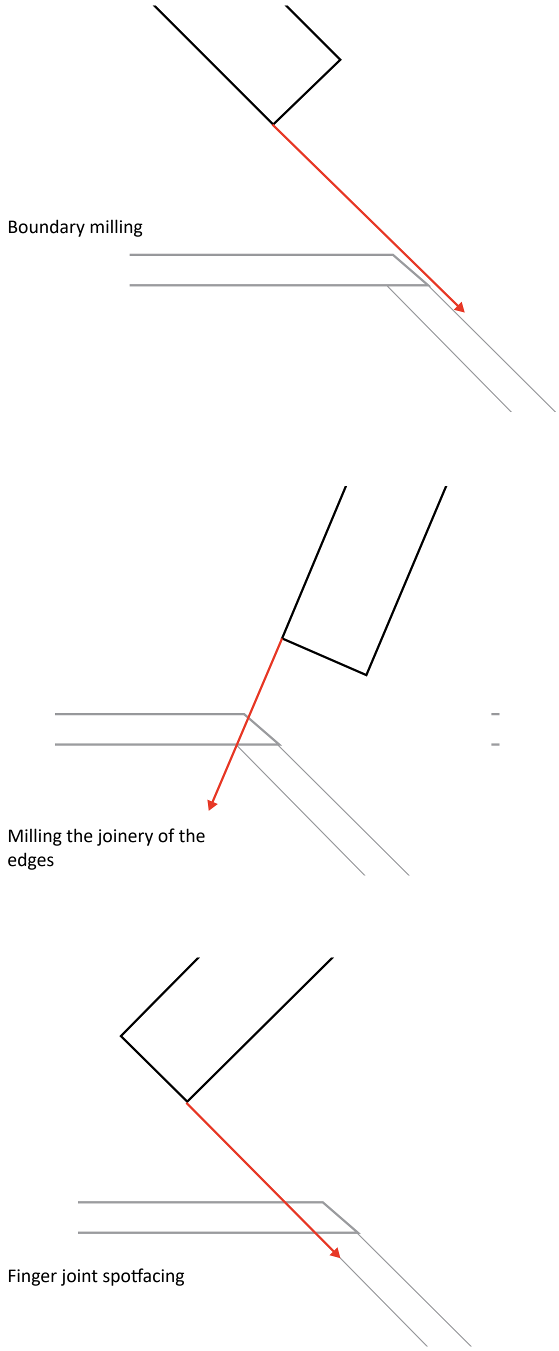

Figure 17 (Author, 2020)
Geometric relationship between the robot and the plysheets, within 3 steps of fabrication.

1. Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27

Figure 18 (ICD / ITKE University of Stuttgart, Roland Halbe,2011)
Milling of joinery edges.

Figure 19 (ICD / ITKE University of Stuttgart, Roland Halbe,2011)
Off-site fabrication process using CNC milling for the plate cells.

Assembly

There are more than 850 pieces of unique birch plywood plates, connected by an approximation of 100,000 teeth joineries. The 200 cubic metre pavilion could be shaped only from 6.5 mm plywood sheets, meaning that only 2 cubic metres of its gross volume is being enclosed. 59 building pieces are assembled off site, ready to be joined on site after being weather-proofed. [1]

Figure 20 (ICD / ITKE University of Stuttgart, Roland Halbe,2011) Assembling plate cell made of plysheets.

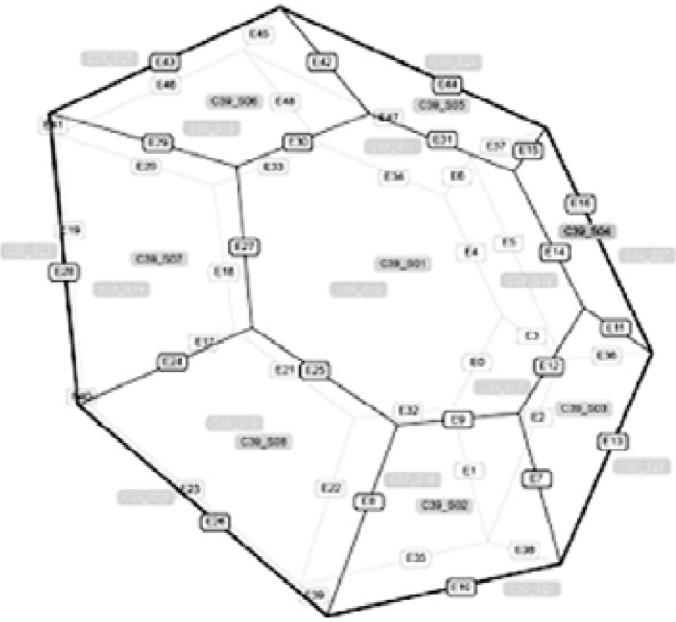

Figure 21 (ICD / ITKE University of Stuttgart,2011) Topological analysis of plate connectivity.

Figure 22(ICD / ITKE University of Stuttgart, Roland Halbe,2011) Assembled plate cell, ready to go to the site.

Figure 23 (ICD / ITKE University of Stuttgart, Roland Halbe 2011) Finger jionts connecting the plate.

Figure 24 (ICD / ITKE University of Stuttgart, 2011) Base assembly.

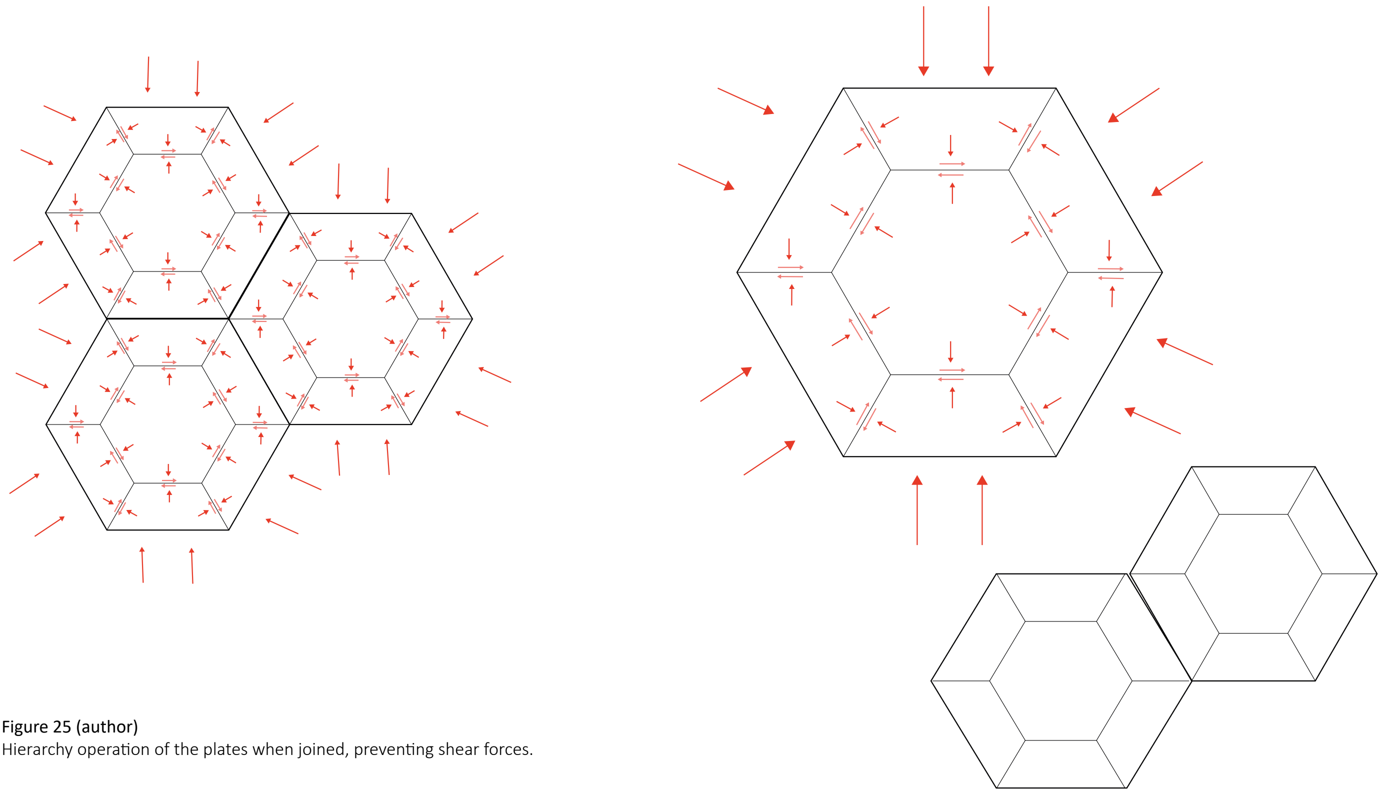

Figure 25 (author)
Hierarchy operation of the plates when joined, preventing shear forces.

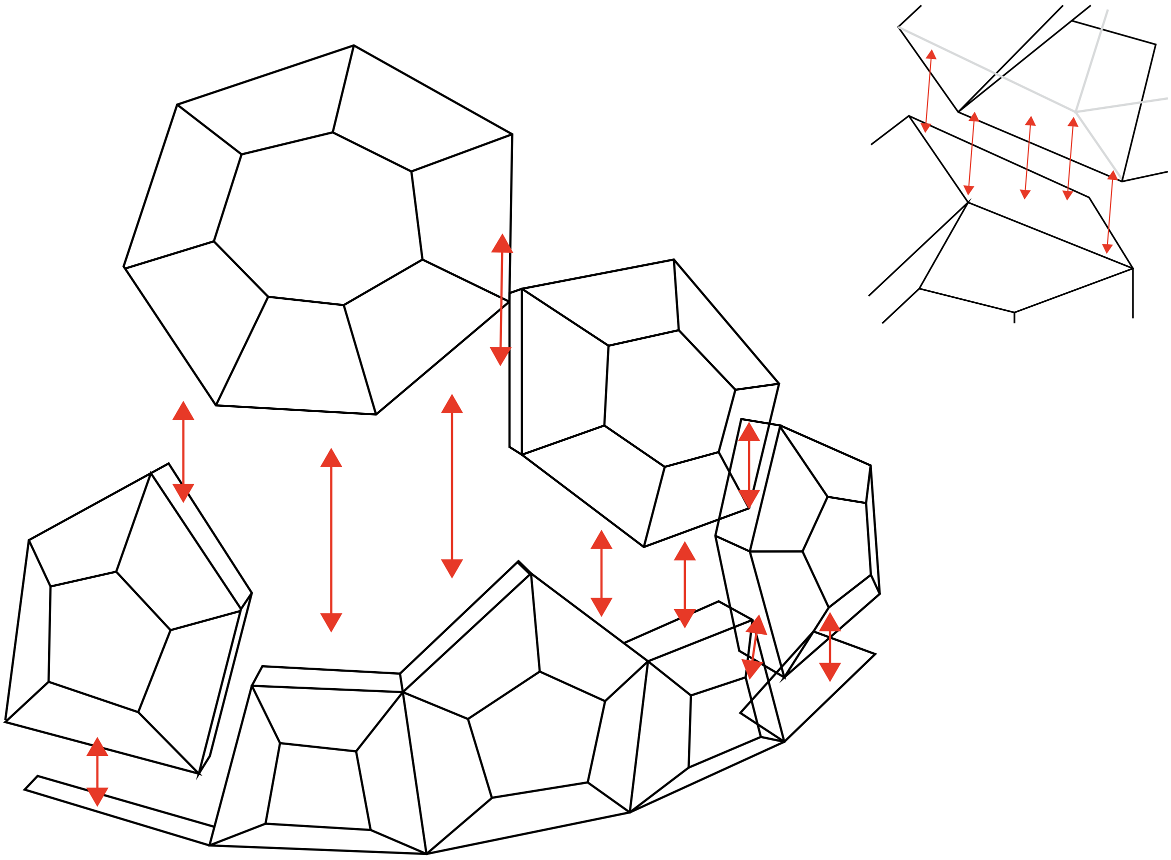

Figure 26 (author)
Diagram of the assembly process of the “cells” with one another.

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1. Waimer, F., Magna, R., & Knippers, J. (2013). Nature-inspired structural optimization of freeform shells. Structures and Architecture, 1177–1182. https://doi.org/10.1201/b15267-163

Figure 27 (ICD / ITKE University of Stuttgart, 2011)
Assembling process on site-Step 1.

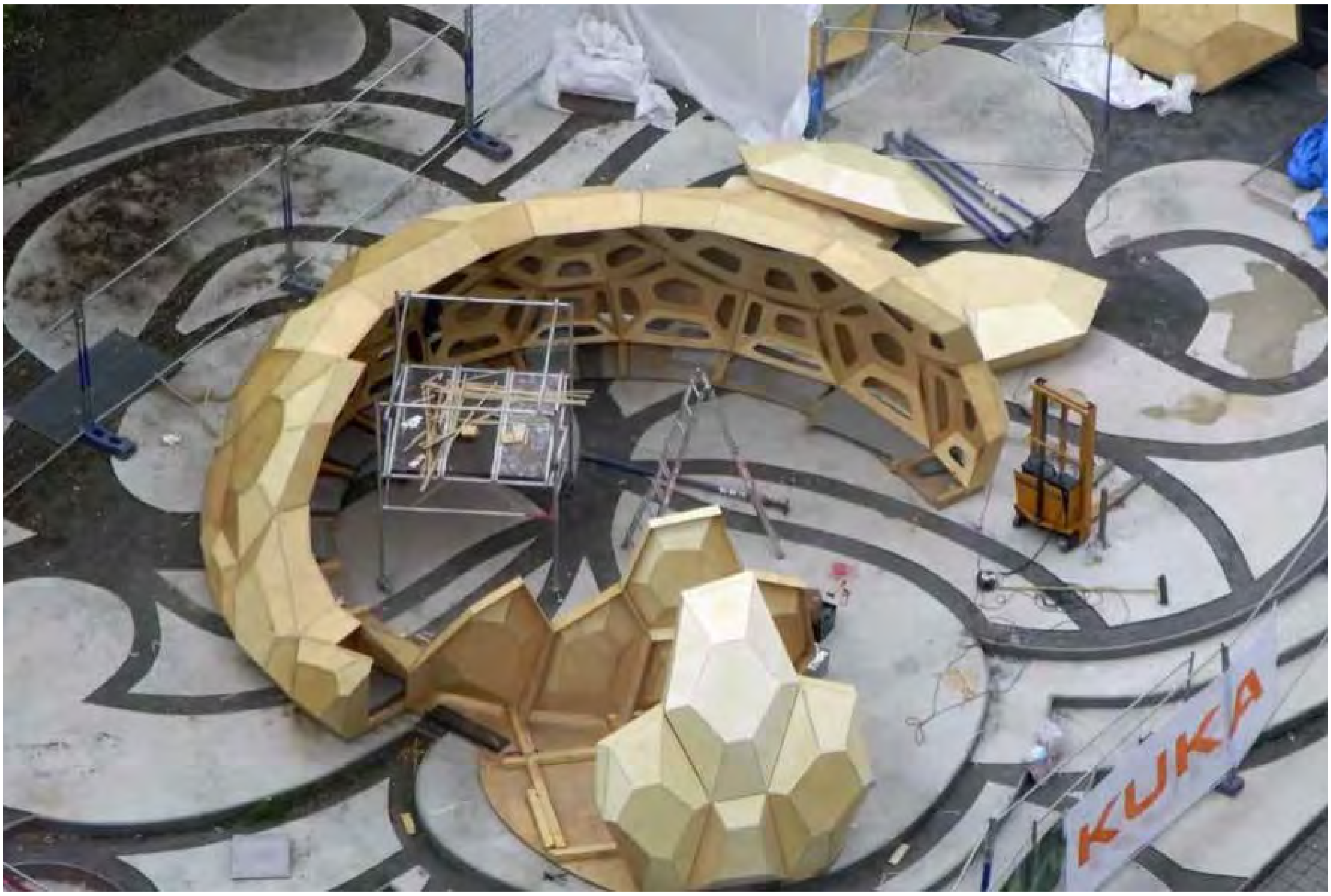

Figure 28 (ICD / ITKE University of Stuttgart, 2011)
Assembling process on site-Step 2.

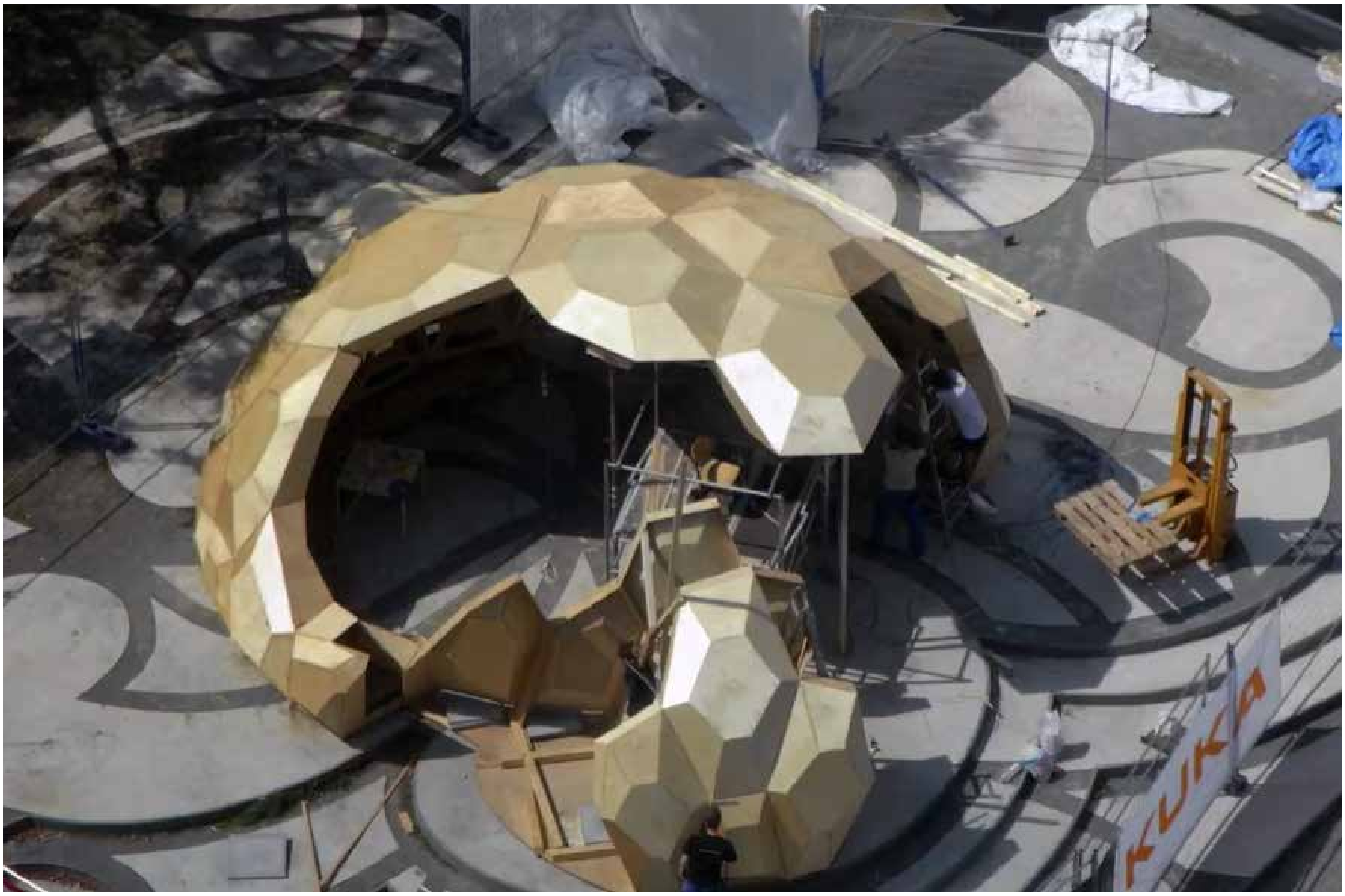

Figure 29 (ICD / ITKE University of Stuttgart, 2011)
Assembling process on site-Step 3

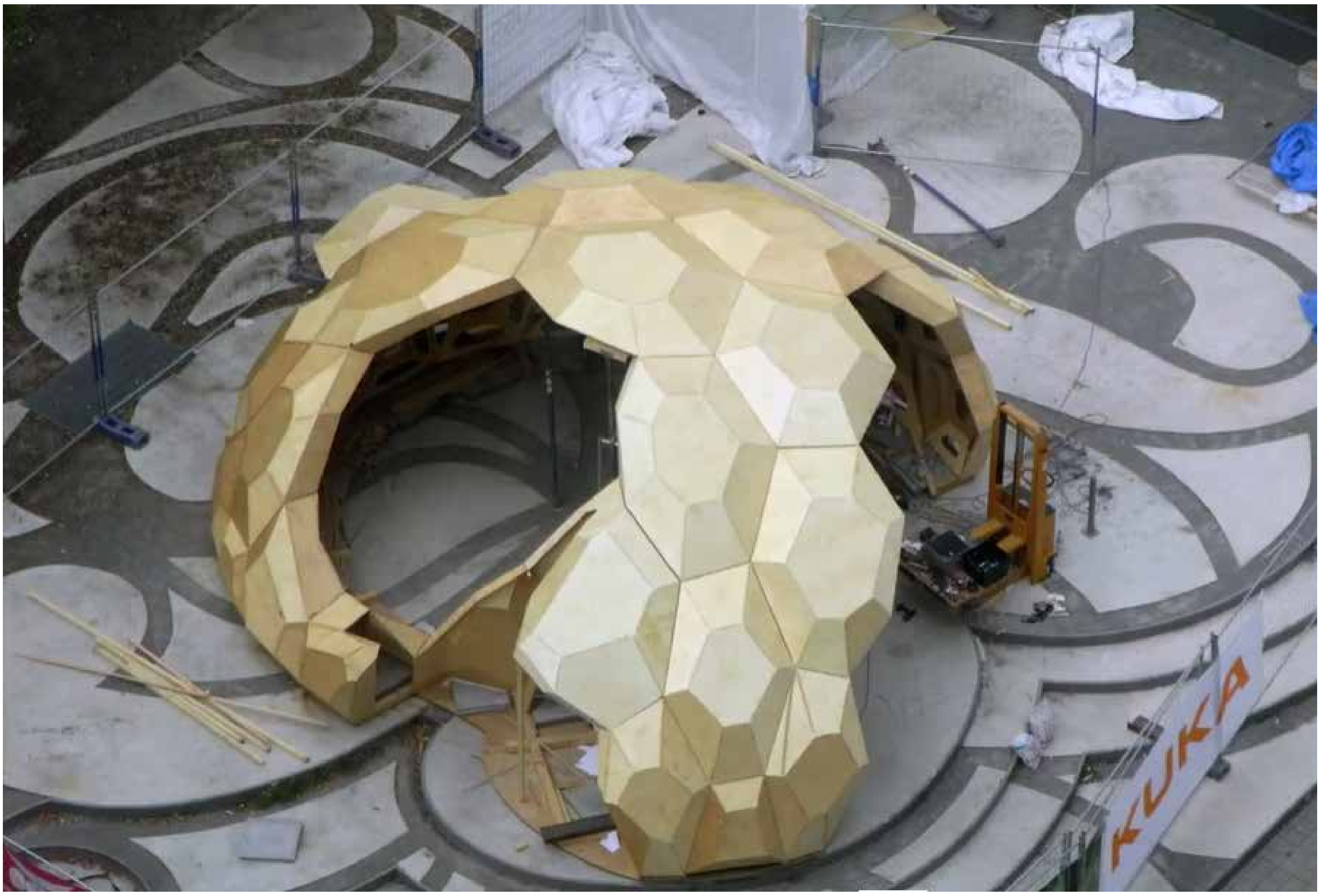

Figure 30 (ICD / ITKE University of Stuttgart, 2011)
Assembling process on site-Step 4.

Figure 31 (ICD / ITKE University of Stuttgart, 2011)
Aerial view of the Research Pavilion by night.

Conclusion

This pavilion is an example demonstrating the potentials of future technology, including fabrication methods as well as design methodologies. It is an experiment pushing boundaries and questioning existing methods. By implementing the abstracted properties from the sea urchin, including the finger joints and the plate structure, it is clear that the outcome is successful, and can be used as an example for future experimentations, maintaining the same logic, or even advancing it.

An important feature of this pavilion, has to be its structural durability, form flexibility, and appropriate material choice. It manages to be, like all successful biomimetic examples, energy and material efficient, as well as resilient.

What could be a negative impact of such an outcome, is not experimenting further from the prototype and as a result, energy would be used only for the pavilion showcase. This applies to all prototypical examples, however this is part of the progress in the field.

Future applications

From this specific example, many questions and thoughts arise in regards to what can be done next. Since the pavilion is constructed by a plate structure and finger joinery, It is inevitable to not apply this principle in other architectural or engineering examples. From the example, it is possible to think of temporary housing, sustainable span arrangements, flexible and expandable structures, as well as customized user design.

Research pavilion 2012

The research pavilion of 2012 by ICD/ITKE University of Stuttgart uses a very different material than previous year: Glass and Carbon fibers, inspired by the fibrous structure of the exoskeleton of arthropods.

Biological inspiration

The goal of this design was to strategically explore new systems beyond existing typologies. These existing typologies are rooted on a system of calculability, which stems from the introduction of structural analysis in the second half of the 19th century. To break away from this system, architects discovered long ago that one can see nature as an inspiration. Its structures are fundamentally different, as they are not ruled by calculability. Natural structures are multi-layered, highly differentiated systems tuned to the specific requirements, while being composed out of basic elements with highly diverse and interrelated functions.

Numerous attempts to mimic natural structures have been made before, but they were always limited by the constraints of serial production and calculability. However, with the introduction of digital fabrication and computational design, these barriers can be eliminated, which opens up opportunities to create new typologies.[1]

This research pavilion aims to create such a new typology, by trying to translate the performance of biological structures into architectural design. This is done by conducting integrative research of biomimetic design strategies, advanced digital simulation and robotic fabrication. An interdisciplinary research is set up between architects and engineers of the University of Stuttgart, and biologists of the University of Tubingen.

Figure 32 (ICD / ITKE University of Stuttgart, Roland Halbe,2012) Research Pavilion 2012
Photo of the 2012 research pavilion made of glass and carbon fibers.

1. Schwinn, Tobias & La Magna, Riccardo & Reichert, Steffen & Waimer, Frederic & Knippers, Jan & Menges, Achim. (2013). Prototyping Biomimetic Structures for Architecture.
2. M.S. Aziz, A.Y. El sherif, Biomimicry as an approach for bio-inspired structure with the aid of computation, Alexandria Eng. J.(2015),http://dx.doi.org/10.1016/j.aej.2015.10.015
3. BD Editors, Biology Dictionary, (2019) [online] available at: https://biologydictionary.net/arthropod/ retrieved on 30-09-20

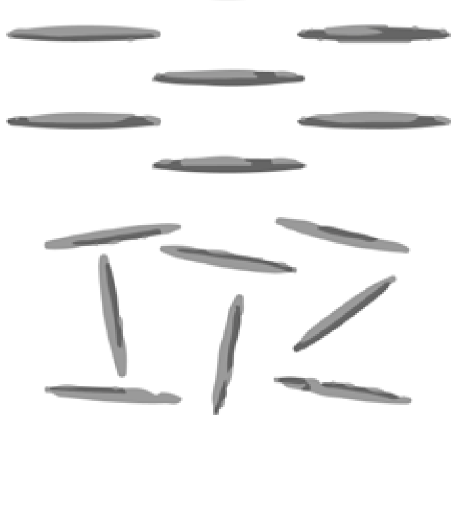

Figure 33. (ICD / ITKE University of Stuttgart (2012), Photo of lobster hook.
Figure 34 (Author) illustration showing fibre orientation within the lobster hook, and showing difference of isotropic and anisotropic organisation

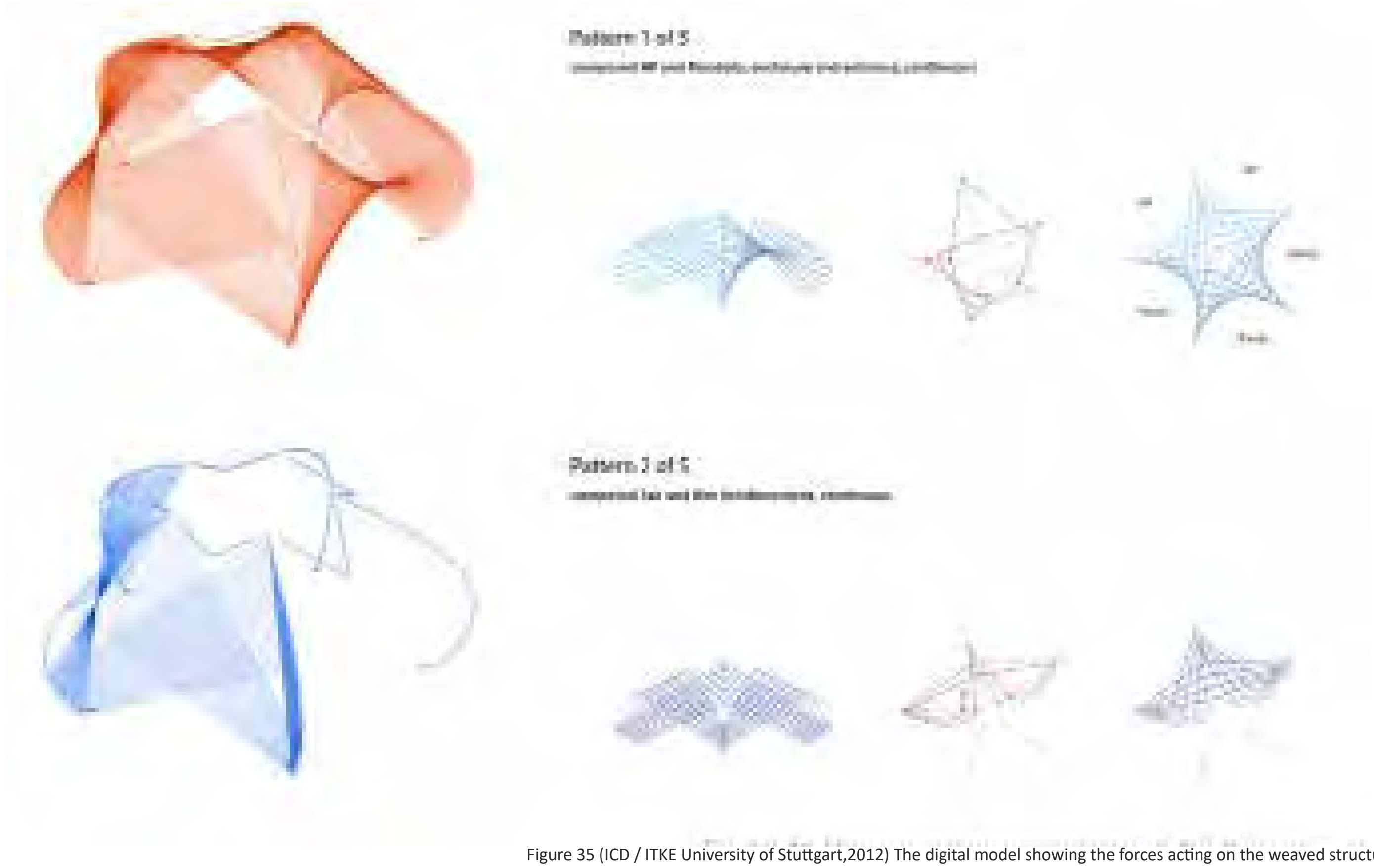

Figure 35 (ICD / ITKE University of Stuttgart,2012) The digital model showing the forces acting on the weaved structure

Considering the design methods of technological pull, which was the case for the previous pavilion, and biological push, the latter is the case for this pavilion: "Performative principles of structural morphology of the biological role model's natural fiber composite were abstracted with respect to an architectural application."[1]
The project starts with investigating an example from nature to discover its characteristic properties.[2]
By then abstracting these, they can be implemented to create an architectural design. For this design, inspiration was found on the level of the organism, in the exoskeleton of arthropods. In particular, the American Lobster has been investigated to instigate biomimicry for this design.

The American Lobster

The American Lobster belongs to the family of Arthropods, which are invertebrates that have an exoskeleton, a segmented body and jointed appendages.[3] It has a strong, but lightweight structural shell. The body consists of different parts: strong claws, legs that transfer the body weight to the surface below and a tail that is softer and more flexible. When the material composition of the lobster body is investigated, it becomes visible that it is composed out of fibers.
According to their place in the body and their particular position on this part, the fibers are organized differently. This variation is due to different requirements in terms of force and load distribution. The structural behavior within the cuticula varies between isotropic and anisotropic throughout the body, which makes the separate parts distinguishable. This enables the abstraction of distinct arrangements: The legs of the arthropod deal with predicted loads in similar directions, which is why they have a unidirectional fiber arrangement to acquire the best weight-strength ratio. In other, larger parts of the body where the direction and strength of forces is unpredictable, the fibers are in helicoidal arrangement. This tailored differentiation of fiber composition in the body creates a structure that is highly differentiated and tuned to specific requirements. As a result of this efficient use, the exoskeleton of the lobster is very lightweight.
The structural morphology of the fiber composite of the lobster is abstracted for architectural application. This knowledge is transferred to a fiber reinforced composite technology, which is constructed by a custom robotic filament winding fabrication process.
In the exoskeleton of the American Lobster, the fibers are distributed and oriented based on forces and function. This same principle is applied in the pavilion structure. The pavilion is composed out of fiber composites with a strong bond between the matrix and fibers. The manufacturing will be an additive process, by applying fibers in varying directions, using multiple types of fiber and by varying the fiber-matrix ratio. This will result in a one-piece, continuous shell with a pentagonal footprint, with three open and two closed sides. This to create openings in the pavilion, but also to demonstrate the adaptability of the model. To assemble the pavilion, it will be weaved, or wrapped, around a temporary structure which will be removed one the fibers have hardened.

Material strategy & Fabrication

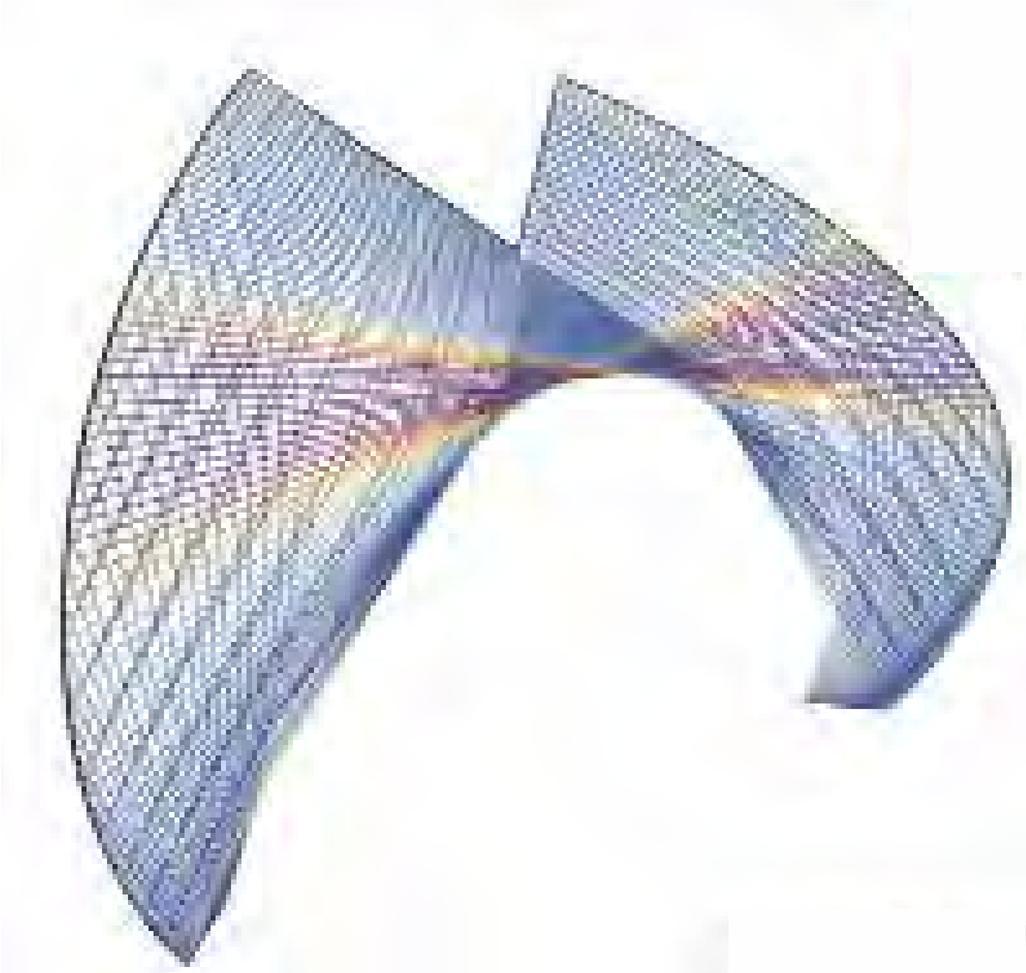

Figure 36 (ICD / ITKE University of Stuttgart,2012) The digital model showing the forces acting on the weaved structure

To achieve a one-piece, lightweight monocoque the pavilion is composed of glass and carbon fibers. The glass fiber creates the enclosure, and the carbon fibers provide strength where needed. The design is made by filament winding. To provide the necessary structural reinforcement, to create the desired openings and closed places and the desired shape, a winding logic is developed. This resulted in five different winding patterns either for the glass fibers or the reinforcing carbon fibers.

A computer model is made to model the pavilion. The model bases its load calculations on the Finite Element Method, which is a mathematical method that approximates the forces in complex models. The design is put into software using this method as a tool for form finding and an analysis of the prestresses in the fibre lay-up.

To create the structure, it will be weaved, or wrapped, around a temporary structure which will be removed once the fibers have hardened. The fibers are led through a resin bath before being guided onto their position on the pavilion, after which the resin-saturated fibers can cure. As the fibers are wound over the temporary framework, the layers are gradually built up. Eventually, previous, hardened layers will act as a mold for the layers building up on top of them. This eliminates the need for a separate mold, which is often needed when working with fiber reinforced polymers. These molds are time and material-intensive, but this is often compensated by high numbers of production. So, for this stand-alone design, minimizing the need for molds was a central concern during the project, which became one of its defining features.

In this project one can find a biological push, as the design originated from the understanding the finetuned fiber organisation within the exoskeleton of the American lobster. This knowledge was abstracted and applied to create a one-piece fiber pavilion, created by robotic filament winding. In contrast to traditional building materials, this approach tailors its material distribution very precisely to the acting forces, as to efficiently transfer loads in a very lightweight structure. The same goes for the varied isotropic and anisotropic fiber organization. In the loadbearing 'columns'the fibers are organized in a more unidirectional way, and for the parts in between they have an anisotropic organization to provide strength in multiple directions.

Assembly

To accurately follow the digital models calculated positioning of each fibre, this filament winding process will be executed by a custom robotic fabrication setup. The setup consists of a 6-axis Kuka robot that is used to wind the fibers in the correct pattern and position, but in order to provide the needed range for this, a seventh axis is introduced by putting the temporary framework on a turntable. In this way all parts of the pavilion construction become within reach of the Kuka robot. As the fibers are led through a bath of resin before being wound in place, the gradual buildup of layers that harden during this process eventually act as part of the support for the consequent layers. when fully hardened, the support structure is demounted, removed, and the pavilion is ready to be placed.

Conclusion

The design process clearly has the manufacturing and assembly in mind, which results in this ultra lightweight, woven structure that gains architectural quality from its expression of the structural system. This is visible due to the two different colors of the glass fiber and carbon fiber and the weave pattern itself. As a research pavilion, these and other fiber structures are innovating construction approaches, but the used material cannot be considered sustainable. This would be the major point of critique for this approach, but as this is a research project it could offer an initial step towards incorporating more sustainable, natural materials for this approach as well.

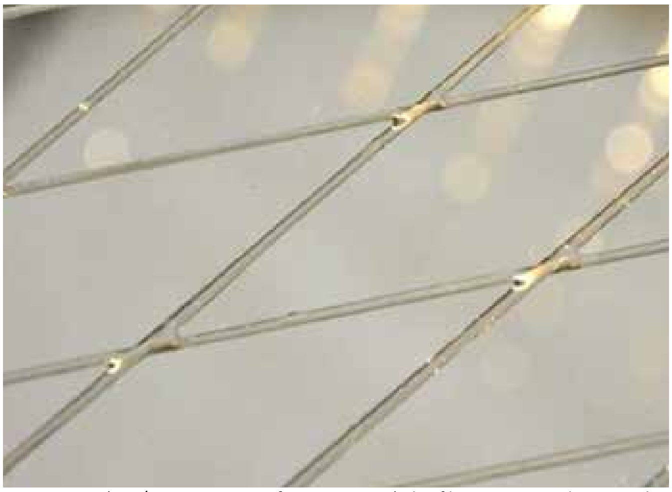

Figure 37 (ICD / ITKE University of Stuttgart,2012) The fibers are covered in resin, that hardens out and provides strength

Figure 38 (ICD / ITKE University of Stuttgart,2012) The setup for assembly with a 6-axis Kuka robot

Figure 39 (ICD / ITKE University of Stuttgart, 2012) The weaved roof pattern

Figure 40 (ICD/ITKE University of Stuttgart, 2012) The fibers are wound by the 6-axis robot on a temporary framework placed on a turntable, creating a 7th axis.

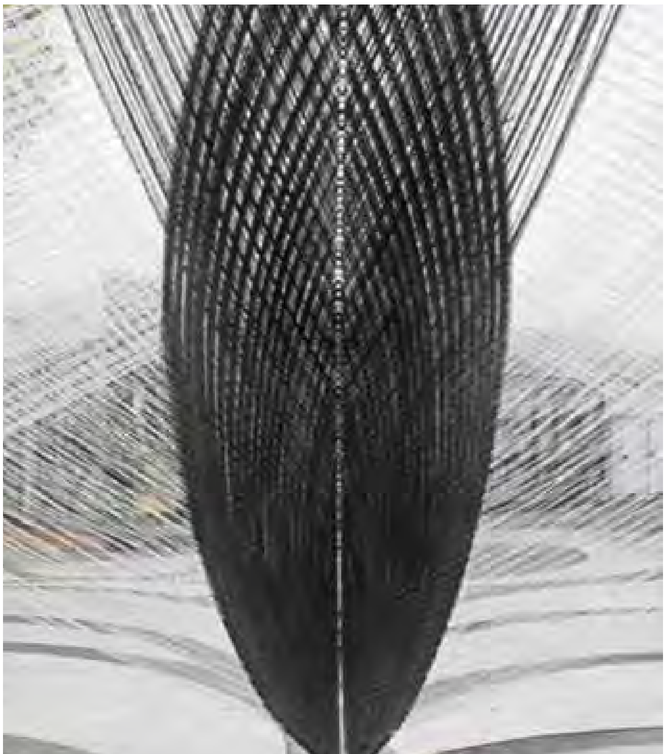

Figure 41 (ICD / ITKE University of Stuttgart, 2011) one of 5 'columns' that bear the loads, therefore being composed out of mostly carbon fiber

“

The implementation of design principles derived from nature is proposed as a methodology to meaningfully populate the expanding design space that is offered by the machines.

”

- Menges, A., & Schwinn, T, 2012-

Conclusion

Biomimicry is a term used in many fields, including the built environment. It uses nature as inspiration to find solutions, due to its methods and analogies of growth derived from many years of evolution. Biomimicry is based on abstracting properties from a natural phenomenon in order to optimize a solution. It is a way of design thinking, meaning that it uses biology's analogies for creative problem solving in the design spectrum. This method of design thinking is divided into two categories of approaching design problems. There is firstly the Top-Down approach which derives from a human based problem, searching into natural organisms in order to find an appropriate solution. Secondly, there is the Bottom-Up approach which focuses on an already known feature or function which a natural organism has, interpreted into the needs or problems. In the specific examples which have been investigated, these approaches are made visible. Starting from the oldest one, the "Pallazzetto dello Sport" by Pier Luigi, follows the Bottom-Up approach, as biological research based on mechanical information, was the key for the inspiration of the structural design. In contrast with "Pallazzeto dello Sport", the other two Research Pavilions of 2011 and 2012, have been similarly designed, following the Top-Down approach. There was a pre-existing design need, whose solution needed to be found from an organism's property. Based on these examples, some of their possible applications are made clear. Currently, biomimicry is only fit for the design of certain pavilions, small scale temporary buildings, and even large public structures. It is mostly experimental as it is still unknown how the architecture field will accommodate its application in the future. However, some benefits from the experimentations are taken into consideration, such as the material efficiency and accuracy, as well as the possibility of creative design forms, which refer back to the applied natural property. With the need to change the condition of the built environment and the construction industry, biomimicry seems to be the right solution. The reason is because it embeds new technological solutions with the combination of pre-thought strategies which result in environmentally efficient and architecturally expressive outcomes, which is what is needed during such times of development and environmental devastation.

Figure 27 (ICD / ITKE University of Stuttgart, 2011)
Aerial view of the Research Pavilion by night.

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Image References

Figure 1. ICD/ITKE University of Stuttgart. Exterior view of Research Pavilion 2012. [Photo]. https://www.icd.uni-stuttgart.de/projects/icditke-research-pavilion-2012/

Figure 2. C. Polyviou (2020) Top-Down and Bottom-Up approaches for abstracting properties from nature. [Diagram] Self made.

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Figure 6. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Research Pavilion 2011 [Photo] Retrieved on 20th of September 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 7. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Close image of the finger joints [Photo] Retrieved on 20th of September 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 8. ICD / ITKE University of Stuttgart (2011) Plan view [Drawing] Retrieved on 20th of September 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 9. ICD Stuttgart (2011) and C. Polyviou (2020) Sea urchin exoskeleton and finger joints [Photos and Diagrams] Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27 and Self made.

Figure 10. ICD / ITKE Stuttgart (2019) and C. Polyviou (2020) Sand dollar plate structure and finger joints [Photos and Diagrams] Available at: https://www.janknippers.com/archives/portfolio-type/holzpavillon-bundesgartenschau-heilbronn-2019 and Self made.

Figure 11. Magna, R. (2013) Translation into voronoi cell applied into 3D geometry. [Diagrams and Photo] Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27

Figure 12. C Polyviou (2020) Method ensuring convex and flat plates for anticlastic geometries. [Diagram] Self made.

Figure 13. C. Polyviou (2020) Geometric relationship between the robot and the plysheets, within 3 steps of fabrication. [Diagram] Self made.

Figure 14. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Milling of joinery edges. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 15. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Fabrication process of plate cells. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.dezeen.com/2011/10/31/icditke-research-pavilion-at-the-university-of-stuttgart/

Figure 16. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Assembly of plate cells. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 17. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Assembled plate cell. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 18. ICD / ITKE University of Stuttgart (2011) Topological analysis of plate connectivity. [Diagram] Magna, R. L., Gabler, M., Reichert, S., Schwinn, T., Waimer, F., Menges, A., & Knippers, J. (2013). From Nature to Fabrication: Biomimetic Design Principles for the Production of Complex Spatial Structures. International Journal of Space Structures, 28(1), 27–39. https://doi.org/10.1260/0266-3511.28.1.27

Figure 19. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Finger joints connection. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 20. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Finger joints connection. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.oliverdavidkrieg.com/?p=667

Figure 21. C. Polyviou (2020)Hierarchy operation of the plates when joined, preventing shear forces. [Diagram] Self made.

Figure 22. C. Polyviou (2020) Diagrammatic assembly process [Diagram] Self made.

Figure 23-26. ICD / ITKE Research Pavilion 2011- Assembly Time Lapse. (2018). [Video]. YouTube. https://www.youtube.com/watch?v=5oFtvYlcZWQ

Figure 27. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Research Pavilion, 2011 exterior night view. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 28. ICD / ITKE Research Pavilion 2011- Assembly Time Lapse. (2018).[Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 29. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Research Pavilion, 2011 exterior night view. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 30. ICD / ITKE Research Pavilion 2011-[Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

Figure 31. ICD / ITKE University of Stuttgart, Roland Halbe (2011) Research Pavilion, 2011 exterior night view. [Photo] Retrieved on: 29th of September, 2020. Available at: https://www.archdaily.com/200685/icditke-research-pavilion-icd-itke-university-of-stuttgart

CNC Milling & Routing

Collective research conducted by Bas Veerman and Bas Vissers

Abstract:

Before the invention of digital manufacturing principles, craftsman had to craft every element close to perfection. Nowadays the demand for well-crafted elements still exists, the demand has even grown further. In this chapter, the digital fabrication technique CNC milling and routing is further explained. Manufacturing with CNC makes sure that complex elements can be constructed with high precision in high volumes.

This chapter will explain the definition of CNC milling and routing, the difference between the two, the different machine axis, the machine components, and the workflow of working with CNC controlled routing and milling. In the final parts of the chapter, six case studies will be explained to clarify the use of CNC milling and routing in the construction industry.

Image on the right
1. BUGA wood pavilion
(icd.uni-stuttgart,2019)

Definition

CNC milling and routing

“Computer Numerical Control” (CNC) is a fabrication method where a computer system performs the basic controlling functions over the movement of a machine tool using a set of coded instructions. **[1]**

In this chapter we will focus on the fabrication process of CNC milling and routing. CNC Milling and Routing uses subtraction of material, in a manner similar to carving, to shape a designed element. In the construction industry CNC routing and milling have two main roles. It could be used to produce architectural elements of complex geometries and very detailed formwork for the off-site and on-site casting of materials with for instance double curved geometry. A wide range of materials is compatible with CNC milling and routing such as timber, foams, plastics, metals, fibres etc. There are multiple types of machines and methods used for CNC. The applications of this fabrication method depend on what type of CNC machine is used.

Advantages
Due to the digital fabrication process, CNC has the ability to mass produce irregular objects with one and the same machine, making mass customization possible without increasing costs. “It is just as easy and cost-effective for CNC milling machine to produce 1000 unique objects as to produce 1000 identical ones” **[2]**.

While in the early 1900’s design had to be reduced to the essential to make mass production of the house possible, using manufacturing to create a machine for living. Now the process is inverted, with factory production that is no longer connected to the mass production of standardized objects, but for mass customization. A second advantage of using CNC is the ability to maximize the arrangement and number of different components produces from a volume and therefore also minimizing the amount of waste, due to the use of coding **[1].**

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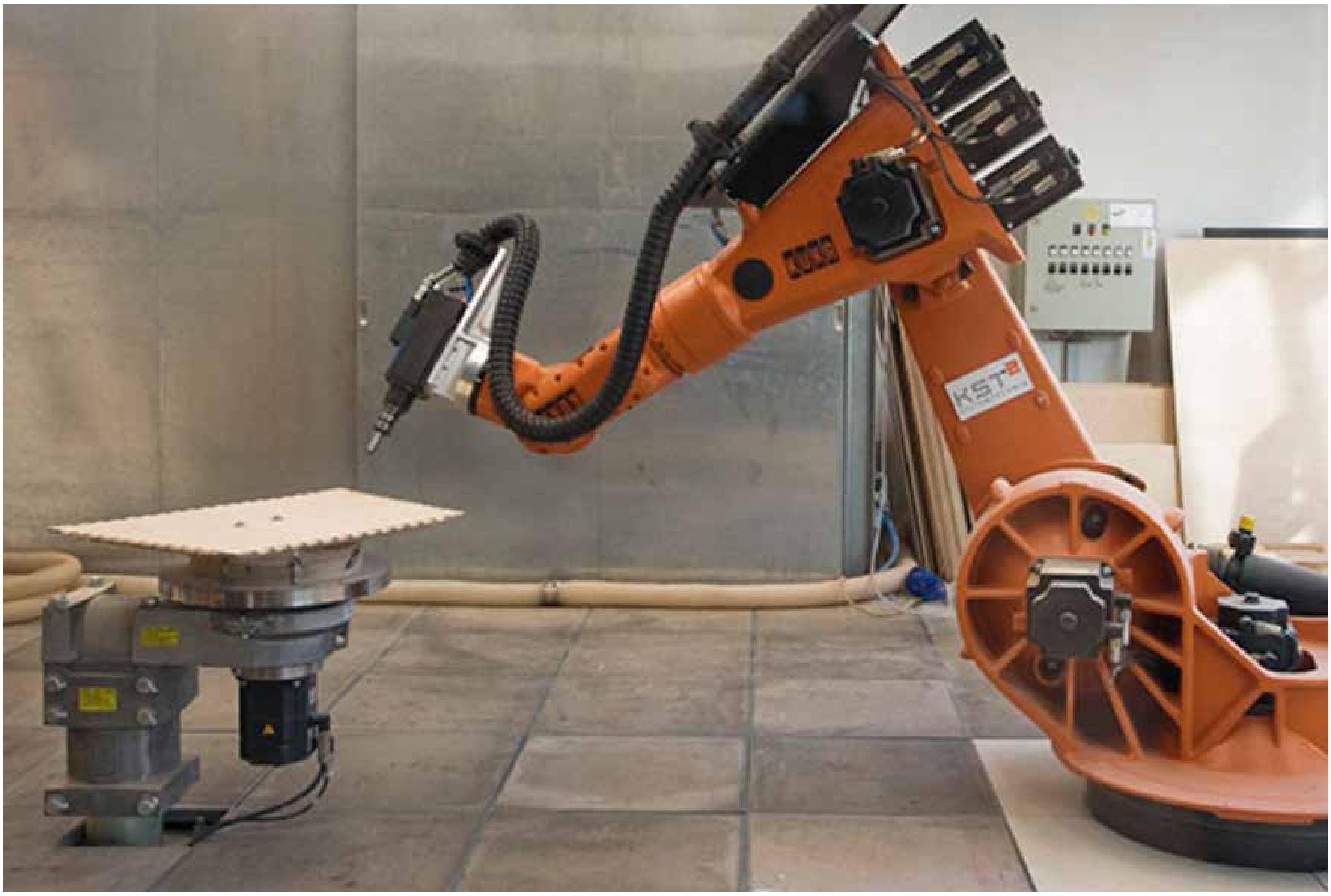
2. CNC routing (Open Systems Lab,2019)



3. CNC Milling (icd.uni-stuttgart,2019)

Difference CNC milling and routing

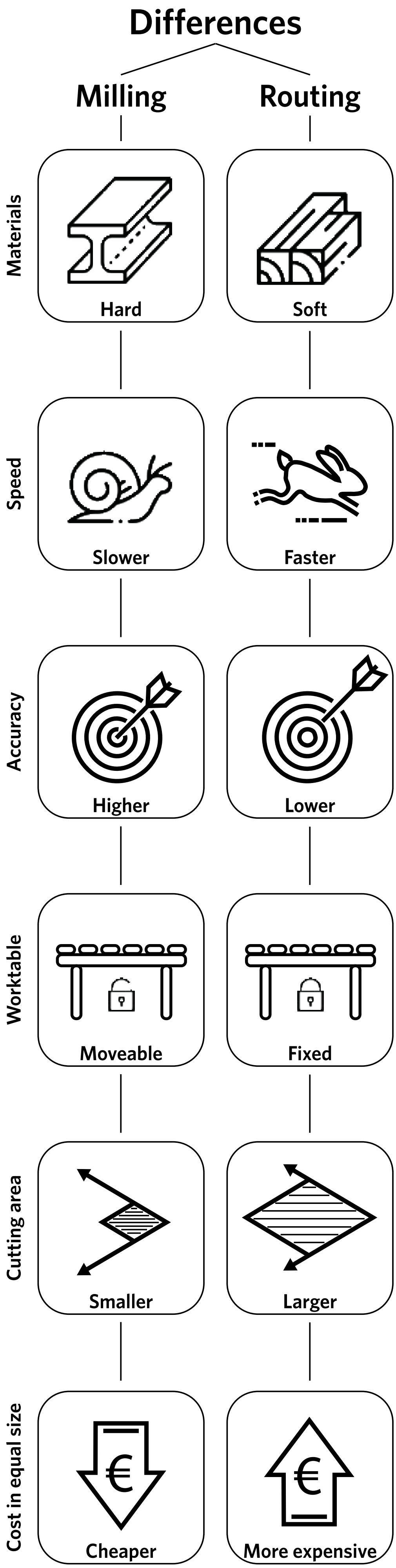
In the construction industry, the two most commonly used processes in which CNC is used are CNC milling and CNC routing. Milling and routing are similar to each other as they both use a rotating cutter to subtract material, which can be done in an almost endless number of ways. For the most part, CNC mills and routers can perform the same tasks. However, there are a few key differences between the two that can be found in their functionality and range of operations. **c**

CNC Milling

Milling can be used to create small, singular architectural components or formwork out of an endless amount of materials like woods, metals, plastics and foams (Seely, 2004). Milling makes use of a cylindrical tool that can rotate in various directions and move along multiple axes, making it possible to create a wide range of shapes, slots, holes etc. Also, it is possible to move the work piece across the milling tool. Although the operation is slower compared to routing, higher precision is possible and a wider spectrum of materials can be chosen, as stronger materials can be cut too. **[1] [3]**

CNC Routing

CNC Routing works similar to CNC Milling but is used to cut large, flat sheet materials instead of smaller block materials (Seely, 2004). Because it works with sheet materials, the work field is usually greater in the X, Y and Z direction. Therefore, Routing machines usually have a fixed table with a spindle that moves along the X, Y and Z axis. This is limited opposed to CNC Milling and therefore also less accurate, but there are many advantages too. Routing is usually only used to process softer materials like woods or plastics. Because the density of these materials is comparable, the router cutting head is able to subtract a much larger amount of material within a shorter amount of time. Also, the cutting area is much larger compared to CNC milling. **[1]**



4. Difference CNC milling and routing

Applications

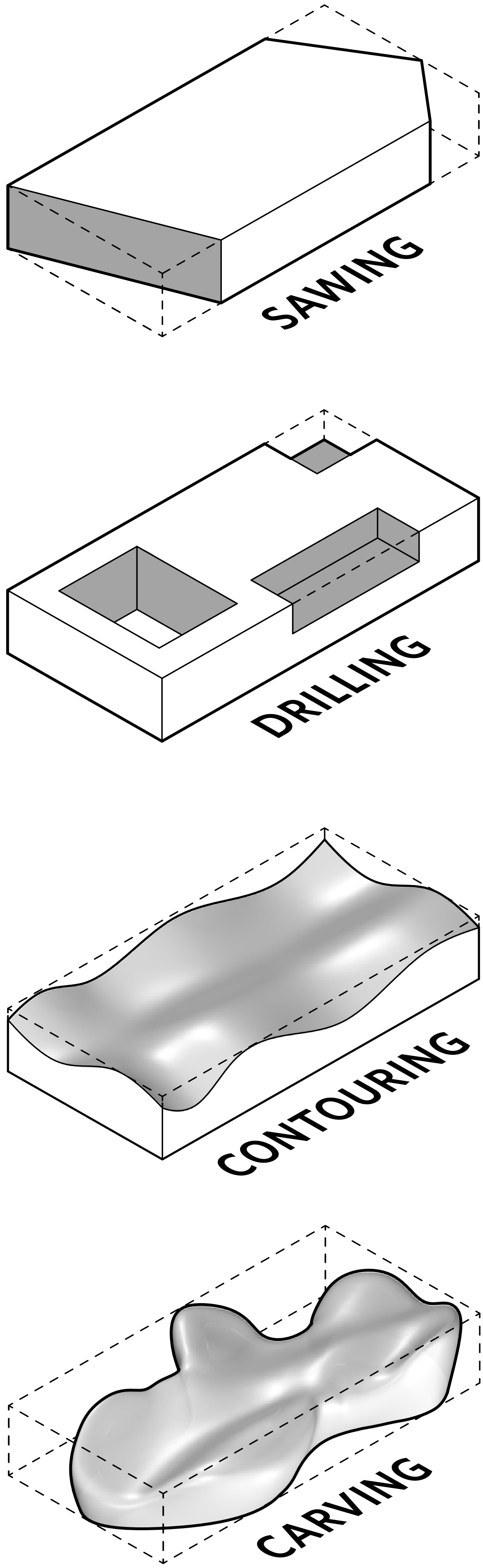
CNC Milling and Routing could be used for multiple applications and an almost limitless combinations and types of shapes and apertures may be achieved due to the spectrum of different cutter forms and sizes available. These are the applications most commonly used in CNC Milling and Routing:

Sawing
Where large quantities of linear cuts are required, routers may lose their efficiency in relation to other equipment such as circular saws but a number of tooling attachments are now available to augment routing operations if required. **[1]**

Drilling
This is perhaps the most familiar process. Small diameter holes are made using a corresponding sized router, which is sunk into the material as with a conventional drill. A large diameter hole may be produced by routing along its perimeter outline and then removing the waste disc left behind.**[1]**

Contouring
Contouring is used to make three-dimensional features into flat sheet material. Contours could be made both internally and externally. **[1]**

Carving
Carving is used to fabricate contoured 3D surfaces that may feature complex curvilinear geometry. Excess material is first removed using a ball-nose cutter and then once the rough shape has been carved, pointed detail tools are used to create intricate surface features and a high level of finish. **[1]**



5. Possibilities with CNC milling and routing

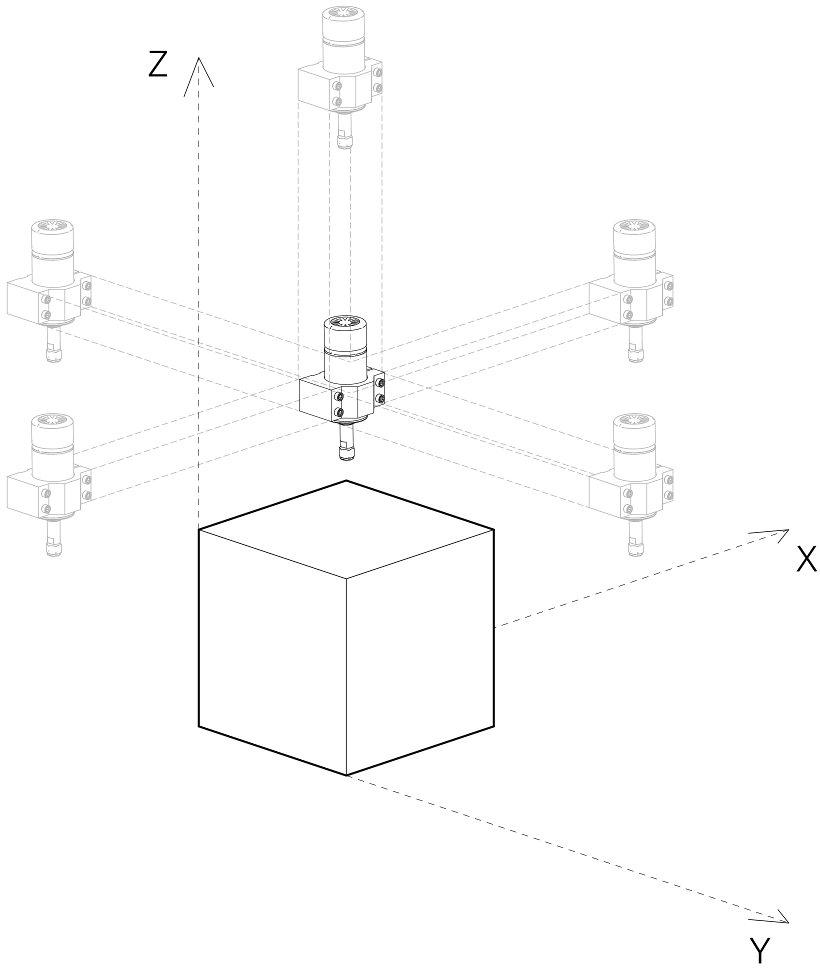
CNC-Axes

CNC milling and routing

CNC mills are usually identified by the number of axes it can operate in. X and Y represent the horizontal movement, while Z is used for the vertical movement. However, also diagonal movement is possible across the vertical plan, which could be used for more complex elements. Generally, most CNC milling machines use 3 to 5 axes. Control by 3 axes should already enable cutting at any desired point within the work field. However, not everything is possible, as the component that is being processed could sometimes block the operation due to its position. The two extra axes that are provided with 5 axes milling machine enable every possible operation due to the two rotational axes. This makes reaching internal areas of the component and creating overhangs easier. **[1]**

Machines can either have a fixed or moving worktable on which the material to be processed is mounted. A moveable worktable is often more economical but give limitations on the size and weight of the mounted element. Fixed worktables take away these limitations through the use of moving machinery. However, operations need to be able to move with precision and speed while withstanding the forces experienced during the cutting process. **[1]**

There are multiple types of CNC machines that can be used for different tasks. The basic principles of the CNC remain the same with using different materials. The complexity of the designed element that has to be manufactured determents the type of CNC that is required. When needing a lot of movement in the z direction, one could best choose for the milling. Routing is beneficial when lots of movement in x, and y direction is needed. **[4]**



3 -Axes

With 3 axes CNC, the milling / routing tool is controlled to be able to move simultaneously alongside the x, y and Z axes. In this type of CNC controlling the workpiece remains stationary. It is mostly used for parts that do not require a lot of depth and detailing. The main purposes of 3 axis CNC machining are Automatic operations, Cutting Slots, Drilling holes, and cutting edges on flat surfaces. **[5]**

Image
6. 3-axes CNC

4 -Axes

With 4 axis CNC, the processing of the workpiece is the same as with 3 axis CNC machining. Next to this there is an axis added (X1) which makes it possible to process the sides of the workpiece. The fourth axis makes the workpiece turn, making it possible to reach the sides of the workpiece. **[5]**

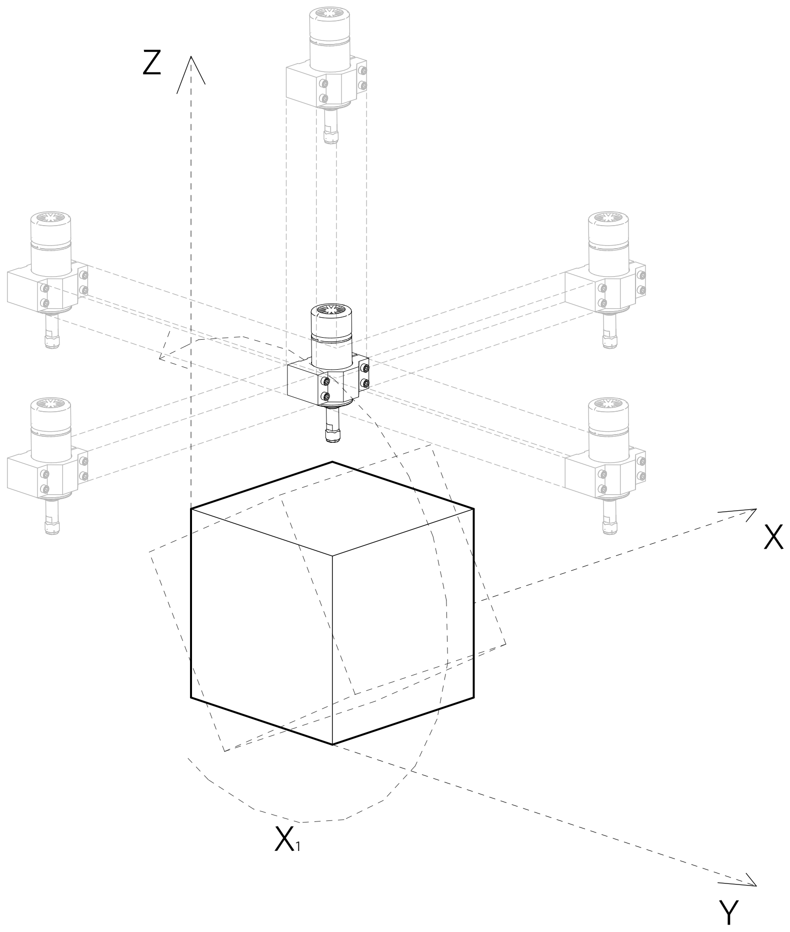


Image
7. 4-axes CNC

5 -Axes

With 5 axis CNC machining it is possible to process the workpiece from 5 sides. In addition to the standard 3 axes, there are two axis rotary axis added. This type of machining is beneficial when components require a great deal of intricacy and quick precision. The process is often used to create complex solid parts that otherwise have to be casted. **[5]**

Image
8. 5-axes CNC

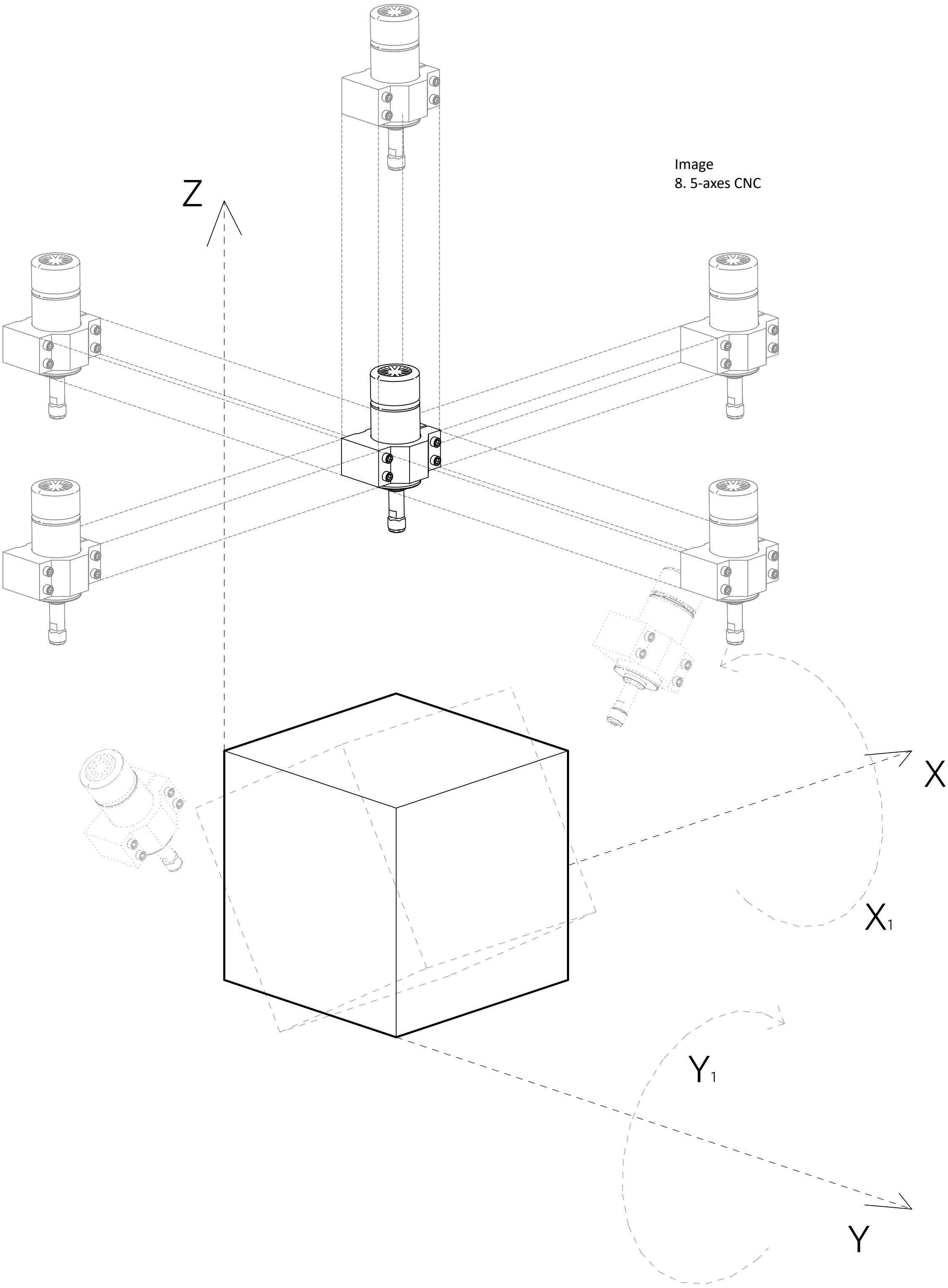


Image on the right
9. Cambride Mosque
(Menges,2020)

CNC machine parts

CNC milling and routing

Control panel
The control panel is mainly considered as the brain of a CNC milling machine. The machinist/controller feeds the G-code (required dimensions) using the keyboard which, in turn, instructs the axis motors to move the cutters and other components.

Table
The table holds a workpiece stationary for the entirety of the milling process. The workpiece is mainly to fit to the metal/wooden/plastic table using T-slots and metal clamps.

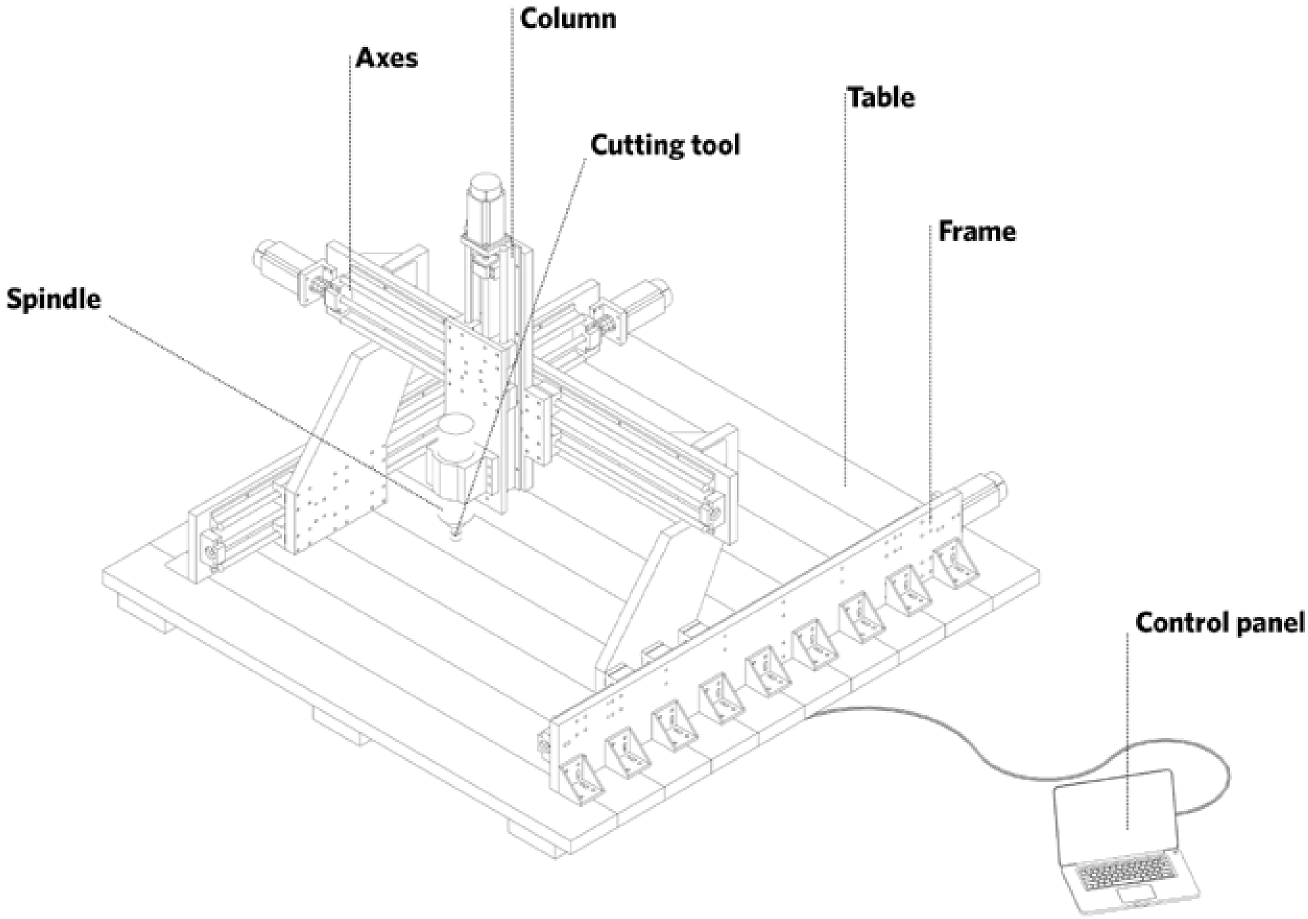
Column
The columns run along the axis for giving the backbone to the milling part.

Cutting tool
A cutting CNC machine is simply attached to the column. This moves across the axis for giving the desired shape to the CNC machined parts. for milling and routing their are many cutting tools available:
End mills, Face mills, Fly cutters, Twist drills, Taps and thread mills, Single to six flute end mills, Engraving tool, Countersink milling tool, Cutting diamond, Foam mills.

Frame
As the name suggests, a frame offers sturdy support to the machine offering them with maximum rigidity to withstand cutting forces.

Axes
Axes play a pivotal role in CNC. The axes in the CNC milling machine permit a cutting tool/workpiece for moving around to obtain the maximum possible precision.

Spindle
The spindle consists of the rotating assembly, which holds the cutting tool and the motor that runs the entire workpiece.**[5]**



10. CNC machine parts

Workflow

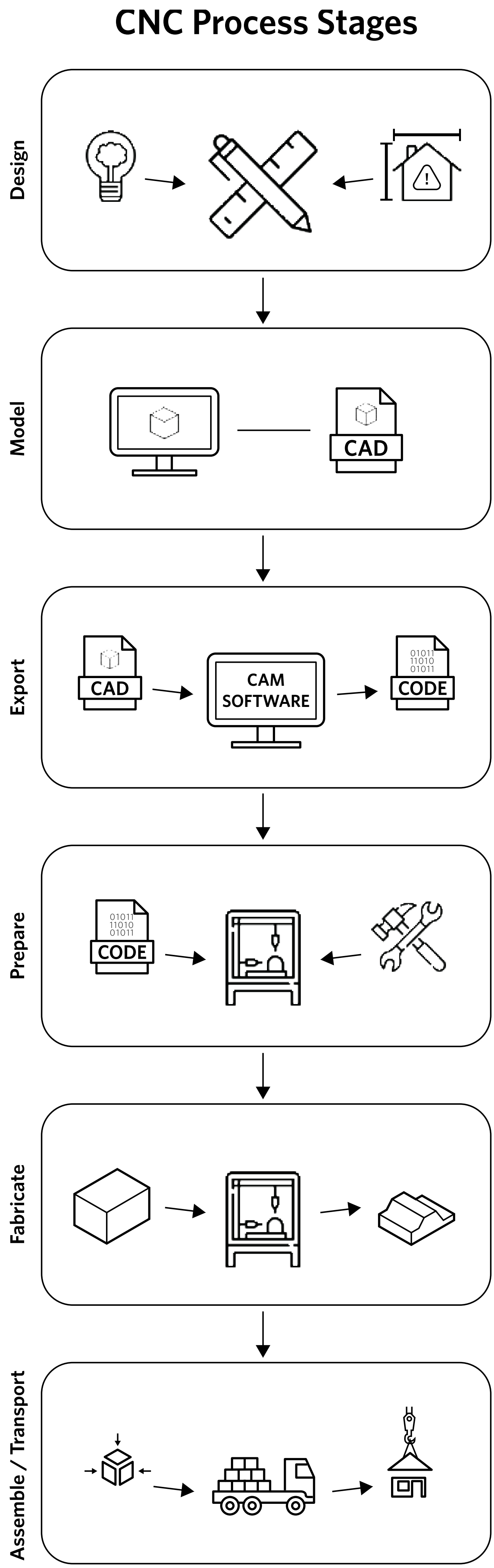
CNC Milling and Routing use computerized controls to operate the tools that are needed to subtract material to get to a desired shape. Working with CNC makes it possible to shape a large variety of materials in a number of different ways. However, the workflow of getting from the design to the final product remains largely the same for all material and applications. **[6]**

There are six main stages in CNC manufacturing process:

1. Designing
2. Making the CAD-model
3. Exporting the CAD-model
4. Preparing the CNC machine
5. Fabrication
6. Assembly and Transportation

Step 1: Designing
When making a design for CNC milling/routing it is important to identify the objective, specifications and requirements of the project. This step is required to identify the risks, challenges, restrictions, but also possibilities for CNC. In this way, the project could be planned without unexpected changes. A great advantage of using CNC is the ability to test during the early phases of design using prototypes that make the transition to final product over time. **[6]**

While CNC milling/routing provides a large amount of geometric freedom, there are some restrictions that depend on the available capabilities of the machine type, material, and tools. When planning the design there are some key restrictions to consider: **[4]**



11. CNC milling and routing workflow diagram

The geometry of the tool

Most of the tools that are used in CNC processes have a cylindrical shape with a flat or spherical end. This causes for restrictions in the geometry of the desired product. Internal vertical corners will for instance always have a radius, no matter how small the diameter of the tool.

Tool access

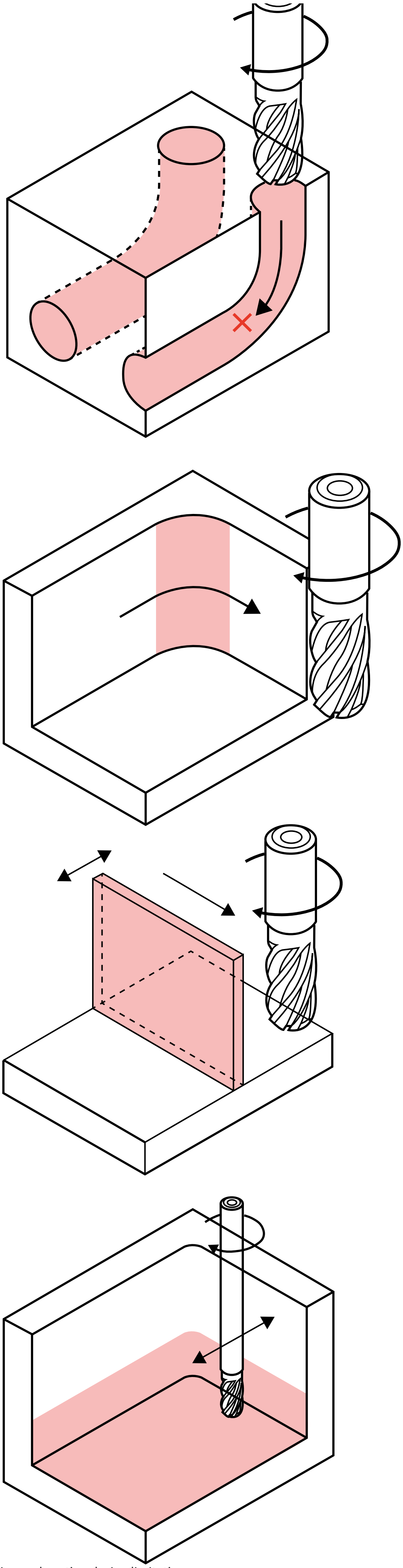
It might seem obvious but surfaces than cannot be reached by the cutting tool cannot be CNC machined. This restricts the designer in the possibility of having hidden geometry inside the workpiece. It also sets a limit for the dept of undercuts.

Workpiece stiffness

Due to the forces applied to the workpiece by the CNC process, there is the possibility that the workpiece will start to deform or vibrate. To prevent this from happening, the designer should consider the minimum thickness of a material that is related to strength and the maximum aspect ratio of tall features.

Tool stiffness

To prevent precision loss or even failure of the tools used in the CNC process, the designer should limit the depth of narrow cavities. In the CNC process, tools often fail because of a large ration between diameter and length of a tool. **[4]**



12. CNC milling and routing design limitations

Step 2: Making the CAD-model
To use CNC manufacturing, a 3D design is needed created with CAD software. This allows designers to make a model of their design. By using CAD, the model contains information like geometry and dimensions. This information is needed to manufacture the element. **[7]** In the design process, it is important for the designer to aim for the fewest required subtractions possible. Simple design reduces the run time of the CNC machine. **[8]**

Step 3: Exporting the CAD-model
Once the design in CAD is finished the information has to be exported to a file compatible for CNC. The CAD-model runs through a computer-aided manufacturing (CAM) software. This software will extract data such as the geometry and produces a code that is compatible for CNC operation.

This coding can be seen as a language for the machine. The code used for CNC manufacturing is the G-code. This code controls the movements of the CNC machine. The code contains information like when the machine should move, the direction, how fast to travel, when to travel, what path to take, and when to turn on and off. The code has a direct effect on the fabrication process and with that on the end result of the manufactured object. **[1]** Next to the G-code there is also the M-code which controls removal and changing the parts of the machine such as the tools or the safety cover. These codes form the CNC program.

Step 4: Preparing the CNC machine
Although, the work is mostly done by the CNC machine, a skilled workshop technician or machine operator may come in handy, particularly when CNC with more than 3 axes is used. **[1]** Ones the program is generated, the operator will load it into the CNC machine which will then be ready for production. Before the actual manufacturing can begin, the operator must prepare the machine. The preparations mainly exist out of attaching the right tooling for the different types of subtraction and fixating the workpiece into the machine. The right tools have to be chosen for the execution process of each material, just like in manual drilling or cutting. **[1]** Once this is completed the CNC machine is ready to run the program that was generated in step 2. **[7]** The way a workpiece is fixated is determent by the geometry of the workpiece. When a workpiece has to be manually replaced during the process it might cause minor inaccuracies. Therefore 5-axis CNC is often used for complex parts. With 5-axis CNC the workpiece is moved around by the CNC machine itself. **[1]**

Step 5: Fabrication
The machine is now ready for operation and will run the generated program to end up with the desired element. The speed of the manufacturing depends on the machine that is used, the material and the complexity of the design.

Step 6: Assembling the elements
The last step, which requires manual labour is the assembling and transportation of the elements. Depending on the scale of the elements that are produced, multiple elements could be preassembled off-site or on-site. Due to the high precision of the elements, no further actions are required besides connecting the elements.

13. CNC milling machine in operation on timber element (Blumer Lehmann AG, n.d.)

Image
14. Elbphilharmonie concert hall (ArchDaily,2016)

Project
Elbphilharmonie concert hall (acoustic panelling)

Architect
Herzog & De Meuron

Location
Hamburg | Germany

Year
2016

Program
Concert hall

Image
15. Interior of the Elbphilharmonie hall (ArchDaily,2016)

Design philosophy

Concert halls aim to deliver the best concert experience for its visitors. Next to the often spectacular architecture of the concert halls, performance of the hall is equally important. The Elbphilharmonie hall made an effort to achieve excellent acoustics that are in harmony with the architectural language of the building. Concert halls that where built before the 20th century had high acoustic performance since they had a lot of irregular surfaces caused by ornamentation.

After the 20th century ornamentation was often left out of concert halls which might have come to the expense of good acoustics. Architecture has always been influenced by the advances in technology and engineering. One of this advances is digital fabrication which makes it possible to create complex shapes faster, cheaper, and more detailed. In the Elbphilharmonie hall, the architects and acoustic engineers had a close collaboration to make acoustic panelling that is closely connected to the architecture of the building while having the best performance as possible. The interior wall is clad with acoustic panelling that has been designed to achieve sound diffusion (image 15). **[9]** "Sound diffusion is the even scattering of sound energy in a room. Non-diffusing, reflective surfaces in concert halls can lead to a number of unwanted acoustic properties, which can be rectified in part by adding diffusers. A perfectly diffusive space is one where acoustic properties such as reverberation are the same, regardless of the listener's location". **[10]**

The irregular shapes in the Elbphilharmonie hall are designed as randomly placed, individually shaped cells for specific regions of

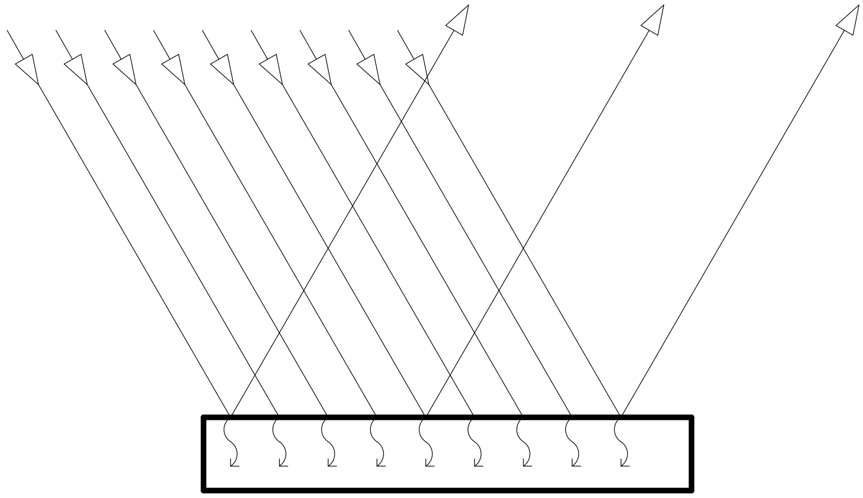
Image
16. Acoustic panels Elbphilharmonie concert hall (ArchDaily,2016)

the concert hall. Different cells define an acoustic panel made from gypsum fireboard which is then connected to the interior wall. The randomness of the cell pattern caused that each one of the ten thousand panels had to be unique. Therefore, the designers started to implement a process of parametric designing that would eventually be linked to digital fabrication techniques. **[9]**

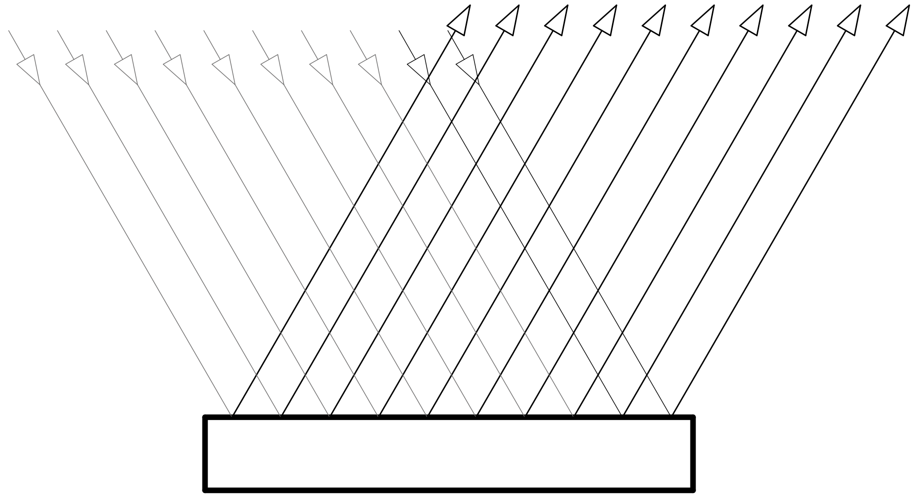
The parametric design phase:

The parameters for the panels where predefined by the acousticians, they consisted out of width, depth, and randomness of the cell pattern. To generate the cell pattern, the 3D modelling software Rhino was used together with plugins to define the one million unique cells. (image 18). The pattern was initially based on a two-dimensional grid of Voronoi seeds. The individual appearance of the cells was based on the shape of the roof of the building. The placement of the control points where driven by six parameters. Lastly the control points where projected onto the shape of the walls and ceilings.

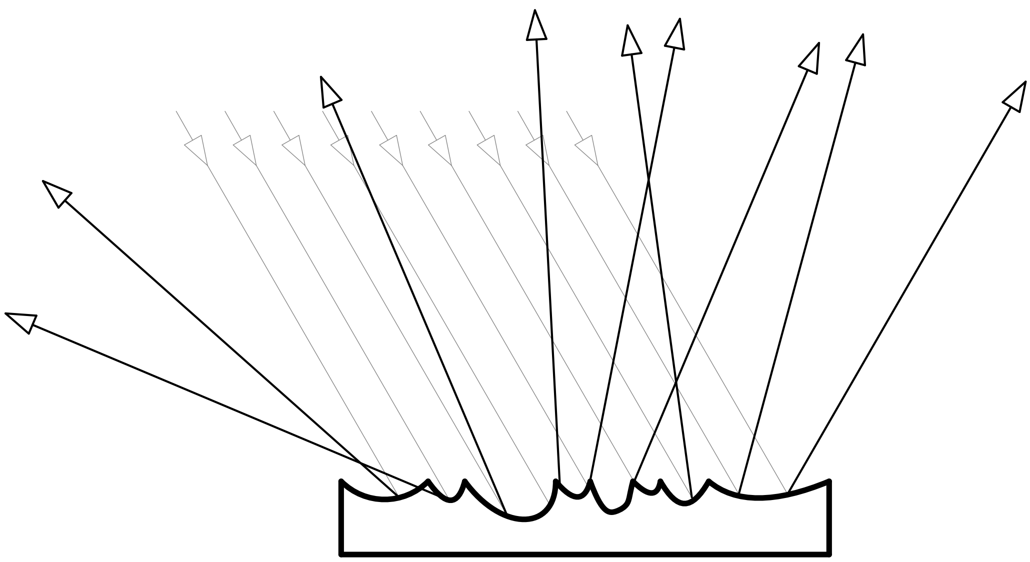
Special attention was given to the continuation of the pattern on the seams between each connected panel. When the final parametric design had been defined, the next step was to transfer the CAD based data of the panels into data that could be used for digital manufacturing of the panels by using CNC milling (Image 19).



Absorption



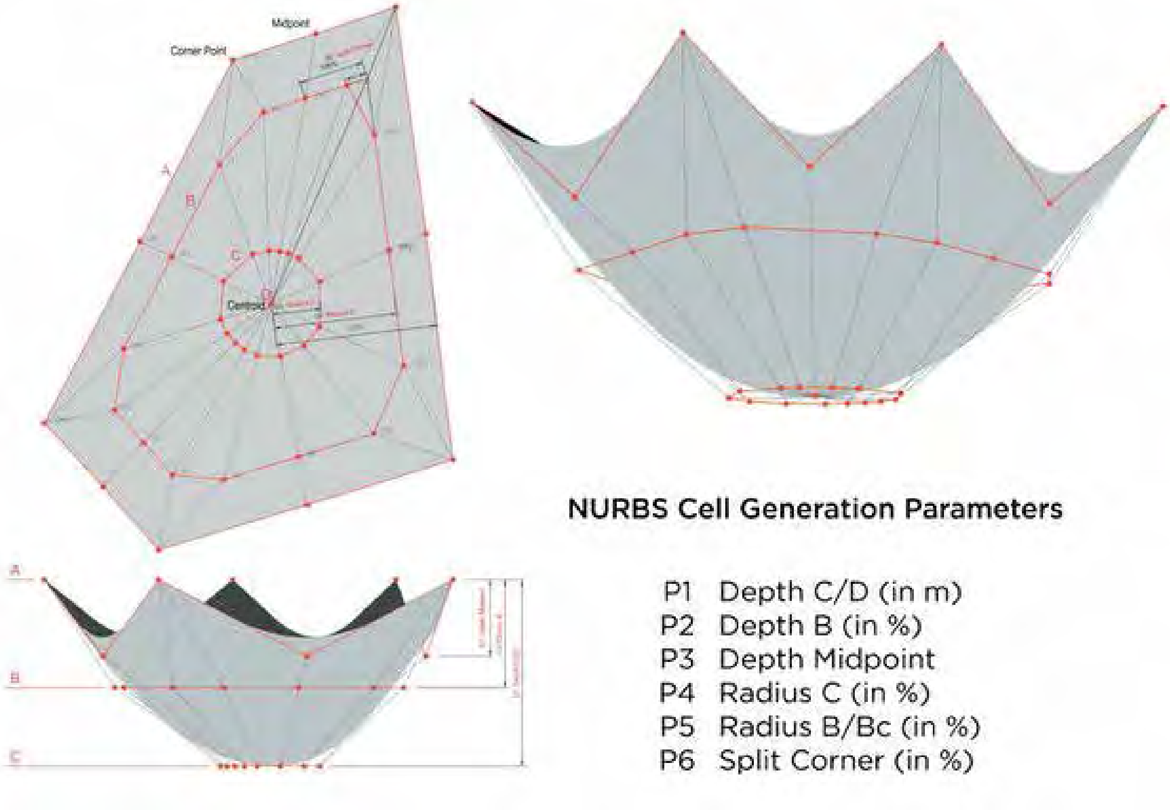
Reflection



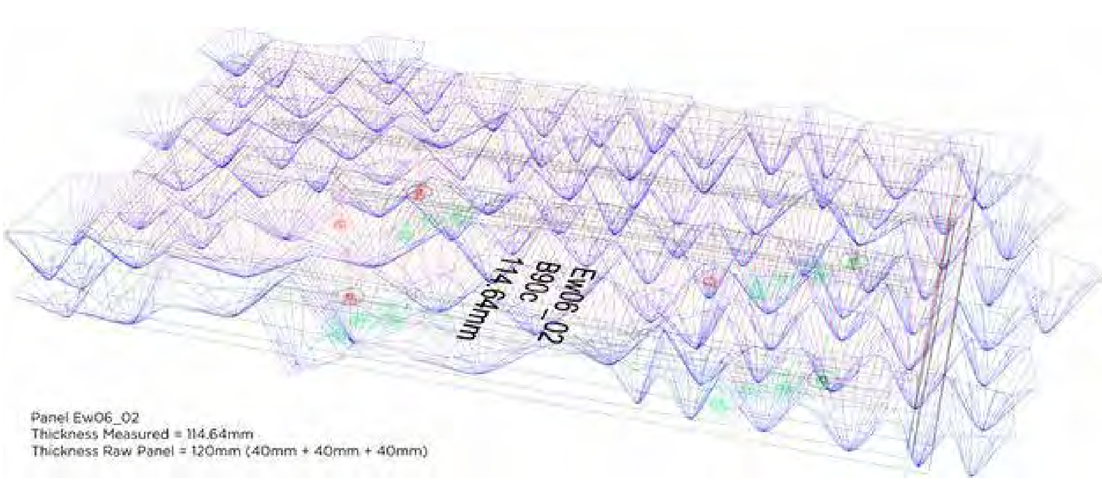
Diffusion (used in the Elbphilharmonie concert hal

Image

17. Acoustic panels Elbphilharmonie concert hall (Diffusion)



18. 3D model of 1 out of 1.000.000 unique cels (Menges,2017)



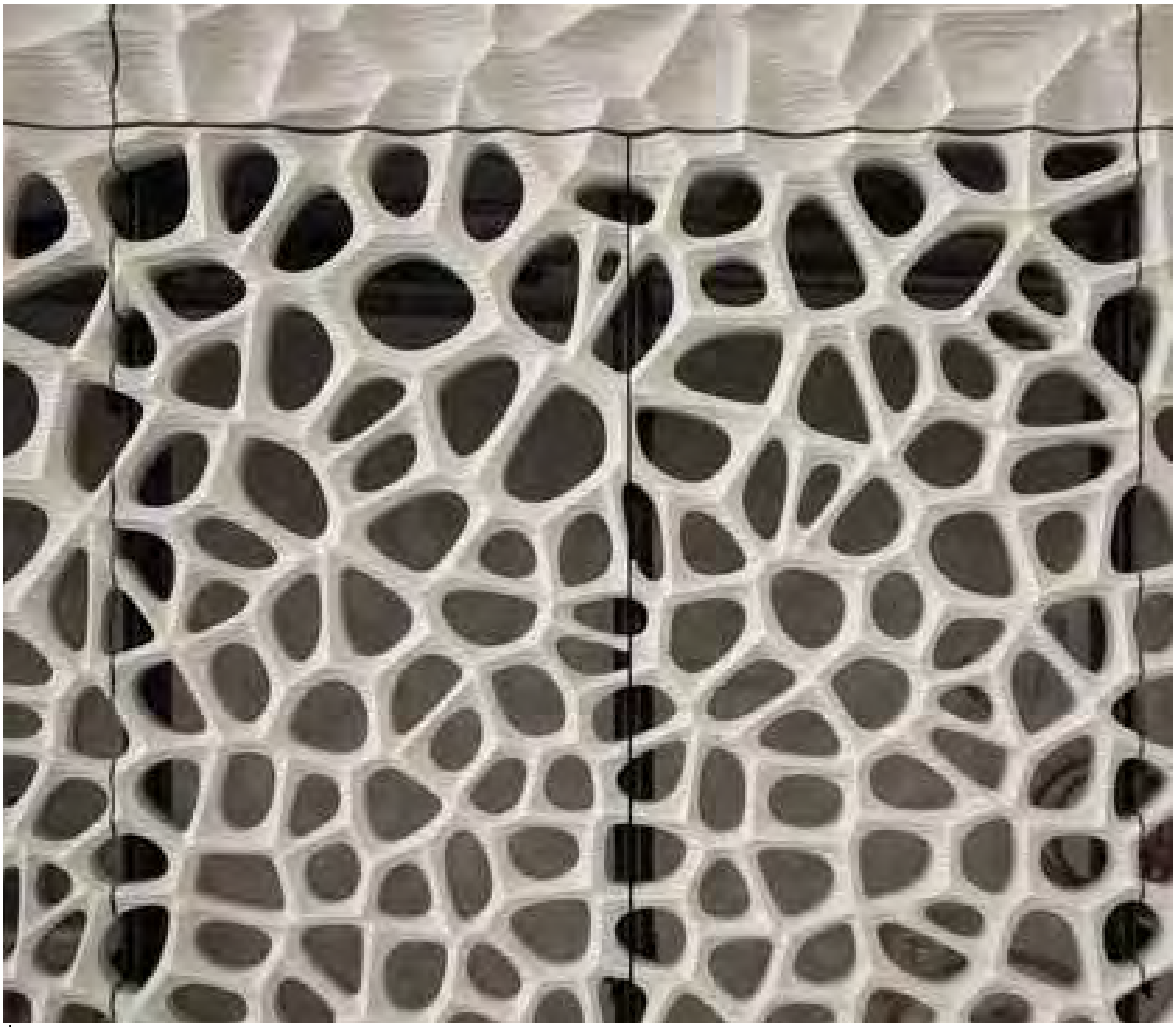
19. 3D model of a Acoustic panel (Menges,2017)

Image
20. Acoustic panels Elbphilharmonie concert hall 3-axis CNC (Menges,2017)

Panel fabrication:

As each panel was unique, the 3d models of the panels where further automated to make them compatible with the CNC fabrication process. Because of the large surface to clad, 10.000 panels had to be CNC machined. Each panel was first prepared to size. After the laminated gypsum fireboard was cut to size, the two stages of CNC milling started. The first stage used 5-axis milling of the edges and milling of the holes in the back needed for the connection between panel and wall. After this process, the panel was flipped and placed on a 3-axis CNC milling machine. The second stage of CNC milling started by flipping the panel onto a 3-axis CNC machine to mill the pattern on the front of the panel. To subtract material from the

panel a ball-end cutter was connected to the CNC controlled machine. This resulted in a rough final surface texture. (Image) After the panels where milled, they were coated with a clear lacquer. Lastly the substructure behind the panel were attached to the previously milled holes in the back of the panel. After this the panels where ready for shipment to the project site where they are manually installed to the interior surfaces. **[9]**

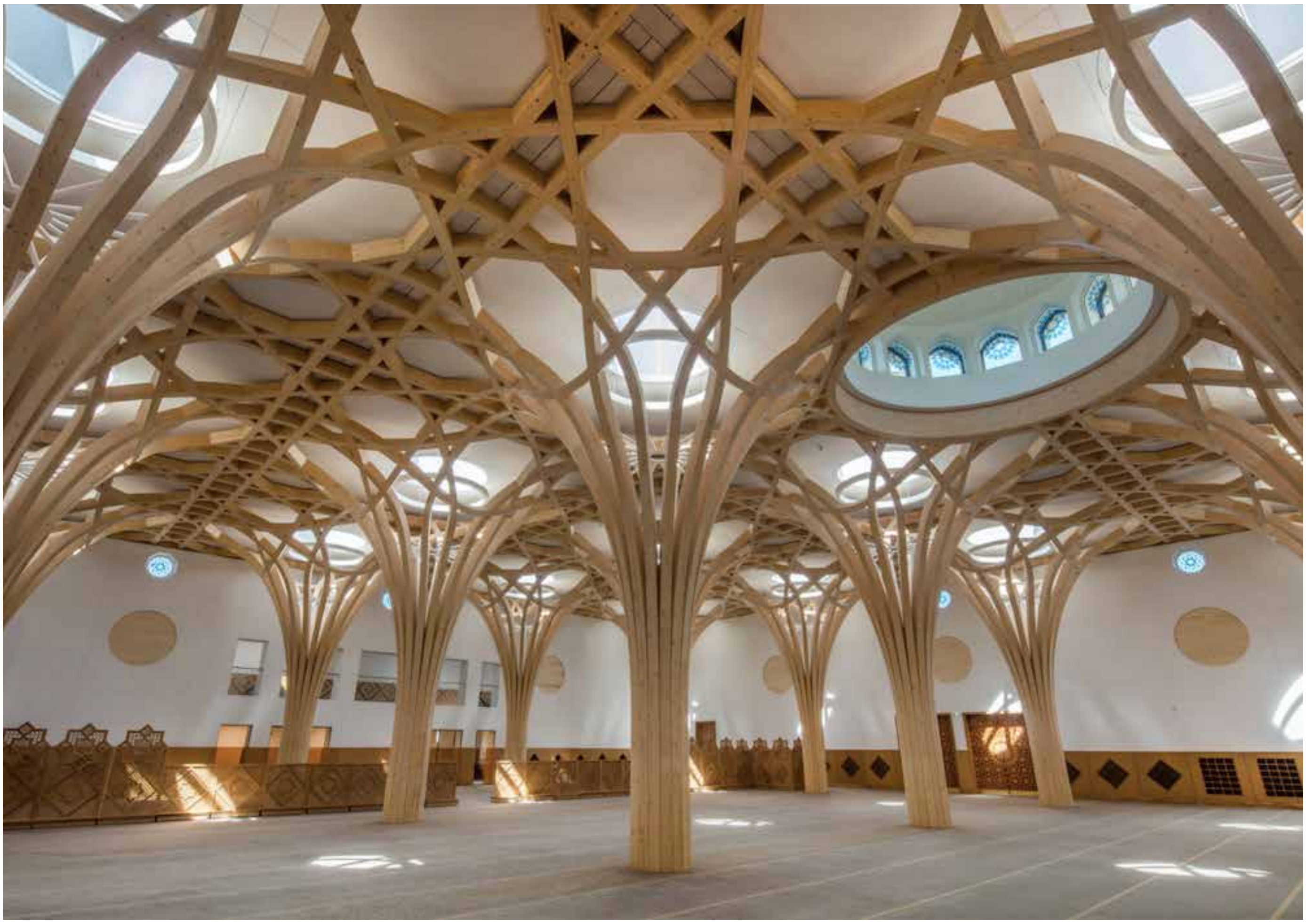


Image

21. Acoustic panels Elbphilharmonie concert hall (ArchDaily,2016)

The benefit of CNC fabrication in the Elbphilharmonie hall:

During the construction period of the concert hall, 5-axis CNC milling was not often used in construction. This project was the first to mill such a large quantity of unique panels out of gypsum fireboard. By implementing digital fabrication techniques like the CNC milling, only 20 out of 10.000 panels had to be replaced during construction. This is an error rate that is virtually impossible to achieve when fabricating such panels by hand. The CNC milling made it possible to combine performance of acoustic panelling with the architectural language of the building in a most efficient and beautiful way.



22. Cambridge Mosque interior (Wood Awards, n,d,)

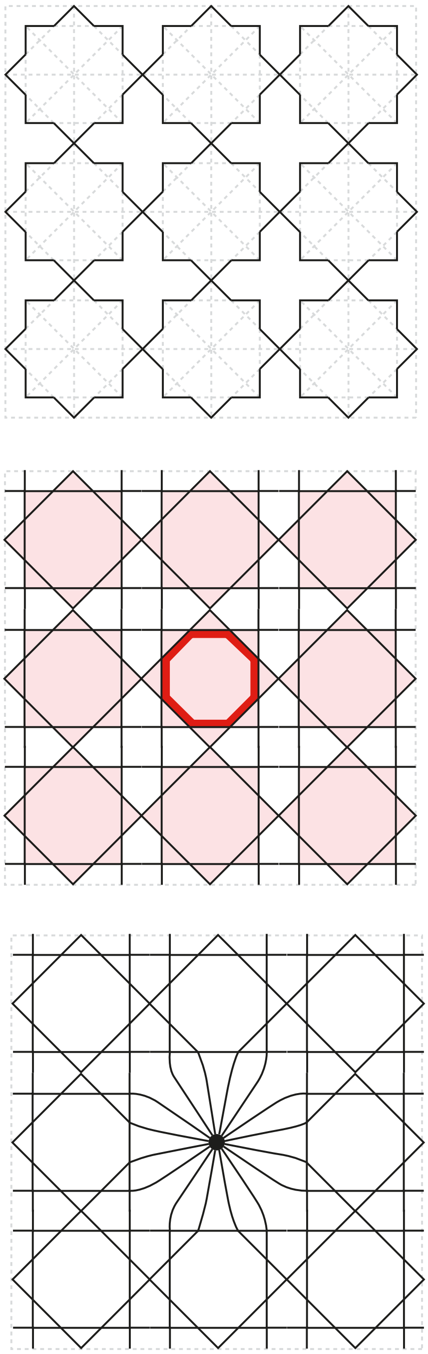
Project
Cambridge Mosque

Architect & Structural Engineer
Marks Barfield Architects | Blumer Lehmann

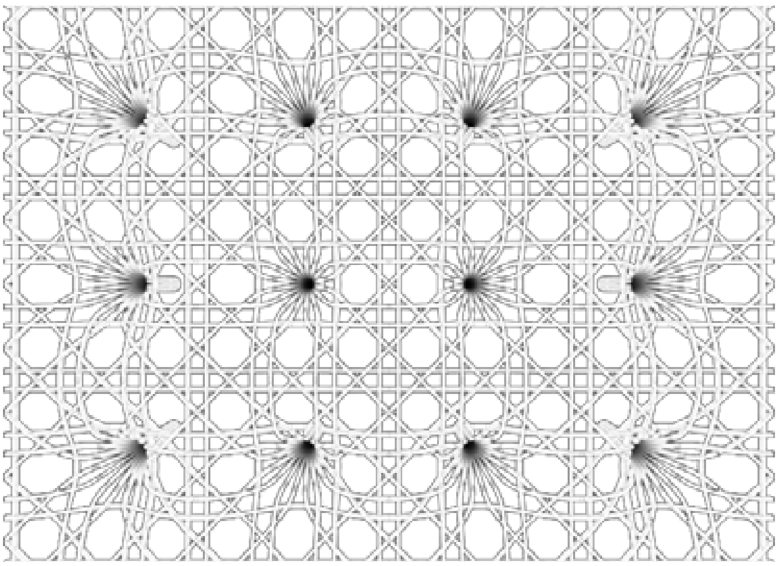
Location
Cambridge | UK

Year
2017

Program
Public | Religious



23. Cambridge Mosque origination of geometry structure



24. Cambridge Mosque truss system overview (Design-to-Production, n.d.)

Design philosophy

The timber structure of the Cambridge Mosque is inspired by the garden of paradise and translated into 30 supporting trees that are built from doubly curved laminated timber beams.**[11]**

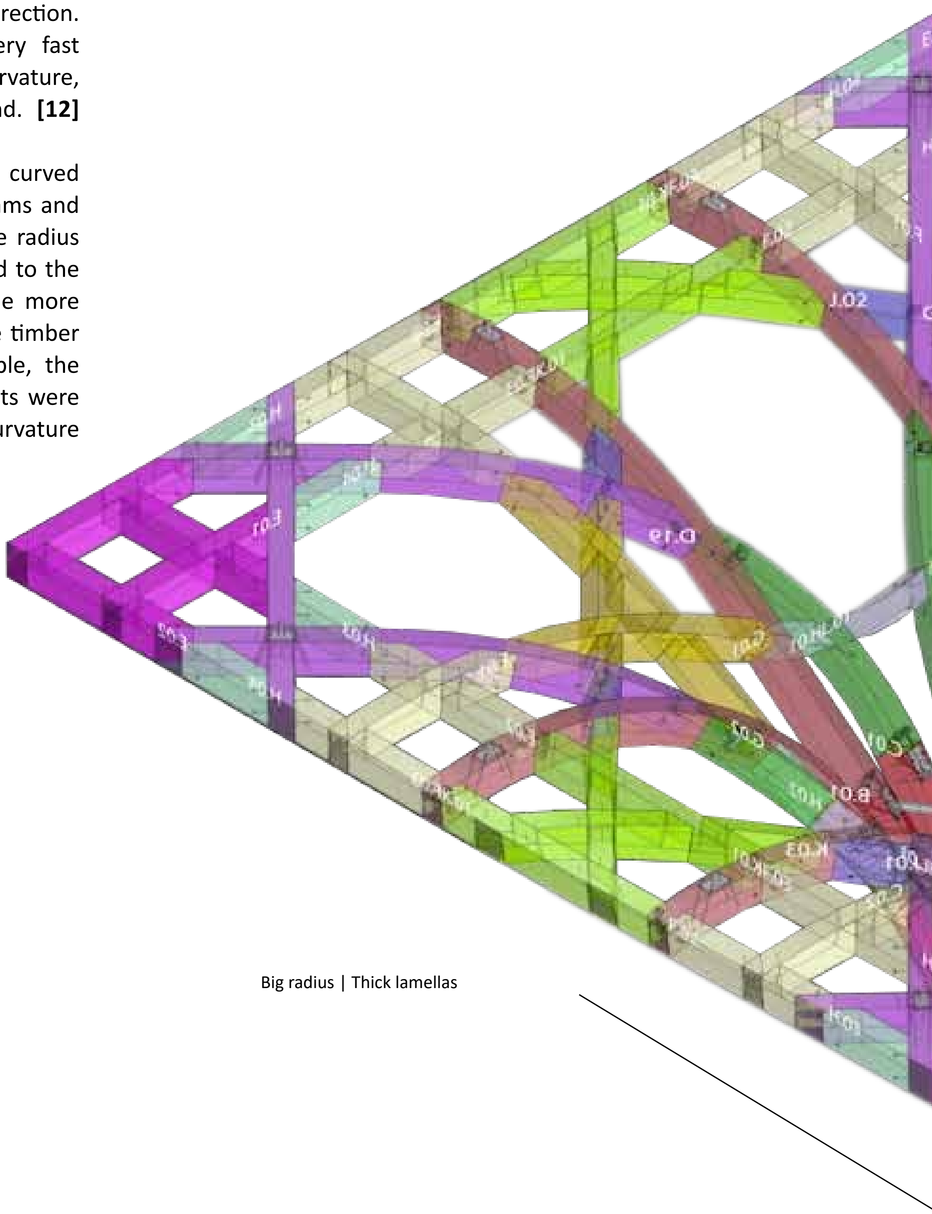
The structure follows an octagonal pattern that is common in Islamic culture. The geometry of the structure is not planned to be build with timber, but rather an architectural gesture that is translated in timber. **[12]**

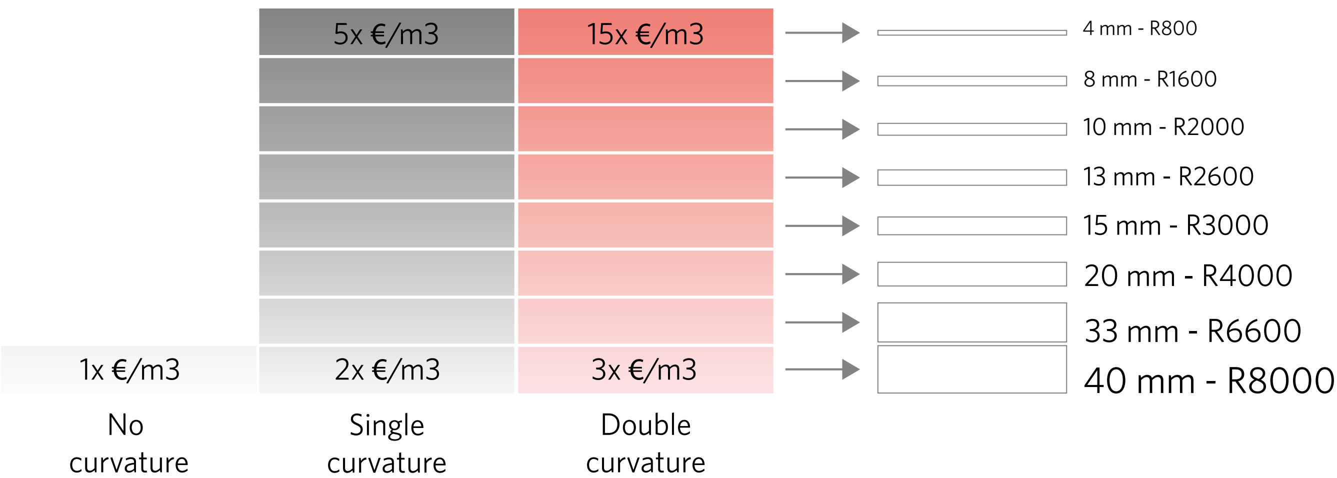
The structure is very complex, consisting of 2746 components with 145 variations. Fabrication of this structure was not possible without the use of CNC milling, that was used to make the elements of the structure with high precision. **[13]**

Segmentation of the structure

The doubly curved, laminated timber beams of the structure are not made out of one continuous piece but are segmented. The problem with timber is that you always have to follow the fiber direction. In the case of the Cambridge Mosque, the structure has a curved surface, which means that in order to make a feasible structure, the timber has to be bended so that the surface is following the fibre direction. However, bending timber can become expansive very fast when strong curvature is needed. The stronger the curvature, the thinner the lamellas, as they are easier to bend. **[12]**

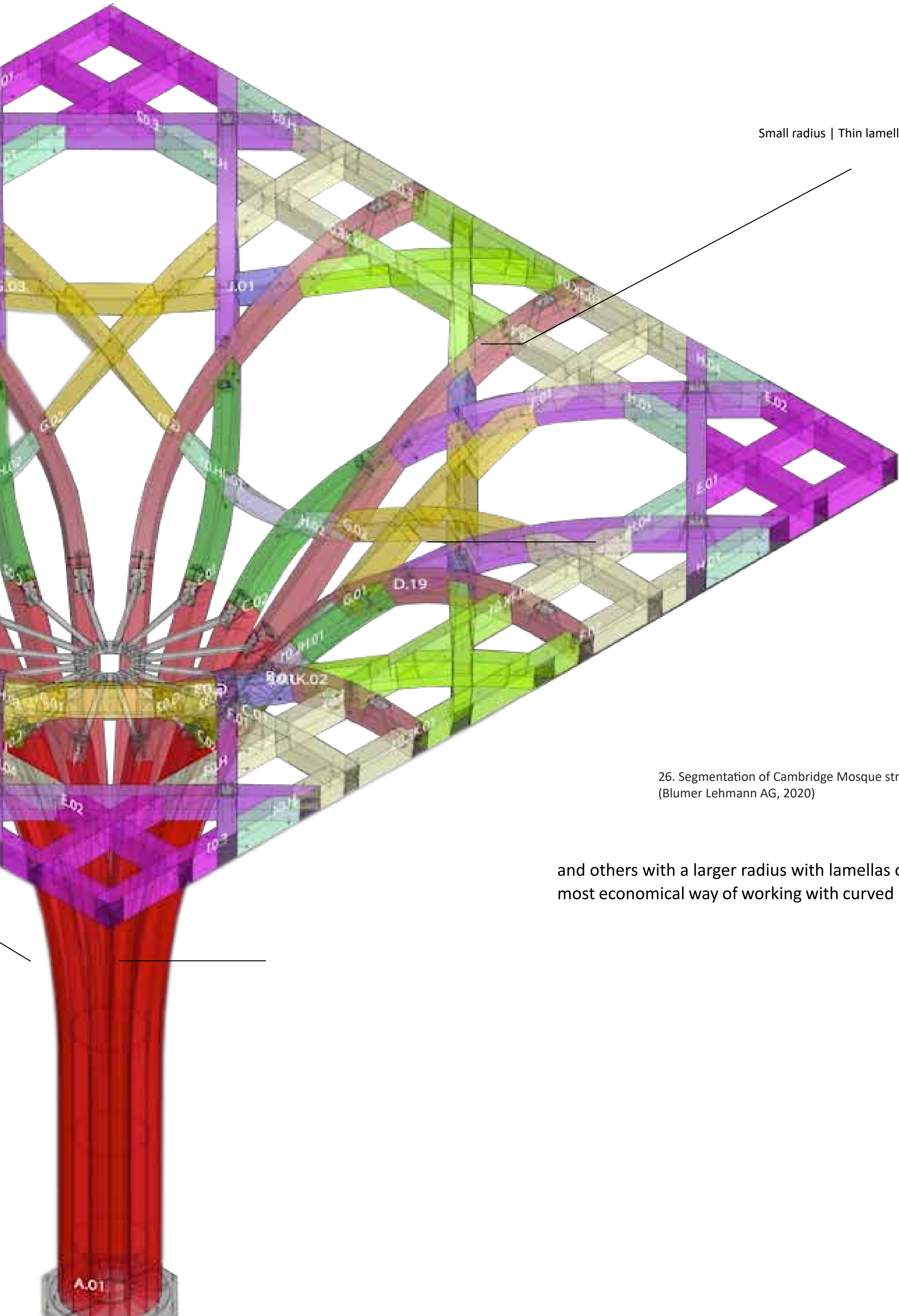
As can been seen in the table on the left, a single curved beam is 2 to 5 times more expansive than straight beams and double curved beams 3 to 15 times, depending on the radius of the curvature that is needed which can be translated to the thickness of the lamellas. The thinner the lamellas the more expansive the structure becomes. In order to make the timber structure of the Cambridge Mosque financially feasible, the structure is devided into segments, in which some parts were made with thin lamellas resulting in beams with strong curvature





25 Geometry and cost of laminated timber structures

Small radius | Thin lamellas



26. Segmentation of Cambridge Mosque structure
(Blumer Lehmann AG, 2020)

and others with a larger radius with lamellas of 40 mm, which is the most economical way of working with curved laminated timber. **[12]**

27. Timber element after processing with CNC milling (Marks Barfield Architects, 2020)

CNC milling

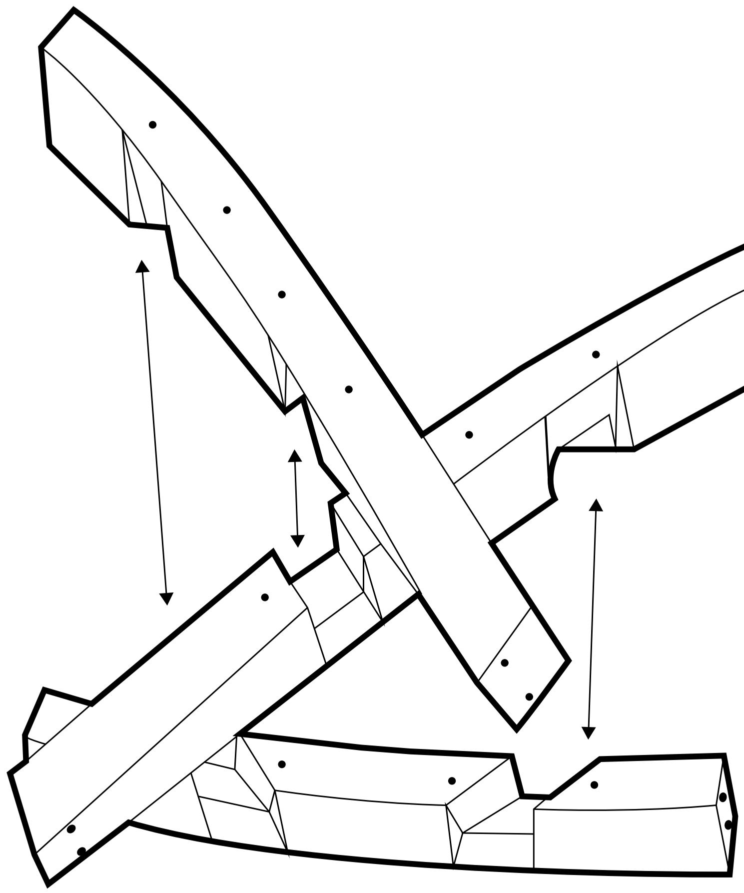
In order to produce the in total 2746 components that have 145 different variations, mass customization and high precision is needed. This is made possible with the use of CNC milling. It provides a solution for producing an unlimited variation of products with the accurcy needed, while being economically attractive.

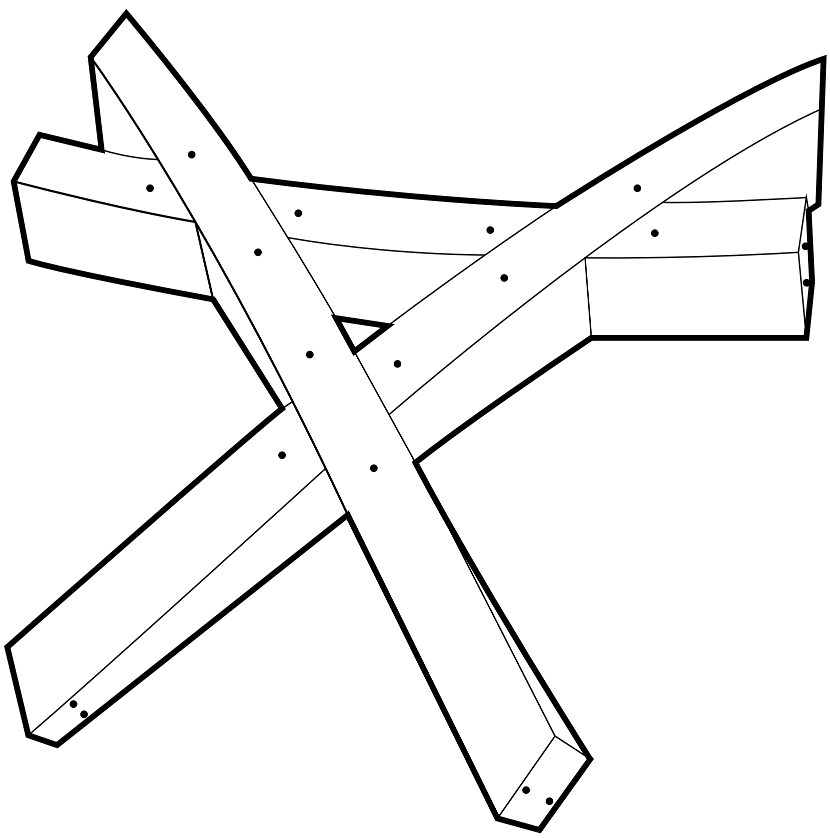
For the Cambridge Mosque, for which the structural timber elements are produced in Switserland, a CNC milling machine with three aggregates is used. Two can be found in the top, which is very useful for identiacal pieces. “We can use one aggregate to produce one piece and have the same NC-code at the same time producing the second part with the second aggregate.” **[12]** The third aggregate can be found on the bottom and makes it possible to process the timber from 6 sides, resulting in very high precision. **[12]**

Because all the elements are prefabricated, transportation is important to take into account. This causes for limitations in the element sizes for transportation. Preassembly is done as much as possible to to limit the amount of activities on site, but parts that are too big for transportation are assembled on site. **[12]**

Assembly

The separate parts are placed together in the correct sequence and with their interlocking parts in the correct position. The principlle of this approach is seen in the image on the right.





28. Assembly of the CNC milled elements


29. Timber structure element of Cambridge Mosque ready for transport (Blumer Lehmann AG, n.d.)

The benefit of CNC fabrication in the Cambidge Mosque

The use of CNC milling in this project made it possible to create a structure that is impossible with the use of manuel labour. In combination with parametric design it was possbile to create 2746 components with high precion in which 145 variations were needed. It provides a solution for producing an unlimited variation of products with the accuracy needed, while being economically attractive.

30. Cambridge Mosque interior (Wood Awards, n.d.)

Image
41. Wikihouse pilot project (urbanNext,2020)

Project
Wikihouse

Company
Wikihouse

Location
-

Program
Open source construction system

Image
42. CNC router, Wikihouse part fabrication (urbanNext,2020)

Design philosophy

The Wikihouse principle aims to create architecture that is available for everyone. The project approaches the design of a building as if one was designing with Lego's. To do this, Wikihouse uses opensource information. **[15]**

The design of the different parts of the buildings focuses on being cut able by a CNC machine, being lightweight and being cheap. The design of the structure is based on the principle of press fit assembly. This means that there is no glue involved when assembling the different parts. The result of this is a circular design that can be adapted

to the changing needs of the client. The goal is to create an architecture that is based on a social economy where people can build their own neighbourhoods instead of buying it from a developer.

The construction documents for Wikihouse parts are then free to download and can be adapted to the needs of the downloader. The opensource 3d models can be adapted with free software like SketchUp. **[16]**

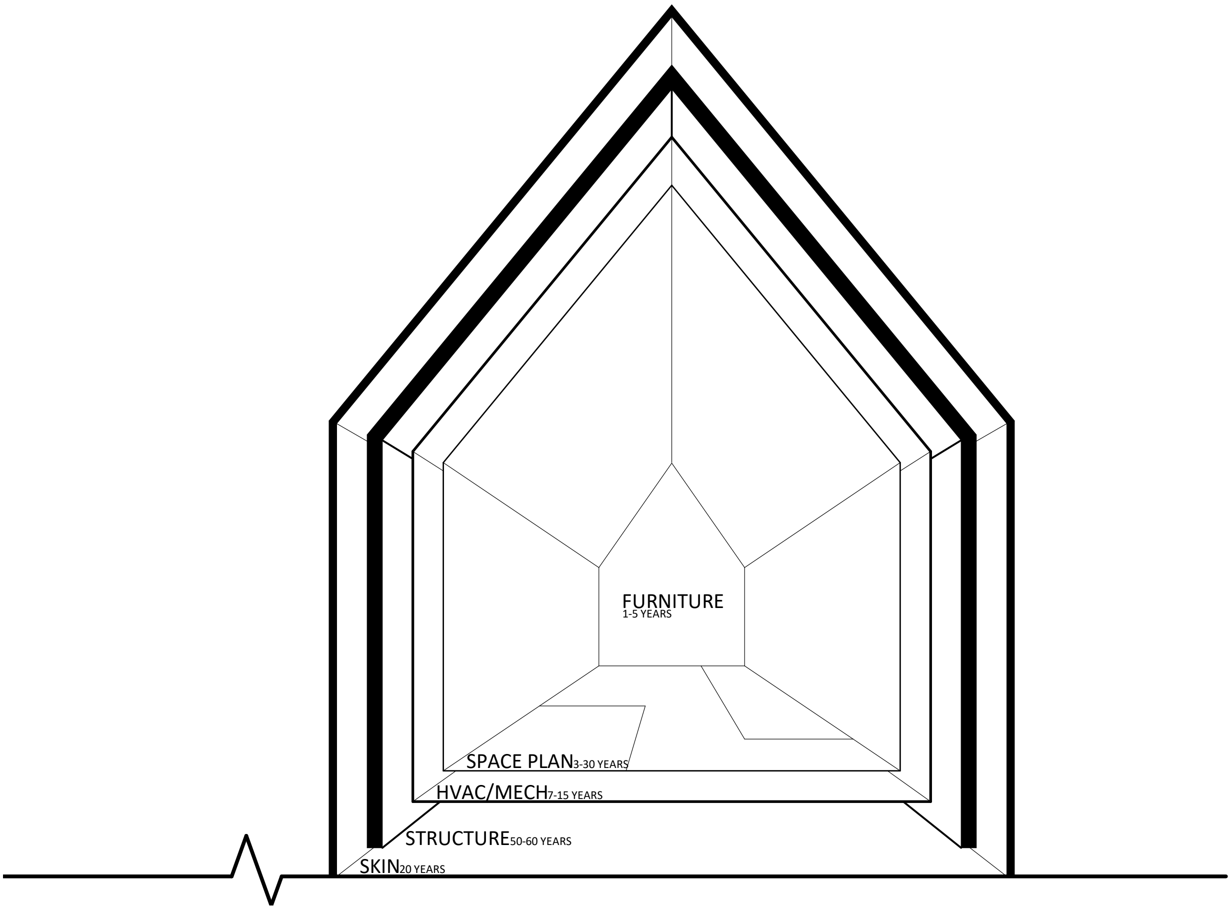


Image
43. Building layers

The design phase:
The design principle that is used by wikihouse Is based on the principle of design for manufacturing and assembly (DFMA). This means that there is a change in the process of “making a building.

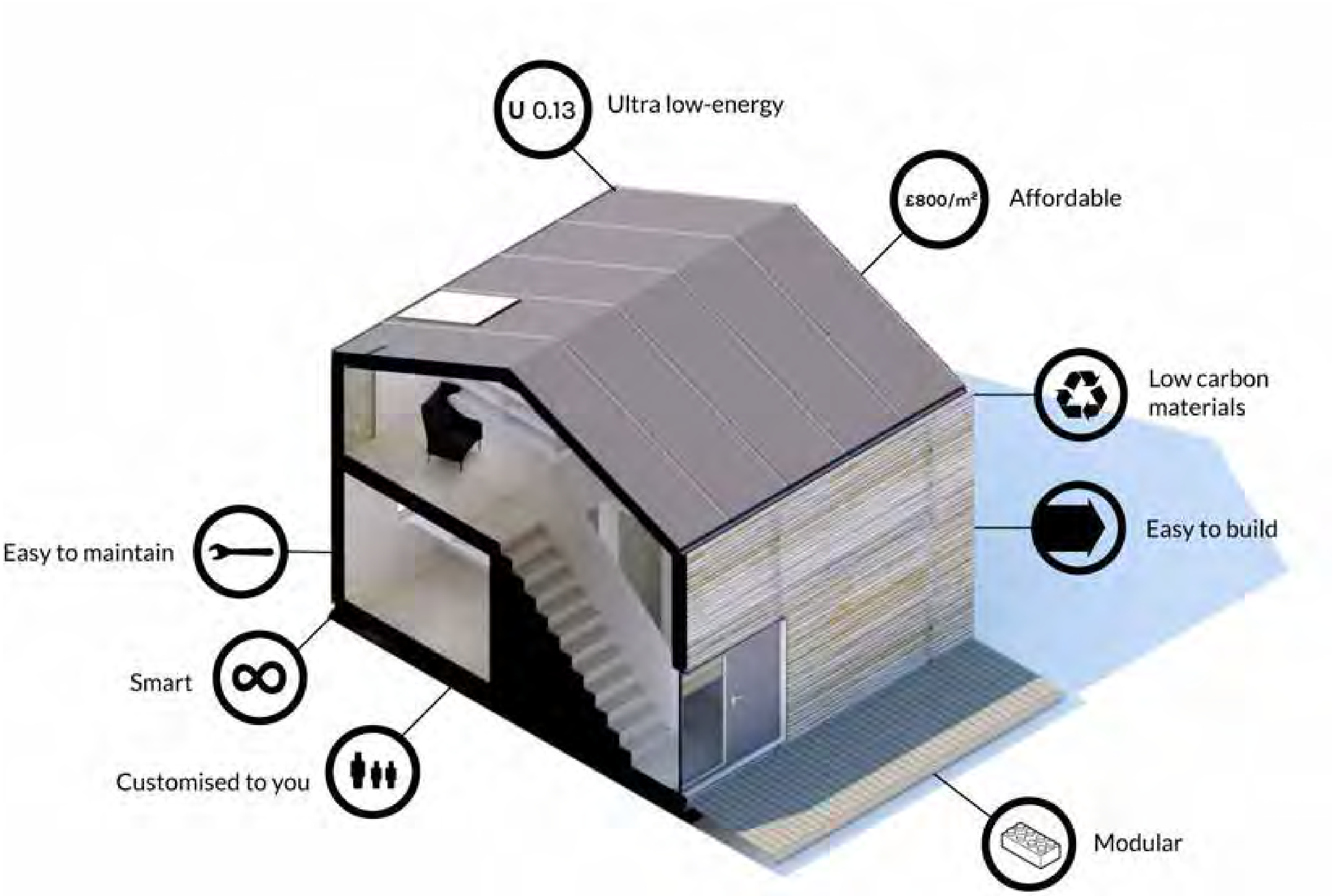
The approach that Wikihouse uses looks more like the process of making a car. In this process a material is transformed into a part on massive scale, after which the car is assembled. This means that the deign is divided into modular parts that can be produced with new technology and that can be tested in factories which will result in higher quality and less mistakes. Next to the car, IKEA is an important example of how DFMA is powerful in terms of making furniture available to everyone. Wikihouse aims to use this process in order to make buildings. The challenge with buildings is that it is not a one-size-fits-all product like a car. Wikihouse deals with this challenge by designing standardised building components like LEGO pieces that can be rearranged by the client making it possible to create unique individual buildings. This of course is limited to the margins of the parts that are available. Another benefit to using the standardised parts is that they can be replaced when needs change. **[15]**

When looking at the lifespan of a building, one sees that the building lifespan can be divided into layers. By using DFMA, these layers can be approached separately. This will make a building more flexible and sustainable. The design for manufacturing reduces costs, time, and material waste. The design for assembly reduces time, costs and the need of skill during the construction. It also reduces work on site and transfers the work environment to a safe factory environment. The design is made in digital software like BIM software that can produce the construction documents for the digital manufacturing. **[16]**

The fabrication:
Wikihouse aims at using web driven fabrication tools like 3D printers and CNC machines to fabricate the parts that are needed for the building.

The aim is to go from a centralised factory to smaller and local micro factories that can produce parts with CNC. Pilot projects of the Wikihouse already used these micro factory style CNC machines that will use CNC routing to cut parts out of 18mm thick plywood sheets. In general, these sheets will have dimensions of 1220x2440 mm. This size makes it possible to cut the parts with relatively cheap CNC machine setups. The CNC routing will cut the sheets from one side making it possible to use a 3-axis CNC machine router.

The G-code that is extracted from the CAD software is then loaded into the control panel of the CNC machine. This G-code defines the movement direction and speed of the router that cuts the part out of the plywood sheets. The key with this fabrication method is to find the right balance between speed and precision. Since the Wikihouse project is based on press fit construction, the parts need to fit together perfectly. **[17]**



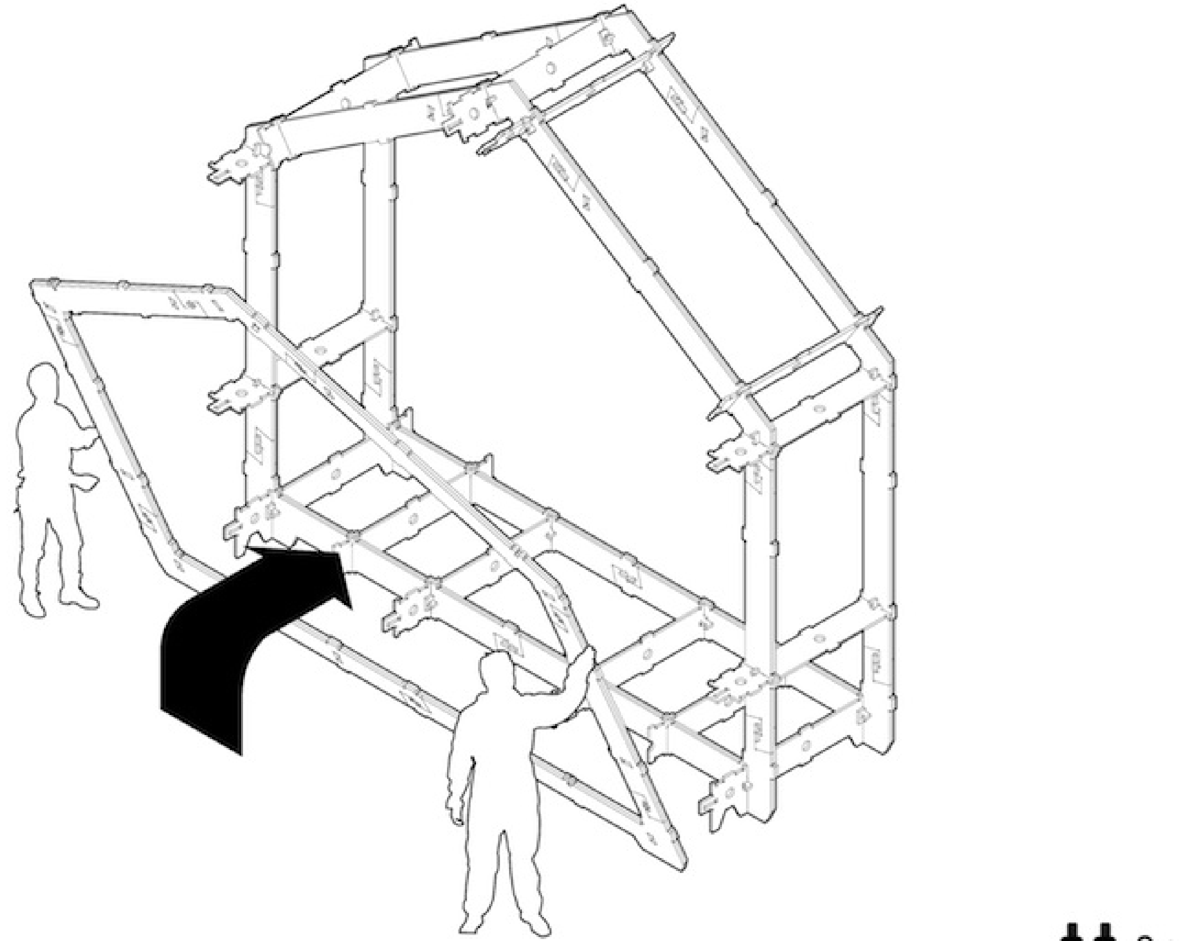
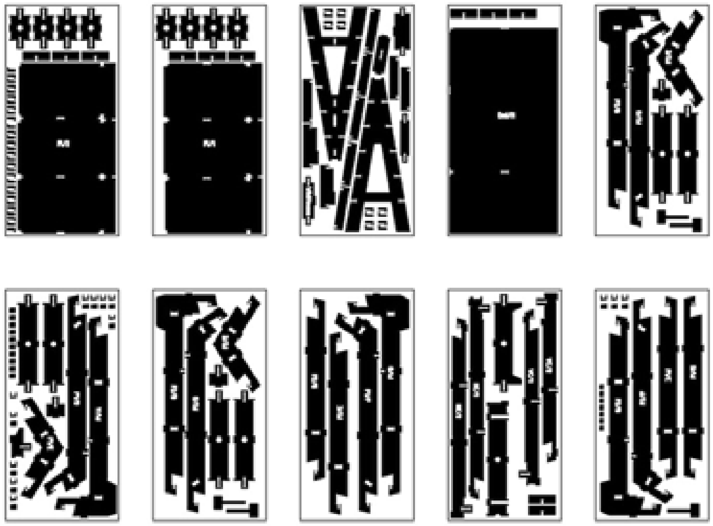
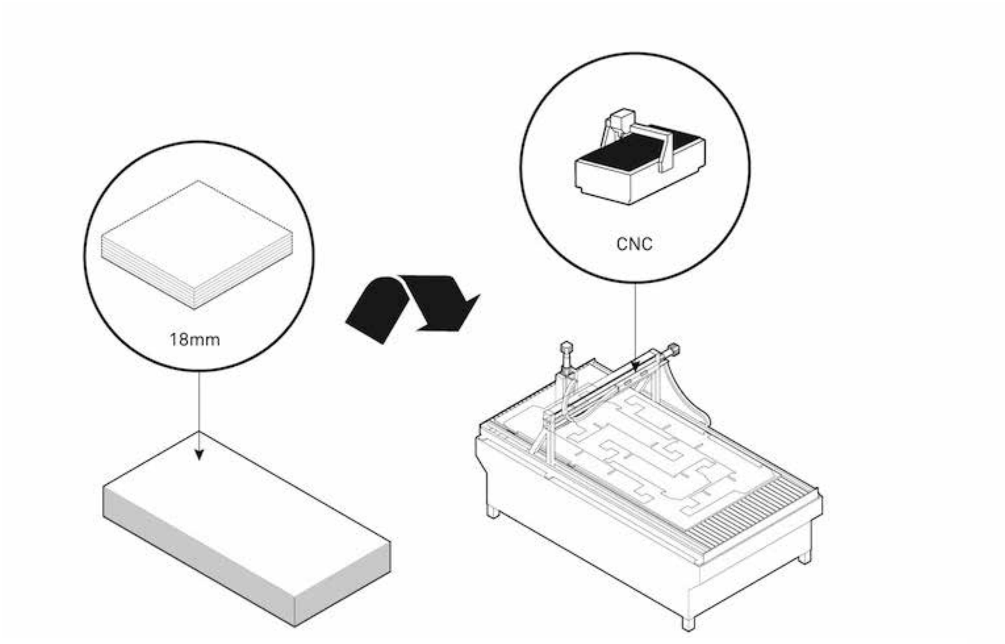


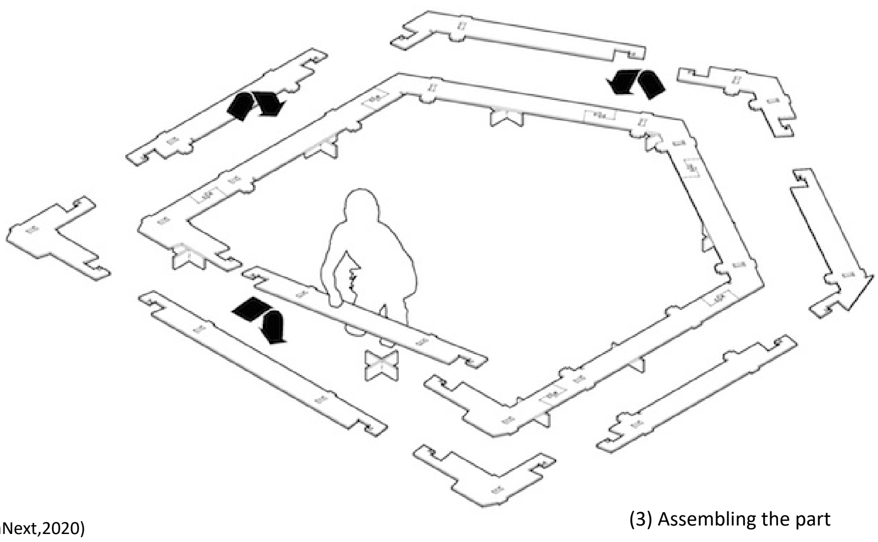
Image
44. Components & assembly of the Wikihouse (urbanNext,2020)



(1) Loading the cutting profiles



(2) Preparing the CNC router



45. Construction process (urbanNext,2020)

(3) Assembling the part

Image
47. Parts of a Wikihouse (urbanNext,2020)

The benefit of CNC fabrication in the Wikihouse concept

The benefit of using digital manufacturing like CNC in this project is that it decentralises the construction process. This makes construction accessible for a wider population. It reduces costs and construction time on site. Next to this, the Wikihouse is based on opensource information. This means that the design of the parts can be optimised by everyone. The Wikihouse uses new technological advances to change the conservative construction industry.

Image

48. Confluence Park River Pavilion (ArchDaily,2020)

Project

Confluence Park River Pavilion

Architect

Lake|Flato Architects & Matsys design studio

Location

San Antonio | United states

Year

2018

Program

Pavilion

Image
49. Confluence Park River Pavilion (ArchDaily,2020)

Design philosophy

The Confluence park pavilion is located in San Antonio, Texas and is the central outdoor classroom of the Confluence Park. The project was commissioned with three main objectives, the first was to create an educational environment where the community could learn about the importance of water in the regional ecosystem. The second objective was to create an architectural landmark that would upgrade the identity of the under-appreciated part of the city. The final objective was to fabricate the pavilion with a low budget.

Normally a building is designed to keep water away from its structure, in this pavilion the water should be directed by the buildings structure to a water reuse system. The design team came up with a design that is inspired by the water collection of a leaf. The double curvature of a leave makes sure that the tree can direct and collect water to their root system. In order to achieve the previously mentioned goals the designers had to rationalise the geometry of the pavilion to fabricate it.

The choice for concrete caused that the pavilion had to be divided into several parts that were more manageable during construction. Next to this, visitors of the pavilion had to be able to see the water running down into the funnels, this meant that architecturally, the pavilion could not be casted as a whole. **[18]**

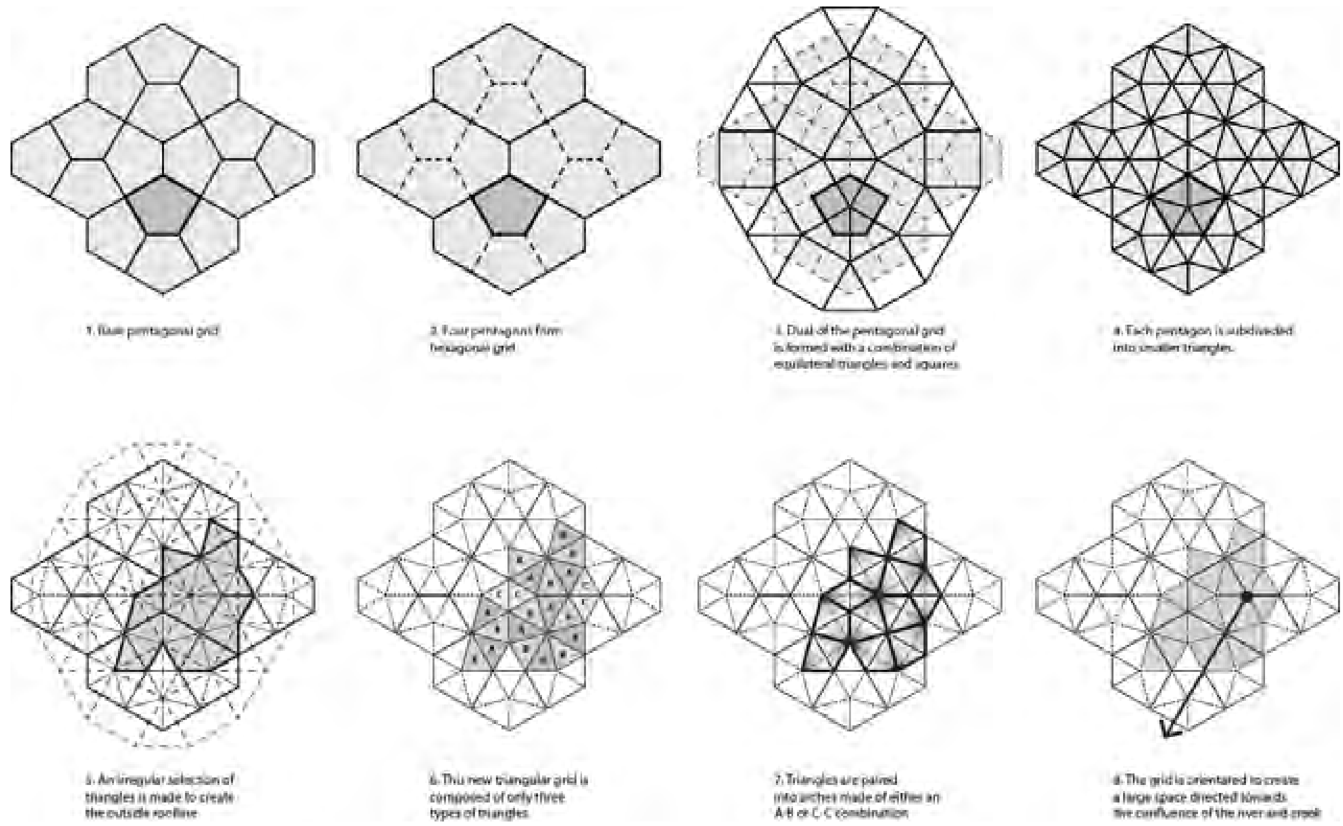


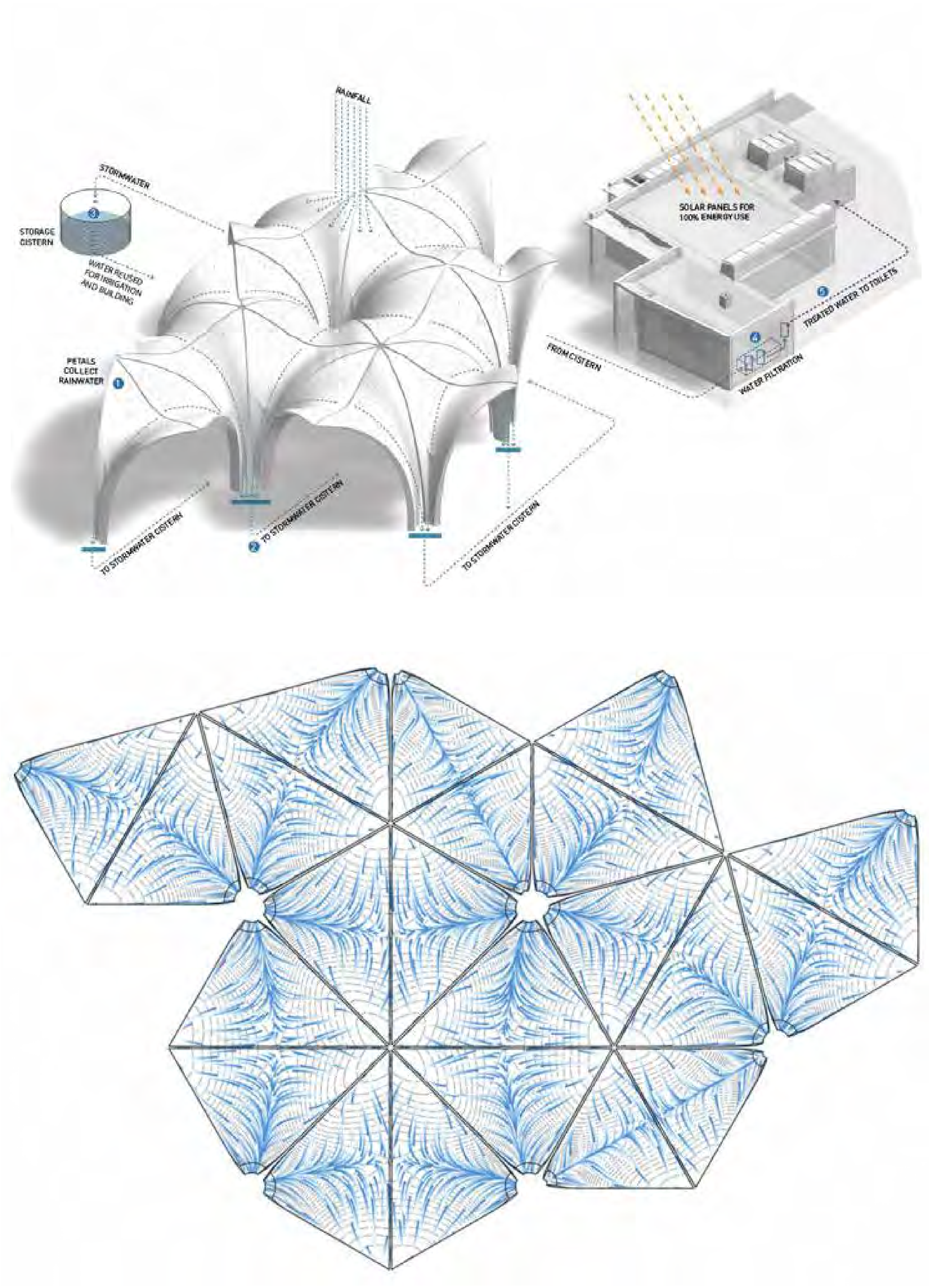
Image
50. Confluence Park River Pavilion grid options (ArchDaily,2020)

The design phase

Now that the concept was defined, the designers started looking for modularity in the design to keep the costs low while still creating a unique pavilion. Despite the search for modularity, the designers where not looking for a monotonous pavilion. The designers developed several grids where the repetitiveness of the parts, and the quantity where the key parameters. The aim was to reduce the amount of moulds needed for the fabrication to further lower the costs. The tension between a strict modularity and the design philosophy of randomness, led to the use of an irregular tilling grid (Image 50)
.
The final grid that was chosen led to 3 unique triangular roof shapes (A,B,C) that would be repeated to form the pavilion. The centre of where multiple triangles would meet, was designed to be a funnel trough which rainwater could be collected to be reused for the toilets. The final shapes of the triangular arches where tested by means of 3D models to see how much shade and how waterflows would work.

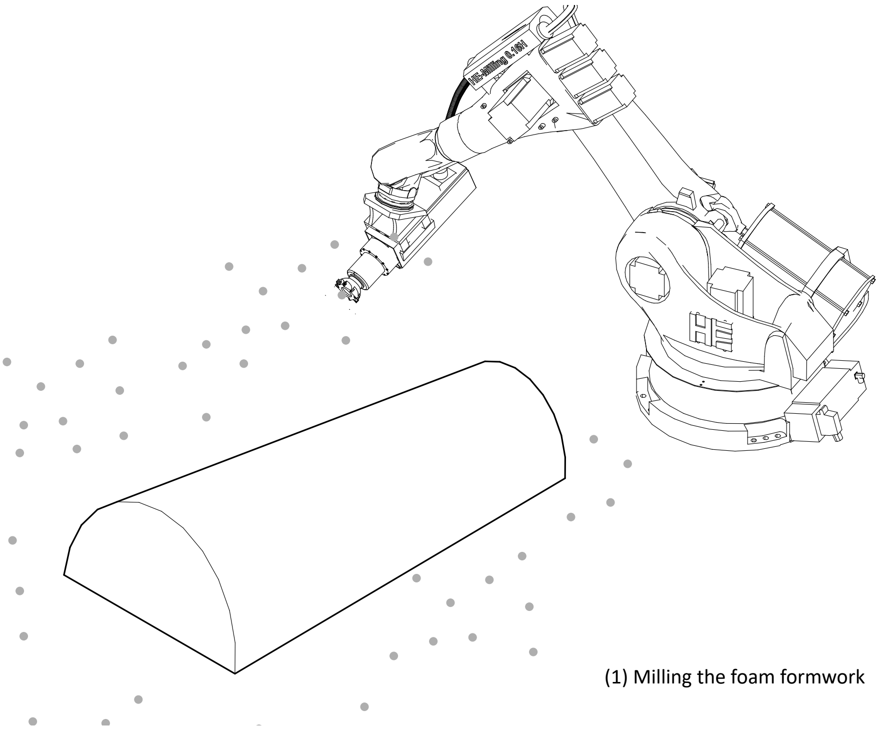
There were three main objectives for the curvature of the arches, first it had to be a double curvature due to structural reasons and to collect water. Secondly the thickness of the arch was variable according to the amount of coverage the reinforcement needs at specific points. And last the curvature should be continuous from arch to arch.

A rainwater collection simulation was made to test the waterflows to make sure water would not un in between the arches. **[19]**

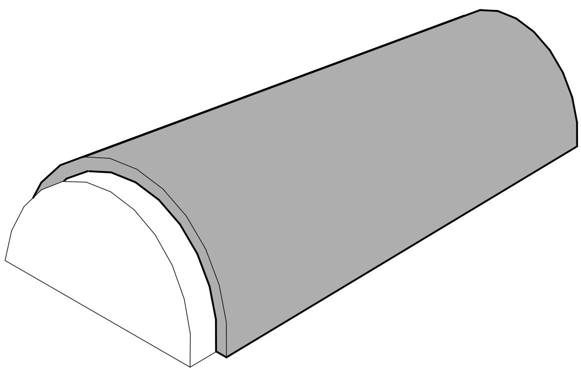


Image

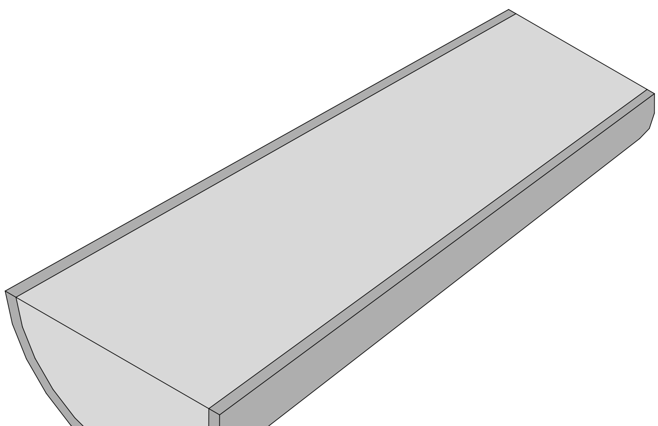
51. Confluence Park River Pavilion, Water management (Mark Lentzkow,2018)



(1) Milling the foam formwork



(2) Placing the fiberglass mould



(3) Pouring the reinforced concrete

52. Fabrication process

Image
53. Confluence Park River Pavilion, petal fabrication (Mark Lentzkow,2018)

Petal fabrication:

Once the shape of the concrete parts was defined the contractor calculated the pricing for wooden moulding of the different parts. This way of traditional fabrication turned out to go way over budget. After these first calculations the team decided to switch to means of digital fabrication for the moulding. The final choice was to make the formwork out of fiberglass. Fiberglass would meet the necessary construction tolerances and turned out to be more durable and could withstand multiple castings. **[18]**

The three unique formwork modules (A,B,C) were fabricated using five to seven axis CNC milling machines to mill the forms out of foam. After the milling of the foam, the fiberglass composed moulding with a core of balsawood was applied over the foam. The main benefit from this method is that the shapes that were milled where highly accurate and thus forming the perfect moulding for the concrete.

After the fiberglass moulding was complete the reinforcements where positioned and the concrete was casted into the formwork. The side that was casted on the fiberglass formwork had a smooth finish whereas the exterior side of the arches were exposed to air making it more rough. This makes the exterior concrete function like a canyon where water can run alongside the groove. Lastly the exterior was broom-finished in the direction of the waterflow, channelling the water down into the funnels.

After the concrete was fully dry, the petals where tilted up and placed in position to form the pavilion. **[19]**

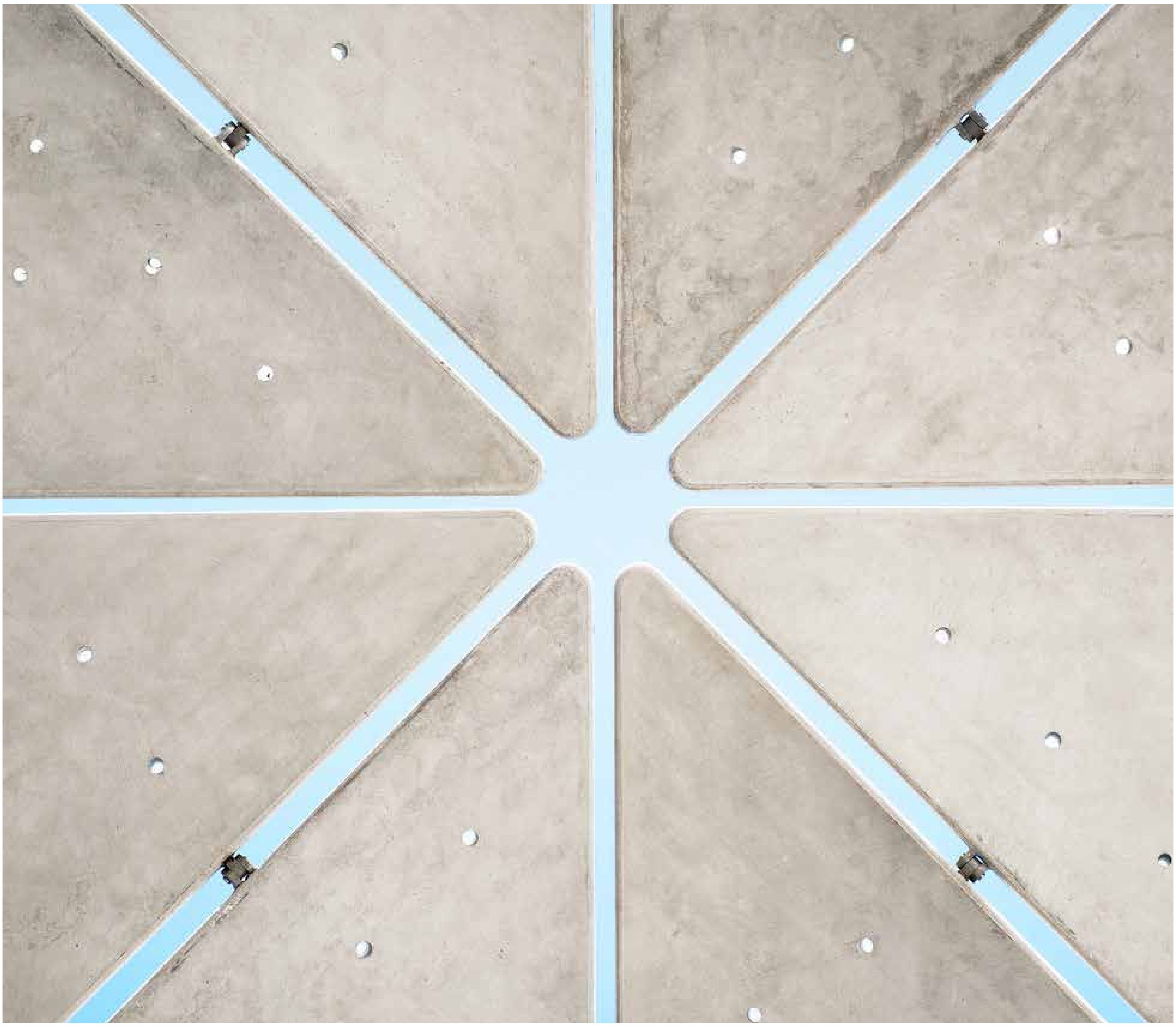
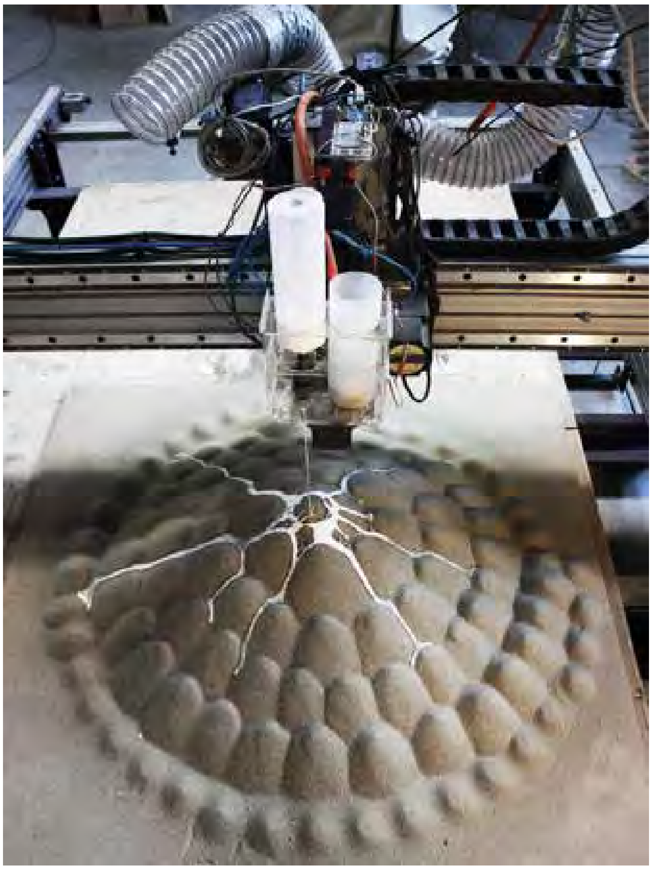


Image
54. Confluence Park River Pavilion (ArchDaily,2020)

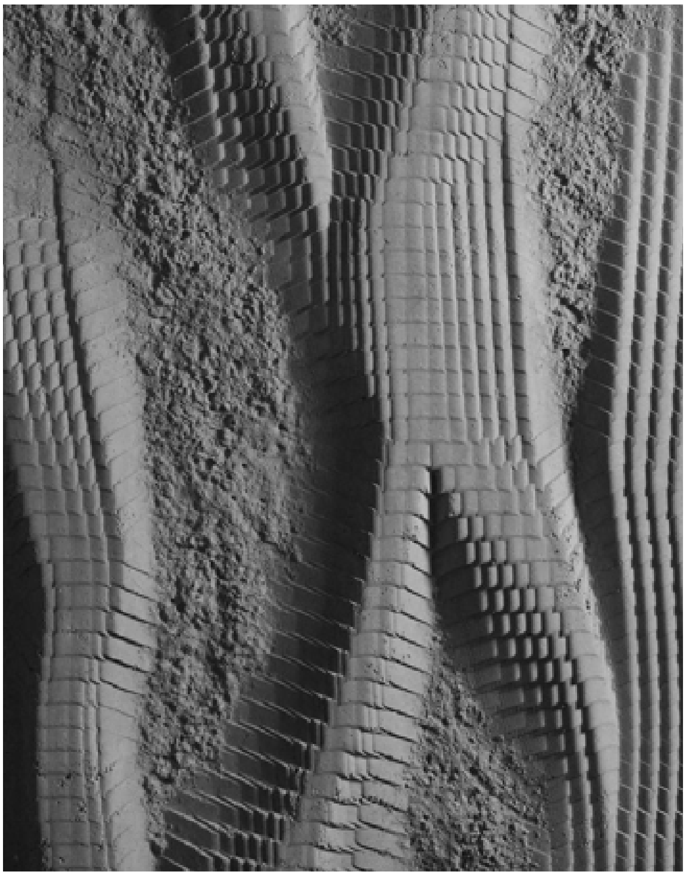
The benefit of CNC fabrication in the Confluence park pavilion

The main benefit of the digital manufacturing was that it made it possible to create an architectural landmark of complex geometry with a relatively low budget. In architecture it is often the case that the lower budget projects use traditional construction methods. This project has proven that digital fabrication like CNC can not only give architects a certain form freedom, but it can also reduce the cost of construction.

Image on the right
55. Confluence Park River Pavilion
(ArchDaily,2020)



56. ARE(A)NA sand moulding (Fabbots, 2012)



57. Procedural Landscapes 2 sand moulding (Gramazio Kohler et. al, n.d.)

Project
ARE(A)NA

Developed by students of
IAAC Barcelona

Location
Unbuilt

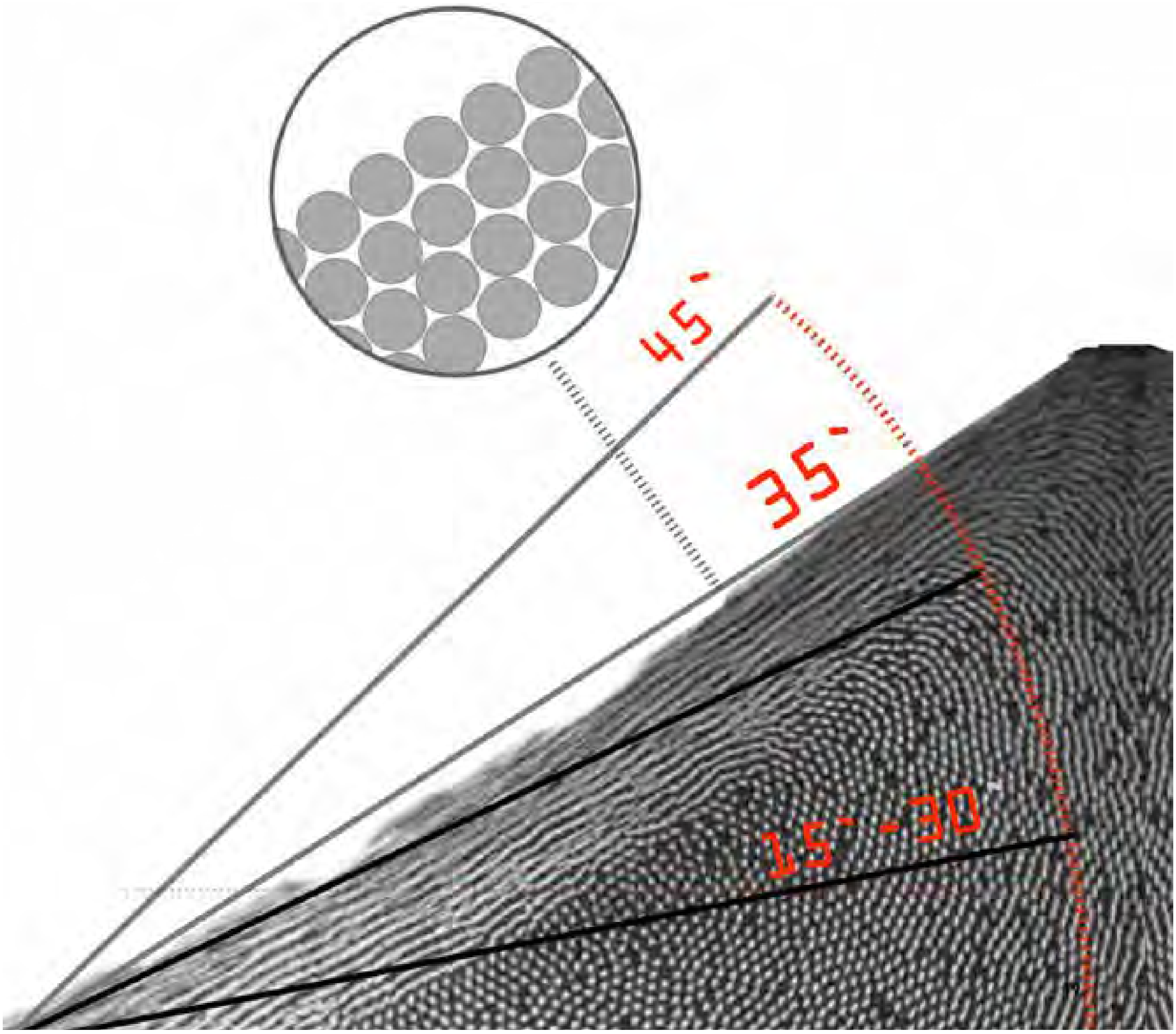
Year
2011

Project
Procedural Landscapes 2

Architect & Structural Engineer
Gramazio Kohler Research, ETH Zurich

Location
Zurich | Switzerland

Year
2011



58. The natural flow of sand forms piles of 35° in ideal condition due to self-organizational laws (Karakana et. al, 2011)

Design philosophy

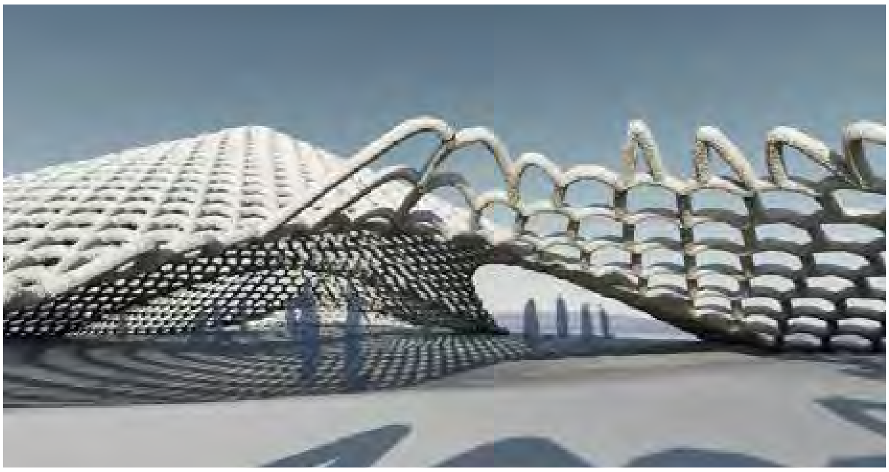
Formwork made by subtractive fabrication methods prove to be very efficient for mass production of identical parts, but are very wastefull when producing unique ones. The ARE(A)NA and Procedural Landscape projects both propose the use of granular materials, with in this case sand, as a reusable molding material to fabricate structures (ARE(A)NA) and elements (Prodcedural Landscapes). The moulding is created by the use of CNC, which is able to create the desired pattern or geometry by means of controlled process of sand collection and distribution.

Sand has been used for centuries to build structures, due to being abundant, cheap, natural and easily accesible. Now, with digital technologies available, the traditional material is used in combination with innovative and experimental approaches. Due to the fine grain of sand, it has the potential to create forms and patterns, which emerge from the interaction of the individual grains within the limits of the self-organizational laws. By letting the material define the parameters of the project, a highly controlled, yet very simple process is possbile, in which a limited set of rules enables for the exploration of many options. **[20]**

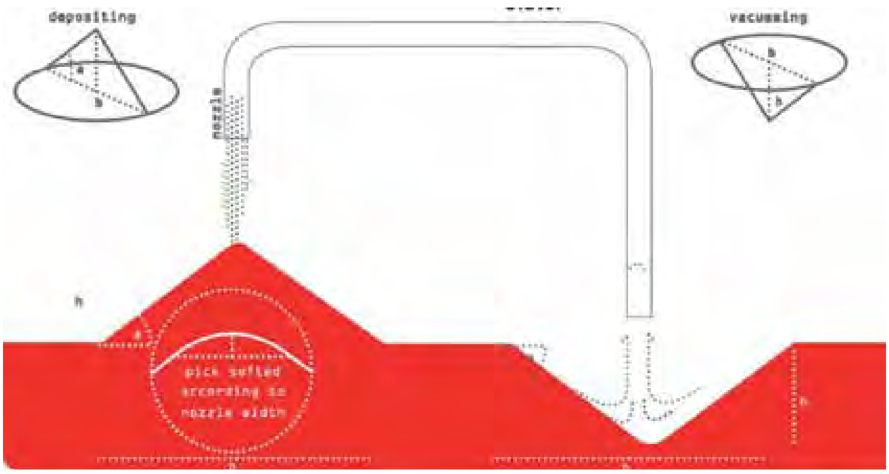
Procedural Landscapes 2

In the Procedural Landscapes 2 project, sand is used as formwork for the production of unique concrete building elements. Due to the use of sand as formwork, no additive nor substractive actions are required resulting in minimum waste. The sand is precisely controlled by the use of CNC, which makes it possible to create an unlimited amout of shapes within the self-organizational laws of the material. **[21]**

59. Procedural Landscapes 2 concrete element manufacuring with sand moulding (Gramazio Kohler Research et. al, n.d.)



60. Emerging structure when using ARE(A)NA production method
(Karakana et. al, 2011)



61. Method of creating sand pile moulding (Karakana et. al, 2011)

ARE(A)NA

The aim of the ARE(A)NA project is to numerically control the process of sand pile formation that acts as a mould to itself. CAD is used to configurate the sand piles and is translated into a g-code, meaning a sequence of computated point coordinates that can be directly fed into the machine. This process happens directly on site and involves a CNC controlled process of sand collection and redistribution, rearranging the environment into a configuration of piles and cavities. By neither adding nor removing material, the moulding appears from its direct environment. A liquid binder is poured on the uncohesive sand grains of the moulding, causing for solidifactions of parts of the sand. The sand and binder together form a structure upon drying, using the underlying sand as moulding. Given that only where there is a binder sand gets solidified, the rest of the sand acts as a temporal scaffold. When the loose sand is removed, inhabitable spaces appears magically on the ground. The geometry that is created is totally based on the self orginazational laws of the sand grains **[20;22;23]**

The most important advantages of using sand as a moulding material is the fast and low cost production method. The material acts as a mould to itself. Additionally, since it is all sourced onsite, the transportation costs are eliminated making it an economically and environmentally sustainable design solution. **[20]**

62. Moulding vs. structure (Karakana et. al, 2011)

The benefit of CNC fabrication in the ARE(A)NA and Prodcedural Landscapes 2

CNC is in these case beneficial for the production of moulding while minimizing waste. The sand can have an unlimited amount of shapes and configurations within the self-organizational laws of the material. These shapes present unique formwork options for panels or even structures.

63. Lab experiments (Karakana et. al, 2011)

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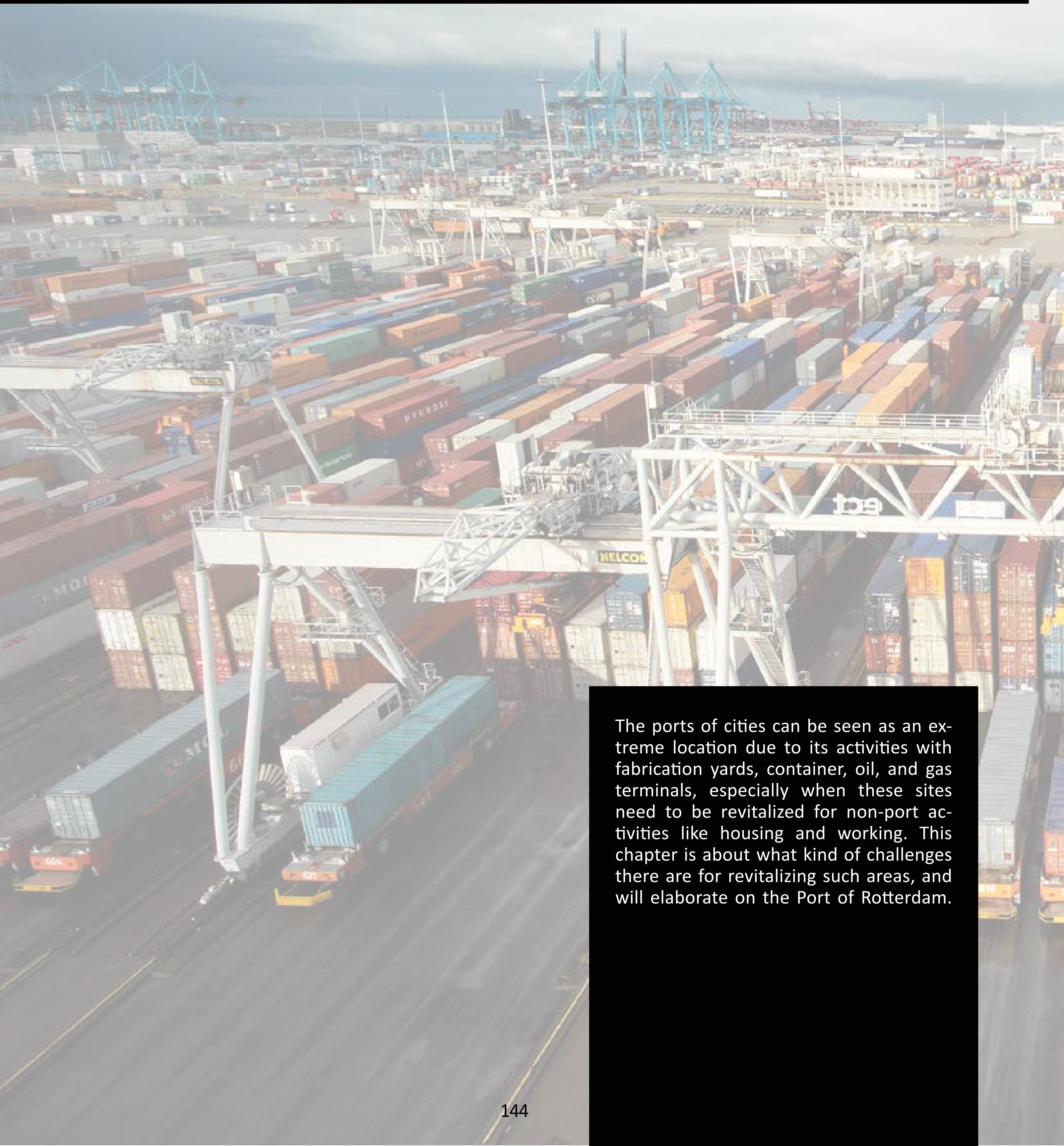
ROTTERDAM

ANALYSIS

PORT ARCHITECTURE

Collective research conducted by Nick van Slageren

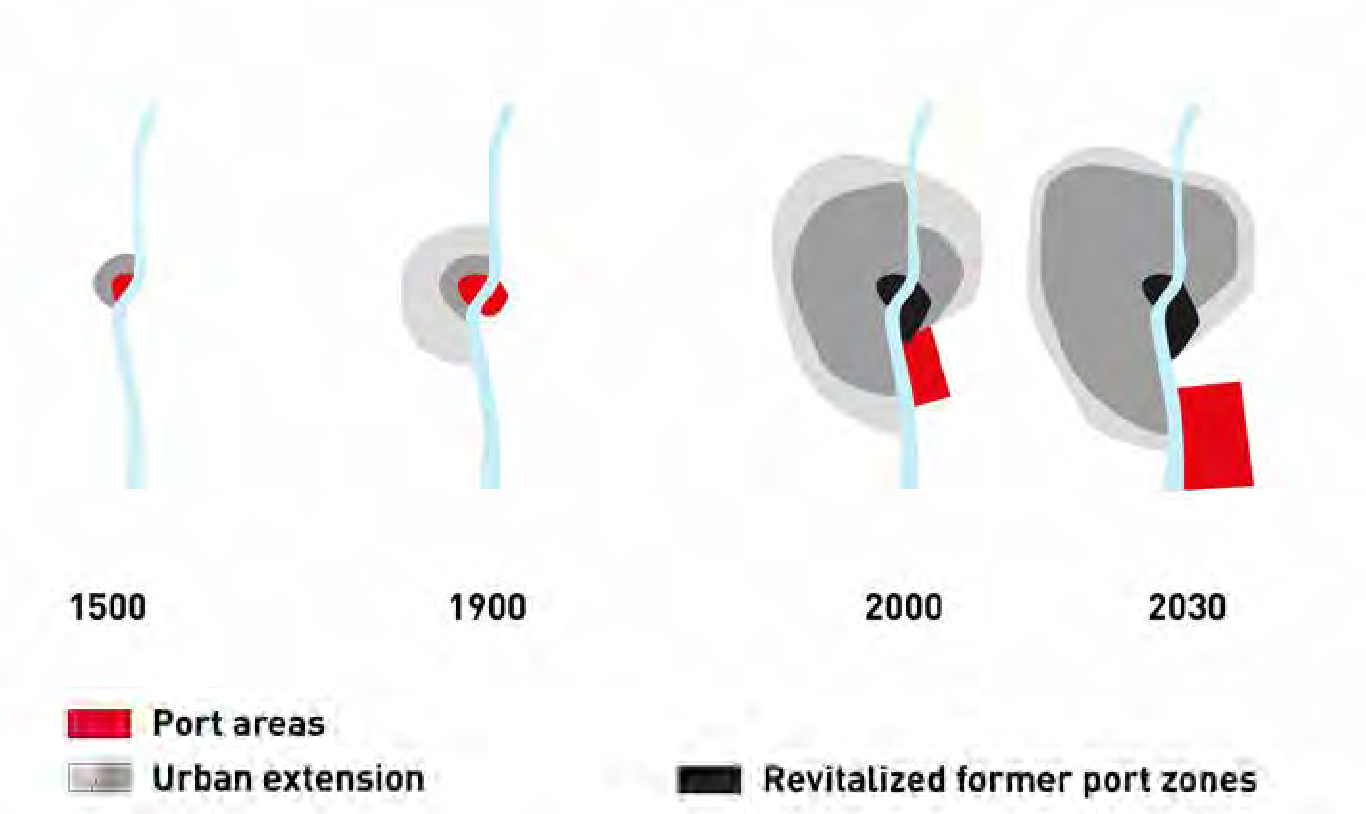


The ports of cities can be seen as an extreme location due to its activities with fabrication yards, container, oil, and gas terminals, especially when these sites need to be revitalized for non-port activities like housing and working. This chapter is about what kind of challenges there are for revitalizing such areas, and will elaborate on the Port of Rotterdam.

E.1 Container terminal of the Port of Rotterdam

Port-out City-in

Port cities like Rotterdam are crucial nodes for the global supply chains and linking the production centers to consumers. In the recent decades the ports of cities are affected heavily due to the growing demands and globalization. Ports all over the world are restructured time over time due to the economic and technological changes. They are constantly expanding and distancing themselves away from the city. Especially during the second half of the 20th century when the demands for containerization of maritime cargo and the requirement of new, larger terminals became higher and higher and therefore ports had to expand faster than ever. This historical development of city port is shown into the abstracted diagram below. It shows how the "primitive" inner-city port of 1900 is transformed towards highly modernized complex industrial sites that are being removed from the inner cities. The former locations are revitalized overtime.



E.2 Historical development of port-cities based on (Sanchez, 2019)

E.3 Figure on the right | Redevelopment of Katendrecht in Rotterdam

Canary wharf london

An example of port renewals is the “Canary wharf” in London. This former area, The London Docklands, was back in the days of the British empire the largest port in the world. In 1969 the docks were closed due to their small size and difficult labour relations. In 1981 the Britsch central government decided to redevelop the area for housing and working. In a time, frame of 20 years the former docklands were transformed into a dominating financial hub which changed the face of London completely. Canary Wharf is now known as the largest urban redevelopment project in Europe.

E.4 The London dock’s around 1900

E.5 Canary wharf revitalized

E.6 Canary wharf revitalized

E.7 Former port area in Helsinki

Port of Helsinki

Most port cities start to rethink the relationship between port and cities, also Helsinki. Major changes like the relocation of the main industrial port facilities have been made. Nowadays the inner-city port is a crucial infrastructure for trade and passenger traffic. Already in the 1970's started the redevelopment of the waterfront of Helsinki. Since 2008 a masterplan is made for transforming the former port areas into a mixed-use neighborhood that keepis the passenger traffic port activity. This plan will ensure in the future housing for 30.000 residents and 20.000 workplaces.

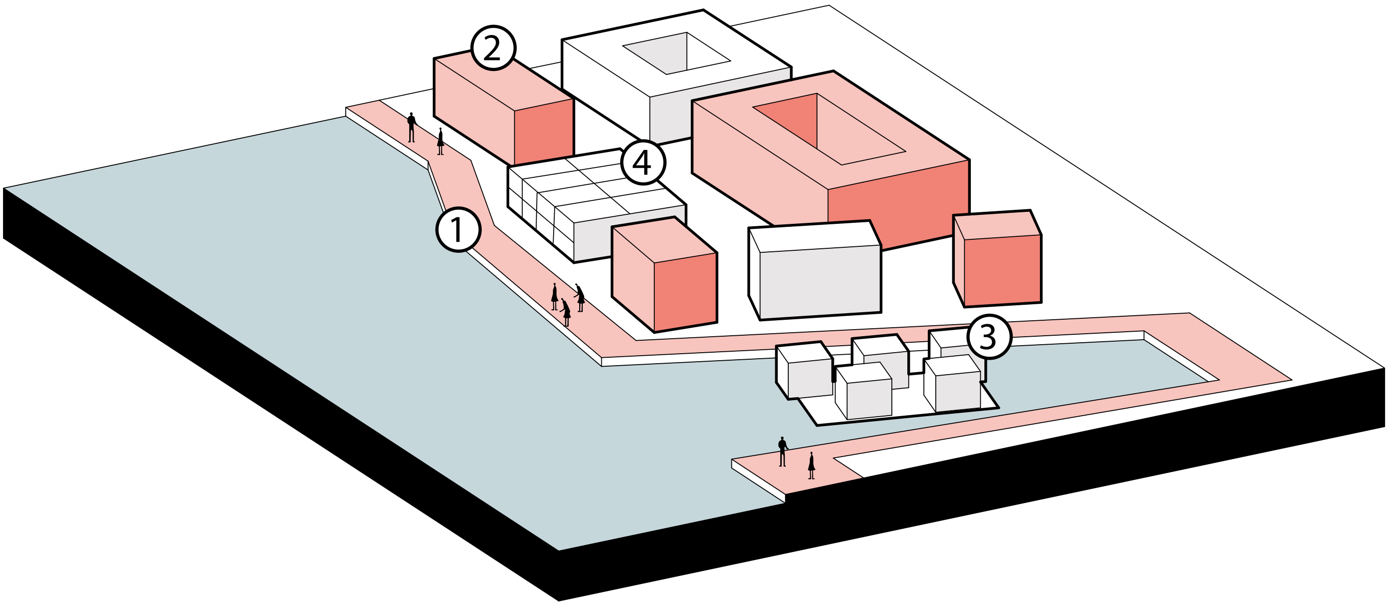
E.8 Visualisation of the masterplan

E.9 Visualisation that shows how passenger traffic actvities are combined with city functions

Guidlines for a redevelopping port wastelands

Around 30 years ago, port wastelands began to appear in the inner cities. The main reason, therefore, was that port activities had to be relocated due to the shift to container traffic. Port cities saw the opportunity to renew those areas for more non-port activities. But still, until today there is much debate on how to redevelop port wastelands for the future. Some port cities develop the new port facilities outside the city, which create a clear separation between port and city function. However, other port cities try for new strategies that consist of a balanced mix and integration of port and city functions. (AIVP,2015)

AIVP is a worldwide network of nearly 200 port cities. They support other cities to help them with facing the challenges of redeveloping port areas with newly implemented strategies. In the research document "Plan the city with the port" they formulated guidelines to provide decision-makers and stakeholders with a support tool for addressing the challenges. The guidelines that are focused on the spatial aspect are summarized in an abstracted way in the diagrams below.



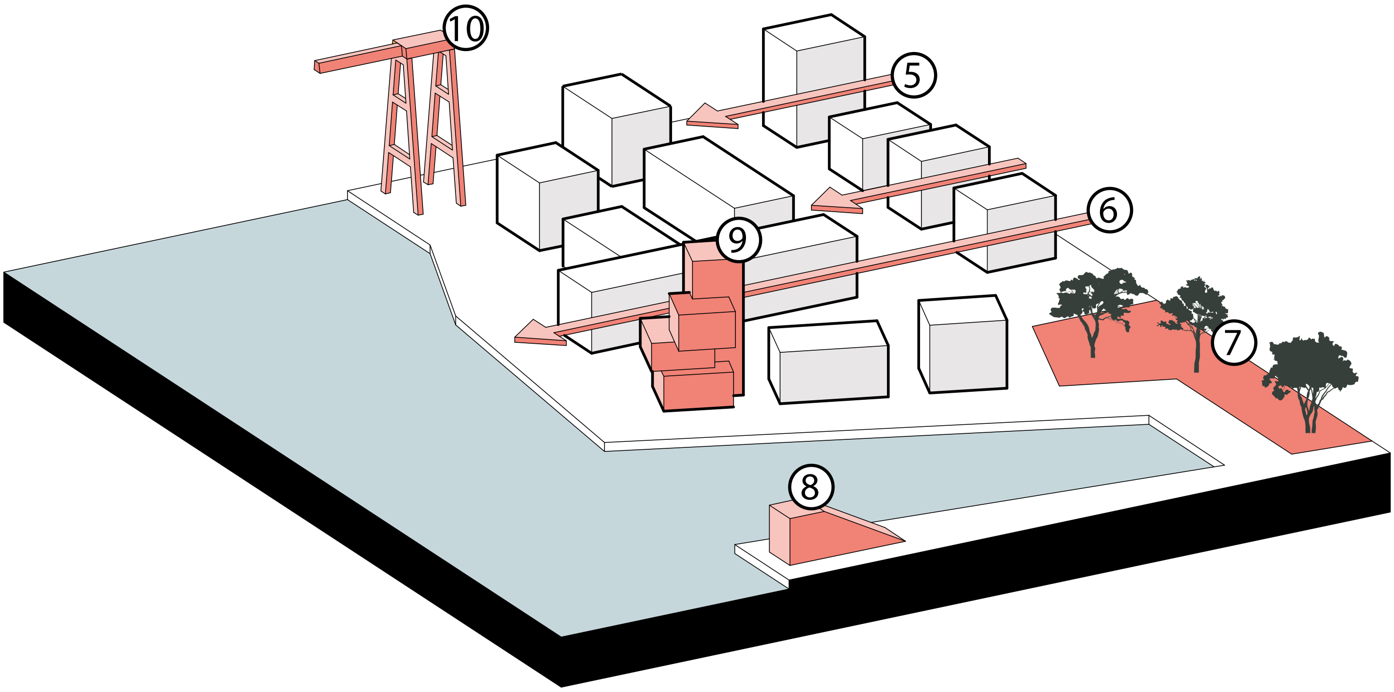
E.10 Guidelines

1. Share the use of the water and waterfront between urban and port functions.

2. Mix of urban and Port functions. This can be done in a horizontal or vertical way. It will reinforce the area's identity and its attractiveness, both to economic stakeholders and to the general public.

3. Move the city to the water, such as floating restaurants and housing boats. In many cases they help reconnect the city to its port and help to create a lively waterfront.

4. Remain flexible and avoid freezing land uses. The urban plan can adapt to the changing need in the future by using more modular or prefabricated buildings which are easier moveable.



E.11 Guidelines

5. Highlight and improve the transitional elements between city and port. Better connections can be made with bridges, footpaths, etc. Careful choices on materials and visible elements need to be made for creating an interesting transition between the two different areas.

6. Conceive a type of spatial organization which allows or preserves scenic views of the port and the water. Factors that can be altered for optimizing the views are empty spaces, visual perspectives, buildings heights and volumetric shapes.

7. Create green buffer areas. This allows the and port to coexist easier next to each other and provides more living space.

8. Showcase port city landmarks and scenery with special viewing platforms.

9. Put an emphasis on architectural / sybolic elements

10. Preserve port elements like cranes which enhances the identity of the area.

What are the challenges for transforming a port?

A city port with a mix of urban and port functions creates challenges that need to be solved, especially the ones that are environmentally related. The urban plan needs to be carefully designed. Problems can arise by not taking care of how new connections between port and city functions are made.

Noise

It is important to take into account the noise from the remaining industry when creating mixed function areas for working and living. Also noise disturbance can arise from docking containerships. Challenges have to be solved on how the noise disturbance of port areas next to urban functions can kept to a minimum.

Air

Good air quality is important for the health and livability of the redeveloped port areas. The degree of nitrogen dioxide (N2) and the particulate matter (PM10) are important such areas and indicate how healthy the environment is.

Soil

The soil quality is essential when revitalizing areas from industrial to urban activities. There is a higher chance that the soil is polluted due to the port activities. Also, most industrial sites contain lower soil quality, which isn't suitable for housing.

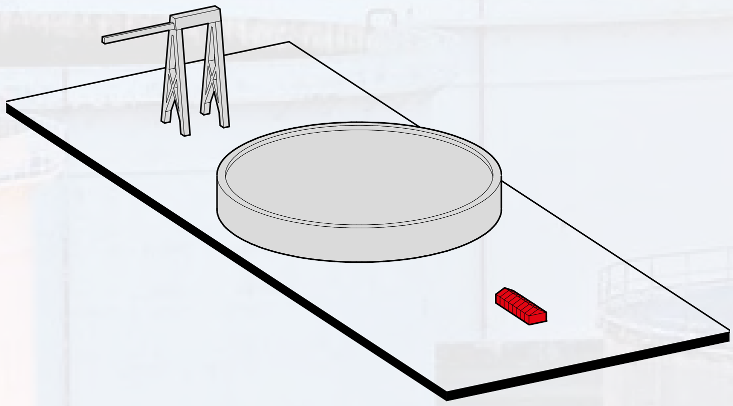

1122

Overflooding

Ports are placed outside the dikes. This means that these areas have a higher risk for overflooding. Typically such sites are raised and will not have problems with overflooding. Due to climate changes, the risk for overflooding becomes more significant due to higher sea levels and more extreme weather.

Scale

The differences in scale between port and city functions are extreme. The figure below is a comparison made between a crane (height of 60m), Oil silo (diameter of 85m and a height of 22m), and eight stand row houses. Therefore, the human scale becomes an essential aspect of revitalizing such sites.



E.11 Oil terminal in Rotterdam

A.12 Largest containership docking in the Port of Rotterdam

Port of Rotterdam

We now take a closer look at the Port of Rotterdam, which is also the area that is going to be researched for the graduation studio Xtra Big House.

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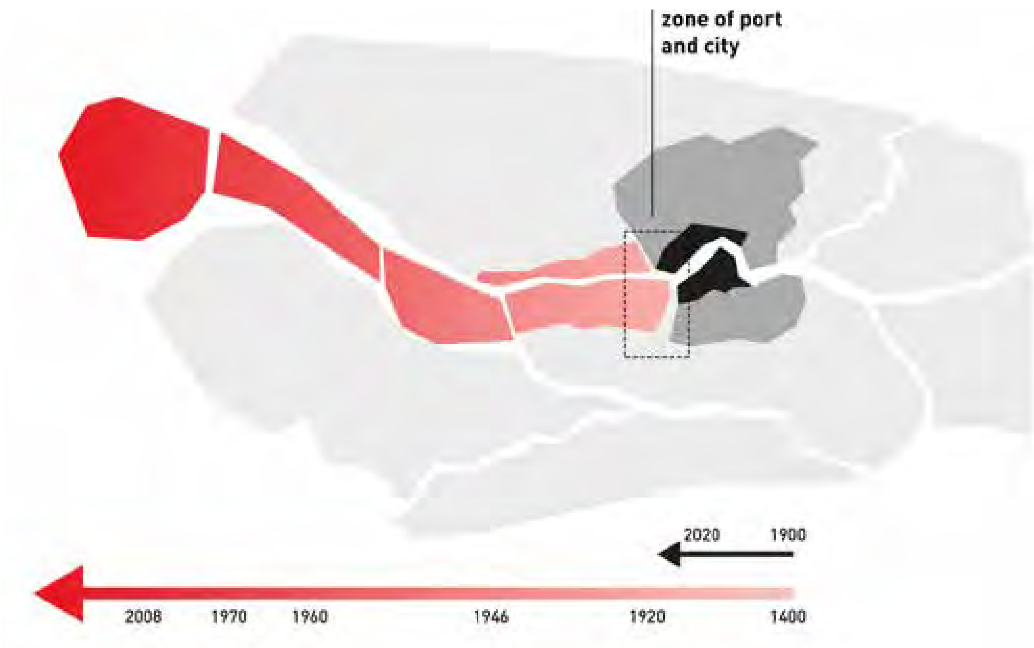
The Port of Rotterdam is still today the largest port of Europe with a length of 40 km. It consists of multiple harbour basins with industrial terrains that ensures the supply and disposal of (petro) chemical and the storage/transhipment of goods. The Port of Rotterdam is quite busy. In 2018 467.354 million metric ton on goods and products stored and around 80 thousand ships are docking every year. This gives a good idea on how massive the Port of Rotterdam is.

The figure above is a schematic overview of the Port of Rotterdam. The port consists manly out of five large areas: Eemhaven & Waalhaven, Petroleum haven, Europoort, Maasvlakt and area with a collection of smaller ports. Each area has its focus on different activities.



The port of Rotterdam is through time expanded to the west coast and had eventually to build a new island, the Maasvlakte 1 and 2 in the North Sea, to expand even more. The general theory of Port-out and City-in, which is shown in the first paragraph, is also visible in the Port of Rotterdam. Rotterdam is moving their port activities away from the city and is revitalizing the inner-cities port for new and non-port activities. This is the black highlighted areas in the diagram. For most port-cities and also for Rotterdam, have still tensions between port and city functions. This creates a transition zone, which is marked in the diagram. The municipality has to decide on how to make these areas future proof. Will it keep the port functions, or will it be devoted to housing and working?

Port of Rotterdam
Historical background

The first existence of the Port of Rotterdam starts around 1250 alongside the river the Rotte. This is also the reason why the city is called Rotterdam. The port was very small and was meant to transfer goods with the nearby market and resulted in a faster-growing city. Around the 17th century, the port became the most important place for fishers.

In the second half of the 19th century were important developments made that can be seen as the start of how Rotterdam became the biggest port in the world. Lodewijk Pincoffs saw the possibilities for transforming the fishing port into an international city port. New developments were made for ports, quays, warehouses and sheds alongside the river “Nieuwe Maas” on the island Feijenoord.

Due that Rotterdam not is located next to the sea, but alongside a river, was making it more and more difficult for bigger ships to reach the city. When an important waterway was silted up, a new channel was made in 1866 and called “De nieuwe waterweg” which created a direct connection with the sea.

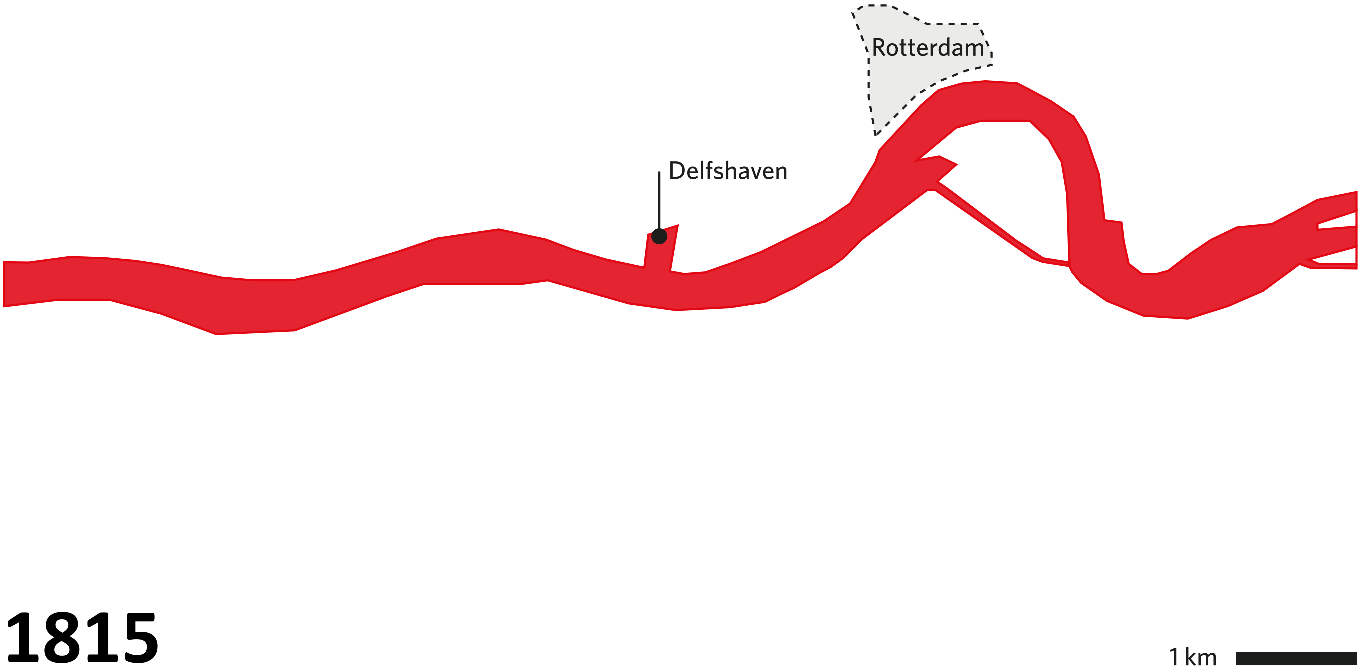
In the 20th century, the port of Rotterdam was totally modernized and became one of the most important transit ports of West-Europe. The whole city began to grow towards an inner-city with stately buildings with a strong appeal. But the second world war changed Rotterdam heavily. More than 50% of the ports were damaged due to the bombings. The reconstruction of the port lasted until 1950. De-

A.13 Photo's of the Port of Rotterdam in different times.

spite this, the recovery of trading in the ports went quickly also due to the German industry, which also began to recover. Already in 1950 expansions were needed to along with the growing demands. This was the start of Eemhaven and the Botlek which were developed on the west side of the city. In the following decades, the port had to expand more and more also due to the large ships which supplied the city of Rotterdam with oil. The areas which are called "petroleum haven", "Europoort" and the "Maastvlakte 1 and 2" completed the Port of Rotterdam..

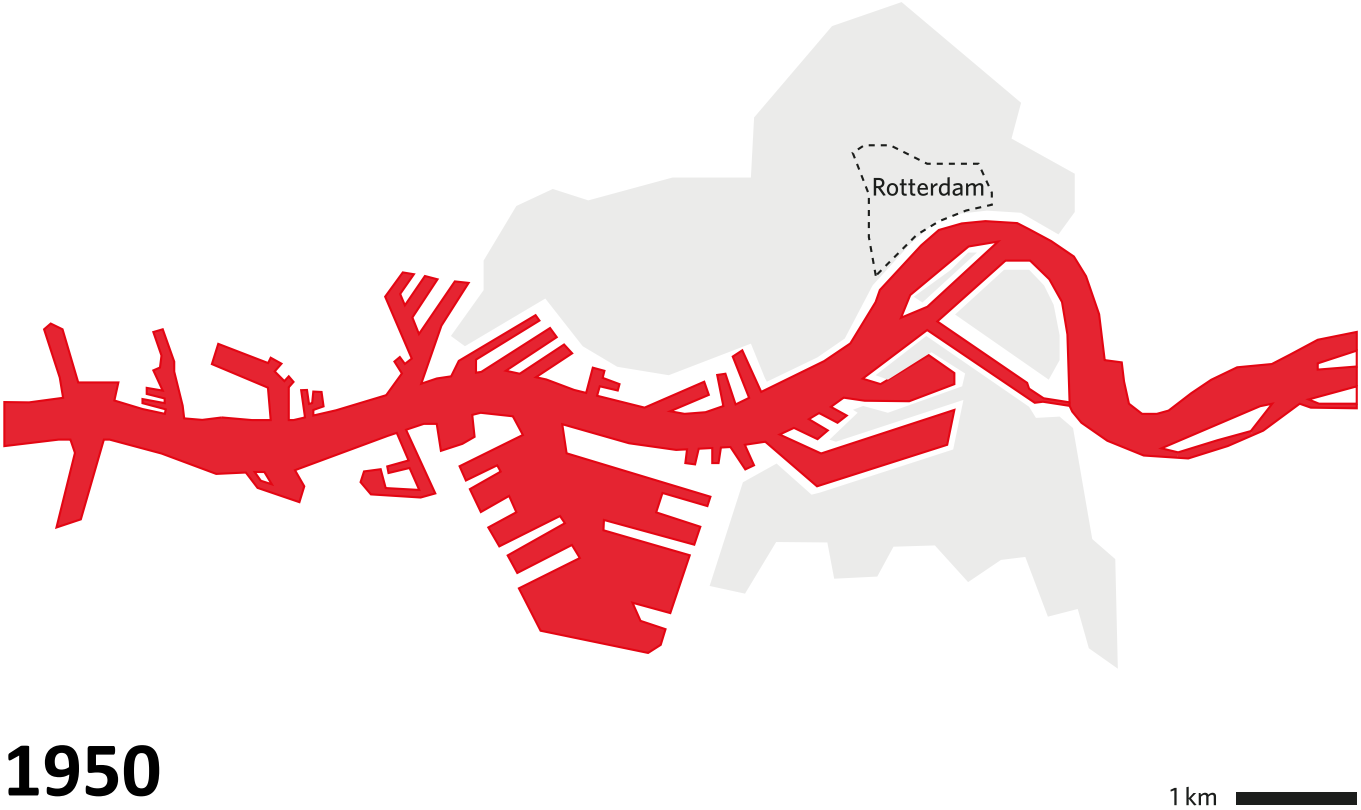
Port of Rotterdam
Development

In the following diagrams is in further detail the development of the port of Rotterdam visualized, for this are the periods of 1815, 1915, 1950 and 1975 chosen. It's becoming clear that Rotterdam extended the port with multiple quays and eventually past Delfshaven grew.



1815

E.19 Development

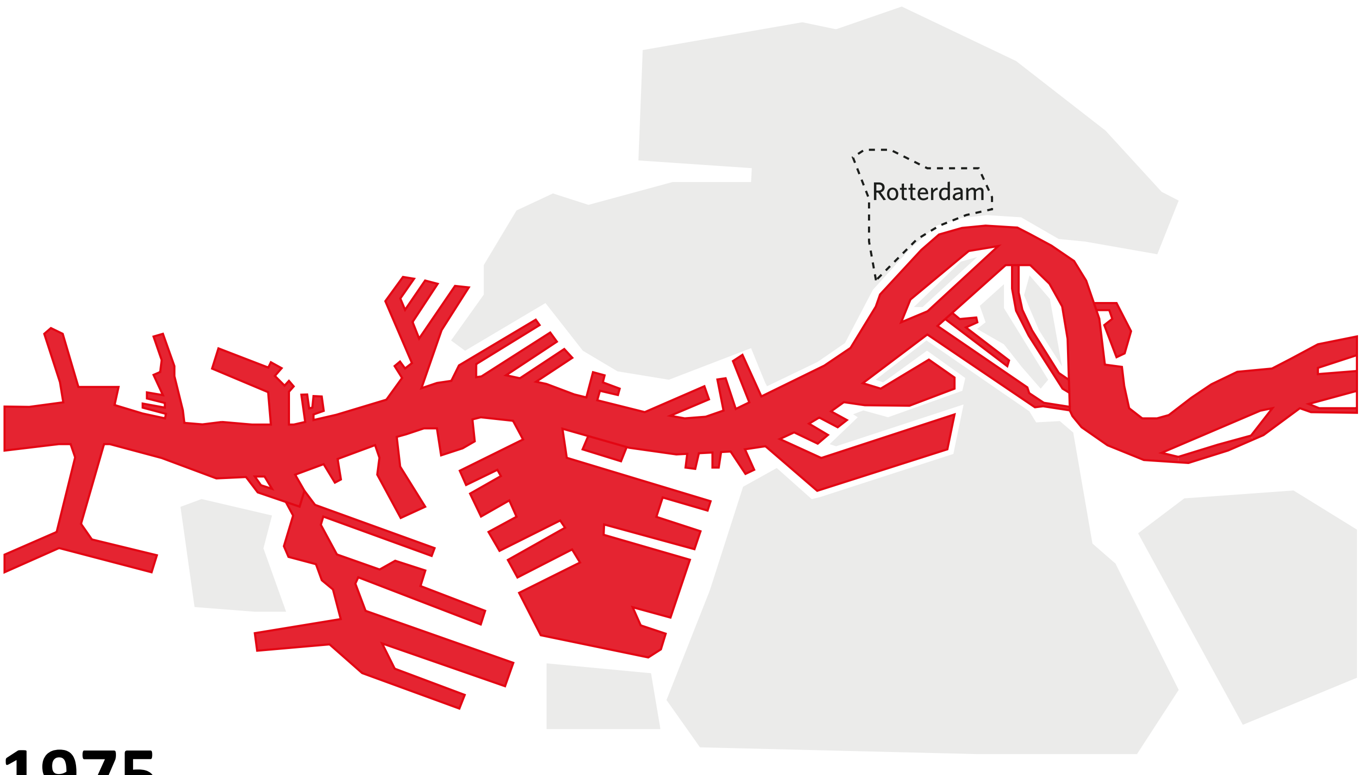


1950

E.20 Development

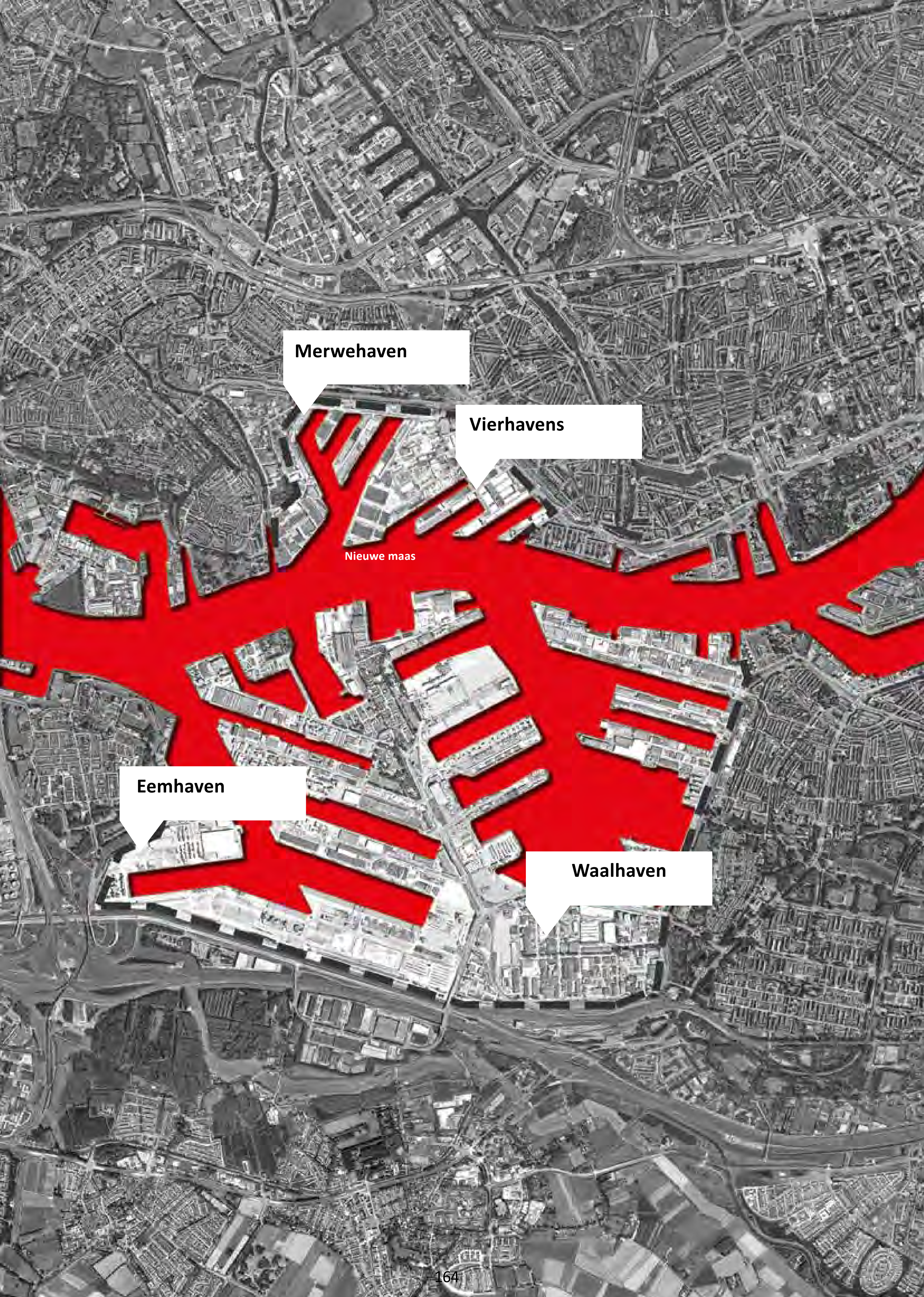
1915

E.21 Development



1975

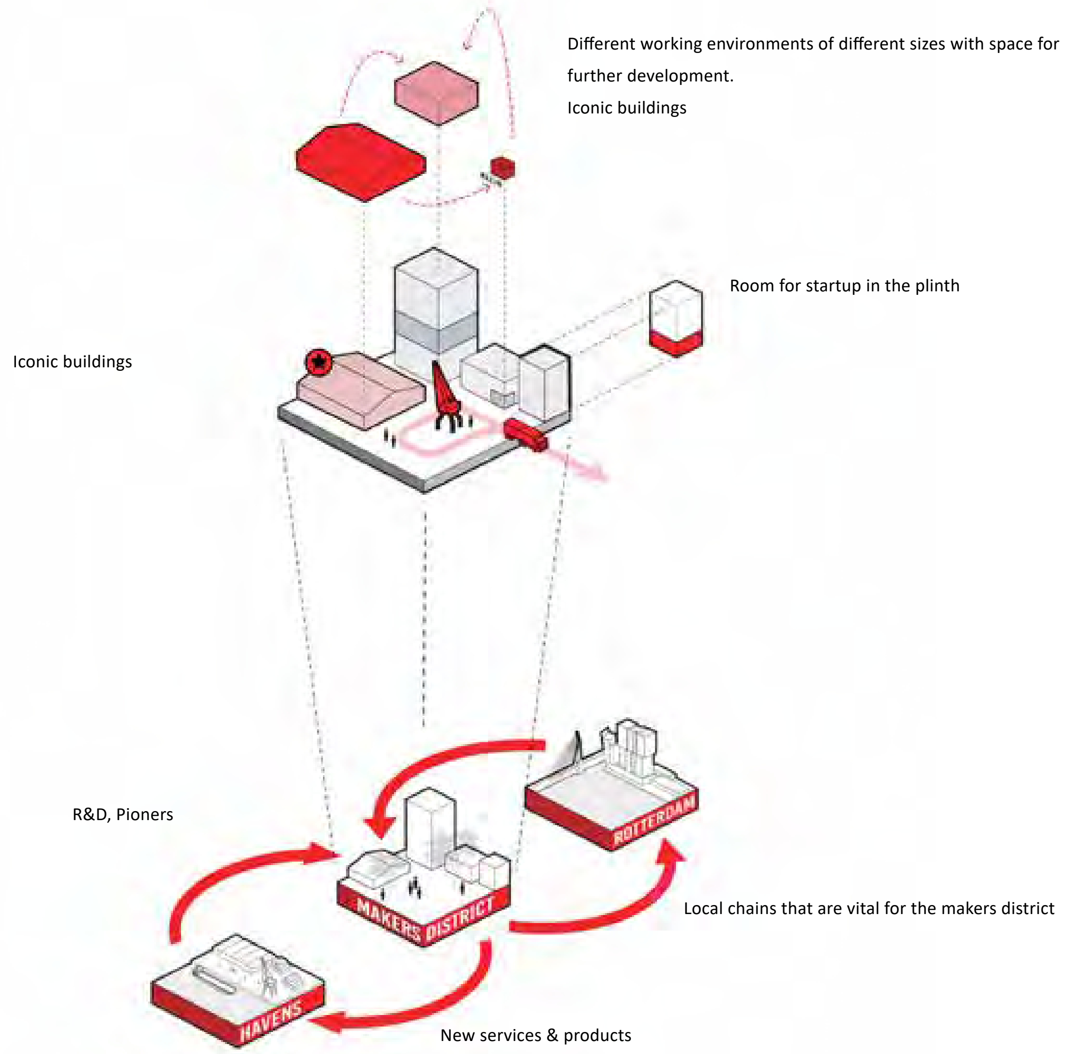
E.22 Development


Merwehaven
Vierhavens
Nieuwe maas
Eemhaven
Waalhaven

Also, the municipality of Rotterdam wants to redevelop the inner-port areas of the city. Their goal is to create a better relationship between port and city by creating an area with a mixture of urban and port functions.

In 2011 the municipality of Rotterdam made a structural vision for the inner-city port. In this report, they looked at the challenges for transforming the port areas in a sustainable way for new urban zones until 2030. By revitalizing Eemhaven, Waalhaven, Vierhavens and Merwehaven, the former inner-city port will become an environment which is clean, green and healthy. This is going to be achieved with low energy and climate-resistant buildings. In the end, this area will enhance the attractive appearance of the city.

For the areas, Vierhavens and Merwehaven is a new masterplan developed by Devla landscape architect and urban designer. The masterplan is focused on revitalizing that area into an innovative makers district whereby city and port functions collaborated. It offers space for new and innovative startups with various growth opportunities and to get young people of the city acquainted with the technology. The diagram below shows different design rules on how they want to achieve this.



A.14 Concept from Devla architects

A.15 Figure on the left | Overview of port areas in Rotterdam

Port architecture

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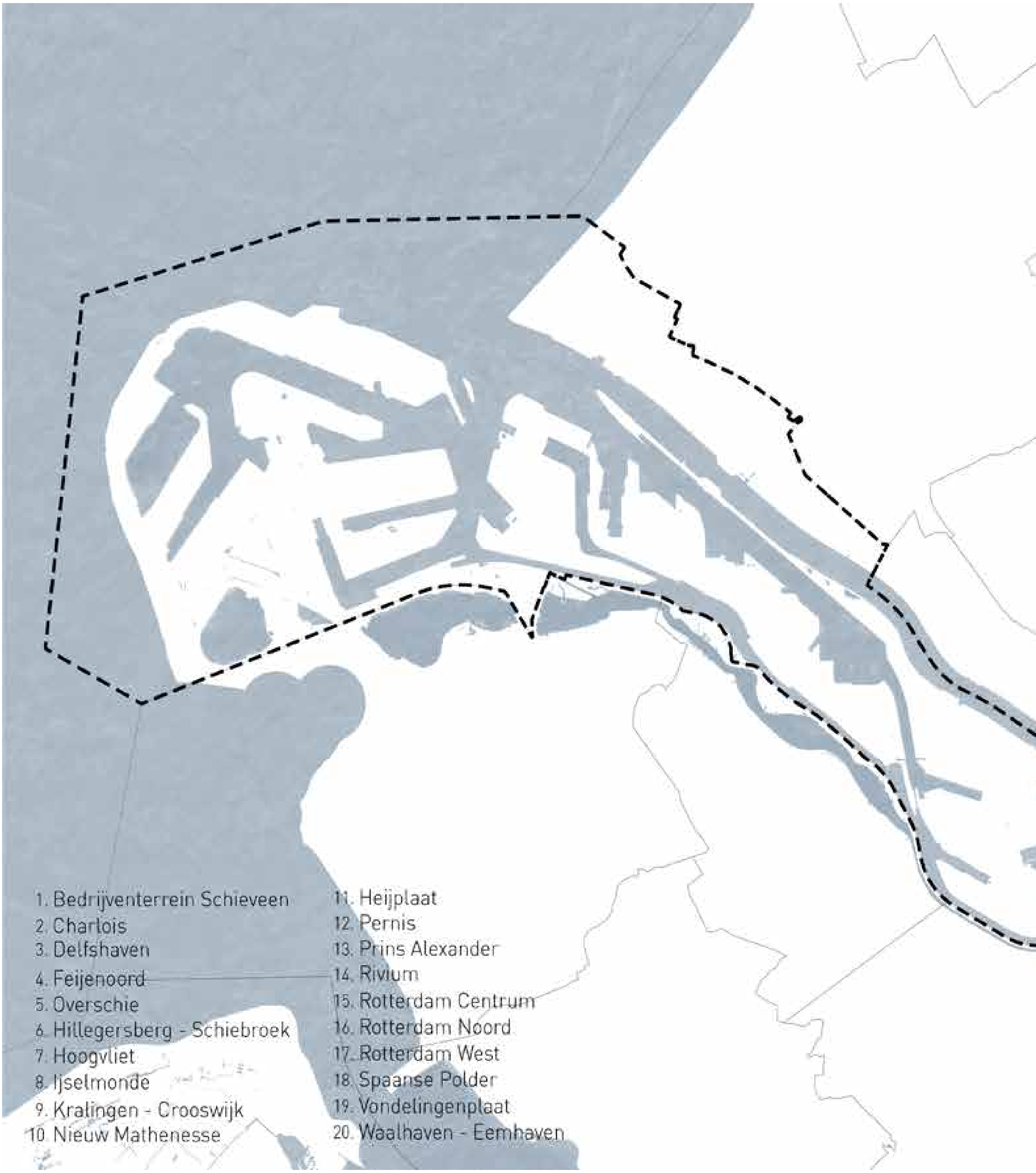
ROTTERDAM

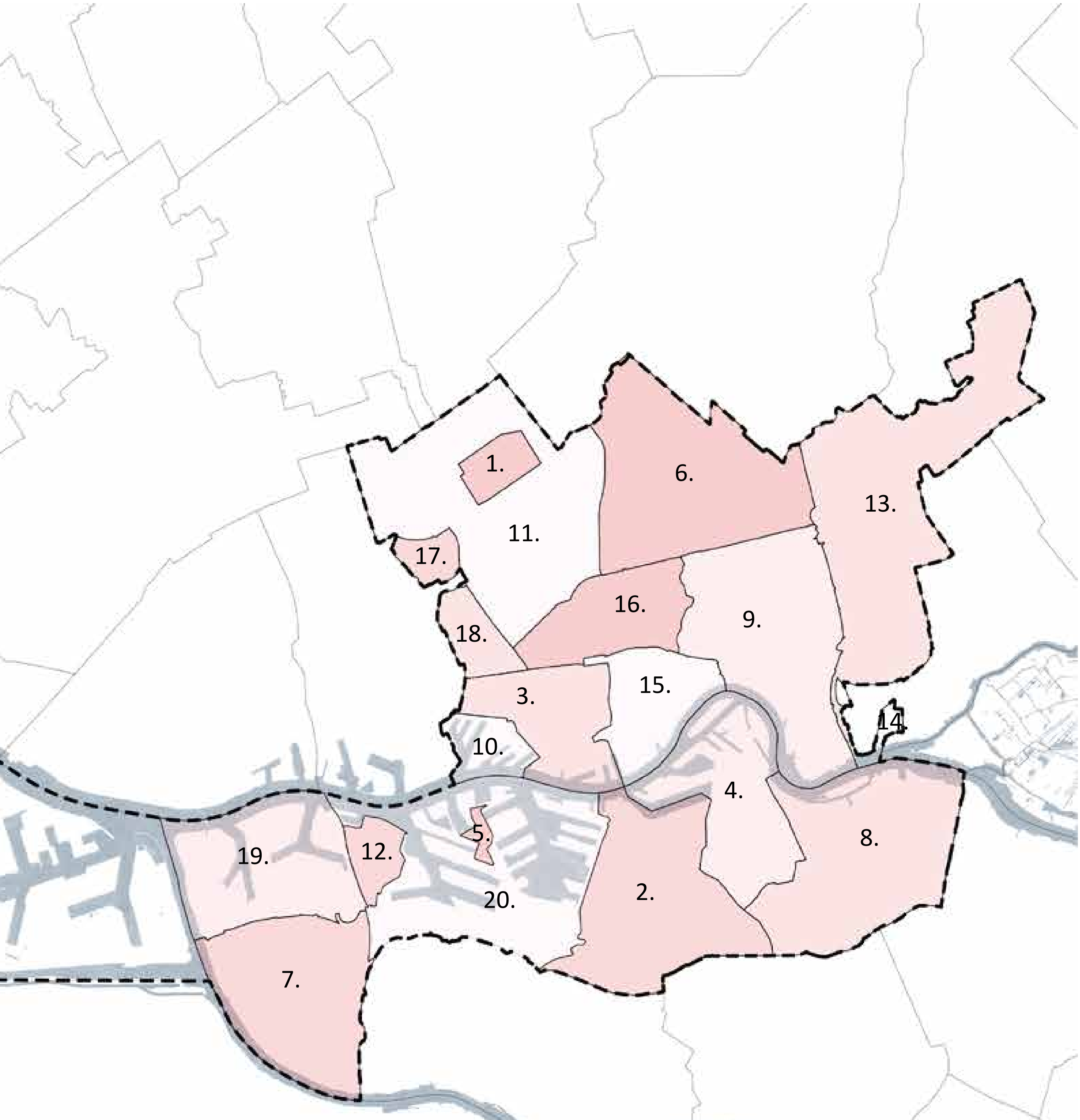
MAP ANALYSIS

Collective research

Neighborhoods



Collective research, map made by Sjoerd Harrems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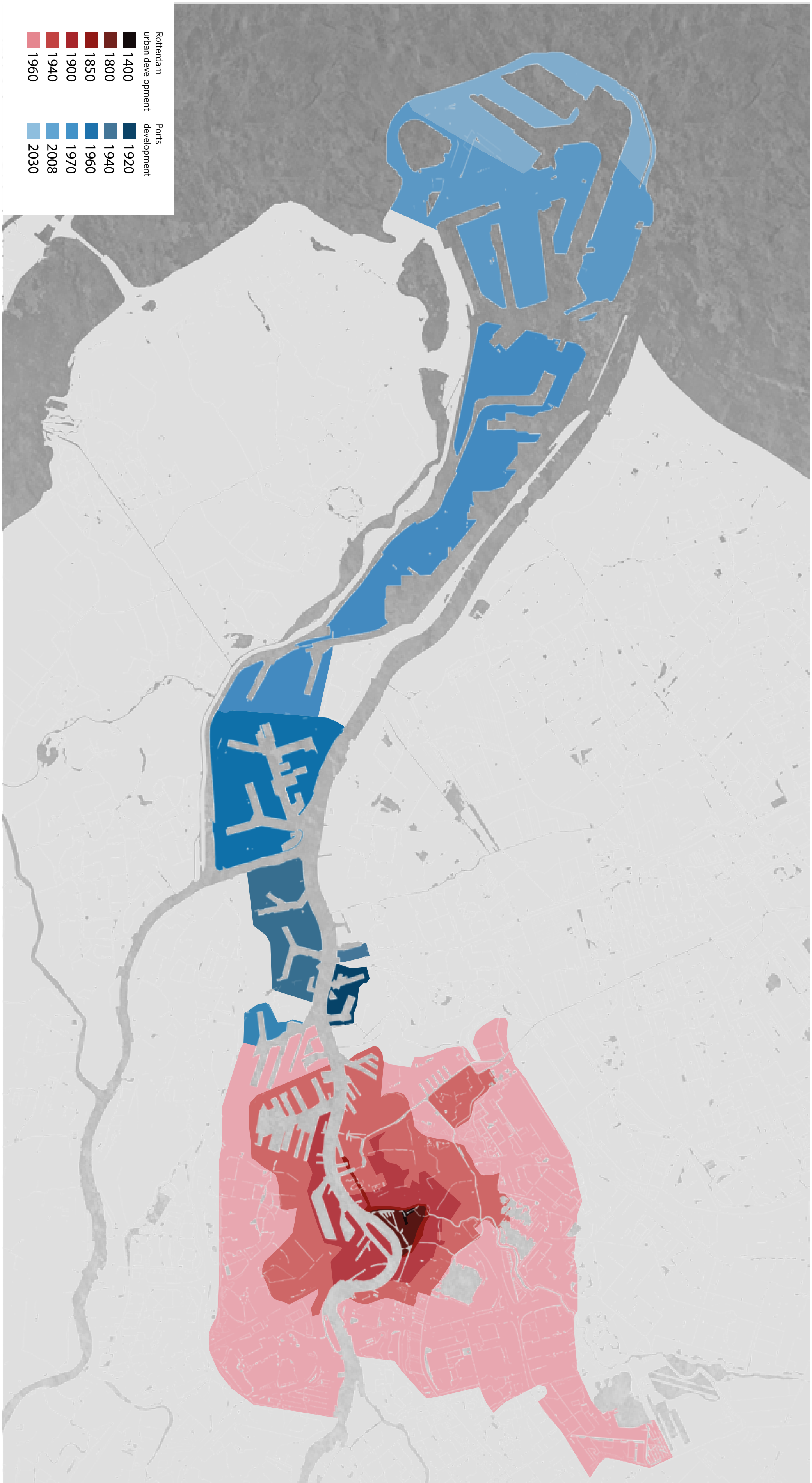
Green structure

Collective research, map made by Christina Poliviou & author

Historical development



Collective research, map made by Tadeusz Skorupa

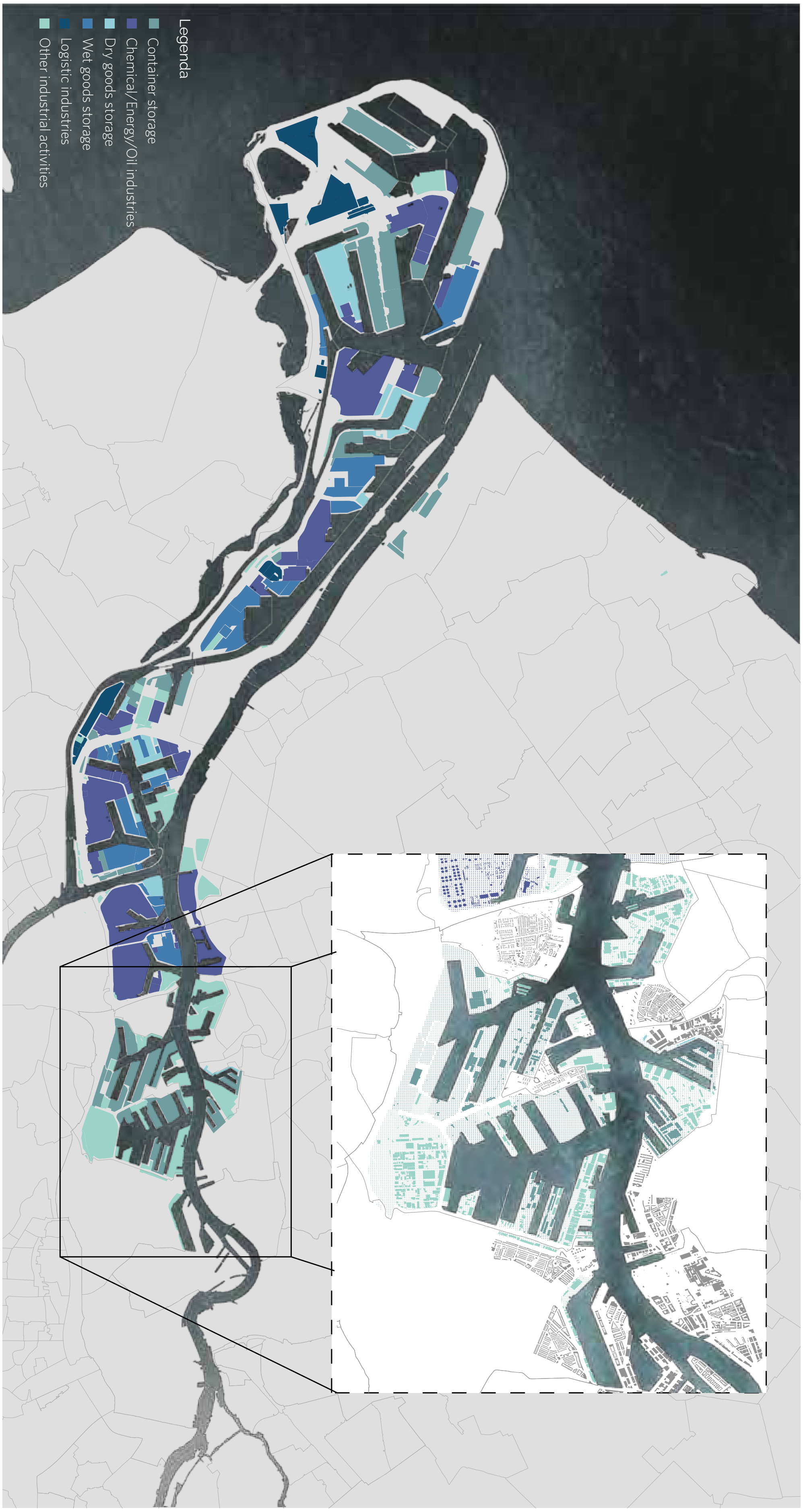
Population Density

Collective research, map made by Andrea Cavaggion

Area Functions

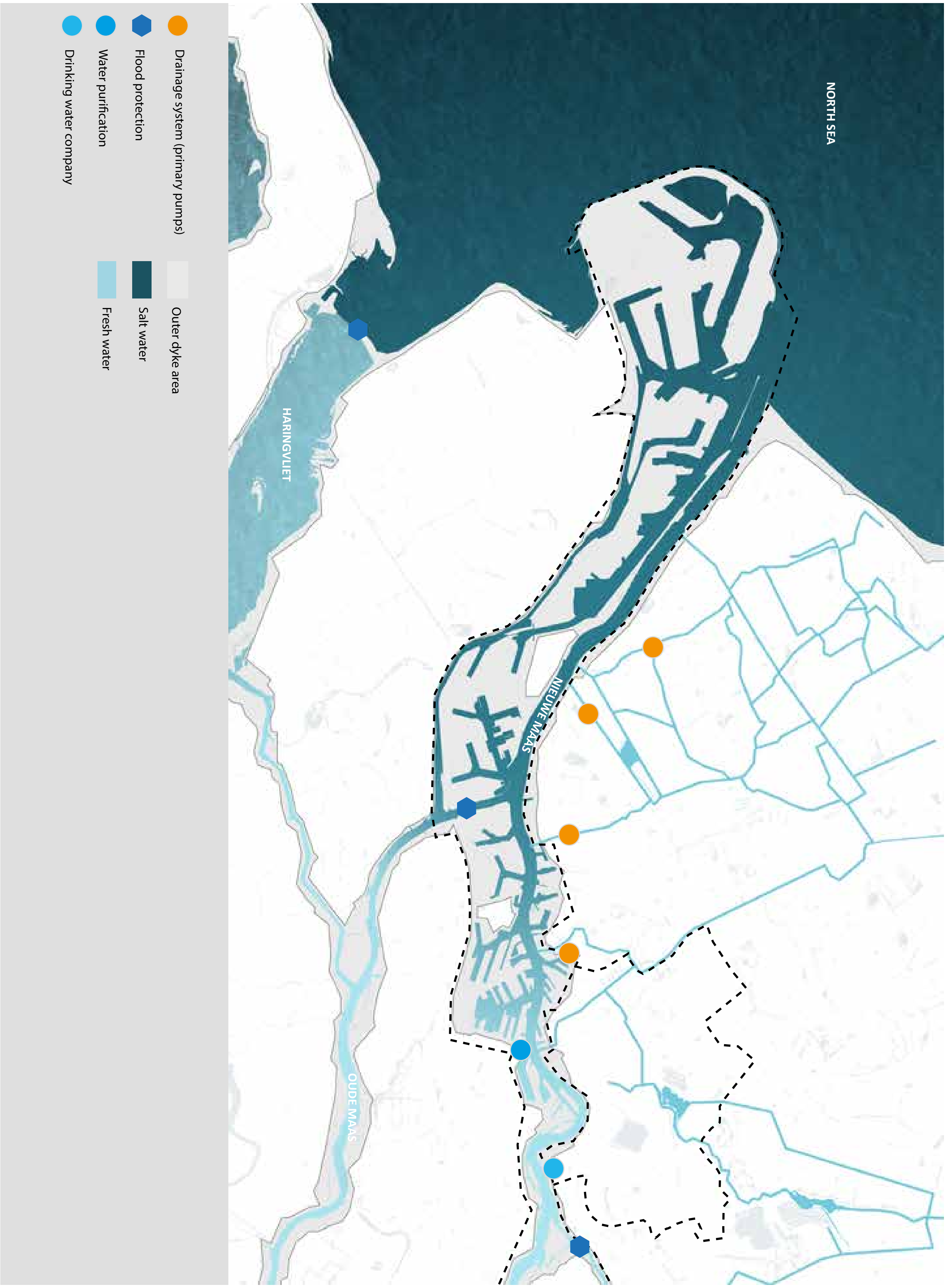
Collective research, map made by Sem Joosten

Port Use



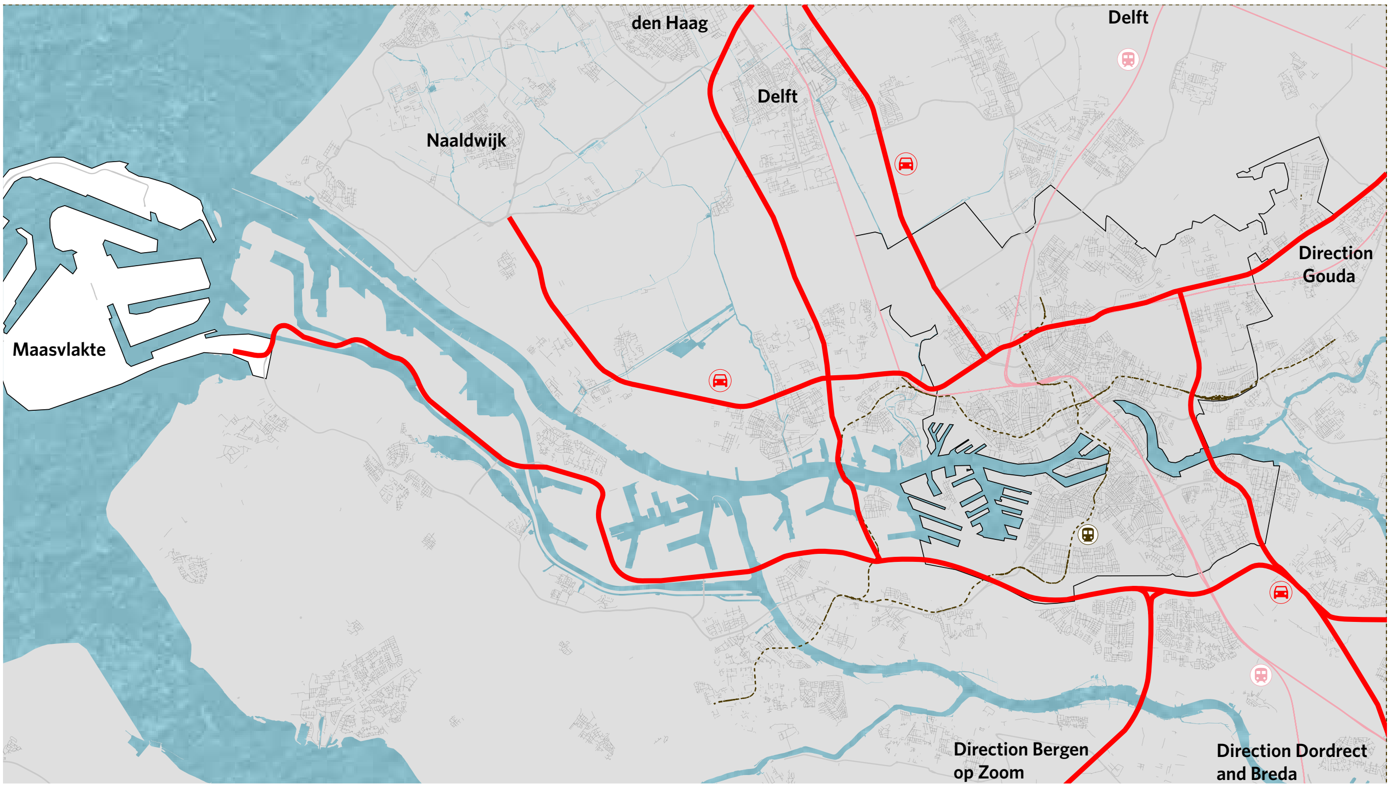
Collective research, map made by Shijie Xiao

Water



Collective research, map made by Bas Vissers

Infrastructure



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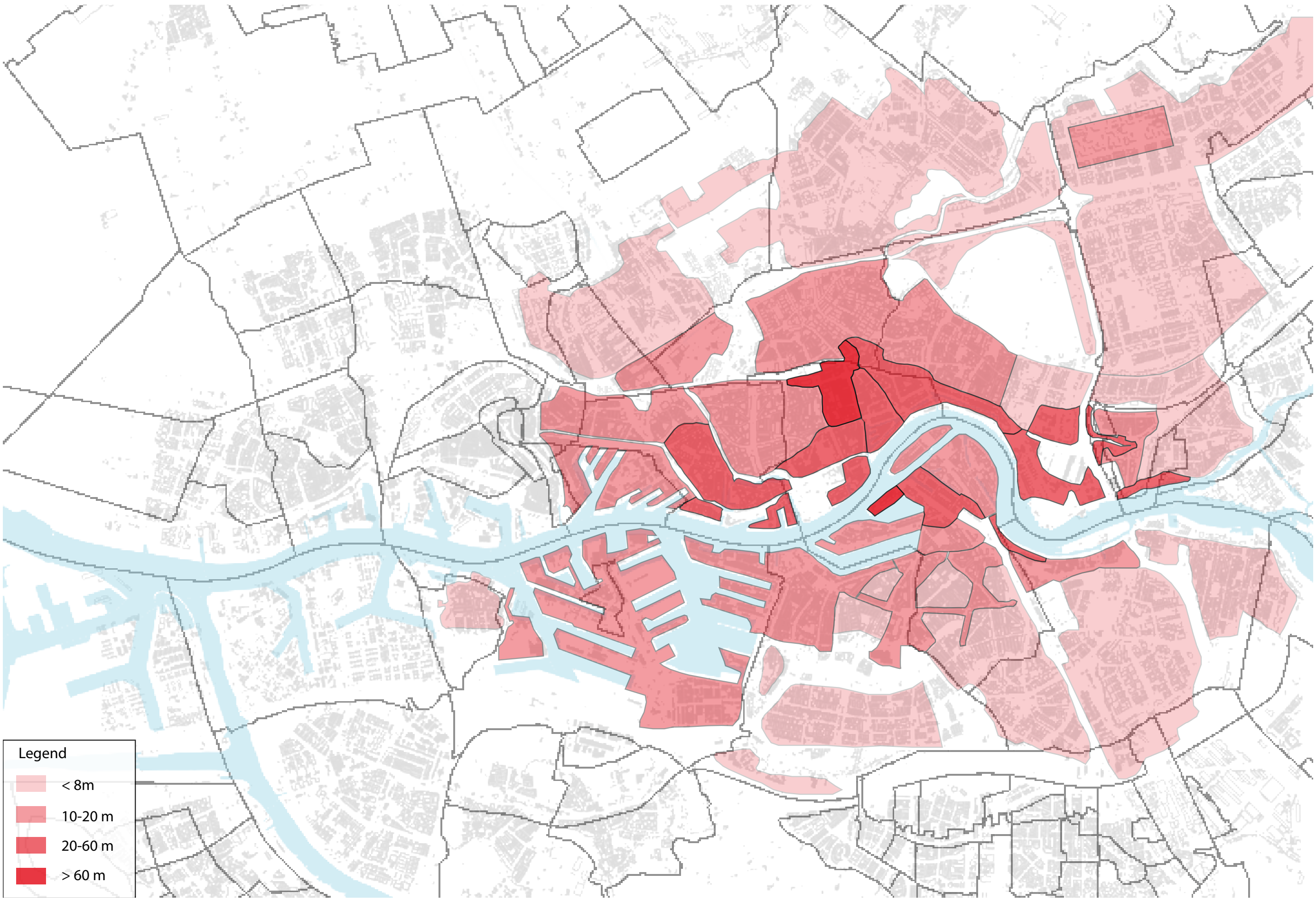
Building Heights



Collective research, map made by Alex van Eekelen

Greetings from Rotterdam

+++++++++++++++++++++++++++++++

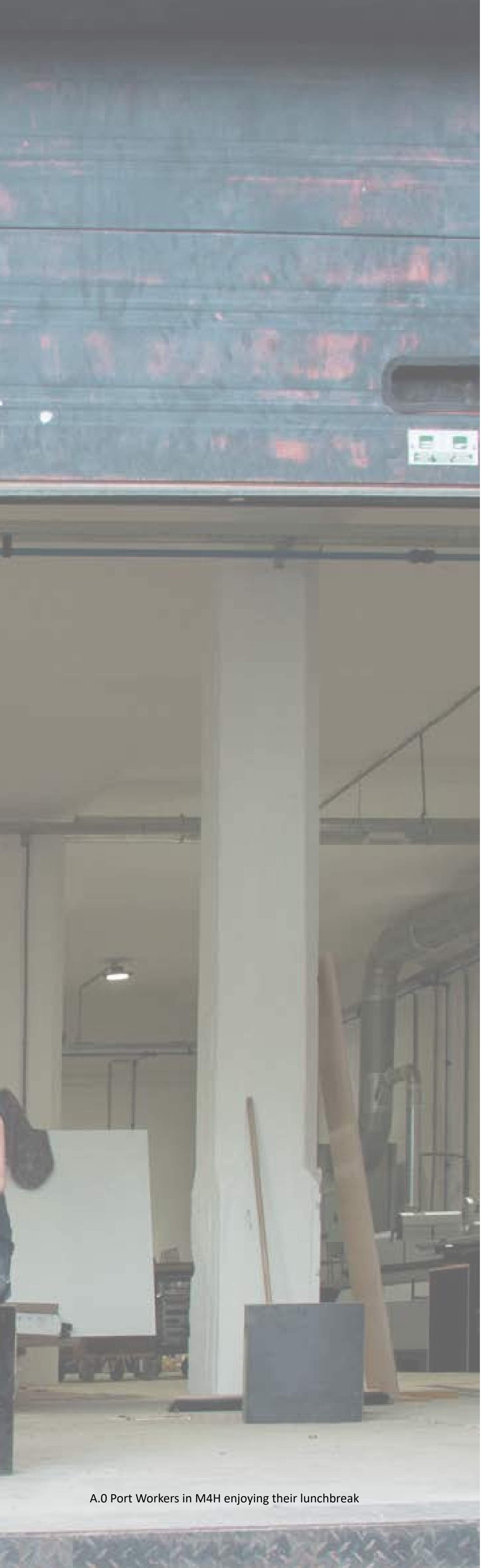
This was a short exercise to design postcards as if they were from Rotterdam from the future. These postcards show hopes, fears and our current situation in a critical light on the problems we are facing and how to possibly tackle them. For each card a different graphic style is tested: fully image-based, mixed image and illustration collage and a fully illustrated option.

Fears - Urban Heat Islands, Floods and Pandemics
Rising water levels
posing problems with
dykes, but also in 'stone'
urban spaces
Urban heat island problems
increase
Pandemic problems
affect society long-term

Hopes -Harbor identity & Biodiverse, 'natural' green space
reconnecting after pandemic
Keeping elements of
Rotterdam identity
Actively designing for
restoring biodiversity
Accomodating water fluctuations

Present
Digital life > real life
Individualisation/loneliness
Drone technology
Electric transportation
flexible working (from home)
technological
extension of humans

Future
(Re)introducing:
human scale
green & biodiversity
integration of ‘smart’technol-
ogy for
sustainable & ethical goals
circularity
mixed use & meeting
living beings > profit

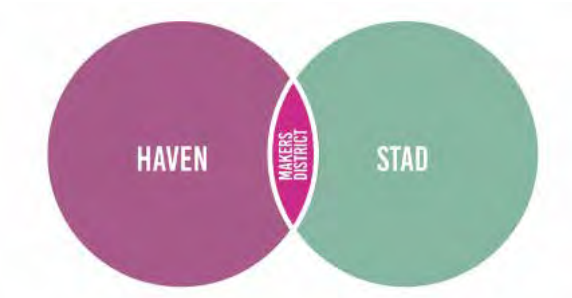

A.0 Port Workers in M4H enjoying their lunchbreak

M4H - Merwe Vierhaven

The chosen port location for this project is Merwe Vierhaven, in short M4H.

It is situated on the edge of both port and city, making it an transitional area with an interesting tension between the two activities. The city and residential activity is to be extended into this area, and the necessary transformation to make the area fit for this mixed port-and-people use is set up by the Port Company and the municipality of Rotterdam in a 'Spatial Framework' document. This chapter informs about this plan; 'Het Ruimtelijk Raamwerk'.

M4H - Ruimtelijk Raamwerk

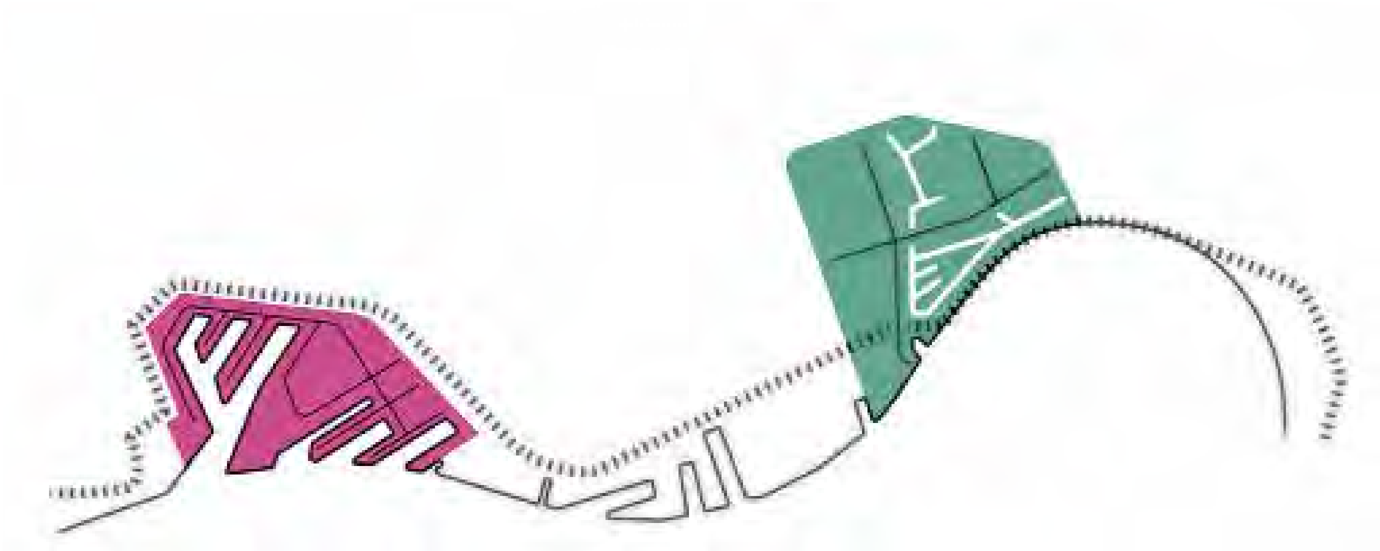


A.1 The Maker District as a transitional area between port and city (Municipality Rotterdam, 2019)

Merwe Vierhaven, or M4H, is designated as one of the transformation areas that will become an intermediate, mixed use space, combining Port and City. M4H and the RDM terrain form the Rotterdam Makers District. The municipality collaborates with the Port company to transform this into an innovative living and working environment that is optimally suited for innovation. To do so they have developed a 'Spatial Framework' ("Ruimtelijk Raamwerk") together with stakeholders and other interested people to set up the outlines of the development of the area.

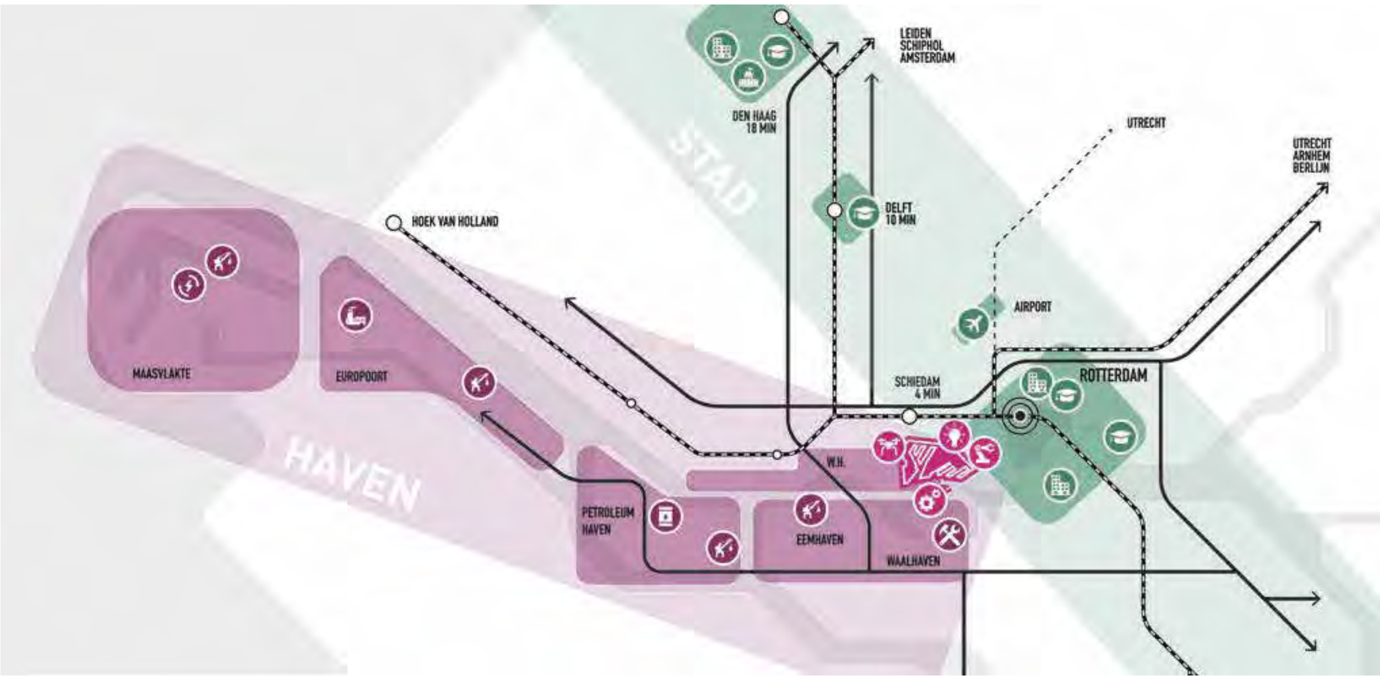
The area will be the home to innovative companies and where circular applications are developed, but also tested. The area will function as a living lab and real-life showcase of the circulavr future of the city and port.

As one sees in the images below, the M4H area is about the size of the city centre of Rotterdam, and is situated on this shifting zone between the Port and City. It has space for industry, but will also be transformed to accommodate a significant part of the housing program of Rotterdam. In this way the need for new housing can be answered within the bounds of Rotterdam itself. To create a successful development of M4H, it needs a mix of environments, greenification, well organised traffic flows, focal points for meeting and a good connection to its environment.



A.2 M4H and the city center of Rotterdam (Municipality of Rotterdam, 2019)

M4H and the City center in comparison



A.3 M4H and the city center of Rotterdam (Municipality of Rotterdam, 2019)

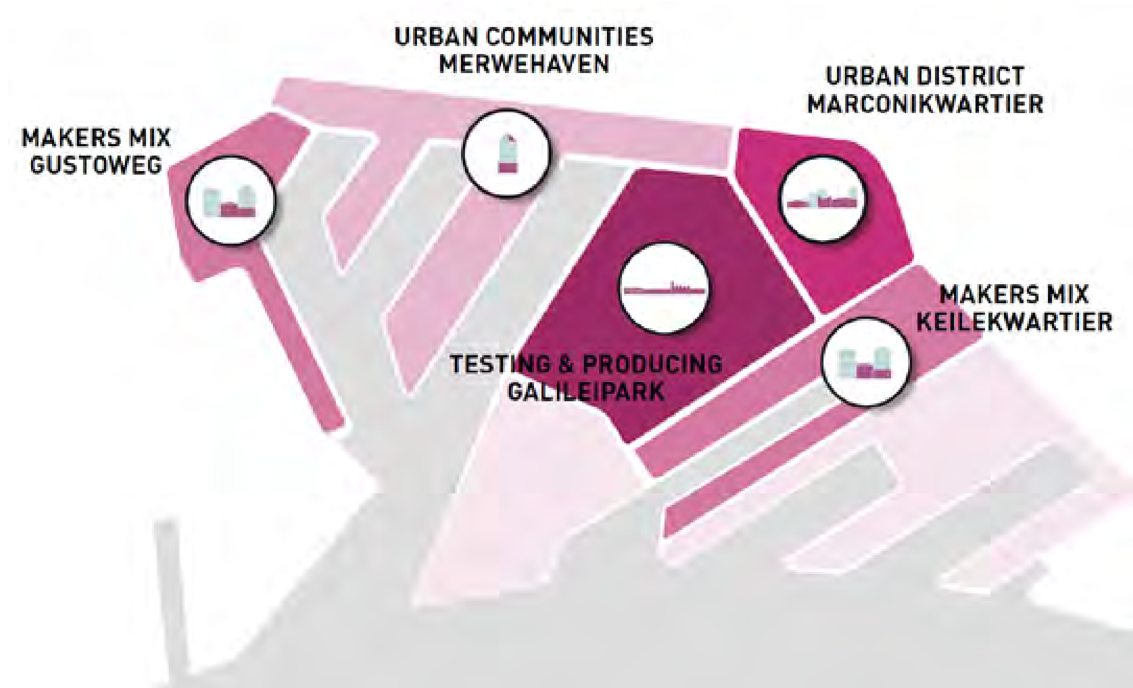
M4H the intermediate space between Port and City

Neighborhood division

The M4H area is in itself an intermediate space, as it is located between Port and City. Making it an important transitional space that links the two places together. On the next page is an image showing the neighborhood division, that each accommodate a different composition of functions.
Galileipark: Larger manufacturing companies that need environmental space. It will also house hospitality, ciltue, education, events and other functions that contribute to an energetic ambiance. This area does not have housing.
Marconi Quarter: This will be the most urban mix of living working and facilities, having the highest density. It is connected to the Marconisquare intersection.
Keilequarter and Gustoroad: Working and housing environment with space for craft- and creative manufacturing companies, forming a transitional zone to both working areas adjacent to both sides of M4H.
Merwehaven: The urban working and living environment with emphasis on housing and related functions as schools, shops and restaurants.

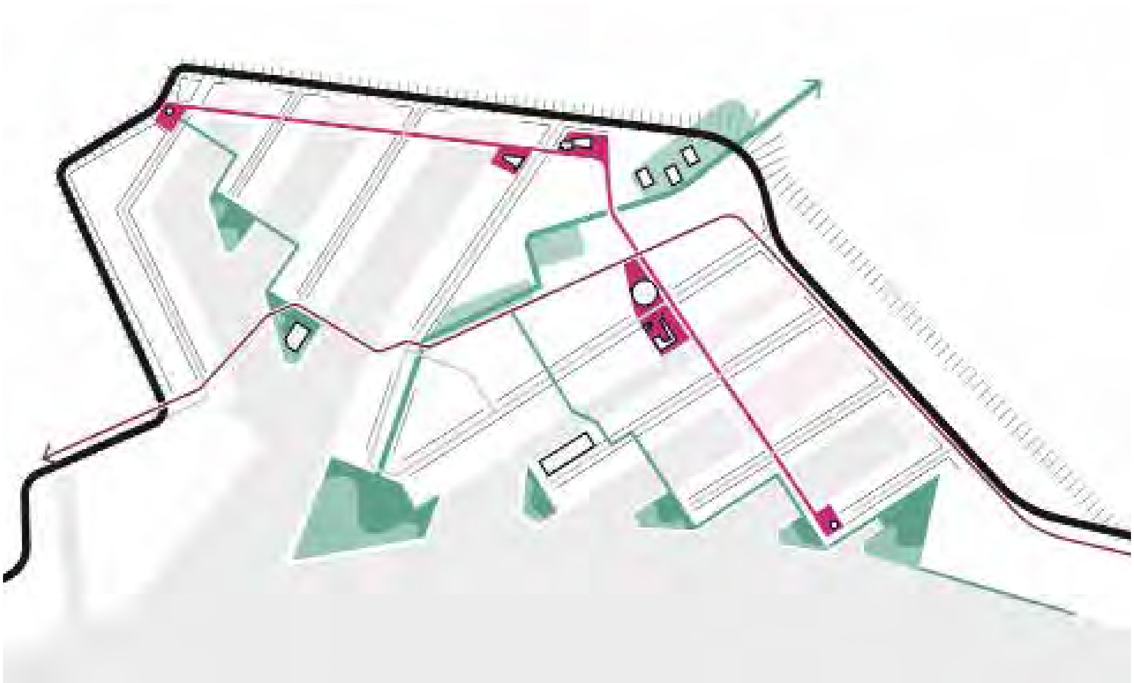
Infrastructural strategy and the public space

By creating new access points to the Schiedamseweg the connection of M4H to its surroundings is improved. By separating heavy and slow traffic as much as possible by allocating each their own main route, the area becomes safer and accommodating to cyclists and pedestrians. A regional bike route will cross over the water and over the quays to add a distinctive feature to the plan.
THe two main routes intersect at two main focal points: The Citrusveiling and the Ferro-Gashouder. These two monumental buildings will get a public function to increase liveliness in the area.
The setup of the infrastructure encourages people to travel by foot, bike or public transit, for example by introducting a fine grain network of bike paths.
Parking will no longer be across the street, but organised on several mobility hub spots, where one also finds shared cars and other forms of shared transport. A green structure of parks on the edges of the quays connects the surrounding neighborhoods to the waterfront.



A.4 The neighborhoods of M4H (Municipality of Rotterdam, 2019)

The Neigborhood division

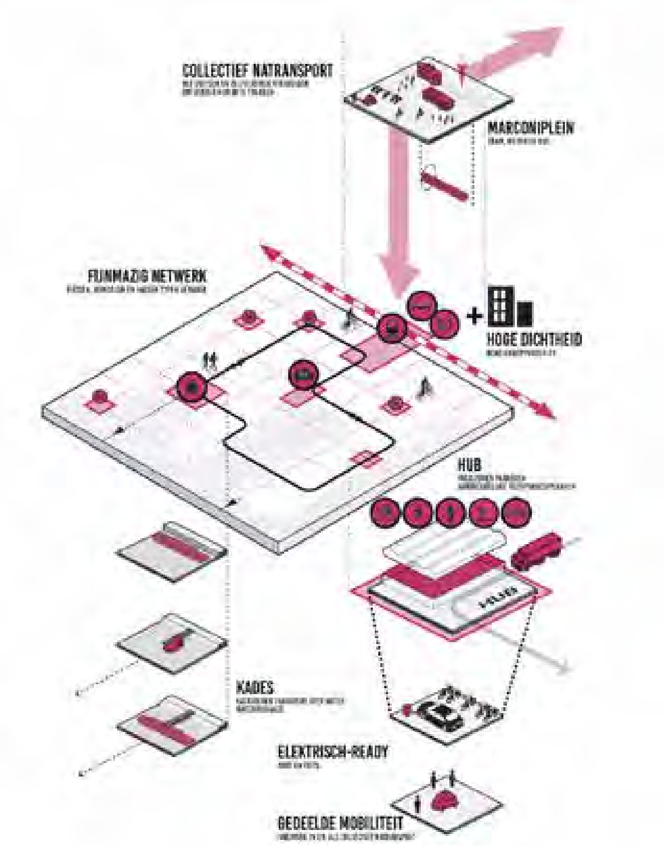


A.5 Main infrastructure and green structure of M4H (Municipality of Rotterdam, 2019)

Main structure

A.6 3D impression of layout of the area, highlighting main structure (Municipality of Rotterdam, 2019)

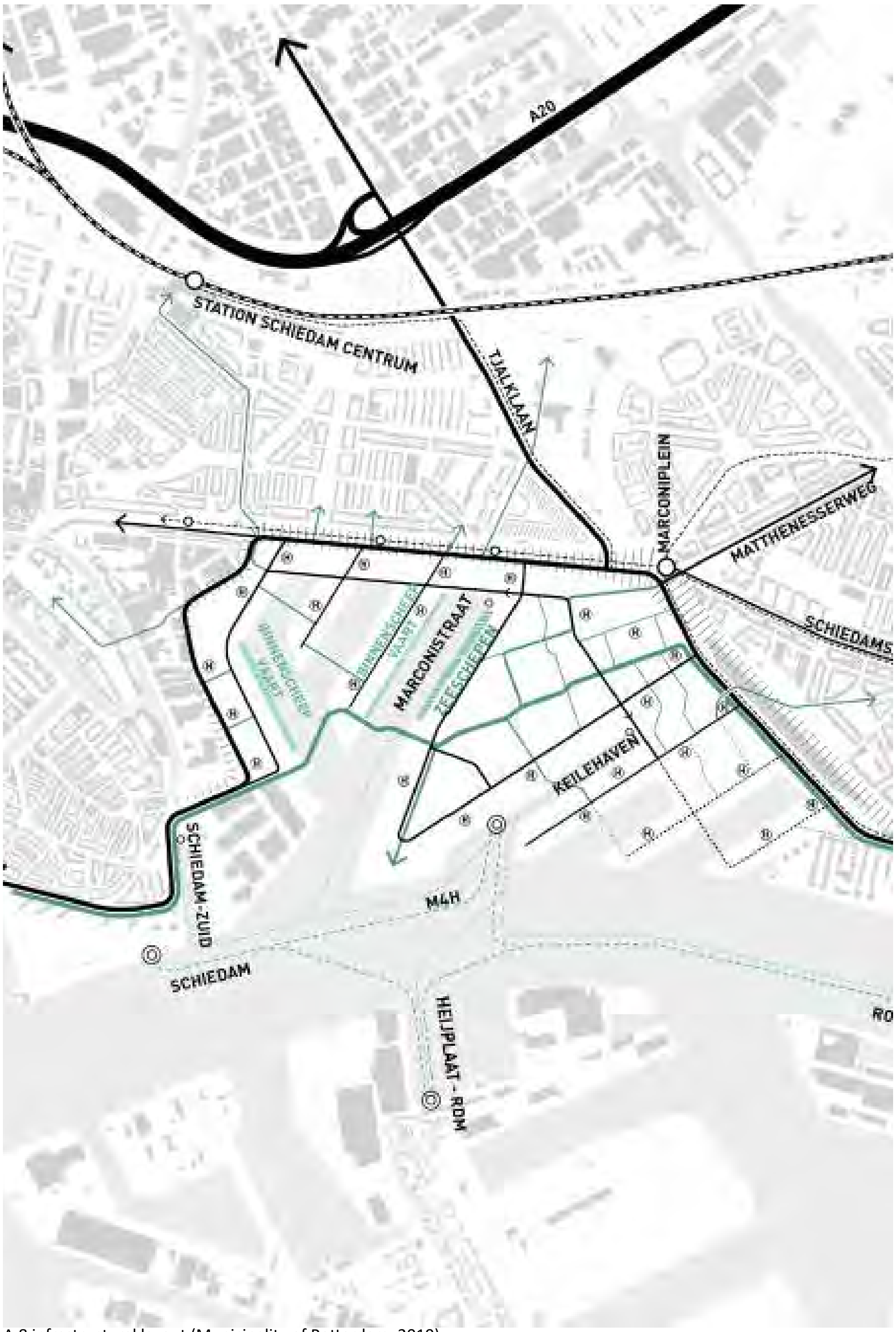
3D impression highlighting main connecting route with key buildings



A.7 transport strategy featuring a shared transport mobility hub (Municipality of Rotterdam, 2019)

Vision for sustainable district development

1. M4H permanently accommodates different types of makers, both bigger and small companies.
2. M4H chooses sharing facilities over private ownership.
3. M4H provides space for experiments and learning.
4. M4H produces and uses sustainable energy.
5. M4H values waste streams and aims to reuse or repurpose them
6. M4H enables the option of sustainable mobility.
7. M4H functions as one, climate-resilient system
8. M4H builds onto theindustrial capacity and quality of the area.



A.8 infrastructural layout (Municipality of Rotterdam, 2019)

The Proposed infrastructure

Interpretation for the Oasis Retreat design
The design project will use the spatial framework as a basis to inform design desicions. The infrastructural division for heavy and light transport, the green quays and the bike route will be integrated into the design.
The design focuses on one quay in the neighborhood with the highest residential composition: the Merwehaven. The project will transform this into a retreat in a lush green oasis in the urban, in which a community cluster and shared and public functions are combined in a mixed use design.

A.8 the proposed green structure (Municipality of Rotterdam, 2019)

The Proposed green structure

Text Source
Municipality of Rotterdam (2019) Ruimtelijk Raamwerk M4H. retrieved from https://m4hrotterdam.nl/wp-content/uploads/2019/07/DLA-M4H-17028-Boekwerk-190627-LQ.pdf on 12-11-2020

Image Source
Municipality of Rotterdam (2019) Ruimtelijk Raamwerk M4H. retrieved from https://m4hrotterdam.nl/wp-content/uploads/2019/07/DLA-M4H-17028-Boekwerk-190627-LQ.pdf on 16-11-2020

LOCAL ECOLOGY

OF ROTTERDAM

It might be unexpected, but there are over 800 plant species to be found in Rotterdam throughout the year. Some of these are seasonal, others are there year-round.

The urban-industrial character and scarcity of agraric area determine the composition of flora. The soil of Rotterdam is rich in nutrients, which is seen in the presence of grassland.

For this project, the incorporation of green is key. This is done by creating various zones with a range of vegetation that is edible, that attracts birds, bees and butterflies, and more cultivated green infills. To do so properly, it is important to incorporate local and native green, as this creates the desired ecological richness. When one furnishes a green space with mostly non-native and exotic plants and trees, it becomes an ecological desert that does not accommodate the fauna that could otherwise thrive in the area.

In the Port area specifically, the landscape is mostly paved, but it also has parts that correspond with river banks and one finds similar plants to a dune-like landscape.

To set up a mix of these native and local plants and trees with edible vegetation, and green that attracts bees, birds and butterflies, which are often overlapping categories, a catalogue is set up in a table on the following page.

Scherpe Zegge, a local grass on the Rotterdam Waterfront (Boll H)

area/Category	Name	dutch name	Native	edible	bees	butterflies	birds	Size
Herbs	Oregano	oregano						XS
	Chives	bieslook						XS
	Peppermint	munt						XS
	Thyme	thijm						XS
	Rosemary	rozemarijn						XS
	Chamomile	kamille						XS
	Lavender	lavendel						S
Vegetables (bloom before harvest)	Peas	erwten						M
	Beans	bonen						M
	Tomato	tomaat						M
	Cucumber	komkommer						M
	Zucchini	courgette						M
	Squash	pompoen						M
	New Zealand Spinach	Nieuw-Zeelandse Spinazie						M
Edible	Raspberry	Framboos						M
	Blueberry	Bosbes						M
	Morus Nigra	Moerbei						L
	Leek	Prei						S
	Wild Garlic	Daslook						S
	Yellow dogwood	Gele Kornoelje (bessen eetbaar)						L-XL
	Almond tree	Amandelwilg						L-XL
	Wild Apple tree	Wilde Appelboom						L-XL
	pear tree	perenboom						L-XL
	plum tree	pruimenboom						L-XL
	white plum tree	kwets (witbloeiende pruimenboom)						L-XL
	Prunus Padus	Gewone vogelkers						L-XL
	grapes	druiven						M
Butterfly	Large Nettle	grote brandnetel						M
	Sweet Vernal Grass	Gewoon reukgras						M
	Tufted hairgrass	ruwe smele						M
	Eupatorium	koninginnekruid						S
Bees	Hemlock	Hemelsleutel						M
	Autumn Aster	Herfstaster						M
	Wall Pepper	Muurpeper						M
	Lavender	Lavendel						M
	Catnip	Kattenkruid						M
	Blue button	Blauwe Knoop						M
	Coneflower	Zonnehoed						M
Bee - spring	Beeleaf	bijenblad						M
	Cranesbill	ooievaarsbek						M
	Laburnum	goudenregen						M
	Rhodondendron	rodondendron						M
Bee - summer	lady in green	juffertje in het groen						S
	phacelia	phacelia						M
	wild privet	wilde liguster						M
	Heliopsis	zonneogen						M
Bee - autumn	yarrow	duizendblad						M
	clematis	clematis						M
	ground ivy	klimop						M-XL
Bee - winter	Hellebore	kerstroos						XS
	winter aconite	winterakoniet						XS
	snowdrop	sneewklokje						XS
	hazel	hazelaar						L-XL

Sources

Remko Andeweg. (2010). Natuurlijk Rotterdam: Afscheid van het spoorwegemplacement aan de Marconistraat. Straatgras, 22(2), 42–45. available at: https://natuurtijdschriften.nl/pub/538304/STGR2010022002003.pdf retrieved on 15-04-21

Hoffman, M. (2012). Inheemse en uitheems plantensoorten in stad en landschap. Wageningen: Plant Publicity Holland.

I Also want to thank the team of Bureau Stadsnatuur Rotterdam, whom have consulted me and provided me with useful sources.

Image sources:

Boll, H. Scherpe Zegge, [Photo] Wilde Planten. Retrieved from: https://wilde-planten.nl/scherpezegge.htm

Massant, W. Hazenpootje, Ecopedia. Retrieved from: https://www.ecopedia.be/planten/hazenpootje

Hillewaert, H. Wilde Appel. Wikipedia. Retrieved from: https://nl.wikipedia.org/wiki/Wilde_appel#/media/Bestand:Malus_sylvestris_fruit,_Vosseslag.jpg

area/Category	Name	dutch name	Native	edible	bees	butterflies	birds	Size
Local - Riverside and water bank species of freshwater tidal zones	angelica	grote engelwortel						S
	spindle tuft	spindotterbloem						S
	orange springseed	oranje springzaad						M
	sharp sedge	scherpe zegge						M
Urban species	longleaf grass	langbaardgrassen						M
	kite	wouw						M
	grey mustard	grijze mosterd						M
Local - nutrient rich soil	glossy oat	glanshaver						M
	cocksfoot	kropaar						M
	field arthyrus	veldarthyrus						M
	Jerusalem artichoke	aardaker						XS
	cow parsley	fluitekruid						M
	yellow nailweed	geel nagelkruid						M
	big witchweed	groot heksenkruid						S
	broad-leaved helleborine	brede wespenorchis						S
Local - stone area	crested ray	gevlamde fijnstraal						S
	Roughetail	Ruige fijnstraal						S
	pale morning star	bleke morgenster						S
	oriental rocket	oosterse raket						XS
	hairy hogweed	behaard breukkruid						XS
Local - old city walls	lingonberry	tongvaren						XS
	stonecrop fern	steenbreekvaren						XS
	blackstalk	zwartsteel						XS
Grassland and ruinous vegetation (like dune-landscape)	yellow shorestraw	geel walstro						XS
	common clover	gewone rolklaver						S
	hare's-foot	hazenpootje						S
	wild reseda	wilde reseda						M
Former railroad terrain and struweelrand	elm	iep						L-XL
	red dogwood	rode kornoelje						L-XL
	rowanberry	lijsterbes						L-XL
	dwarf mistletoe	dwergmispels						S
	willowherb	wilgenroosje						M
	woodruff	bosrank						M-L
	melon torch	melige toorts						M

This catalogue offers a wide range in terms of size, sort, functions, colors and scents that offer a varied mix to create a varied and local ecology-supporting infill of the green structure of Merwe Vierhav-en, and this project in particular.

The Oasis Retreat Design

Urban strategy

Green heart of M4H

The Green oasis serves as an addition to the green structure of the randstad, and acts as a green heart of the local area. following the strategy set up by the 'Spatial Framework', the other quays will feature green parks at their ends, which are connected with a bike rout that creates a squential alternation of water and green space to the cyclist.

Accessibility and connectivity

The location has been chosen to provide the highly urban and industrial area with a refuge from the hectic urban lifestyle. By building on one of the quays, three of the four sides are surrounded by water, creating open space and distance from the built context. This creates a more secluded and calm place, as by making the quay a car-free zone and designing for pedestrians and cyclists.

The choice for the specific quay is made as it is most land-inward and therefore most shielded from the heavy traffic by water.

The area is accessible for supply and waste collection trucks and cars when needed to ensure the community cluster can always receive necessary services and accessibility. Parking is situated at the connected side of the quay, where pathways and shared bikes are ready to lead the people to the cluster.

The bike path crossing the waters is part of a larger route, and improves the connections of the quays.

Adapted Spatial Framework for the Oasis Retreat Original image: (Municipality of Rotterdam, 2019)

Adapted Spatial Framework for the Oasis Retreat Original image: (Municipality of Rotterdam, 2019)

Case Studies

Introduction

In the design proposal, the focus is on a revitalisation of a formerly very industrial area to make it fit for living. Transformations are necessary to achieve the needed spatial quality to attract people to settle in this area. As explained in the analysis, the area lacks qualitative green space, or hardly any green.

The architectural approach to this is to interweave the built and the natural. To investigate this, two case studies that each integrate building and vegetation in their own way serve as inspiration for the design concept.

The Oasis terraces, designed by Serie Architect creates building and landscape in one block, whereas Penda takes a much more fragmented and permeable approach.

Case study: Oasis Terraces

Architect
Serie Architects, Multiply Architects

Location
Punggol, singapore

Year of construction
2015

Size
27.400 Square meters

Program
Communal gardens, play space, gyms, retail space, dining, learning space, healthcare.

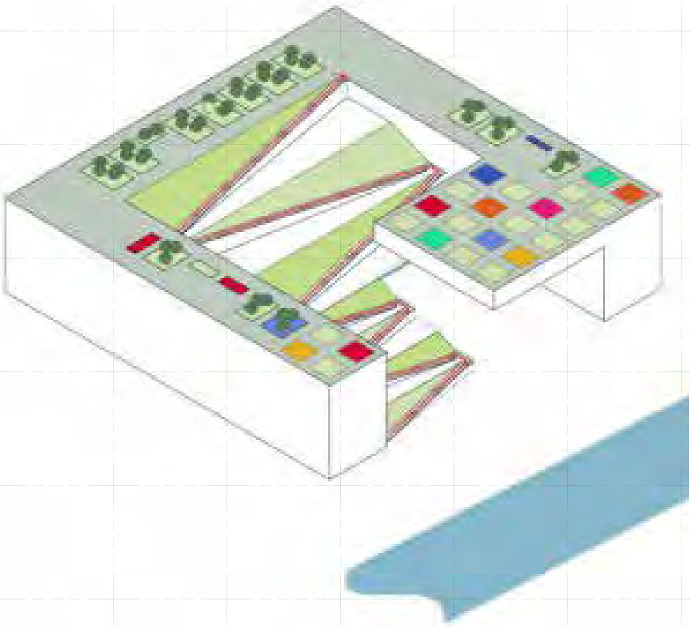
A.1 Oasis Terraces, (Hufton+Crow)


A.2 The lush green internal space, (Hufton+Crow)

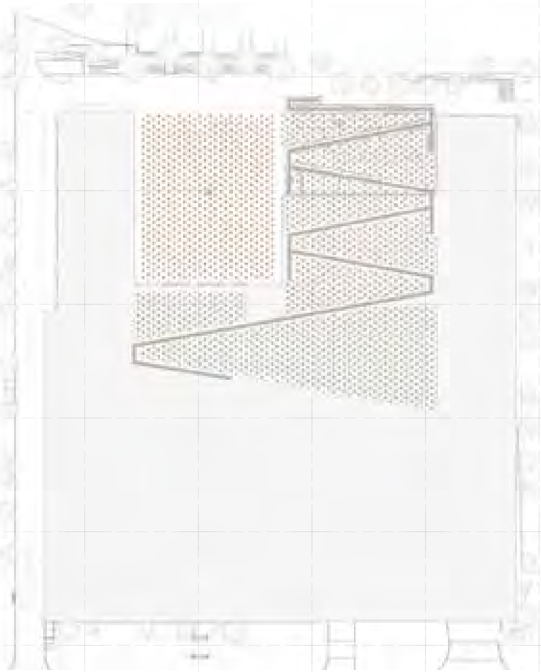
A green heart

Whereas often a built structure becomes the central marker of a space, here the green becomes the heart of the building. The building is situated in an area filled with high rise and functions as a community center and polyclinic for its public housing neighborhood.

A.3 Floorplan of the first floor, showing the sloping landscape shaping the interior spaces of the building (Serie Architects, 2015)



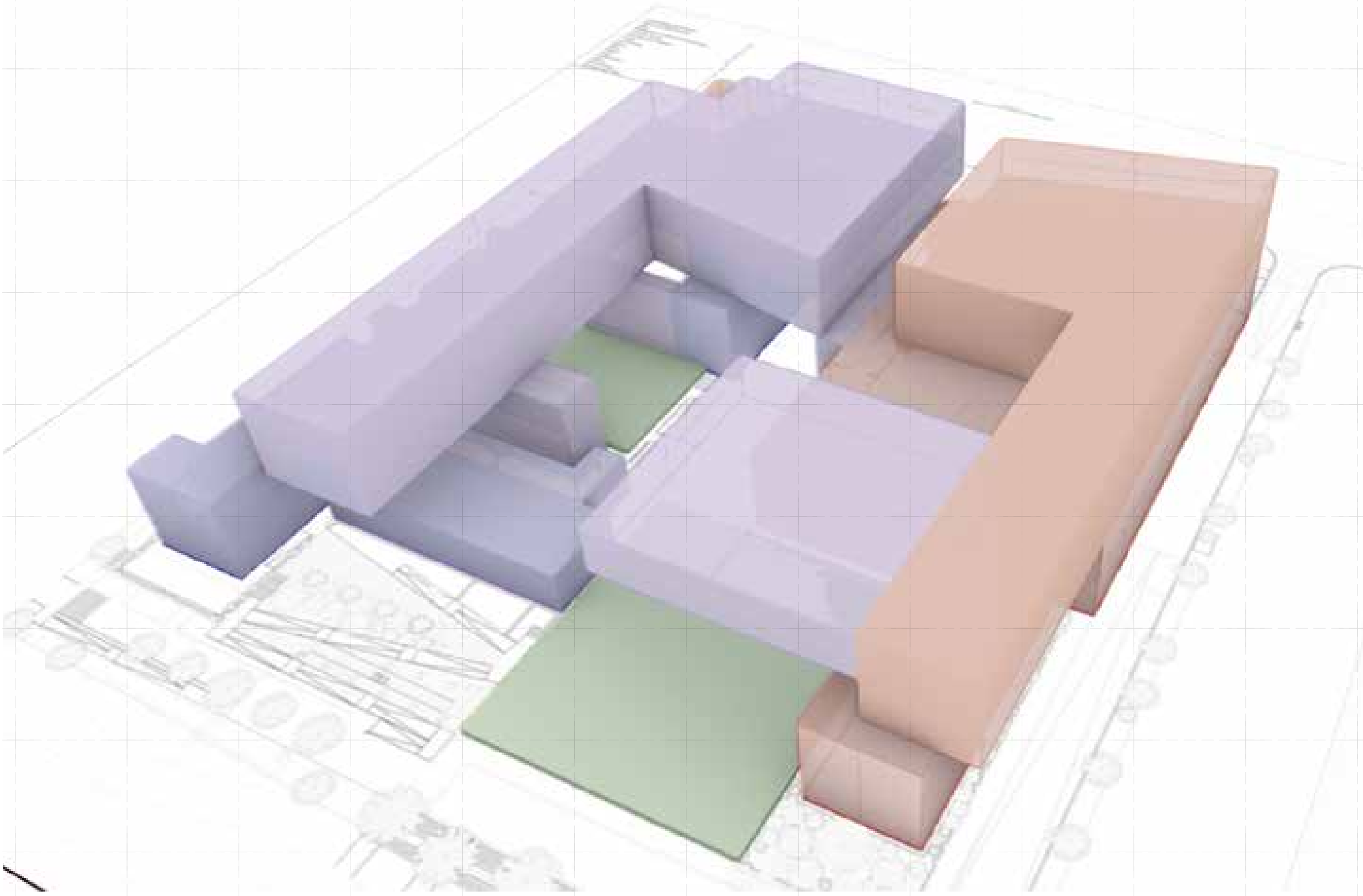
A.4 Floorplan of the first floor, showing the sloping landscape shaping the interior spaces of the building (Serie Architects, 2015)



A.5 Analysis map showing the route and public space.

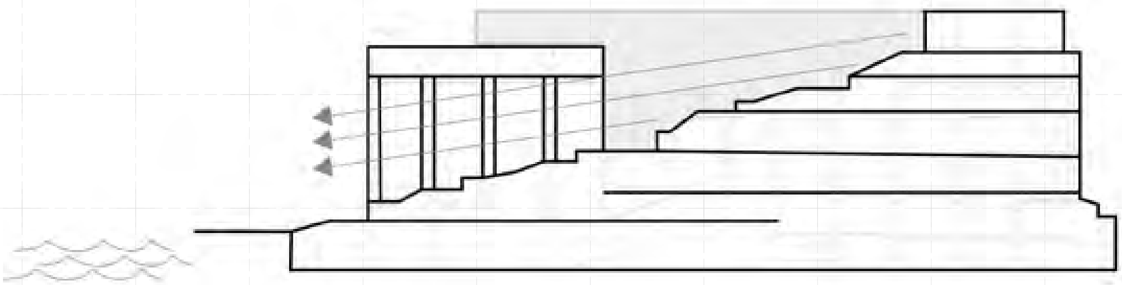
- Public plaza for interaction and events (covered)
- Sloped pathway
- Adjacent public park (exposed)

A.6 Analysis map showing the used green in the plan. The rooftop gardens are not included in this image



A.7 Functions

- Rehabilitation center and other medical facilities
- Commercial (Shops)
- Commercial (Restaurants)
- Green = plaza (internal = atrium)



A.8 Diagrammatic section showing the visual connections to the water.

Green Community center

The design demonstrates the local ambition of the integration of community and landscape. Gardens and terraces are organised alongside the public program, and the maintenance of the gardens are intended to bring residents together.
A large covered plaza accommodates public events and functions as a vibrant heart for the community.
The gardens provide space to play, interact with neighbors and create a meandering pathway through the lush green to arrive at one's medical appointment or other destination in the center.

Mixed use

The program is planned around, but also under the landscape. of sloped terraces. By putting glass under the slopes, this allows daylight and a connection to the green for the program below. With this orientation, the visual connection with the water remains intact and uninterrupted almost everywhere. It also invites the adjacent activities to extend into the gardens, thereby creating a flexible boundary between interior and exterior. The overall architecture is open and light, with the covered plaza acting as an intermediate space between inside and outside.


A.9 Section showing the layering of the 'landscape' and other program (Serie Architects, 2015)


A.10 Impression of the gardens, pathway and adjacent program. (Serie Architects, 2015)

Text Sources:

Serie Architects, (2015) Punggol neighborhood and Polyclinic, Serie architects retrieved from: https://www.archdaily.com/909142/punggol-neighbourhood-and-polyclinic-serie-architects-plus-multiply-architects
Serie Architects (2015) Oasis Terraces, retrieved from: https://www.serie.co.uk/projects/369/oasis-terraces

The exposed elevations of the building are also filled with vegetation to act as a climatic buffer.

Interpretation of project

The inverted approach of having a landscape within the building instead of a building within a landscape creates an experience where one is in contact to the green in all places. The surrounding activities are invited to extend and mix in this enclosed shared space. This offers interesting oppportunities for creating a community cluster. By creating this layered relationship of landscape - building - sloped landscape - access to built functions above, a multi-sided building is desinged with different characters and relation to the outside space for whats built above and below. The approach allows for a play with enclosed and open spaces, and intermediate spaces and gradual transitions. The sloped pathway through the green, along which there is plenty of spaces to linger, offers important potential to build a community.

A.11 The lush green internal space, (Hufton+Crow)

Image Sources:

A.1, A.2, A.11: Hufton+Crow, (2015) [Photo] retrieved from : https://www.serie.co.uk/projects/369/oasis-terraces
A.3, Am4, A.9, A.10: Serie Architects, (2015) [Images and drawings]: retreaved from : https://www.serie.co.uk/projects/369/oasis-terraces

Case study: A Thousand Yards

Architect
Penda

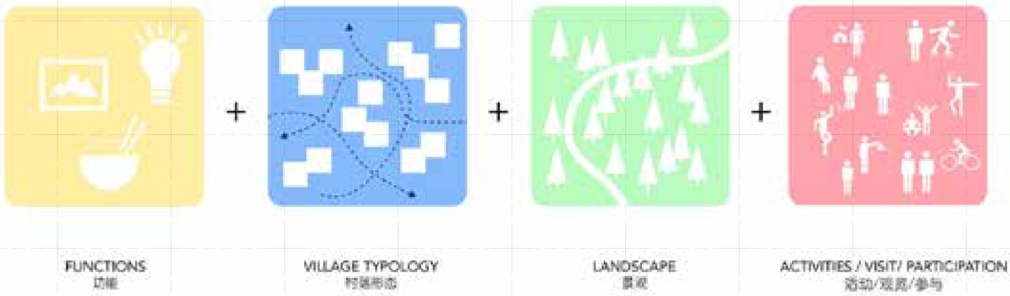
Location
Beijing, China

Year of construction
- (Competition design 2019)

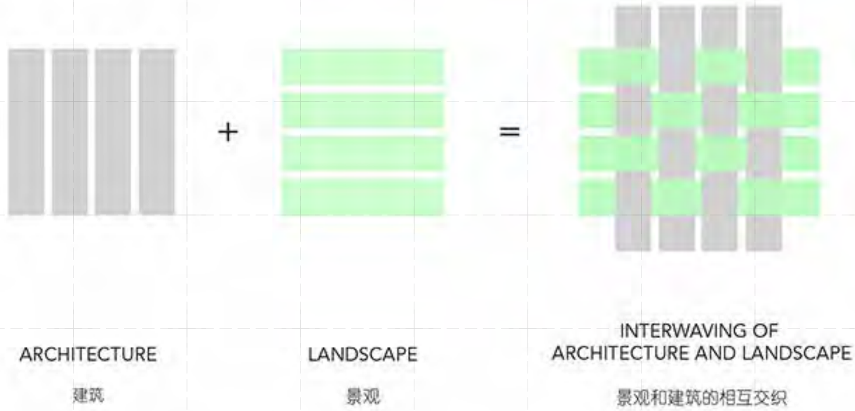
Size
30.000 Square meters

Program
Horticultural gardens, multifunctional hall, restaurant, exhibition space, lab and education, green houses, services, vertical farming.

A.1 Bird's View impression image of the Pavilion (Penda, 2019



A.2 Conceptual Design diagrams (Penda, 2019

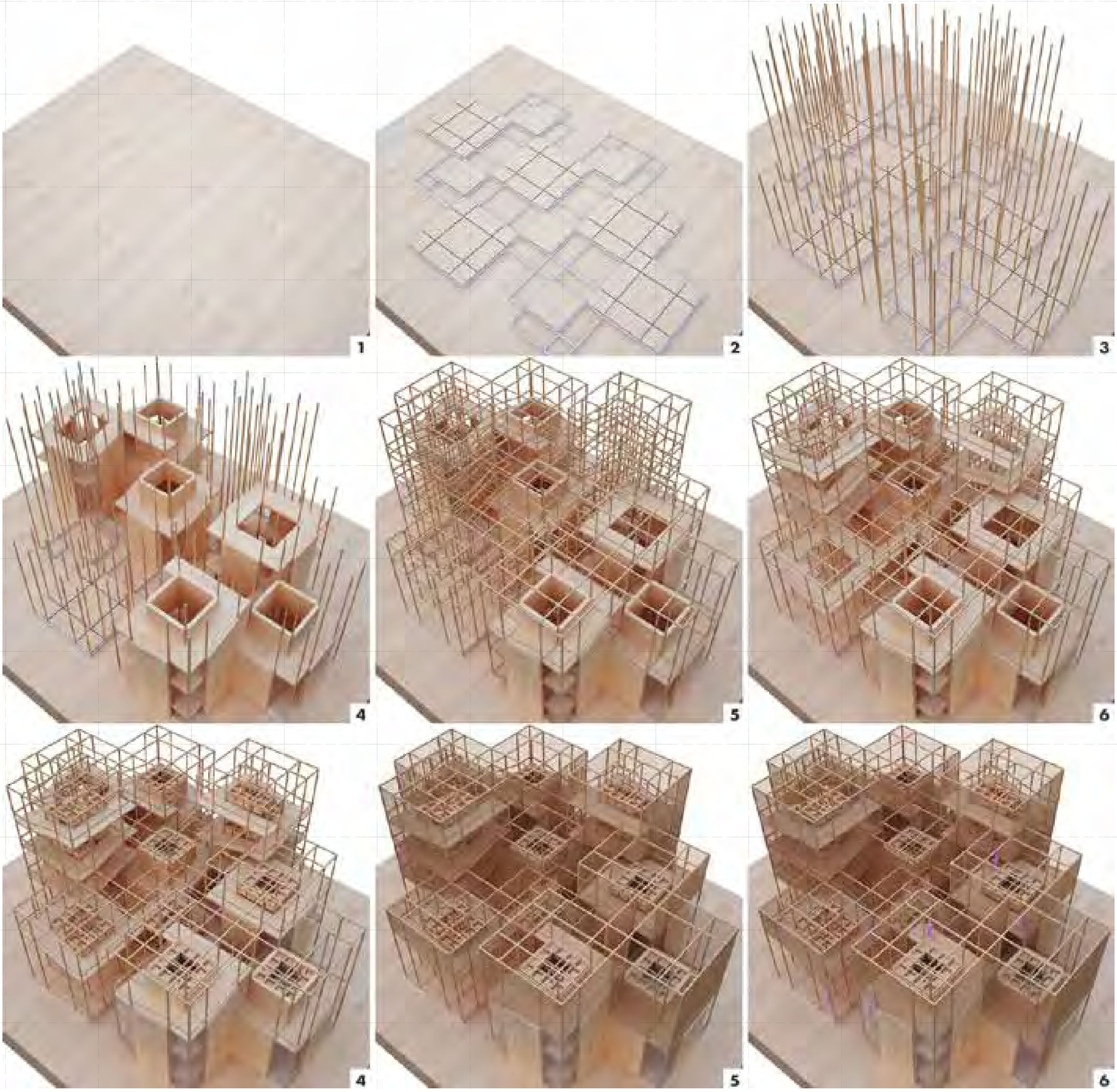


A.3 Conceptual Design diagrams (Penda, 2019

The modular wooden village

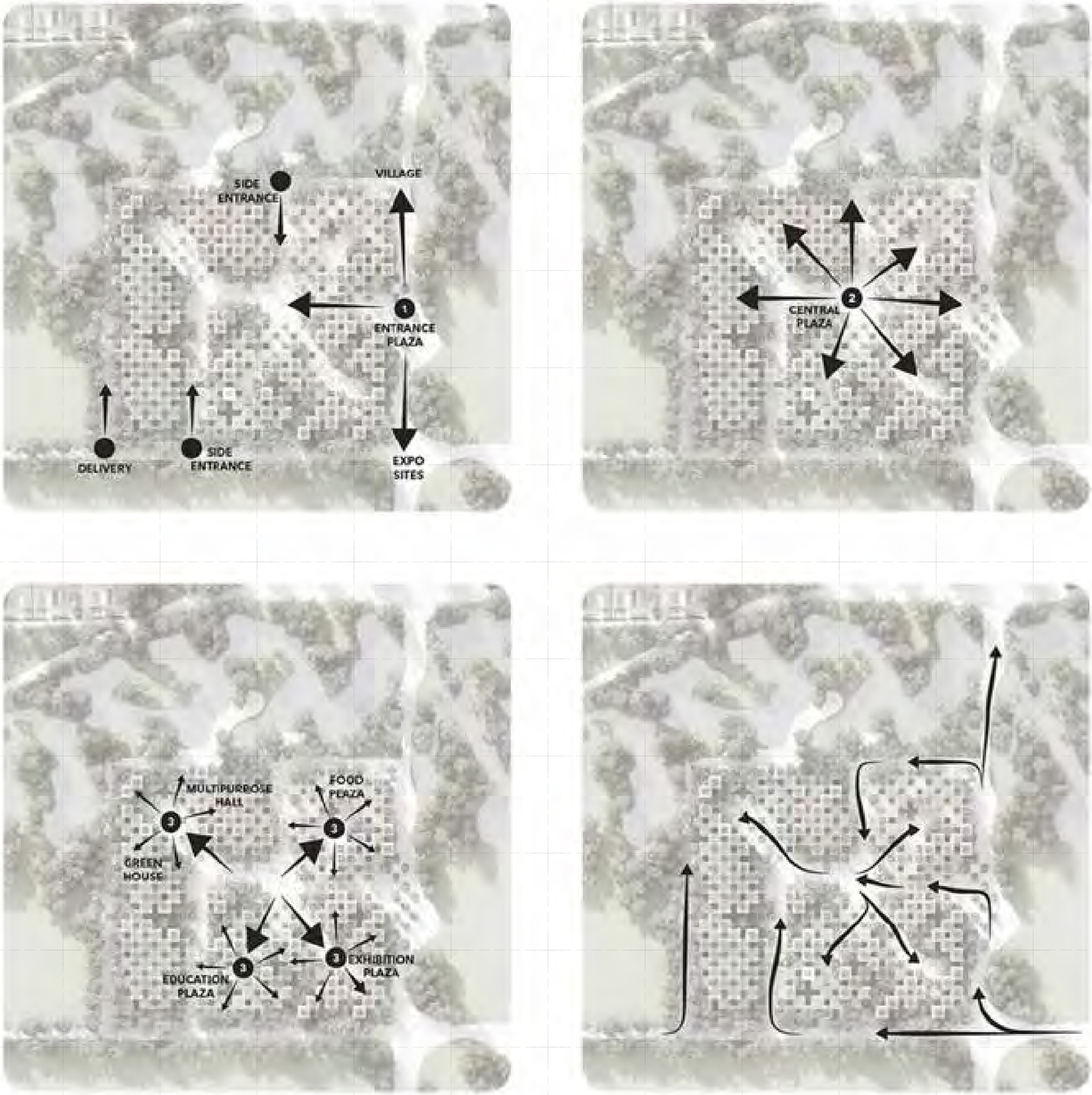
Architcture studio Penda has plenty designs featuring wooden frames and prefabricated modular timber buildups, and this project is no different. It is designed to host the International Horticultural expo of 2019 in Beijing, China. The project covers 30.000 square meters and is designed to be easily transformed into student housing or other future uses .

The project challenges the conventional approach of an exposition by dispersing the exhibition spaces, routes and thereby also the public over many small units, rather than one large building. The plan thereby spans a large area, but with small units that emanate a village-like ambiance. The experience of the exhibition becomes much more dynamic and individual, as people do not have to queue and follow a singular path. To further immerse the people in the horticultural experi-ence, visitors are given seeds and encouraged to plant them somewhere in the planters that are along the



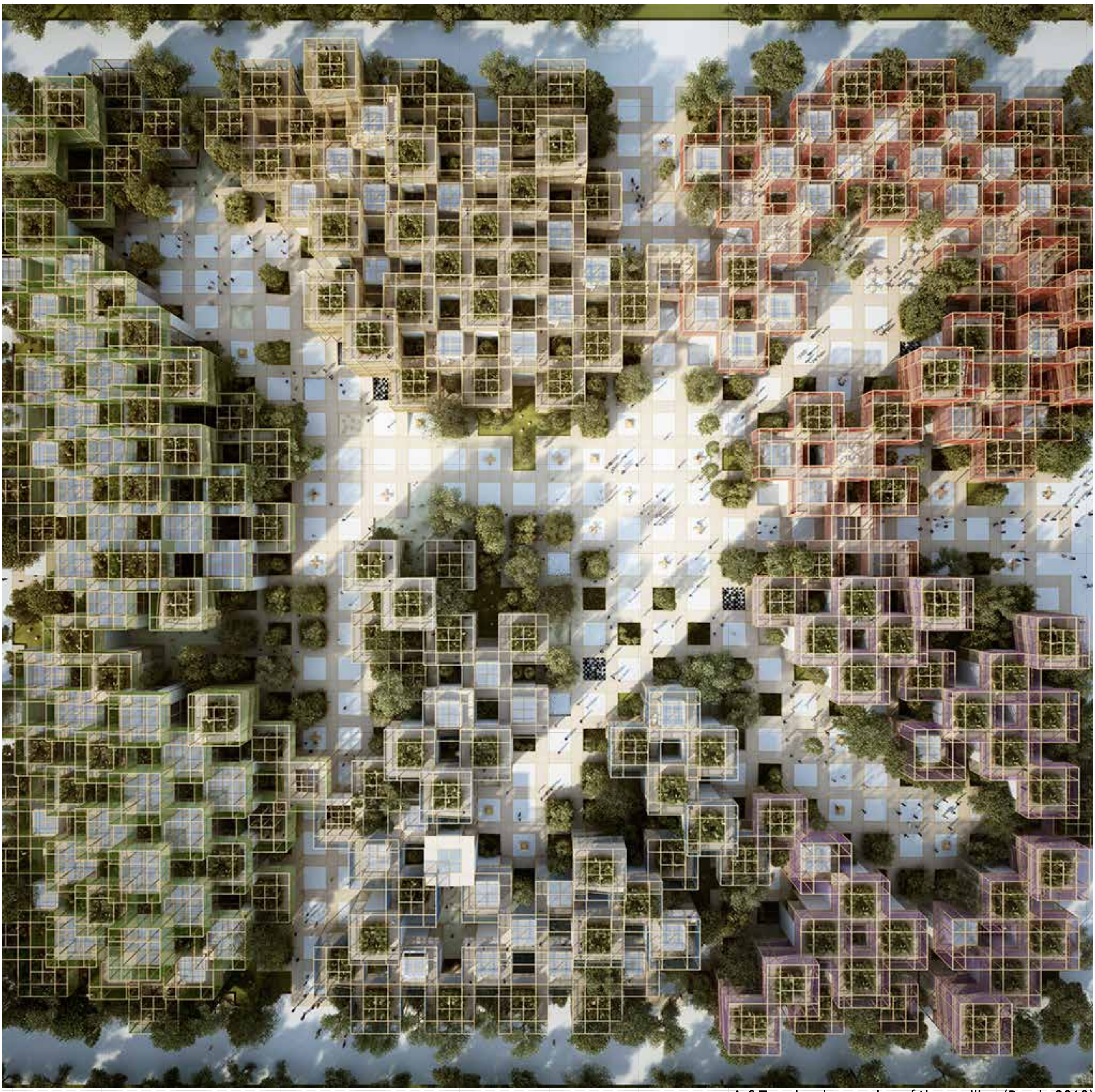
A.4 A model showing the structural buildup and infill of the modules (Penda, 2019

pathway structures.
By working with a modular grid stucture, the design infill can be built up out of components that fill in the framework in a varied way.
The organisational structure of the modules and smaller cells is inspired by traditional rules of urban planning in ancient Chinese culture. Closed units are alternated with slightly smaller units for green. The offset space between the frame and green infill is used for a connecting pathway and further circulation.



A.5 The routing and circulation of the pavilion (Penda,2019)

The main entrance is situated on the east side of the project, with two main entrances on the north and south façade (1). All three entrances are connected to the main plaza from which visitors can go explore the different areas of the pavilion (2). Each section is allocated a main function, being, food, exhibition, education, green house and a multi-purpose hall (3). As people are free to choose the direction and order in which they go through the different parts of the pavilion, inviting to explore and thereby making each experience of the pavilion unique (4).



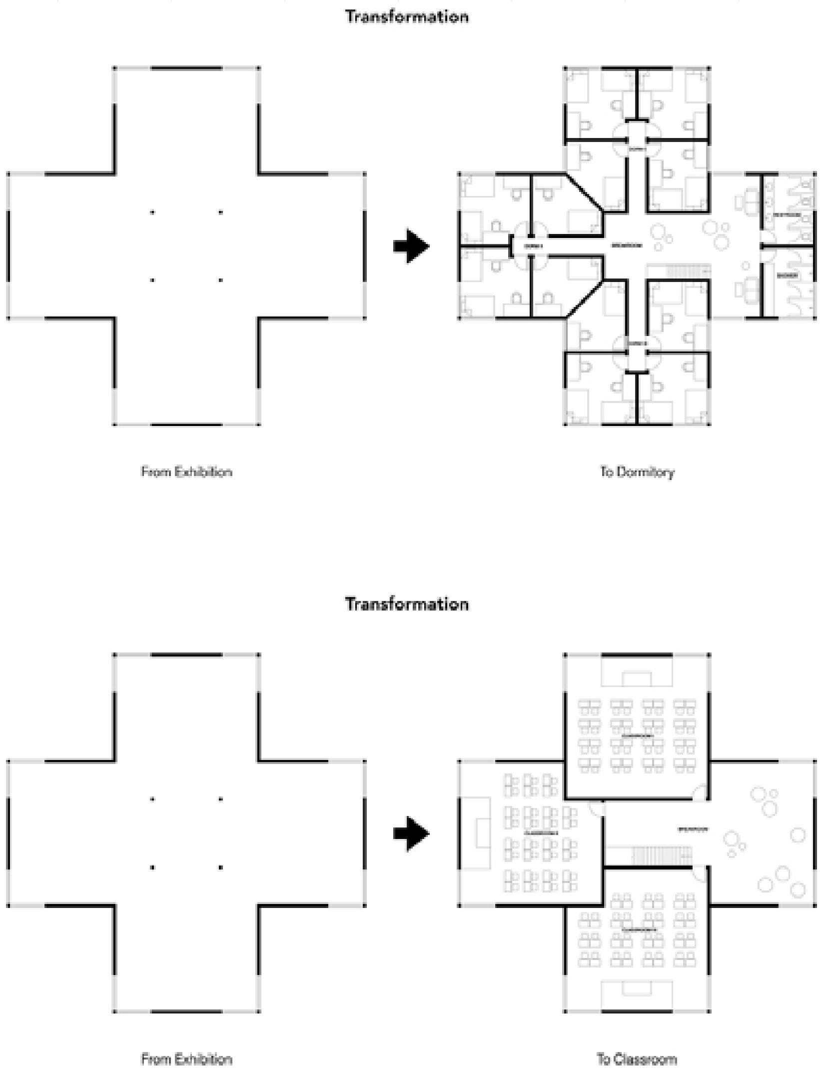
A.6 Top view impression of the pavilion (Penda,2019)

As the functional organisation is distributed in zones, each have their own area. To mark this, the semi transparent façade wrap made with coloured rope is colour coded to each function.

Green = Greenhouse
light Blue = Urban Gardening
Red= Food Court
Yellow = Multi-purpose hall
Blue = Lab & Education.

By using this approach the visitor is able to orient themselves and the functions are differentiated in a subtle, and in another context neutral manner. This approach fits completely within the grid design and is also easy to change or remove if desired for future changes or transformations. However because of this abstract way of signage, it is probably not even necessary. This increases the resilience of the structure as it does not have to undergo massive transformations, as the for example transformation of an office building to residential space would.

A.7 An interior impression of part of the pavilion (Penda,2019)



A.8 Two options for future transformations of the pavilion. (Penda,2019)

The rope façade infill creates a diffuse transition from one space to another, making them all connected and providing an intermediate transition space to the interior spaces. It acts as a decorative, but also practical design element as it also functions as the balustrade alongside the edges.

The image above shows two possible transformations of the pavilion after the expo event. One shows the setup of student dormitories, the other that of classrooms. The 8x8m grid that is largely uninterrupted by columns allows for plenty of other infills as well.

By designing event spaces that are used shortly for their initial use while keeping in mind its future transformed uses, one works with a much more sustainable approach than when it would be completely tailored to its singular function that is much shorter than the lifespan of the building itself.

Interpretation of the Project

From the previous chapters on biophilic design and biobased materials, the beneficial effects of incorporating these elements into a design have become clear. When experiencing the expo, or the later transformed building, one is in constant contact to green, and by having diffuse boundaries also have the sensorial connections to their surroundings. By dispersing the expo over a large area and a multitude of spaces, one is encouraged to explore and discover, another part of biophilic design thinking.

The architect intends to promote a ecological co-existence with our natural environment
The intermediate spaces the open frames and the semi-transparant infills create allow for a fluent, gradual transition from inside and outside, creating a flow in which green and building co-exist in one structure. By having the stacked volumes that overlap and are connected with a pathway also offer a basis for community forming in combination with the green and recreational functions.

The modular grid with just a few variations can be prefabricated with standard elements, and can accommodate public and private, and interior and exterior functions with one system. This makes the system adaptable and thereby more resilient.

An important note is that it does not appear to have been executed, which is why one cannot determine whether this particular project is structurally and economically feasible in the way it is currently presented in the renders. Nevertheless, the project offers multiple interesting facets that serve as inspiration for future designs.

The Oasis Terraces project and this pavilion design by Penda offer two approaches to integrating building and green into one structure as inspiration and have informed the design of this graduation project, the Oasis Retreat.

Text Sources:
Penda, A Thousand Yards (2017). retrieved from https://www.behance.net/gallery/47359603/A-Thousand-Yards on 19-02-21
Frearson, Amy (2017) retrieved from https://www.dezeen.com/2017/01/19/penda-thousand-yards-pavilion-modular-wooden-village-beijing-horticultural-expo/amp/ on 19-02-21

Image Sources:
Penda, A Thousand Yards (2017). retrieved from https://www.behance.net/gallery/47359603/A-Thousand-Yards

A.9 a perspective impression of the pathway, connecting the different spaces (Penda,2019)

The Concept

M4H transformation for people

The project is situated in M4H, a transitional zone of City and Port which is to be transformed to accommodate residential use. The development of the area is intended as a living lab to explore new ways of living.

This community cluster is offering a green oasis to retreat in the urban. It offers what is often lacking in highly urbanized cities and industrialized ports; qualitative green space and community.

Blurred boundaries are essential in the architectural design of this project, to optimize the contact with both the green and the community. Ones daily life is strongly embedded within the green on different levels, and the spatial design uses intermediate spaces to create a gradient of spaces in which one can engage anywhere on the spectrum of extrovert interaction to introverted retreat.

By integrating this principle on both the small and big scale, the opportunity to live and retreat in the green also becomes accessible to the public community of Rotterdam and beyond.

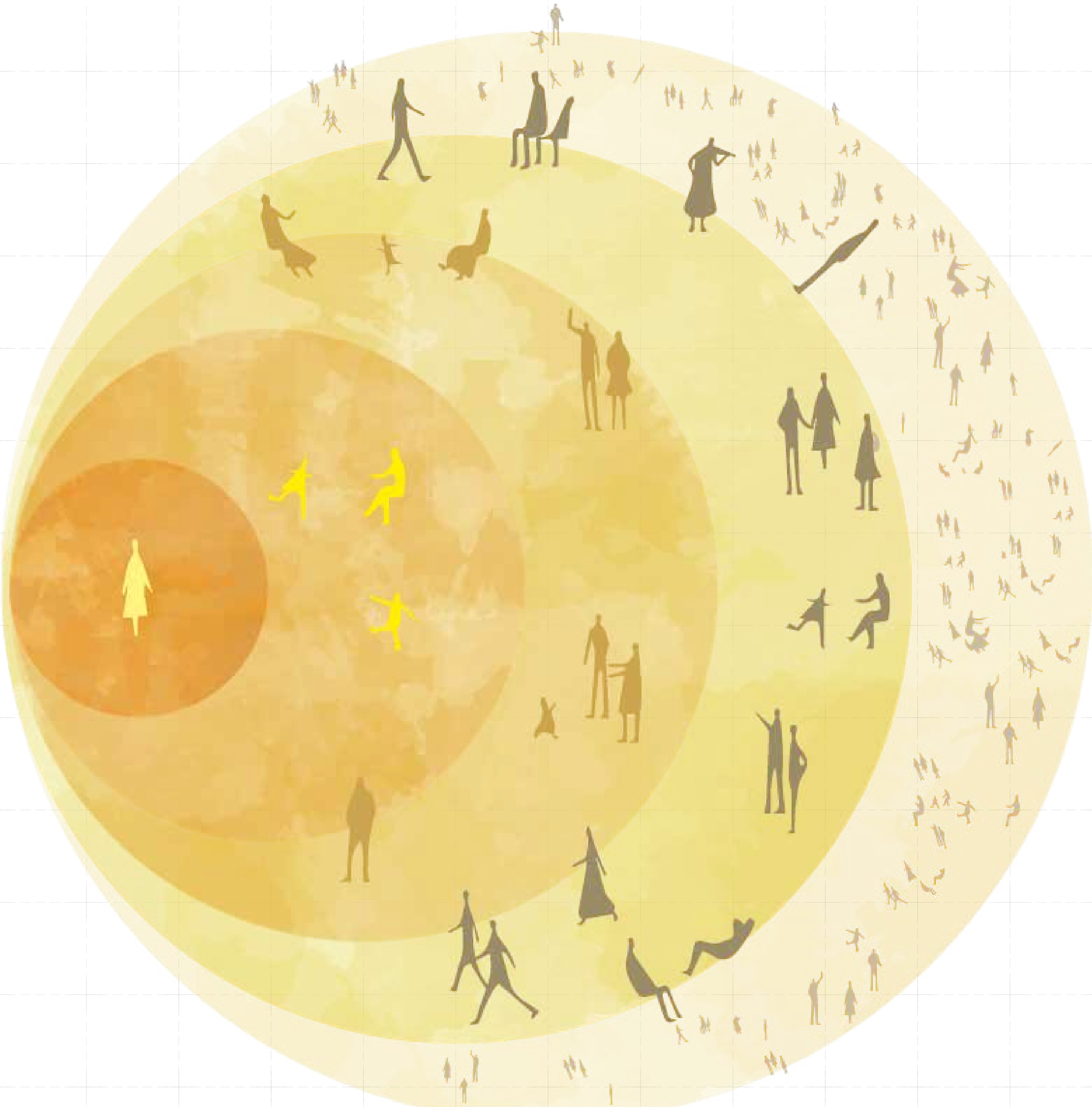
The Concept
Blurred Boundaries

From introverted retreat to extravert interaction, and the blurred boundaries between the different gradients

The principle of blurring boundaries is essential to this project. This is two-fold: To be immersed in the green and in contact with nature, and to have low thresholds (figuratively, but also literally) to be in contact with neighbours and others to form a community. By doing so one's daily life is immersed in the green and part of a community in which spontaneous interaction is facilitated.

These blurred, soft boundaries are found in the large scale where one can interact with their community members or visitors of the area in an active or more observant way, or retreat to ones salvaged private space. On top of this, this concept is translated into the materialisation and facade design, playing with softness of light and the tactility of materials.

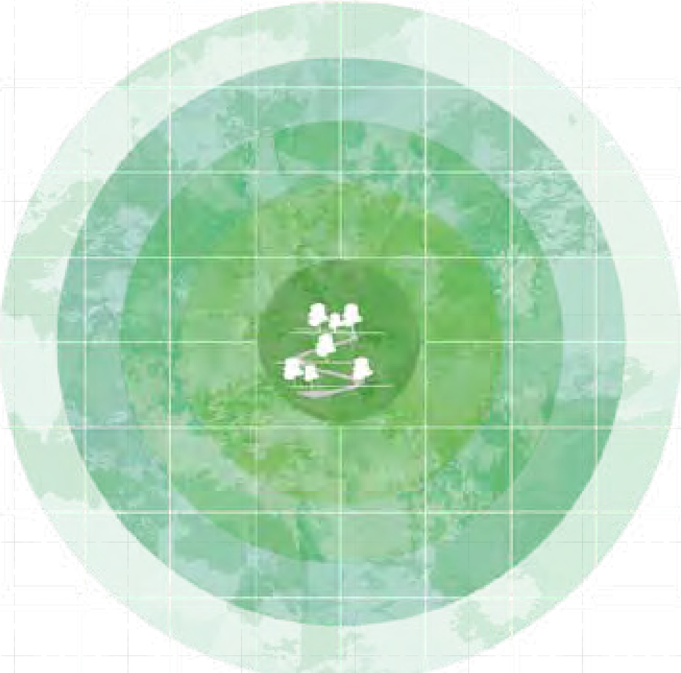
The Concept
Community



The gradients of community

Within the Oasis Retreat there are several levels of community, with each their different kind of relationships and connections to each other. These levels range from the most intimate and personal to the public and communal.
The self is the most personal relationship, followed by ones family. The third layer is the community cluster; the close-knit community of neighbours who share porches, green space, facilities. They are in regular contact, albeit by coincidence or by invitation. The residents know each other and their interaction is facilitated by providing shared spaces, which are enclosed by semi- shared, semi-private and finally private spaces. This creates an inviting atmosphere to chat to a neighbour on the shared porch, to stay for a drink while grocery shopping or to share a walk in the park.

The Concept
Retreat in the Urban



The Oasis acts as the green heart of the community cluster

The design is organised with multiple green zones, and the internal oasis landscape functions as the heart of the project, creating a place for interaction, relaxation and recreation for all. The pathway connects all and functions as a red thread, or 'backbone'. The used permeable framework structure ties it all together as a unity of smaller subclusters.

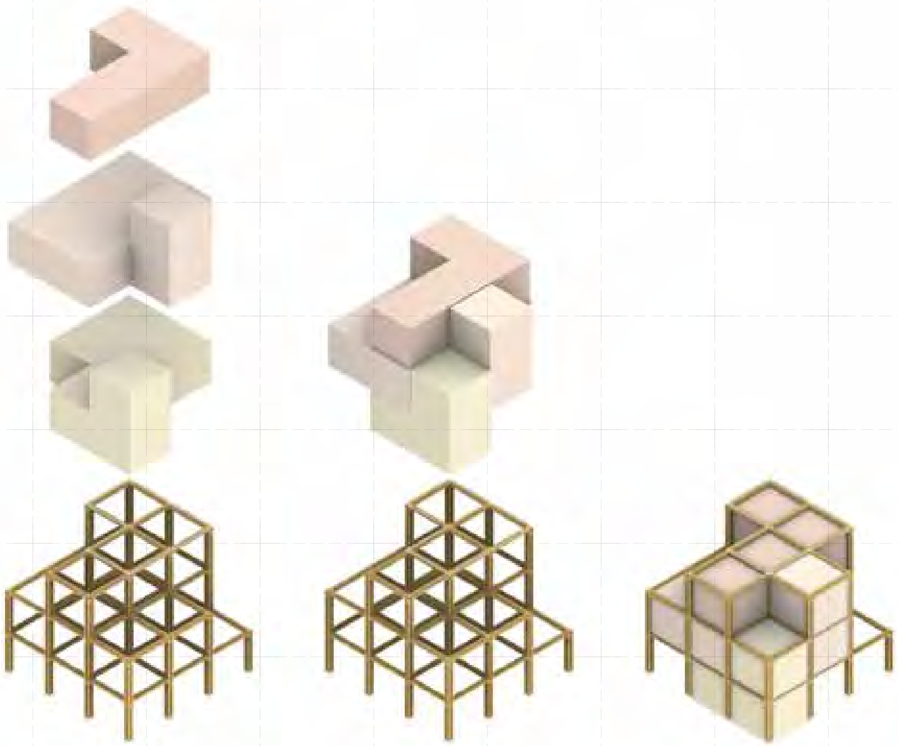
Living in the green has been proven to improve people's wellbeing and benefits the local environment and ecology. In the Oasis retreat, this relation to nature is intensified: one lives with the green. By using a range of green structures, landscapes and infill and by integrating it with the building structure on multiple scales, the green encapsulates the building, and the building encapsulates the green. This allows for a direct contact with the green or water on all places and scales, in which inside and outside flow over into each other.

The Oasis Retreat project is also a statement on the importance of rekindling our inherent relation with nature, and to design with, and for nature by reallocating man-claimed space to restore balance.

Biophilic aspects are also incorporated by working with natural materials, meandering paths to explore a sequence of spaces, creating a denial and reward experience. The internal oasis is designed as a layered landscape
The perforated shutter panels mimic the light filtering of treetops, creating varied light patterns throughout the day. The shutters help create the desired combination of direct and indirect light. All residences have waterside and/or oasis views and are open to at least two sides, allowing natural ventilation.

Ster House- Delution Architects
Image source: Delution Architects, 2019. Retrieved from https://www.archdaily.com/946766/ster-house-delution-architect on 21-01-21

The Concept
Grow & Ungrow



Volumetric diagram showing the volumetric 'tetris' infill of the 3D plot

Resilience

The permeable framework is filled in with void, green, terrace or interior space, thereby holding together the interior& exterior and green in one coherent framework.

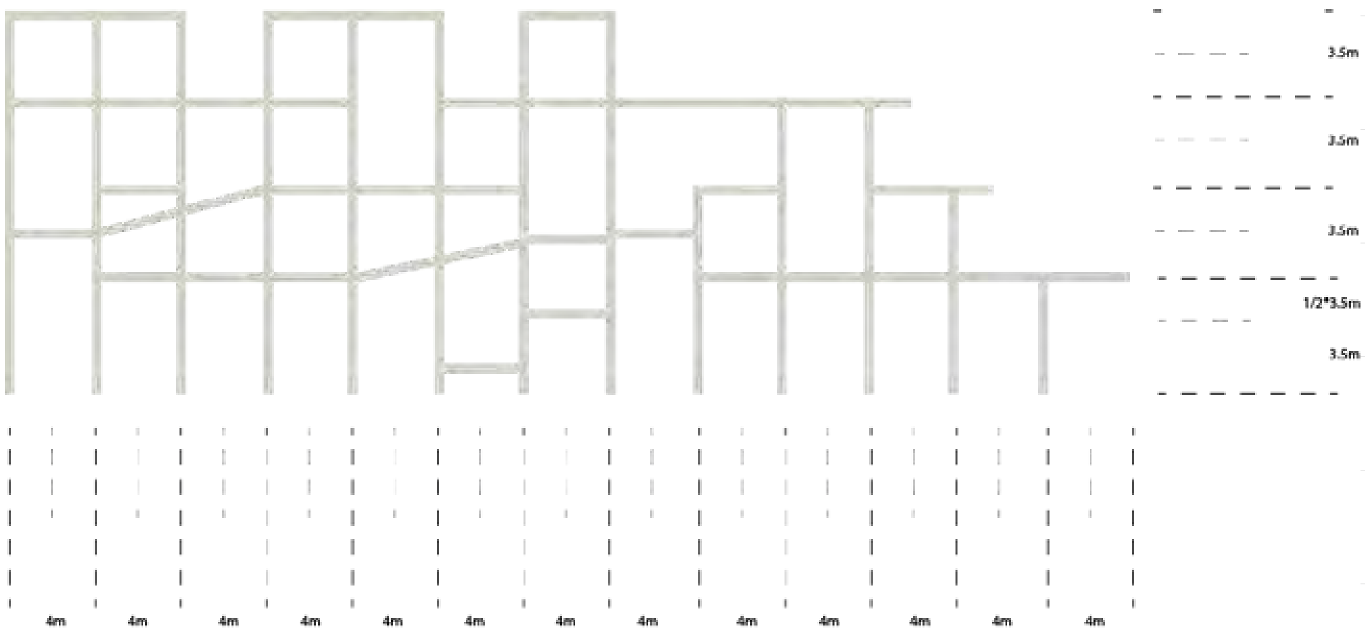
The structural system is based on a grid and on a principle of growing and ungrowing. This is to increase resilience by having a flexible and adaptable structure and infill, using a straightforward construction principle comprised of CNC milled, prefabricated components. The columns are milled with support coves, which can be placed anywhere, but as a standard will be placed on single or half storey heights.

Affordability & Customisation

Another reason for this setup is that housing becomes more affordable and accessible.
The principle is to buy or rent a 3D plot, being a framework of 3 layers of 3x3 grid cells.

According to one's financial means, they can opt for a more or less filled in house. Throughout time, it is possible to let the house grow or ungrow along with the user(s) and their changing needs. In this way the house can grow and adapt over time, spreading the costs over a longer period, thereby making the housing more affordable. This also allows residents to make their house their own, tailored to their personal preferences.

Digital Fabrication



The structural setup with the grid

Structure

The grid-based structure will be a CNC-milled column and beam framework structure. By means of mass customisation the beams and columns are prefabricated with single or double length, support coves at single or half height, in the desired numbers.

Skin

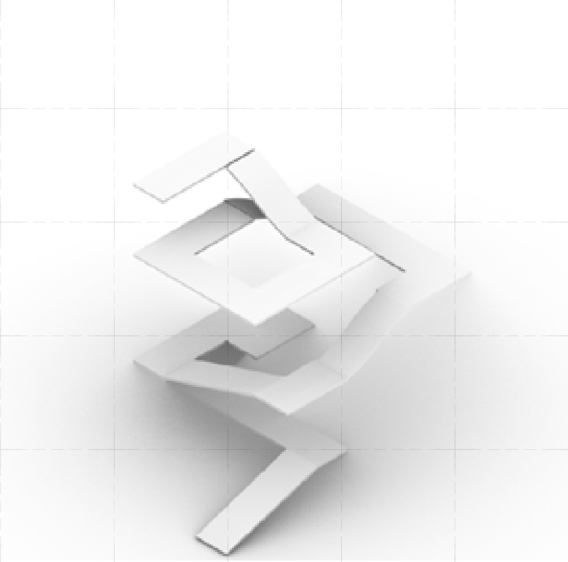
Digital fabrication and parametric design are excellent vessels to design for the desired softness of this design. It is applied for two elements: The façade shutters and a 3D tile ceiling.

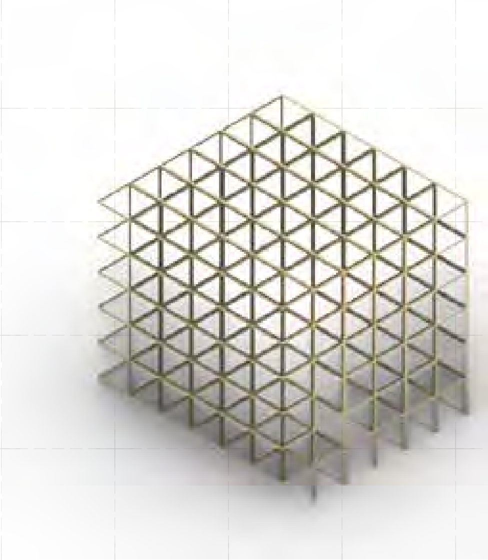
The wooden shutters are perforated according to a parametric pattern based on attractor points of an abstracted image of Rotterdam vegetation. This creates a play with abstracted shapes and varied densities. The perforated panels filter the light, creating a play of patterns in the internal space, and creating an intermediate separation between spaces, or the interior and the outside world.

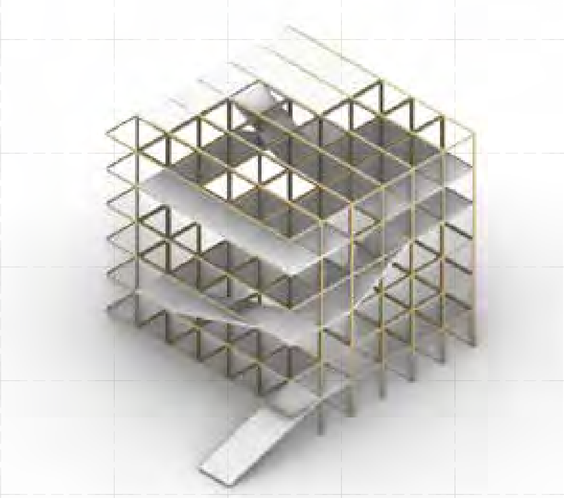
The 3D tile is based on a parametric setup that is based on sinus graphs. the wavy curves of the tile create soft shadows and form an abstract reference to waves and other curvy forms found in organic shapes. it forms a countershape to the orthogonal framework.

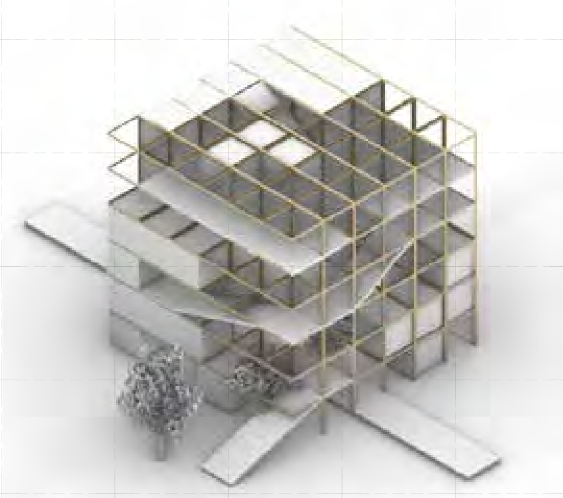
Design Development

Preliminary designs

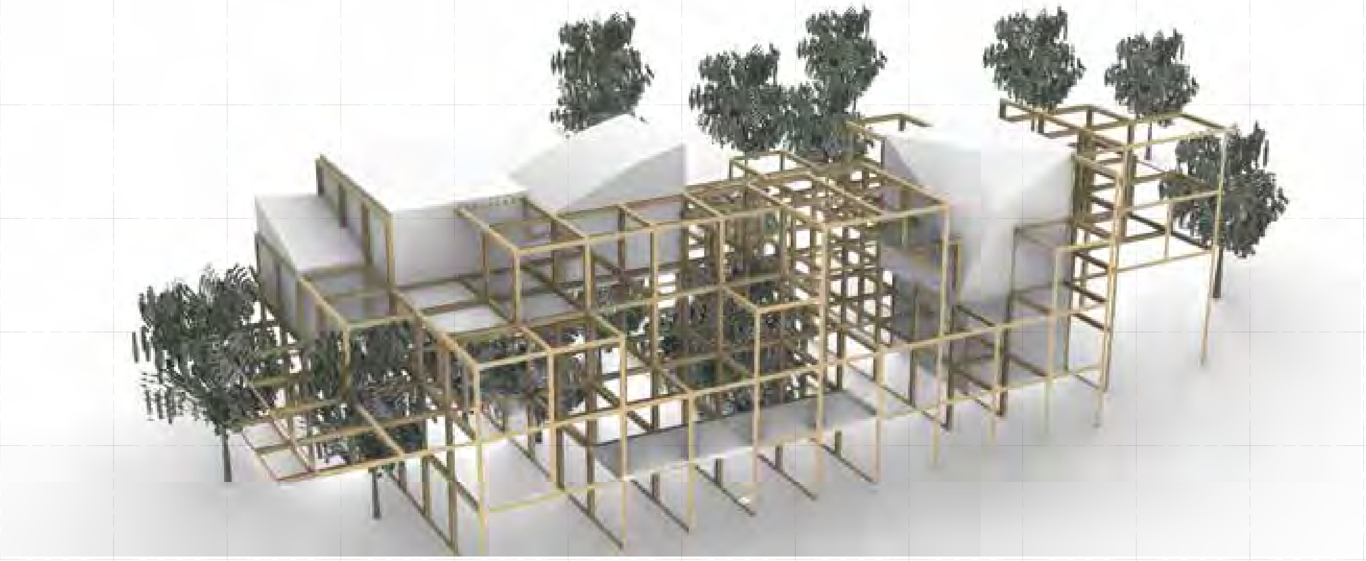


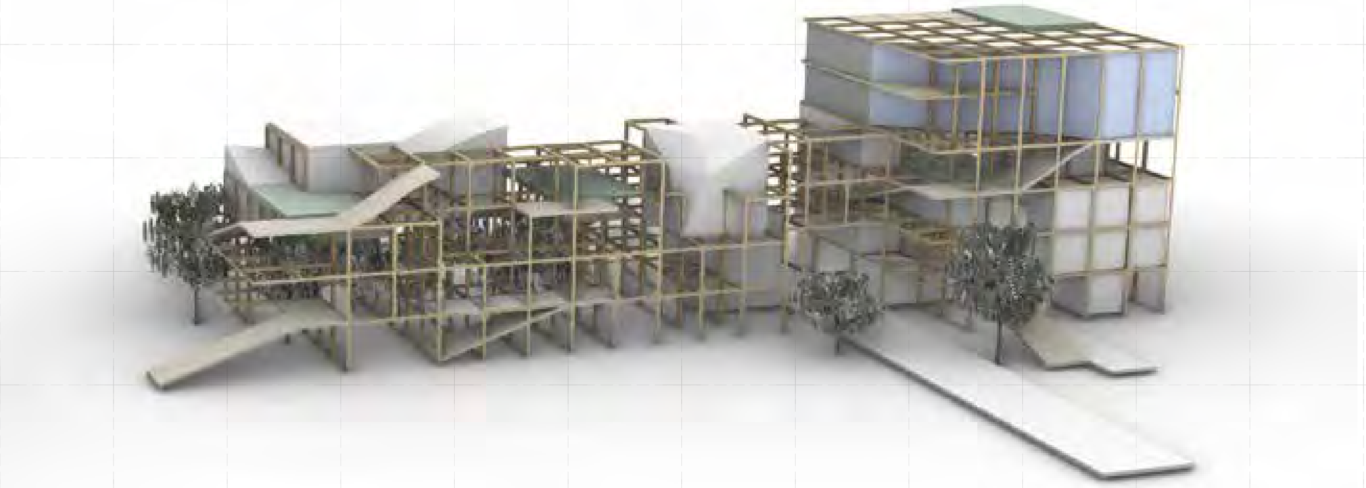




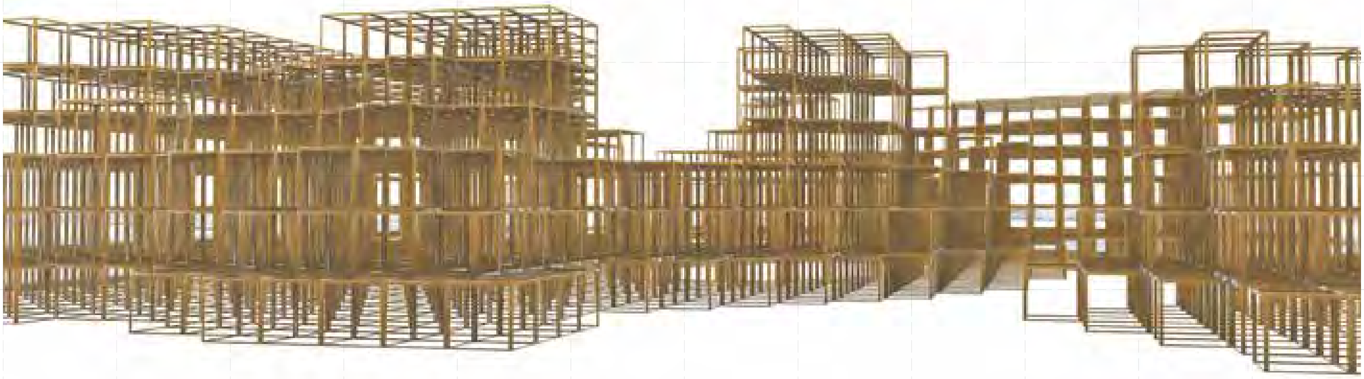


The design of the framework, form, and infill has been explored with different approaches. In these images, the conceptual approach to combine pathway green and volume into a framework is shown step by step.

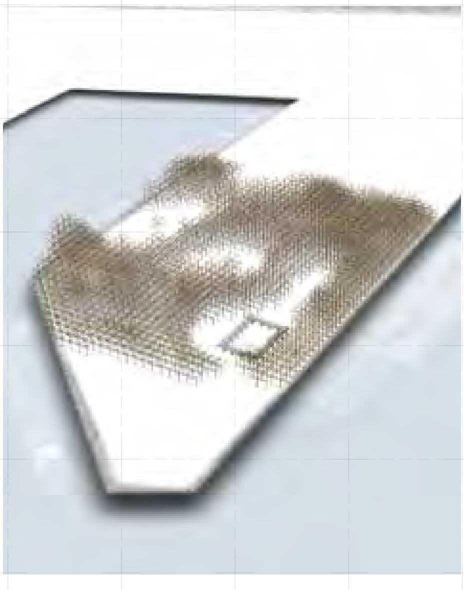


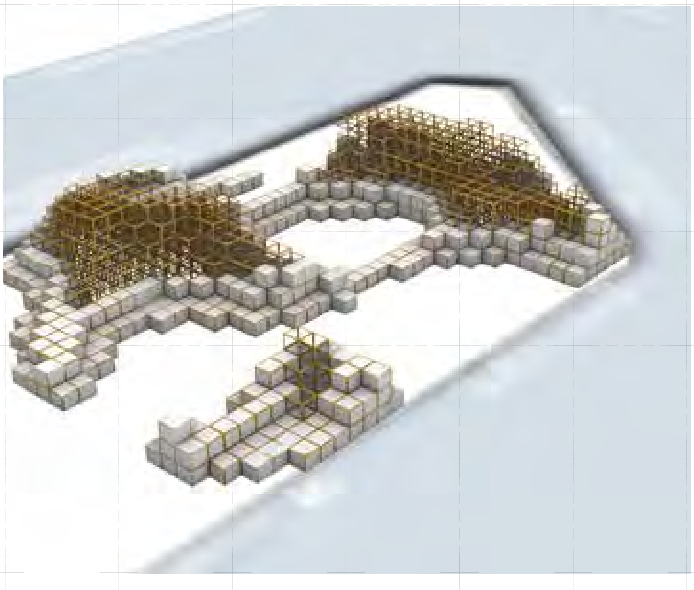


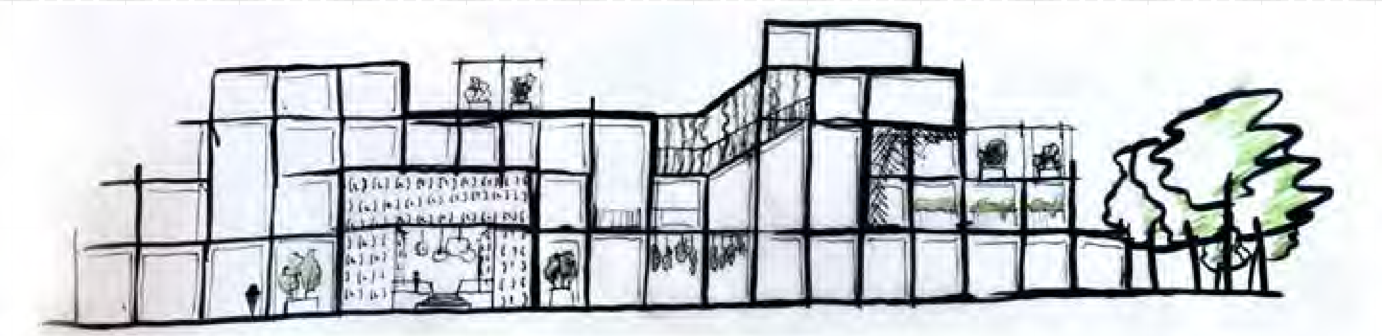
This conceptual image shows tree house villas in an open framework that spans over trees. The second image shows a possible combination with a spa volume and denser infill of apartments.



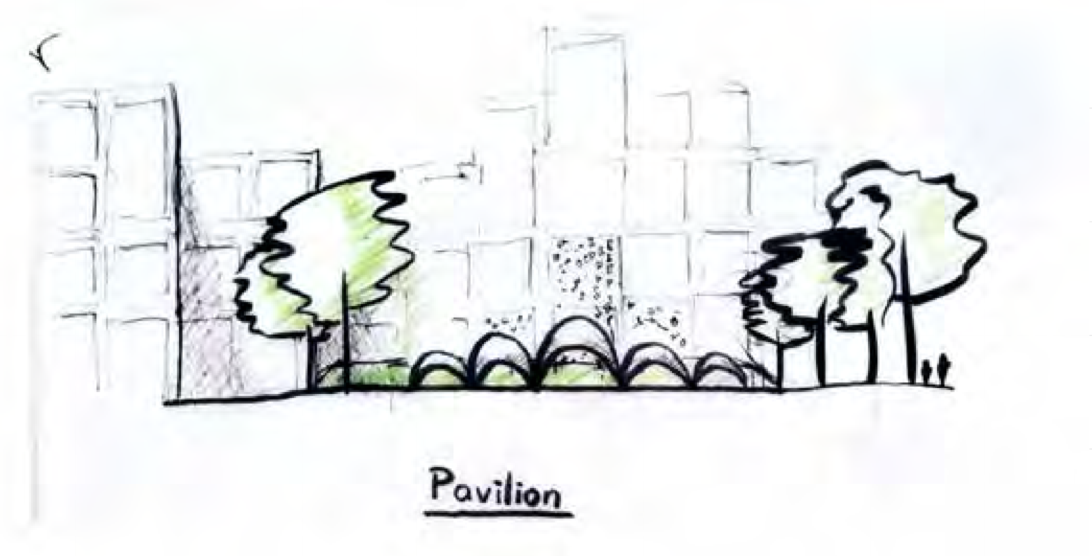
Here we see tests of a parametric approach of the concept. By defining the desired green areas, and removing an x amount of frames based on their distance to them, the spaces are opened up. The second step was to populate the grid with voxels at the closest edges to either one of the green spaces.



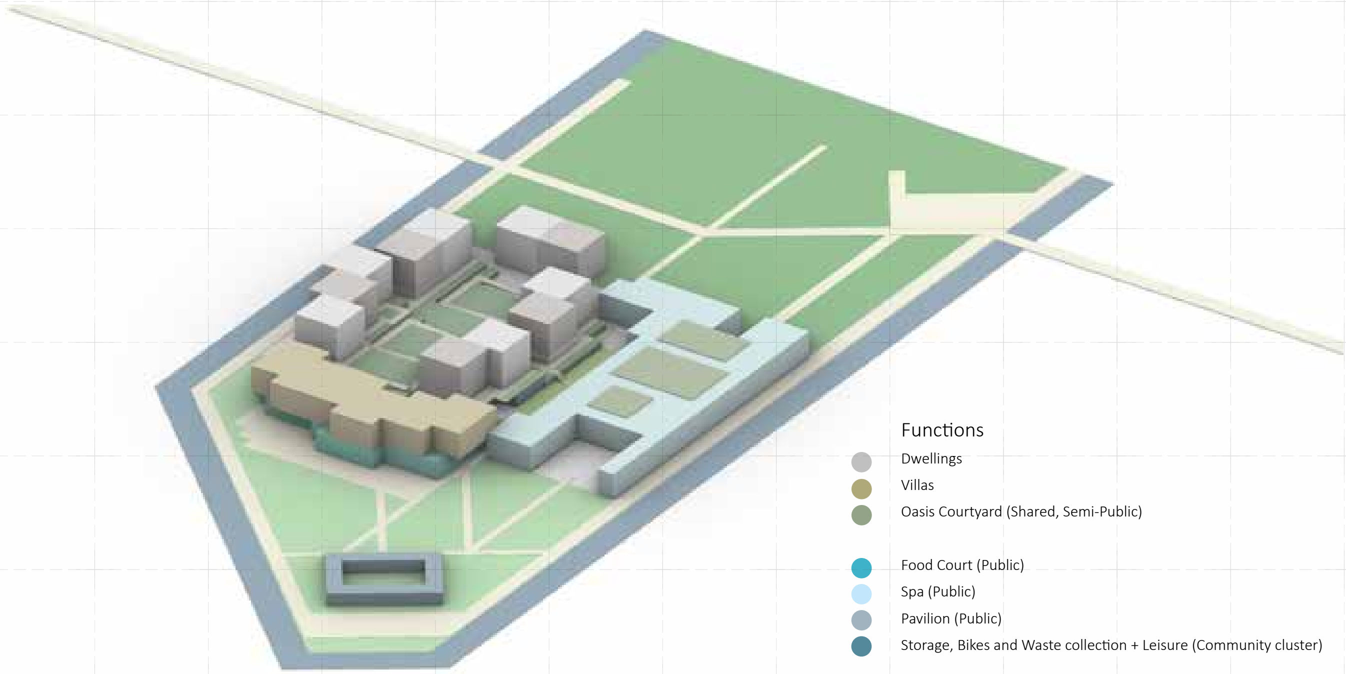




These two sketches are explorations of the integration of the curved, parametric pavilion and 3D tile in the context of the orthogonal framework.



All of these steps in the design development phase have contributed to the end result of the final design.



The Functions

Design Strategy

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The Oasis retreat houses a community cluster, spa, food hall, pavilion and lush green space. It offers relaxation, interaction and retreat space in the green for the residents of M4H, Rotterdam and beyond.

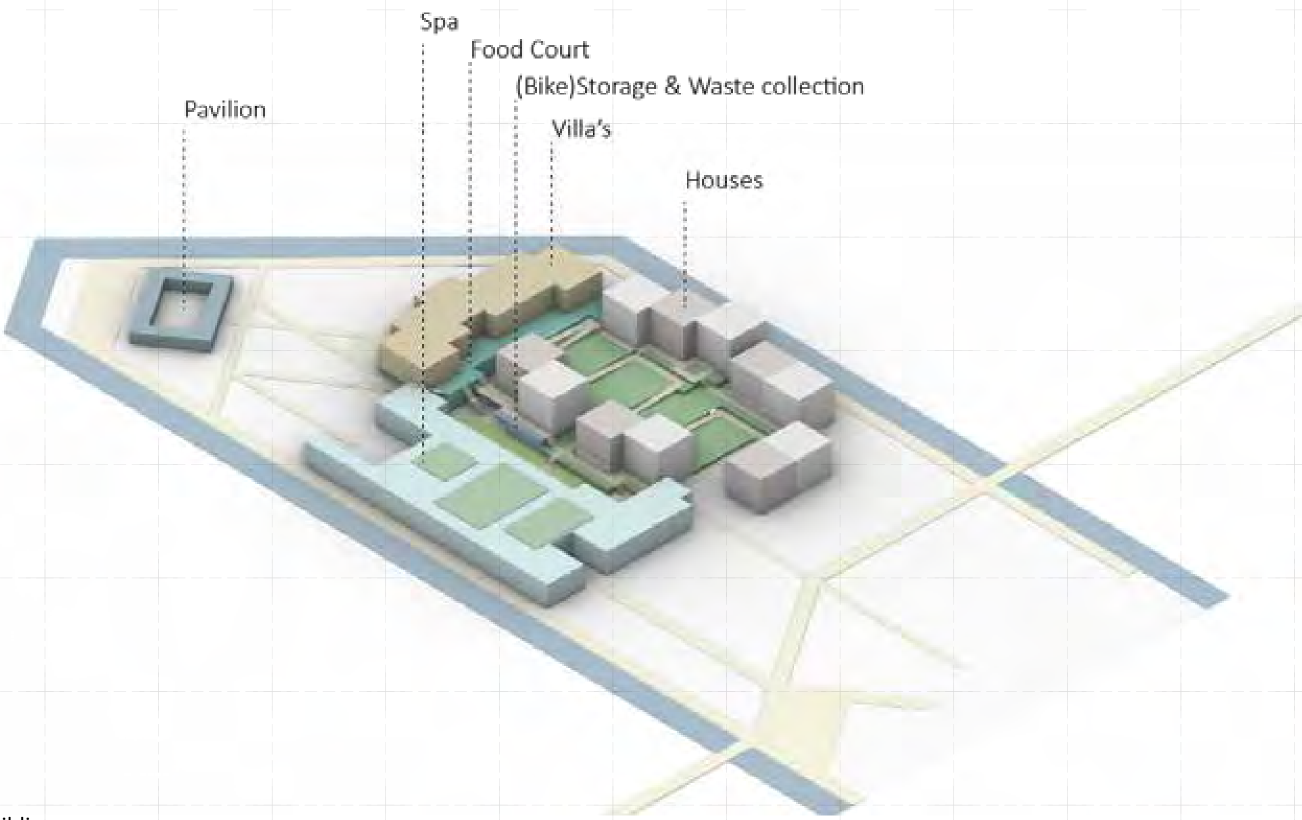
Living in the green
The green is the heart of the building, and building and green intertwine. This large courtyard is designed as a stepped landscape that creates a gradual transition along the levels. it is the key focal point of the project area. A pathway through the green areas provides access to the functions as a backbone to the plan.
The program is planned around and under the rising landscape, making for a layered relationship between the green and the building.

Biophilic Design
Natural materials, shapes and more abstract references to nature are also incorporated in the design. One experiences the sounds, smells, sight and touch of the Rotterdam flora and fauna, the changes throughout the seasons and throughout the day. The meandering paths invite to explore. Places to retreat are facilitated within the home and on the larger scale by shared porches, the green spaces the pavilion and the spa.

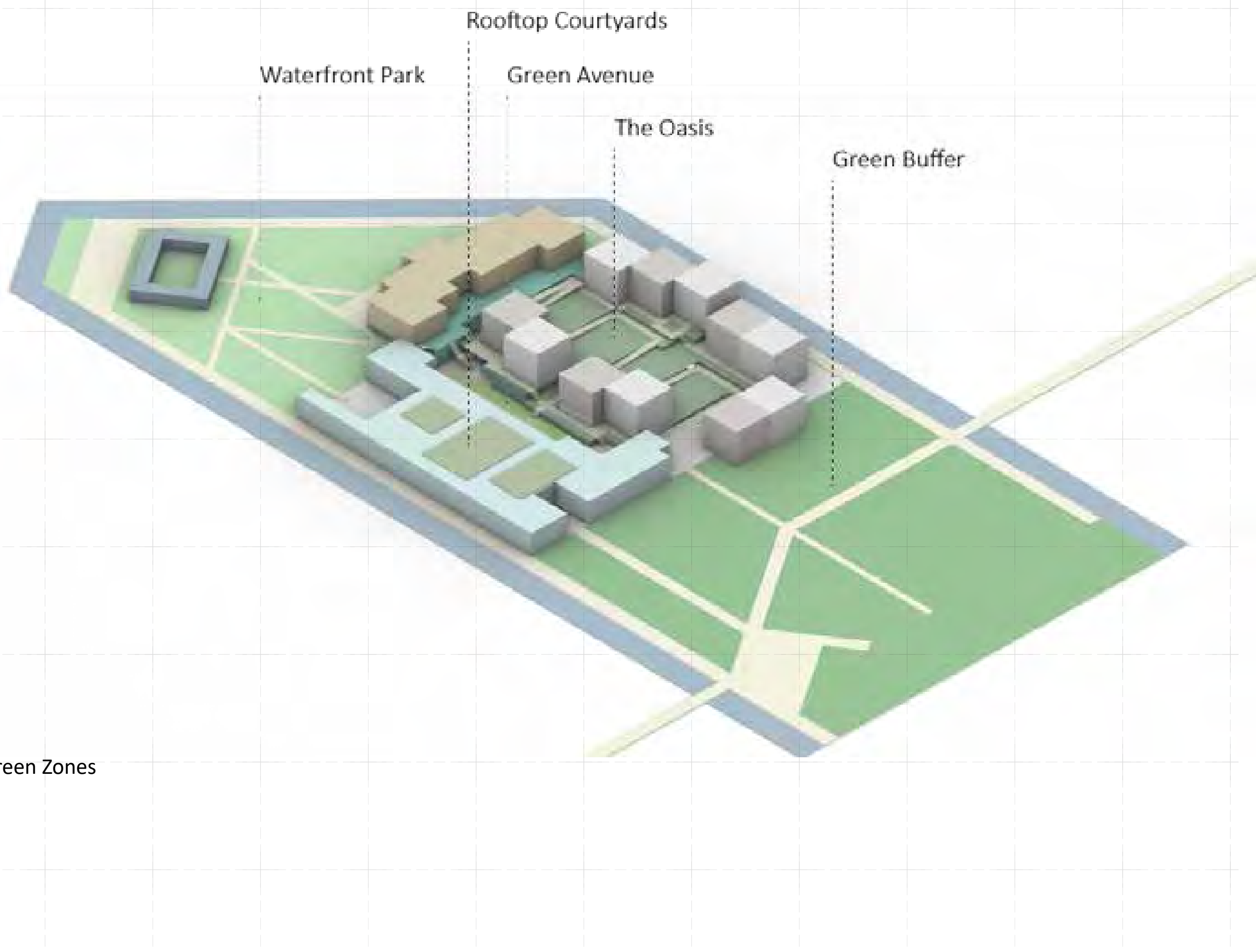
By incorporating this large qualitative green, the local climate is improved in terms of air filtration, heat mitigation and water runoff. Nature is once again invited in the port area and is given space to co-exist with mankind in a reintroduced balance. Besides the short-term benefits, on the long term this approach will benefit us and our environment as well, as the ecological balance is improved.

Grow & Ungrow
By designing a flexible structure and infill that can accommodate both interior and exterior spaces housing a private or public program, the design can respond to a change in demands or wishes throughout time, making it resilient. It can respond to changes on both a scale as small as 1/9 of one unit, or as big as the whole location.

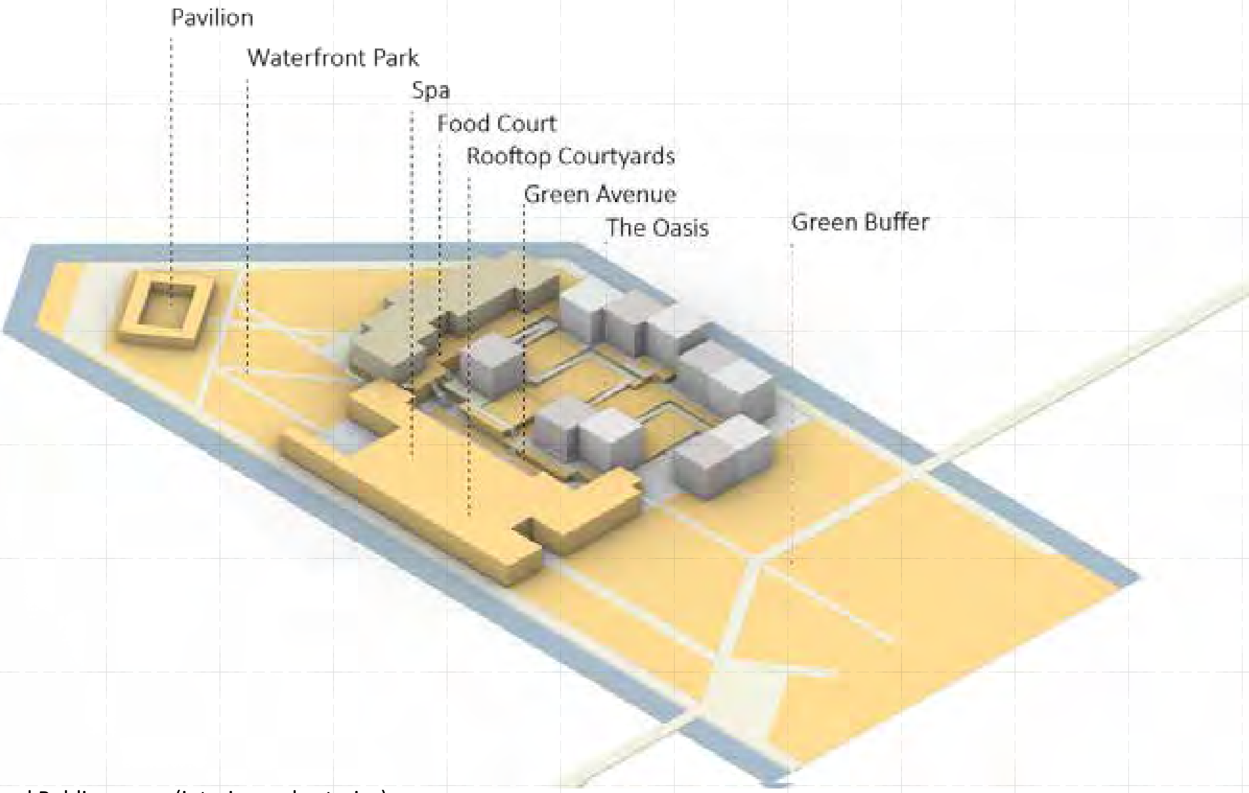
Community
A food court accomodates for groceries and serves as a restaurant in which several local companies serve their customers. Together with the aforementioned functions, green spaces and pathway, these spaces are designed to invite to linger and explore. This to soften boundaries and thereby minimize the threshold for interaction to facilitate the forming of community.



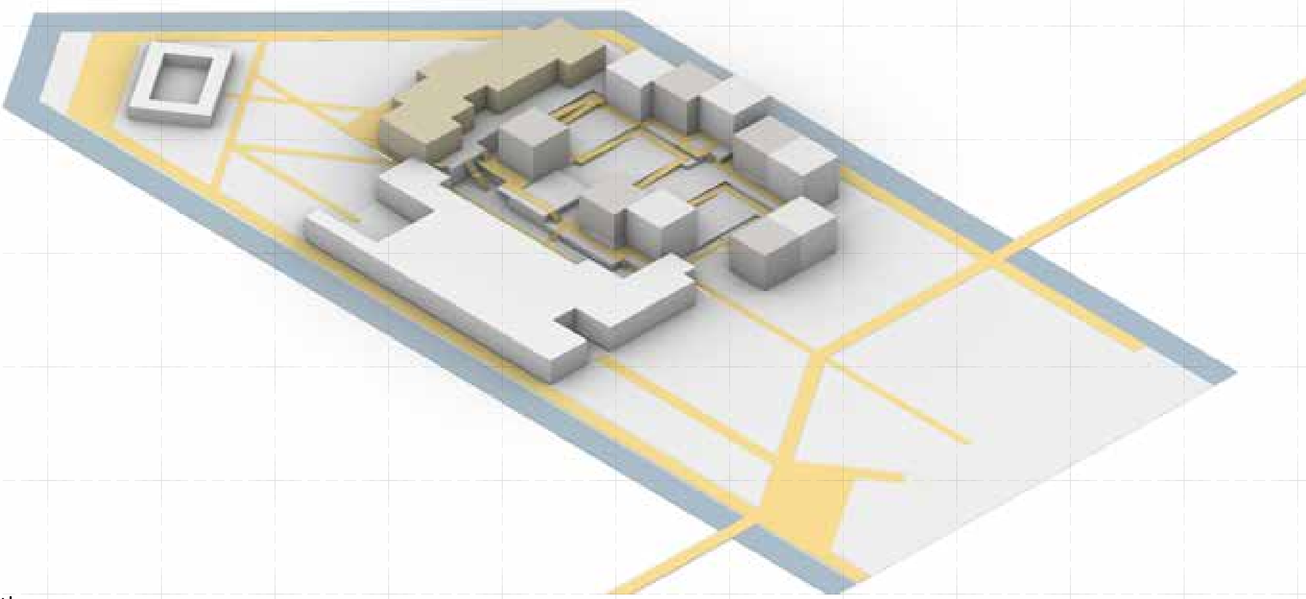
The Buildings



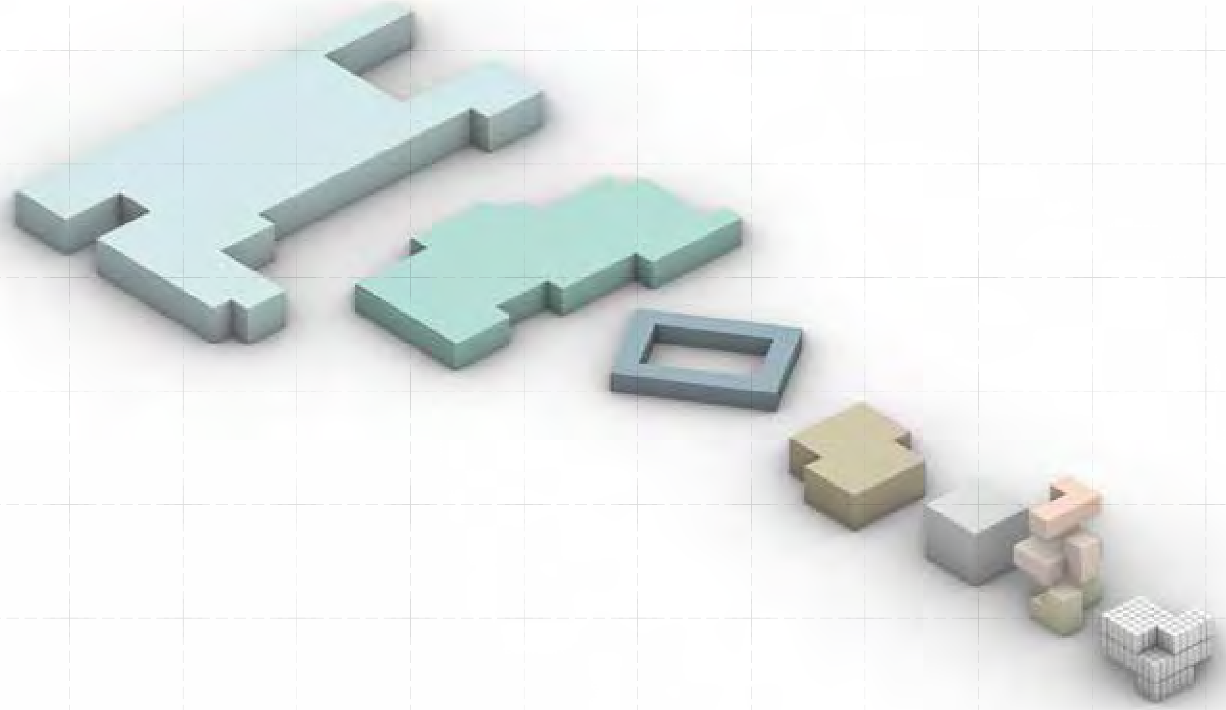
The Green Zones



The Shared and Public spaces (interior and exterior)



The Pathways



The volumes of the functions, all based on the grid measurement, organised from the big to finer grain.

Community/Public
Spa - Food Court - Pavilion

Private
Villa - House - house layers - 3x3 division of single grid cells for interior infill

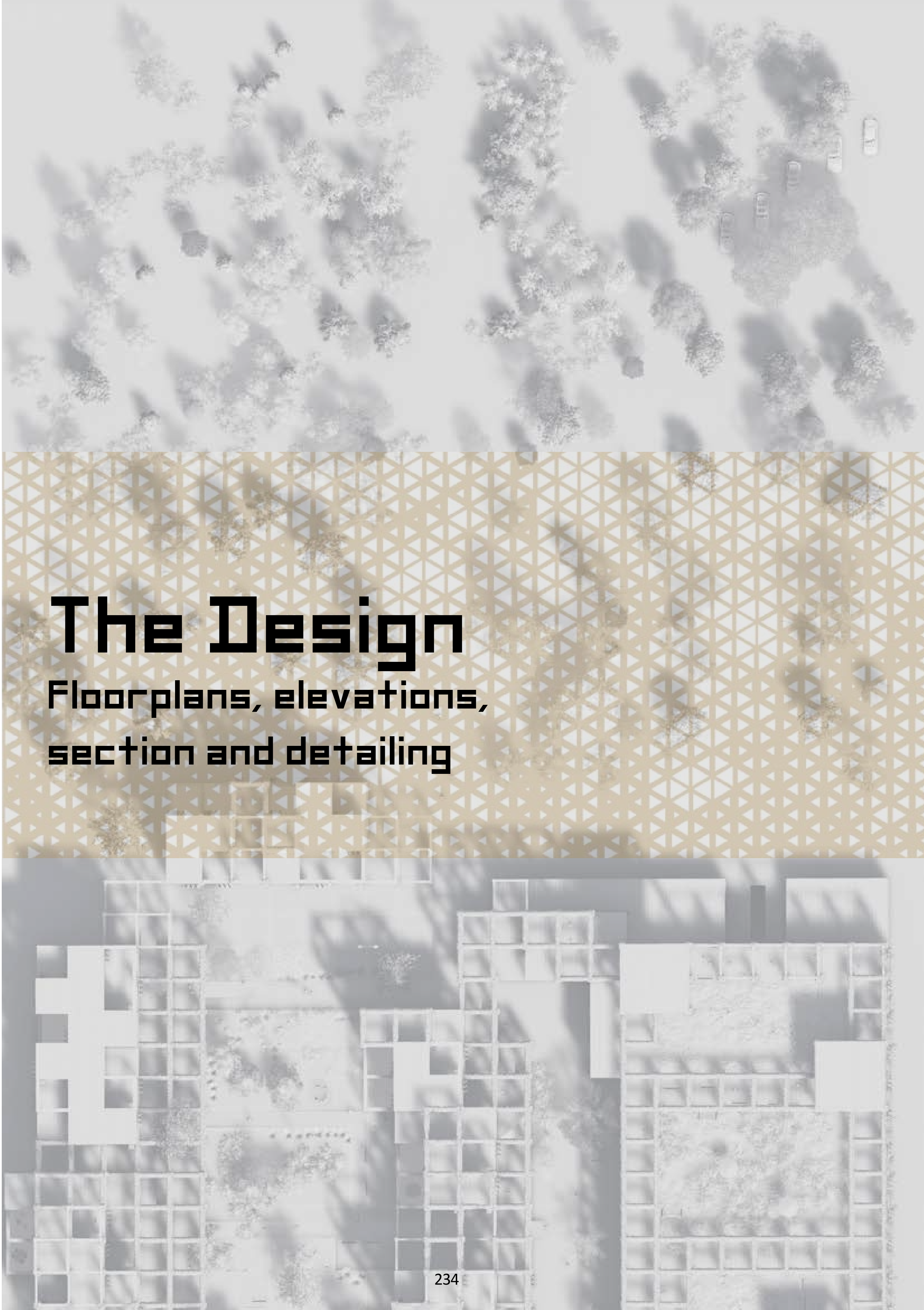
Fine Grain

The case study of Penda's Thousand Yard pavilion showed a repetitive structure filled with elements that shape spaces for domestic and public functions. If the elements are neutral, as opposed to the typical office building or iconic house shape, this makes it more suitable for transformed use.

By using the different heights for beam support and either the single (4x4m) or double (8x8m) grid size for column placement, each function applies the optimal structural infill. The food court being the most open with a 1.5 storey high space and a 8x8m column placement. Using the same column grid but spread out over two stories, the large volume of the spa has the least openness, but avoids the hard boundaries of solid walls by double shutter panel placement. The houses are placed in small groups with an offset to eachother and use the 4x4m grid, which is internally subdivided in parts of 3, so this is where one finds the finer grain.

In the chapter on Affordable housing, the case study of the Half House by Alejandro Aravena shows an approach of providing the occupant with a complete basis for a house and a structure that can be filled in and adapted through time. By taking this approach, Living in the Oasis Retreat is accesible to wider range of people, and people can finance expansions or modifications in phases.

The Food Court, and spa are the two built public functions that attract the neighbours and people from beyond to enjoy the area.



The Design

Floorplans, elevations, section and detailing

Functions

- Oasis Landscape
- Food Court
- Spa
- Pavilion

The Ground Floor

The First Floor

The Second Floor

The Third Floor

The Fourth Floor

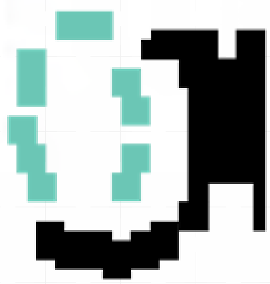
Housing

The Housing concept is based on the idea that one buys or rents a three-dimensional plot of 3x3x3 grid cell units, in which they can choose the infill of the framework to fit their needs and financial means.
There are also three spacious villas following the same principles in different dimensions.
The framework can remain a void, or encapsulate green, terraced or covered space or a series of enclosed volumes.

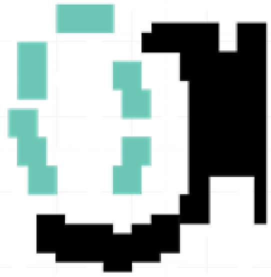
This approach allows easy modification, in which the house grows along with the occupants phases in life. The permeable framework also forms an intermediate between inside and outside, in which a clear delineation of the beginning of building and end of vegetation is obscured.

The goal was to design the residences as a small version of the oasis retreat, so there is plenty of natural light in all spaces, and each house features terraces, balconies and/or a winter garden. The Houses and Villa's are designed with vides and open spaces to let the activities and spaces flow over into eachother.

The main difference of the housing types is the place and orientation of the staircase.
Especially type A shows the sequential expansion options that one could make.



House type A
1:400



House type B

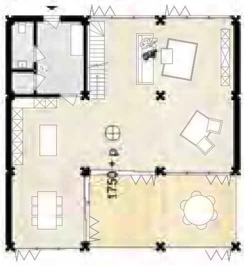
1:400

C1.1 - FL0

C1.1 - FL1

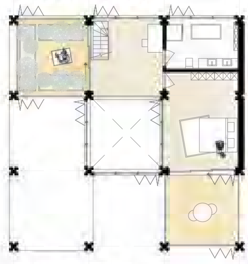
C1.1a - FL2

C1.2 - FL0



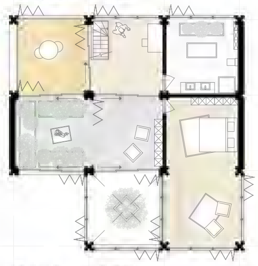
C1.2 - FL1

C1.1b - FL2

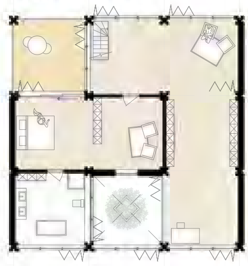


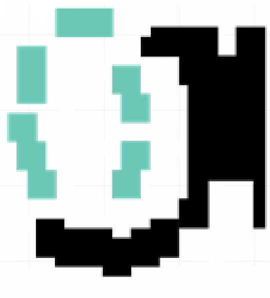
C1.3 - FL1

C1.2 - FL2



C1.3 - FL2





House type C

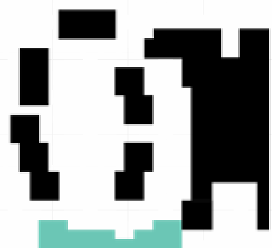
1:400

The Villa

The Spacious villas offer unobstructed waterfront and park views andand feature two large terraces, and a spacious atrium that functions as a personal ‘zen-garden’. Together with a sauna and a pool, the villa offers a personal spa and wellness experience. The floorplan of the living is wrapped around the atrium and pool along the open facades. All these spaces have shutters to open up the functions to one another, and with interior shutters the spaces can be subdivided when desired. The villas are also expandable as desired.

The Villa

1:400



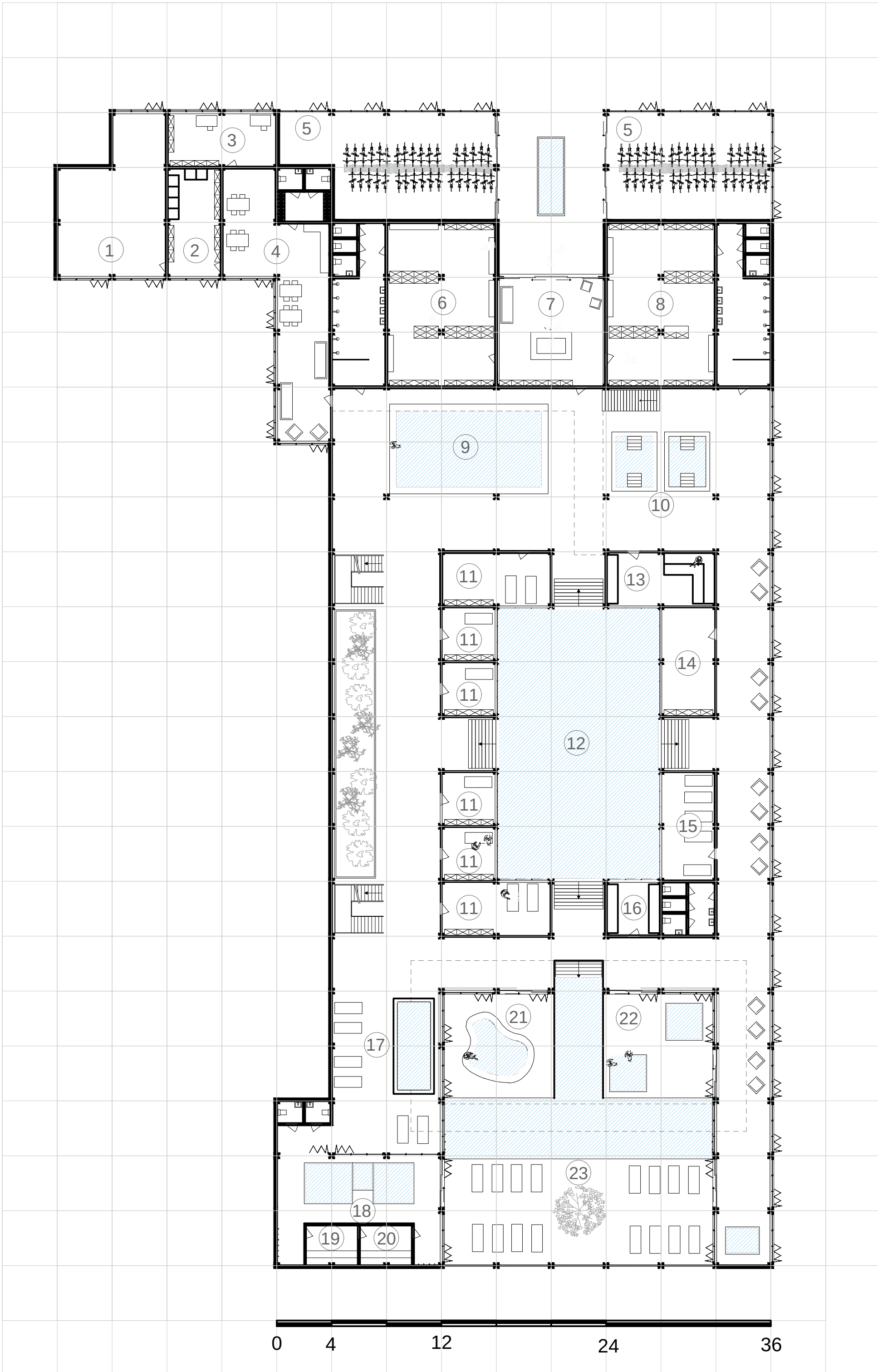
Spa & Food Court Design

The Spa

The spa provides a retreat for relaxation to the people of Rotterdam and beyond. When visiting the area, one will experience the lush green, the absence of heavy traffic before entering the spa. After a day of relaxation and retreat one can extend their stay by discovering the green spaces and the pavilion of the Oasis Retreat or enjoy a nice meal in the food hall.

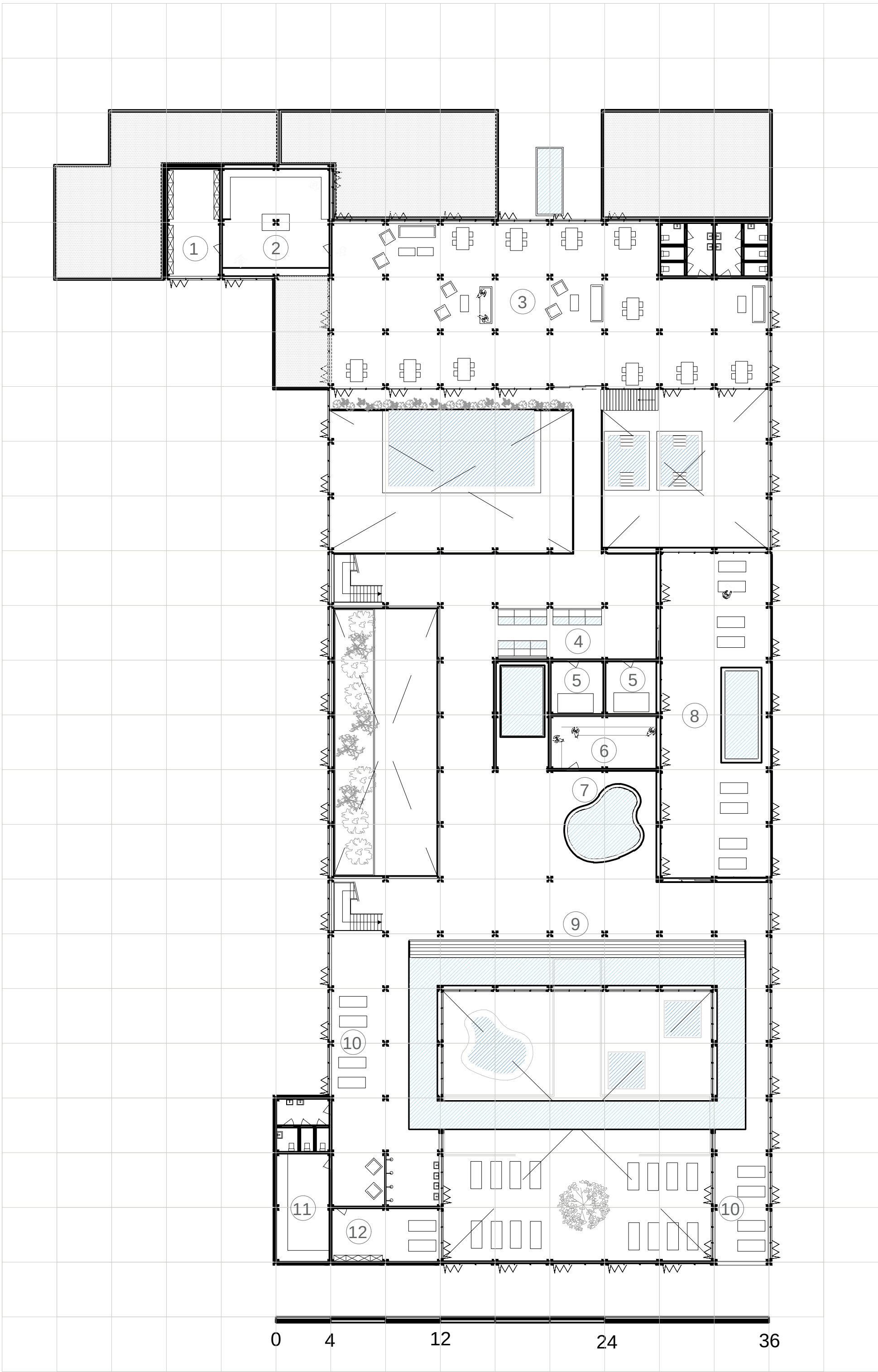
The Spa covers two floors and offers various baths and wellness treatments, as well and its roof functions as a public roof garden. To ensure privacy but let through daylight, double shutters are placed on the façades.

The large pool has a key feature: a 3D parametric tile. In the Appendix, one finds the development of this tile.



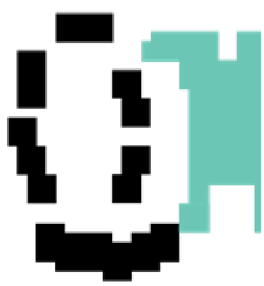
The Spa

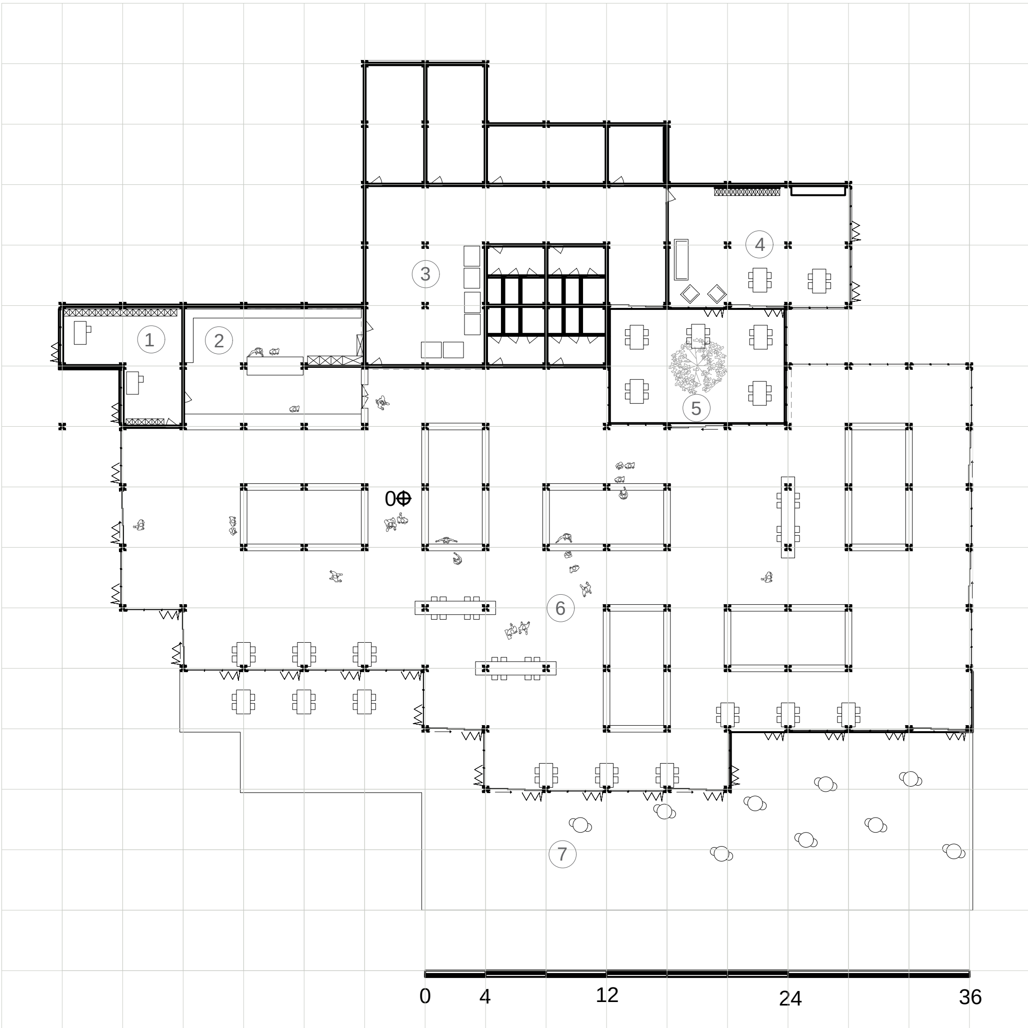
1. Technical services
2. Laundry room
3. Office
4. Staff room
5. Bike storage
6. Ladies dressing room & Showers
7. Reception
8. Gentlemen's dressing room & showers
9. Whirlpool bath
10. Hot & Cold bath
11. Treatment room
12. Pool with 3D brick ceiling
13 Dry Sauna
14. Meditation space
15. relaxation room
16. Wet Sauna
17. relaxation area
18. turkish Baths
19. Hot Room
20. Warm Room
21. Bubble bath
22. Jaccuzzi's
23. Sunbathing area



The Spa

1. Technical services & storage
2. Kitchen
3. Restaurant
4. Foot Baths
5. Solarium
6. Turkish steam sauna
7. Whirlpool
8. Terrace
9. Sky infinity pool
10. relaxation area
11. Dry Sauna
12. Treatment room





The Food Court

1. Office
2. Kitchen
3. Storage, Food storage and waste collection
4. Staff room
5. Atrium
6. The Food Court

The Communal Living Room

The Merwe Vierhaven is not sufficiently accommodating to people as of now, as basic amenities are limited and not on walking distance of the project location. The Food Court serves as a place to do your groceries, shop from local enterpreneurs and have a bite to eat. The setup for this is inspired by Vershal het Veem in Eindhoven. On The ground floor of the transformed Philips Factory, the hall fills cubicles with market stands and bar tables. It also features a small supermarket. The vibrant ambiance makes one eager to stay and taste fresh local produce when they come to shop.

The Food Court will be set up in the same way, making use of the column grid to create spacious market stands from which one can buy their fresh daily groceries, where they run into their neighbours with whom they can grab a bite or drink before returning home. Part of the sold produce comes from the edible vegetation of the cluster.

The floorplan is deliberately open and is easily changed to a different configuration as desired. The 5.25m high ceiling makes it a space that can also be adapted for other public functions. The transparent façade lets the space flow over onto the sunny terrace and allows unobstructed waterfront views. The shutter panels can be used to filter light when desired.

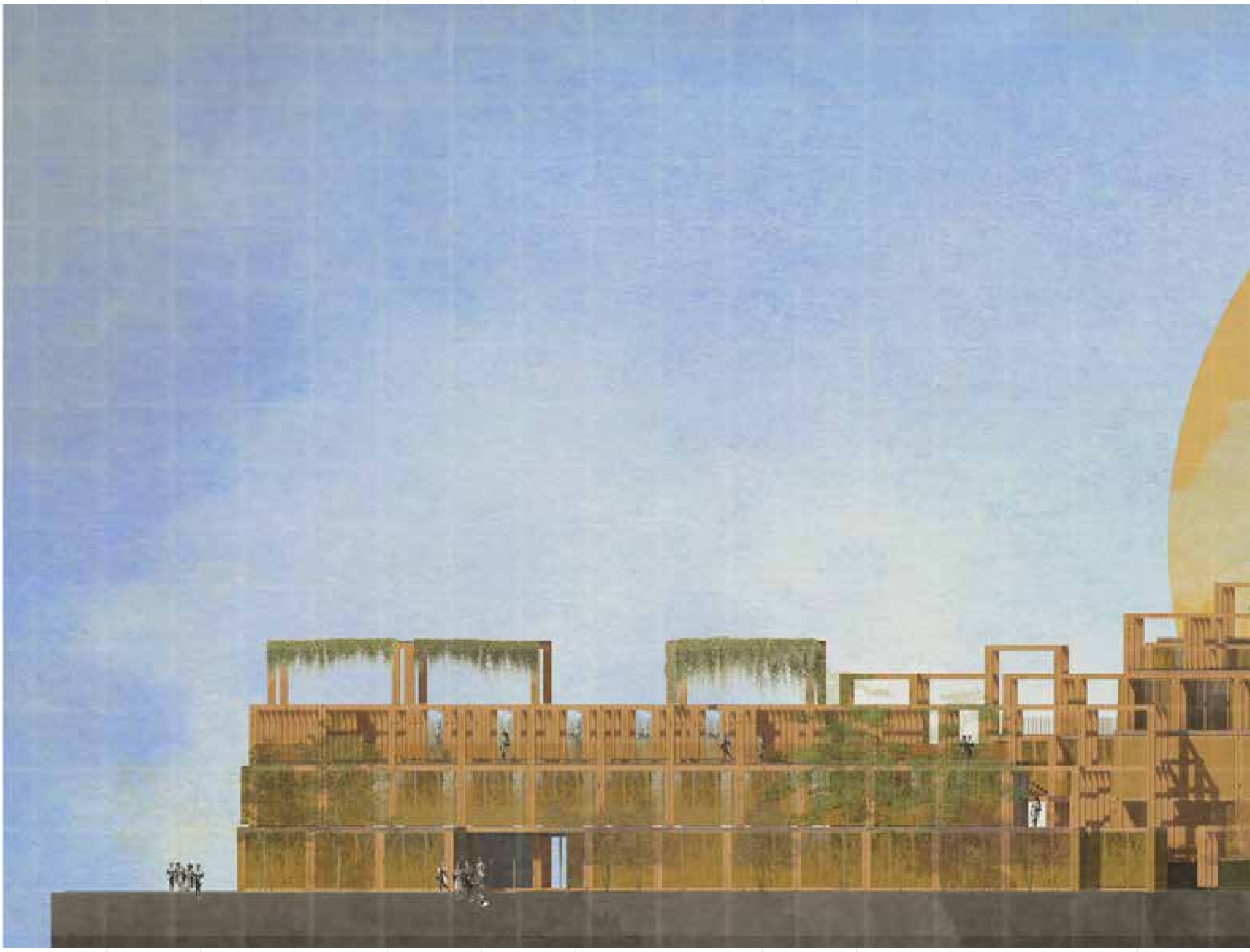
The Food court is part of the community cluster, and it would be encouraged to host a weekly communal dinner here, on which the court could be reserved for the community members. In this way, it becomes a large communal living room for the community. It is an important addition to the cluster as it offers a place to interact and relax during all weather and seasons.

Vershal het Veem, Eindhoven (Vershal het Veem, 2017)

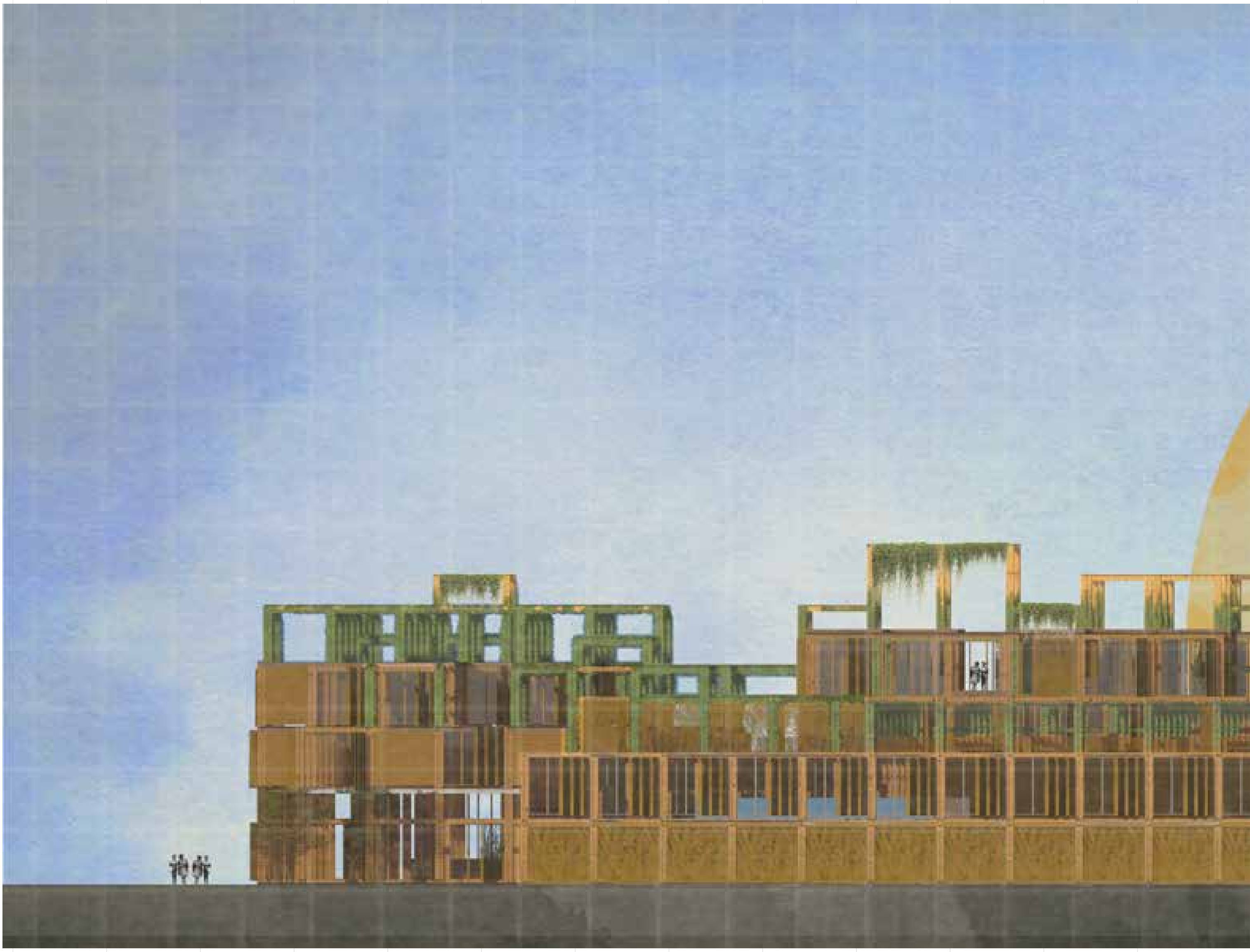
Vershal het Veem, Eindhoven (Vershal het Veem, 2017)

Images Source: Vershal het Veem (2017) retrieved from : https://www.google.com/maps/uv?pb=!1s0x47c6d96bdb19eb0f%3A0xf55c47019ad1f3ba!3m1!7e115!4shttps%3A%2F%2Flh5.googleusercontent.com%2F-p%2FAF1QipOqN-e3kk5R19RKHxw9kTdger9QD7X5bxsv9Kqb%3Dw120-h160-k-no!5svershal%20het%20Veem on 12-05-21

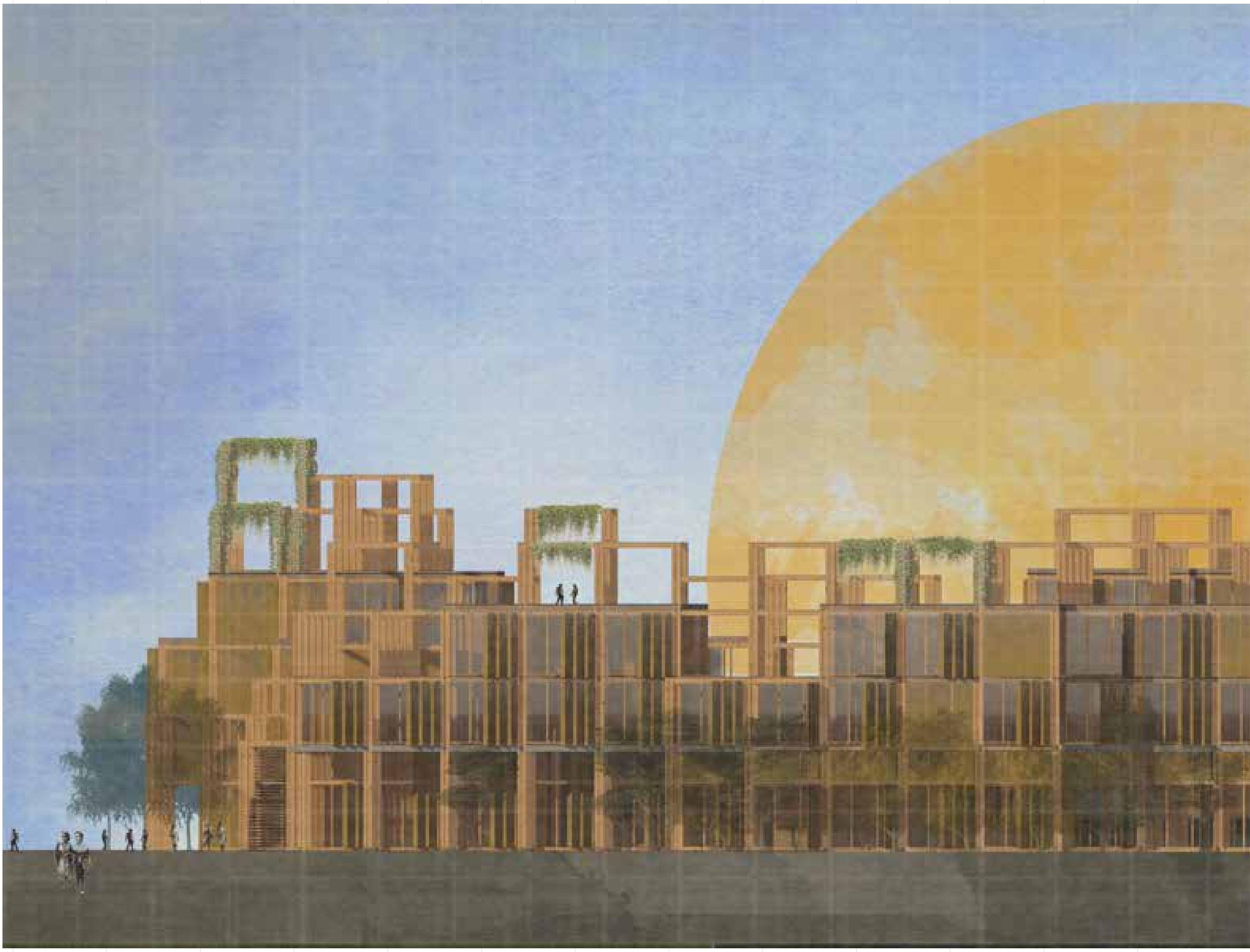
Elevations
- North



Elevations
- East



Elevations
- South



Elevations
- West

Section

Family House

The "Oasis"

Section

Here one sees the gradual height increase the "oasis" makes, thereby creating a gradual passage from the ground floor to 1.5 story height. by pulling the landscape up, program can be tucked underneath ((bike) storage, waste collection). The building and the landscape are intertwined and function as one whole.

Storage
& Bike parking

Villa's
Food Court

Oasis retreat by night

The Façade

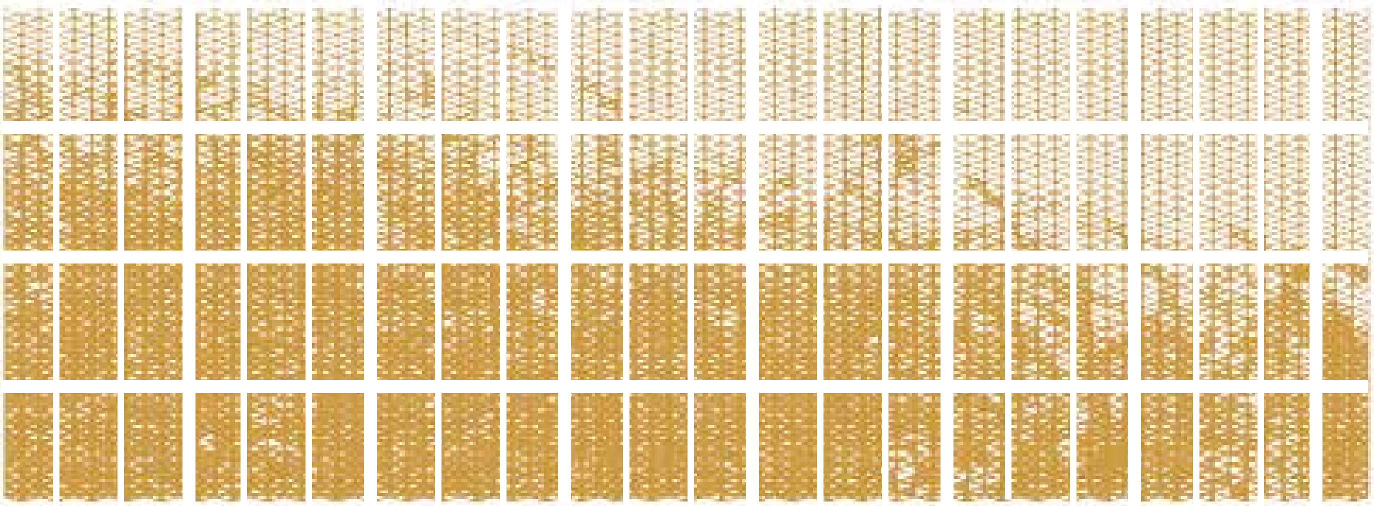
The Façade with foldaway shutters

Blurred Boundaries
In line with the concept of blurred boundaries, the façade is equipped with perforated foldaway shutters. If they are closed, the facade is flush, emphasising the column design.
The shutters filter light and provide privacy.
The Façade is always permeable for daylight, creating intricate shadow patterns that change throughout the day. The same works for the evening with artificial light from the interior to the exterior. By also preferring shuttered façades over solid walls, the built volumes become 'lighter', and the interior and exterior always remain in relation to eachother. As one opens and closes the different shutters throughout the day, this gives depth and playfulness to the façade, that changes along with the day.

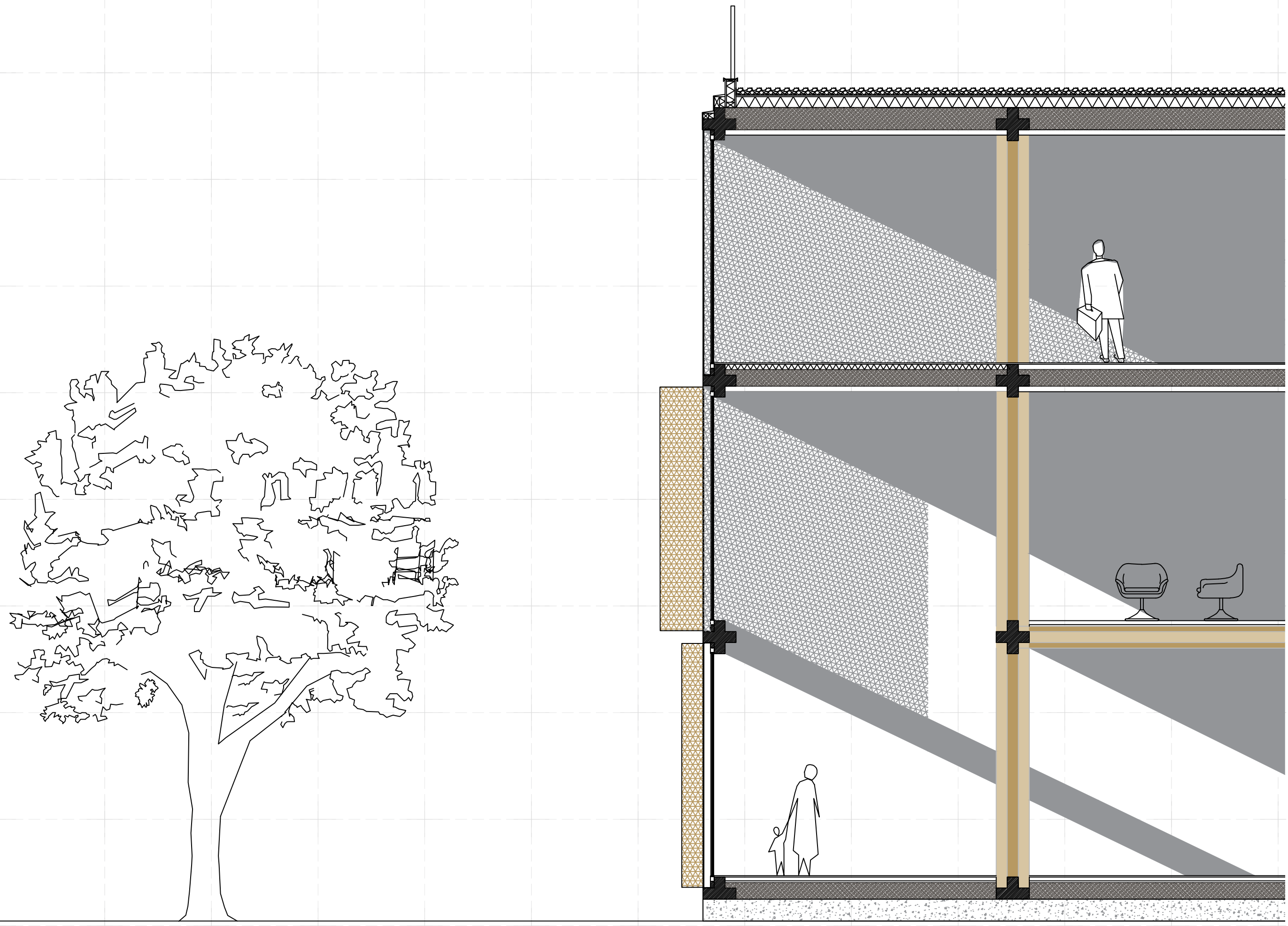
Privacy
For the spa and bathrooms, where more privacy is desired, two shutters will be placed behind eachother with their patterns mirrored, thereby preventing a direct visual connection, but still allowing some light in.

Parametric design & digital design
The abstracted pattern on the façade is parametrically designed, based on an image of local Rotterdam vegetation. The image is abstracted and subsequently the brightness of the pixels informs the size of the triangular openings.
The panels are digitally manufactured from identically-sized wooden panels, that are then individually perforated by lasercutting. The panels will be treated for weather protection.

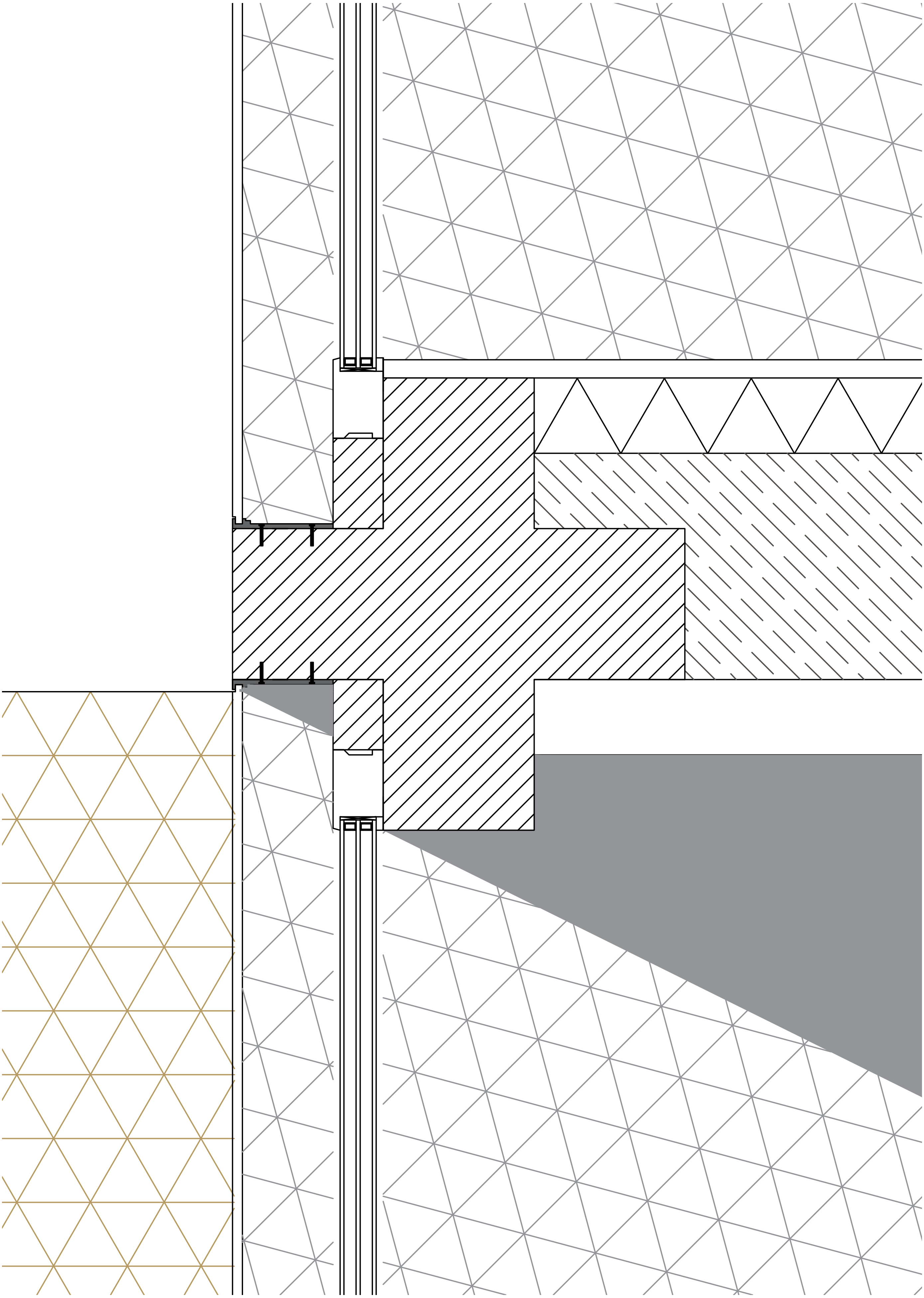
The Façade



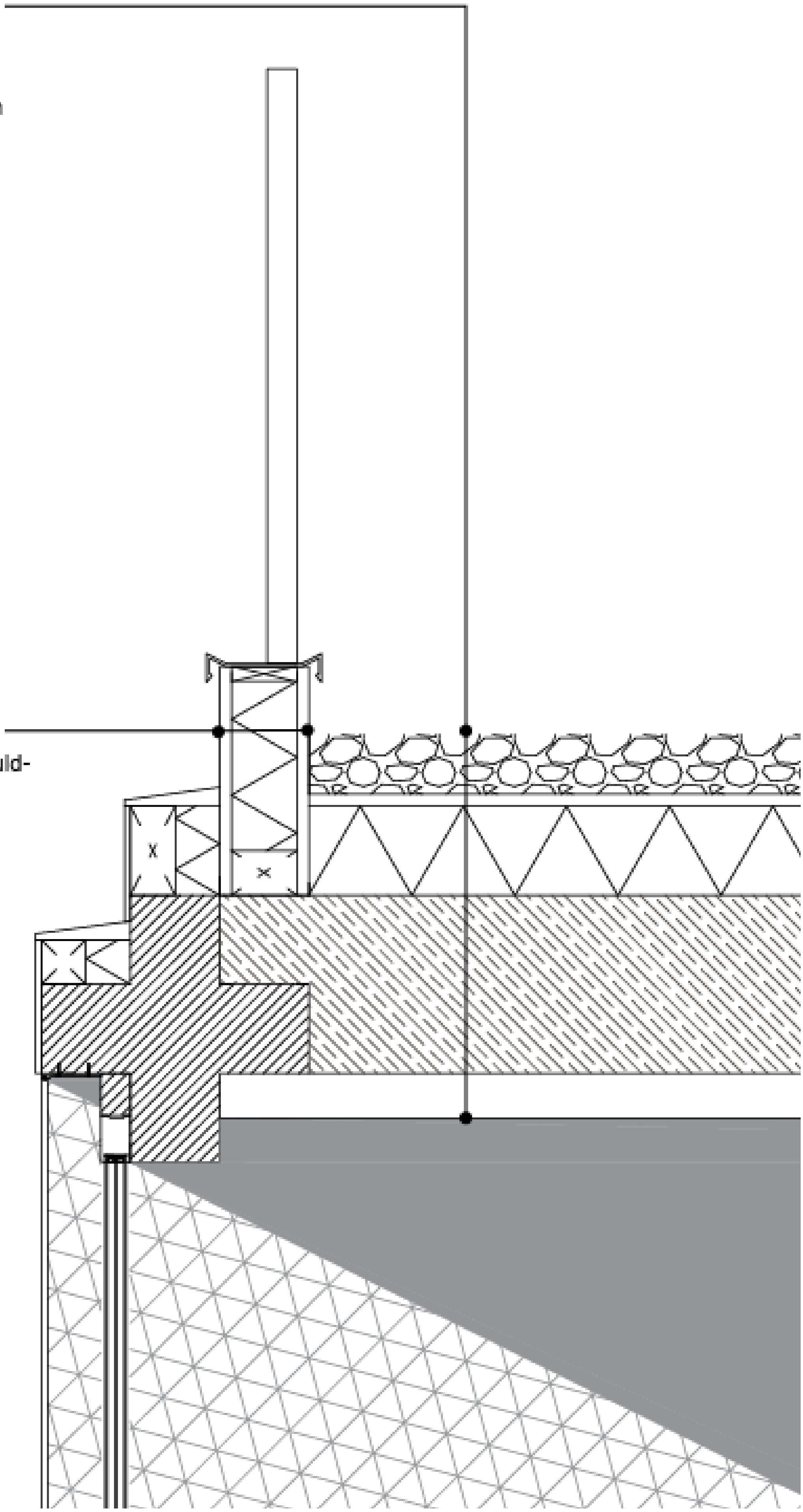
Conceptual panel division with abstracted image, fabricated by mass customisation



House section 1:50

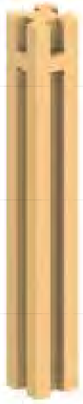


Flush window and shutter placements detail. 1:5

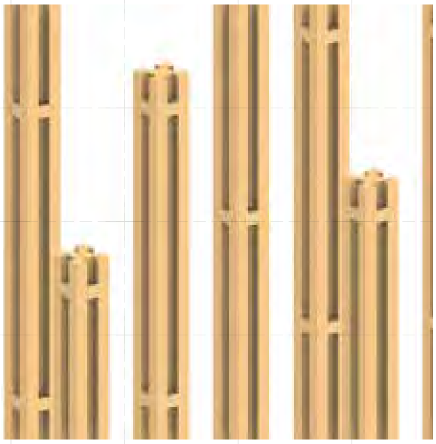


Roof detail for green roof with balustrade, 1:10

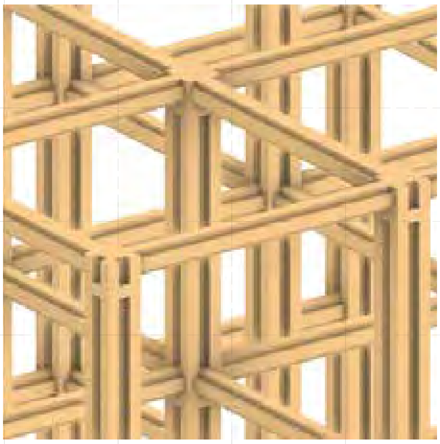
The Structure : Grow and Ungrow



The column



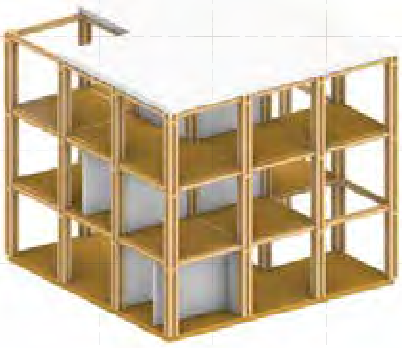
Set of columns



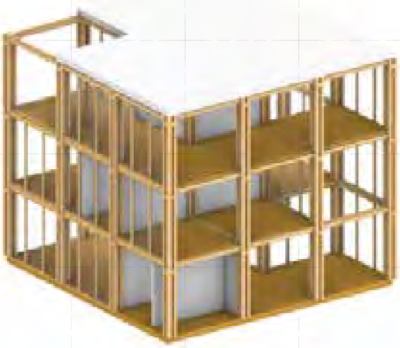
Cross-beams

The framework

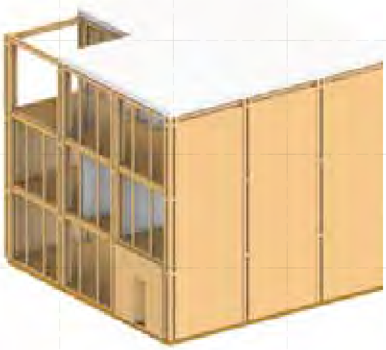
Floor & roof plates



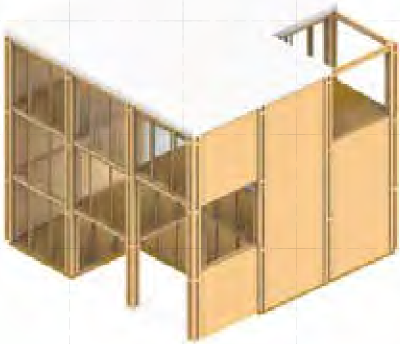
Interior walls



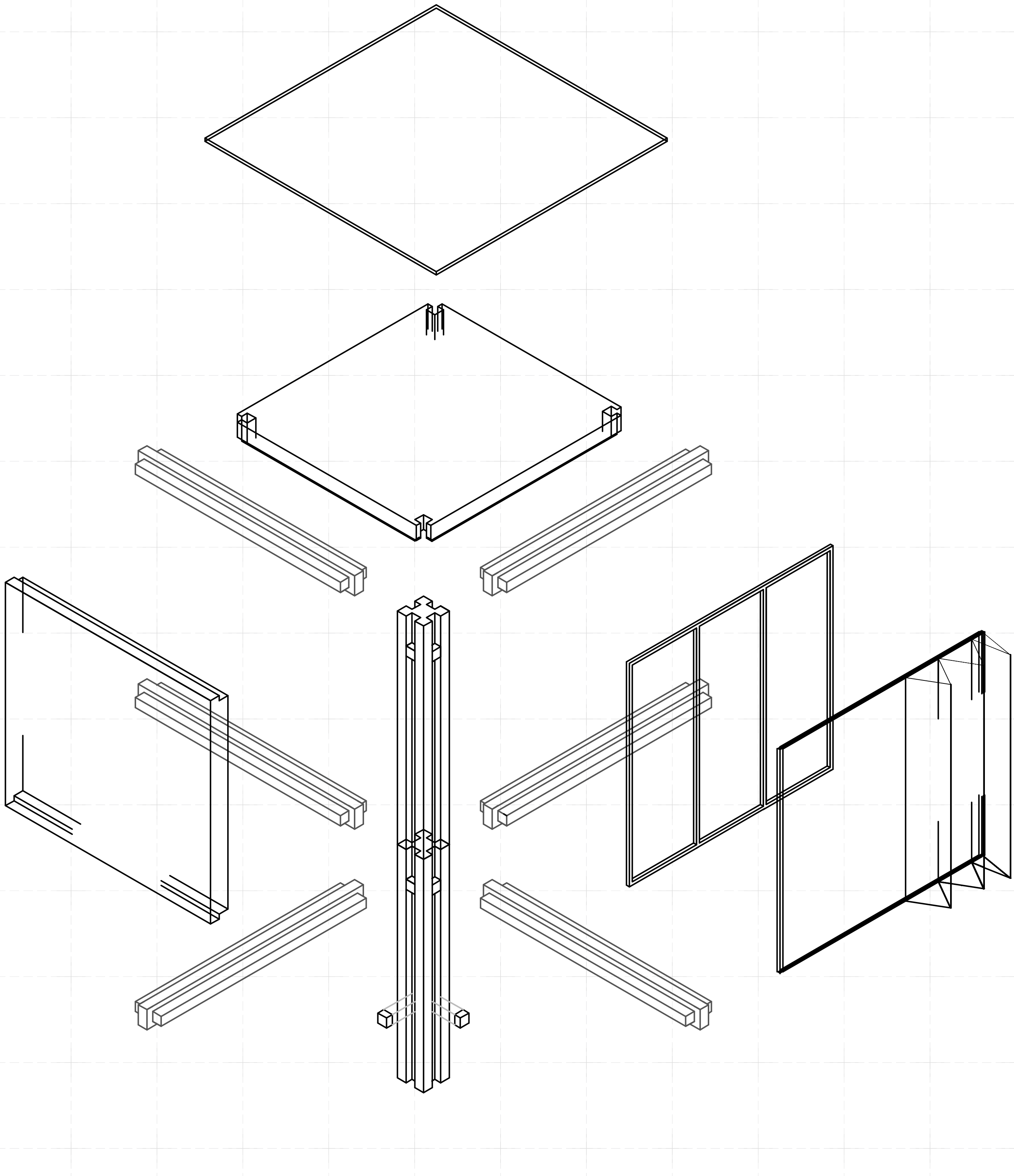
Windows



Exterior walls



Cross-beams

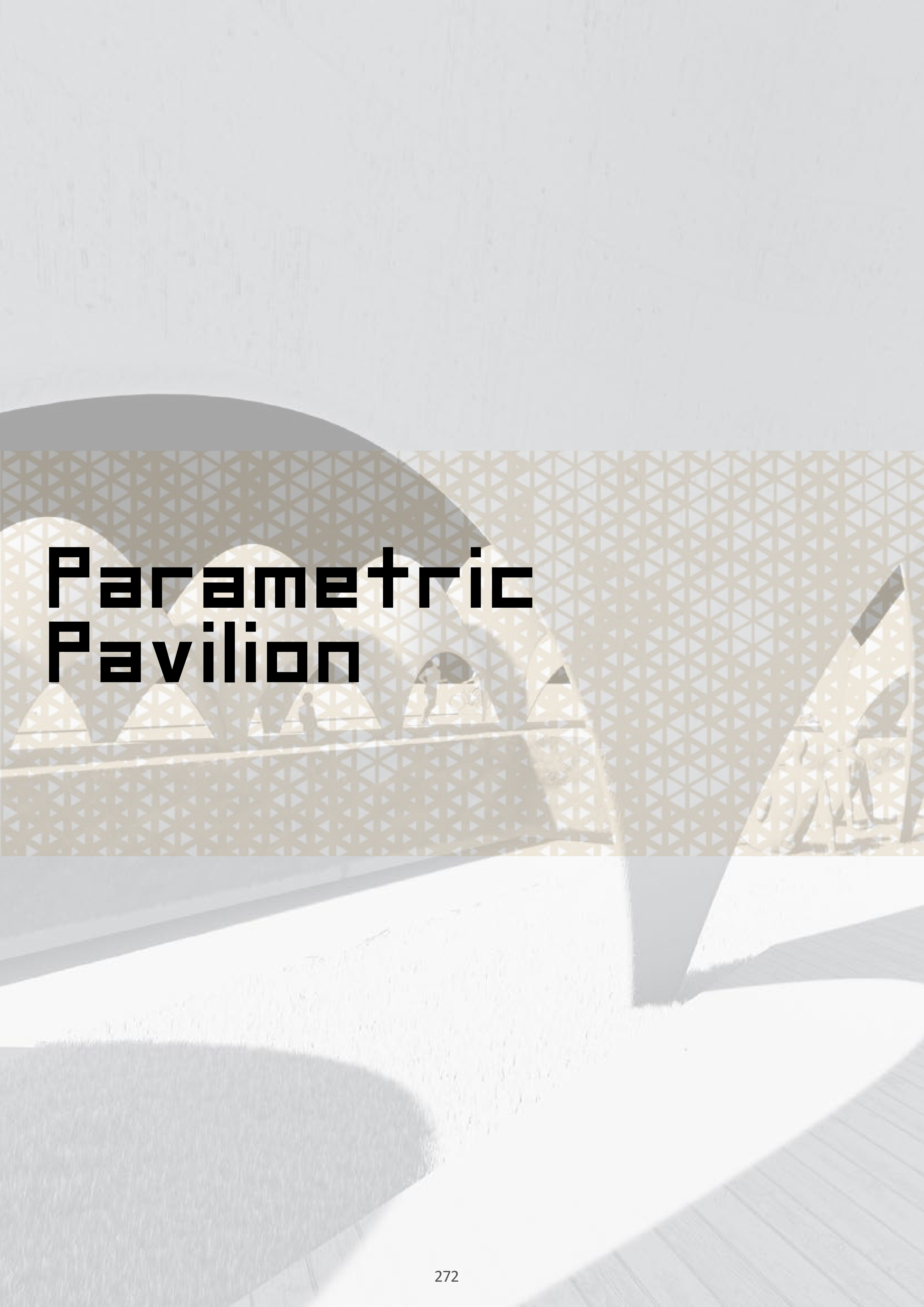


Exploded Axonometric

This image shows the structural buildup and flexible icomponent-based infill of the structure. the wall and shutter placement is as such that the façade becomes flush with the columns and beams when the shutters are closed.

The columns are CNC milled with coves either on full or half storey height. However, when after time an addition at another height is desired on the existing structure, it is possible to add cove blocks with either a steel shoe profile or bolts on the desired height. This approach is favorable as it minimizes the standard exposed flat surface of the coves to the weather. The cove elements are made with a small inclination to help with water runoff. All (partially) exposed columns and beams will be treated and coated to prevent weather damage.

Parametric Pavilion



The Pavilion is situated at the waterfront it offers a place to retreat. The group of vaults of grouped around a body of water. It provides shade and coolness during summer, and shelter from the rain.

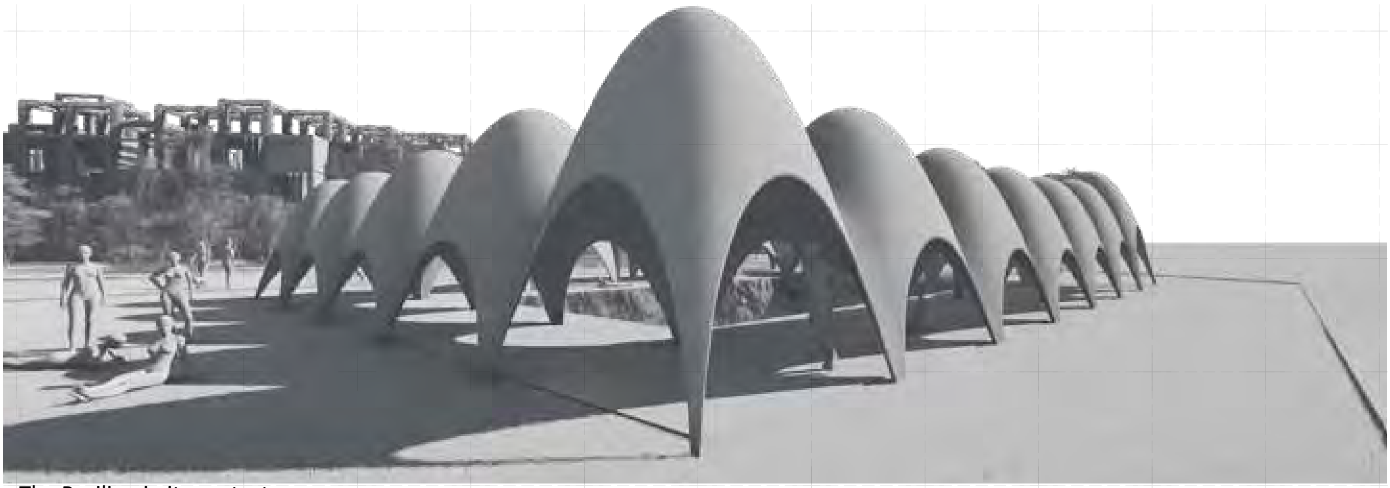
The pavilion delineates a space under itself and within the group of vaults, creating intermediate spaces with soft, informal boundaries.

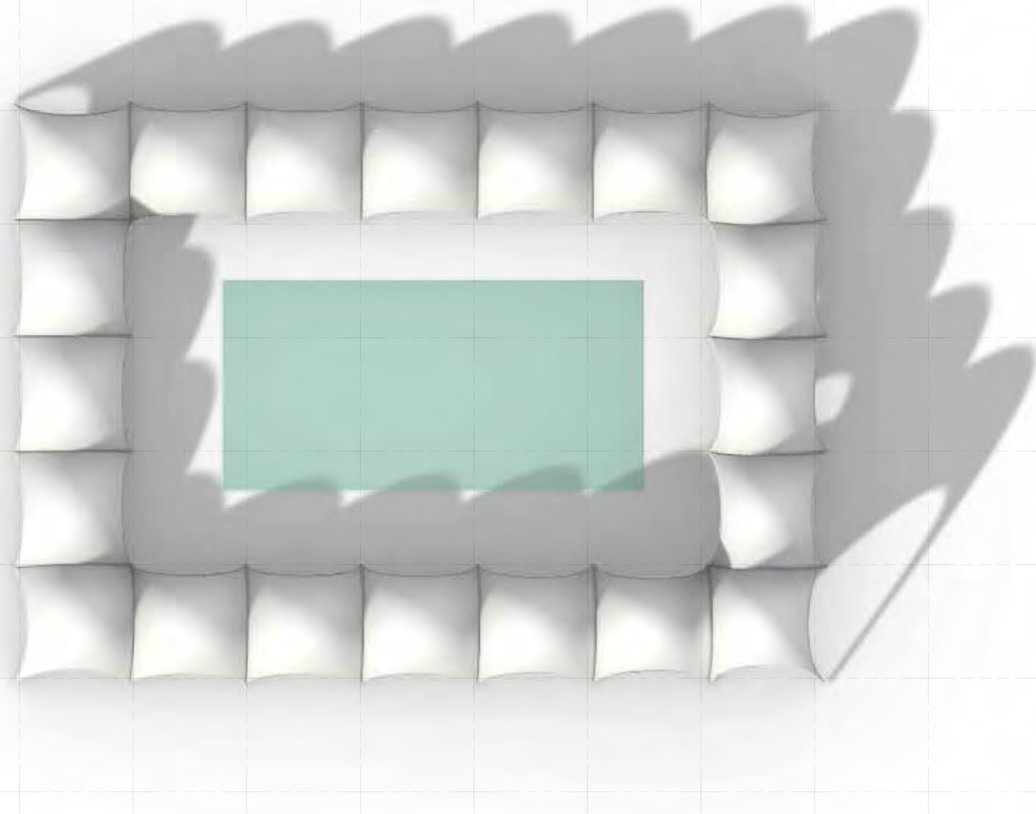
The Pavilion

The Concept
The pavilion creates a covered space and a semi-enclosed internal space with a body of water. The pavilion offers shade and a place for retreat.
It is inspired by vaulted architecture, one of the oldest principles in building. The model uses a parametric system based on catenary curves. The load strength on these catenary meshes is varied by using attractor points. The loads are stronger towards these manually defined points and create a gradual increase in height for each of the vaults.

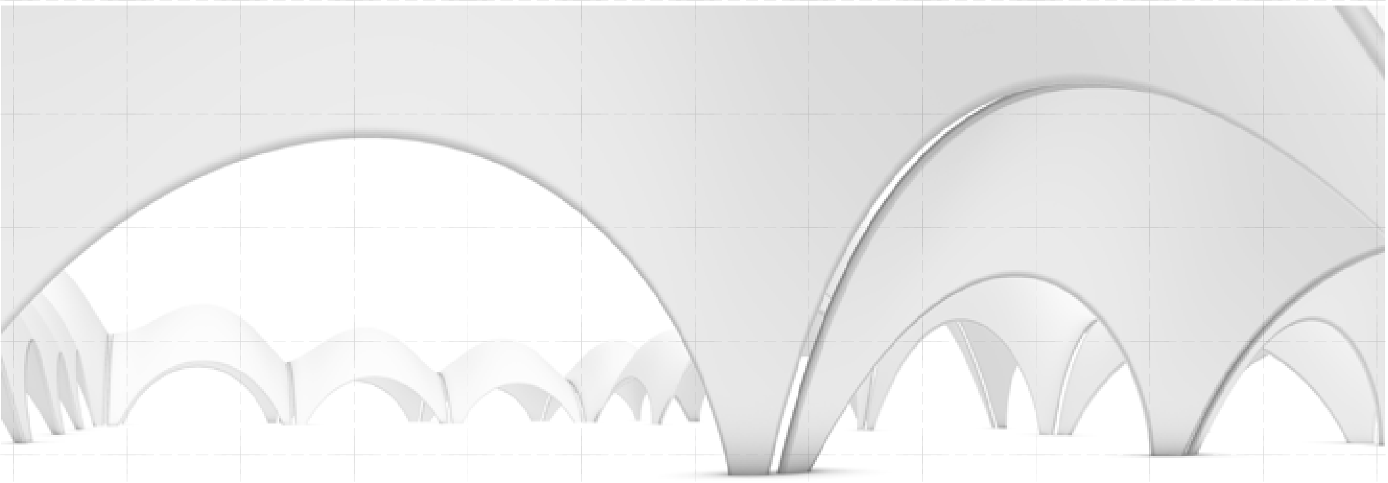
The Parametric design
The starting point for the model is a subdivided surface with the same rectangular grid as the framework of the general design. The internal squares are culled out, thereby leaving the border, which will remain linked to eachother. This method results in the gradually increased vaults that are all slightly different, can be separately produced, but fit neatly against each other. There are three ‘entrances’defined in this way, one middle and two corner vaults.

For further explanation of the design and manufacturing, please see the appendix.


The Pavilion in its context

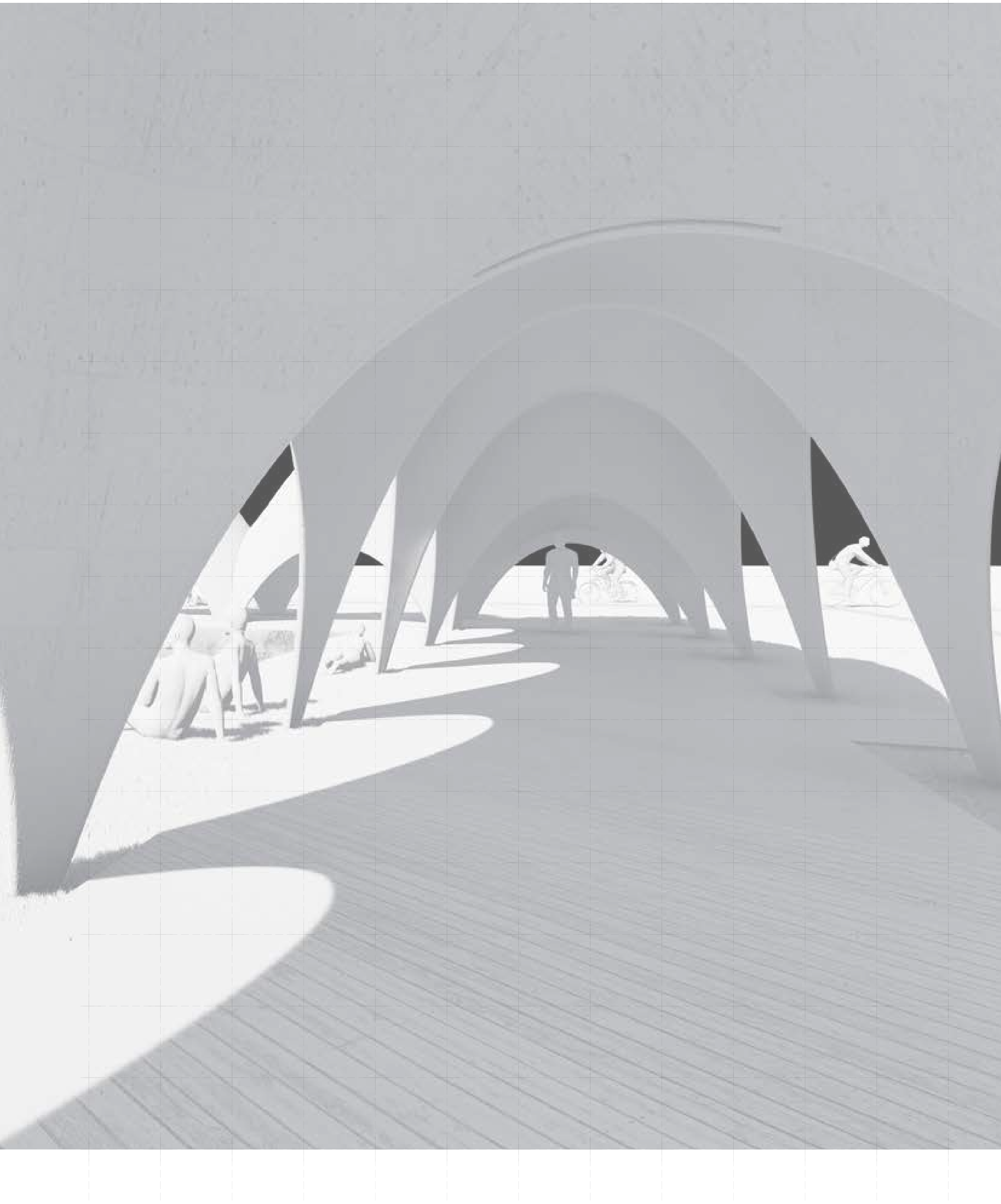


The Pavilion is based on the grid size of the framework

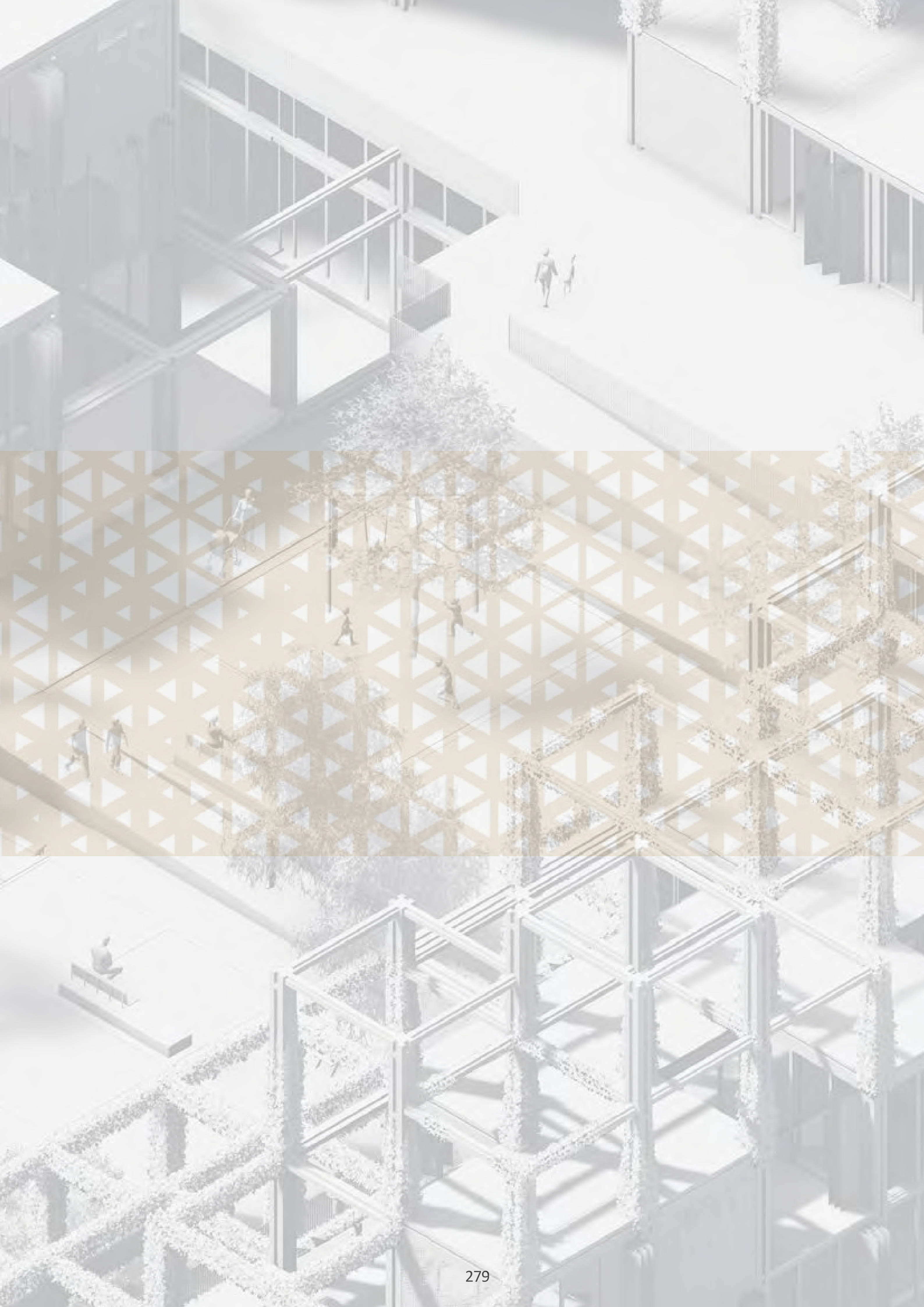


(preliminary design) showing the vaults with a spacing that lets in light

Impression of the Pavilion



Impressions

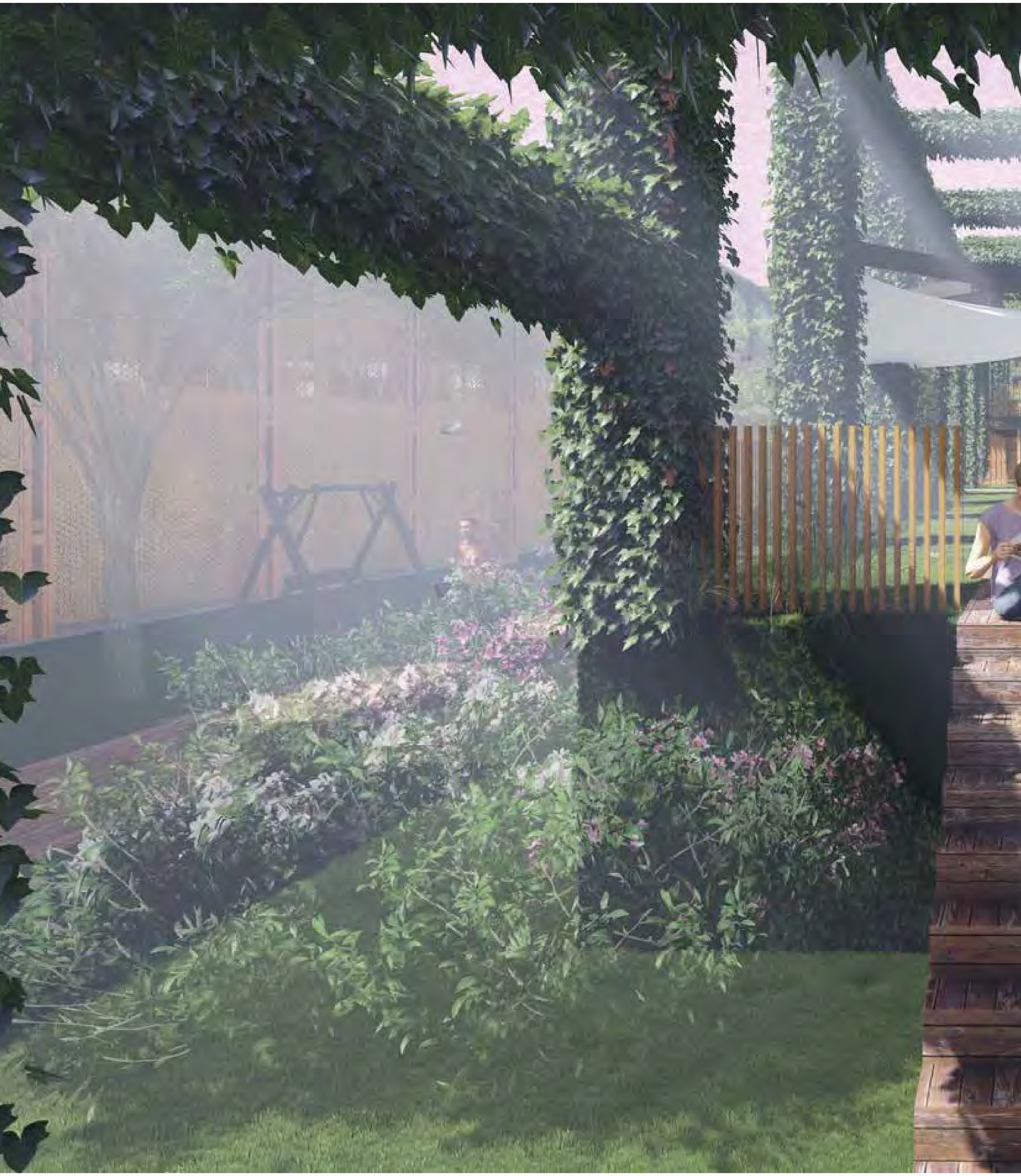


Top View

Isometric Bird's perspective

The stepped oasis courtyard

Oasis view from villa platform



The green avenue between spa & houses

House section, with shared porches, path and oasis on the left

Interior view of shutters

The Food Court

The 3D brick ceiling of the spa pool

Conclusion

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The Oasis Retreat is the resultant of a broad and elaborate research and design-based research and development.

Wellbeing & Blurred boundaries

The concept of a lush, green retreat in the urban setting of the Port of Rotterdam has taken the shape of a permeable structure with public and private infills, all based on the concept of blurred boundaries. This to deal with the wellbeing of people by bringing them in close contact with green and their community. These interactions take place on different intensities as desired. Thirdly, the wellbeing of the people is served by designing the area, but also the smaller scale of the project as retreat spaces. One can retreat and 'switch off' by going to the park or courtyard, or by seeking refuge in their personal cocoon in their private bed- or bathroom.
As our wellbeing is also influenced by our environment this has played a part in the design development as well.

Resilience

The principle of resilience was of key importance to this project. For one, by creating a design that incorporates a large quantity of green, where asphalt is replaced with natural soil and vegetation.
This helps mitigate heat stress, improve the quality of the air and will be a significant improvement in terms of water runoff and retention. Since the infill of the green is based on native, local species, the biodiversity and ecological richness of the area is revitalised in a durable way.
The M4H area transformation is planned by the municipality as a living lab to explore new ways of living, that incorporate shared facilities. This project shows that despite dealing with a highly urban, and currently industrial area, it is possible to design a complex that improves quality for its residents and neighbors, but also for the local ecology and for mitigating climate change issues.

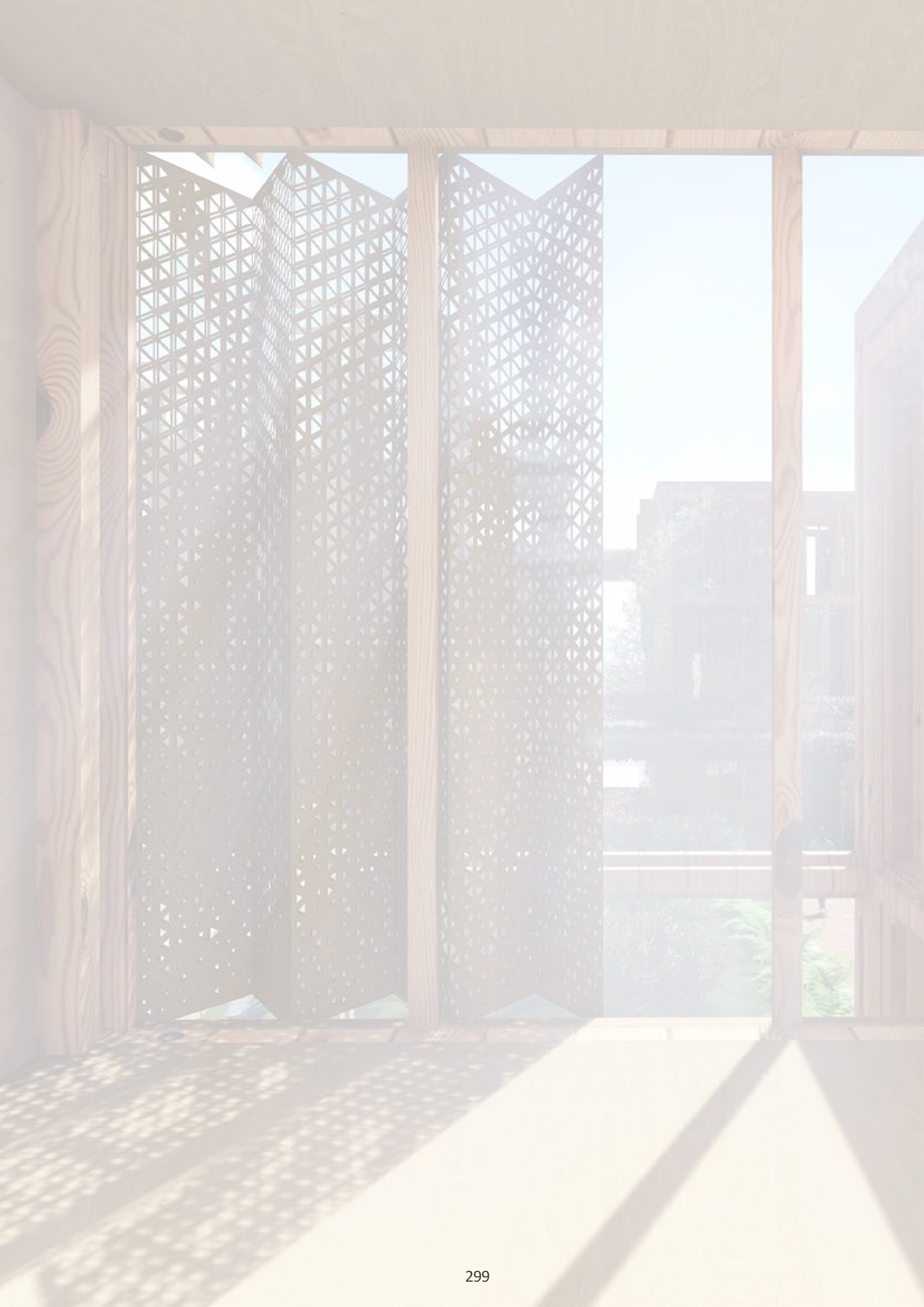
Grow & Ungrow

The project is easily expanded, densified or modified by using prefabricated components that are easily modified and with dimensions that can accommodate residential and public functions. with this structural system and within the grid , the framework accommodates both public and private functions, to which the component composition can be adapted.
The permeable framework is filled with void, vegetation, semi-enclosed or enclosed space, bringing the spaces and vegetation together in one whole.

The project has incorporated aspects of each researched topic, in part by means of digital fabrication and digital manufacturing.

For Future reference

This graduation thesis and project provides an answer to broadly shared societal challenges: Wellbeing, climate change and a lack of green and human scale in highly urbanized areas. Part of the answer lies in the past, by rekindling the relationship with green, and part lies in the future. The current and future technological advancements create endless opportunities to do better for ourselves and our environment.



Discussion

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As with all projects, the work is never finished, can always be improved and brings up reccommendations for future research.

One of the limitations of the project is that it is disputable whether it is sufficiently integrated with its local context. The idea of an Oasis is to create a surprising contrast, which is surely achieved with the burst of green and the predominance of wood in the used materials. The context is taken into account by working with simple shapes, by working with local ecological vegetation and by adhering to the height and grain sizes of the surrounding buildings. It might have been possible to integrate more aspects of the identity of the Port of Rotterdam.

The focus in this project was really to bring back green in the area, but it can be argued that the role of the water could have been embedded stronger into the design. Right now this is done by having waterfront views from the houses, villas, food court and even spa, by having a waterfront park with as stepped platform to the water., and a bike route crossing over the water. The Spa and Pavilion have a water related function, but in terms of a port area, it rather forms a contrast with the local context.

The desire for resilience by means of adaptability and icorporating biophilic design have been a trade off. The design is now based on orthogonal shaped elements, rather than components or complete units that have an organic shape or are strongly inspired by biomimicry. The case studie of Palazetto Dello Sport inspired the carved out cloumn structure, but as it has been strongly formalized to orthogonal basic principles. Considering this, the research on biophilic design, biobased materials and biomimicry is definetily part of the design, but could have been integrated more strongly.

The potential costs of the project and the resulting accessibility have not been calculated for this project. Therefore, it could be that the housing in its current design could be limited to the middle and higher class of society. However, the system can easily accommodate smaller houses and apartments, so it could be tweaked for this.

A recommendation for future research would be on the next phases that come after this project, when bigger transformations take place, and when new units are starting to get stacked on top of eachother and the roof garden of the spa

Parametric Designs

appendix

ROZENBURGER REGEN
THE STARS UNFOLD (LIGHTBOX)
THE PARAMETRIC PAVILION
THE 3D TILE

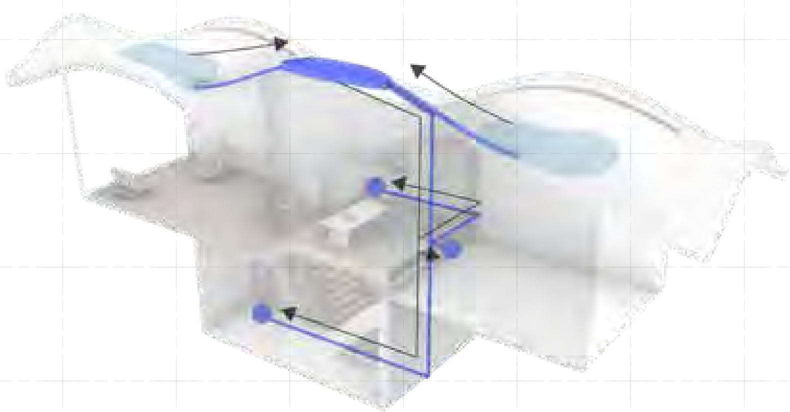
ROZENBURGER REGEN

The brief of this exercise was to design a small building on Rozenburg in the port of Rotterdam that had both a residential and a water-related function. This design is a retreat space designed for water collection and reuse. This was one of the first design exercises in which Rhino and GRashopper were used. The roof and staircase are both the result of a parametric design.

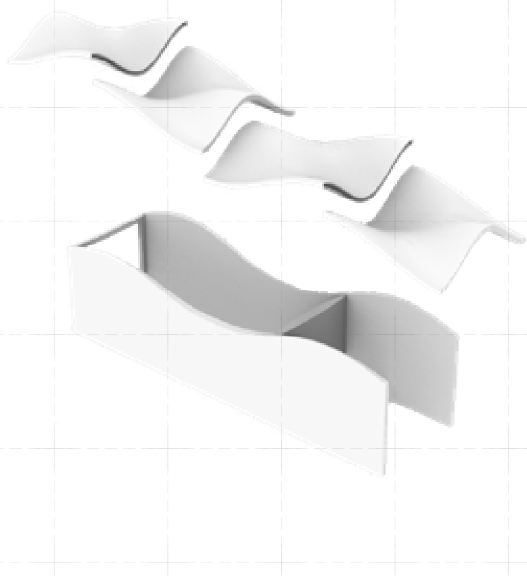
The pavilion accommodates a single/couples retreat and a public semi-enclosed space under its undulating roof. The construction consists of pretensioned and reinforced recycled concrete elements.
The roof shape directs rainwater runoff to two ponds, from which a rainwater filtration system collects the water, filters it and redistributes it to the kitchen, bathroom and to a tap point in the public area.
The public area provides a place for retreat and introspection, shelters visitors from bad weather and provides freshly filtered water. With the wave-inspired roof and staircases, and the private and public rainwater reuse , The pavilion makes visual, and inspires a sustainable approach to water reuse within the Port of Rotterdam.

Functions

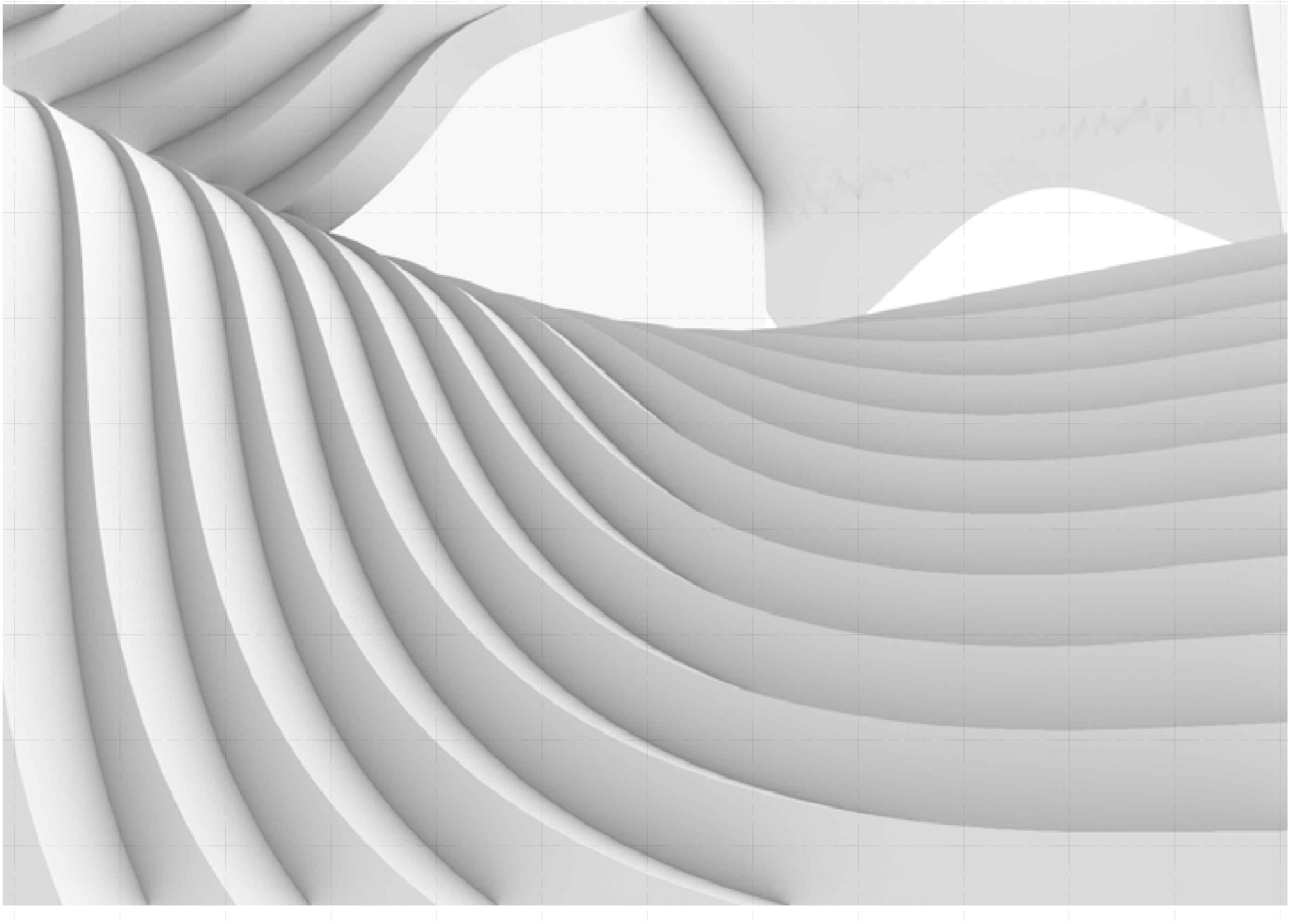
Rainwater reuse



Construction




The location on Rozenburg Island


The shape of the stairs is inspired by rolling waves, and the gills of fish

The undulating roof covers the private and public part, and is used for water collection

The roof creates a different spatial experience depending from where you stand

The Stars unfold


The Jali Façade by Amit Gupta and Britta Knobel Gupta.

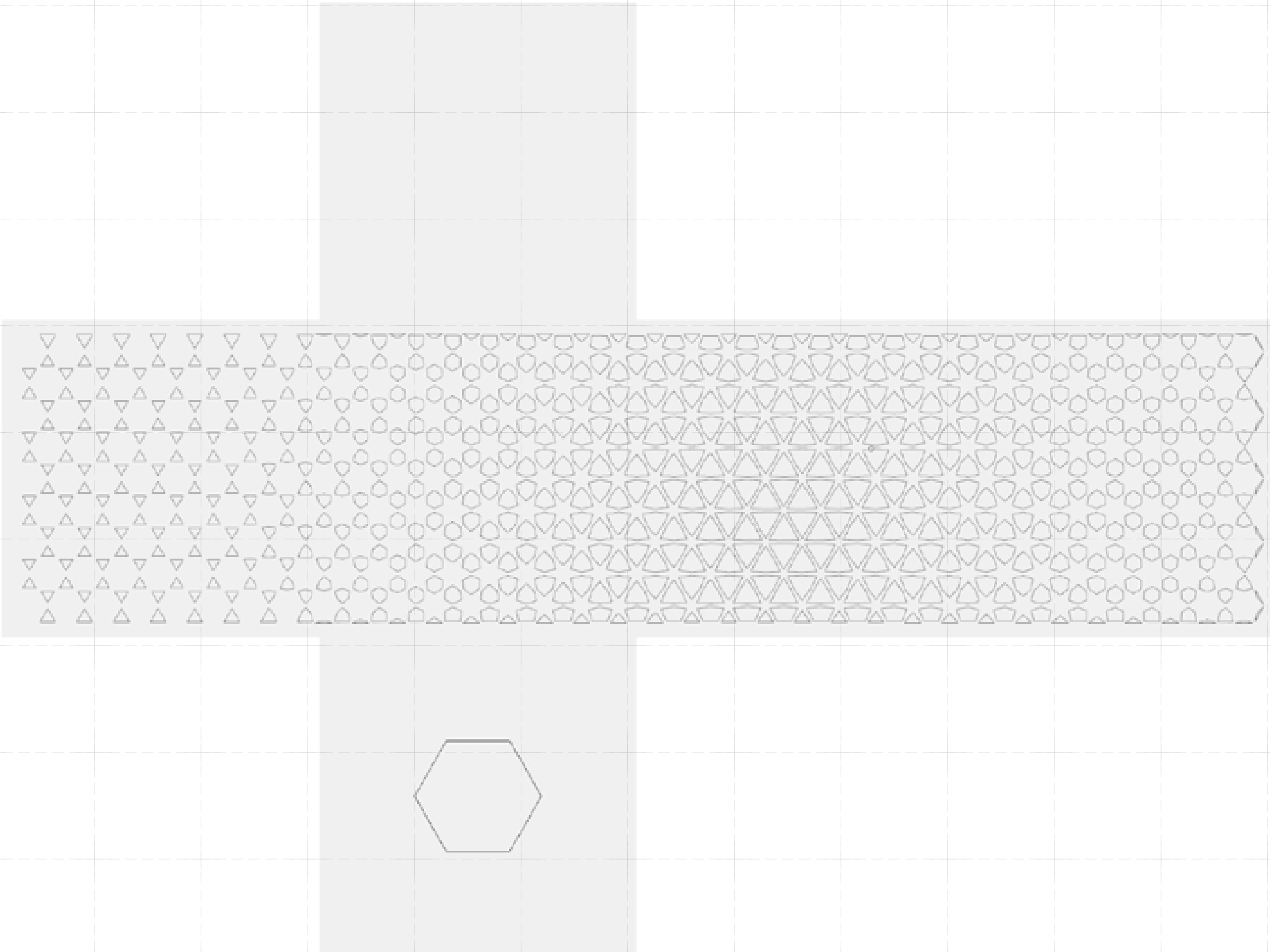
The Stars Unfold
As a prequel to the general design, this varied perforation plays with a gradients and a shift between openness and closedness.

Concept
The inspiration for this exercise was the GRC Jali Façade. The façade has a pattern that gradually shifts in density, making the open pattern become more closed further along the façade. This approach can also be applied to have one pattern over the total façade, but making it very open where much light is needed, and very closed where there is less or no need for façade openings. This can be achieved with the use of one or more attractor points.
This approach is used for this exercise as well. The façade of the reference project is based upon hexagons and triangles, but if one would trace around this you could also read it as a star pattern. Here the pattern will be based upon stars, with openings between them that become more open or closed based on their distance to an attractor point.
The open space between the more or less thick legs of the stars are gradually changed from hexagon to triangle, thereby also incorporating this geometry.

The construction of the star pattern is based on a hexagonal grid, which all have a central circle, with a diameter based on its distance to the attractor point. The middle of the edges of the hexagons form the points of the stars, the thickness of the body is determined by the intersection of center to angle lines with the sphere based on the attractor point distance.

Parametric design
The first script iteration is elaborated and finetuned.

Image Source: Amit Gupta and Britta Knobel Gupta, 2018. Jali Façade. retrieved from https://www.surfacesreporter.com/articles/20901/grc-jali-facade-by-architects-amit-gupta-and-britta-knobel-gupta on 12-12-21



The light box

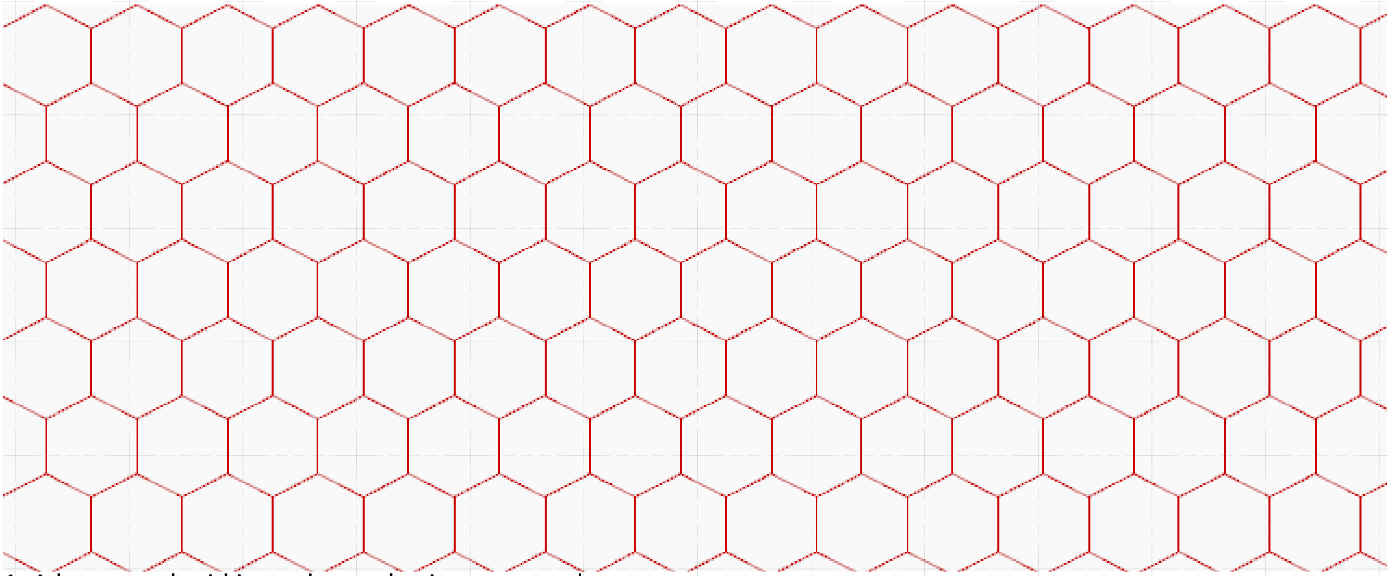
As initially planned, the base surface is now four sides long, creating a continuous pattern along the sides of the cube.

As the star pattern bases its points of the star on the middle line of the hexagon edges, two stars share each of these points. Being a point, it has no thickness and is therefore not yet suitable for lasercutting. As the geometrical composition finds its basis in hexagons, the idea was to add a layer of hexagons with its center at the points of the stars, and with an inverse response to the attractor point. By doing this the hexagons are bigger where more thickness is needed as the stars have thinner legs, and the other way around.

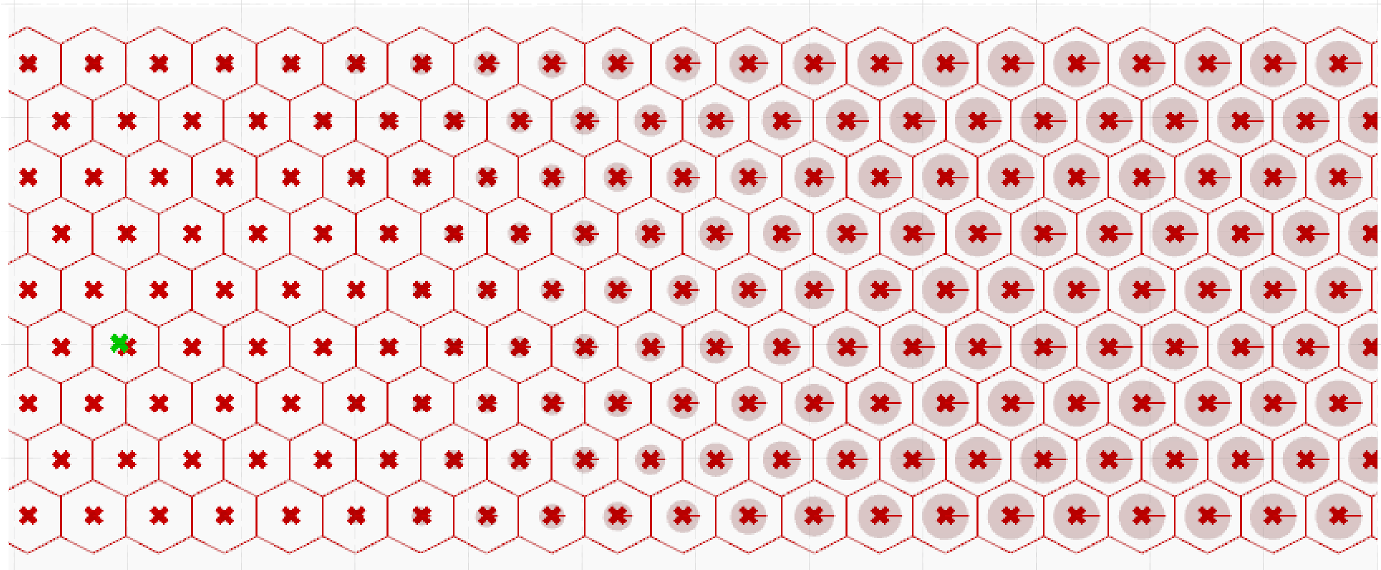
In the previous iteration, the absence of thickness at the points of the stars was solved by creating hexagons here. However the pattern, and the different components of the script became unnecessarily complicated. For the third iteration, the creating of necessary thickness was done with a straightforward approach without adding new geometries to the pattern.

As the stars should remain and the inbetween spaces are to be cut out, the curves are shattered to become separate elements, wich are then joined in a a different combination to form the in between shapes with one group. To thicken the stars, these shapes have to become smaller, which is done by offsetting the curves and creating closed curves again.
On the sides, some shapes are not closed as the hexagonal grid already stopped, thereby not providing the points to create lines that would close the shape. This is fixed by culling the pattern, finding their endpoints and connecting a line through them.

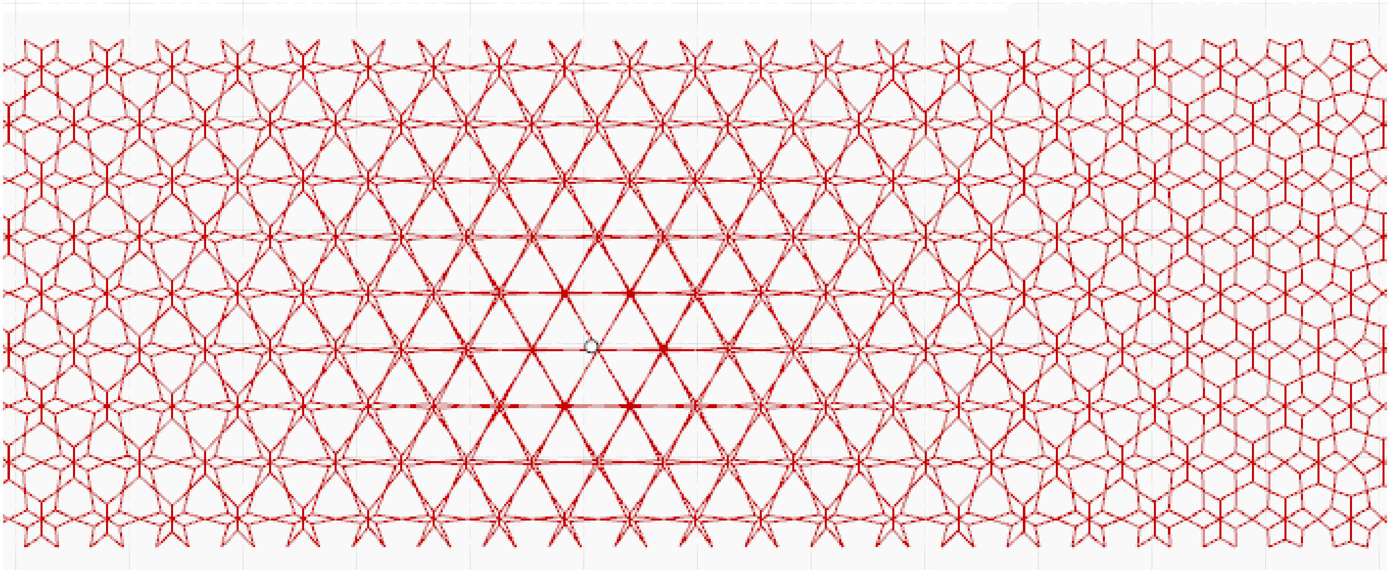
After these edits and adding small extra edges to glue the cube, it was ready for lasercutting and assembly. by having some shapes only engraved and not cut, the light pattern becomes even more varied.



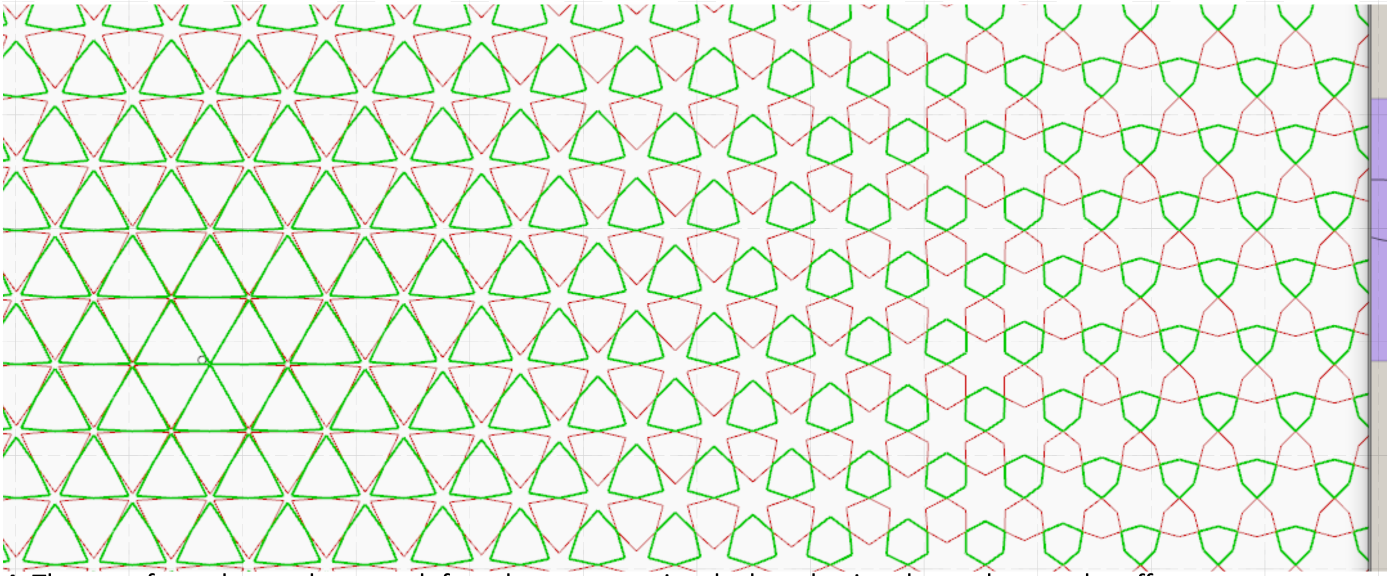
1. A hexagonal grid is made as a basis to create the stars.



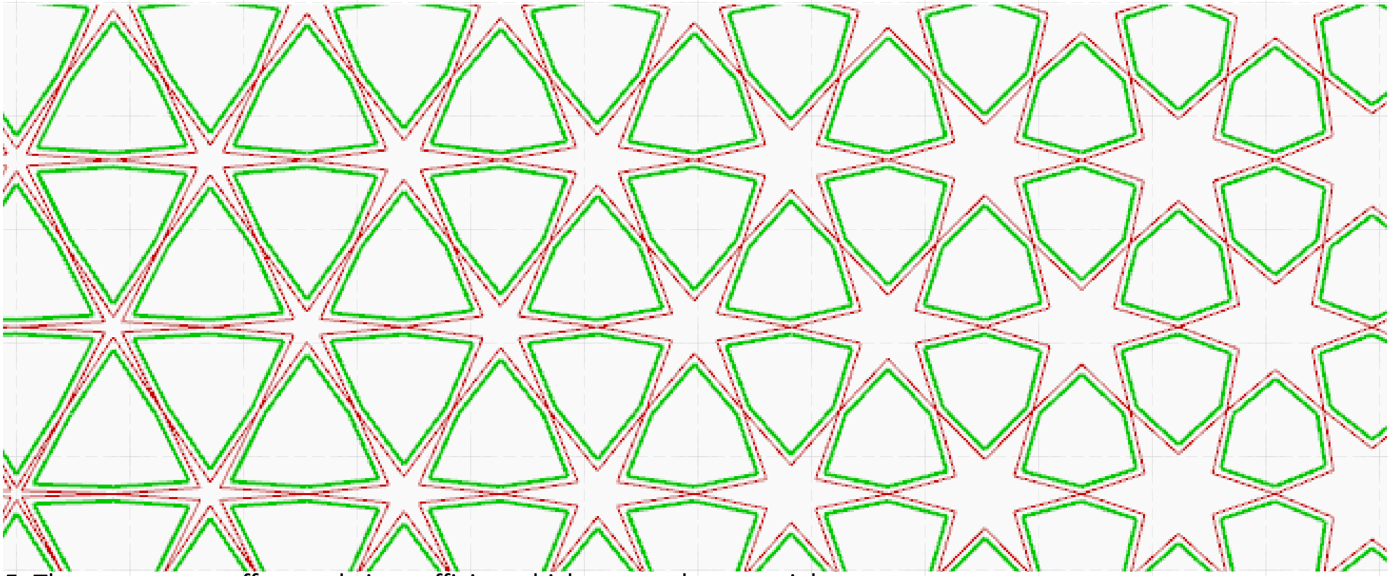
2. An attractor point is manually chosen and the distance towards it is made to affect the radius of the circle. an intersection of corner point lines and this circle form the inner corners of the stars.



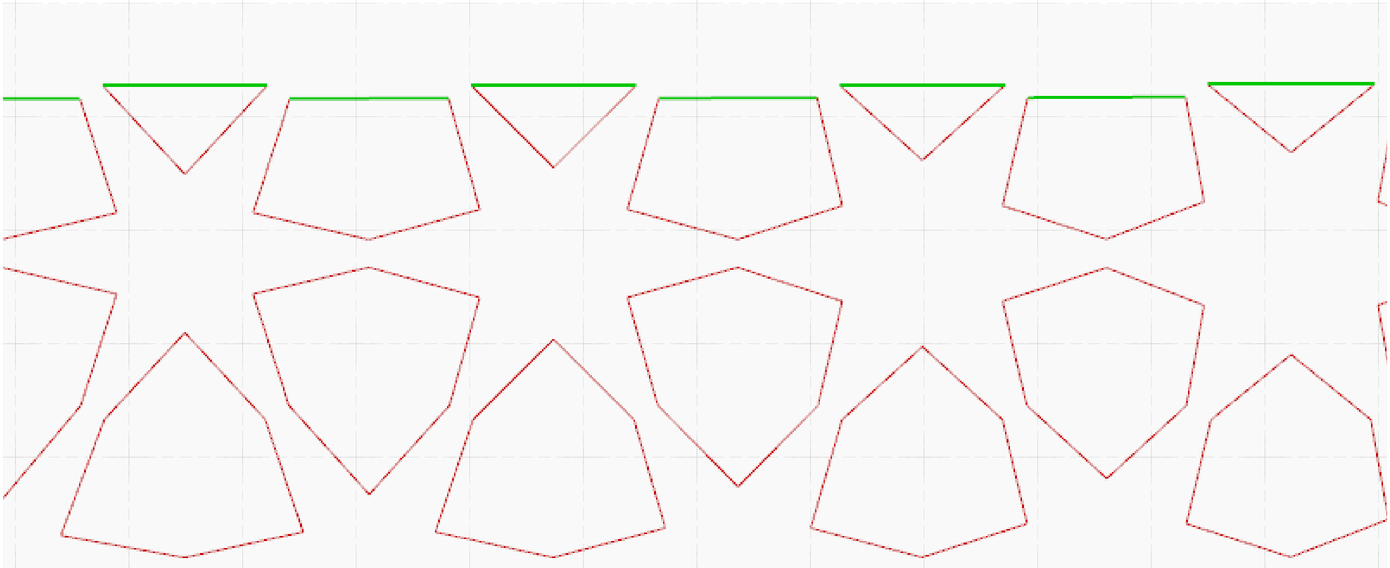
3. The star pattern as desired, nut not yet fit for lasercutting: there is no thickness where the points of stars meet and the thinnest stars will burn away.



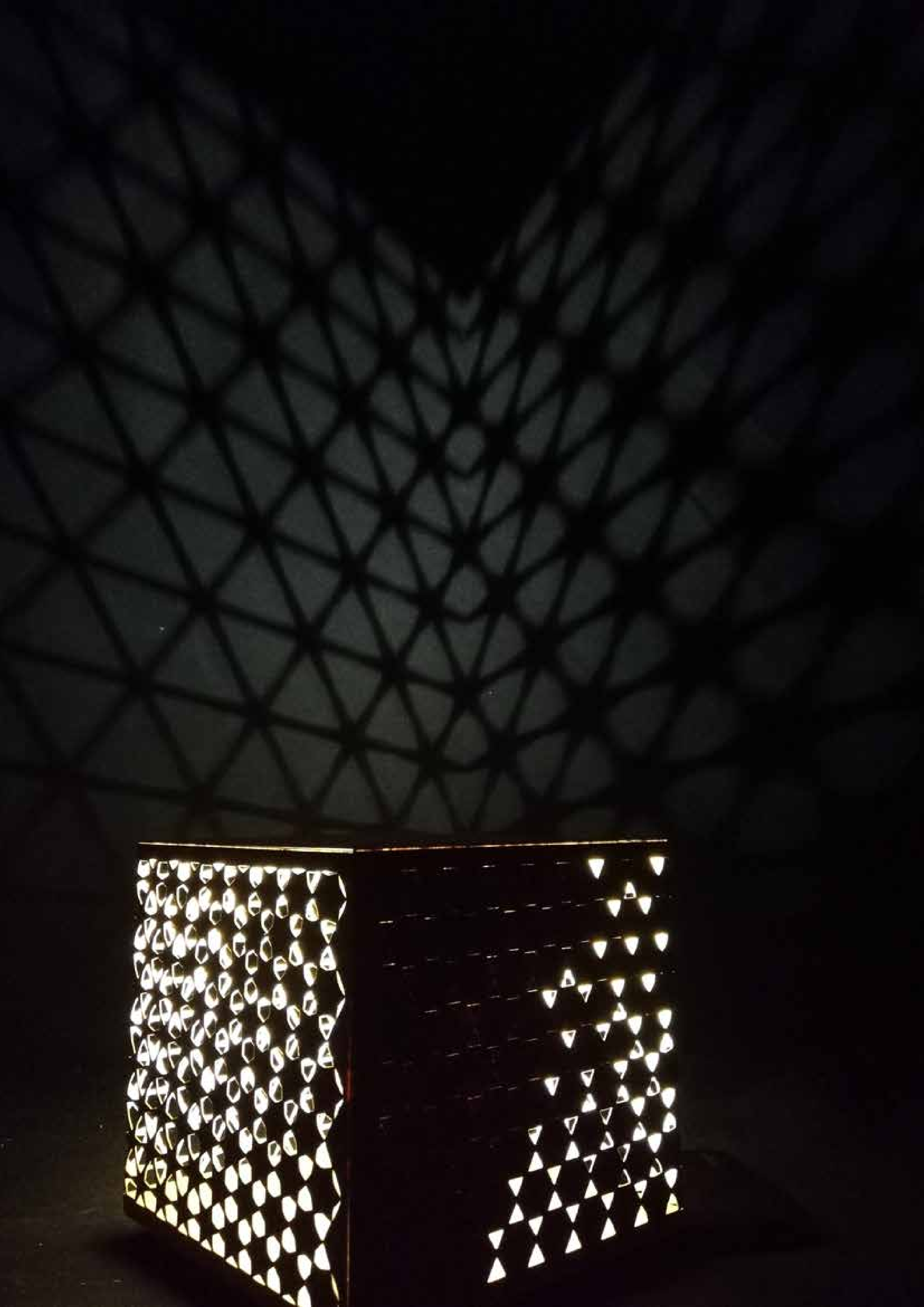
4. The stars form shapes that morph from hexagon to triangle, by selecting these, they can be offset to create the cutouts.



5. The cutouts are offset and give sufficient thickness to the material



6. The edges of the pattern are also connected to eachother to complete the shapes. The box is ready to be prepared for lasercutting and assembly!

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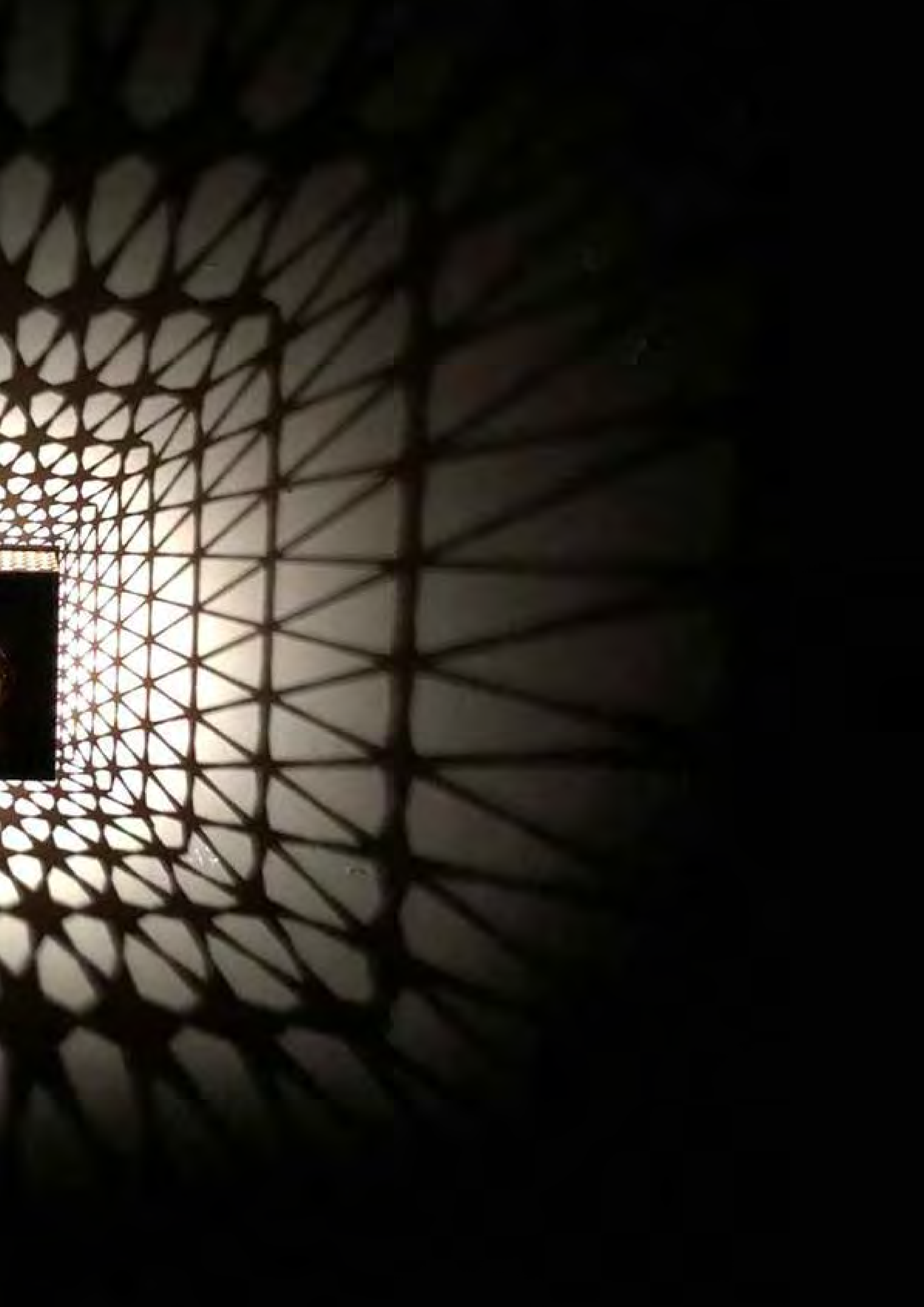
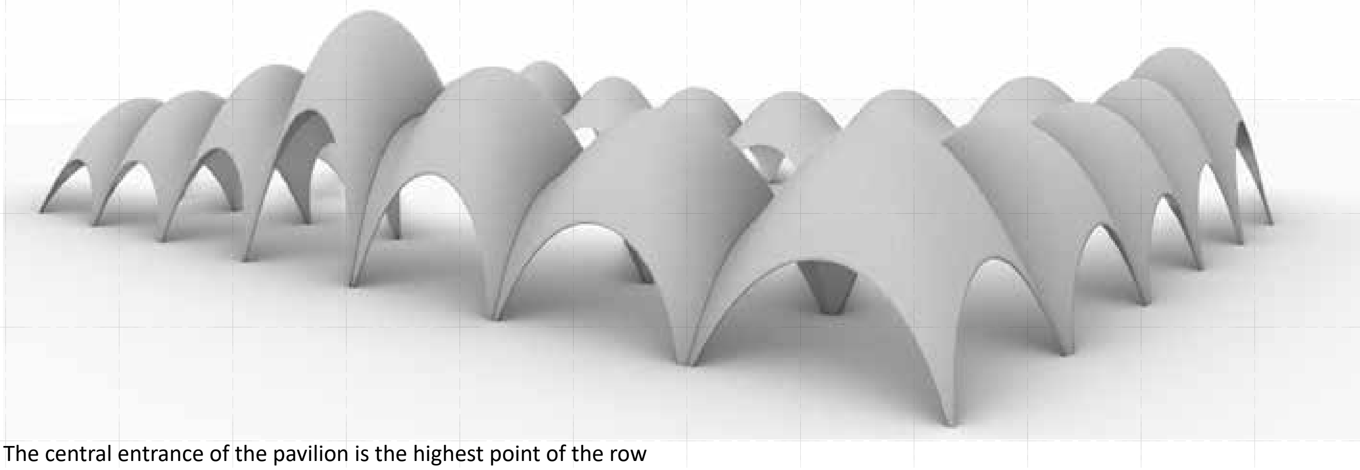


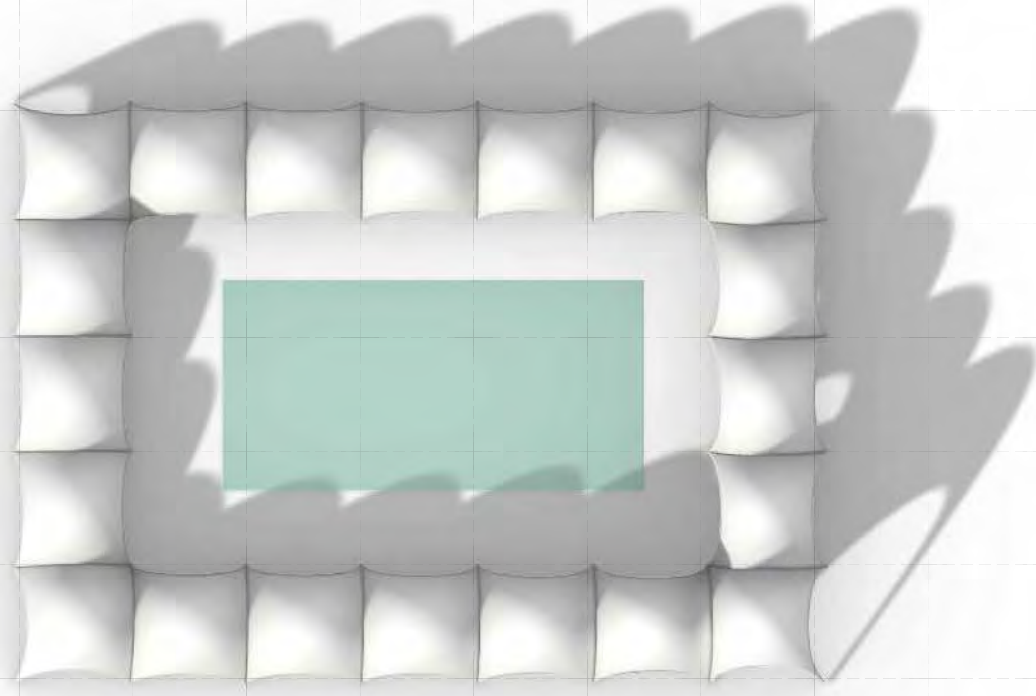
The Pavilion

The Concept
The pavilion creates a covered space and a semi-enclosed internal space with a body of water. The pavilion offers shade and a place for retreat.
It is inspired by vaulted architecture, one of the oldest principles in building. The model uses a parametric system based on catenary curves. The load strength on these catenary meshes is varied by using attractor points. The loads are stronger towards these manually defined points and create a gradual increase in height for each of the vaults.

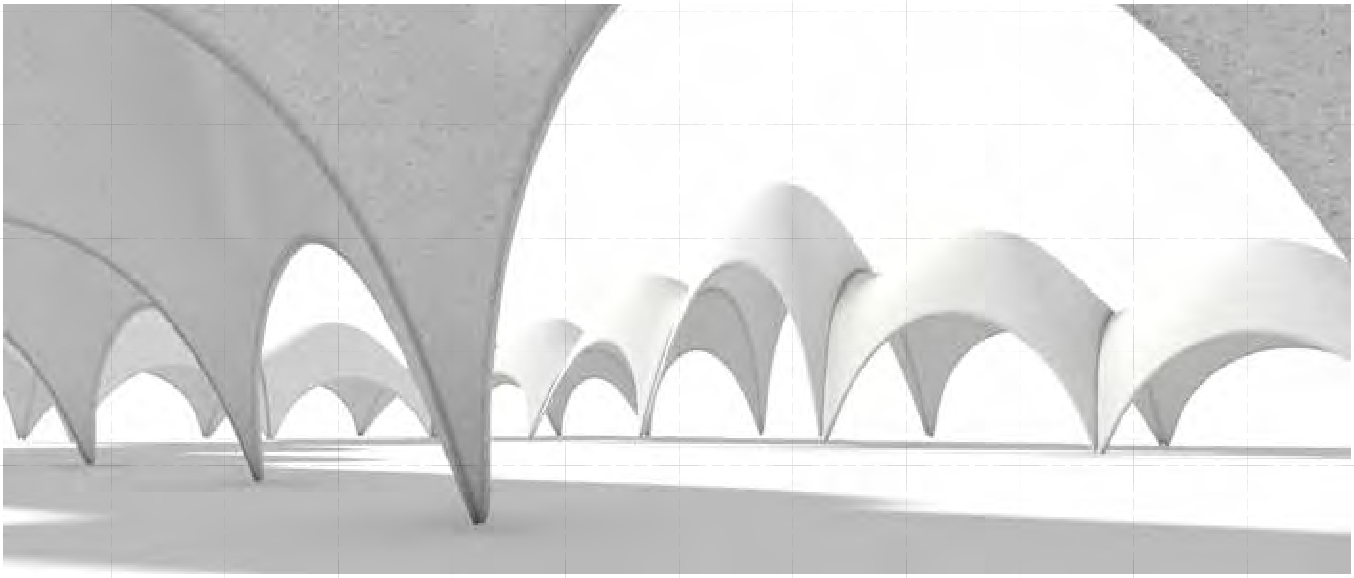
The Parametric design
The starting point for the model is a subdivided surface with the same rectangular grid as the framework. The internal squares are culled out, thereby leaving the border, which will remain linked to eachother. This method results in the gradually increased vaults that are all slightly different, can be separately produced, but fit neatly against each other.



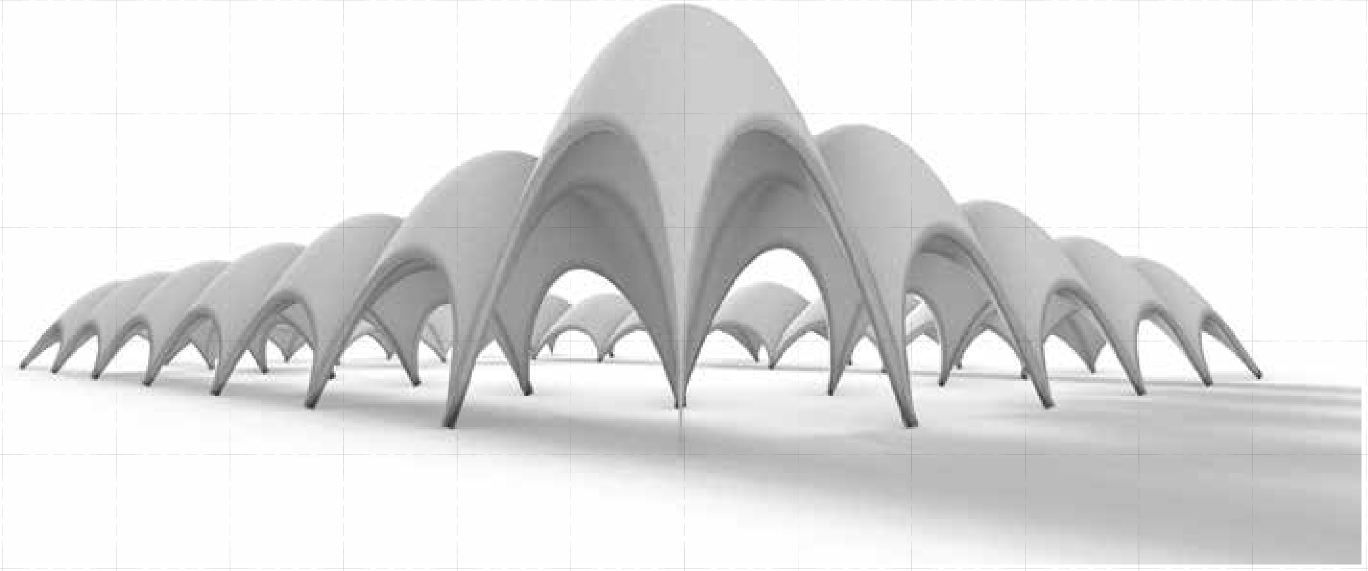
The central entrance of the pavilion is the highest point of the row

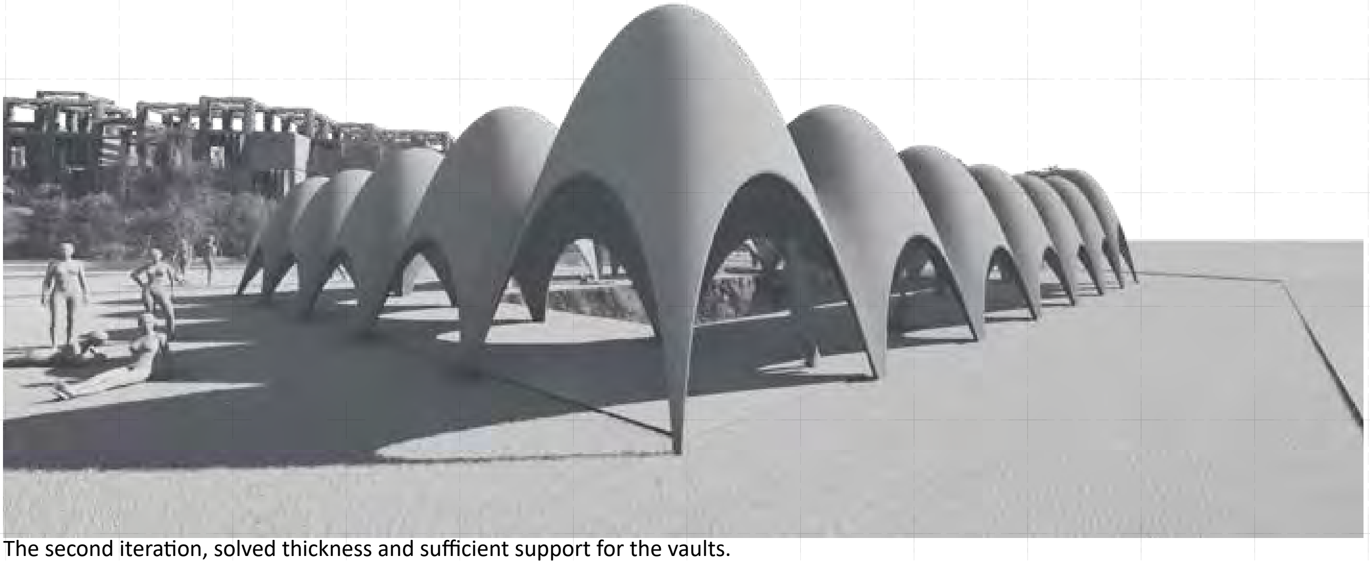


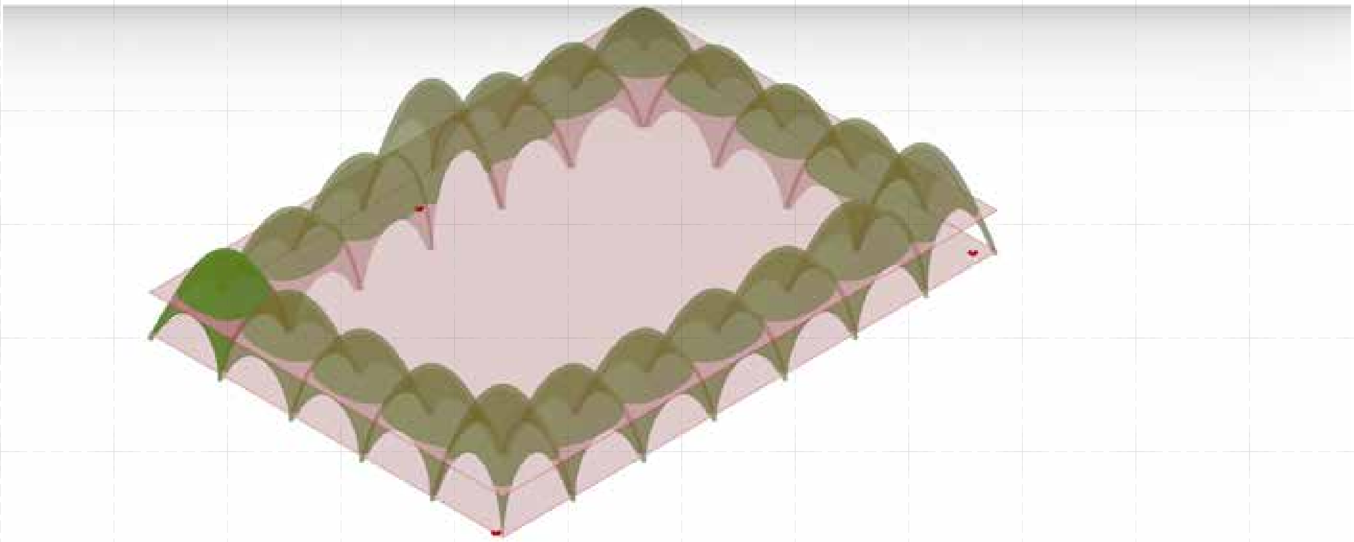
The pavilion is designed according to the 4x4m grid



A view of a preliminary design, the support is too little.


The first iteration, the legs have insuficcient thickness.

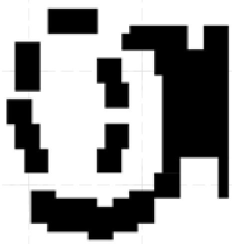

The second iteration, solved thickness and sufficient support for the vaults.



The model shown in Rhino with the two planes used to tweak the pavilion

Tweaking the design
The result from the parametric design in Grashopper is a mesh that is given thickness, however the first iteration had two problems. The first is that the legs of the highest vault had hardly any thickness, which is structurally impossible. Another problem was that the heights of the vaults are not high enough to walk underneath them.

This is solved in a second iteration by tweaking the parameters and by adding two planes in the model. one is placed a bit above the ground and acts as a cutting plane, thereby removing the thinnest parts and giving the pavilion a sturdier footing. The second plane is a visual aid placed at 2 meter height to ensure a continuously accessible path underneath the vaults.



The separate vaults

Fabrication method

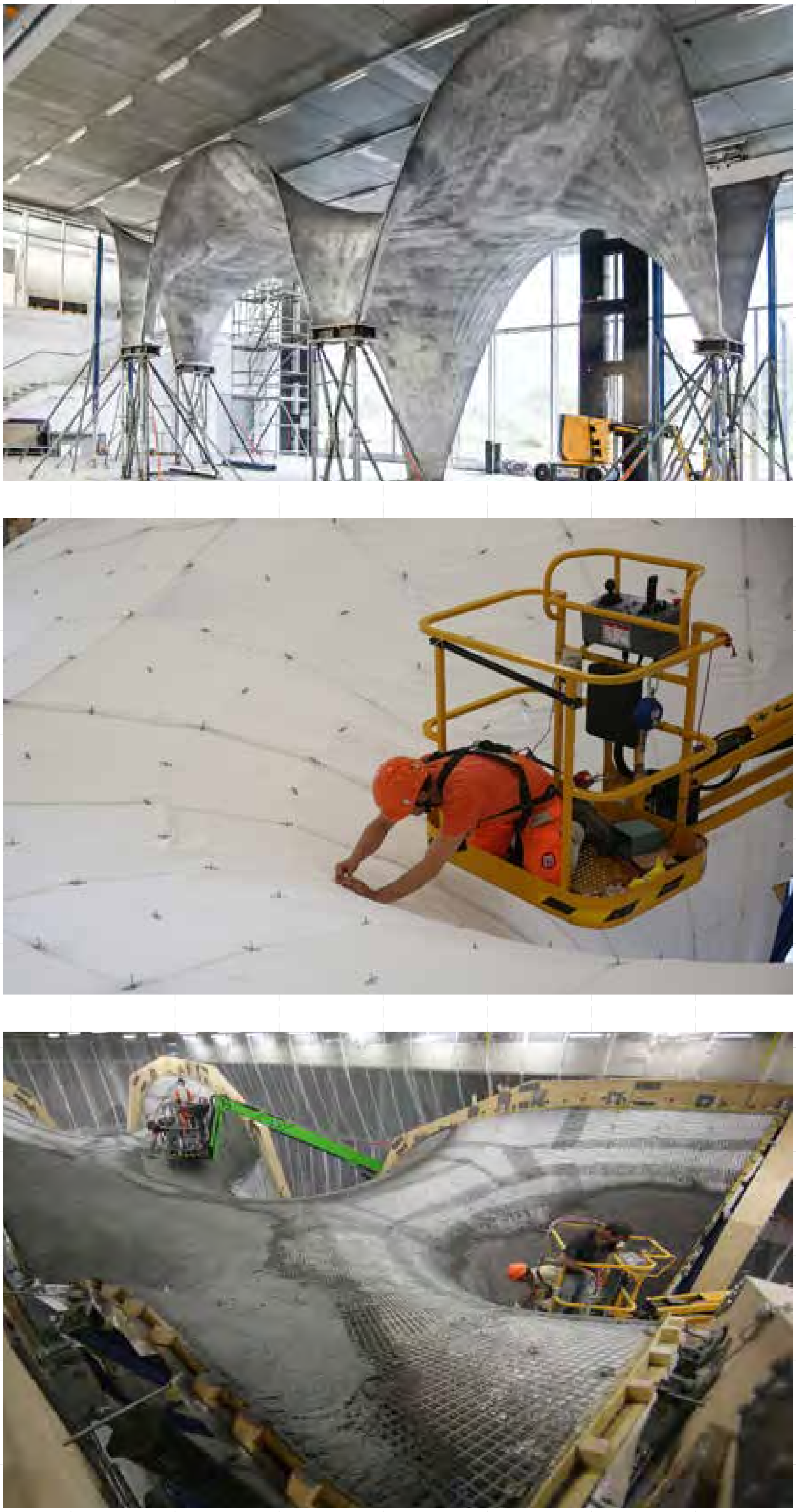
This will use a similar construction method as developed by Block Research Group from ETH Zürich and Supermanoeuvre; a formwork systum of a network of (steel) cables and a polymer fabric stretched into a reusable scaffolding structure[1].

The concrete is sprayed on top of this formwork and should have a consistency that allows it to stick to the formwork wihout sliding off with the curves, while remaining liquid enough to be sprayed on.

This approach saves a lot of waste in terms of formwork material, and allows to create a thin shell. The main reason to choose this method however is that this approach allows the necessary form freedom to create this multi-curved surface that should look like an airy, draped blanket, and by using a fabric-based formwork one has the right properties at hand to create the desired ripples, pleats and curves.

For this pavilion, each vault will be cast separately to be able to transport it to the site after prefabrication.

1 https://www.archdaily.com/882360/this-ultra-thin-concrete-structure-was-constructed-using-a-novel-steel-net-formwork-system



The construction process of the ultra-thin concrete structure

Image Source: Naida Iljazovic, 2017 HiLo, retrieved from https://ethz.ch/en/news-and-events/media-information/background-information/HiLo.html on 14-04-21)

The 3D Tile

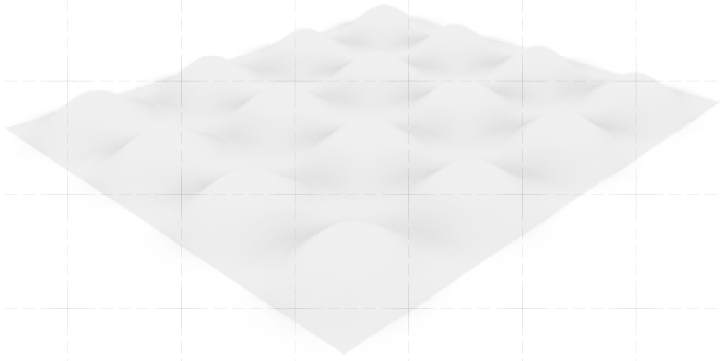
The goal for this exercise was to create a three-dimensional tile that could be cast from a 3D printed mould.

The reference project for this exercise is the Boiler Suit by Thomas Heatherwick. The undulating facade is subdivided in double curved elemements, and the waved shape is a result of sinus graphs that alternate eachother.

Image Source: Edmund Sumner, 2007. Heatherwick Boiler Suit. retrieved from https://www.dezeen.com/2007/08/20/boiler-suit-by-thomas-heatherwick/ on 04-03-21

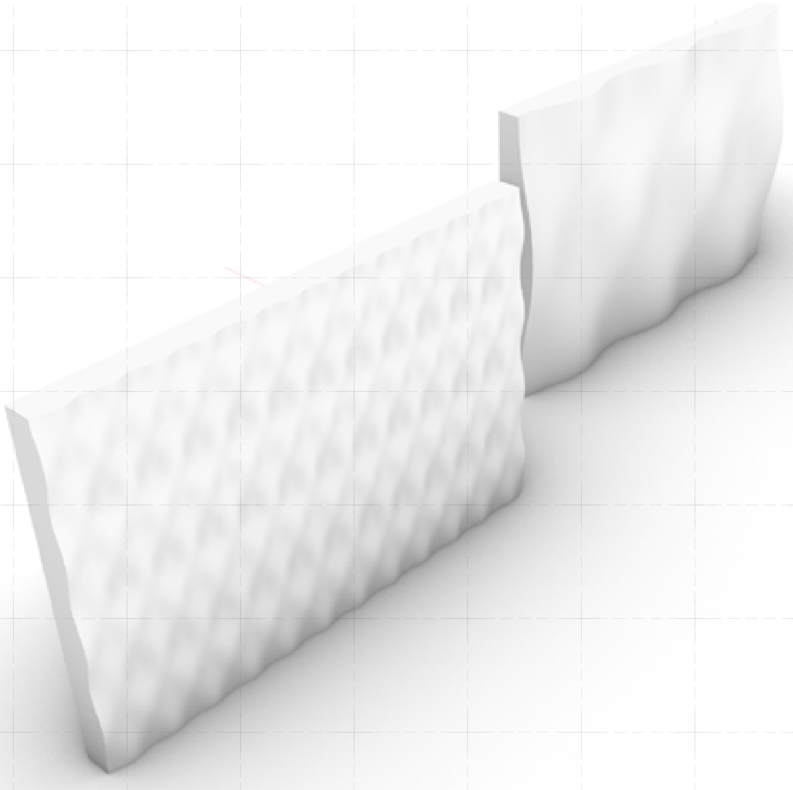
Parametric tile for ceiling

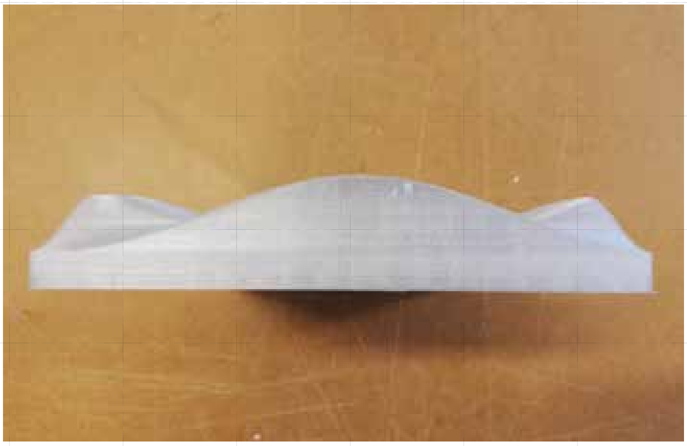
This parametrically developed tile is based on a computational manipulation of sine curves.
In the image above we see a first try at achieving this effect. The curvature is however not yet as desired as it ony goes in one direction, and the curves are not alternating.



In the image of the second iteration the wave pattern is subtle, and on the small scale it resembles a weaved pattern.

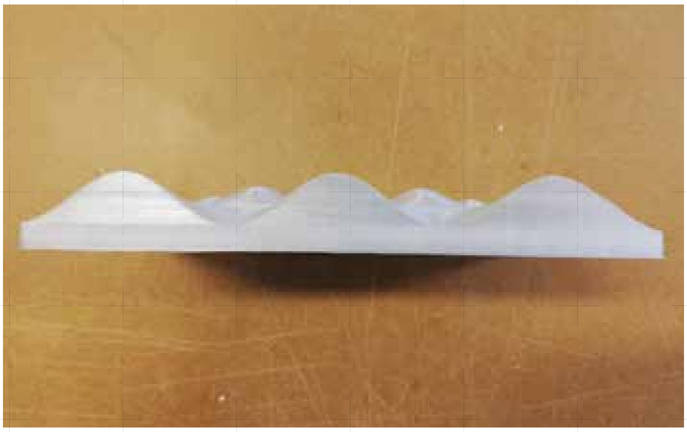
In the third and last iteration, the proportions are tweaked to emphasis the curvature and to create more depth. The tile will be applied on the ceiling of the large bath of the spa.





Fabrication

These tiles are going to be digitally fabricated through 3d milling of foam blocks which are to be used as molds for the pouring of glass fiber reinforced concrete (GFRC). GFRC is a lightweight material that is ultra-resistant. A coating will be applied on top of it, which shall reflect the water movement of the pool below.



On the right hand side we see an image of a panel prototype, which was fabricated by 3D-printing a mould and pouring gypsum.

The undulating curves of the tile express a softness and tactility, and create a play with soft shadows.