Top house

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TOP HOUSE

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TU/e 2021

Tutors: Prof. ir. J.D. Bekkering (Supervisor)
Ir. J.P.A. Schevers
Dr. Dipl.-Ing. I.C. Nan

Graduation studio BIG HOUSE (45ECTS)

Master Architectural Urban Design and Engineering

This Graduation Project was carried out in accordance with the rules of the TU/e Code of Scientific Integrity

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This Graduation report is written by Roy van Asten.
It forms as the completion of the Master Track Architectural Urban Design and Engineering (AUDE) at the Eindhoven University of Technology (TU/e).

During this one-year Graduation project, I have been guided in the research and design process by Juliette Bekkering, Jan Schevers, and Cristina Nan. I would like to thank them for their guidance and motivation during this period, especially in the extraordinary context of an ongoing COVID pandemic. This pandemic caused many serious disruptions in the course and logistics that are part of a Graduation project. Despite this, the whole project team managed to progress in this situation.

I would like to thank my fellow students in the Graduation Studio as well for their collaboration on many aspects of the project.

Special thanks go to Zeeshan Ahmed, who guided us in the exploration of Digital Manufacturing. He helped us to dive into new theories regarding the manufacturing of architectural elements and allowed us to do experiments with the 3D concrete printer at the TU/e.

Lastly, I would like to mention Laurens van der Wal and Sebastiaan van Kints from Dakdorpen. They are involved in the project location of this report and provided me with documentation and information about the location. Moreover, I had the opportunity to discuss the progress of my project with them and they provided me with valuable clues to complete my Graduation project.

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INTRODUCTION

In this Graduation report, the processes and results of a one-year Graduation Studio are presented and discussed.

The name of the Graduation Studio is ‘Big House’ and relates to formulating an answer to the question of how future housing will be shaped by architects.

“The challenge of the studio is to investigate, through analysis and literature research, what the house of the future is and what its relevant features are. With that knowledge every student will design a BIG house for a specific client.
There will be opportunities to develop a new architectural language that justifies social changes, the new wishes with regard to comfort, lifestyle, representation, functionality, sustainability, use and spatial experience. Materiality and the perfect detail will be playing a central role.”
Description of the Graduation project according to the project brief. (Bekkering, 2020)

Research into the State of Art of the Big House is conducted. This resulted in the reasoning behind the research question and completion of this project. Relevant themes connected to Big House were investigated, leading to strategies to come to a final design for a Big House.

This Big House fulfills the requirements that are defined. These requirements are defined for this project specifically and might not apply to other occasions in which a Big House is designed. It is a result of a one-year itinerary in which research and personal interests resulted in a site-specific, custom-made design.

Broad explorations of the concept of Big House and more specific literature research into the relevant themes resulted in four central topics which define the execution of the project: Affordability of Housing, Densification of Cities, Urban Climate Resilience and Digital Manufacturing.

The central research question of this project provides an answer for, calls:

How can new settlements with affordable and ecological housing be developed in urban areas?

SUMMARY

The affordability of housing is one of the societal challenges the architects and urban planners are facing in their job to shape the living environments. The shortage of affordable housing is partly caused by high demand and a lacking supply. The solution to this problem is found on the supply side. The creation of housing space in the location where this is needed, mainly in urban areas, increases the supply and decreases the price.

At the same, a growing urban population poses other challenges, especially when additional housing is provided. Further building up the urban environment would affect the presence of qualitative open spaces and thereby affect the quality of life in cities. New urban residents would be facilitated with housing space, at the expense of existing urbanists who see the remaining green areas in their neighborhood vanishing.

So, a hybrid solution should be found that allows for a sufficient addition to the urban housing stock, while maintaining green structures in the city. To achieve this, vertical extensions of existing buildings, ‘Optoppen’ in Dutch, offer an effective solution. This strategy uses the structural capacities of existing buildings and does not need additional ground to build on. It offers both financial and spatial advantages, as precious space in the urban context can be used for other purposes than housing. An existing building in Rotterdam is the location where this strategy is implemented.

To enlarge the positive environmental impact of this Optopping even more, an ecological rainwater management system is implemented. This approach has two-sided positive outcomes as well, as this network contributes to a climate-resilient urban living environment and it provides the inhabitants with a pleasant green context.

In the context of this new approach regarding housing, Digital Manufacturing appears to be a promising technique to execute this new type of architecture. Digital Manufacturing provides an automated, quick, reliable, and potentially cheap alternative to traditional manual construction chains. Concrete Liquid Injection Printing is explored as possible technique to implement Digital Manufacturing in architecture. Many possibilities regarding geometrical freedom are found, however the scalability of this technique forms an obstacle for largescale implementation in this particular project.

The resulted design proposal on top of another building in Rotterdam shows the spatial qualities that can be created within the many limitations an existing rooftop has.

STRUCTURE OF THE REPORT

This Graduation report is composed of five main chapters, which structure the research and design steps that have been made during the past year.

First, the Background of the Research is discussed. This chapter deals with the primary reasoning behind this Graduation project. What is the motivation behind the chosen project direction? Which themes play a central role in the project and will be further researched? What requirements does a Big House need to fulfill in this project? This results in a Research scope and Research question that will define the course of this project.

Then Research to existing knowledge and tools regarding those themes is discussed. This research provides basic starting points to come up with a design proposal for the research question.

The starting points for the design are structured in a Design Strategy, which includes specific methods to execute the designing process.

The defined Design Strategy results in the selection of a location, which is suitable to implement this strategy. The analysis of this location will be discussed in this report.

This process finally leads to a Design that formulates an answer to the central research question of this project.

The report will be concluded with a discussion of the results and the future implications they might have on the built environment.

Common research conducted in collaboration with other students within the Graduation Studio is attached in two Appendices. The first Appendix contains a catalog with case studies written by R. van Asten, E. van Dieteren, and C. H. Wong. Research on these case studies helped in the definition of the research scope and research question of the project.
The second Appendix contains a research book on Digital Manufacturing. This booklet was produced by D.C. Breukelaar, A.D.K. Rozema, C.H. Wong, R. van der Heijden, M.P.M. Peeters, J.W. van Wegen, R. van Asten, E. Boon, and J.P. van Zeijl. It explores the background and possibilities Digital Manufacturing has to offer for the production of architecture.

RESEARCH SETUP

The Graduation project that is presented in this report starts with explorative research into the main topic of the Graduation studio: Big House.

In order to achieve an understanding of this topic, multiple case studies were inventoried. The case studies have in common that they give different possible interpretations of the meaning of “Big” in relation to housing.
From this inventory, the Research scope and Research question are derived that define the further continuation of the Graduation Project.

Specific themes, which are considered relevant for this project, are discussed later in this report. Research on these topics provides knowledge and design tools to define a design strategy.

For this design strategy, more specific methods and concrete examples are examined. They define the decisions that lead to the final product of this Graduation studio.
This final product provides an architectural answer to the question: How can new settlements with affordable and ecological housing be developed in urban areas?

1. BACKGROUND OF THE RESEARCH

1.1 CASE STUDY INVENTORY

1.2 RESEARCH SCOPE & RESEARCH QUESTION

CASE STUDY INVENTORY

By Roy van Asten, Esmee Dieteren and Chi Hou Wong

The starting point for this Graduation Studio was the exploration of the State of the Art regarding housing and more specifically regarding Big Housing. In order to get an overview of realized projects, which contribute to the understanding of the theme of Big House, a catalog was made in collaboration with Esmee Dieteren and Chi Hou Wong. This catalog displays several case studies that relate to the theme of Big House. The case studies were selected considering three subtopics: Boundaries of the Big House, Social Issues, and Emerging Technologies. According to these topics, the case studies were ordered and evaluated for their contribution to the development of the future Big House.

Boundaries of Big House relate to the definition of Big regarding the size. A wide range of buildings was selected that seem interesting in terms of size. On the one hand, relatively small dwellings, with clever use of space and surprising solutions are found. Also, the way a house represents its size appears a very interesting theme when inventorying case studies of Big Houses.

The theme of Social Issues is linked to social structures and the way housing facilitates this. Many case studies in this category appear to offer long-term and short-term solutions for large social groups, with different demands regarding housing. Possible solutions that were found include Social housing and Community living but also sheltering for more vulnerable people.

Emerging Technologies comprises case studies in which the application of new technologies is clear. Multiple technologies, which are believed to contribute to the future housing supply and the associated case studies, are discussed.

The entire catalog can be found in Appendix 1. In this chapter, the case studies which gave the most important insights for this graduation report are elaborated on.

Quinta Monroy

This social housing project was realized by ELEMENTAL architects in Iquique in Chile in 2003. This project illustrates a very unconventional approach to house 100 families in a location they had occupied for 30 years. The project allows for qualitative dwellings for a very limited budget in a relatively expensive location.
Important boundary conditions were the Housing Policy and a $7.500 subsidy for each dwelling (including land acquisition, infrastructure, and building). Although the land prices are relatively high in this specific area, the goal of the project was to accommodate the 100 families in the same site and not in a cheaper area. Normally social housing projects in Chile are developed in very cheap and remote areas, far away from facilities such as work, transportation, and healthcare. This leads to very inefficient land use. Also, a good location for the dwellings will allow for a constant of even rising value of the properties, which makes the investment more interesting. Still, the high land prices and the limited budget made it very hard to house the 100 families. A $7.500 budget allows for a rough 30m2 of the area to build on. Making very narrow dwellings with the width of one room seems logical. However, when a family decides to enlarge the dwelling by building on the front or the back of the building, it will block daylight and fresh air in the existing rooms, and it will create a linear organization in the building with multiple rooms in a sequence, which affects the privacy of each room. A high-rise building could also be possible, but this would not allow the families to expand their dwellings in a later stage, which is something the architect considered important for this target group. Four starting points were important for the design of this social housing project:

1. Create enough density to fit in the limited area while preventing overcrowding.
2. Create collective spaces, which is an intermediate between private and public spaces. It provides restricted access but also contributes to the social system in the families.
3. Create structures that can facilitate later expansions instead of limiting this. In this way, later expansions will not negatively affect the value of the dwellings.
4. Create dwellings that will be delivered to the families unfinished to limit the building costs.

Especially this last point, to deliver half-finished buildings, seems very strange for an architect. Still, this approach is expected to be very beneficial for future property value. The architect provides
the families with an expandable structure in which only the essential elements are present, such as kitchen, bathroom, stairs, and carrying walls and floors. These elements will be executed within the $7.500 budget and the families themselves can later expand the dwellings to a maximum of 72m2 with functions like bedrooms and storage. In this way, a qualitative core within a limited budget is delivered, which can be later be enlarged without affecting the spatial quality and value of the properties. (Fracalossi, I., 2008)

Figure 1.01
Quinta Monroy housing unit (Palma, C. , n.d.)

Figure 1.02
Core housing units at delivery (Palma, C. , n.d.)

Figure 1.03
Housing units after expansion by the residents (ELEMENTAL, n.d.)

Urban Village Project

This project still is in a conceptual phase and is being developed by SPACE10 and EFFEKT Architects. The Urban Village Project is a communal housing project which focuses on the topics of “Liveability”, “Sustainability” and “Affordability”. It rethinks how houses are being designed, built, financed, and shared in future cities. Climate change, growing city populations, and rising housing prices are big challenges for which urban populations need to formulate answers. This project proposes a solution.

Local water supply, renewable energy production, local food production, and local waste processing are important elements for a more sustainable community. Apartments in different layouts for different individuals, couples, or families are provided. They are built of Cross Laminated Timber, which reduces the environmental footprint compared to other building materials. Moreover, the dwellings are modular and demountable, which allows for easy adaptations and recycling of building parts. The standardized building systems of the Urban Village Project can be prefabricated on a large scale. This allows for cheaper production and more control for the communities over their property.

Also, the share of recourses leads to better affordable living conditions. People living in the communities together pay for and share basic needs like rent, electricity, water, heating, maintenance, etc. Additional needs like food, insurance, transportation, and recreation could also be collectively arranged. Lastly, people can buy real estate shares to become owners over time. (SPACE10, n.d.)

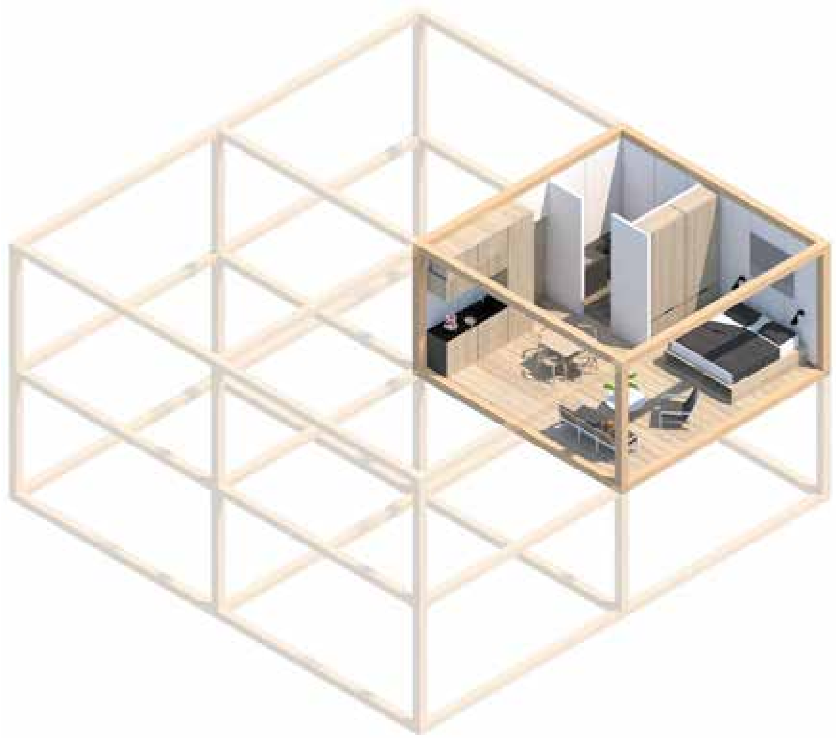


Figure 1.04
Small housing module (SPACE10, n.d.)

Figure 1.05
Large housing module (SPACE10, n.d.)

Expandable House

The Expandable House provides affordable living space for the fast-growing population in Asian cities. It is based on the existing informal settlements in tropical areas and the changing dynamics in these areas. The construction is based on a so-called 'Sandwich Section': the developer or government provides the foundations, floors, and roof (the bread) and the residents provide the infill based on their specific needs and budget. Other functions like shops or cafes are also possible. The roof can be manually hoisted to raise the building to a maximum of three floors.

This vertical densification helps to reduce the area needed to house the ever-growing population and to spare land for agriculture. Collecting rainwater, generating solar energy, and managing domestic waste on a local scale gives a more reliable infrastructure than the centralized system for water, electricity, and sewage.

Manually hoisting the floors, rainwater, and solar energy collection and managing domestic waste using septic tanks has been tested since 2018. The prototype has reached its maximum size of three floors and 108m2 floor space. The next step is testing this concept on a township level with public spaces, energy and water sharing, and cooling. This is done with mockups. Developers work on acquiring sites for commercial implementation.

The expandable house contains technologies that can be adapted to the local characteristics. It could therefore be applied in the development of many towns in tropical areas.

Figure 1.06
Expandable House (Teteris, C., n.d.)

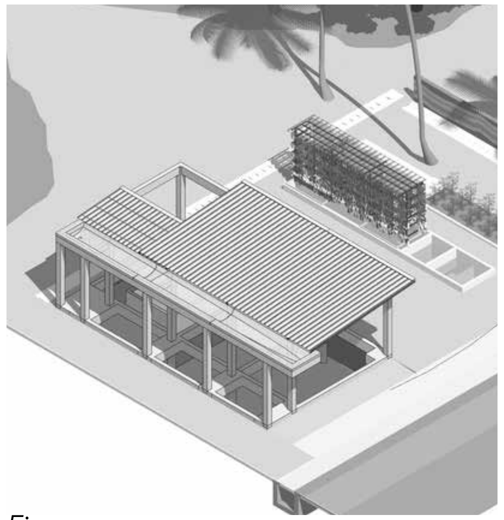


Figure 1.07
Bare structure on ground floor [Urban Rural Systems, n.d.]

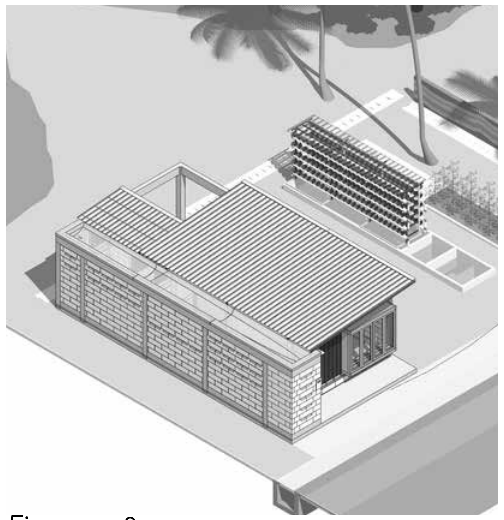


Figure 1.08
Structure with infill on ground floor [Urban Rural Systems, n.d.]

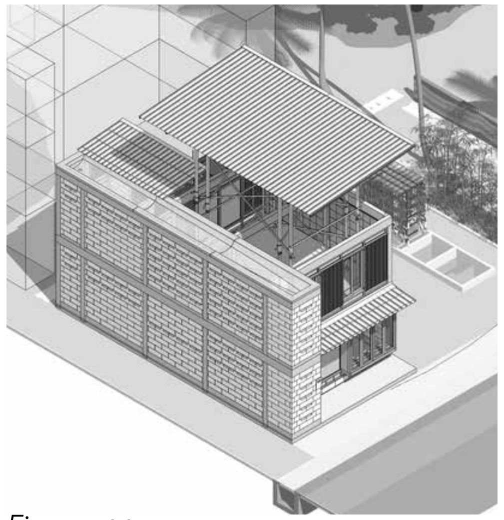


Figure 1.09
Two floors with infill [Urban Rural Systems, n.d.]

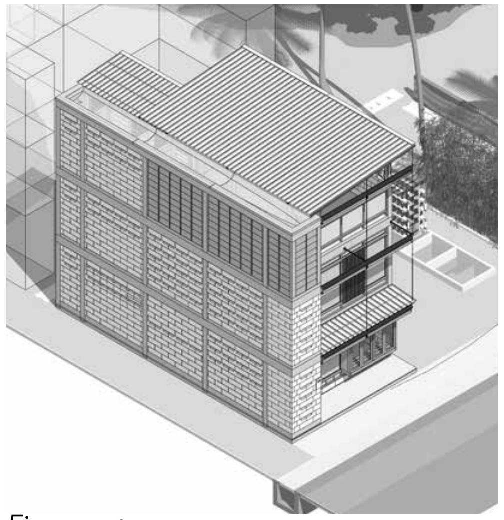


Figure 1.10
Three floors with infill [Urban Rural Systems, n.d.]

Figure 1.11
Interior view [Teteris, C., n.d.]

Nishinoyama House

Another case study, which is not included in one of the categories in the Catalogue, is the Nishinoyama House in Kyoto, Japan. Although not mentioned in the Catalogue this project shows some very interesting elements regarding housing at a smaller scale.

The Nishinoyama House was designed by Japanese architect Kazuyo Sejima from SANAA Architects and completed in 2014. The complex, comprising 10 dwellings, is located on a sloping plot with limited space. Despite the small space and the large program, Sejima managed to incorporate a lot of open space in the complex, allowing the units direct access to the outside on many sides. Each unit does not form a solid volume but instead consists of multiple smaller volumes which surround the inner garden.

The gardens show a variety in atmospheres, ranging from public gardens on the street side to covered inner gardens surrounded by a single dwelling. The architect tries to stimulate the inhabitants to use the outdoor space as a primary living space. By doing this contact between the inhabitants is strived for as an addition to the private atmosphere that can be found inside the units. (SANAA Architects, 2016)

Figure 1.12
Inner gardens (SANAA Architects, 2016)

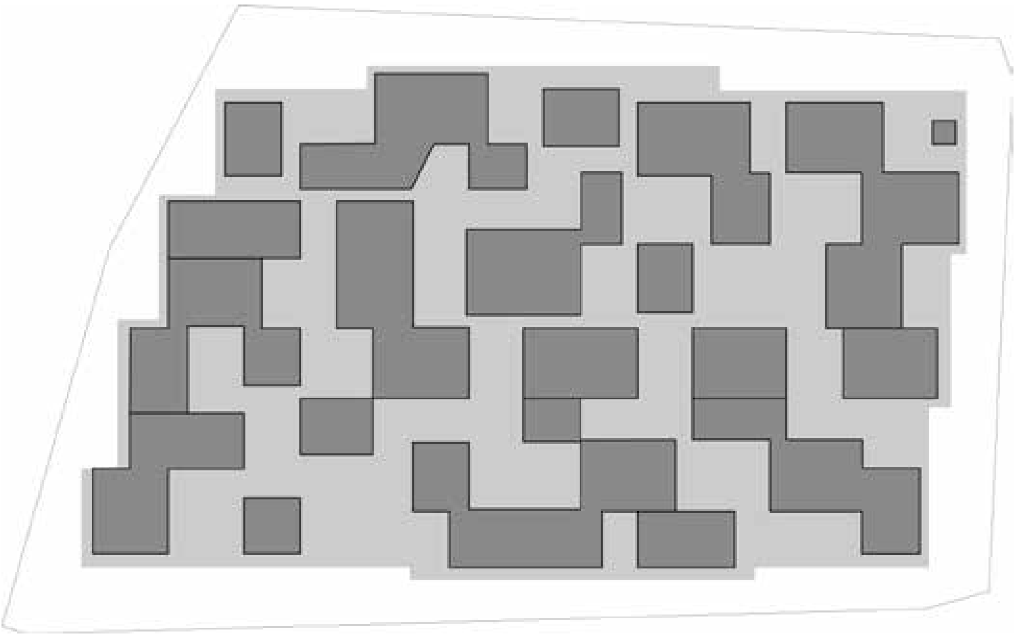


Figure 1.13
Floorplan scheme

Figure 1.14
Aerial view of roof pattern (Bann, 2016)

Naked House

Another case study by a Japanese architect, which appears to be interesting for this research, is the Naked House by Shigeru Ban in Kawagoe. Just like the design for the Nishinoyama, as discussed before, the most important starting point was stimulating social contact between the users of the house. According to Shigeru Ban, the client wanted a house that "provides the least privacy so that the family members are not secluded from one another, a house that gives everyone the freedom to have individual activities in a shared atmosphere, in the middle of a unified family." (Shigeru Ban Architects, 2016)

The outer shell of the building is made of sheets of reinforced plastics and the interior is arranged using movable boxes from timber frames clad with textile. The textile allows daylight to enter the boxes. They can be moved freely in the house. In this way, the interior can be rearranged by joining boxes together to form one large room. In this way, the privacy of each family member can be alternated with the collectivity of family life. The boxes can be positioned in a quiet corner of the house and used as sleeping cells, or they can be put at the window during the daytime and be used as a study place. If the family needs room for collective activities, the boxes could even be placed outside the house to allow for maximal indoor collective space.

Figure 1.15
Naked House exterior (Hirai, 2016)

Figure 1.16
Naked House interior (Hirai, 2016)

Figure 1.17
Naked House interior (Hirai, 2016)

Over time architects have tried many approaches to create liveable environments for everyone. Especially more vulnerable groups deserved attention in providing them with qualitative housing. During the 1960s and '70s, new forces emerged to improve living environments. (Preiser et al, 2015) New design approaches contributed to a more effective way of achieving this. 'Differentiation' instead of 'uniformity' was one of the starting points for this new approach. For example, the participation of vulnerable users, like disabled people, resulted in more social buildings. Procedures like Post-occupancy Evaluations and Environmental Impact Assessments have become common in most design approaches, just like the social impact of the built environment. Differentiated architecture aims at serving the needs of people in a differentiated way. Still, miscommunication between the users' needs and the architect's intentions occur, resulting in ineffective buildings. (Preiser, W. et al, 2015) People must be able to identify themselves in buildings. To create humane architecture an 'imaginable structure that offers rich possibilities for identification' is needed (Norberg-Schulz, C., 1986).
For a long time, architects failed to create this differentiated architecture, leading to the anonymous modernist building blocks of the 1950s and '60s. (Haddad, E., 2009) A new approach, which pays attention to local specifications instead of global conventions, evolved.

In this catalog, some case studies can be found that manage to adapt to local needs and traditions, in order to formulate an answer to the design question. The social housing project in Iquique, Chile by ELEMENTAL for example focuses on the important family structures that are present
in Chilean communities and the possibility to enlarge the dwellings if wished by the residents. (Fracalossi, I., 2008)
Another project by Urban Rural Systems in Nongsa, Indonesia has a similar approach for expansion possibilities, but this time aimed at communities in tropical areas. It allows the local people to build their own houses according to their budget and wishes, but within a structural frame to ensure a minimum level of safety and quality. (Abdel, H., 2020)
The Urban Village Project by SPACE 10 and EFFEKT Architects tackles topics such as "Liveability", "Sustainability" and "Affordability" by developing a communal housing type, in which people share the available resources. A flexible, prefabricated building system is proposed, which can be adapted to changing needs. (SPACE10, n.d.)
The Naked House by Shigeru Ban shows a similar client-based approach, in which a very flexible dwellings arrangement is offered to meet the demands of the client in different settings. (Shigeru Ban Architects, 2016)
Lastly, the adaptation to topographical parameters in the Nishinoyama House by Kazuyo Sejima shows the spatial effects that can result from this. Relatively dense, yet spacious and pleasant living environments can be created while adapting the layout to site-specific elements. (SANAA Architects, 2016)

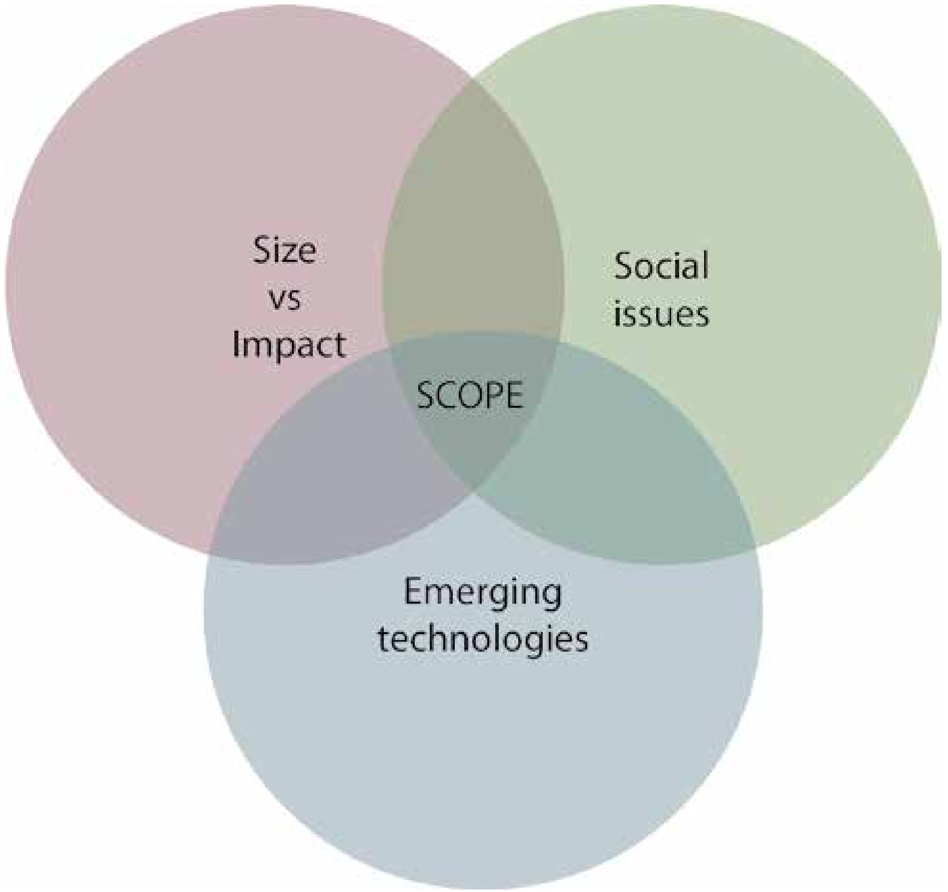
Currently, the circumstances in the housing market are characterized by increasing housing prices, exhausted resources, and a changing climate. At the same time, new technologies and building methods are developed, which can provide a solution for those issues. Housing types like eco-housing, co-housing, and off-grid housing get more and more attention, partly driven by the disapproval of the pressure housing puts on its environment. People start to look for alternatives and architects need to find them. Offering solutions to those challenges defines the 'bigness' of a housing project, rather than the physical dimensions or exclusivity of a building. This defines the requirements a Big House needs to fulfill in this Graduation project.

RESEARCH SCOPE & RESEARCH QUESTION

From the inventory of case studies, and more particularly from the examples that were discussed in the previous chapter, interesting starting points for the execution of this Graduation Studio are derived. In order to provide suitable housing for future generations, which is affordable and does not further exhaust environmental resources, differentiated design approaches are required. Central elements in this differentiated design approach are client-based and location-specific parameters, which define the program, layout, and execution of the final project. Regarding the central theme of this Graduation Studio, Big House, it is concluded that 'big' does not relate to size-specific properties, but rather to the underlying social, spatial, and technical parameters that define the design. The overall impact is considered more important than the dimensions.

In this Graduation Report four topics play a central role:

1. Affordability of Housing
2. Densification of Cities
3. Urban Climate Resilience
4. Digital Manufacturing



The first three topics are directly derived from the preliminary case study inventory that is discussed in this chapter. The affordability of housing is a big challenge. Research, included in this report, shows that a growing population puts pressure on the housing market, as demand and supply do not match. The Densification of Cities will appear to be a vital part of tackling this issue. Besides, the lack of affordable housing, the growing urban population also causes environmental effects on the urban environment. This, in combination with a changing global climate, requires an ecologically based strategy for the way living environments are planned.
The fourth topic of Digital Manufacturing is discussed later in this report. Digital Manufacturing will appear to be a promising technology for future housing production. Moreover, it has a big potential to contribute to a more custom-made, differentiated production chain, which is at the same time quicker, cheaper, and more reliable than traditional construction processes.

This Graduation project will focus on the affordability and ecological integration of future housing schemes. Additional research in this report will focus on finding knowledge and tools to come up with an architectural proposal for the relevant topics defined in this chapter.

The central research question for this Graduation project calls:

How can new settlements with affordable and ecological housing be developed in urban areas?

2. RESEARCH

AFFORDABILITY OF HOUSING

The affordability of housing is getting a lot of attention in public debate. Especially younger people, who try to make a start on the housing market by buying their first house, are facing tough challenges. This is mainly caused by the sharp increase in housing prices. Although this phenomenon occurs in many developed countries around the world, the Netherlands shows a relatively sharper increase in housing prices than other OECD[1] countries. (Renes, Thissen, & Segeren, 2006) See figure 2.1.
According to Robinson, Scobie and Hallinan, the consideration of whether a house is affordable or not, is related to the share of income that is spent on housing and what share of income is left for other expenditures. This is a hard-to-define balance, which cannot be fully quantified. (Robinson, Scobie, & Hallinan, 2006)
However, housing prices rising faster than wages logically disturb this balance, as has been happening in the Netherlands for the last years. (Rabobank, 2009) The rise of housing prices and the decrease in affordability show regional differences as prices are higher in areas where there is a higher demand. In the Netherlands, this is most evident in the urban area of the Randstad. See figure 2.2.
This information helps to identify the most suitable locations for housing construction in order to increase the affordability of housing. (Renes et al., 2006) So urban areas could be considered the location with the most acute deficiency of affordable housing.

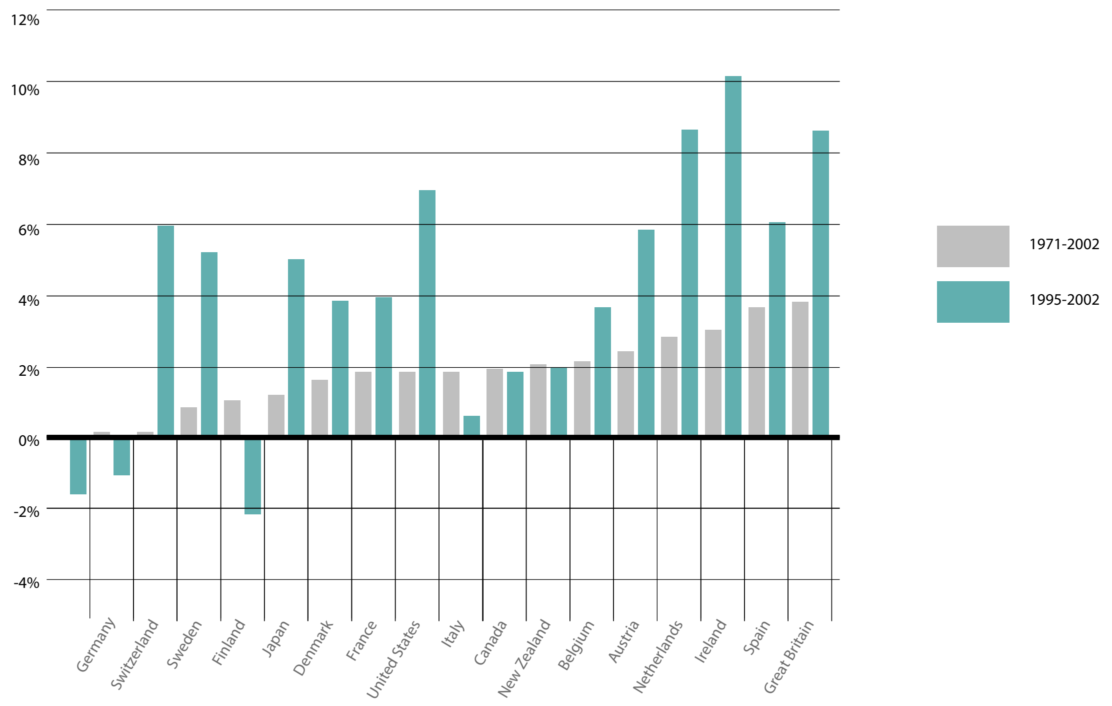


Figure 2.01
Average yearly increase of housing prices in OECD countries
(Renes et al., 2006)

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[1] *Organization for Economic Development*

Rising house prices are for a large part due to a lagging housing supply in combination with increasing demand over the past years. According to Renes et al., sufficient building locations for new housing projects and more flexible government regulations could help to expand the housing stock and thereby prevent extreme housing prices. Less regulation would enable developers and contractors to realize new housing space quicker as a reaction to increasing demand. However, the pace is housing development also depends on other factors, such as the availability of ground. The scarcity of land in the Netherlands is at the same time a cause for the cautiousness of authorities, as building projects potentially threaten the availability of public open space. Government policy will remain important to steer housing development without affecting precious open space.
But even with more ground available and with a solid land-use policy from the government housing ground prices still account for a large share of the developing costs of housing projects. In the Netherlands, the share of ground prices on the total expenditures of housing development rose from 13 to 34 percent between 1976 and 2009. (Bouw en Wonen, 2010) In other places, like Auckland (New Zealand) and San Francisco (United States) land costs respectively exceed 40 and 80 percent of the property price. (McKinsey, 2017)
So, there is an important task for authorities, developers, and architects to ensure the future generations of affordable and livable housing space. Especially combining a quick production of a considerable number of houses while preserving the remaining open spaces in cities seems challenging.

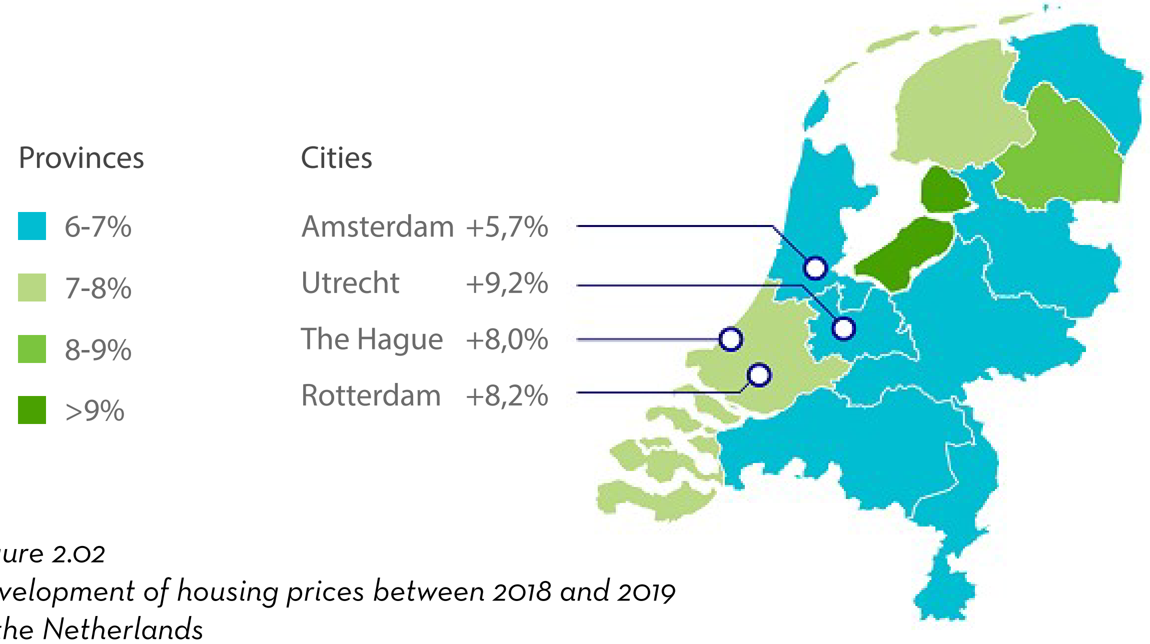


Figure 2.02
Development of housing prices between 2018 and 2019 in the Netherlands
(Rabobank, 2009)

DENSIFICATION OF CITIES

Densification of existing urban areas is often considered a sustainable way of developing living space for an increasing urban population. Urban sprawl on the other hand reflects an inappropriate and unsustainable way of using scarce space. (Pelczynski & Tomkowicz, 2019) It also negatively influences people's behavior, which results in even more damage to our living environment. Comparative studies in the Netherlands and Flanders show that a loosely planned land-use pattern with many suburban areas as a result of urban sprawl, results in less efficient use of infrastructure than a more strict land-use pattern. (De Vos, 2015) The Belgian region of Flanders has many suburban areas, which require a lot of infrastructures to connect all areas to bigger cities. Moreover, such a widespread pattern of settlements stimulates more car usage. On the other hand, the active clustering of facilities according to the Dutch land-use regulations, seems to result in more movements by walking, cycling, and public transportation and less need for extensive infrastructure networks. This trend of densification has been strong in the Netherlands since 2000 and is expected to be contributing to the development of living space for the coming years. (Claassens & Koomen, 2017)

Densification of existing cities aims at efficiently using the already occupied natural resources and reducing the need for using new resources. In this report, space is considered one of the most important natural resources. Pelczynski and Tomkowicz identify four methods of urban densification:
1) transforming existing building by adapting functions or unused spaces
2) intensification of the urban tissue by building up open spaces (horizontal extension)
3) intensification of existing buildings by building below or on top of them (vertical extension)
4) replacing existing building by demolition and new building
Besides the efficient use of space densification also has the potential to enhance the technical, spatial, and esthetic qualities of existing infrastructure, spaces, and buildings.
However, densification of cities involves several risks that need to be taken into account when choosing a densification strategy. The most important threats of densification are increasing heat stress and less recreational space caused by the loss of open space and the loss of local identity and urban heritage when densification is not carried out carefully. Table 2.1 shows the four different densification methods along with their advantages and disadvantages.

	Advantages	Disadvantages
Densification method		
Transformation	1. Relatively inexpensive compared to other methods 2. Improved state of existing buildings regarding energy efficiency and appearance 3. Little impact on surroundings 4. Preservation of open urban spaces 5. Preservation of possible historical elements	1. No usable floor area added 2. Limited space for new functions 3. Nuisance for existing co-users of the building 4. Technical limitations from an existing building 5. Possible restrictions from monumental regulations
Horizontal extension	1. Addition to usable floor area on the location 2. Impulse for neglected areas 3. Possible preservation or enhancement of urban landscape	1. Loss of open spaces 2. Higher construction costs than transformation 3. Reduction of sunlight to adjacent buildings 4. Adjacent buildings must not be affected 5. Limited space for new developments
Vertical extension	1. Addition to usable floor area on the location 2. Preservation of open urban spaces 3. Preservation of existing buildings and infrastructure 4. Relatively inexpensive compared to horizontal extensions 5. More design freedom in form and function 6. Possible improved state of existing buildings regarding energy efficiency and appearance 7. Limited impact on adjacent buildings	1. Nuisance for existing co-users of the building 2. Reduced sunlight for adjacent buildings 3. Possible restrictions from monumental regulations 4. Considerable impact on urban landscape 5. Potentially complex engineering issues
Replacement	1. Much design freedom in form and function 2. Potentially building with high spatial and technical quality 3. Potential improvement of urban structure 4. Potential increase of urban diversity	1. Reduction of existing building stock and resources 2. Relatively high investments 3. Risk of losing local identity 4. Potential decrease of urban diversity

Table 2.1
Advantages and disadvantages of densification methods
(Pelczynski & Tomkowicz, 2019)

In terms of financial investments and limited use of open space, Transformation appears to be the most favorable method for densification, as it requires the smallest investments and does not occupy more space. However, when an increase of the building stock is strived for, transformations do not seem to have a big impact, as no floor area is added. When considering the addition of floor space and the preservation of open space as targets for densification, a vertical extension would be considered the most efficient method.

The various challenges that are linked to every densification strategy, including vertical extension, demand clear decision-making in order to successfully implement a strategy in an urban environment. Amer, Mustafa, Teller, Attia and Reiter identified three phases that are relevant for decision making regarding a vertical extension. For their research, the term ‘roof stacking’ was adopted. Firstly, local policies and regulations need to be taken into account when planning a vertical extension of buildings. This includes the identification of areas with potential population increase and the associated need for densification. Important regulations include the monumental status of the existing building, maximum height, daylight requirements, and accessibility to transportation modes. Secondly, the structural capacity of existing buildings needs to be determined. This could be possible with detailed data if available for the particular building. Otherwise, estimations need to be made based on the size and construction type of the existing building, this will of course give less certainty during the rest of decision making compared to exact data. In the third phase, which is the architectural configuration, exact measurements and decisions are made, based on the first and second phases. These decisions include the number of floors, connection to sewage and sanitation, and layout. (Amer, Mustafa, Teller, Attia, & Reiter, 2017)

According to UN Habitat 50% of the world population lives in urban environments and this percentage is expected to rise to 70% in 2050. (UN Habitat, 2006) In this report challenges regarding urban planning have been identified. A growing urban population exerts pressure on the affordability and livability of urban housing. An interest in urban sustainability has grown in relation to the increasing urban population. Landscape ecologists potentially have an important role in planning cities considering a sustainable and climate resilient urban development. (Ahern, 2013) In order to build climate resilient cities interdisciplinary strategies, shared by urban planners and landscape ecologists, are required. According to Ahern there are five strategies to achieve urban resilience. 1) Biodiversity 2) Ecological networks 3) Multifunctionality of space 4) Redundancy and modularization of urban networks 5) Adaptive designs

Biodiversity

Ahern describes Biodiversity not only as a collection of different species in an urban environment, but also as diverse set of tools to respond to changing circumstances. Greenery for example contributes to a healthier and more attractive living environment but also enhances the rainwater drainage in cities. It functions as addition to the central sewage system and thereby creates a more diverse and resilient water management network.

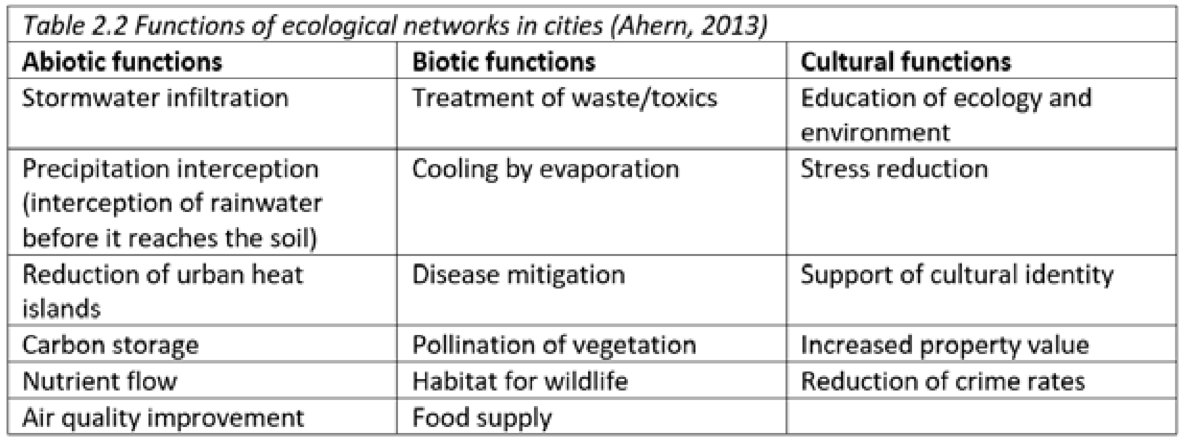


Table 2.2 Functions of ecological networks in cities (Ahern, 2013)

Abiotic functions	Biotic functions	Cultural functions
Stormwater infiltration	Treatment of waste/toxics	Education of ecology and environment
Precipitation interception (interception of rainwater before it reaches the soil)	Cooling by evaporation	Stress reduction
Reduction of urban heat islands	Disease mitigation	Support of cultural identity
Carbon storage	Pollination of vegetation	Increased property value
Nutrient flow	Habitat for wildlife	Reduction of crime rates
Air quality improvement	Food supply	

Ecological networks

Ecological networks provide connectivity in urban networks. Connectivity is often highly developed for functions like transportation, communication, and energy, but the connectivity of urban ecosystems is often overlooked in urban planning. Ecological networks can provide connectivity to urban functions like water management, pedestrian movements, and recreation. Ahern organizes the functions of ecological networks in three groups: abiotic functions, biotic functions, and cultural functions. See table 2.2
In ecosystems, abiotic factors include all non-living factors, such as temperature, light, soil composition, and water. Biotic functions include all living factors, such as forests, lakes, and organisms. Cultural function regard human behavior and social implications.

Multifunctionality

Since space is limited in urban environments and will be even more limited when densification strategies are implemented, as explained earlier in this report, efficient, multifunctional use of space is vital for resilient cities. Multifunctionality can be achieved by 'spatial stacking', where different functions operate at the same location at the same, or by 'time shifting', in which the same location can fulfill different functions at different times. (Kato & Ahern, 2009) Green structures can often provide a hybrid functionality for transportation, recreation, water management, and natural habitat. Researchers have been questioning how to plan for multifunctional urban networks. According to Ahern planners and designers should take the opportunity to integrate this multifunctionality into their plans.

Redundancy and modularization of urban networks

Ecological redundancy is a method to spread ecological risks. Much urban infrastructure nowadays has been highly centralized many urban systems such as transportation and sanitation rely on this central infrastructure. According to Ahern, these systems are therefore not 'safe to fail', as the infrastructure is not redundant enough. For resilient urban systems redundant, modular elements are suggested. (Ahern, 2013) Urban rainwater infiltration systems are described as a good example of a modular system. Storing rainwater locally in smaller networks provides more decentralized and less vulnerable protection to flooding than traditional centralized sewages.

Adaptive designs

Contrary to conservative design approaches, which are often applied by urban designers as a safe and pragmatic solution to acute issues, adaptive designs are proposed as a more innovative and flexible approach. Adaptive designs are rather based on uncertainty, experiments, and hypotheses than on existing knowledge and practices. (Gunderson, 1999) Experiments with new materials and systems are a good way to shape adaptive designs. According to Ahern design experiments can be applied to explore innovations for different ecological networks as described in table 2.2. These experiments should lead to new research questions and design approaches to formulate answers to the challenges for resilient cities in the future.

One of the many ecological challenges cities are facing is rainwater mitigation. As the global climate changes, extreme rainfall and extreme draught in different seasons are occurring more often. This results in peaks in rainfall during winter, which again causes flooding. On the other hand, summers are getting hotter with long periods without rainfall, resulting in draughts, which damages natural systems and agriculture. In the urban context, this effect is even stronger as many parts are paved. Rainwater is prevented from sinking into the surface and is centrally drained by the sewage system. The overload of sewage systems with extreme peaks in rainfall causes flooding and nuisance. Especially during the summertime, this urban context suffers from heat stress and draught as rainwater is not stored locally. Rainwater runoff, in which rainwater is directly drained into the sewage, makes up the largest share (55%) of rainwater transportation in cities. See figure 2.03
In natural environments, rainwater runoff is much smaller (10%). Much of the water evaporates and thereby contributes to a cool more pleasant environment. (STOWA, n.d.) This ecological process potentially improves the future urban climate to a great extent, especially in the context of a changing global climate.
According to Fassman-Beck, Voyde, Simcock and Hong the configuration of the built environment contributes to the mitigation of rainwater runoff. Streets and buildings could slow down rainwater flows, so rainwater is stored on the surface for a longer time than draining into the sewage. Studies have been executed to compared different rooftop layouts which slow down rainwater flows. (Fassman-Beck, Voyde, Simcock, & Hong, 2013)

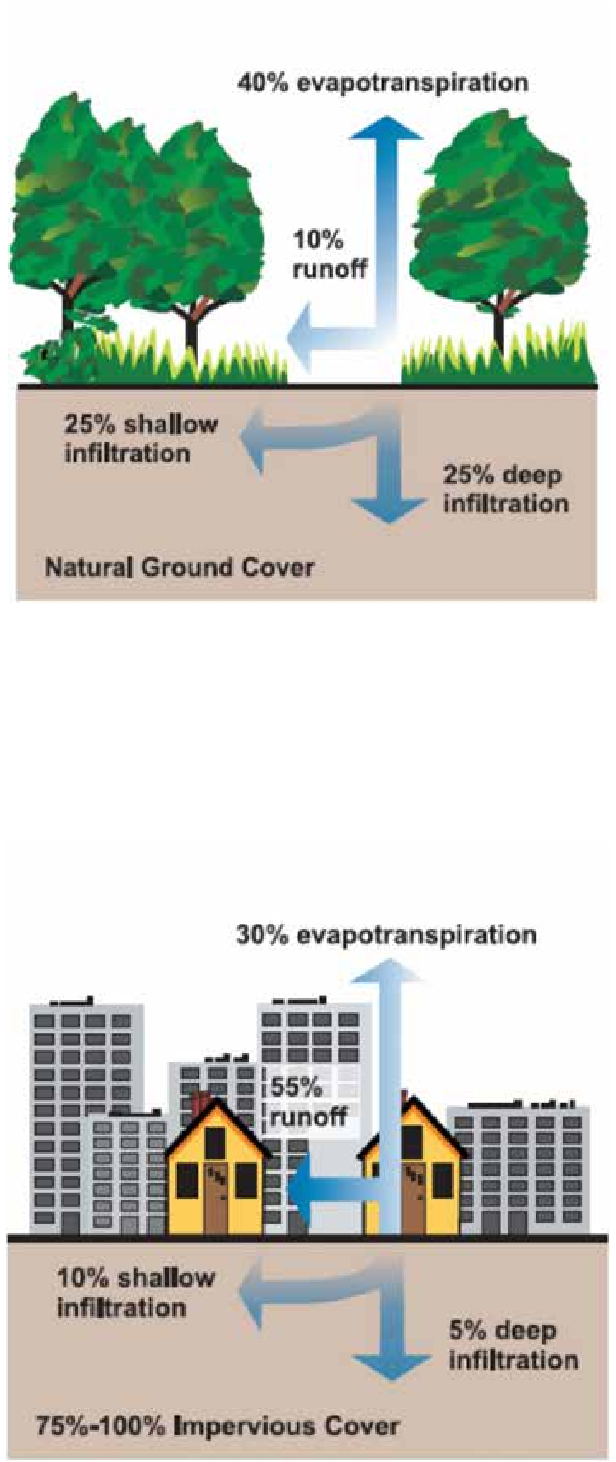


Figure 2.03
Rainwater processing in natural and urban environments
(STOWA, n.d.)

DIGITAL MANUFACTURING

By
D.C. Breukelaar R. van der Heijden R. van Asten
A.D.K. Rozema M.P.M. Peeters E. Boon
C.H. Wong J.W. van Wegen J.P. van Zeijl

Besides examining new solutions for future housing challenges, the Graduation Studio of Big House has a second theme, which has a big potential relevance for the way architecture is shaped in the future. In this project, the possibilities of Digital Manufacturing are explored and implemented in the final design. In a research group of nine students, with the help and guidance from Zeeshan Ahmed and Cristina Nan, the relevance and potentials of this new manufacturing technique are explored. The most important findings of this research are discussed in this chapter. The complete research booklet on Digital Manufacturing can be found in Appendix 2.

Nowadays the Architecture, Engineering and Construction (AEC) Industry is characterized as a relatively traditional industry regarding production processes. Compared to other industries, such as car industries, digitalization and automation proceed slow. (Craveiro, Duarte, Bártolo, & Bartolo, 2019). Construction processes are considered rather inefficient with complex supply chains and many parties involved. (Ding, 2008) Improving the efficiency of construction processes potentially generate large financial benefits. It is estimated that a 1% increase in productivity could around $100 billion in construction costs. (World Economic Forum, 2016).
Digitalization has radically changed other industries, such as automotive, aeronautics, and aerospace industries. The AEC Industry on the other hand is considered one of the least digitalized industries of all. See figure 2.04

Digitalization could be achieved by implementing Robotics and Automation in Construction (RAC). This is beneficial in terms of labor productivity and quality of the products, as human errors are largely eliminated. (Balaguer & Abderrahim, 2008; Gerbert, Castagnino, Rothballer, Renz, & Filitz, 2016; Liu, 2017a)
RAC is especially promising for on-site construction as off-site prefabrication has already been successfully implemented in AEC Industries. Potentially the precision of robotic production also has a positive environmental impact as less waste is produced. (Ilhan et al., 2018; Kim, Chi, Wang, & Ding, 2015)
Moreover, robotic production could be easily implemented in a continuous production chain, from design to construction and management, as buildings are already designed and managed digitally. It will simplify the whole production chain. (Ilhan et al., 2018; Kim et al., 2015; Liu, 2017b; McKinsey Global Institute, 2017).

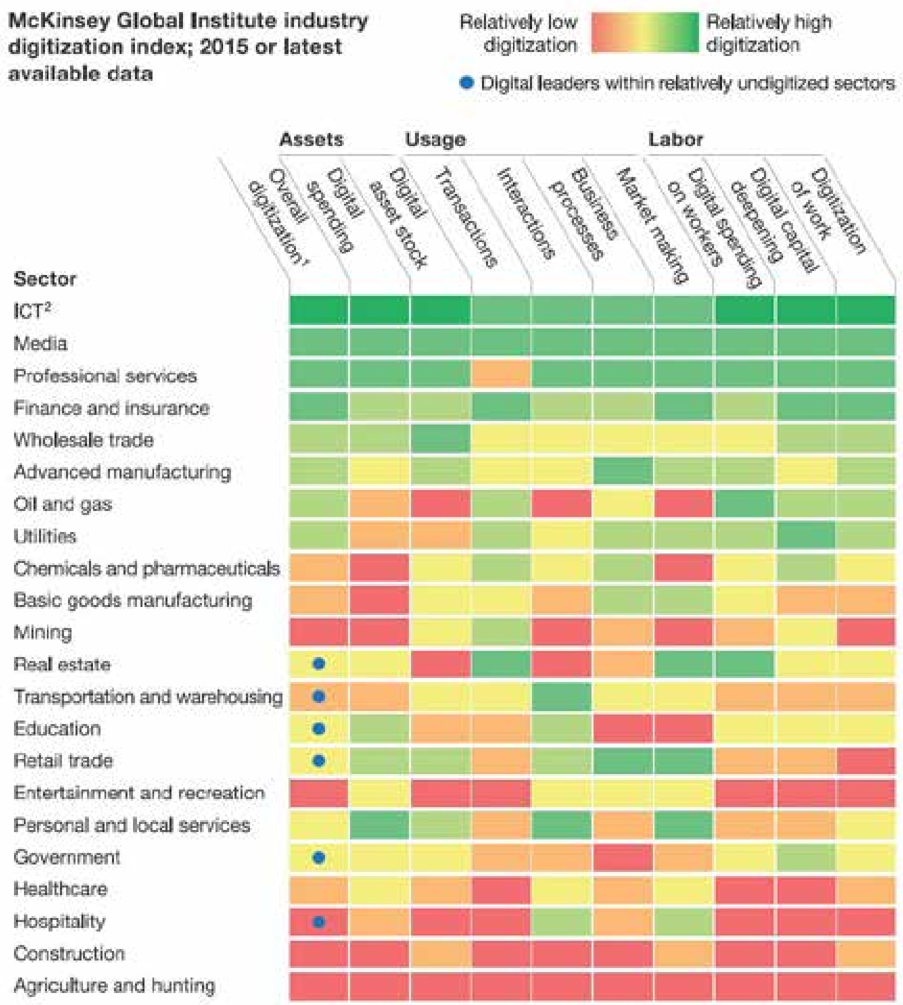
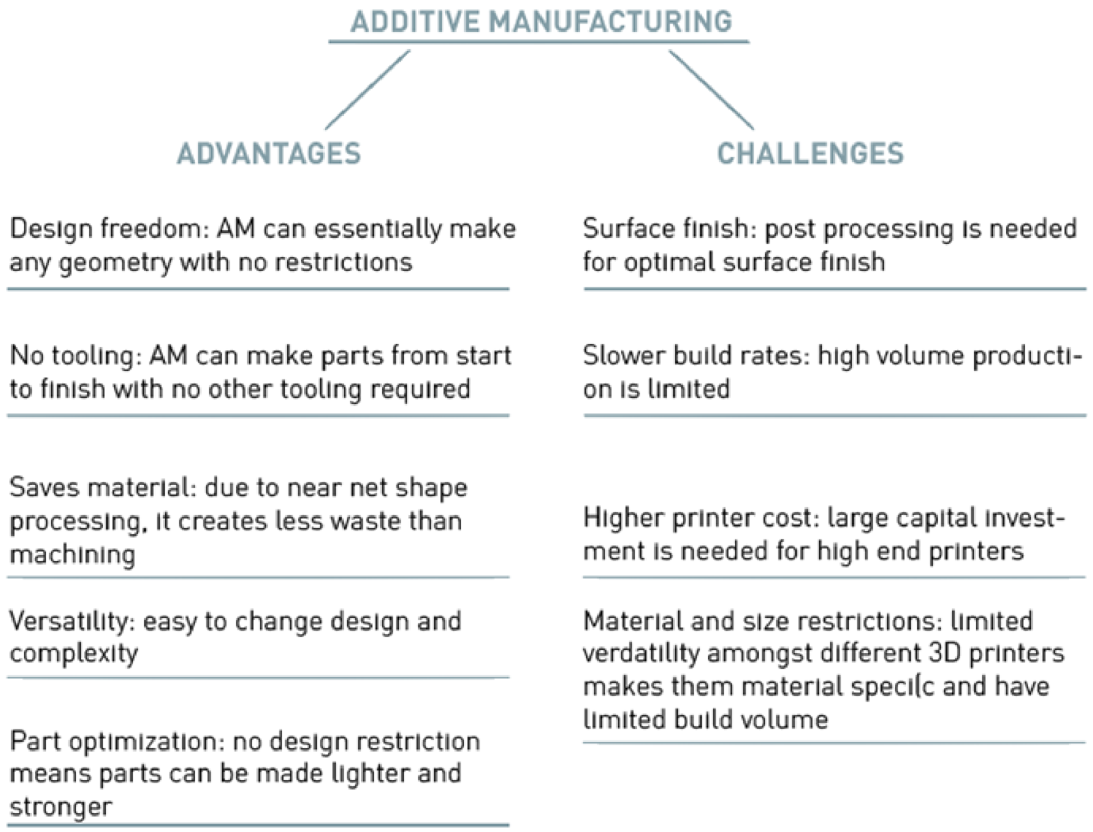


Figure 2.04
Industry Digitization Index; 2015 or latest available data [10]
(McKinsey Global Institute, 2017)

Additive Manufacturing (AM) is a form of manufacturing in which materials are added and joined to form an object. Additive Manufacturing used to be called Rapid Prototyping and nowadays is often mentioned as 3D printing. (Gibson, Rosen, & Stucker, 2014) AM can be steered by a Computer-Aided Design (CAD) which is sliced into horizontal layers. The design will then be built up by a printer layer by layer. (Paulo Davim, 2019a)
Contrary to Additive Manufacturing is Subtractive Manufacturing (SM), where materials are subtracted instead of added to create an object. One of the advantages of AM over SM is the level of detailing that is possible using AM. As SM requires a cutting tool to subtract material, very thin detail are hard to cut, whereas adding small parts is easier. (Paulo Davim, 2019b). Also, material use is significantly reduced when using AM over SM, as subtracted materials are often discharged as waste. Material use could be reduced by up to 75%. (Bandyopadhyay & Bose, 2019). More advantages and disadvantages can be found in figure 2.5. AM and SM are more elaborately discussed in Appendix 2.



ADDITIVE MANUFACTURING

ADVANTAGES

- Design freedom: AM can essentially make any geometry with no restrictions
- No tooling: AM can make parts from start to finish with no other tooling required
- Saves material: due to near net shape processing, it creates less waste than machining
- Versatility: easy to change design and complexity
- Part optimization: no design restriction means parts can be made lighter and stronger

CHALLENGES

- Surface finish: post processing is needed for optimal surface finish
- Slower build rates: high volume production is limited
- Higher printer cost: large capital investment is needed for high end printers
- Material and size restrictions: limited verdatility amongst different 3D printers makes them material specific and have limited build volume

Figure 2.05
Advantages and challenges of Additive Manufacturing
(Bandyopadhyay & Bose, 2019)

In AEC Industry Additive Manufacturing is mostly applied using concrete, often called 3D Concrete Printing (3DCP). Within 3DCP extrusion-based processes are most common. (Labonnote, Rønnquist, Manum, & Rüther, 2016).
This technique is based on the computer-controlled extrusion of cementitious materials through a nozzle. This material is added layer by layer to create an object in 3D. The shape of the nozzle influences the shape, size, and buildability of the concrete layers (Bos, Wolfs, Ahmed, & Salet, 2016). Buildability refers to the ability of the concrete layers to stick together in the right position, without collapsing or deforming. Imperfection in this could cause the layers to collapse. See figure 2.6
This could be prevented by adding additional support. This support could be printed adjacent to the actual structure. See figure 2.7

For AEC Industries extrusion-based printing has a lot of potential regarding freeform constructions. Complex geometries, which could not be manufactured with a traditional technique like milling, turning, and casting, are within reach with 3D concrete printing. Geometrical freedom is a recurring theme within AEC. (Labonnote et al., 2016)
Further research regarding printing freeform geometries will be discussed in the chapter on Concrete Liquid Injection Printing (CLIP).
Extrusion-based concrete printing is more elaborately discussed in Appendix 2.

Figure 2.06
Buckling of 3D printed concrete structure due to inappropriate buildability (photographed at TU/e)

Figure 2.07
Supporting structure adjacent to the outer layers to improve buildability (CyBe Construction, 2019)

CONCRETE LIQUID INJECTION PRINTING (CLIP)

This chapter on Concrete Liquid Injection Printing is the result of common research by Jorik van Zeijl, Roy van Asten and Eva Boon, with the guidance of Zeeshan Ahmed and Cristina Nan. The Technical University of Eindhoven has been the base for exploring and experimenting with CLIP. CLIP is a project based on 3d concrete extrusion printing.

CLIP is a type of injection printing, which again is an alternative to conventional Extrusion Printing. Extrusion-based Printing works well for different projects such as facades, for example, the Voronoi wall (Figure 2.08) realized by the collaboration between Saxion Industrial Design Research Group, De Witte van der Heijden Architecten, Vertico Large Scale 3D printing, and Trebbe. However, Extrusion-based Printing has its limits, if one wants to print more complex geometries a different technique must be used. The theory behind the CLIP Technology is that it is possible to print in three directions, instead of only horizontal layers. This provides new opportunities for architecture and additive manufacturing. Figure 2.09 shows the suitability of CLIP for printing double-curved geometries. The main principle of CLIP is the use of clay as support material for the concrete. Fresh concrete will be printed according to an automated printing path and will be supported by the clay until is it solid.

CLIP works as follows; concrete is printed in a large container that contains another substance, in this case, clay. Clay is a flexible material and can be reused after each print after some water is added and remixed.

Figure 2.08
Voronoi 3D concrete printed wall
(Vertico, Saxion Industrial Design Research Group, De Witte van der Heijden Architecten, & Trebbe, 2016)

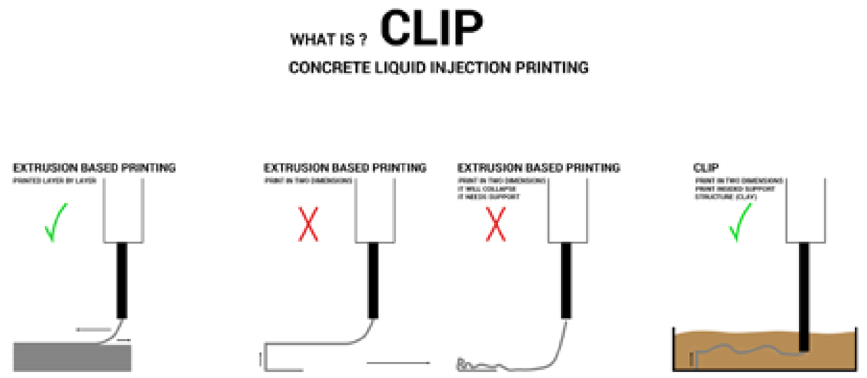


Figure 2.09
The of CLIP for printing double-curved geometries

This is not the first time concrete has been printed in a liquid, other research on Injection Printing has been conducted before, for example by Soliquid. Soliquid has experience with this technique, however, they use gelatine as a substance instead of clay. According to Soliquid this process enables freeform printing without solid scaffolding and allows for material saving, thus answering challenges faced by existing additive manufacturing techniques (Soliquid, 2018b).
Figure 2.10 shows the process of this technique, Figure 2.11 shows the result of such an experiment. (Soliquid, 2018a)

In addition to Soliquid, other research has been done on liquid injection printing, including recent research by Norman Hack at 'The Technische Universität Braunschweig'.
According to Hack, currently, most research in the field of 3D concrete printing is focused on one of three methods: material extrusion, particle bed bonding, material jetting. These three methods have in common that they are all printed in horizontal layers. Hack proposes a new principle that challenges horizontal printing: Injection 3D Concrete Printing (I3DCP). ''This technology is based on the concept that a liquid material (M1) is robotically injected into a material (M2) with specific rheological properties, causing material M1 to maintain a stable position within material M2. Different''(Hack et al., 2020) The advantage of this technology is that you are not hindered by gravity while printing and as a result no support structure is necessary.
Hack conducted experiments according to three principles;

''1. 3D printing of a fine grain concrete into a non-hardening suspension called "CiS" (Concrete in Suspension);
2. 3D printing a non-hardening suspension into a fine grain concrete called "SiC" (Suspension in Concrete);
3. 3D Printing a fine grain concrete with specific properties into another fine grain concrete with different properties, the so-called "CiC" process (Concrete in Concrete).''

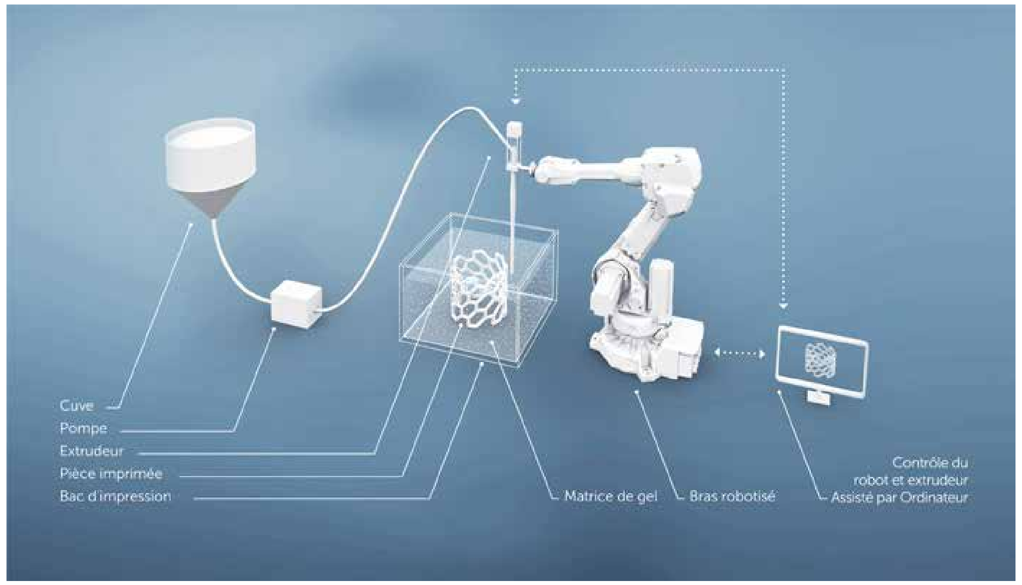


Figure 2.10
Procedure of the Soliquid Injection print technology (Soliquid, 2018a)

Figure 2.11
Result of the Soliquid Injection print technology (Soliquid, 2018a)

Principle 1, abbreviated as CiS, is most similar to the CLIP technique whereby concrete is printed into clay. Figure 2.12 and 2.13 show schematically the process of such a technique and a possible and the possible outcome, a spaceframe structure with a high strength to weight ratio which is difficult to manufacture in other ways.

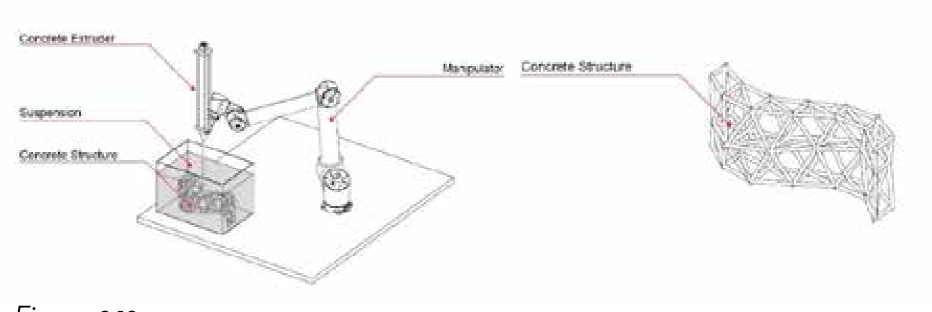


Figure 2.12
Process of CiS technology (Hack et al., 2020)

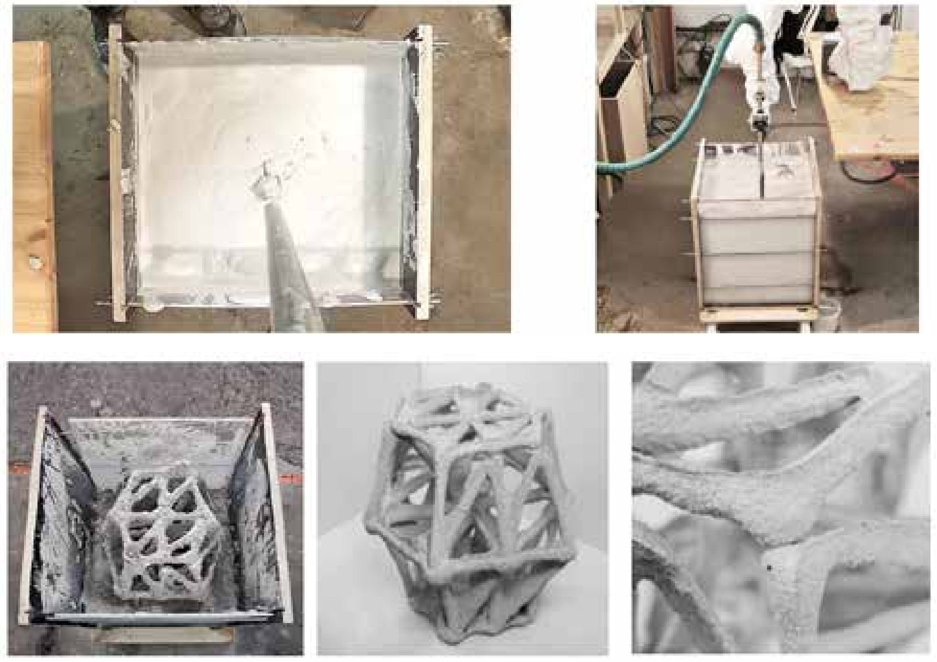


Figure 2.13
Results of CiS technology (Hack et al., 2020)

In this project, the digital manufacturing of double-curved façade elements is strived for.
In order to create one structural whole, a construction has to be devised. The double-curved 3D printed concrete element will build up a façade. Figure 2.14 schematically shows the procedure of CLIP. It starts with a design that is translated into a printing script. At the same time, the box with clay must be prepared, for this, it is important that the substance is not too solid and or too thin. The composition of the clay will be elaborated on in chapter Viscosity. The size of the box with clay is an important parameter for the printing process, as the limited size of the box also limits the size and the number of printed elements. After several printing sessions, multiple parts of the façade are manufactured and are joined together.

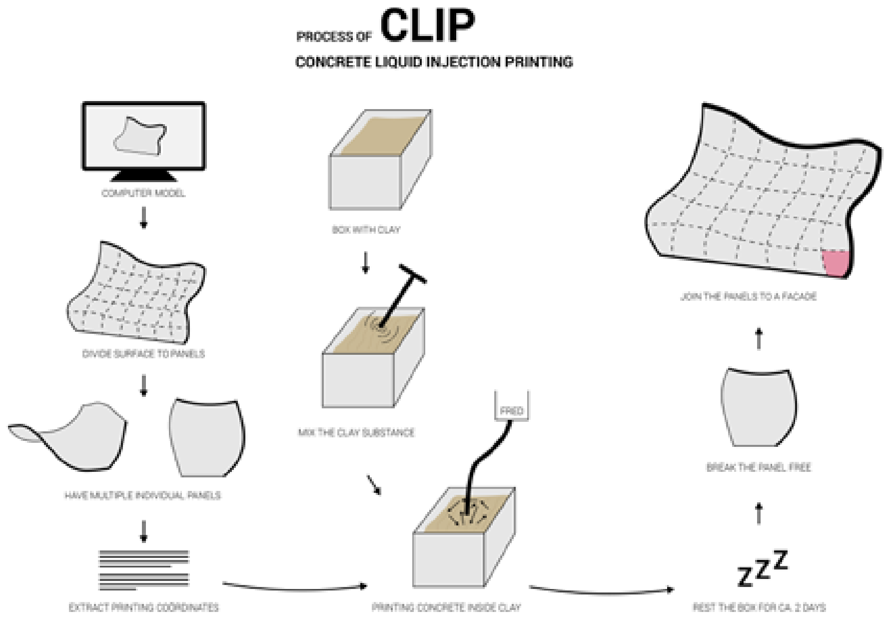


Figure 2.14
Procedure of Concrete Liquid Injection Printing

Preliminary experiments
Several experiments have been conducted, resembling the test of Soliquid and Hack by using gel and clay. This gave a first impression of the behavior of concrete in a liquid.

Conducting this experiment showed that material properties are very important. The type of concrete and the amount of added water influences the printability to a large extend. It is also attempted to print layers on top of each. However, this is not as reliable as using a robotic arm, this is due to the speed of the arm and the pressure of the concrete running out of the nozzle.

In the first experiments the “prints” made did not get an actual form yet. See figure 2.15. The issue that was encountered is the limited pressure that can be applied by hand. To start creating actual forms in the clay, a move to a Concrete 3D Printer was needed. Under the supervision of Zeeshan Ahmed experiments with the 3D concrete at the Eindhoven University of Technology (TU/e) were conducted. This chapter will discuss the technical aspects necessary before actually printing. Important aspects to take into account are the printer and nozzle, the size of the clay container, and the viscosity of the clay.

Figure 2.15
Results from preliminary injection printing experiments

Printer
Many different 3D printers exist for printing concrete. The printer used by the TU/e uses a gantry system which, together with its large dimensions, allows for large objects to be printed with high precision. Despite its size, its high precision still makes it suitable for the smaller scale experiments done in this research.

Nozzle
Normally in 3D concrete printing, concrete layers are stacked on top of one another. For this, the TU/e uses a rectangular printing head, or nozzle, in order to increase the buildability of the layers. Printing in liquid does not necessarily follow this rule of stacking layers on top of another, thus requiring a different nozzle. At first, the printer was used without a nozzle, simply printing with a round tube with a 28mm diameter as shown in Figure 2.16. Using this, the pressure was no issue, however, printing lines were relatively thick.
In order to print with thinner, more detailed lines, a new nozzle was designed and 3D printed. The nozzle design, based upon a previous design by Zeeshan Ahmed, brought the nozzle diameter down from 28mm to 10mm. See figure 2.18. TPU was used as material for printing, using its flexible nature to withstand the high pressure of concrete being pushed through. Using the more common TPE the nozzle would break under the high pressure of the concrete. The use of TPU also caused that the nozzle was a little flimsy as shown in Figure 2.16. To allow for printing, the nozzle required extra support provided by steel rods and duct tape as shown in Figure 2.17. The flexible TPU allowed for printing under pressure while the new support held the nozzle together under the high pressure of the concrete.

Figure 2.15
Printing without a nozzle

Figure 2.16
Nozzle made of flexible TPU

Figure 2.17
Reinforced nozzle with steel rod taped to the TPU

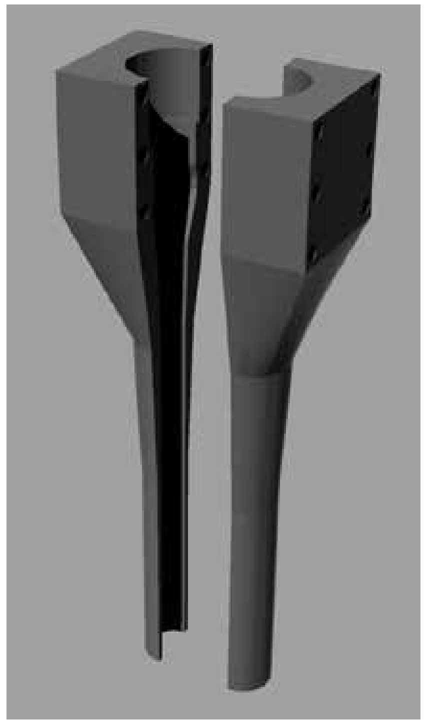


Figure 2.18
Digital model for custom-made printing nozzle

Box
Early printing was done in a plastic storage box filled with clay. This box allowed for the printing of 600mm by 450mm and up to a depth of 150mm. This worked well for testing outside of TU/e since it was just light enough to move the box. The first prints on campus were done using this box as well, shown in Figure 2.19
When printing inside this plastic box, limitations quickly became apparent. Its print bed of only 600x450mm is a limiting factor. Furthermore, an increase in depth was preferred to make 2 prints on top of each other or allow for more extreme curvature. Especially printing multiple prints is required to make the process more efficient since starting the printer costs time and produces a lot of waste. An increase in clay volume was not possible though, since the box was already damaged from moving and almost broke under the weight of the clay.
To overcome this, a new watertight box out of concrete plywood was built, as shown in Figure 2.20, using sealant to make the seams watertight. The dimensions of the new box are 1000mm x 550mm, allowing for one large print or two prints next to each other. Furthermore, this box was built significantly stiffer, allowing for a higher amount of clay in the box. Tripling the total amount of clay compared to the old box now yields a 220mm printing depth. This in itself allows for more freeform and curvature in the prints. Meanwhile, prints with limited curvature can be printed on top of each other, allowing for up to four prints in one go.

Figure 2.19
Printing inside the plastic box

Figure 2.20
A more sturdy plywood box replaced the plastic box

Figure 2.21
Schematic visualization of 3d injection printing inside a box with clay

Viscosity

When injecting concrete in a liquid, in this case, clay, certain properties of the liquid are of importance. In order to print a 3-dimensional path in the clay, it should not be too viscous as the printhead would then not be able to move smoothly through the clay. At the same time, a very thin substance would not be able to carry the concrete that is injected into it, which would result in the sinking of the concrete and not being able to print a 3-dimensional path. This property is called the viscosity of the liquid.
There is neither any quantitative nor qualitative value defined so far for the desired viscosity for concrete injection printing. So for the first experiments, the viscosity of the clay was qualitatively judged upon two criteria:
1. Does the surface of the clay return to a somewhat smooth surface after touching it?
This would mean that the clay is fluid enough to smoothly move the printhead through it.
2. Does the clay carry an object with a reasonable mass?
This would mean that the clay is thick enough to prevent the concrete from sinking.
The clay is bought in solid blocks which need to be mixed with water to create a homogeneous fluid. Adding extra water will increase the fluidity of the clay. Extracting water from the clay is hardly possible and will require waiting time for the vaporization of water. So adjusting the viscosity of the clay is a one-way process from viscous to thin. For this, the experiment starts with a relatively viscous clay substance, which is judged based on the criteria mentioned above. For criteria 1 a line is drawn in the clay using a stick. (See figure 2.22) If the line is filled with clay again afterward, criteria 1 is met. If the line remains clearly visible on the surface, criteria 1 is not met. For criterion 2, a brick is placed on the clay surface. . (See picture 2.23) If the brick remains on the surface, criterion 2 is met. If the brick sinks into the clay, criterion 2 is not met.
If criterion 1 is not met while criteria 2 is, more water is added and mixed through the clay.
This process will be repeated until the point when the clay returns to a smooth surface (criteria 1) or when criterion 2 is not met anymore. The latter means that too much water is added to the clay.

Figure 2.22
Drawing a line to test the viscosity of the clay

Figure 2.23
Putting a brick onto the clay surface to test the viscosity

Figure 2.24
Electricity meter used to measure the resistance of the clay on the mixer

Figure 2.25
Viscosity meter as an alternative to the mixer to measure the viscosity of the clay

To quantify the point where criteria 1 and 2 are met a mixer with an electricity meter is used. For this quantification the following assumption is made: a more viscous substance creates more resistance on the mixer, which will as a result require more power from the electricity network. This increase in power can be measured using an electricity meter which is placed between the mixer and the power outlet. Ideally, a certain viscosity defined by criteria 1 and 2 can be linked to a certain value on the electricity meter, and could therefore be quantified. For this two conditions need to be met:
1. After mixing the clay for a while the electricity meter needs to display a stable value. . (See figure 2.24)
2. This value should decrease while adding water to the clay, as the resistance and therefore the required power decreases.
Multiple measurements with different clay compositions were executed with the same mixer under the same conditions. Unfortunately, no logical relation between the clay viscosity and the measured mixing power could be made. Sometimes no stable power value was displayed while mixing (condition 1), and mostly the required power did not decrease with a lower viscosity (condition 2).

To quantify the viscosity of the clay a different strategy was found. More direct and precise results regarding the viscosity of materials can be obtained using specialized equipment like a ViskoMat. (See figure 2.25) This device gives data with allows for a precise calculation of the viscosity of the clay in N·s/m2. Measuring the viscosity of the clay before printing concrete in it allows for a reliably quantified judgment about the composition of the clay. It also allows for a comparison of 3D concrete printing in different clay compositions. In that way, the composition with the best-printed result can be identified. Unfortunately, logistical issues in the lab caused by the COVID pandemic measures did not allow for the execution of these experiments.

Designs for experiments

Flat prints

To test the CLIP technique, the first prints should be simple geometries designed to see if the technique works and what the limitations are. First, to see how the concrete reacts to the clay, a flat print was made both on a normal print bed as well as in the clay to compare the two. The form is a pentagon since an old model of this form could easily be altered. Furthermore, it is interesting to see how corners react to this way of printing. These prints were done in the first printing session at the TU/e.

The second printing session was based upon a design made by a different project group. This design was to be printed using a support structure of glass beads. For this method, one has to continuously keep adding glass beads next to each level of the print. This is a very labor-intensive process but necessary to support more complex, double curved, or cantilevering geometries while printing with concrete. This makes it an important comparison to CLIP since it comes in as an opportunity to replace the glass beads. With no labor involved other than cleaning the final product from clay residue, ultimately labor costs should be cut.

The last experimentation was conducted using a sequence of designs to see how the print reacts to being printed double curved. Starting from a flat hexagon, resulting in a single curved and a double curved option to discover the possibilities and limitations of printing concrete in clay.

This sequence is shown in Figure 2.26.
The results from the prints of the flat pentagons are shown in figure 2.27 and 2.28

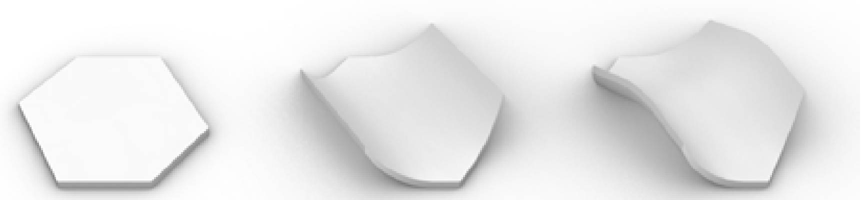


Figure 2.26
Sequence of the design to be printed using CLIP

Figure 2.27
Flat pentagon printed inside the clay

Figure 2.28
Flat pentagon printed on a dry printbed

The first prints of the flat pentagons yielded some interesting results. The pentagon printed on a flat print bed shown in Figure 2.28 and the one printed in the clay shown in Figure 2.27, are distinctly different. The prints on the normal print bed became one entity, a single solid panel. The prints in the clay on the other hand retain visible printing lines, despite being printed with a large diameter nozzle. This is due to the support the clay offers for the printed concrete. On the other hand, from this experiment, it appeared that the resulting panel was relatively brittle. Some small pieces came loose when taking the panel out of the clay box.

The second series of tests was done in collaboration with the other project group as mentioned before. This group used the old technique of glass beads and this experiment focused on the difference between that old technique and the new clay printing. The two results show significant differences. See figure 2.29 and 2.30. Besides the color of the clay, which can be washed off, the layering is distinctly different. The result from printing using the glass beads shows layers but they appear to be nicely stacked on top of each other. The layers of the print in the clay seem to have shifted. This is most likely the result of clay stuck in between the layers during printing, not allowing the different concrete layers to connect well. This also made the entirety more brittle, with layers easily delaminating. If thicker or thinner would remedy this issue should be tested in future research.

Rather than printing the whole sequence mentioned before, the step to the last double curved panel was made directly. The reasoning behind this was that the previous experiments already showed printing flat was an option and single curvature is also possible with regular 3D concrete printing. The panel was printed in two identical pieces since the concrete printer was only coded for printing layers vertically on top of each other. The result shown in Figure 2.31 looks less curved than designed. The actual dimensions are correct though, meaning the likely reason for it appearing less curved is the thickness of the panel and the layer thickness. The simple solution is considering the layer thickness when designing something to be printed.

Figure 2.29
3D model printed using glass beads as support material

Figure 2.30
Similar 3D model print using clay as support material

Figure 2.31
Slightly double-curved object printed using CLIP

With the experiences gained from the different experiments, a final design was made of a combination of multiple double curved panels. The design envelops a combination of double curved panels to discover the potential it has for a facade. In the end, a combination of 4 panels of 50x50cm was designed to show a section of a facade of one square meter, as shown in Figure 2.32. This small section of a facade can be extended in all directions to create one large facade or an entire building. The question arising from this is how to connect the different pieces to make it an actual wall. This will be discussed in the next chapter.

Additionally, a move was made from the vertical stacking of concrete layers to horizontal layering as well. For this a new code was developed by Zeeshan Ahmed and Derk Bos, allowing vertically slicing of planes resulting in horizontal layers. With this new direction of printing, entire panels can be printed at once, rather than having the rely on smaller pieces shown previously in Figure 2.31

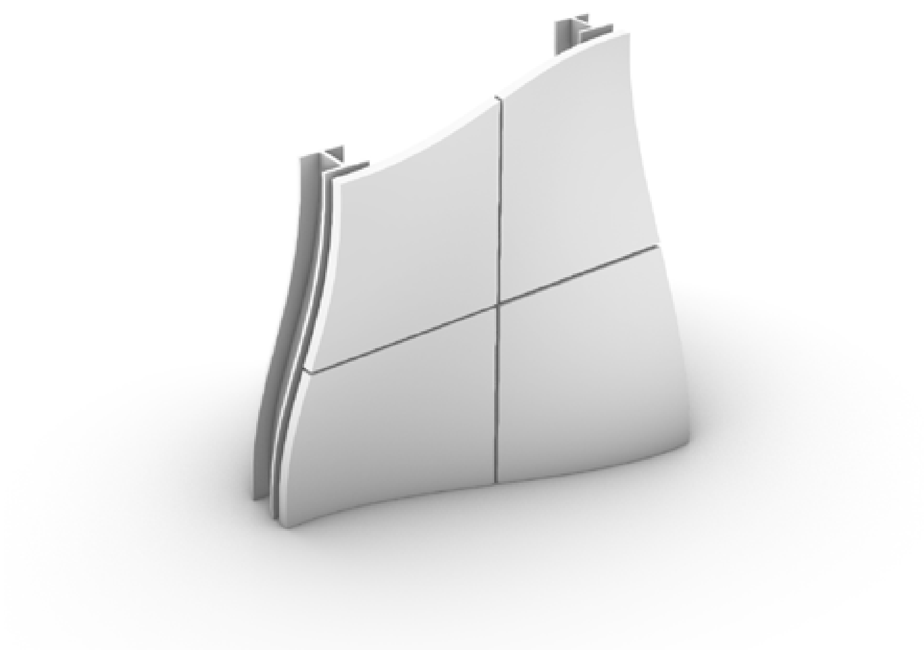


Figure 2.32
Digital design for a double-curved facade composed of 3D printed concrete panels

Back construction

The double-curved concrete panels printed in the clay, need a secondary structure to be used as architectural elements, for example as façade panels. The irregular surface of the double curves geometries require a structure that can adapt to this shape. This construction needs to contribute to the sculptural image that the 3D panels form and therefore the construction should not be visible or disturb the desired shape. An important reference for this sculptural image built up by curved panels is the Heydar Aliyev Cultural Center in Baku (Azerbaijan) designed by Zaha Hadid and constructed in 2007. (See figure 2.33) This project showcases the use of curved concrete panels cast in single-use molds. (Cansuturk, 2017)

These panels are attached to a steel frame that follows the curvature of the façade. The frame consists of a network of steel bars and nodes shaped in a curved form. See figure 2.34. The curved concrete panels are connected to this network at the nodes to create one smooth sculptural image. This form and its structural network are very interesting but rather complex to literally apply in the experiments conducted with Concrete Liquid Injection Printing. However, it gives some good starting points for designing a prototype.

Figure 2.33
Heydar Aliyev Cultural Center, by Zaha Hadid (Cansuturk, 2017)

Figure 2.34
Double-curved concrete panels attached to curved steel frame (Binet, 2021)

As CLIP focuses on 3-dimensional, double-curved geometries it is possible to think differently about merging them into one element. 2-dimensional panels are mostly hanging from a secondary structure as their limited sections do not allow to stack them. 3 dimensional, double-curved geometries however are more suitable to stack on top of each other, and allows for a different construction method than hanging it from a framework. By transferring gravity downwards through the underlying concrete elements also uses the compression capacity of concrete to a greater extent than hanging them from a secondary structure. Also, it puts less stress on the connection between the panels and the secondary structure as the weight of the panels is not transferred to it. (See figure 2.35) The secondary construction mainly provides stability to the stacked concrete elements rather than carrying them. In that sense, it is comparable to the functioning of a traditional cavity wall. (See figure 2.36) A cavity wall consists of a structural inner wall that carries the above floors and façade an in between insulation and ventilation layer and an outer wall which functions as a cladding. The outer wall is connected to the structural inner wall by wall ties to prevent it from falling over. The individual bricks however rest on top of each other instead of hanging from the inner wall.

This principle of compression loads and stability from a secondary construction with wall ties is applied in the structural scheme for Concrete Liquid Injection Printing elements. (See figure 2.37) In this scheme, a relatively simple structural network of straight beams or rods is used. The curved concrete elements are attached to it using anchors which bridge the distance between the elements and the framework. For anchoring the concrete elements bolts with different lengths are fixed to the framework. (See figure 2.38) Holes are pre-drilled in the elements to attach them to the bolts.

Figure 2.35
Structural scheme of concrete panels hanging or standing

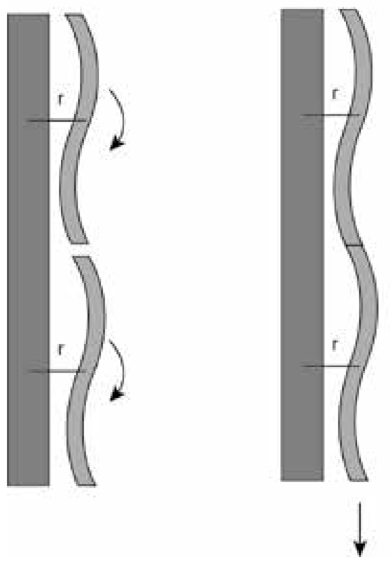


Figure 2.36
Visualization of cavity with wall ties (AE Energy Solutions, n.d.)

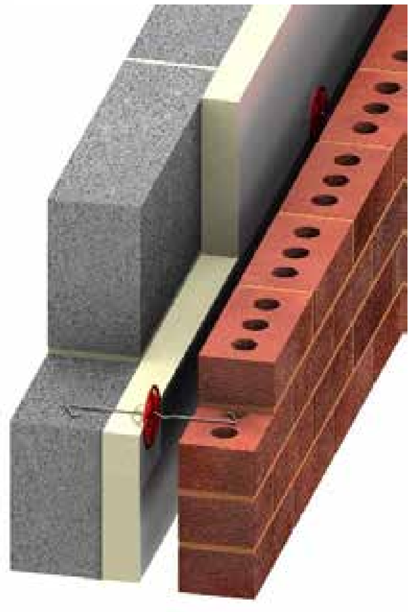


Figure 2.37
Visualization of concrete panels with back construction

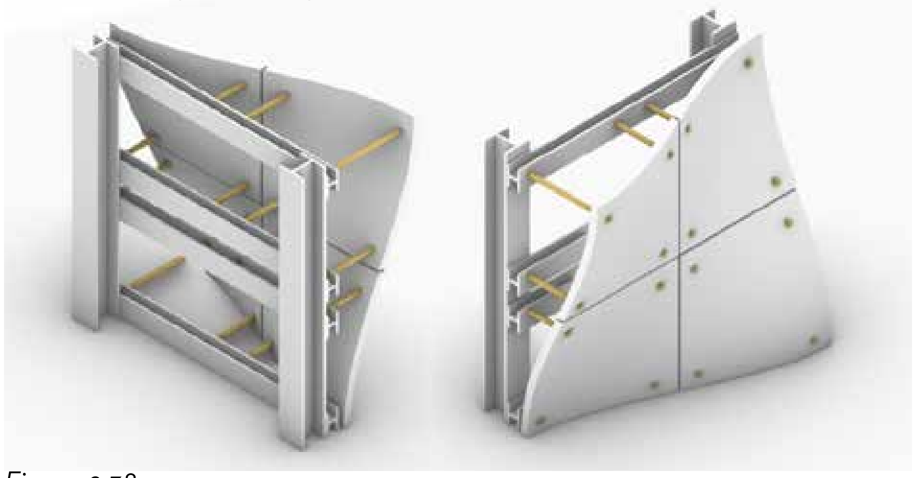
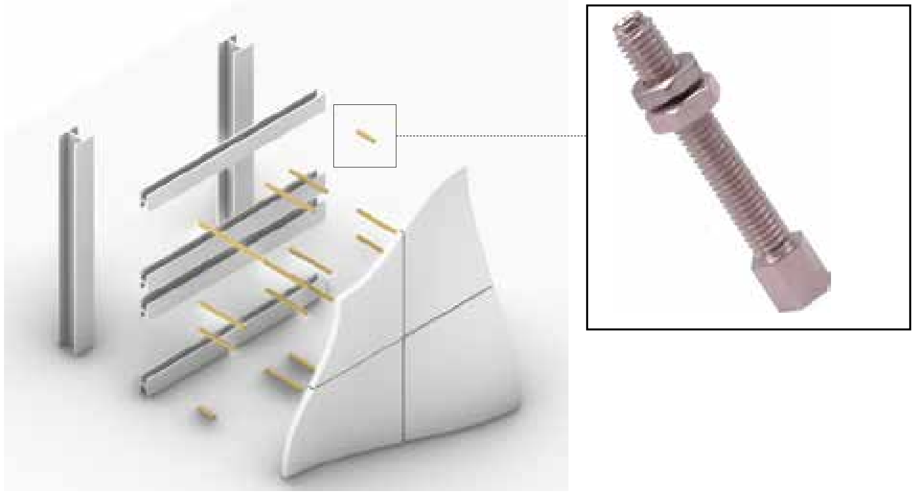


Figure 2.38
The use of bolts to attach the panels to the construction



Conclusions

Due to the COVID-19 pandemic and the associated restrictions on the TU/e campus, there were no possibilities to fully complete the experiments with the 3D printer. Therefore, decisive conclusions regarding the CLIP experiment are hard to make. However, several concrete elements were printed in the early phase of the project and have given us some interesting insight into the way CLIP works.

From the experiments, it became clear that printing double curved geometries are possible using CLIP. The preliminary experiments proved clay is a feasible support structure for concrete, experimentation on the TU/e showed the possibility to print free form inside the clay. The printed elements show the possibilities for new geometries, however, further research is needed to optimize the procedures. Important aspects for future research include the quality of the concrete, the nozzle, and the bonding between the concrete layers.

In this research one type of concrete was used for the experiments, the quality of the concrete seems to highly influence the quality of the printed elements. Additional research is needed to examine if different types of concrete in combination with clay could result in different appearances and in this way influence the architectural expression.

Besides the importance of concrete, the nozzle plays an important role in printing concrete objects. A smaller nozzle potentially allows for more detailed printing. A very narrow 10mm nozzle was used in the first experiments, but deemed to be too narrow as the pressure was too high. Printing without a nozzle produced rough results. The new 18mm nozzle should be tested to see if it will influence the result to be more detailed.

Lastly, the bonding between the layers of printed concrete appeared problematic. When extracting the printed elements from the clay the layers of concrete were easily separated from each other, therefore the elements did not form a solid entity. Possibly the viscosity of the clay influences the bonding between the concrete layers. Clay might flow between the layers of concrete when it is too thin. However, this is not tested during the experiments.

In conclusion, the concept of Concrete Liquid Injection Printing using Clay as supporting liquid has been proven to work. As discussed, many parameters need further elaboration to discover the true potential of the technique. The technical aspects above need further elaboration, followed by research into how curved panels influence architectural expression.

DESIGN STRATEGY

OPTOPPEN

In this report densification of existing cities is identified as an effective measure to tackle one of the biggest challenges for future housing supply: affordability of qualitative housing for a large group of people. At the same time, the increasing size of the urban population exerts pressure on the livability and urban climate. The remaining open spaces in the urban tissue are threatened to be built up with housing to lodge this population. The loss of open spaces potentially negatively impacts living environments as it provides a pleasant context for recreation and living. Moreover, open urban spaces with ecological networks contribute to urban climate resilience, which is an increasingly relevant theme in the context of global climate change.
In this report, the shortage of affordable and ecological housing supply is identified as the main challenge to tackle. By tackling this problem, a contribution could be delivered to meet the definition of a more sustainable built environment. According to the famous report Our Common Future by Gro Harlem Brundtland from 1987, sustainable developments "meet the needs of the present without compromising the ability of future generations to meet their own needs". (International Institute for Sustainable Development, n.d.)
In this graduation report, a proposal is presented that will provide affordable housing for the current demand while preserving and enhancing livable urban structures for the future.
To achieve this goal, a number of design strategies are discussed.

In this report, four methods for the densification of cities were identified. Densification is an important part of future urban development as it will allow for a sufficient housing supply in reaction to increasing demand, especially in urban environments. (Claassens & Koomen, 2017) At the same time densification of existing urban structures requires careful consideration of the livability and resilience in cities. (Ahern, 2013)

Vertical extension of buildings appears to be the most favorable densification strategy as it has the potential to add a significant amount of space in urban areas, which is essential to increase the housing supply in a location where this is needed the most. At the same time, vertical extensions spare remaining open spaces in cities, which contribute to the spatial quality and quality of life of the population. (Pelczynski & Tomkowicz, 2019) Lastly, the absence of the need for more land consumption when applying vertical extensions, potentially reduces the development costs of housing, as ground accounts for an increasing share in the project expenditures. (Bouw en Wonen, 2010)
In Dutch, a new name was adopted for vertical extension of buildings: "optoppen"

This name is based on the fact that a new program is added on top of an existing building. The top of the building is in this lifted upwards. The term "optoppen" will in this report repeatedly be used to refer to the approach of vertical extensions. "Optopping" is the Dutch noun to describe a vertical extension.

Optoppen has been implemented as a design approach in several realized projects. These projects help to identify the focus points which are important to define the design specifications for this Graduation Studio. Many Optop projects represent a rather pragmatic solution to specific design questions. These questions may relate to the addition of housing space to existing housing estates while allowing the inhabitants to stay in their homes during construction. This is the case in the Lage Land estate in Rotterdam, which will be discussed later in this chapter. Design questions may also relate to the addition of floor space to historical buildings while maintaining the historical structure as much as possible. The Black House in London is exemplary for this and will also be elaborated on in this chapter. Both projects give an understanding of the structural properties and building systems that are involved in vertical extensions.
More experimental research regarding Optoppen has been executed as well. Lighthouses in Groningen is a project by DAAD Architecten, which tries to formulate a strategy for developing inner cities into more residential areas. (DAAD Architecten, 2005) For this project, a 1 to 1 scale prototype was realized in the city of Groningen.

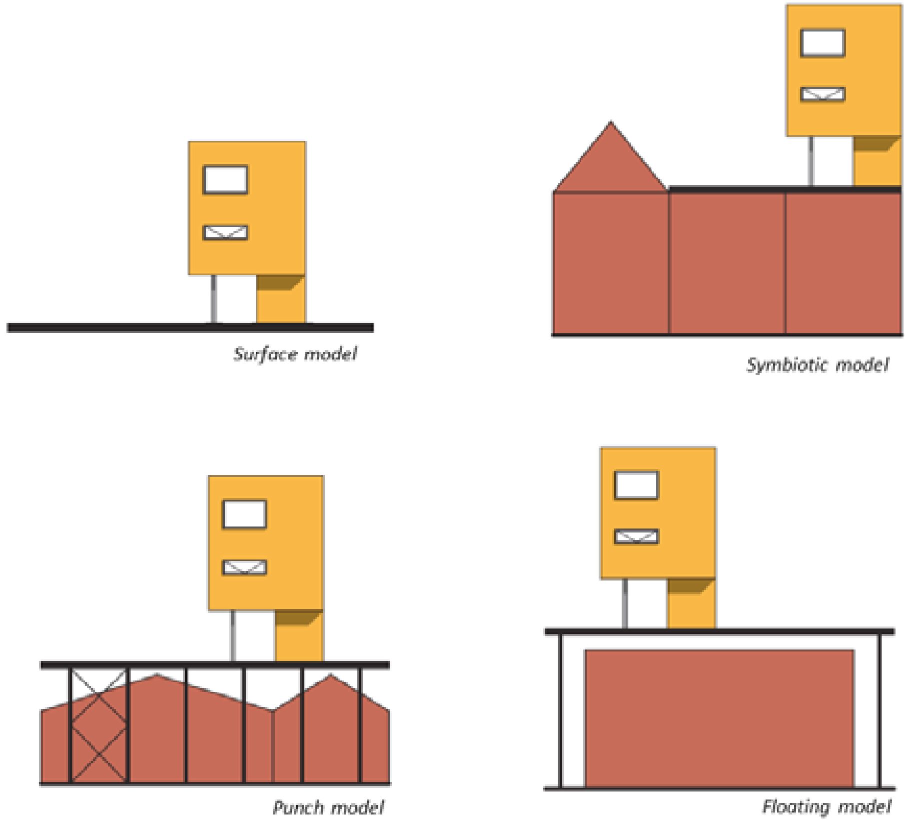


Figure 3.1
Three methods for Optopping plus the traditional surface model.
(DAAD Architecten, 2005)

Lighthouses

The first basic principle for Optoppen, as proposed by DAAD Architecten, is the creation of a new ground level above the existing street level. Existing buildings function as a pedestal for this new ground level, which behaves mostly independently from the Optopping. As minimal interventions in the existing building are required, the nuisance and investments are reduced. (DAAD Architecten, 2005) On this second ground level, a new program can be realized. This program can be temporarily to allow flexibility over time. DAAD Architecten identified four methods to place a building on an existing or new ground level. See figure 3.1.

Firstly, buildings could be installed on the existing ground level on a permanent or temporary foundation, the Surface model. This method of course does not contribute to the strategy of vertical densification and will not be considered in this research.

More interesting is the method in which the new ground level is directly projected on top of an existing building, without any additional new constructions to carry the building. This symbiotic model relies on the structural capacity of the existing building. Most buildings do have the structural space to carry a large additional program without extra structural measures. Exceptions to this are buildings that were originally designed for heavy loads, for example, industrial buildings. When the functions of these buildings change, the loads will disappear and give space for new additions.

If a building appears not to have sufficient structural space for such an extension, additional constructions could be added to the existing building. This construction needs to connect the addition to the existing surface and foundation. The existing building located in between possibly needs to be penetrated by this new construction. This Punch model has a lot of consequences for the integrity of the existing building and will affect the functionality of it during the construction process. However, it allows for larger additional loads on top of the existing building.

Figure 3.2
Hoisting the housing units on new construction (DAAD Architecten, 2005)

Another method to create extra structural space is by building a new construction over the existing building. The advantage of this Floating model is the fact that the existing building will hardly be disrupted by the new construction. The existing building and the new construction are fully independent, which means that the possible capacities of the existing building are not efficiently used. As a result, more investments and space are required compared to other methods.

The Symbiotic model uses the available structural capacity more efficiently compared to the other methods and in that way has the smallest investment costs regarding construction. (DAAD Architecten, 2005)

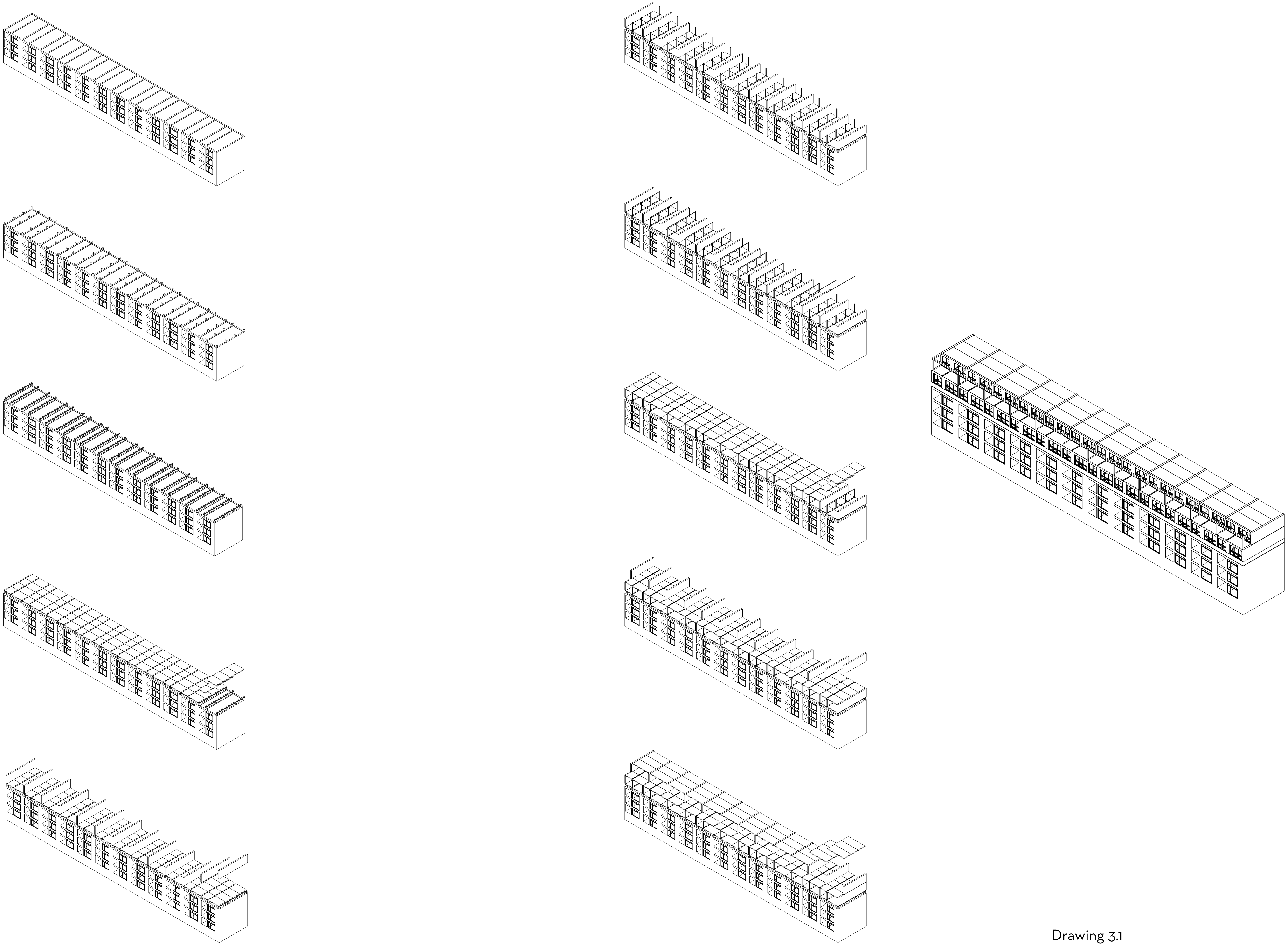
Lage Land
The residential estates in the neighborhood Lage Land in Rotterdam are a typical example of the many gallery flats that were developed after World War Two to deal with the large housing shortage. As mentioned before this shortage is again relevant in urban developments today. The municipality in Rotterdam appointed these estates in Lage Land to be developed to accommodate more dwellings. In order to spare open space, Optoppen of the existing buildings was the selected strategy. (Ter Borch, 2007) The Optopping was designed by Kolpa Architecten and realized in 2004.

Lage Land was developed in 1961 and is characterized by its spacious layout with a lot of green. However, the homogeneous housing stock with many small apartments does not match the current housing demands anymore. The addition of larger apartments in the neighborhood should increase the population diversity and allow inhabitants to move to a larger home within their neighborhood. To reduce construction time and nuisance a steel frame prefabricated building system was applied. This relatively lightweight system required a construction time of approximately ten weeks and allowed the existing inhabitants of the estate to stay in their homes during construction.

The structural grid of the existing building was applied in the new Optopping to efficiently use the existing structural capacity. Sewage and water supply were installed between the old roof and the Optopping and are drained separately from the existing infrastructure.

As the structural capacity of the existing foundations could not be quantified, an additional foundation was added and connected to the existing foundation to provide extra capacity.
On the structural grid of the existing carrying wall, small columns were placed to carry the Optopping. Those columns are the only physical connection between old and new and thereby reduce the impact on the existing building to a minimum. On the columns steel frame floors and walls are installed, stability is achieved by these plane elements. (Ter Borch, 2007)

Figure 3.3
Lage Land housing estate with Optopping (Ley, 2007)

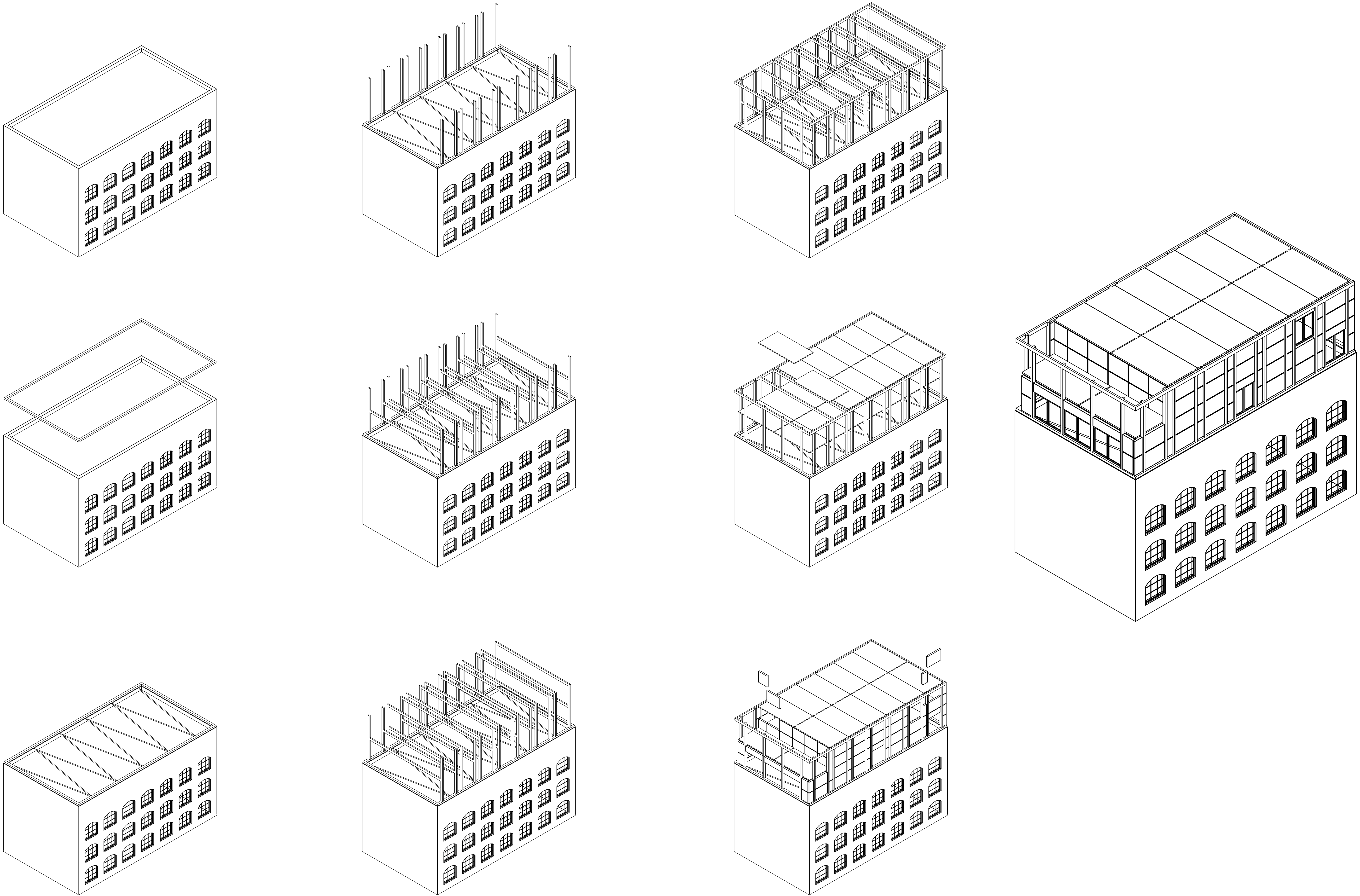


Drawing 3.1
Assembling scheme of the
Lage Land estate Optopping

Black House
For the extension on top of a historical Victorian warehouse in London reducing construction time and nuisance was a key target. The warehouse is used as a workshop for designers who wished for a living on top of their working area. This was designed by Simon Conder in 2016.
Although the brickwork facades and steel beams in the floors allowed for considerable loads (the building used to have an industrial function) the existing foundations of the building formed the bottleneck for the future Optopping. Therefore, lightweight prefabricated timber construction was applied. (Architecture Today, n.d.)

A structural 'grid' could be identified between the window openings the brickwork façade. Timber columns are arranged according to this grid. They are connected to a perimeter ring beam, which is installed on the existing roof edge, this will spread the loads of the new addition equally over the façade. Also, a horizontal steel truss is cast into this ring beam to transfer wind forces. Timber columns and beams connected with steel plates form a portal frame structure. This structure is infilled with lightweight, black weatherboard panels.
Columns, beams, and panels were prefabricated with steel connections and transported to the site to be mounted on the building. (Architecture Today, n.d.)

Figure 3.4
Black House Optopping (Smoothy, n.d.)



Drawing 3.2
Assembling scheme of the
Black House Optopping

LIGHT WEIGHT PREFABRICATED CONSTRUCTIONS

Vertical extension of existing buildings has been present in cities for multiple years already. Especially in inner cities with historic buildings and high rents, refurbishing and expanding existing buildings has proved to be very useful. Many 19th-century "Gründerzeit" buildings in the center of Vienna for example, have been extended vertically applying the so-called attic extension. See picture 3.5

These attic extensions are interesting investments for developers as living space is added in very popular urban areas. However, they do not provide a broad solution for the lack of affordable housing. Many postwar buildings in European cities appear to be very suitable for a vertical densification approach as well. As vertical extension of existing buildings also involves the presence of existing users, the construction process is a vital part of the success of such a densification strategy. By using prefabricated construction elements nuisance for co-users and construction time can be reduced. Especially in urban contexts, short on-site construction times are favorable for the environment but it also gives more financial security to the developers. (Jaksch, Franke, Österreicher, & Treberspurg, 2016) Prefabricated construction methods also provide a low-cost solution to efficiently densify cities and thereby create more affordable housing in the best location.
According to Jaksch, Franke, Österreicher and Treberspurg post-war buildings are very suitable for a vertical extension because of the similarities in construction and layout these buildings have. In their study on so-called attic extensions in the city of Vienna, it appears that refurbishing these buildings by making them more energy efficient in combination with increasing the building density, will contribute to the global climate goals as well.

Figure 3.5
Attic extension on an 19th century building in Vienna (HMA, 2017)

Jaksch et al. identify prefabricated timber constructions as the most suitable system to apply for vertical extensions because of the easy processing, the relatively low weight, and the ease of transportation. They propose prefabricated CLT construction elements to be installed on existing post-war social housing estates in the city of Vienna. Walls and slabs including windproof layers and window frames are prefabricated and transported to the building site. Roof covering, façade cladding, and installations are added on site. See figure 3.7. The entire process of preparation works to the existing building till the interior finishing of the extensions would take five weeks, according to the authors. Additionally, they expect construction costs of prefabricated extensions to be 10% lower compared to traditional on-site construction techniques. (Jaksch et al., 2016) However, challenges of this approach are also identified. More attention to modular dimensions should be given during the early design process and element connections and other details must be designed properly. And although the construction process can be shortened a lot, this requires complex logistics. Lastly, the design of the entire extension is highly adapted to the existing building and does not allow for much design freedom.

Figure 3.6
Post-war social housing estate on Wagramer Straße 164-168 in Vienna (Stadt Wien, n.d.)

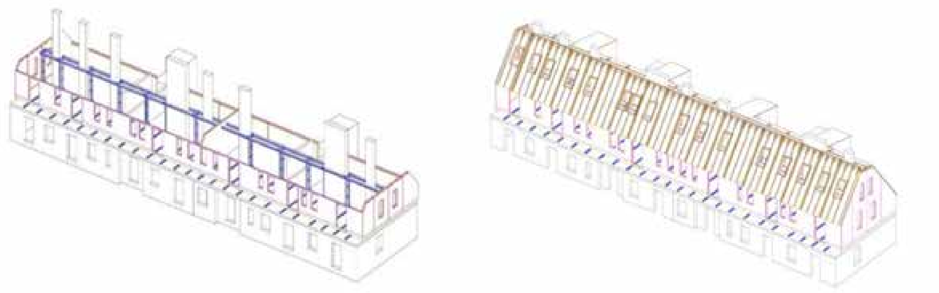


Figure 3.7
Prefabricated walls construction and on site cladding of Optopping
(Jaksch et al., 2016)

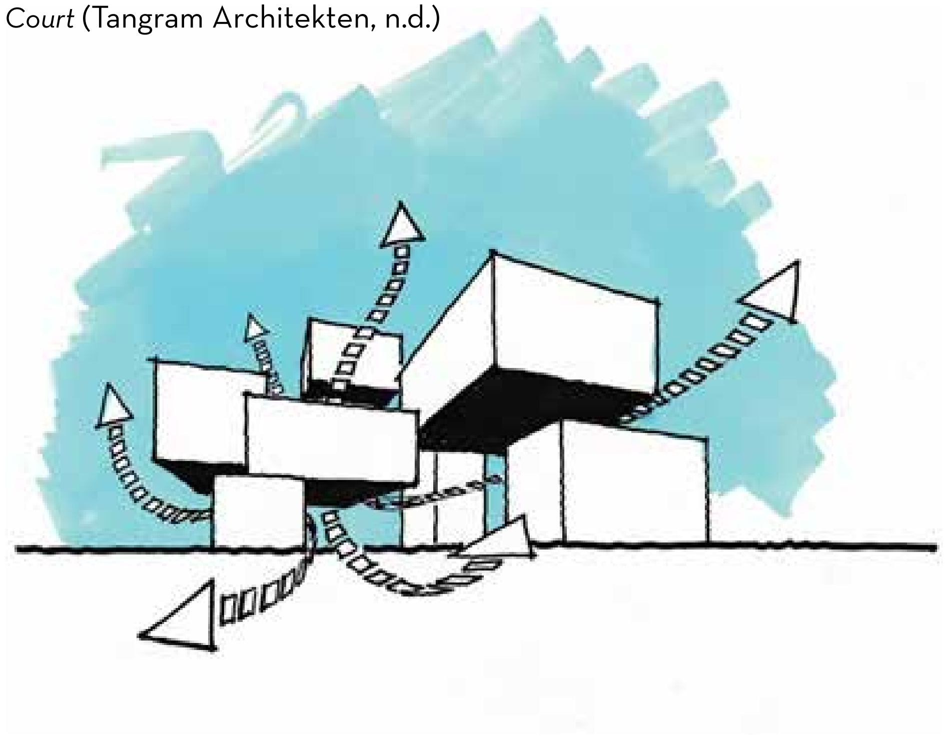
URBAN OASIS

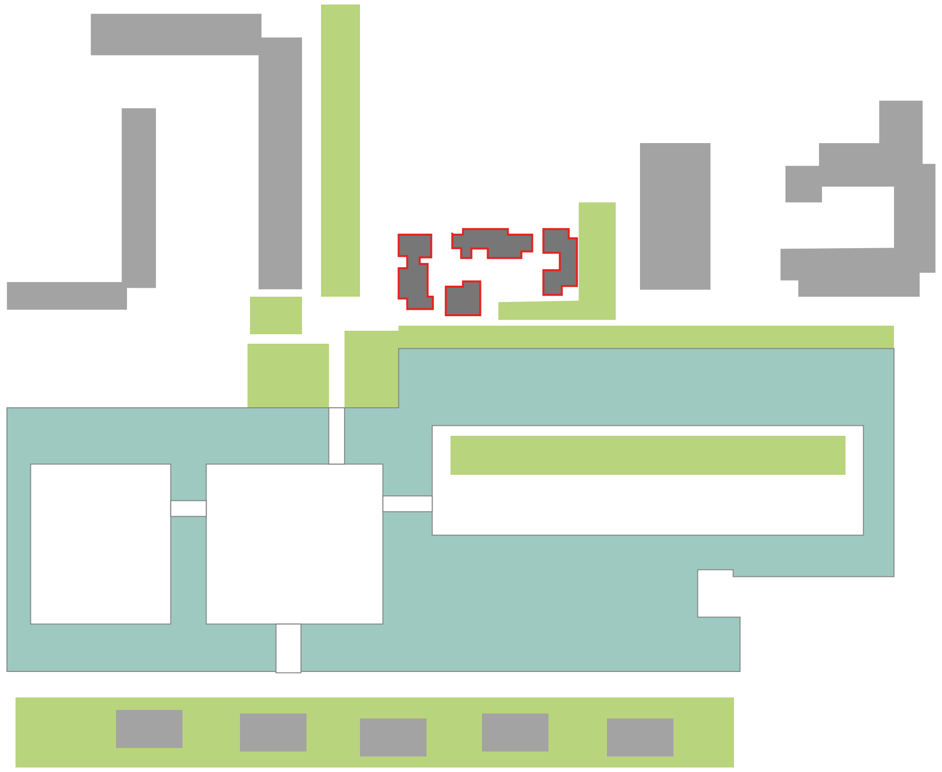
In this graduation project, a highly densified, yet pleasant living environment is envisioned on top of existing buildings in urban areas. An 'urban oasis' providing ecological functions as described by Ahern before, in combination with a considerable addition of housing space, is the desired result of this project.

An interesting reference project for a building as described above is the Crystal Court in Amsterdam, designed by Tangram Architekten in 2008. A number of luxurious urban villas in a park-like environment were part of the design brief. This building was realized on a relatively small plot and therefore the architect had to find a solution to provide enough living program while paying attention to the spatial quality. Although this project aims at a more high-end housing category than this project, some interesting design aspects can be found in this reference project.

One of the goals of Tangram Architekten was to create a 'transparent' building, which does not have a big visual impact on the green environment it is located in. Therefore, it was decided to minimize the footprint of the built-up area and provide as much open space within the plot as possible. The architects proposed four towers, which grow together to the top, representing a tree structure with transparency at the bottom between the trunks and a dense tree crown at the top. Between the trunks, a common area is created which forms a continuation of the open area around the building. Tangram identified the need for collective spaces as an intermediate between the private realm and the urban context. These collective spaces should be controlled by the inhabitant and provide a safe oasis in the big city. (Tangram Architekten, n.d.)

Figure 3.8
Conceptual sketch visualizing the transparant appearance of the Crystal Court (Tangram Architekten, n.d.)





Drawing 3.3
Site plan of the Crystal Court

The result is a sculptural ensemble of volumes that stick out in different directions. The variation of closed volumes and open spaces creates a very airy building, despite the large program which is housed in it. Orientation to the sun and the view over the parky environment were important aspects for the organization of the 36 urban villas.

A concrete construction system was applied to allow for the large overhangs. Western red cedar timber was used for the façade cladding to match the park-like environment. The wood was treated to make it water and UV-resistant. It also preserves the warm brown color wood and prevents it from getting grey over the years. (Houtwereld, 2009) The collective space between the housing volumes is covered with glass. In this way, an atrium is created, which provides an enclosed collective space, which is yet transparent and connected to the environment.

Figure 3.9
Central atrium (Tangram Architekten, n.d.)

Figure 3.10
Crystal Court (Tangram Architekten, n.d.)

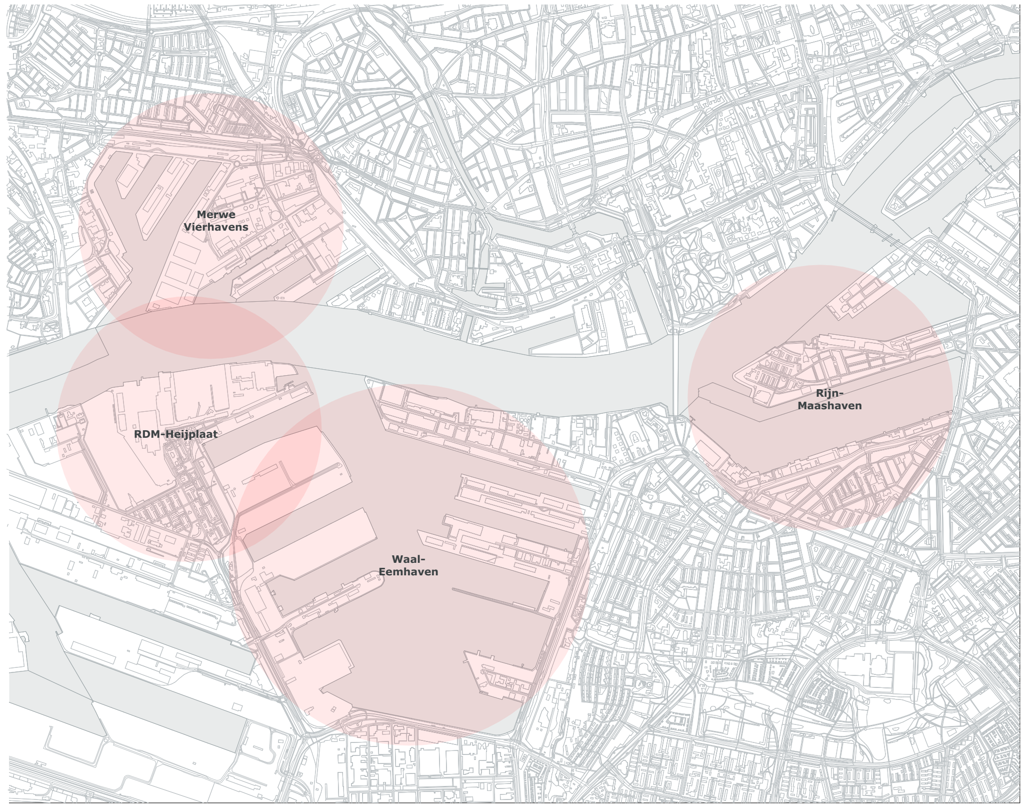
LOCATION

ROTTERDAM

To execute the design strategy as described in this report, a location is selected, which meets the boundary conditions for a successful Optop project. Most importantly, the selected building must have sufficient structural capacity to carry an additional program on top of it. Jaksch et al. identified post-war buildings generally as suitable buildings to execute Optop strategies, as they mostly have a very heavily dimensioned construction and they mostly do not have a monumental status, which would make it hard to apply a relatively drastic measure. (Jaksch et al., 2016)

In the Netherlands Rotterdam is a city that has a relatively large stock of post-war buildings. Moreover, Rotterdam is quite familiar with Optop projects. Several buildings in Rotterdam have been renovated in the past years in combination with an extension of the original program.

In Rotterdam, special attention is paid to the revitalization of former harbor areas. The Stadshavens project, initiated by the municipality of Rotterdam and the port of Rotterdam at creating a diverse living climate for the inhabitants. In this climate cultural and societal facilities, work and living should form one whole. The large harbor area of Rotterdam is believed to be able to contribute to this ambition. It will make this part of the city more accessible and connected to the city while contributing to the solution for the housing shortage in urban areas. A transition of harbor areas is envisioned in which city and harbor become more intertwined. (Gemeente Rotterdam, 2011)
Four harbor areas have been appointed for future development. See figure 4.1



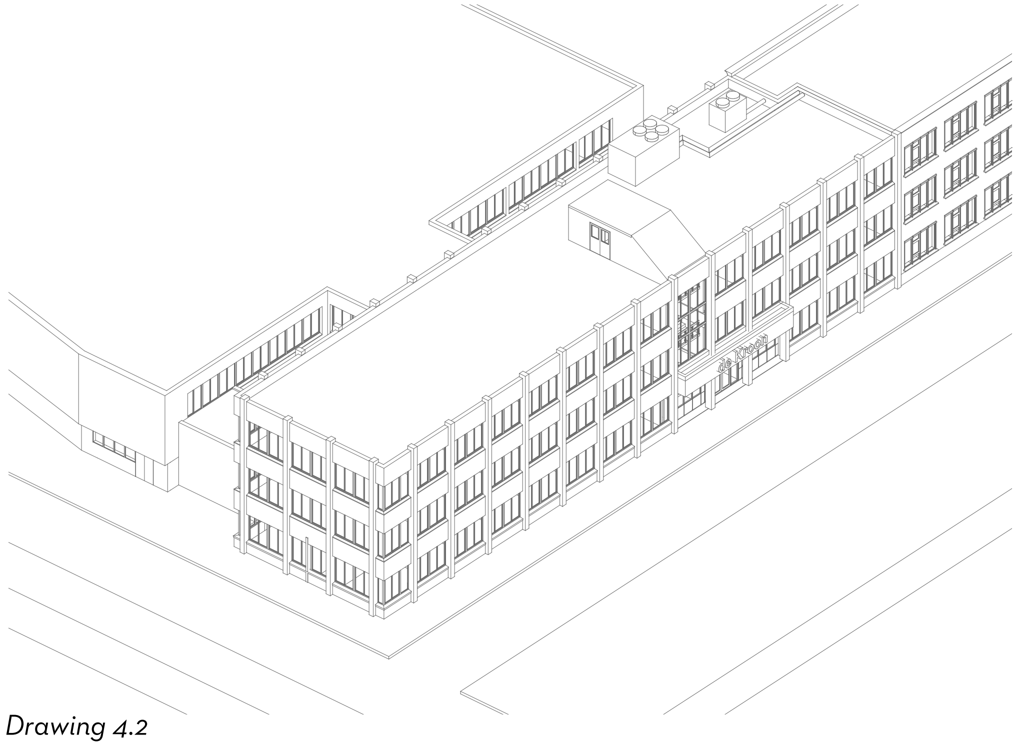
Drawing 4.1
Site plan showing the the future development locations for Stadshaven

DE KROON

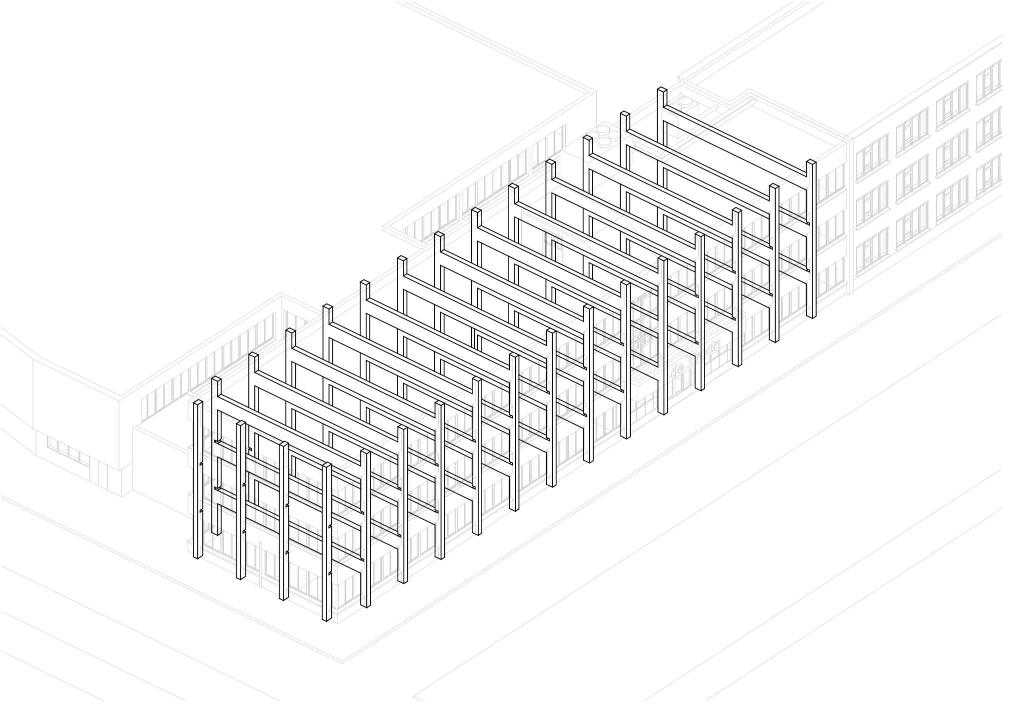
The project location to implement the Design Strategy is located in the middle of these developing areas. In the area called Schiemond. On the outside is not very expressive, but it has a lot of potential for the successful execution of the Optopping strategy.

The building is called De Kroon. It was built in the 1970s as an industrial building for the firm Croon Wolters&Dros. Although not very large in size, the building is characterized by its largely dimensioned construction.
The columns in the facade and the high beams in the ceilings were probably designed for heavy machinery in the building. Now it makes the building very suitable for Optopping. Figure 4.2 and 4.3 show the existing building and the highlighted structural system of columns and beams.

Figure 4.1
De Kroon
(Van der Wal, 2020)



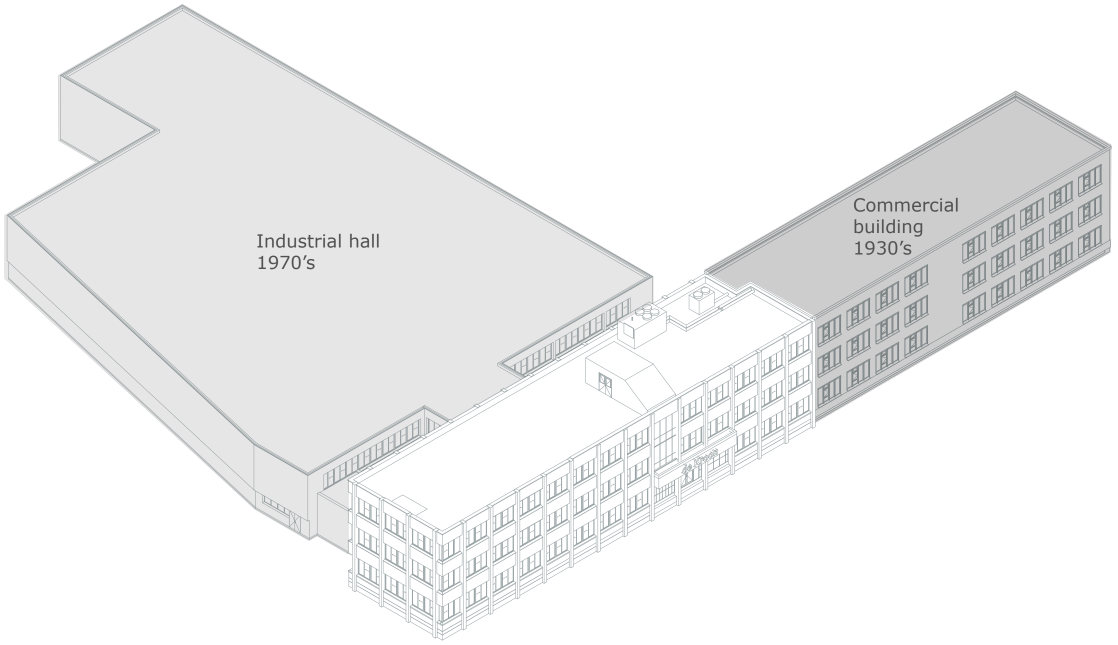
Drawing 4.2
Axonometric view of the existing De Kroon building



Drawing 4.3
Axonometric view of the existing De Kroon building higlighting the structural system

Today De Kroon building is used as a commercial building for multiple small businesses. The part of the building that is selected for the Optopping is part of a larger ensemble of industrial buildings. The ensemble shows a variety of buildings, from different ages and with different architectural and technical qualities. See figure 4.4
The oldest building on this location dates from the 1930s and consists of brickwork facades with timber ceiling and roof constructions. Although very similar to the part where the Optopping is located, in terms of size, this section is not very suitable for adding extra building layers on top.
On the other side, an industrial hall was built around the same period as the project building, during the 1970s. Nevertheless, this hall shows a very different structural system as well. It is characterized by a relatively light construction with long roof spans, typically for industrial halls. Adding extra layers on top of this building does not seem very plausible either. So, the central section with its heavily dimensioned concrete columns and beams is included in the Optopping strategy for this location.
The roof of this section is accessed through a central staircase that runs past all three levels of the building.

In this building, an architectural research and design group is based, as well. They are doing preliminary research on the feasibility of living on top of this rooftop as well. They identified this building as very suitable for this strategy as well. Nevertheless, in this stage, their research mainly focuses on the anthropological and legal implications of such an addition, rather than the architectural implications. Still, there was the opportunity to discuss and share our knowledge regarding the proposed Optopping on this building.



Drawing 4.4
Axonometric view of the building complex

SCHIEMOND

De Kroon building is located in an area called Schiemond, within the district of Delfshaven.

Delfshaven originates from around the year 1400 and grew as a port at the intersection of the Nieuwe Maas river and the Delfshavense Schie canal. This canal was dug by the city of Delft in 1389 to be independent of Schiedam and Rotterdam for their access to the main river.

During the late 19th century and early 20th-century, Delfshaven continued developing as a trading town. However, the economical value of the port diminished when the mouth of the Delfshavense Schie was filled up in 1968.

During World War Two Delfshaven escaped the destruction of the bombing of Rotterdam. Today it forms one of the few historical areas in the city. This historical context results in the increasing popularity of the neighborhood. Also, its maritime history contributes to the quality of this area.

Today many former docklands are being transformed into commercial or residential areas. These areas regain an appreciation for the views, the presence of water, and the dynamics of living and working in this mixed residential/commercial area. The nearby Merwe Vierhavens area is planned to be transformed in the near future as well, as part of the Stadshavens vision of the municipality of Rotterdam.

The transformation of De Kroon to a mixed commercial and residential building contributes well to the revitalization of harbor areas in Rotterdam and Delfshaven specifically.

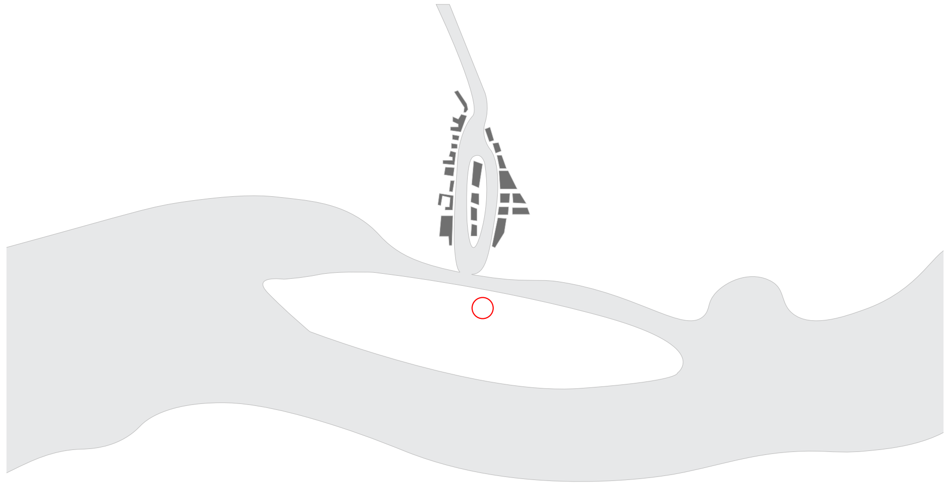
1200

1343

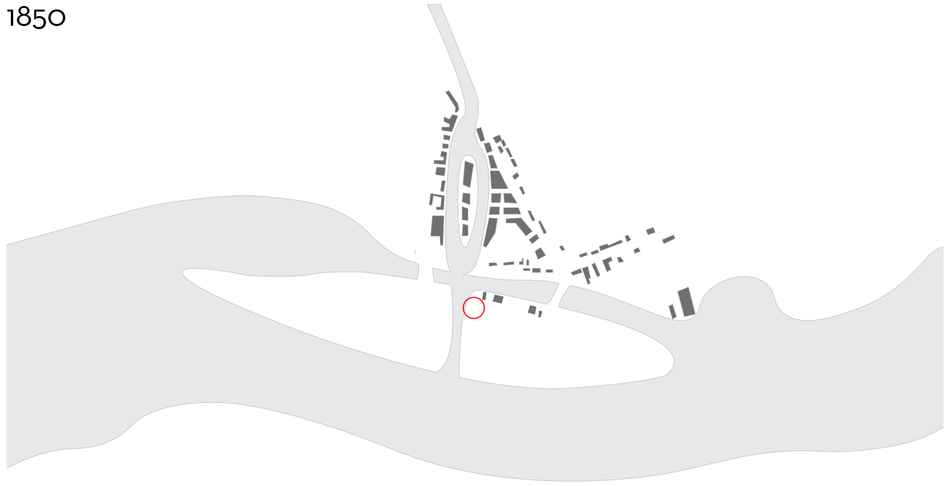
1389

1400

Drawing 4.5
Historical development of Delfshaven



1850



1875

1900

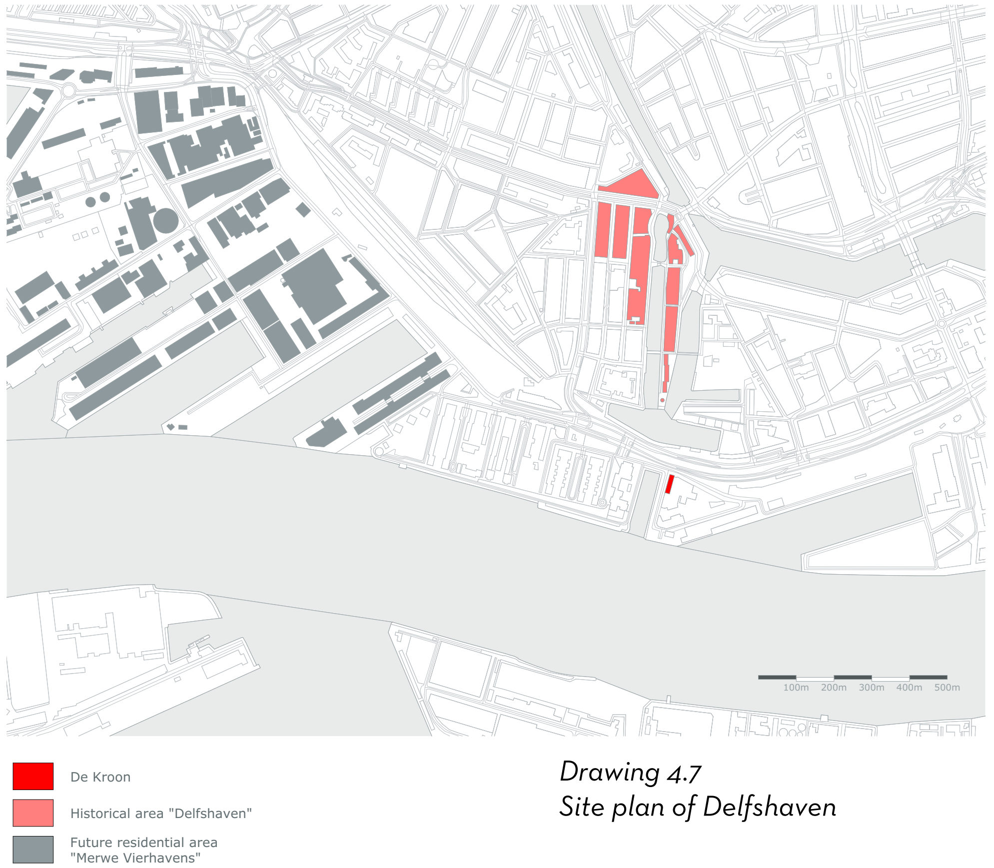
1935

1968

Drawing 4.6
Historical development of Delfshaven

The direct vicinity of the De Kroon building is characterized by a relatively open landscape compared to many other areas in the city of Rotterdam. Also, the heights of the neighboring buildings are relatively limited. Towards downtown Rotterdam buildings heights increase. This results in a nice view of the skyline from the rooftop.
The building is located near the Nieuwe Maas river, which is frequently used by ships leaving and entering the Rotterdam harbor. More specifically, the building lies directly at the mouth of the former Delfshavense Schie canal. This canal was shut off in 1968. All that remains is a remnant of the former canal.

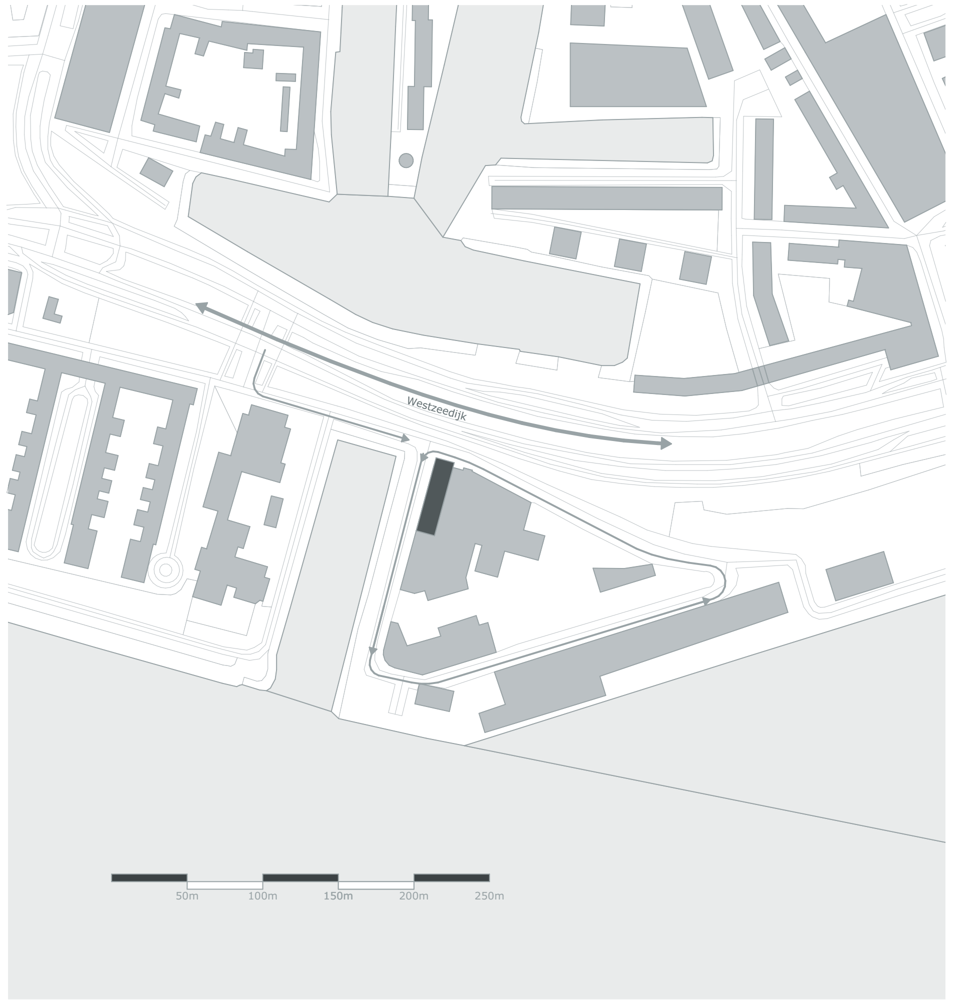
Transportation around the De Kroon building occurs via the Westzeedijk, which is the primary access road leading to the city center to the east and the highway A20 to the west. Also, a tramline connecting the area to downtown Rotterdam runs over this Westzeedijk. As mentioned, the building is part of a large complex of industrial buildings. A ring road leads around this complex, providing access for motorized traffic from all directions.



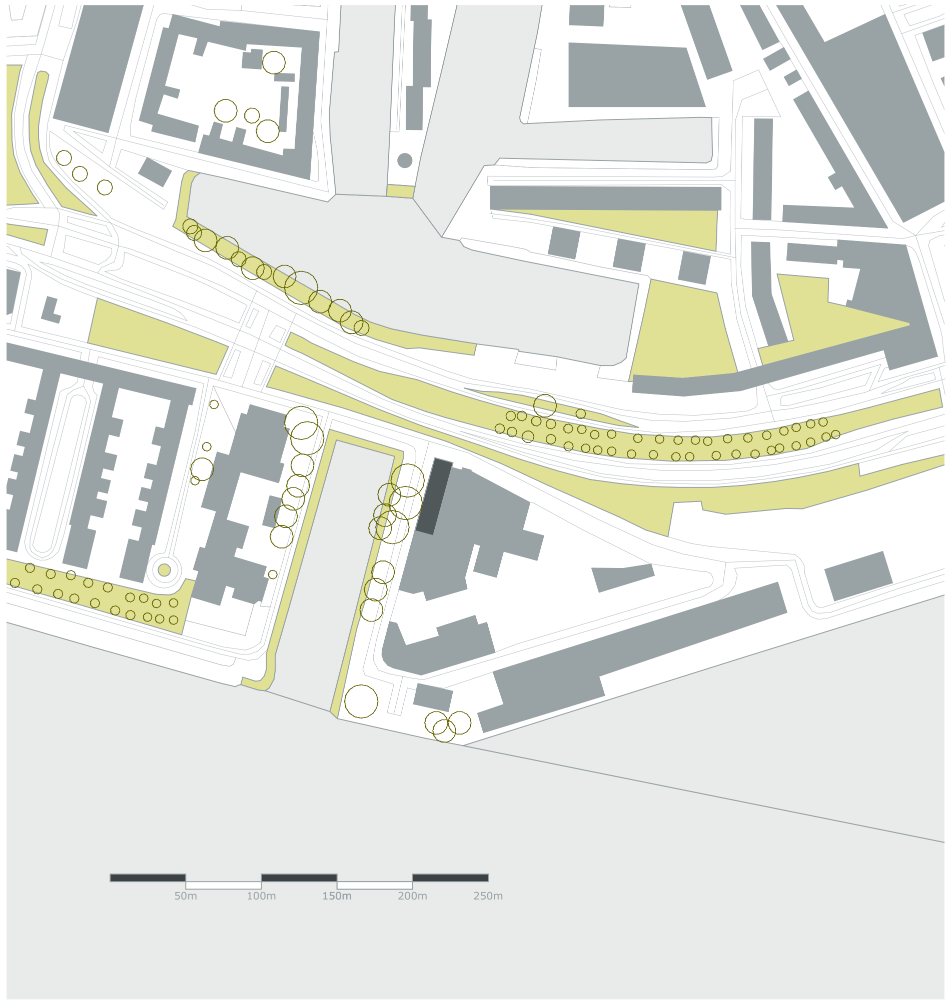
Drawing 4.7
Site plan of Delfshaven

Drawing 4.8
Urban morphology of the area around De Kroon

Drawing 4.9
Mapping of building heights in the area around De Kroon



Drawing 4.10
Traffic flows around De Kroon



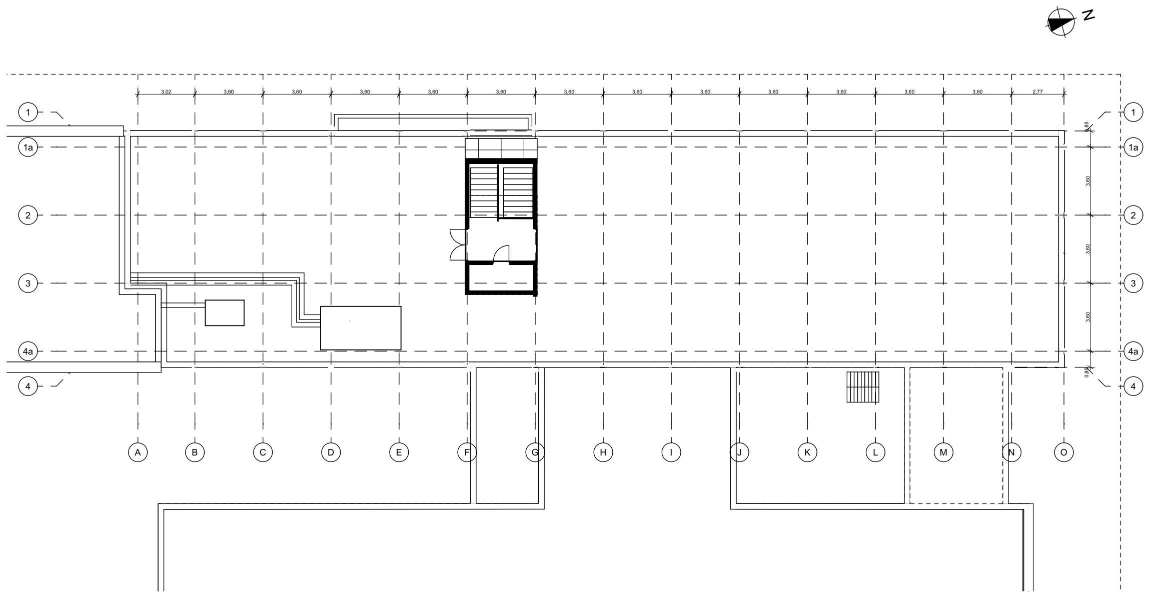
Drawing 4.11
Site plan of De Kroon

DESIGN

DENSIFICATION STRATEGY

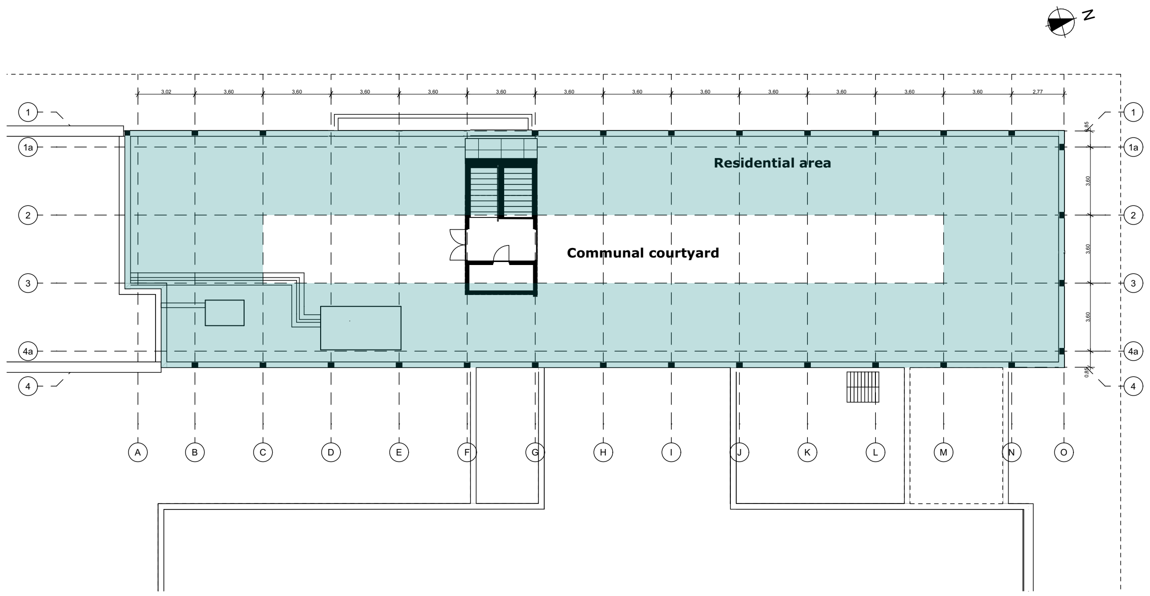
The creation of a highly densified residential oasis on top of an urban rooftop is the main starting point for the final design of this Graduation Studio.
The selected building "De Kroon" as described in the Location chapter offers a lot of structural potentials, which is vital for a successful Optopping strategy. At the same time building on top of this building gives limitations in terms of space. So, a dense, yet spacious layout is strived for to accommodate both sufficient housing space and spatial outdoor quality for the inhabitants and the desired ecological functions.

To provide a secluded communal area, which functions as a place to stay and to meet other inhabitants, a courtyard is projected on the existing roof. This courtyard is surrounded by dwellings. The rooftop has a limited area of 617 m2, which is not sufficient for the planned program of living and recreation. Therefore, a densification strategy for the rooftop, in particular, is needed.



Drawing 5.1
Existing floorplans of the rooftop

Scale 1:400



Drawing 5.2
Zoning of future residential program

Scale 1:400

Stacking of dwellings will be necessary to add a considerable amount of living space on the roof. At the same time, the building gives limitations in terms of structural strength, so unbounded stacking of many layers does not seem realistic in this context. Therefore, an additional construction is proposed.

As the main strategy of Optoppen is based on efficient use of the existing structural properties offered by the building, the additional construction is strictly meant to reinforce the existing structure, not to replace it. Based on the Optop principles, as described by DAAD Architects before, a combination of the Symbiotic and Floating model will be applied in this design. See figure 5.1
The Symbiotic model efficiently uses the structural capacity of the existing building, while the Floating model uses an additional table construction. This table construction is applied to spread the loads from the added housing program. It could also be used to lift a part of this program to create extra space below this construction. In this way, a second ground level is created beside the existing rooftop. See drawing 5.3
For this new layer the existing concrete columns, which form the construction of the existing building, are extended. Together with concrete beams, they build up portals to carry the second ground level. By combining the structural capacity of the existing with the Symbiotic model and adding additional structural capacity applying the Floating model, a total of four layers are added on top of the existing De Kroon building.

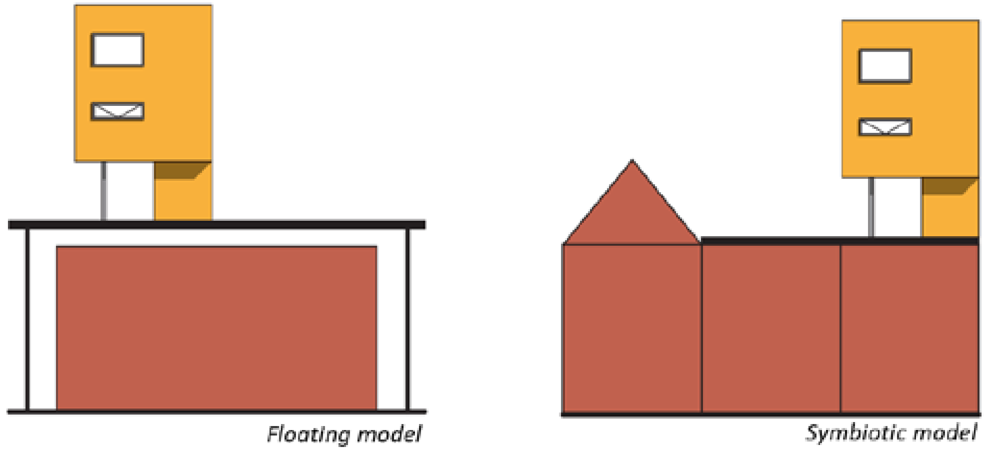
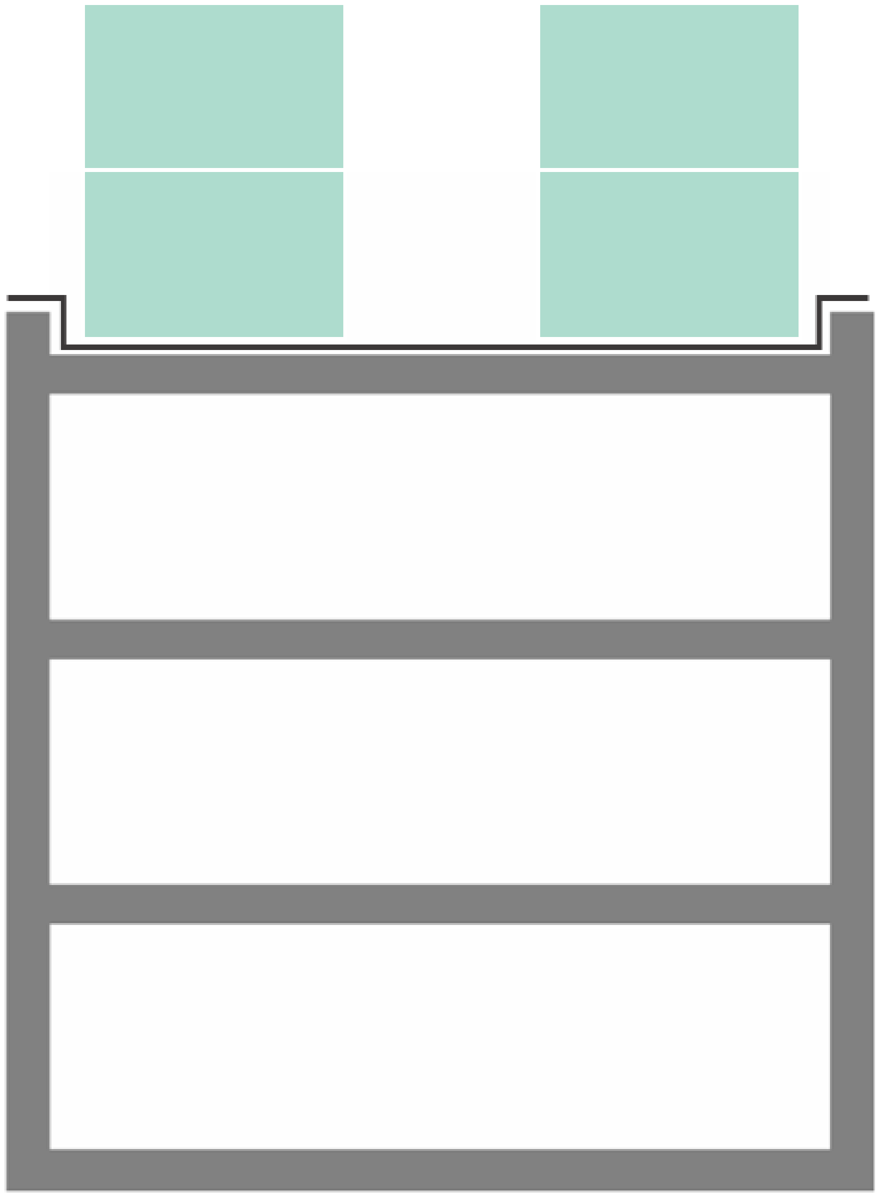
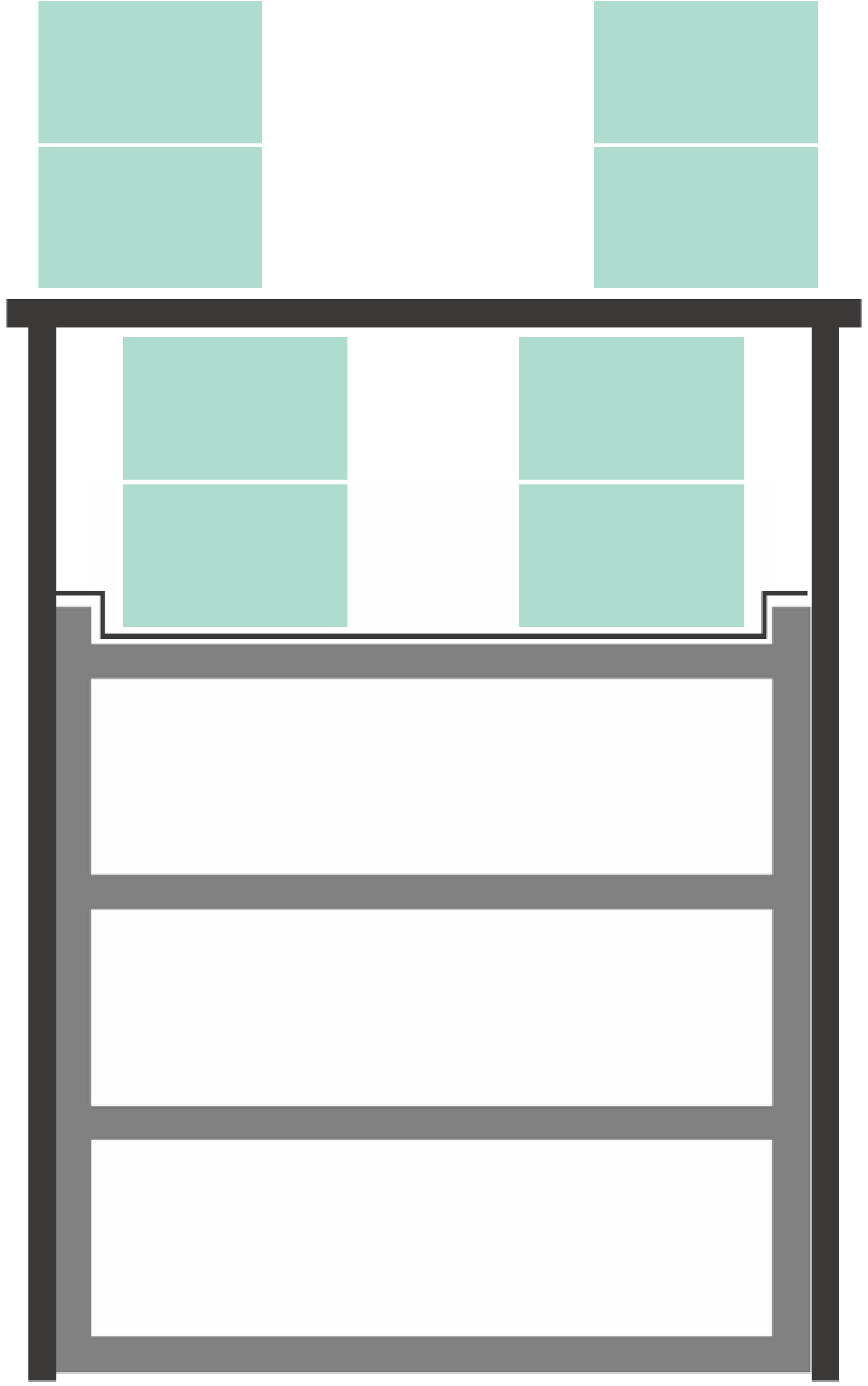


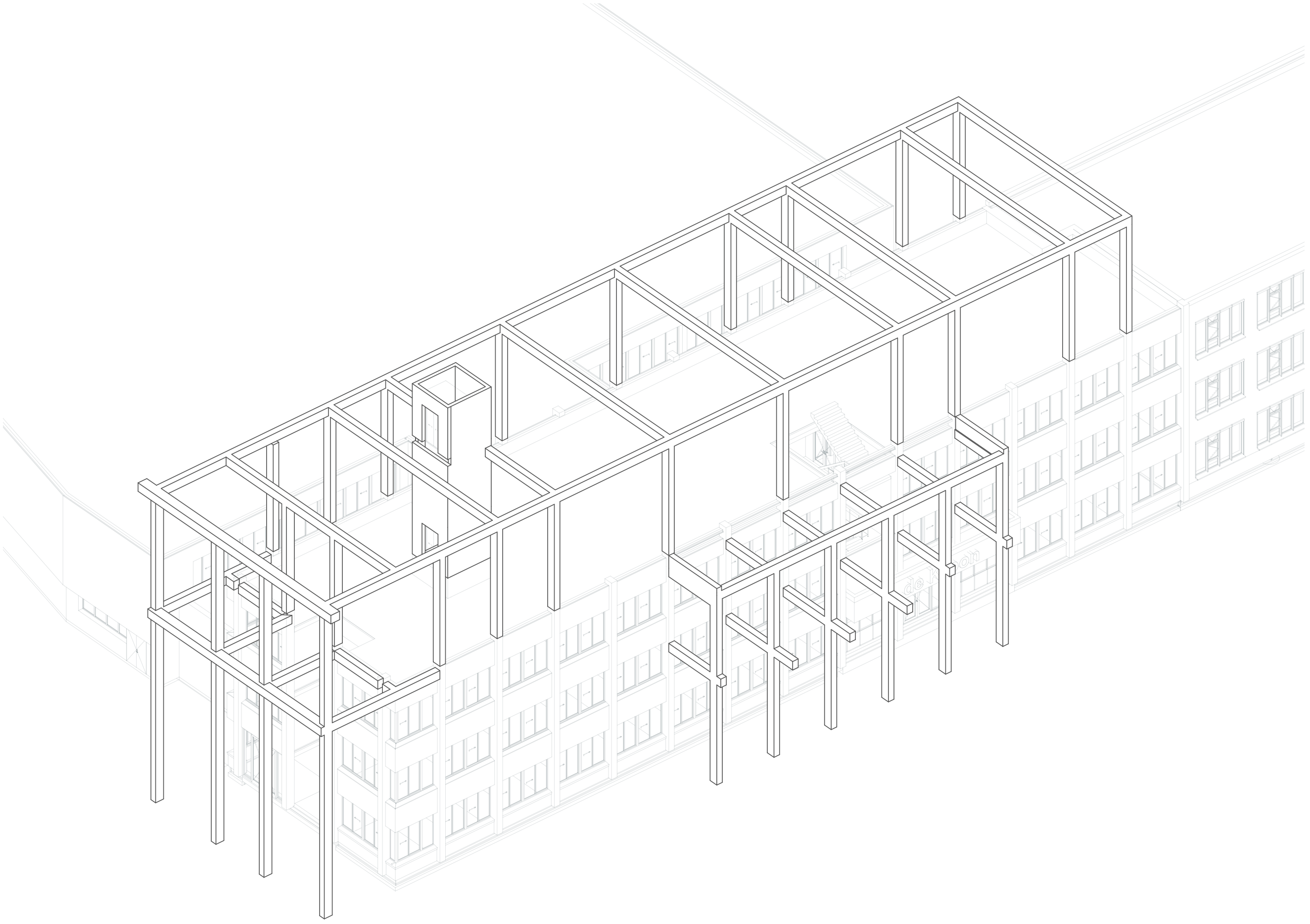
Figure 5.1
Two Optop models from DAAD Architecten applied in the design (DAAD Architecten, 2005)



Drawing 5.3
Schematic section of the future Optopping projected on the roof applying the Symbiotic model



Drawing 5.4
Schematic section of the future Optopping projected on the roof applying the Symbiotic model and Floating model

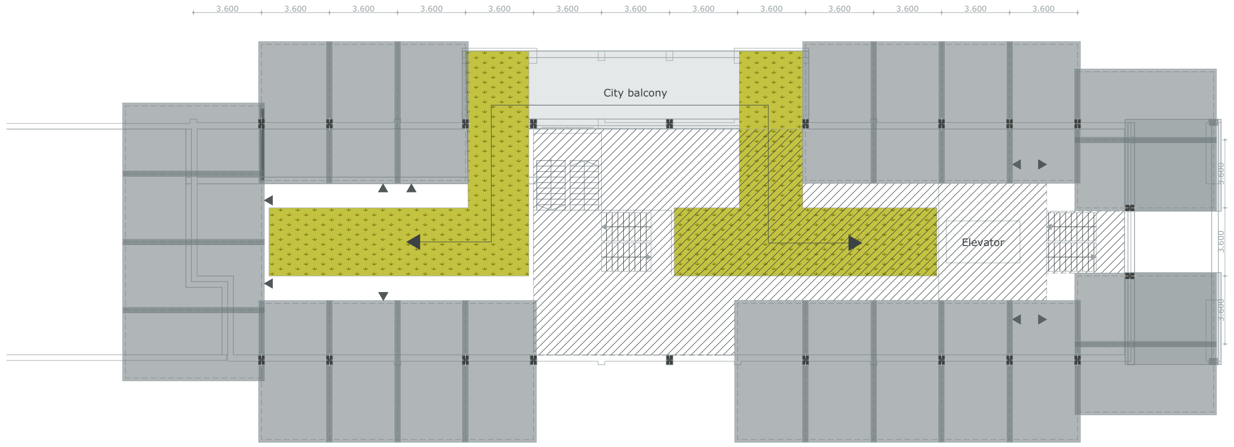


Drawing 5.5
Axonometric view of the construction for the second ground level

LAYOUT AND PROGRAM

The main elements of the program of the Optopping are residential area and communal area. They define the layout, which has been briefly discussed in the previous chapter. Inspired by the Crystal Court building in Amsterdam, which is discussed earlier in this report, a natural and green atmosphere is desired. Green spaces provide a pleasant living environment for the inhabitants and a place to stay beside their private indoor spaces. Additionally, green structures in urban environments are potentially very suitable for ecological functions, as described by Ahern in the chapter on Urban Climate Resilience. They contribute to a livable urban environment, which is capable of handling future urban climate changes.
This green area in the center of the rooftop will be surrounded by the residential program, which will be accessed through this central green space.

The existing staircases which lead to the rooftop, are extended in the Optopping. This circulation area is located in the center of the building. However, the main access from the street to the new program is located at the end of the building. Here a new staircase is planned which runs from the street level up until the top of the Optopping. Also, an elevator is installed in this location. So the Optopping is entered via a primary access at the end of the building and a secondary access in the middle, which also leads through the existing commercial area.



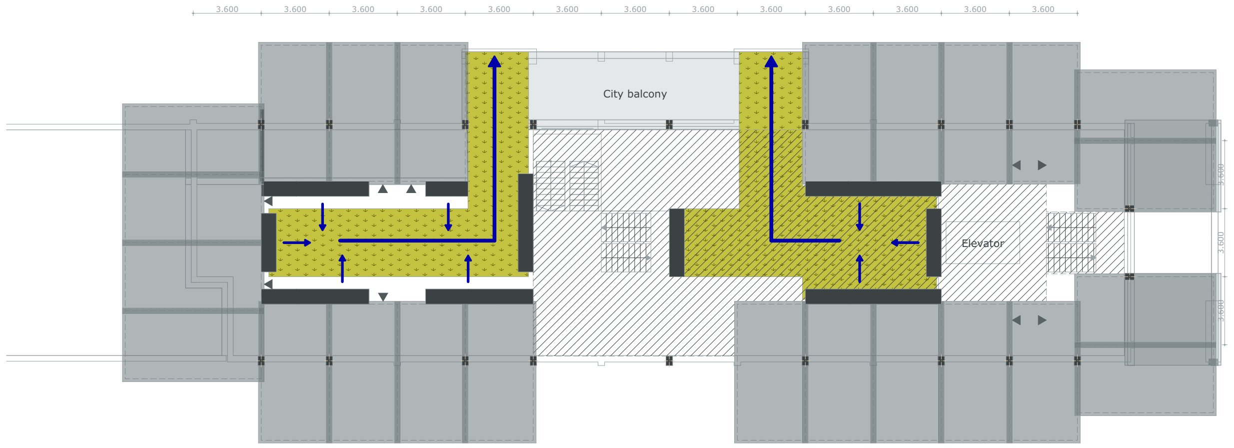
Drawing 5.6
Schematic layout for the residential and communal program
The city balcony functions as a link between the severel communal spaces on the roof
Scale 1:400

Just like Tangram did in their design for the Crystal Court, a safe and secluded residential oasis is proposed. Yet, at the same time, this design is located in a very open area with great views over the harbor area and towards the city center of Rotterdam with its impressive skyline. So, a completely closed-off layout would not use all of the qualities the location has to offer.
Therefore, a transparent atrium is proposed in the center of the new scheme. This atrium penetrates the surrounding living volumes in some places to create a more transparent ensemble. The glass façade of the atrium allows for visual connections between the central courtyard and its context.
On the street side of the building, the communal space is extended beyond the roof edge to make this connection between inside and outside a bit more physical. Here a city balcony is proposed, which functions as an outdoor spout of the atrium. The balcony also links the two parts of the courtyard, which is separated by the central staircase.

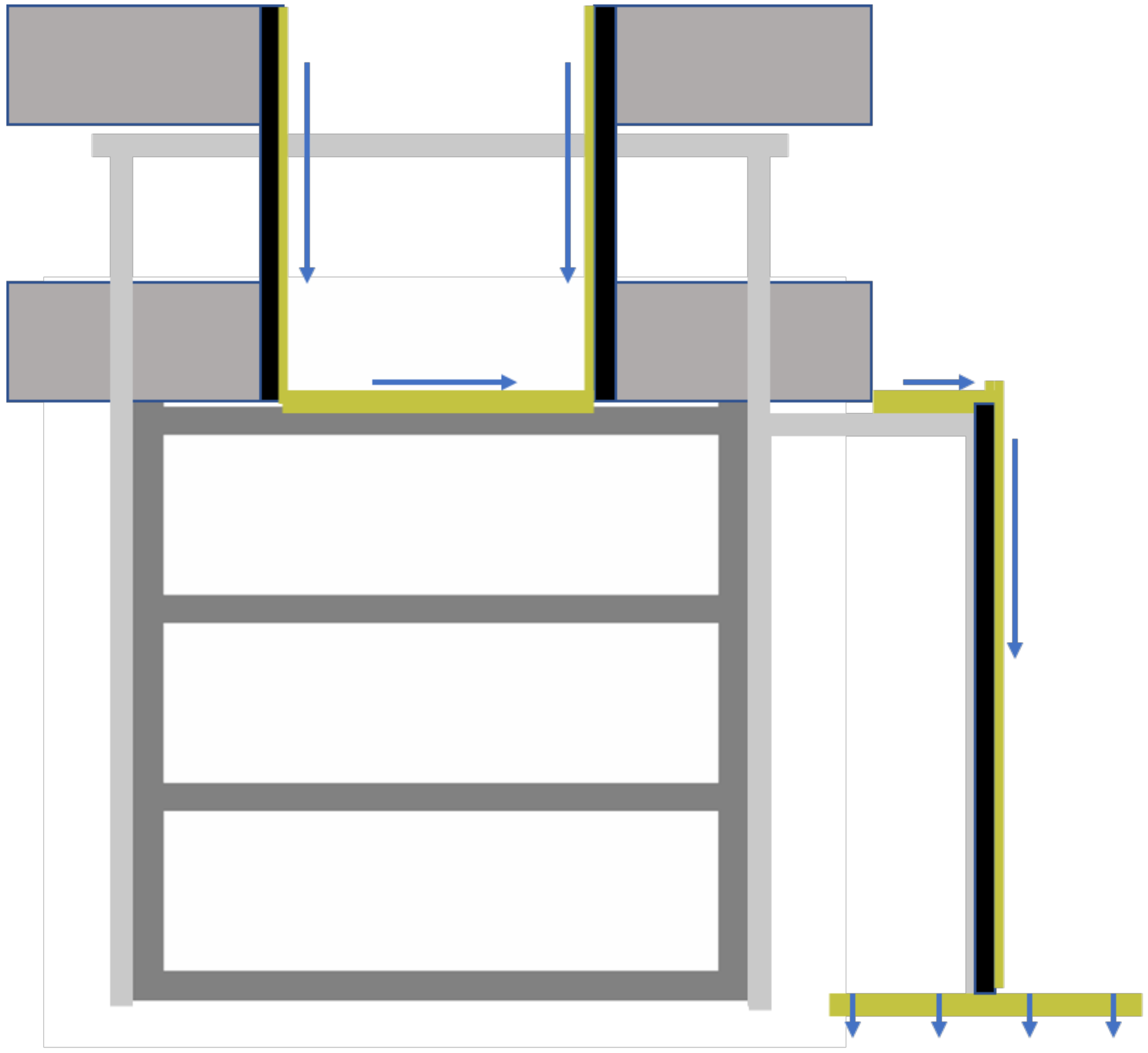
In order to create different atmospheres and climates in the communal areas, a variety of outdoor and semi-outdoor spaces is created. One side of the courtyard is therefore covered with the atrium, while the other part is left exposed to the outside air. The outside part contains the most greenery, while the atrium has more pavement as it functions as an important circulation space.

As mentioned before in this research special attention is being paid to the implementation of ecological networks in urban living environments, as they contribute to urban climate resilience. More specifically the built environment could contribute to more sustainable rainwater handling. In this report, a sustainable rainwater system is not vulnerable to peaks in rainwater, resulting in flooding, on the one hand, and provides the city with cooling by evaporation in hot periods. For this, rainwater needs to be stored locally on the surface for a longer time, instead of being drained into the sewage. Comparative studies have been executed to examine rooftop layouts which contribute to slowing down and storing rainwater on the surface. (Fassman-Beck et al., 2013)
However, a lot of potential can be found on urban facades as well for rainwater mitigation. This design proposes a new façade system that contributes to more sustainable rainwater handling. In this way, an ecological network is implemented in the built environment, which improves the urban climate resilience.

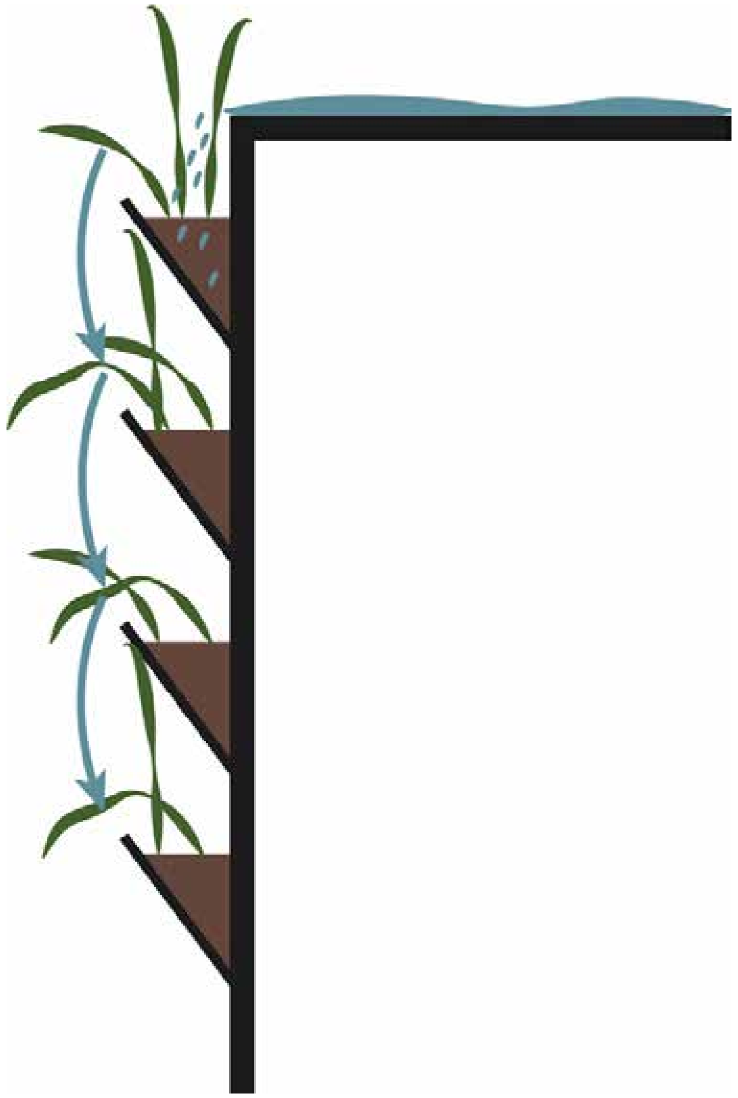
Drawing 5.7 shows the positioning of this façade system in the communal spaces of the Optopping.
The basic principle of this system is draining rainwater from roof surfaces along the façade, like conventional rainwater drainage. However, it is not drained using a conventional pipeline, but using planters, which are stacked along the façade. From the rooftops of the new housing units, water is drained to the green communal courtyard. Through this courtyard, water flows towards the urban balcony from where it is further drained to the surface. Drawing 5.10 shows an early impression of the extended construction op top and next to the existing building and the green façade projected to this construction.
The planters and courtyard are filled with earth and vegetation and can store the rainwater for a long period. In this way, rainwater runoff through the conventional sewage system is mitigated and water is locally available during dry periods. It provides a cool and pleasant environment for the inhabitants of the Optopping. The design and manufacturing of this rainwater façade system are elaborated on later.



Drawing 5.7
Schematic layout for the residential and communal program
The sides of the communal program are bordered by green facades transporting rainwater over the rooftop.
Scale 1:400



Drawing 5.8
Schematic section of the rainwater management system leading rainwater from the rooftops of the Optopping to the surface



Drawing 5.9
Scheme explaining the concept of the green facades storing and draining rainwater from the rooftops

Drawing 5.10
Early impression of the new construction on top of the De Kroon building and the green facades projected on it

The proposed layout for the Optopping on top of this roof offers a lot of space for communal and ecological functions. For this, the residential program has been pushed to and beyond the edge of the roof. Nevertheless, adding sufficient housing space is a vital part of this Graduation project to tackle the housing shortage and the high housing prices that exist in Dutch cities.
As the remaining space for adding residential program is limited, a challenge exists in designing a suitable housing typology that offers the functional and spatial qualities, which should be expected from a Graduation project. Some case studies, which have been discussed before in this report, offer an interesting starting point for the layout of the dwellings in this Optopping.

The first case study which gives good insights into how to deal with limited space, while creating a lot of spatial quality is the Nishinoyama House in Kyoto by Kazuyo Sejima. She made a scheme for 10 dwellings on a relatively small plot. In this scheme, all individual dwellings have direct access to outdoor spaces, mostly from multiple directions. Despite the small plot and the small sizes of the dwellings, this complex offers a lot of spatial quality.

Figure 5.2
Inner gardens of the Nishinoyama House (SANAA Architects, 2016)

Figure 5.3
Aerial view of roof pattern (Bann, 2016)

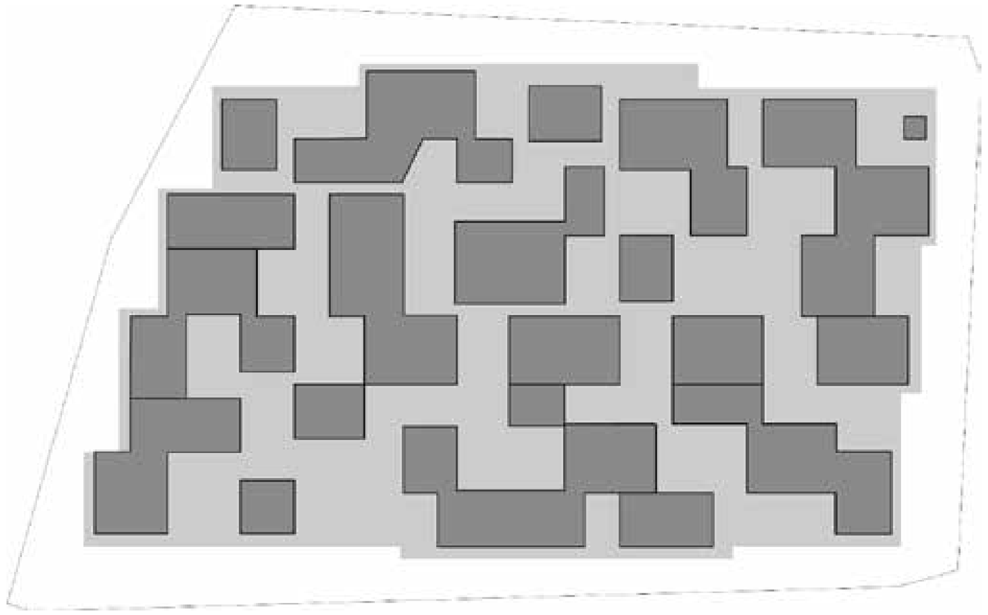


Figure 5.4
Floorplan scheme of the Nishinoyama House

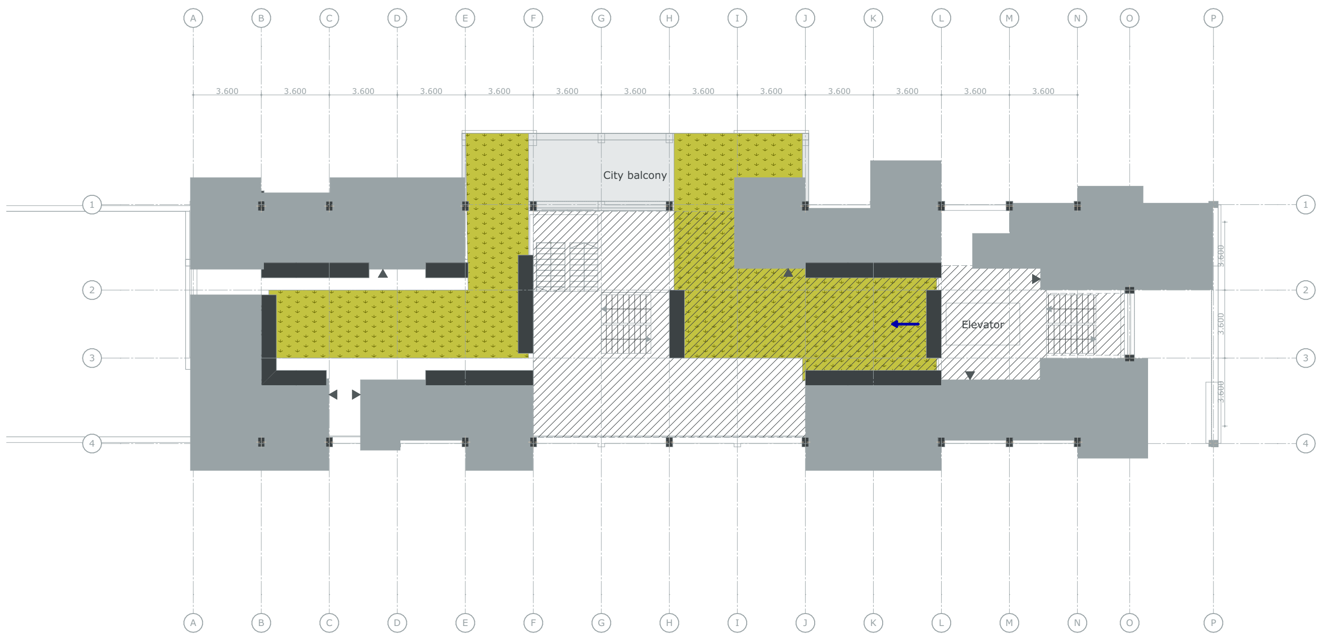
The other case study which is relevant for the layout of the dwellings in this design, is the Naked House by Shigeru Ban, also in Japan. The main principle of this house is facilitating both the collectivity of the family and the privacy of the individual family members. For this, the layout of the house needs to offer a lot of flexibility. The rooms need to be arranged according to the need of the users, whether they need space for collective activities or privacy. This flexibility is also needed in the housing typology that is proposed for this design. As the space for the residential program is relatively limited, spaces need to be used in a flexible, multifunctional way. The principle from the Naked House using movable rooms, appears to be very useful for this rooftop location.

Figure 5.5
Naked House interior (Hirai, 2016)

Projecting the layouts of the Nishinoyama House and Naked House in the layout that has been defined for this design, results in a very spatial arrangement of built-up and open areas on this rooftop. See drawing 5.11

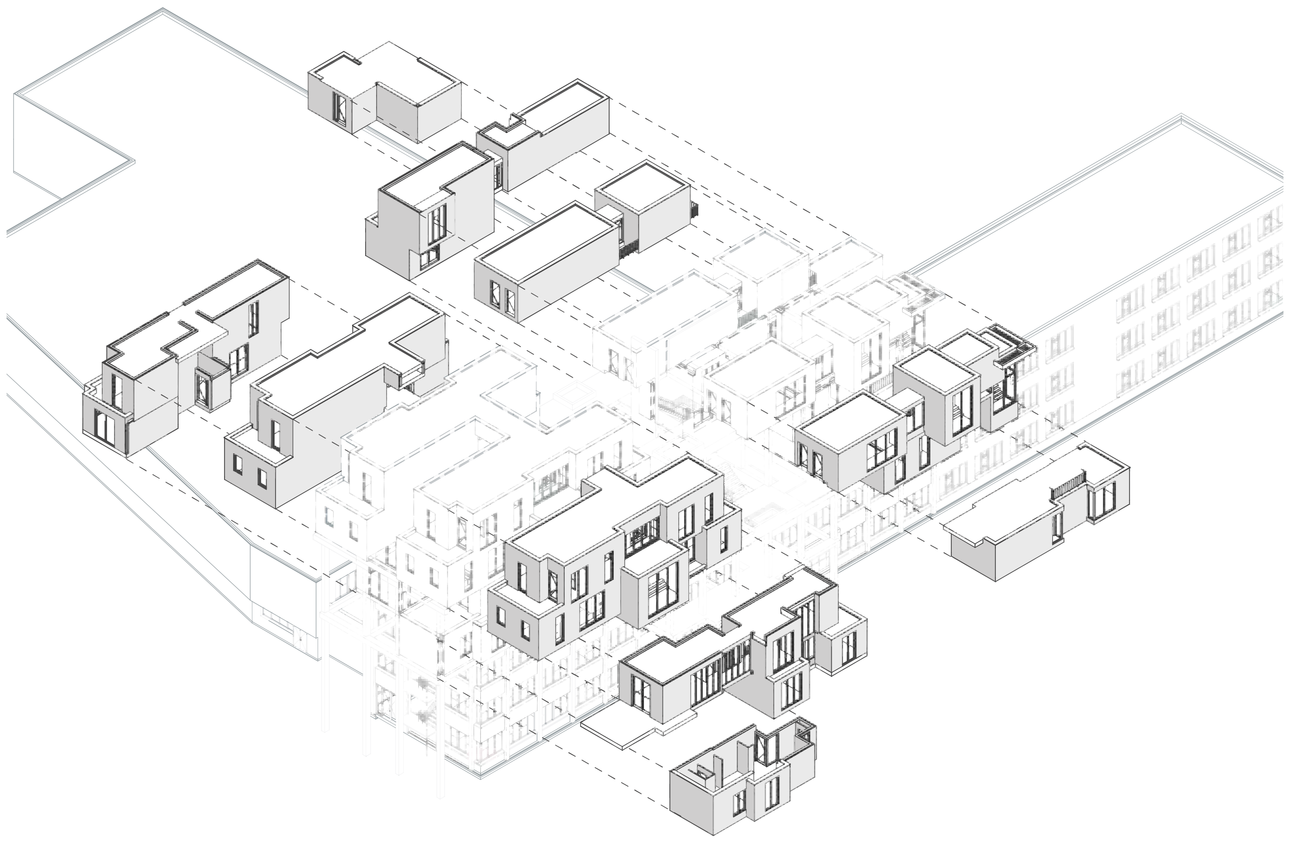
By applying more irregular, less solid, volumes, which are partly hanging over the building, a relatively subtle ensemble is created on top of the De Kroon building. This desirable in terms of volumetric balance between the existing building and the Optopping. A very solid, blunt volume would degrade the existing building. Moreover, as mentioned before, insolation of the bottom layers of this ensemble is an important element to pay attention to. Especially when cantilevering the dwellings over the roof edge, too much volume would block too much sunlight for the spaces below. By alternating different volumes of different sizes over the four layers the Optopping contains, a dynamic, spacious ensemble is shaped. One housing unit could occupy one volume or multiple volumes spread over different layers, resulting in apartment and maisonette dwellings of different sizes.

As in many Optop projects which have been discussed in this report, the existing structural grid influences the layout a lot.



Drawing 5.11
Schematic layout for the residential and communal program projecting the layout of the Nishinoyama House on the rooftop

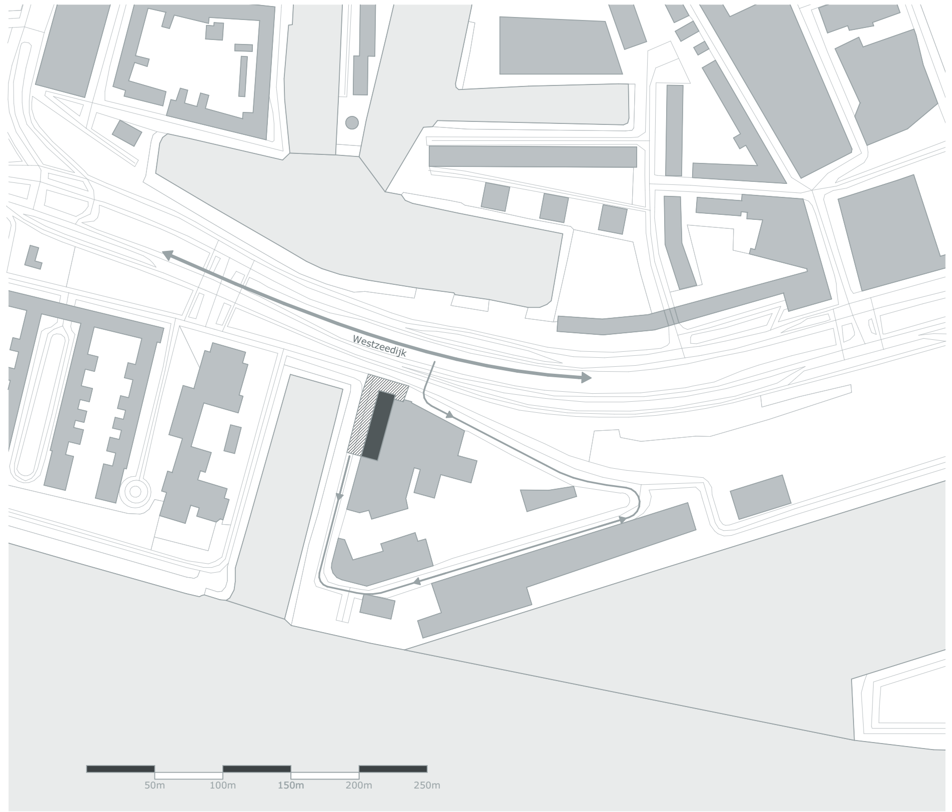
Scale 1:400



Drawing 5.12
Axonometric view of the proposed Optopping highlighting the ten individual dwellings that are realized on top of the roof

The final composition of the Optopping is characterized by the variation of solid volumes containing the residential program and transparent glass surfaces, which allow for some degree of connection between the communal spaces and the urban context. The ensemble of housing units shows an increase in building height. On one side the building is adjoined by another building. A gesture towards this neighboring building is made by a gradual decrease in height towards it. On this side, the Optopping contains three levels instead of four.

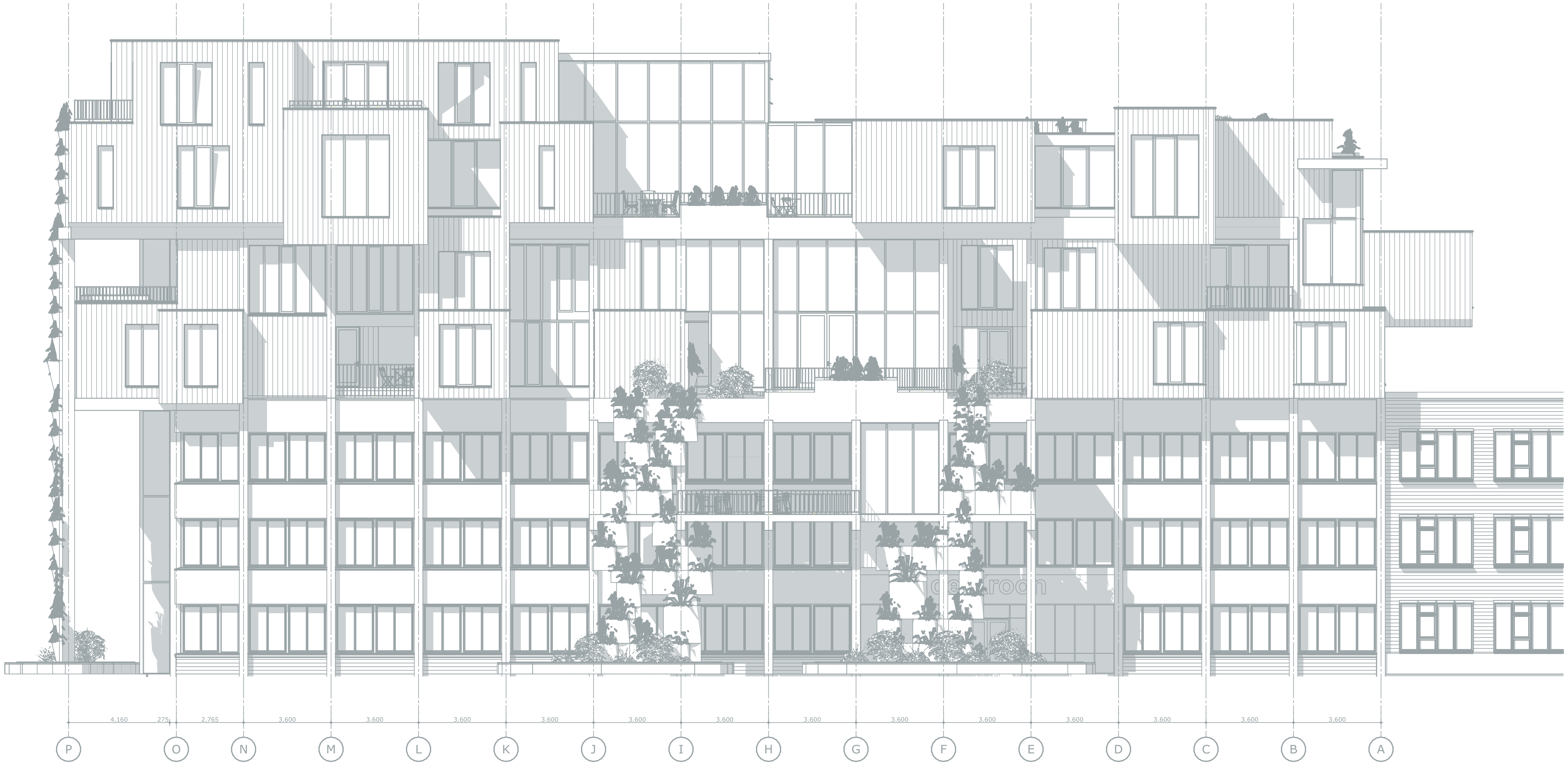
Important elements in the outside appearance of the design, are the green façades that run to the street level. They provide the Optopping with a strong landing on the street level. As mentioned before the green façades contain rainwater which is stored and slowly drained towards the surface. At the landing of the green facades, green areas are created to allow the water to penetrate into the soil. Integrated benches constructed from concrete and wood are part of this landing and provide a pleasant public place to stay at the foot of this project.
The direct vicinity around the De Kroon building is transformed from an industrial access road to a place to stay. Motorized traffic that used to drive past the building will be diverted via a new road, which connects the industrial area to the Westzeedijk thoroughfare.
See drawing 5.13



Drawing 5.13
Site plan showing the new traffic situation around De Kroon

The green facades are composed of many concrete planters which are stacked on top of each other against the vertical planes of the building. Multiple sizes and arrangements of planters are applied. On the outside façade, a varied pattern of planters of different sizes is visible. This creates a very dynamic image that matches the dynamics of the residential volumes.
On the inside of the program, where the communal courtyard with greenery is located, a stricter and ordered arrangement is applied. This again contributes to the quiet atmosphere that is strived for in this space. Planters of similar size and arranged in a regular grid.

Drawing 5.14
Impression of the Optopping with the green facades from street level.



Drawing 5.15
West facade
Scale 1:200

Drawing 5.16
North facade
Scale 1:200

Drawing 5.17
South facade
Scale 1:200

Drawing 5.18
East facade
Scale 1:200

Drawing 5.19
Impression of the new volume on top of the De Kroon building

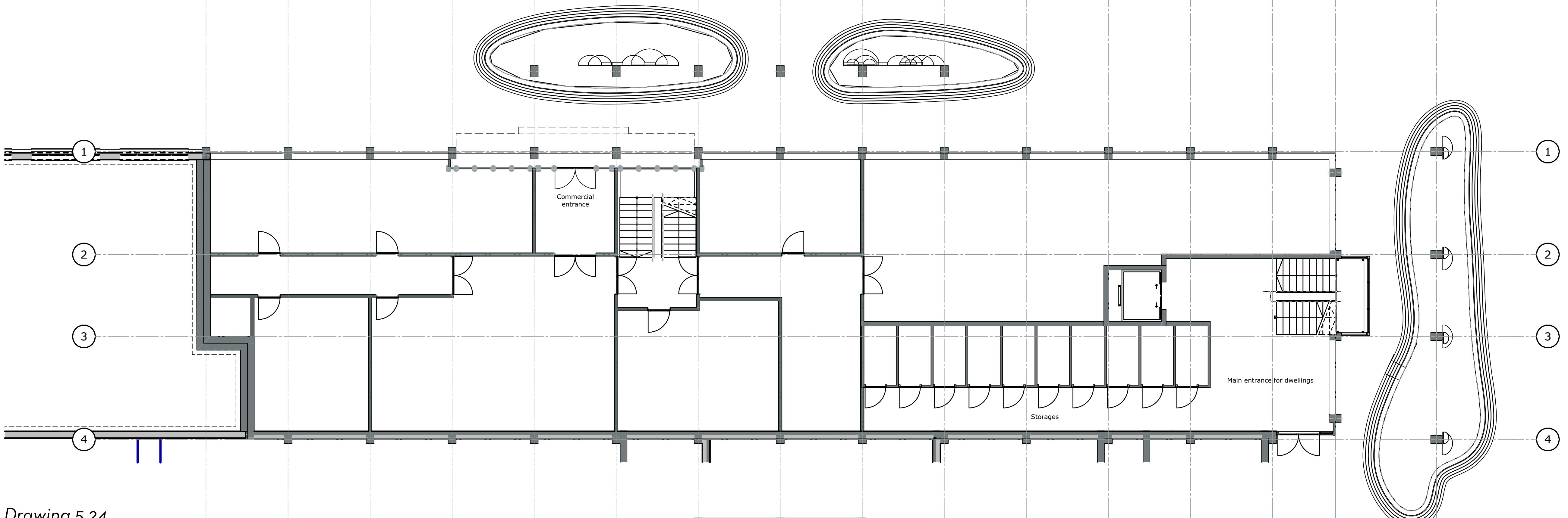
Drawing 5.20
Impression of the new volume on top of the De Kroon building

Drawing 5.21
Impression of the area around De Kroon, where the green facades land on the surface and by doing so, link the Optopping to the public domain

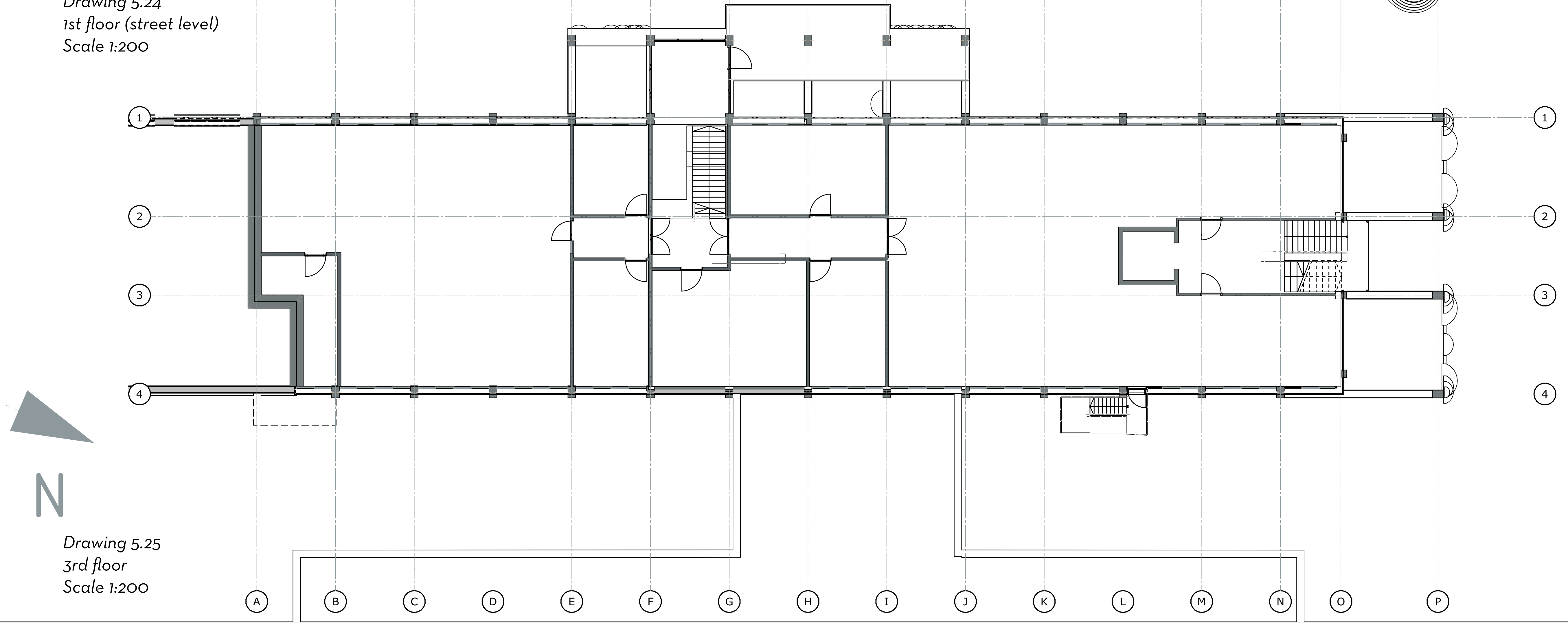
The proposed Optopping houses a total of 10 residential units ranging in size from 40 to 140 m2. Especially the smallest apartments require an unconventional layout to fit in a small, yet sufficient living program for a small household. As mentioned before a flexible dwelling layout provides possibilities for multifunctional use of spaces, and thereby reduces the need for space. Drawing 5.30-5.32 show the flexible layouts some of the dwellings offer for the inhabitants. Inspired by the movable boxes from the Naked House by Shigeru Ban, movable plateaus carrying the sleeping facilities are applied. These plateaus allow for easily pulling out and pushing back the bedroom into the main living space. During nighttime when the inhabitants mainly need space to sleep rather than living space, the bed can be pulled into the living space to provide a nice a more spacious bedroom. During daytime when extra living space is needed, for example when guests are invited into the apartment, the bed can be pushed back into the private area of the dwelling to create extra living space.

Drawing 5.22
Interior impression of 40m^2 studio featuring a movable plateau, allowing to increase or decrease the amount of private and common space in the dwelling

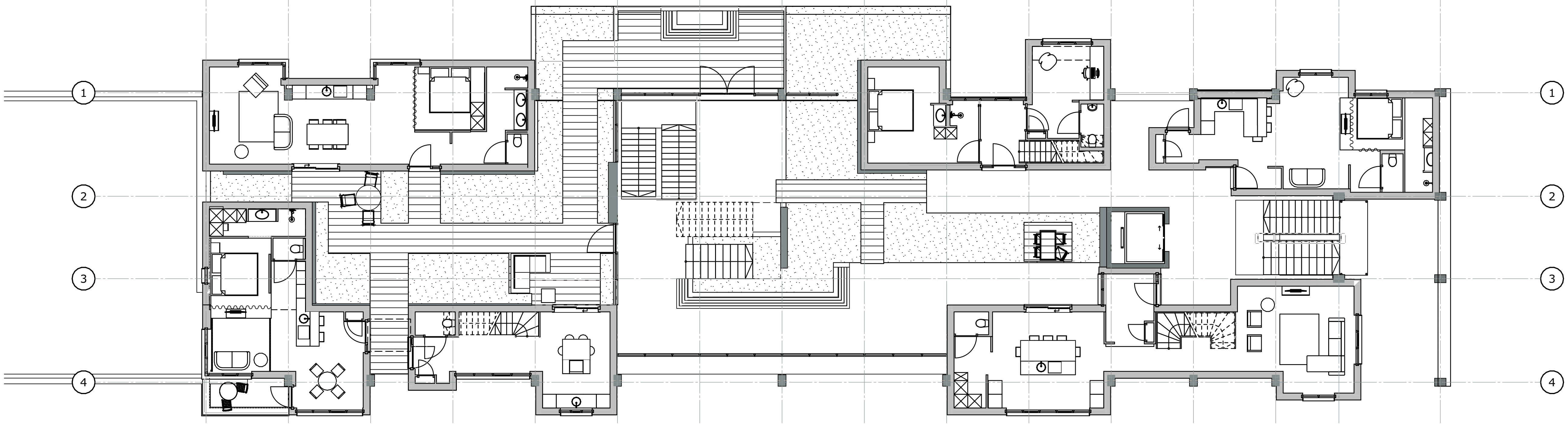
Drawing 5.23
Interior impression of 40m^2 studio featuring a movable plateau, allowing to increase or decrease the amount of private and common space in the dwelling



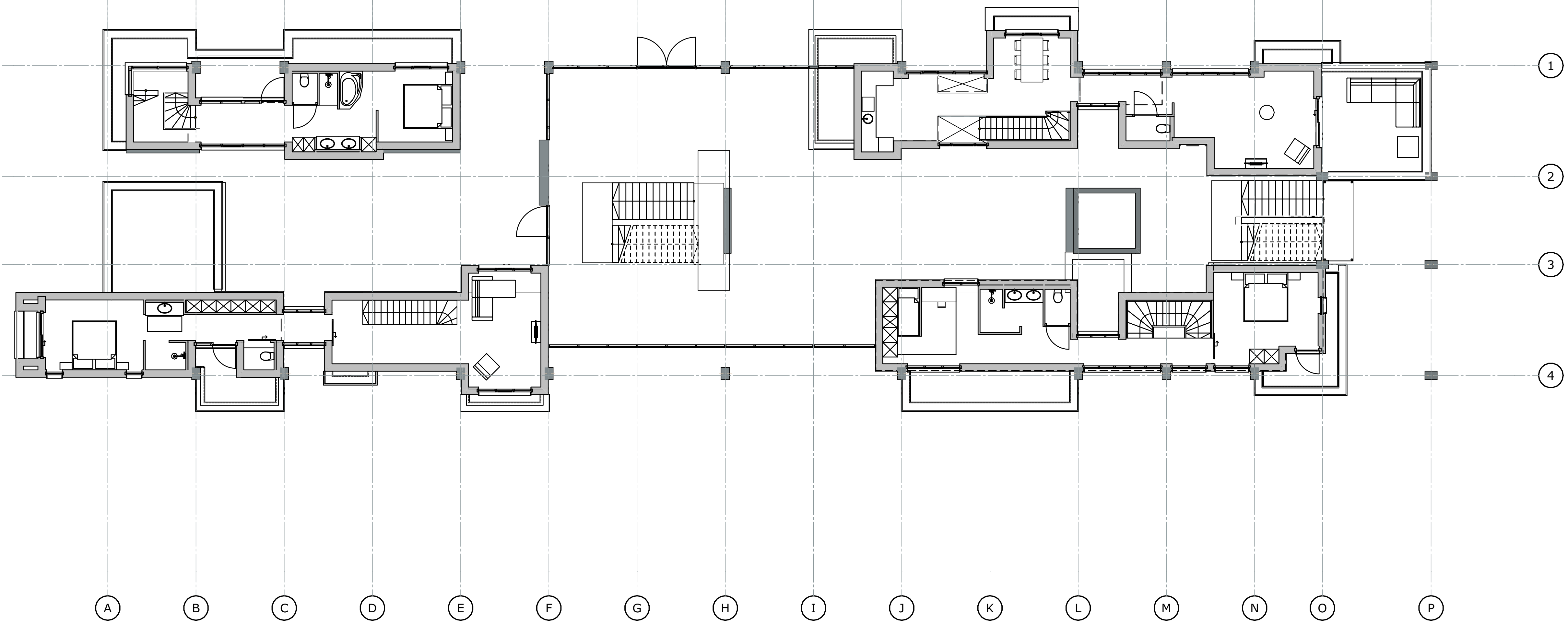
Drawing 5.24
1st floor (street level)
Scale 1:200

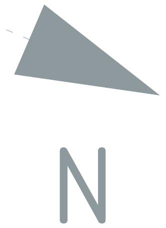


Drawing 5.25
3rd floor
Scale 1:200

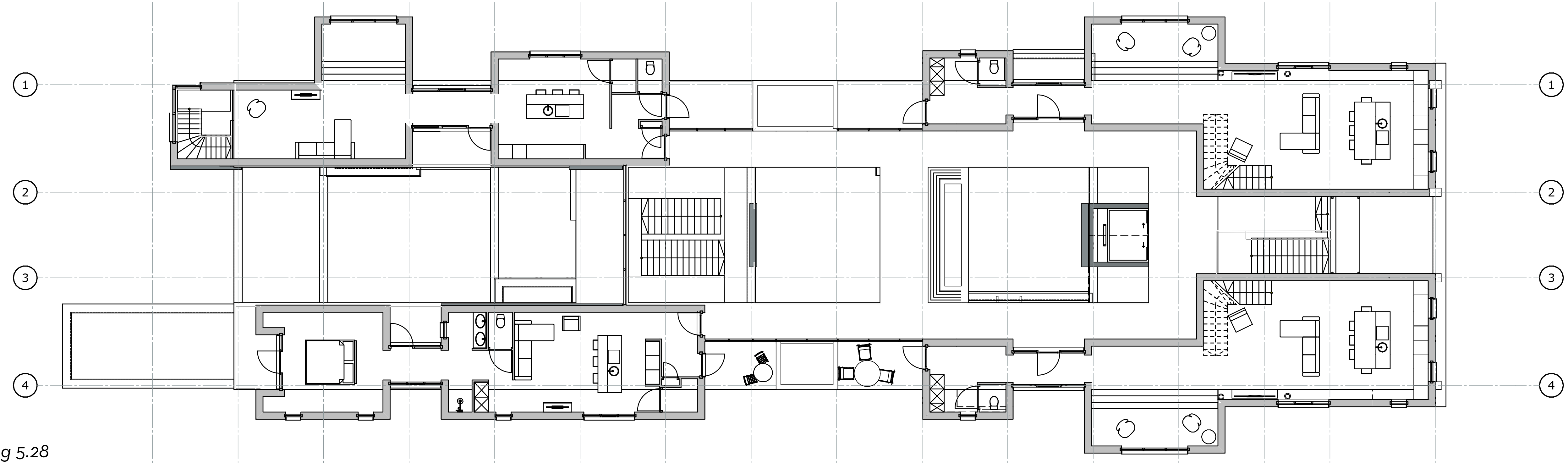


Drawing 5.26
4th floor (roof level)
Scale 1:200

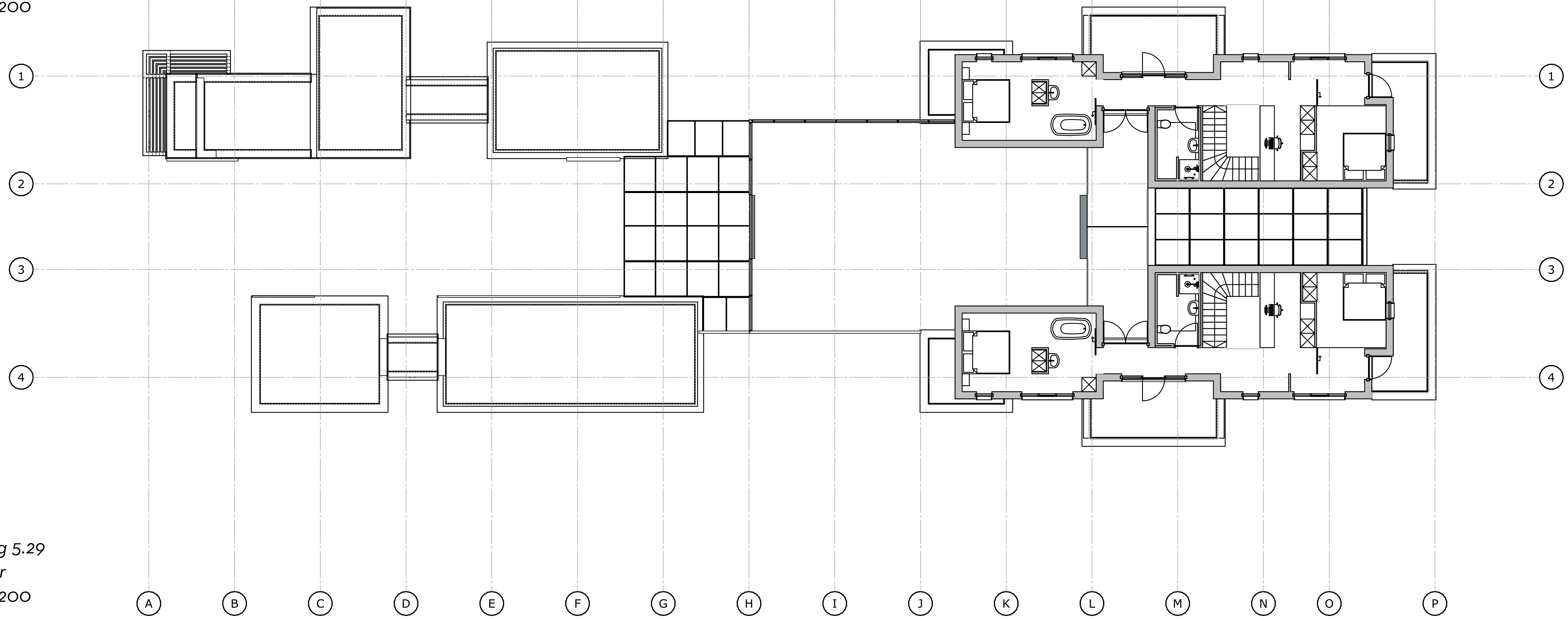




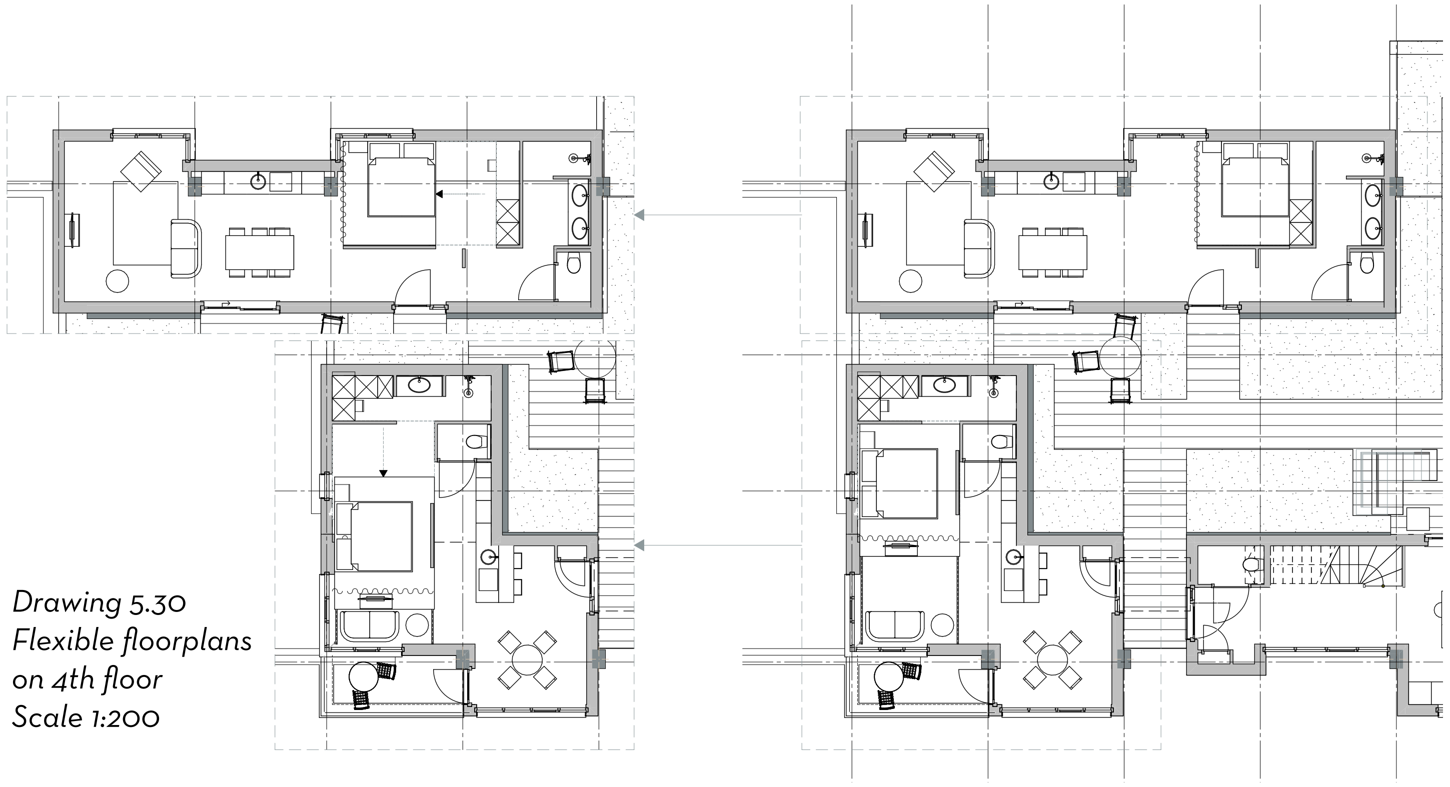
Drawing 5.27
5th floor
Scale 1:200



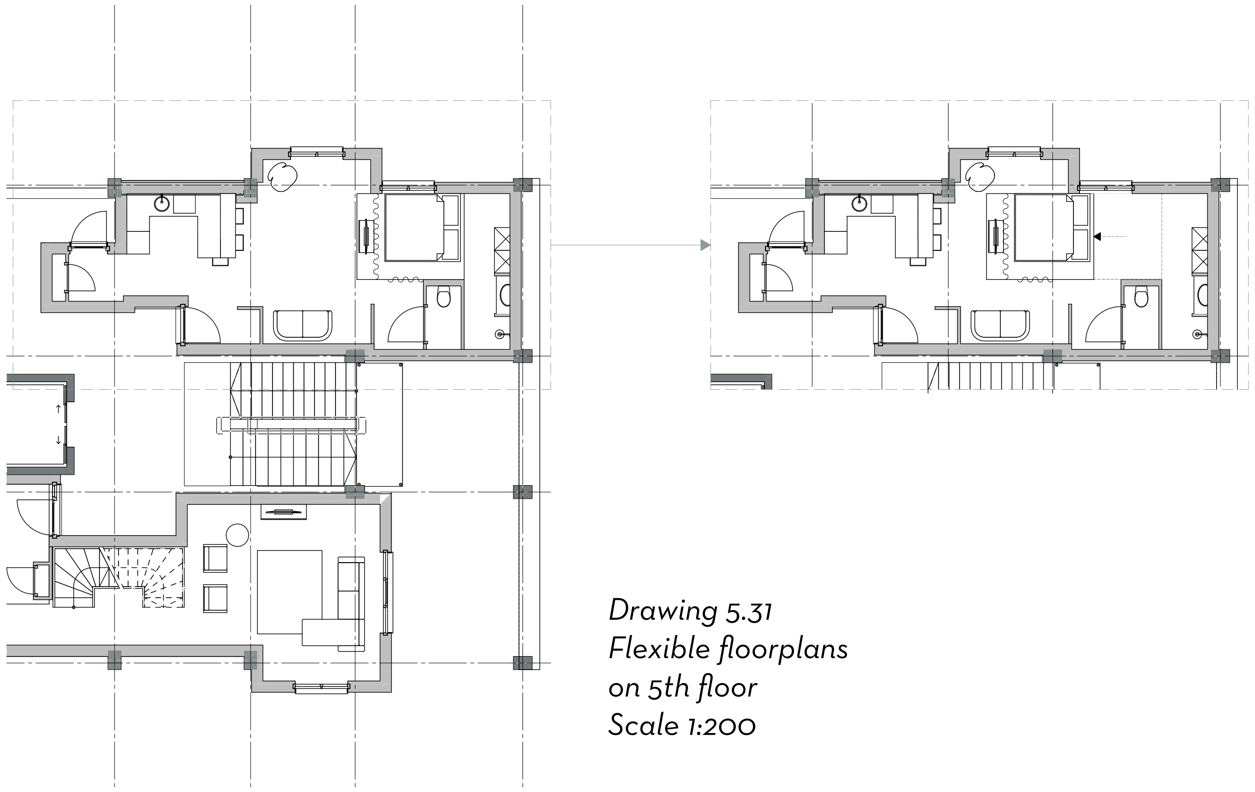
Drawing 5.28
6th floor
Scale 1:200



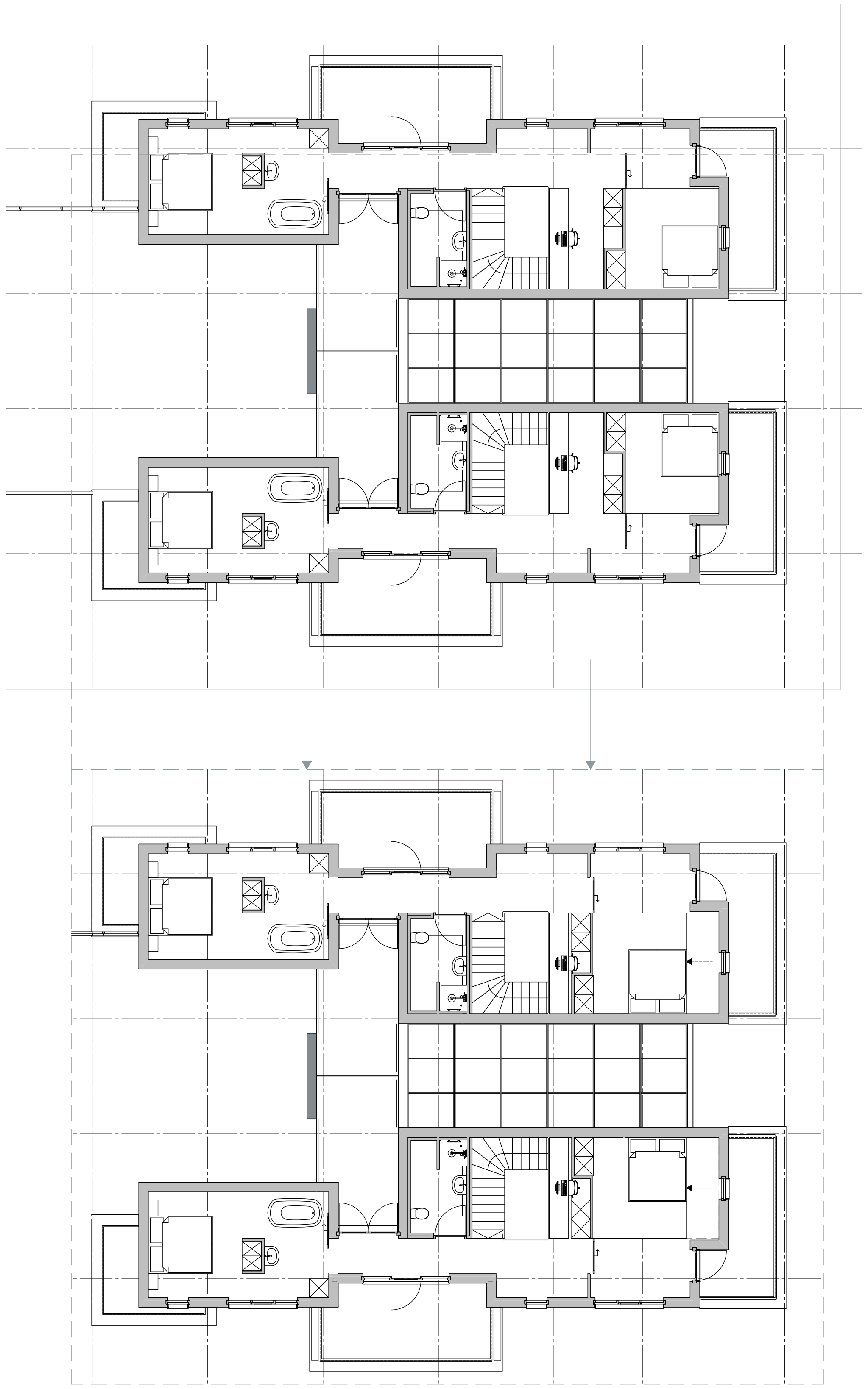
Drawing 5.29
7th floor
Scale 1:200



Drawing 5.30
Flexible floorplans
on 4th floor
Scale 1:200



Drawing 5.31
Flexible floorplans
on 5th floor
Scale 1:200



Drawing 5.32
Flexible floorplans
on 7th floor
Scale 1:200

The communal central courtyard is used as a corridor to access the adjacent dwellings, it houses the ecological rainwater buffer, and it functions as a place to stay for the inhabitants of the Optopping.
A part of the communal space is covered by an atrium while the other part is left exposed to the outside air, in order to create different climates in the urban oasis.

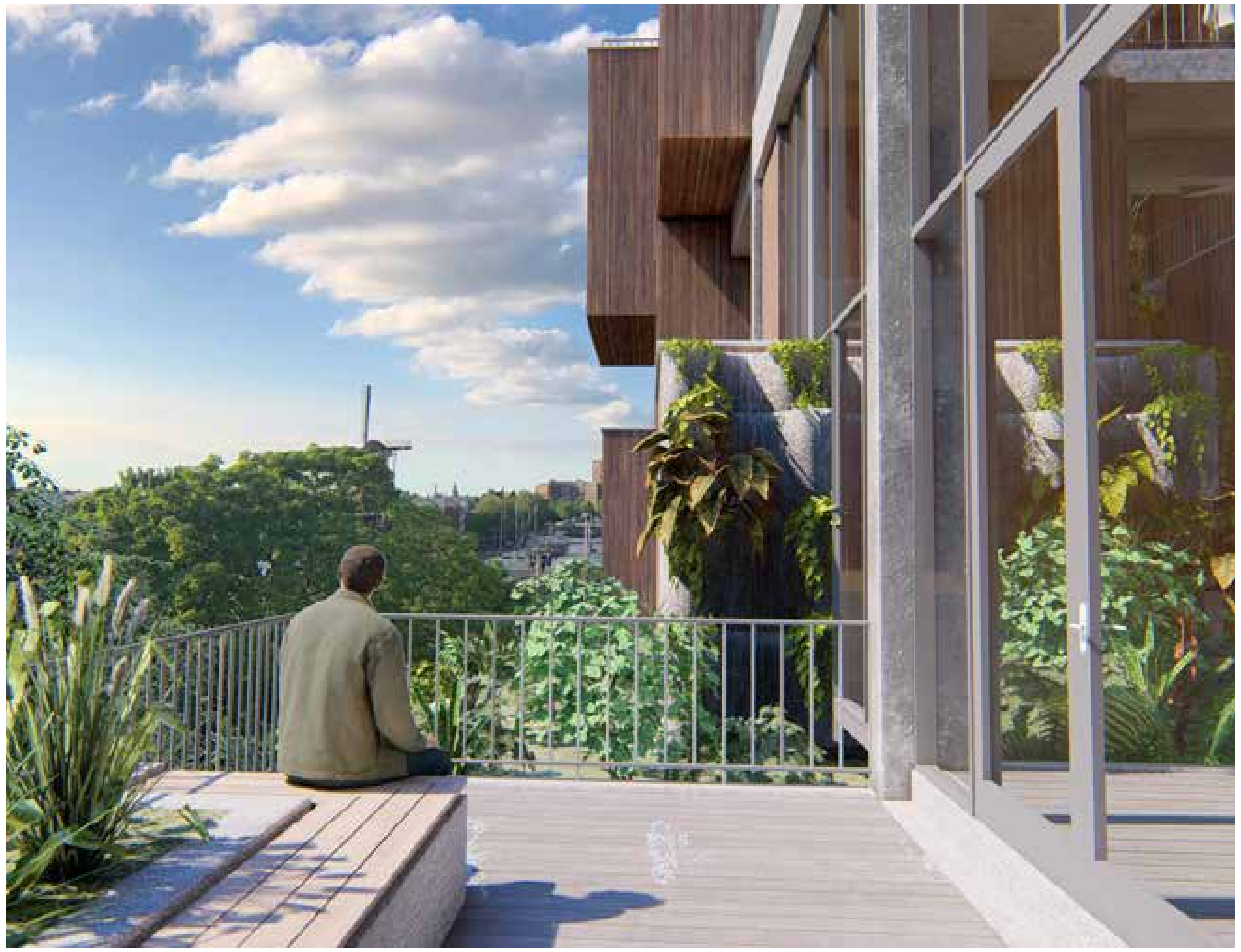
The covered part is materialized differently from the outside part, as it houses the main access routes to the street level and throughout the Optopping. A large part of the atrium floor surface is covered with grey timber. A green vein streams through this timber surface. It is part of the rainwater buffer which stores and drains the rainwater from the roof surfaces. This green area contains vegetation that contributes to the visible and climatical atmosphere in this space. Integrally designed benches made from concrete and wood provide the inhabitants with facilities to use this space as a place to stay.

The outside completely consists of green surfaces with vegetation. It is a bit detached from the central atrium with the main access routes. Only three housing units are accessed through this inner garden. Therefore, more space for ecological measures, as described before in this report, is available. On all four sides of this inner garden green facades descend, draining rainwater into the green network. The dwellings are accessed using timber footbridges hovering over the vegetation. Some parts of this footbridge are wider to provide outside terraces for two of the dwellings. This allows the inhabitants of those dwellings to enjoy the green oasis just outside the front door.

The city balcony in between the atrium and the inner garden comprises the third part of the communal area. It functions as a link between the first two spaces and as a link between the inner courtyard and the urban context. It allows the inhabitants to enjoy the view towards the nearby historical area of Delfshaven. Besides the safe and secluded living environment on the inside of the Optopping, the inhabitants are also provided with a physical connection to the context, as the balcony literally flows into this context.

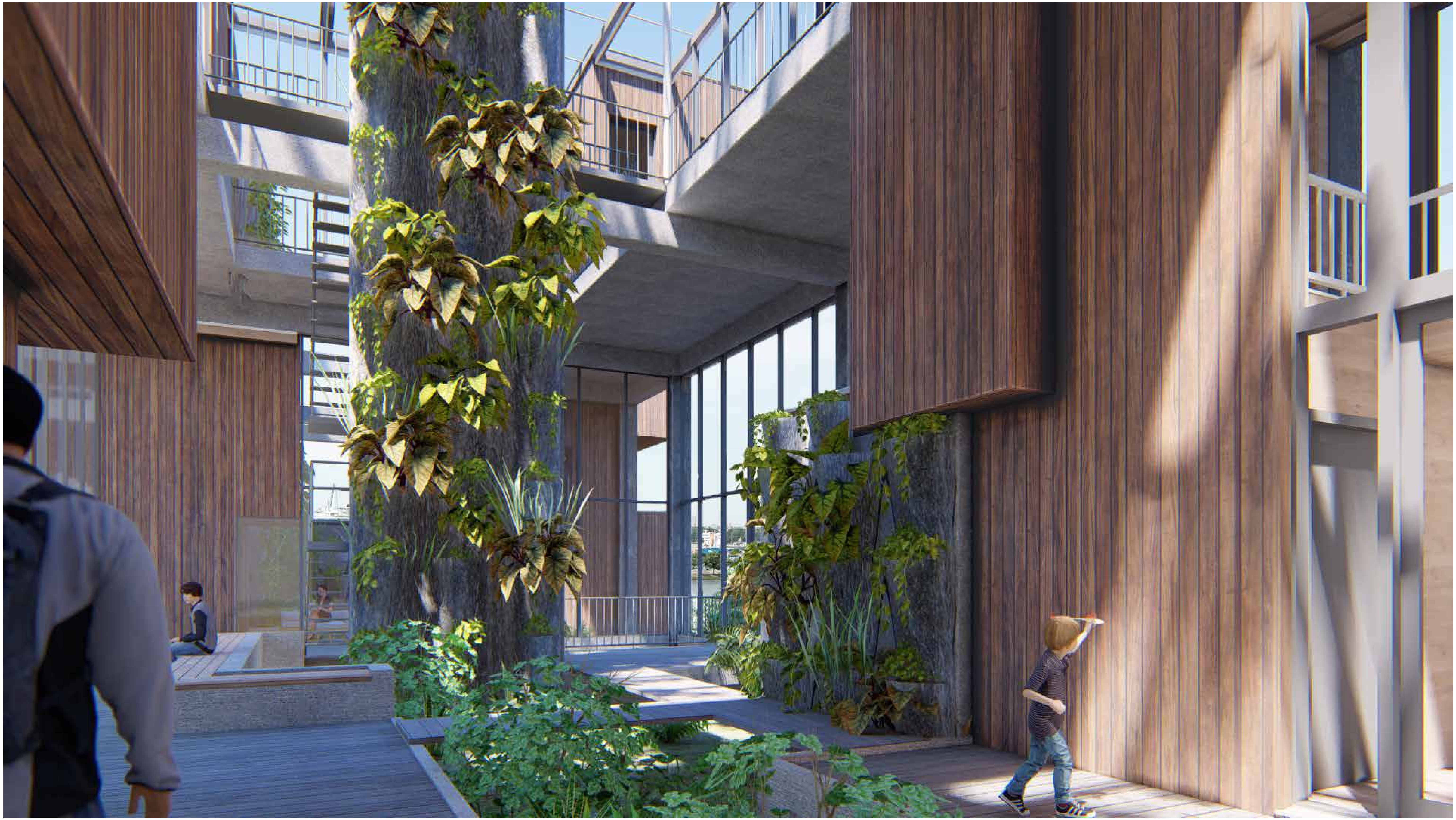
The last communal space to be discussed is located on the second ground level, which is created by the new additional construction. This ground-level platform carries two of the four residential layers of the Optopping and provides accessibility to the adjacent dwellings. Just like many parts of the design, this area contains vegetation as well, albeit not in terms of surface greenery. Two tall green facades, which reach all four levels of the Optopping run past the platform. Just above the platform, the glass ceiling of the atrium is located. From this ceiling metal, planters are hung which contain vegetation as well. This vegetation provides shadow for the communal space below when the sun shines directly onto the glass ceiling. As the platform is elevated above the other communal areas, it offers the best views over the surroundings and towards downtown Rotterdam.

Drawing 5.33
Axonometric section over the dwellings and communal space



Drawing 5.34
Impression of the city balcony

Drawing 5.35
Plan showing the new layout of the roof, featuring a green communal area with adjacent dwellings and green facades



Drawing 5.36
Impression of the central atrium, functioning as access point to the dwellings and as place to enjoy the atmosphere

Drawing 5.38
Interior impression of a dwellings bordering the inner garden and accessing it via sliding doors

CONSTRUCTION

The added concrete structure based on the Floating model from DAAD Architects, as discussed before, has a dominant position in the outside and inside atmosphere of this project. The use of concrete is a logical choice regarding the structural properties that are needed to carry two layers of housing volumes. Moreover, it forms a vertical continuation of the existing concrete structure that is visible in the De Kroon building.

For the infill of this structure, relatively lightweight materials are applied. In this report, the essence of lightweight prefabricated building systems has been discussed. This allows for shorter construction times on-site and requires less structural adaptations to the existing building, compared to using heavy, on-site constructed systems. (Jaksch et al., 2016)

Therefore, a timber building system using prefabricated Cross Laminated Timber (CLT) is applied for the construction of the housing units. As the Crystal Court reference project by Tangram Architekten has shown, the use of wood creates a very warm appearance and fits well in a natural context. As this green environment is clearly present inside this Optopping, timber would be a very suitable building material to apply in this project as well.

CLT is mostly used as structural panels. These panels are built up of glued planks which are layered crosswise. CLT panels can be sawn in large or small surfaces without affecting the structural properties. The design proposal for this Optopping shows a lot of cantilevered parts with different spans. This requires a building system that can handle overhangs without many additional constructions.
Moreover, the panels are prefabricated in the right size and with the needed façade openings, so assembling time on site is reduced. Also, CLT panels have a relatively low mass. For example, concrete panels, which have the same structural performance, are more than 5 times heavier than CLT panels. Concrete has a volumetric mass of 2700 kg/m3, whereas CLT only weighs 470 kg per cubic meter. (Laminated Timber Solutions, n.d.)
The material properties of solid timber also offer good fire safety and thermal insulation.
Lastly, timber constructions, including CLT are known as ecological building materials if produced and recycled in the right way. (RISE Research Institutes of Sweden, 2019)
These properties make CLT a very suitable building material for this design proposal.

Figure 5.6
Mounting of CLT panels (RISE Research Institutes of Sweden, 2019)

Assembling order

The CLT panels will be hoisted onto the existing roof surface and the second ground level above. The existing façade of the De Kroon building is considered capable of carrying the CLT panels, as the main bearing structure of De Kroon, 350 by 500 mm concrete columns, are located in the façade. So, on one side the panels are laid on the roof edge, while the other end hovers over the roof, as there is a height difference between the roof edge and the roof surface. This height difference needs to be bridged to transfer the loads to the existing concrete beams underneath the roof. On the grid of these concrete beams, small columns are installed to reach this height. On these columns, a second beam is placed to form a linear support parallel to the roof edge. See drawing 5.40

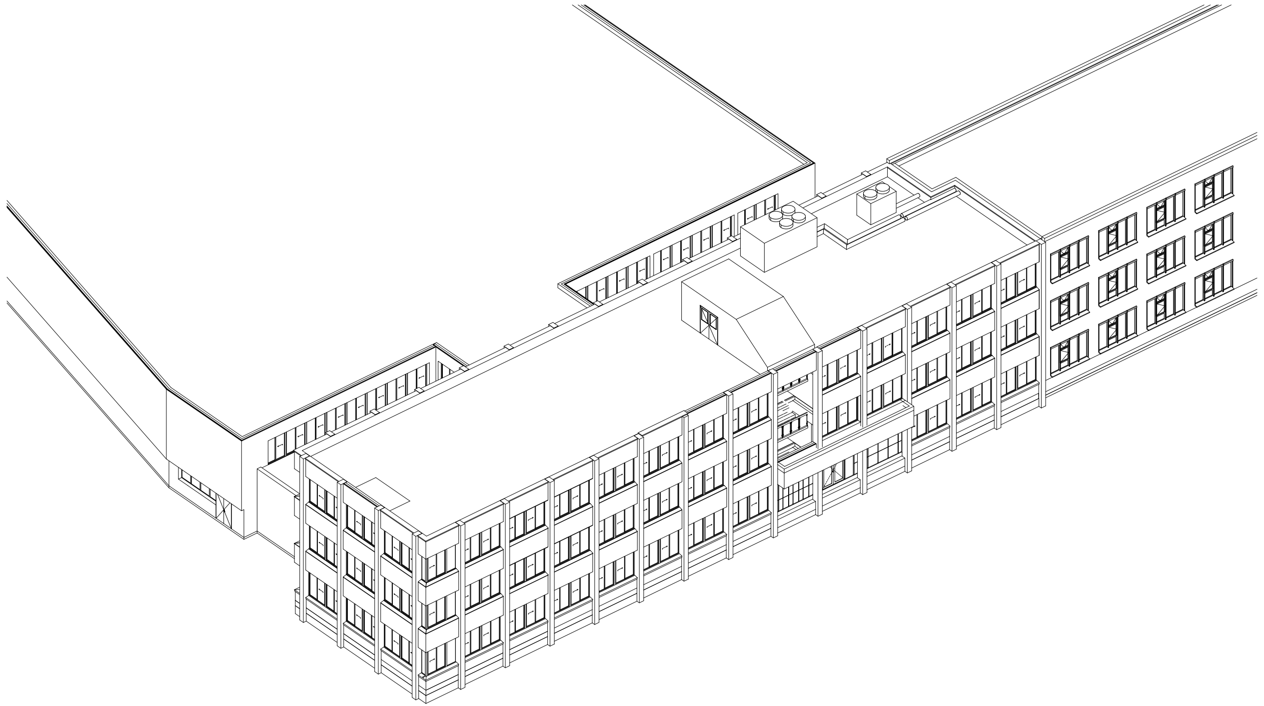
This method of adding a secondary structure on the existing grid is comparable to the technique which was applied in the Lage Land estate in Rotterdam. This social housing estate was renovated and vertically extended with two additional layers. This reference project is discussed earlier in this report.

This linear support also defines the outlines of the green areas on the roof. As this area requires sufficient depth for the earth, containing rainwater and vegetation, a slot is created with the existing roof surface as the bottom. Around this slot, the floor of the atrium and the adjacent dwellings are at a higher level.

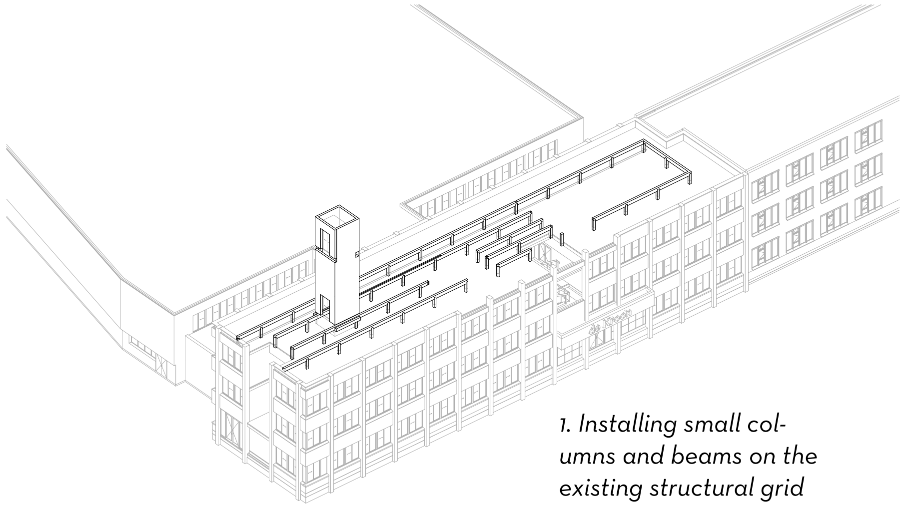
After the roof surface is prepared for the new program the new concrete structure is realized. Concrete columns are attached on top of the existing columns and concrete slabs are installed to create a second ground level for the residential program.

Then the CLT panels, which build up the dwellings, are put into place. The CLT panels will be finished with insulation layers and façade cladding. This will be elaborated on in the chapter on Materialization.

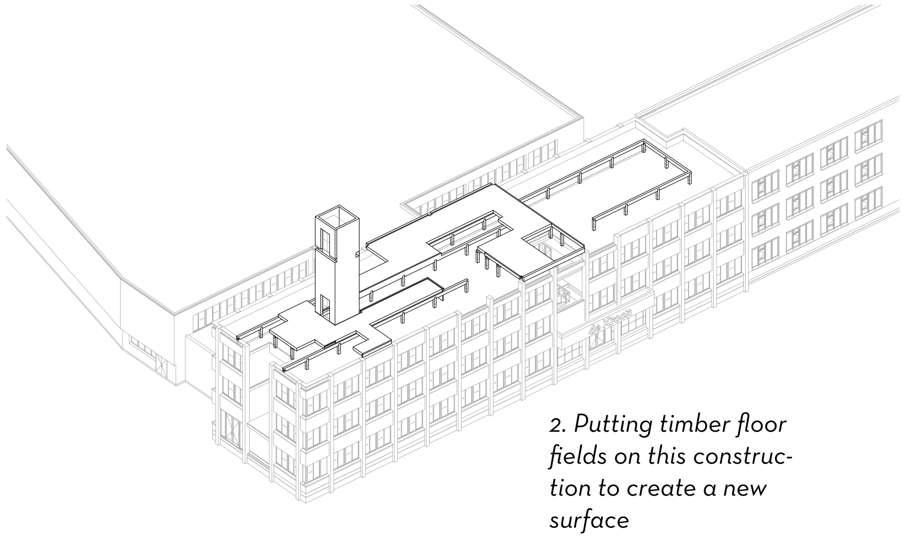
The void that remains between the concrete and timber volumes is partly cover with glass to create the central atrium. See drawing 5.40



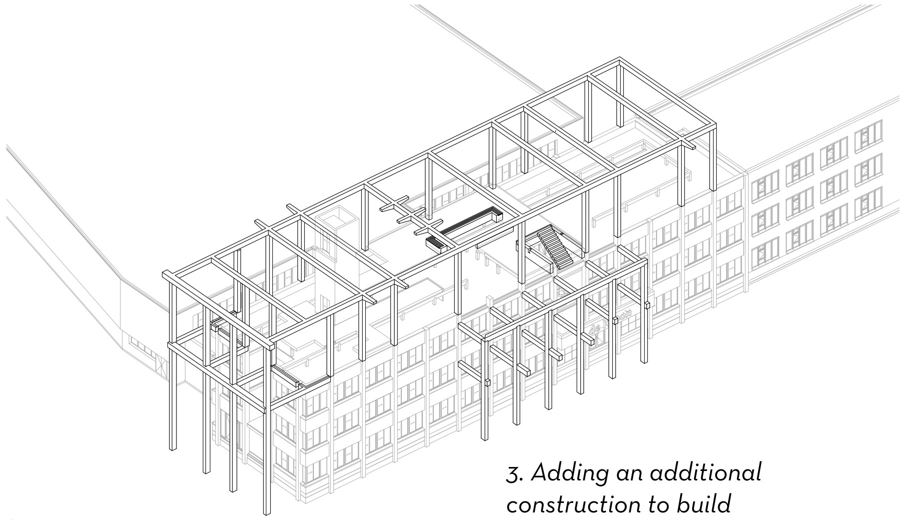
Drawing 5.39
Existing situation of
De Kroon



1. Installing small columns and beams on the existing structural grid

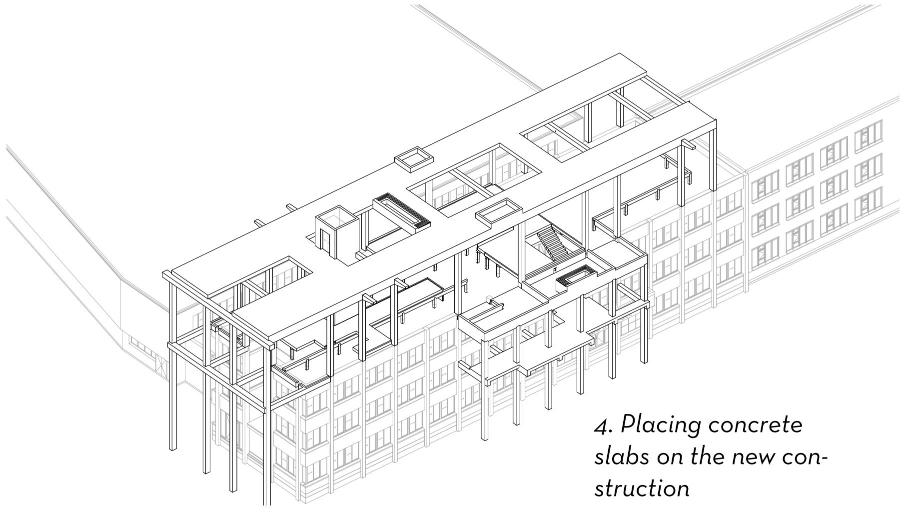


2. Putting timber floor fields on this construction to create a new surface



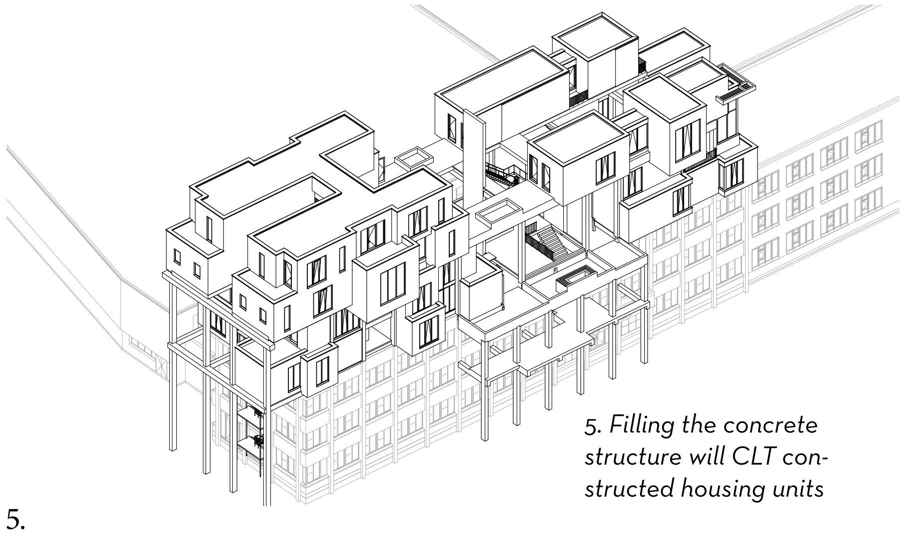
3.

3. Adding an additional construction to build a second ground level above the building



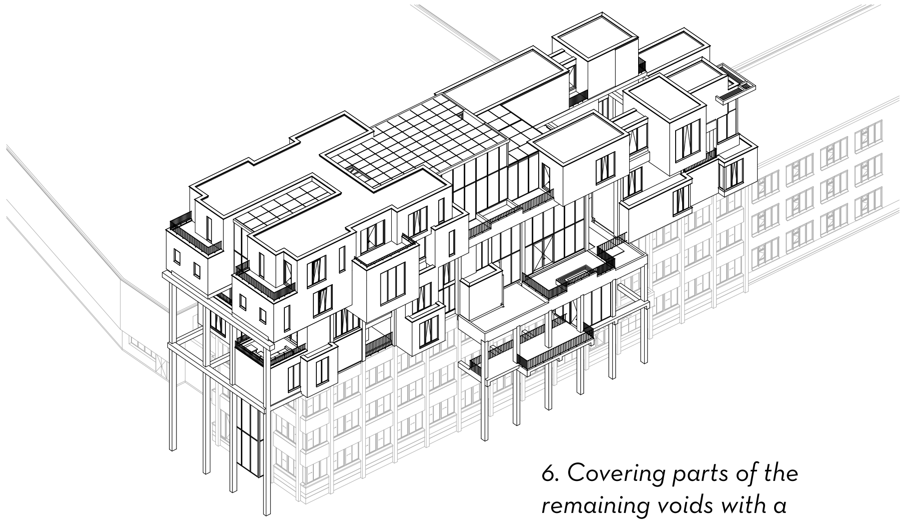
4.

4. Placing concrete slabs on the new construction



5.

5. Filling the concrete structure will CLT constructed housing units



6.

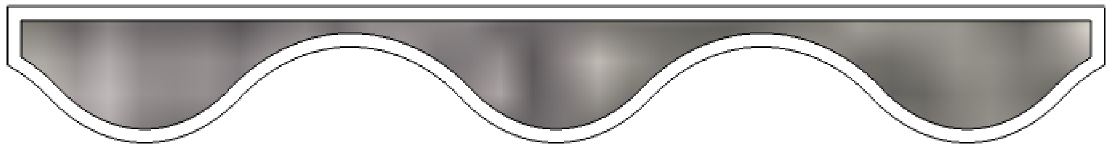
6. Covering parts of the remaining voids with a glass atrium

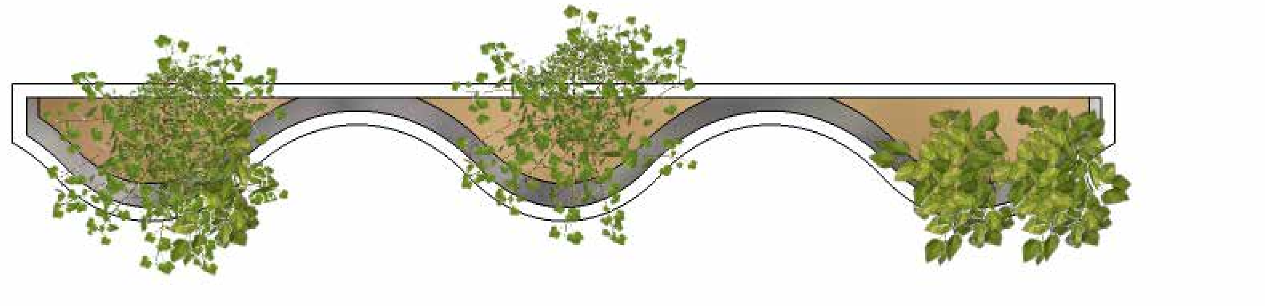
Drawing 5.40
Construction order of the primary components of the Optopping

The concrete planters in this design show a variety in size and arrangement. On the outside façade, they compose a very dynamic pattern, while in the inner courtyard a very quiet arrangement is applied, with planters of similar size ordered in a strict grid. Planters of the same size could be linked to form one body containing earth, water, and vegetation. See drawing 5.42
The exact size and number of planters should be defined before manufacturing. This custom-made approach allows for the implementation of Digital Manufacturing, as this technique allows for quick, custom-made manufacturing based on a digital model. Moreover, the 3-dimensional curved-shaped planters are a good prototype to test the CLIP technique on. Experiments, which were executed with the 3D concrete printer, show the possibility to print objects that resemble the desired shape of the planters.
At the same time, the biggest limitation CLIP has is the size of the container in which the concrete objects are printed. A large sequence of linked planters as illustrated in drawing 5.41 would require a container with clay, which is as big as this sequence. Printing smaller identical planters, which would later be positioned next to each would give the same result, but the custom-made approach is then replaced by a conventional serial production, which would not efficiently use the potential of digital manufacturing.

So, in the case of this particular design proposal, the application of CLIP offers possibilities regarding the production of freeform, custom-made geometries. At the same time the limitations which are inherently linked to CLIP, regarding the maximum size of the printed objects, make it a less suitable technique to apply for the manufacturing of custom-made, large façade elements. A more conventional, serial production chain would probably be sufficient to manufacture multiple planters, which are later linked.

Drawing 5.41
Render of the desired geometry and arrangement of the concrete planters





Drawing 5.42
Top view of the planters with and without vegetation

MATERIALIZATION AND DETAILING

The CLT construction is clad with timber to match the natural atmosphere that is created in this design. The Crystal Court by Tangram Architekten shows how the combination of timber with glass and greenery results in a very light and pleasant living environment. Tangram used Western red cedar timber planks for their facades as this wood has a very warm red/brown color. Moreover, when treated well, this wood provides a very durable façade cladding.

Drawing 5.43 shows the composition of the CLT panels finished with in-sulation and the timber cladding. When installing the CLT panels and finishing them, attention should be paid to the concrete structure that penetrates the residential layers of the Optopping. The CLT panels are placed in between the columns. For the structural performance of the CLT panels, it is of great importance that the panels remain one structural whole, without intersection by any other constructions. So, the concrete and CLT construction need to function next to each other. The CLT panels are positioned at a small distance from the columns to allow for insulation between the two. Insulation also plays a role when detailing the interface between the existing building and the new Optopping. This detailing will be discussed later in this chap-ter.

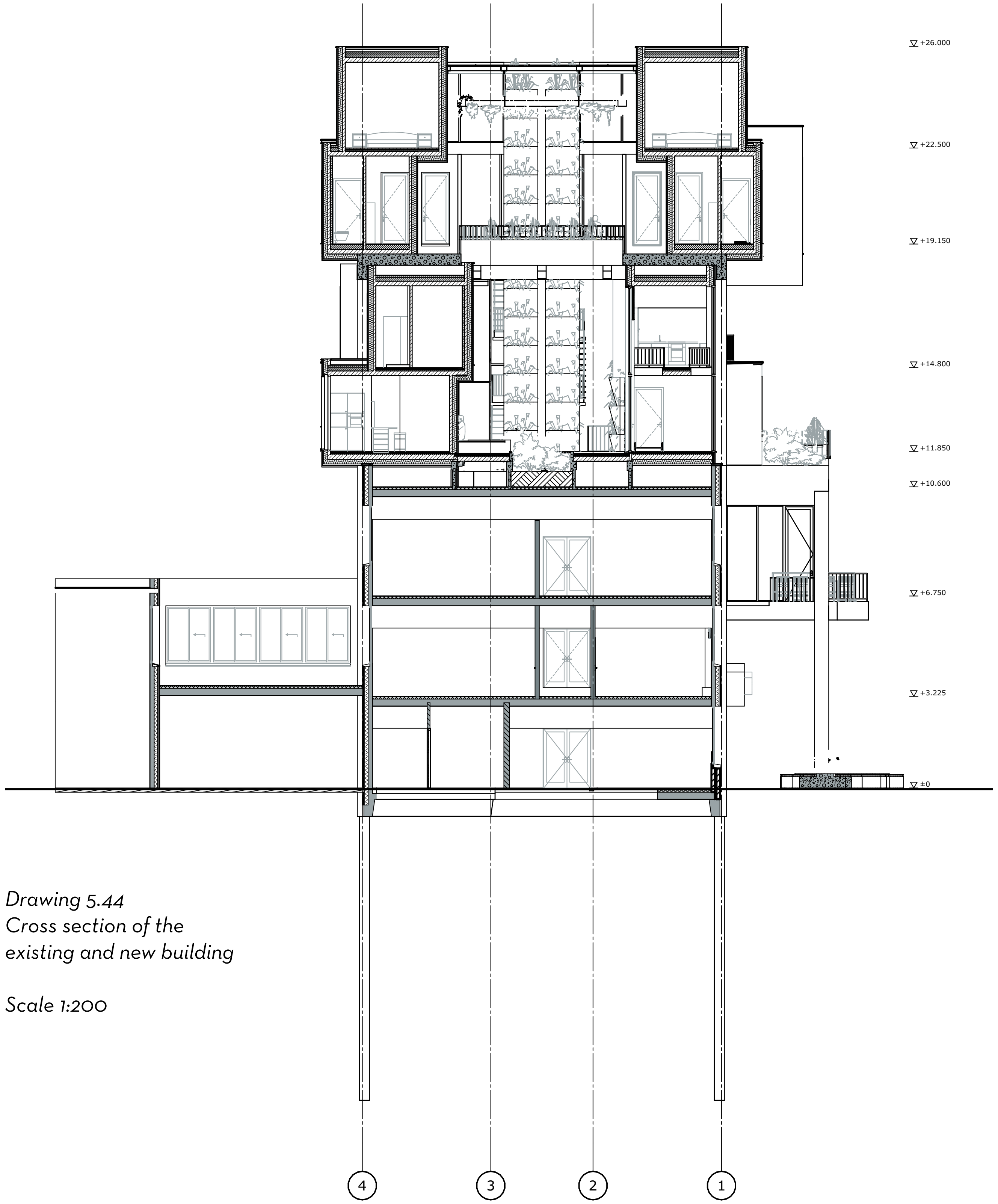
Drawing 5.43
Axonometric section of the existing facade and dwellings resting on it

Several sections of the design are selected for further elaboration in terms of materialization and detailing.
One of the most important themes in this project is the symbiosis between the existing and the new. So, the interface of the two requires attention.

Furthermore, two Optop strategies, the Symbiotic and Floating model, appear in this report multiple times as important design principles. The implications of these principles will be highlighted as well.

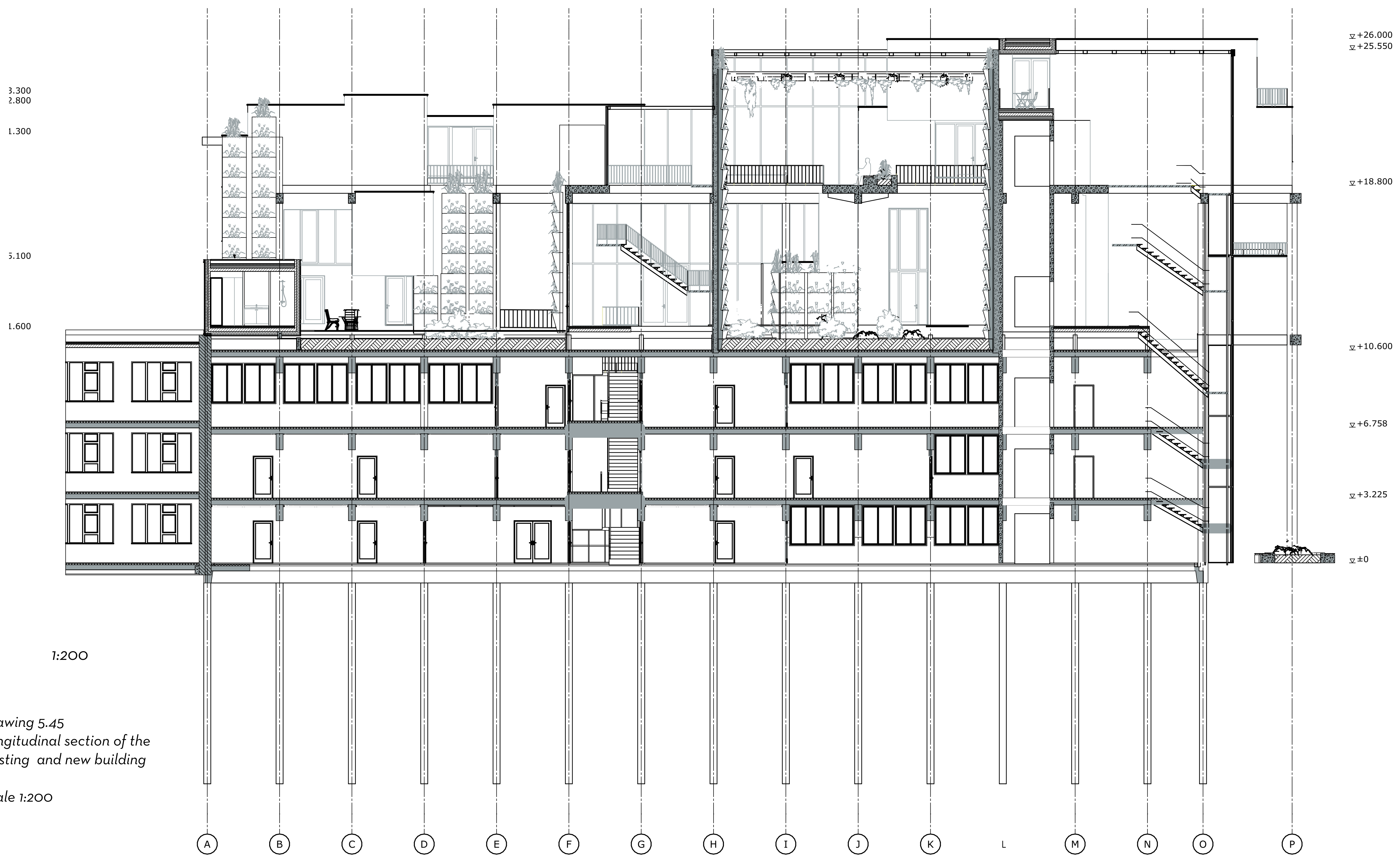
Also, this design features a very dynamic composition, with many volumes cantilevering over the façade. These overhangs create a technical challenge and will be discussed in this chapter.

Lastly, much attention is being paid to the ecological aspects of this design. This topic will be further elaborated on in combination with the Concrete Liquid Injection Printing (CLIP) technique, which has been discussed earlier in this report.



Drawing 5.44
Cross section of the existing and new building

Scale 1:200



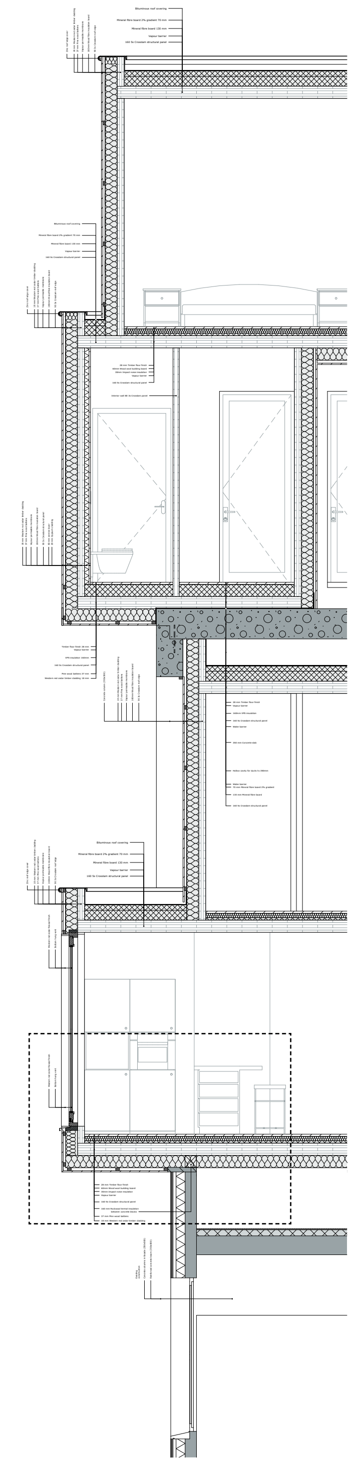
Drawing 5.45
Longitudinal section of the existing and new building

Scale 1:200

At the interface of the existing building and the new Optopping special attention is paid to the insulation. For this, a quite conventional solution is applied to reduce thermal bridges between the concrete roof edge and the CLT panels.
When detailing the connection between concrete floors and the foundation at ground level, an interruption in the insulation is necessary to allow for placing the slab onto the foundation. Insulation blocks are often applied which run through the connection between the slab and the foundation. In this way, the thermal layer of the construction largely continued over the foundation and the floor.
This principle is also applied in the connection between the roof edge and the CLT panels. The CLT panels are carried by concrete blocks which are placed on top of the roof edge. Between those blocks, the insulation layer is continued over the entire CLT floor. See drawing 5.46. The bottom of the CLT floor panels, which hang over the existing façade is clad with Western red cedar timber, similar to the façade cladding.
The facades of the housing units contain bottom hung vents, which provide a safe possibility to ventilate the rooms. Bottom hung vents are applied as the façade openings run from floor to ceiling without a parapet. Conventional casement windows are therefore not allowed as people could fall out. The flat roofs of the housing volumes are covered with bituminous layers.

At the second ground level, CLT panels are placed directly on top of the concrete slabs. To reduce the height difference between the concrete slabs and the interior floors of the adjacent dwellings, no extra construction or spaces are designed between the CLT panels and the concrete slabs. A waterproof barrier prevents water from reaching the CLT panels. Floor insulation is applied on top of the CLT floor panels.
For the spaces below the concrete slabs, a CLT ceiling is installed. This ceiling is fully insulated and in this way functions as a flat roof. Between this flat roof and the concrete slabs, an empty space for ducts and other infrastructure remains. See drawing 5.47

Piping in other parts of the residential program is facilitated with service layers that are installed against the CLT walls. Spaces for sockets and other smaller infrastructure can be premanufactured using CNC milling but larger pipelines must be incorporated in the walls using this service layer. In other parts of the indoor spaces, the CLT is left unexposed to show the building system and materials which are applied.



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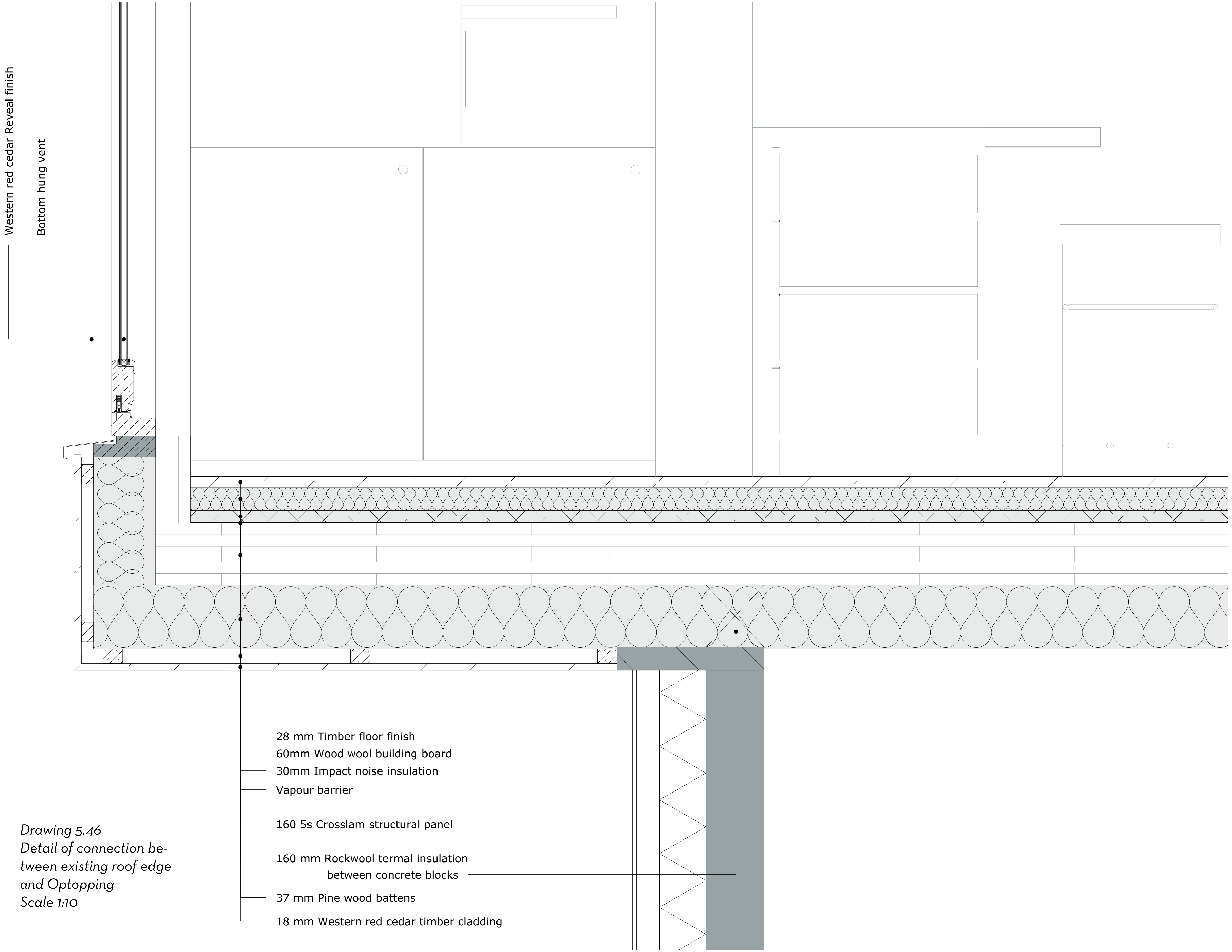
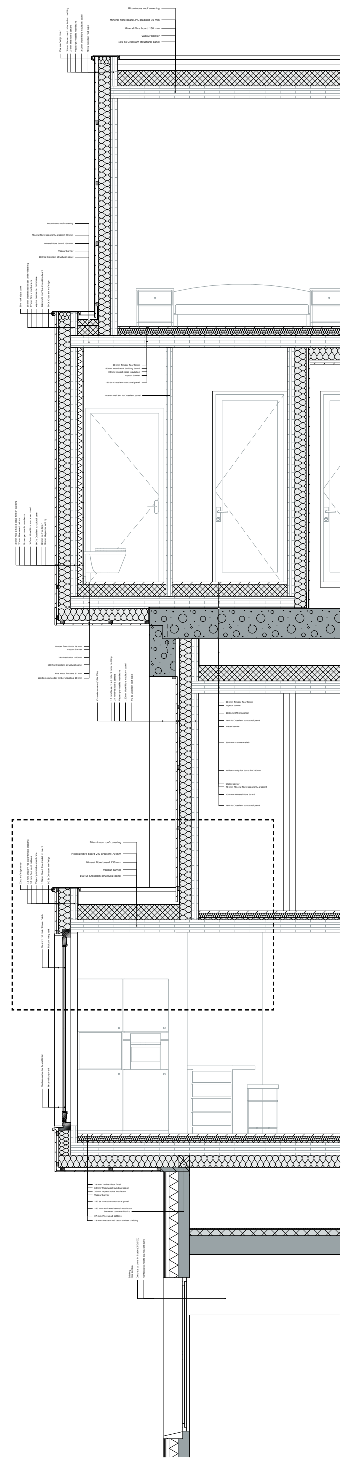


Drawing 5.46
Detail of connection between existing roof edge and Optopping
Scale 1:10



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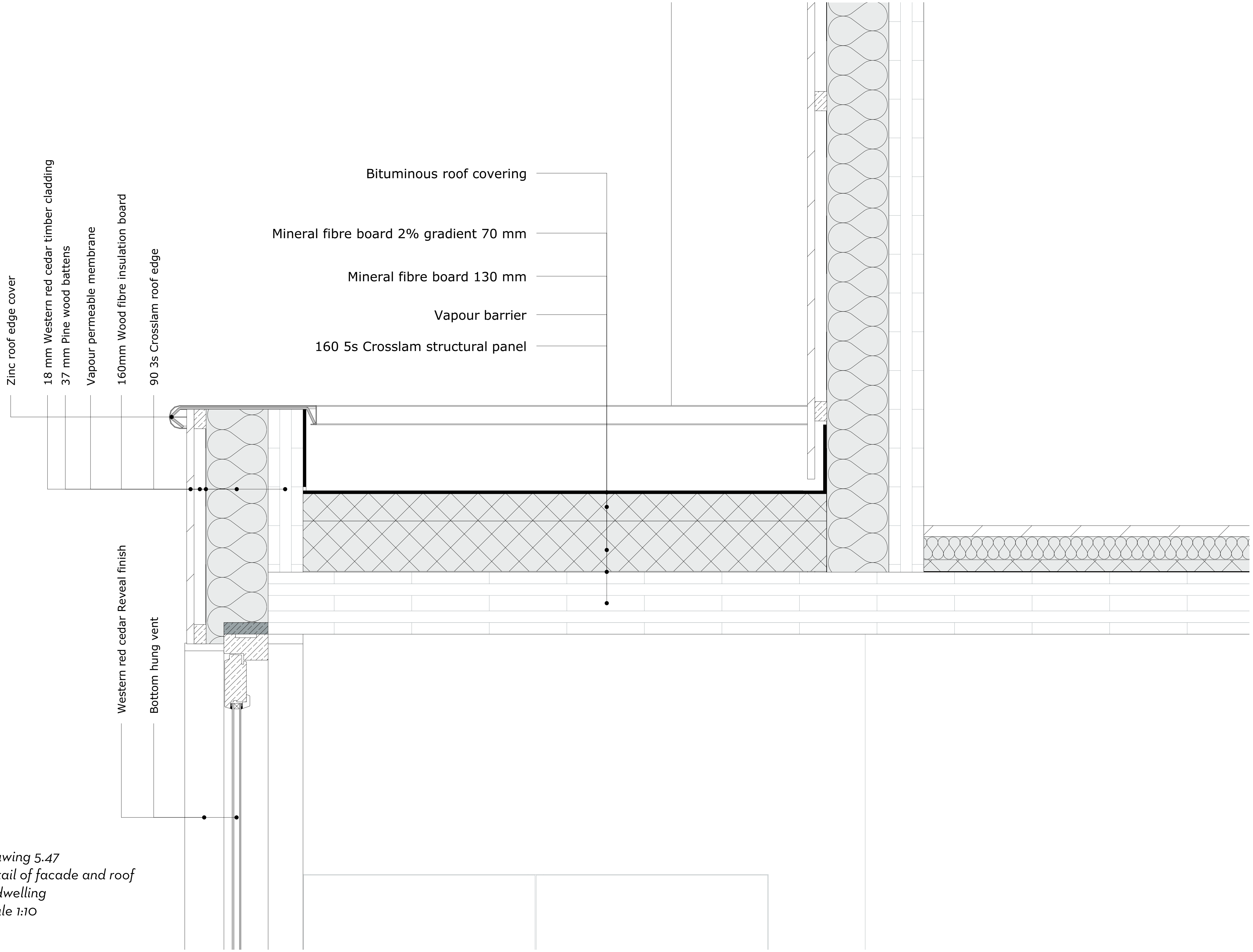
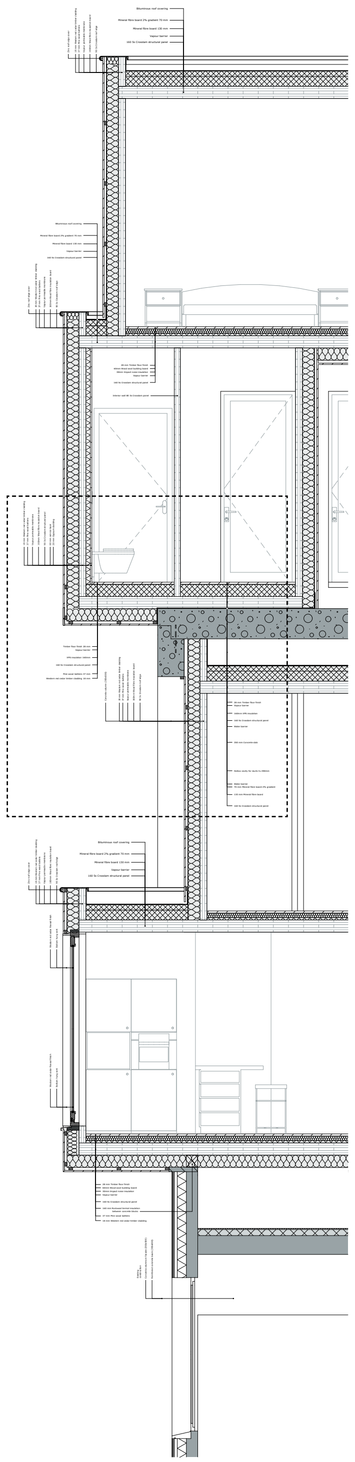


Drawing 5.47
Detail of facade and roof
of dwelling
Scale 1:10



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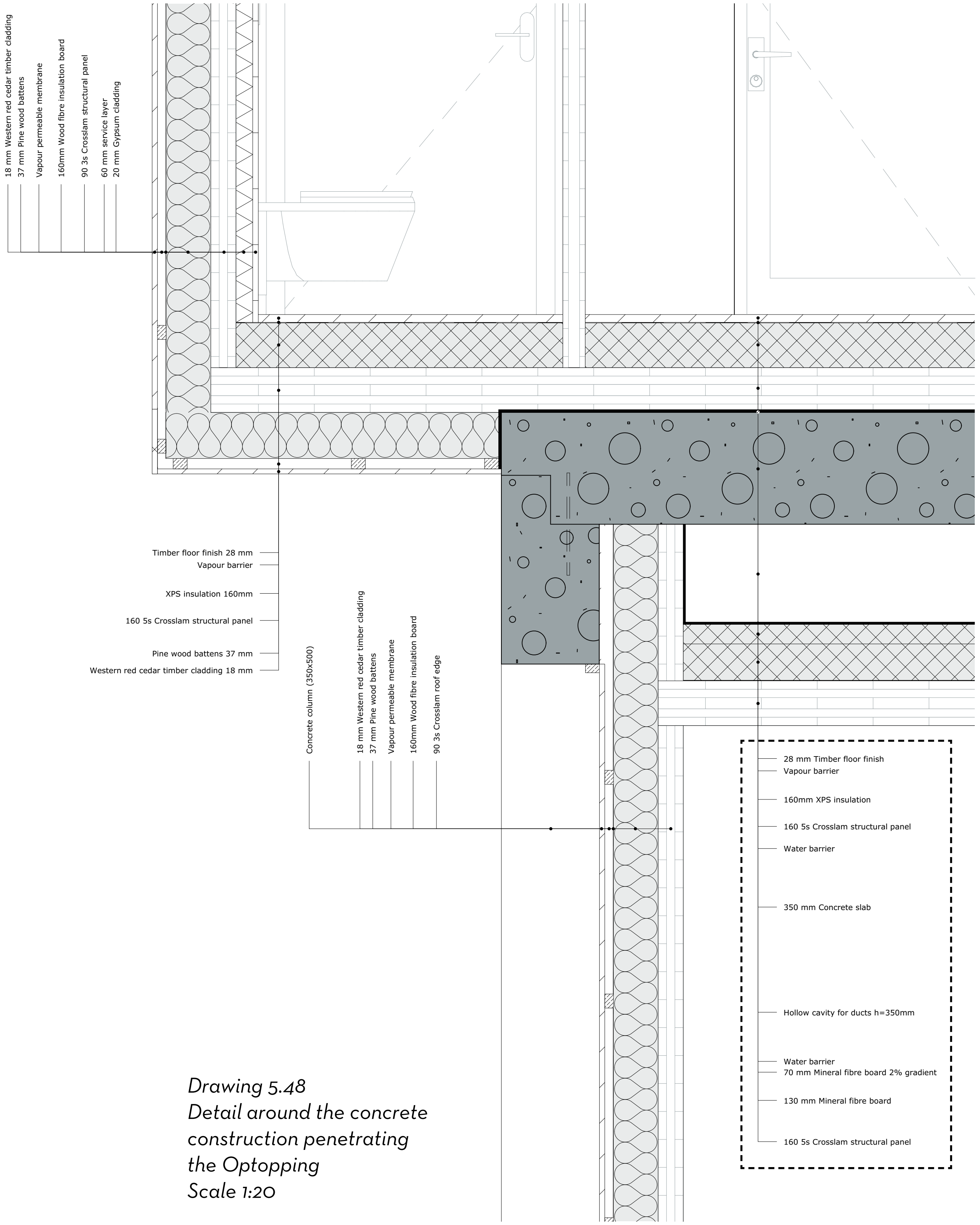


Drawing 5.48
Detail around the concrete construction penetrating the Optopping
Scale 1:20

28 mm Timber floor finish
Vapour barrier

160mm XPS insulation

160 5s Crosslam structural panel

Water barrier

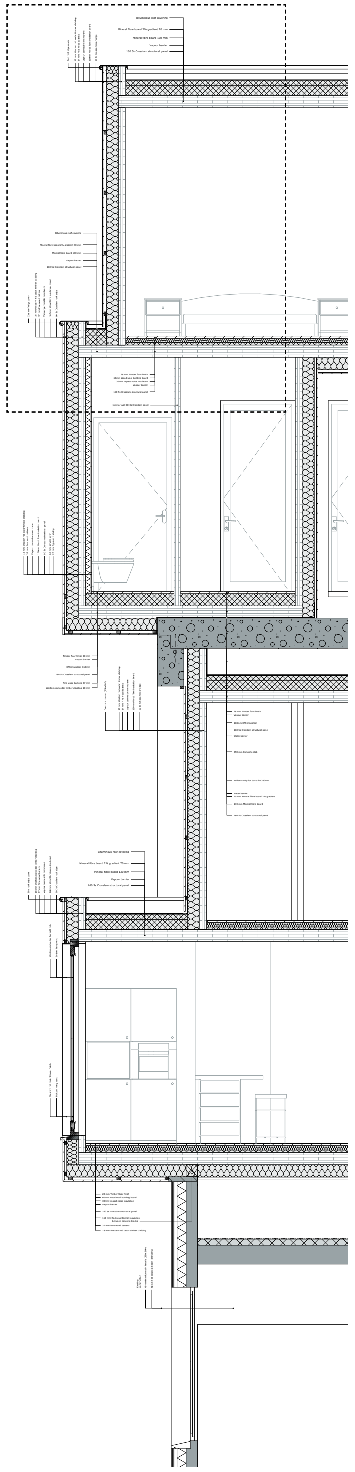
350 mm Concrete slab

Hollow cavity for ducts h=350mm

Water barrier
70 mm Mineral fibre board 2% gradient

130 mm Mineral fibre board

160 5s Crosslam structural panel



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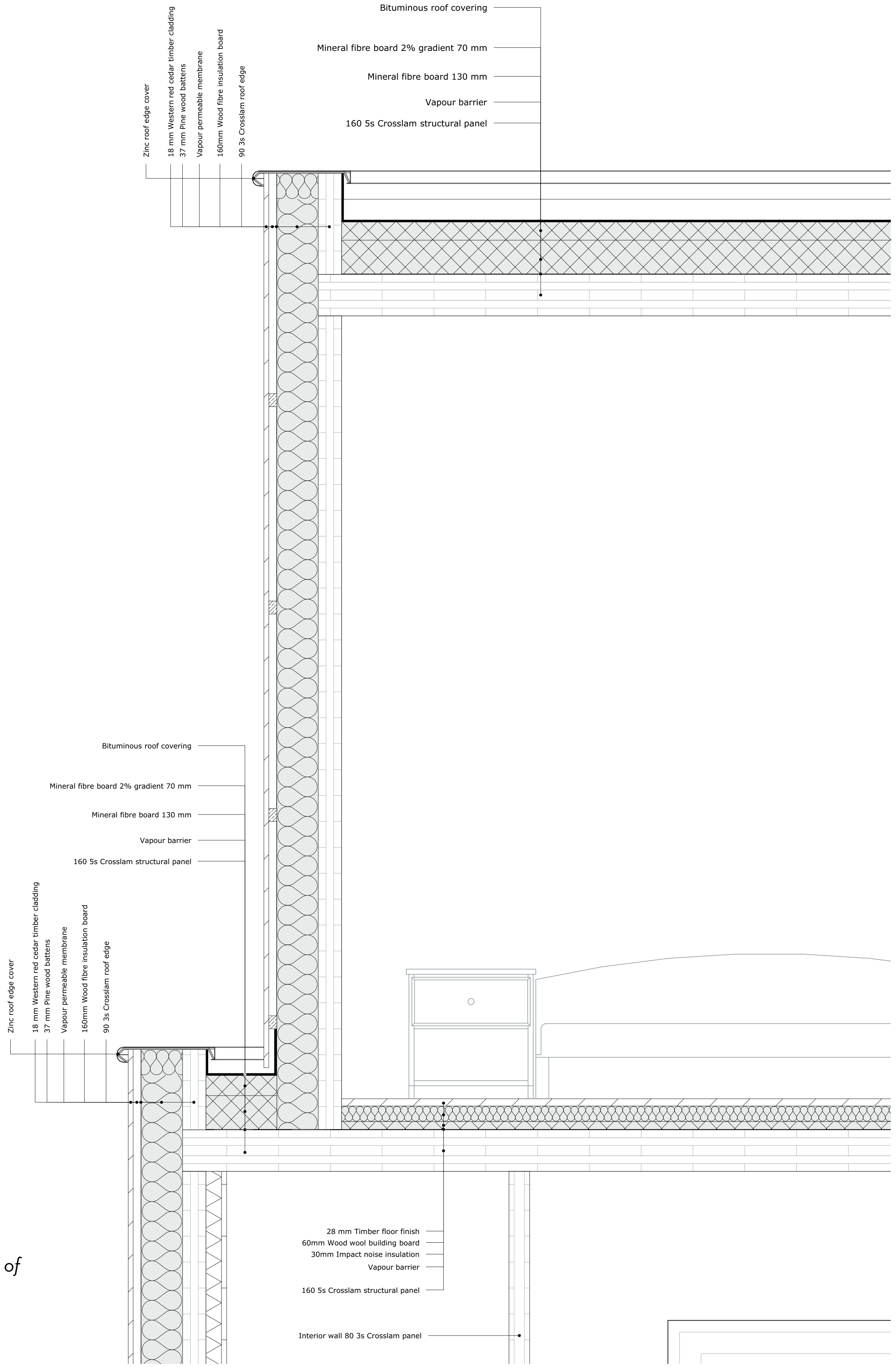


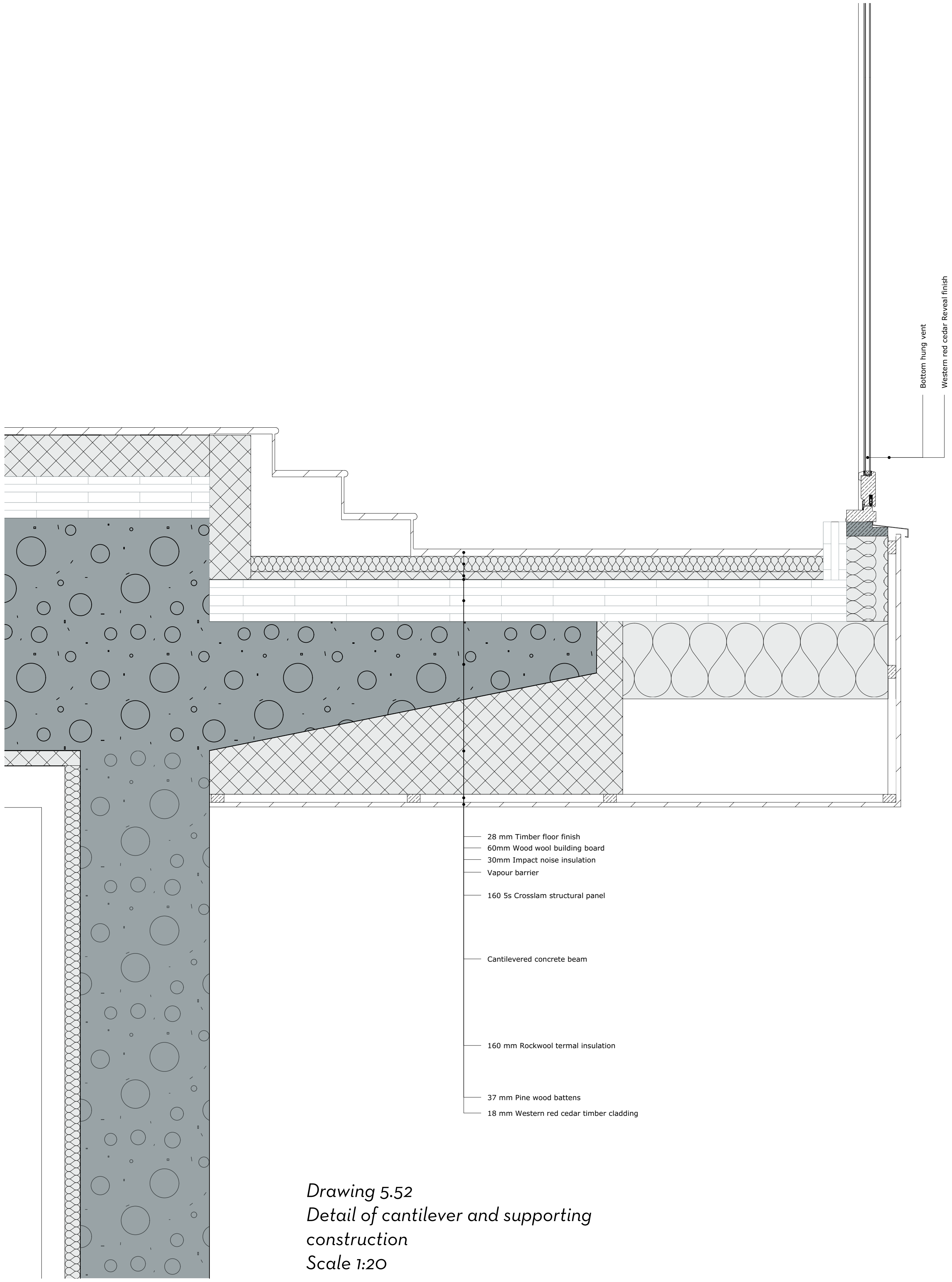
Drawing 5.49
Detail of the top end of
the Optopping
Scale 1:20

Drawing 5.50
Interior impression of the CLT panels as a defining element in the interior atmosphere

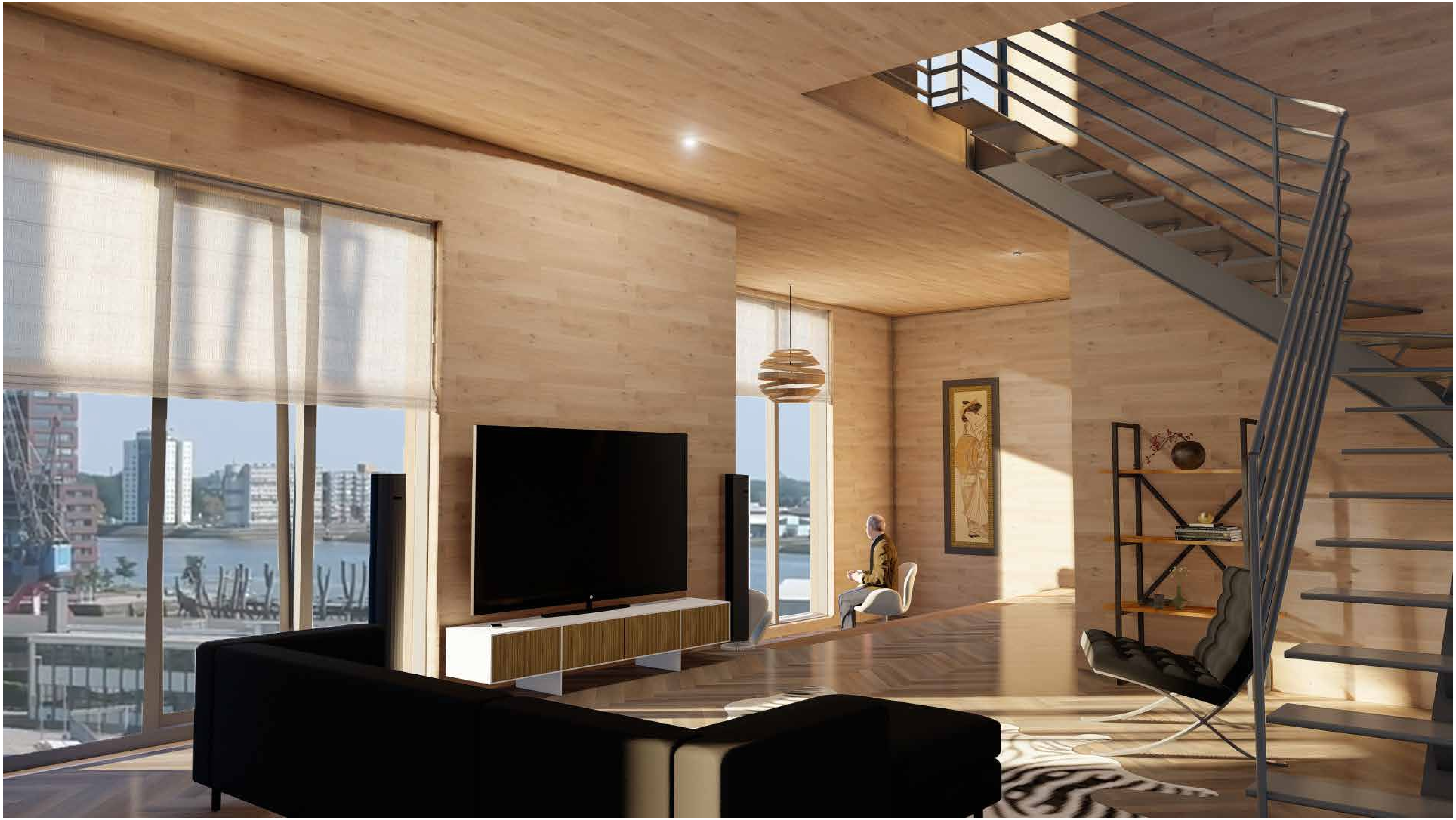
The design proposal for this Optopping features a lot of different volumes, which to a certain extend cantilever over the roof edge. In some sections of the Optopping, the decision was made not to only cantilever parts of the spaces, but also to make height differences in floor levels. Drawing 5.51 shows a section in which such a spatial effect is applied. By cantilevering the space outside the building and also apply-ing some steps, the users of the space can experience walking down the building into the city. By lowering the floor, the net ceiling height increases, which provides an even more generous space. When adding a large window from floor to ceiling a great panorama over the city is provided.

However, as mentioned before, for the structural performance of the CLT panels it is important to continue the panels as one whole beyond the roof edge. When making a height difference in the floor, the CLT floor panel is discontinued in the overhang, and therefore it is not structural anymore. An additional construction is needed to carry the volume hanging over the roof edge. For this, the concrete structure is used. The concrete beams, which carry the second ground level, are extended outwards. A separate CLT panel is placed on top of this cantilevering beam. This allows for building a separate volume hovering above street level.

Drawing 5.51
Axonometric section of one of the cantilevers the design features



Drawing 5.52
Detail of cantilever and supporting construction
Scale 1:20



Drawing 5.53
Interior impression with the view over the surroundings featuring the harbor area and urban skyline
Large floor to ceiling windows facilitate the views and lowering the floorlevels certain places, allows for even higher windows and a more spectacular view

A more extreme overhang is designed on the south side of the Optopping. To allow for more interior space one volume was extended, resulting in a quite long cantilever of 3,5 meters. Contrary to the other overhangs, which were discussed previously, no concrete construction is present here to provide extra support. The overhanging volume should be stiff enough from itself to span the 3,5-meter distance. See drawing 5.54

The span table in figure 5.7 gives a rough estimation for the required thickness of the floors in order to be stiff enough to cantilever 3,5 meters. When calculating with cantilevers, so spans with only one support, the span distance should be doubled. So, in this case, the span distance is 7 meters. As the cantilevering CLT floor panel continues as one structural whole inside the building, it is considered a double span beam roof with a support point in the middle of the panel. (Mayr-Melnhof Holz, 2013)
According to the table in figure 5.7, for a span width of 7 meters, a 220 7ss CLT panel is at least required. This means a 7 layered CLT panel with a total thickness of 220 mm. For now, the thinnest possible floor panel is applied to reduce the weight and the loads for the under-neath constructions.
The structural scheme for this section of the design has not been thoroughly elaborated at this point. Further detailing of this section would require attention for the underneath constructions, as the loads from the cantilevered volume will be concentrated on a relatively small part of the construction. Additional support and foundation are expected to be necessary when technically elaborating on this section.

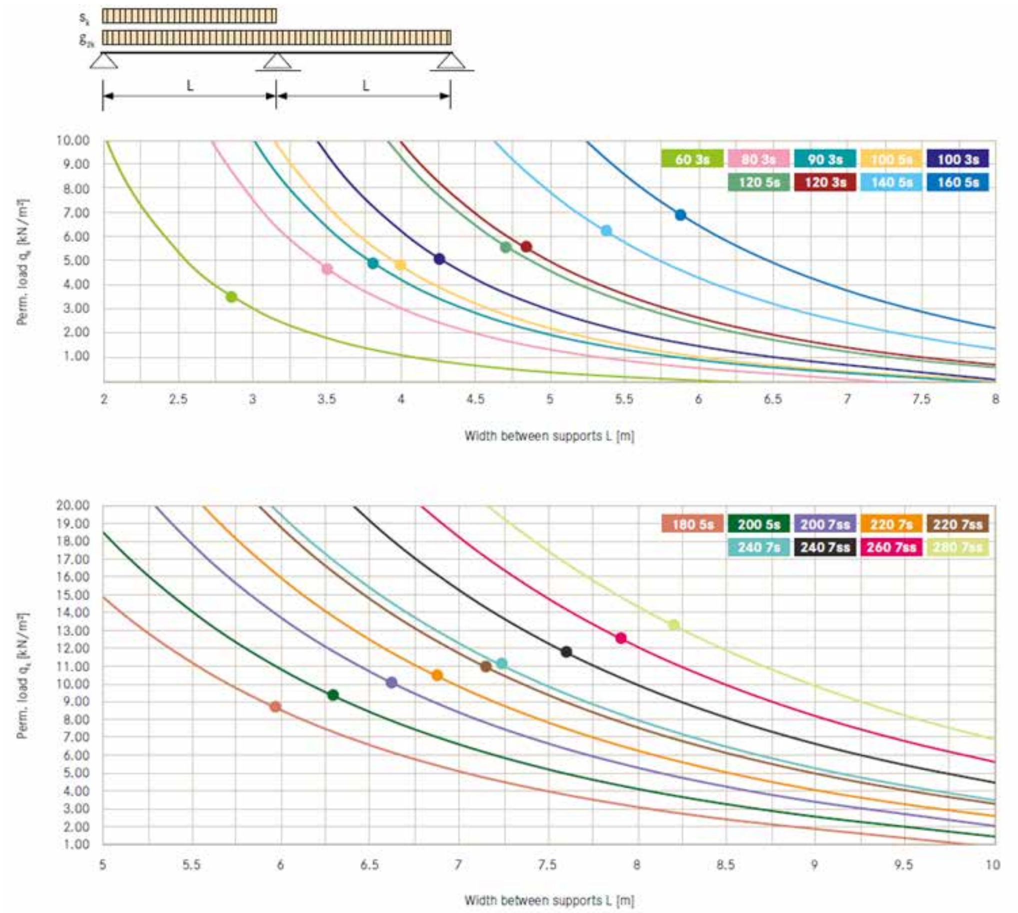
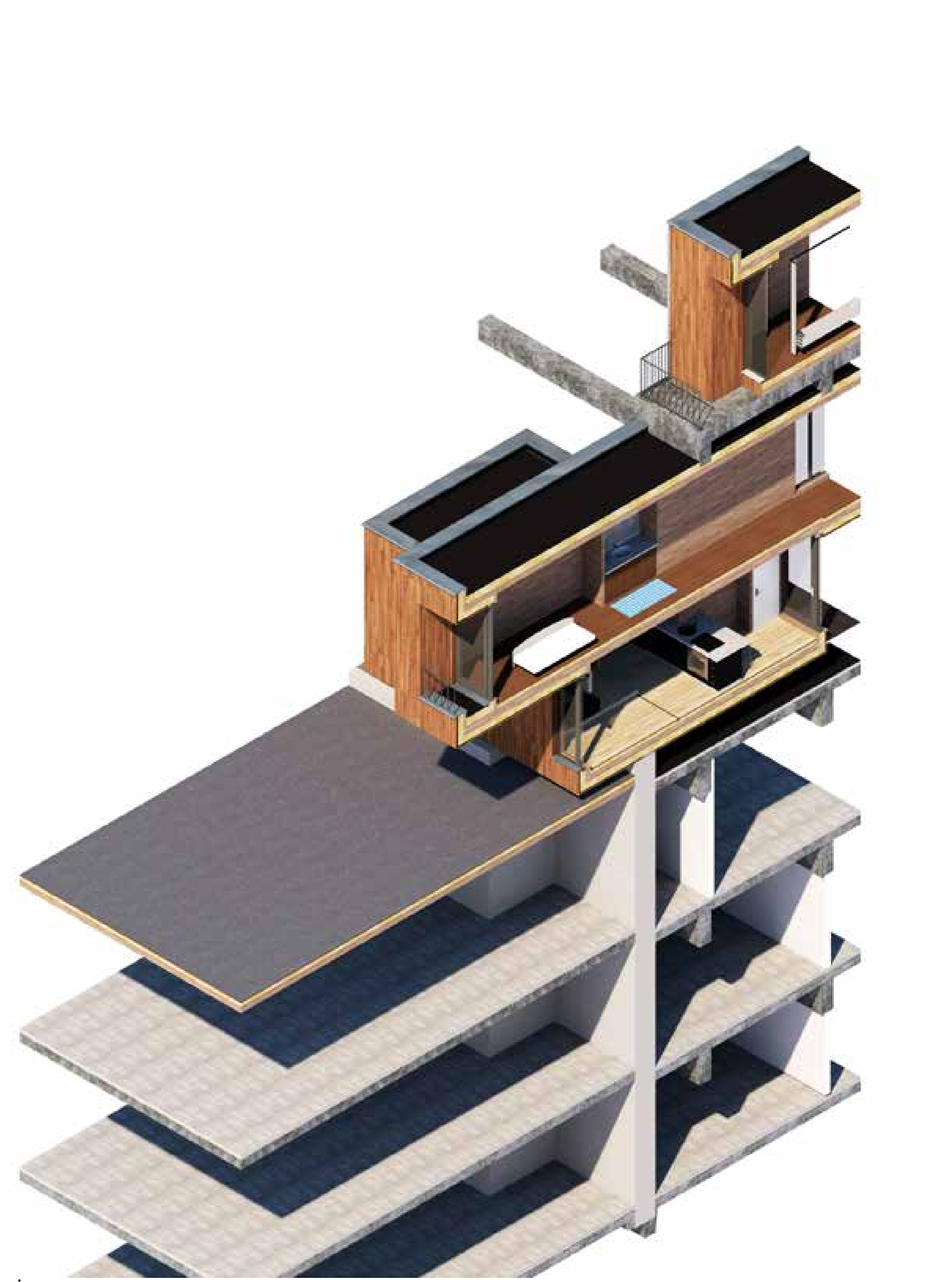


Figure 5.7
Span table for CLT panels
(Mayr-Melnhof Holz, 2013)



Drawing 5.54
Axonometric section of a relatively extreme cantilever, hovering over the neighboring building

Drawing 5.55
Axonometric section of a relatively extreme cantilever, hovering over the neighboring building

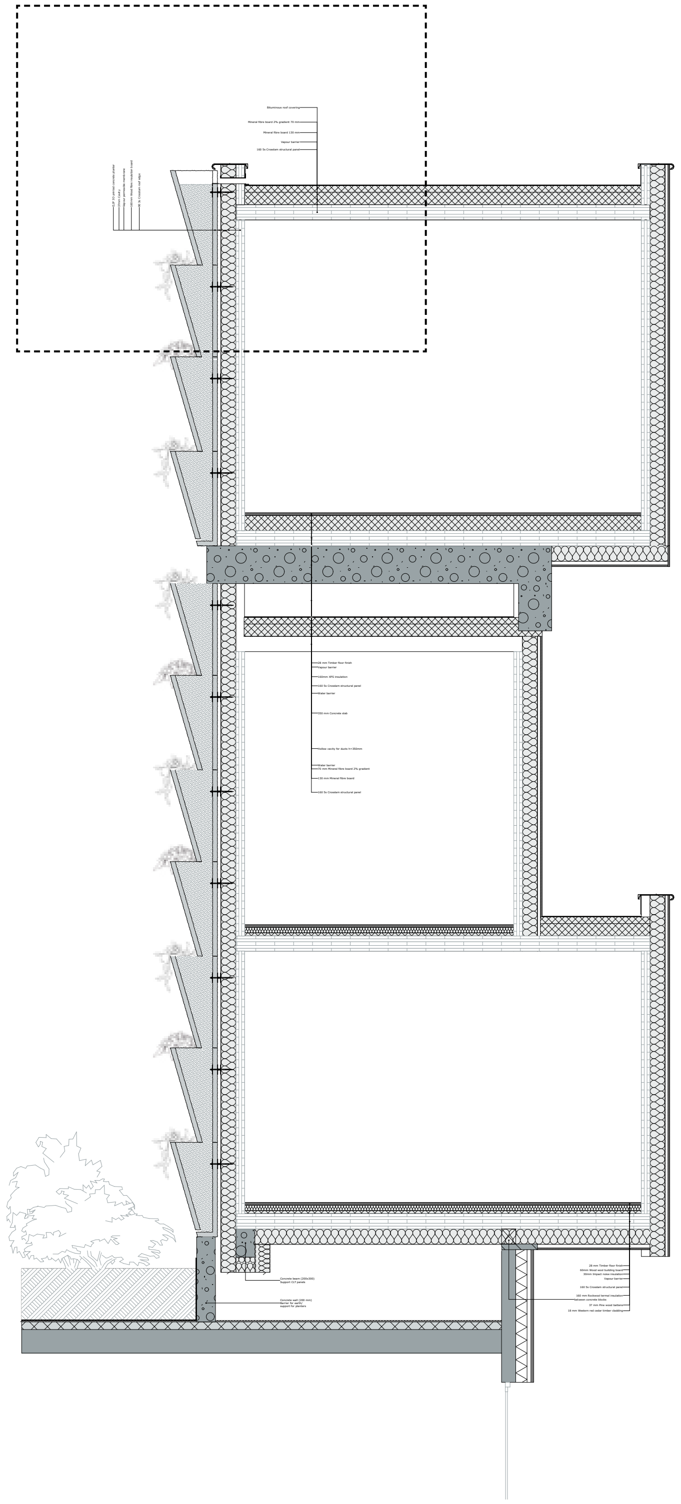
The implementation of ecological networks and digital manufacturing in the way the built environment is planned and built is one of the central themes in this Graduation project. The ecological rainwater drainage system which is proposed in this design consists of green facades that run along the vertical surfaces of the building. This green façade appears to be a very suitable architectural element to examine the possibilities of digital manufacturing. More specifically, Concrete Liquid Injection Printing (CLIP) is the technique that is selected to explore the possibilities of digital manufacturing for the production of architecture.

As discussed earlier in this report, CLIP is based on 3D concrete extrusion printing inside a liquid, which functions as a support for the concrete. In contrast to conventional extrusion-based printing, CLIP potentially gives the possibility to print 3D freeform geometries which are not manufacturable using conventional techniques. Moreover, as discussed in the chapter on Digital Manufacturing, an automated manufacturing chain as an alternative to manual manufacturing, provides a quicker, more efficient, more reliable, and cheaper procedure.
At the same time, in this report it is concluded that CLIP has some important limitations regarding the scalability of the desired objects. For large-scale, custom-made objects a different technique would be more sufficient.
Nevertheless, experiments with CLIP showed that it is possible to produce the desired shape on a smaller scale.

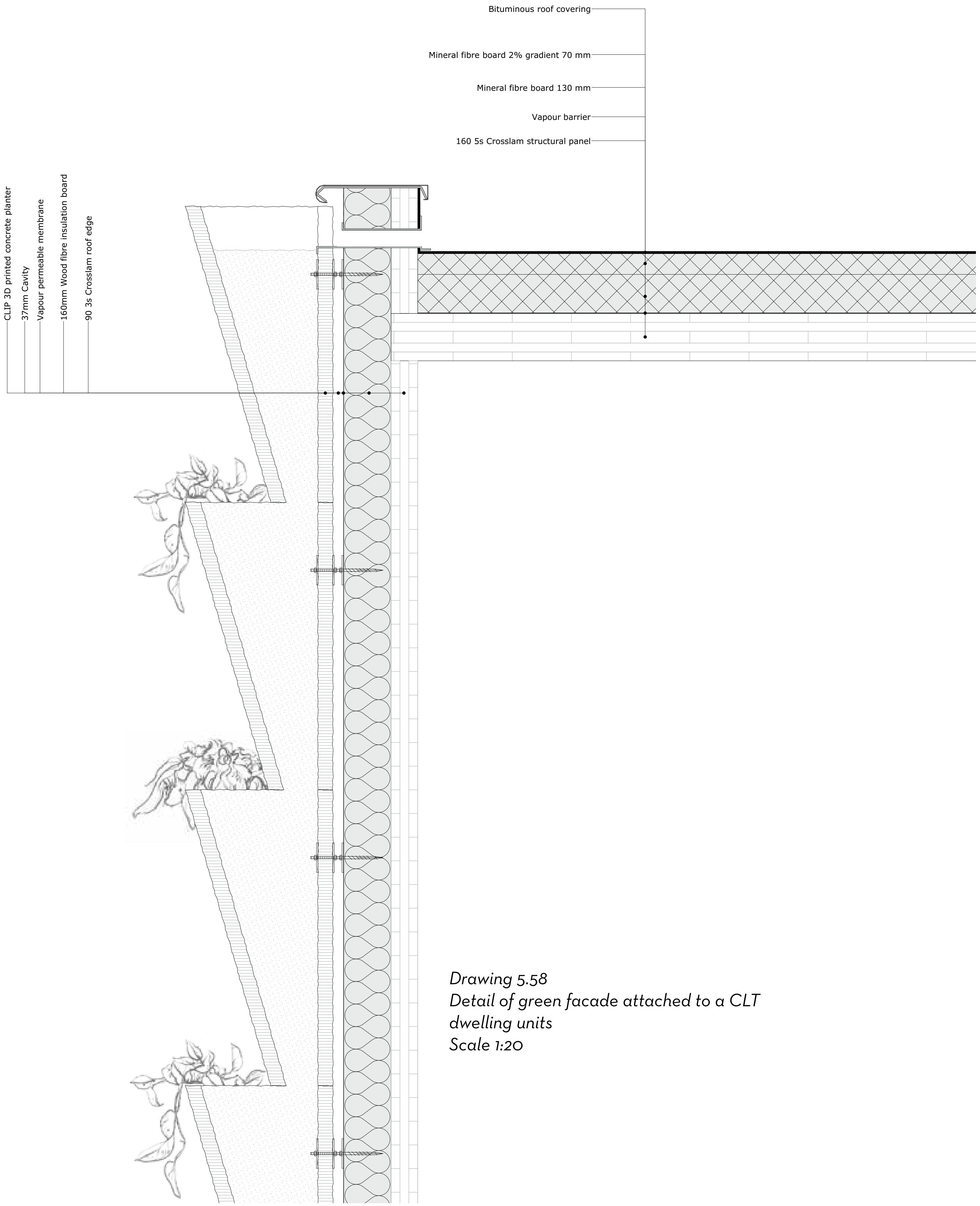
The concrete planters will be arranged over the facades of the Optopping. In the research on CLIP, a back construction is developed, which is based on the stacking of concrete façade elements. Similar to a brickwork façade the individual elements rest on each other and are linked to a secondary construction, which provides stability.

For large parts of this design, a CLT construction is applied, which could function well as a back construction for the concrete planters. Drawing 5.56 shows a section of the design in which the concrete planters are applied as façade elements.
A total of 11 layers of planters are stacked on top of each other. The concrete structure, which carries the upper residential layers forms an intermediate support. So, seven layers of planters are stacked on top of the roof surface, four additional layers rest on the second ground level.
All planters are connected to the CLT construction behind the façade to allow for stability.

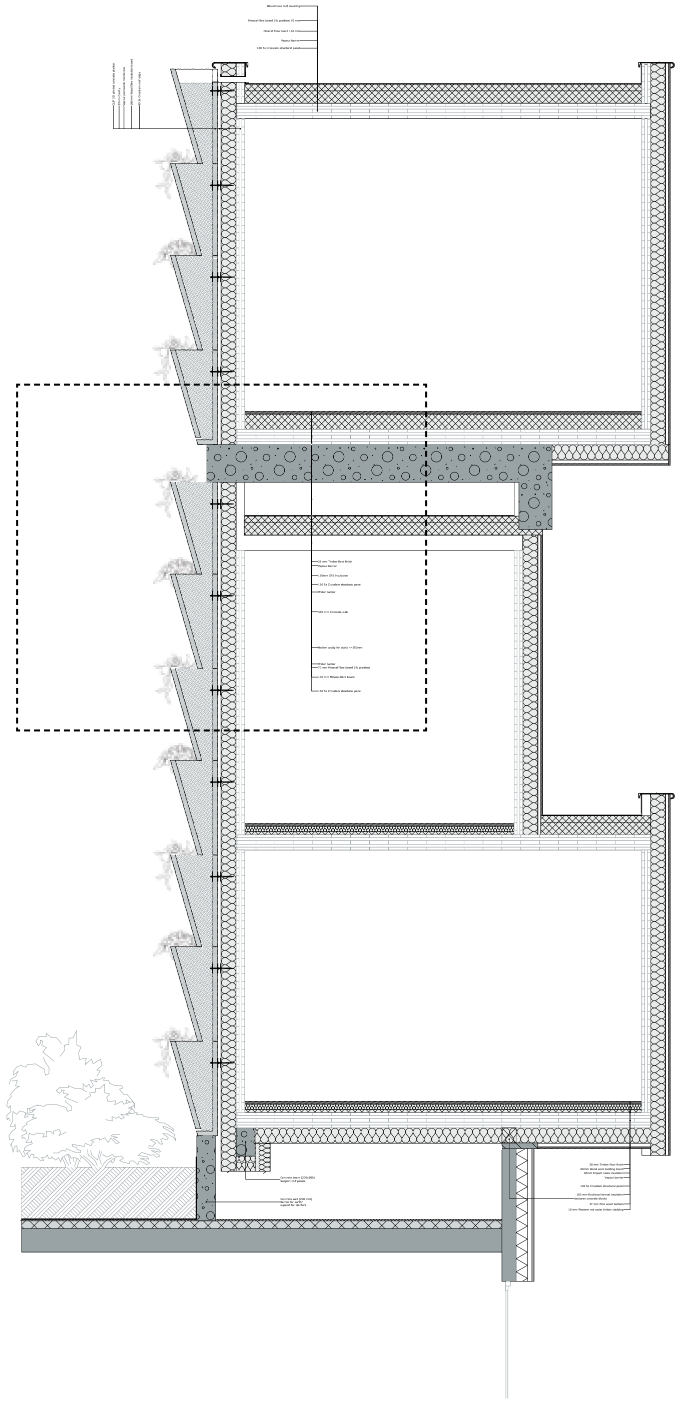
Drawing 5.56
Axonometric section over a green facade attached to a CLT dwelling units



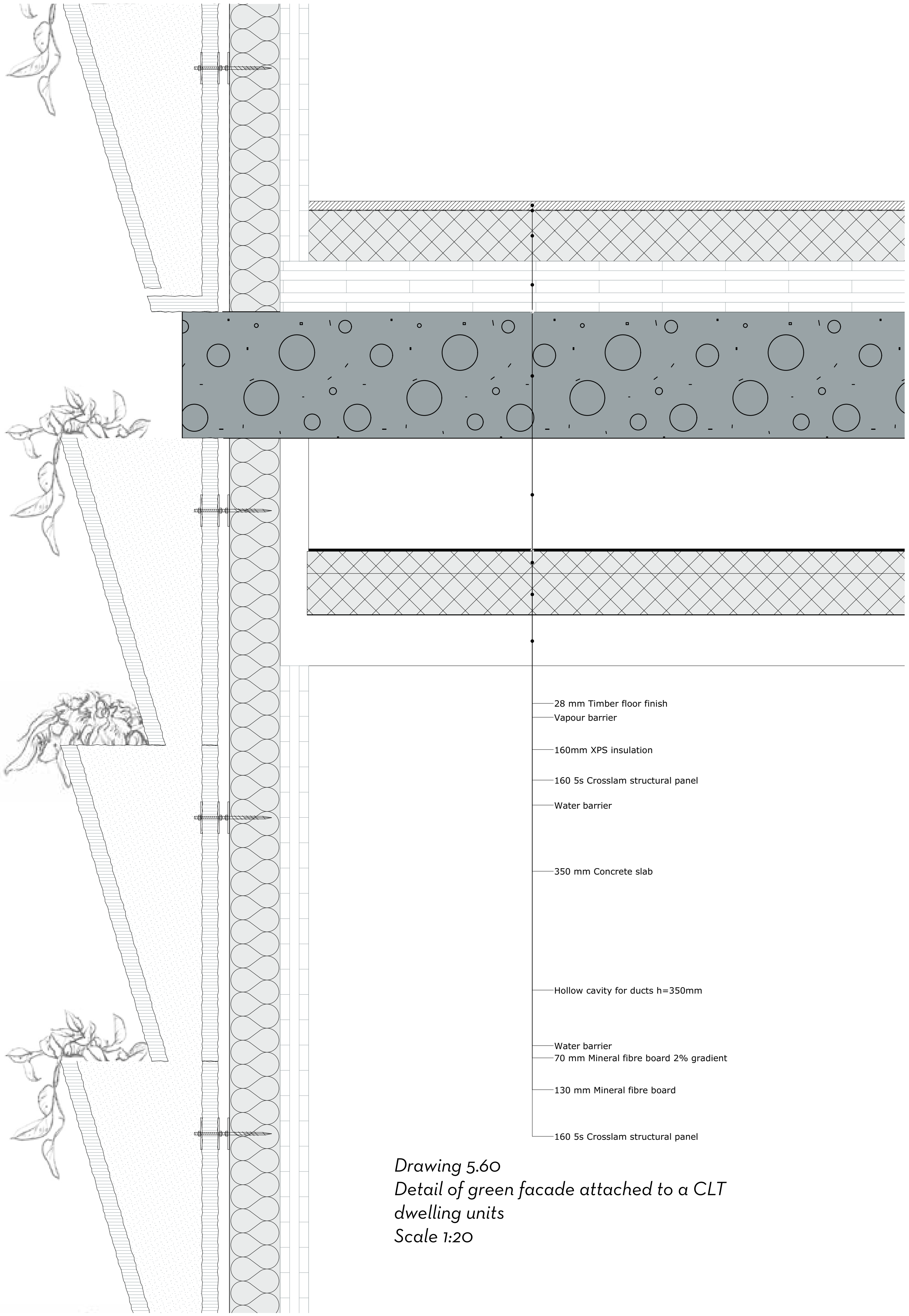
Drawing 5.57
Section over a green facade attached to a CLT dwelling units
Scale 1:100



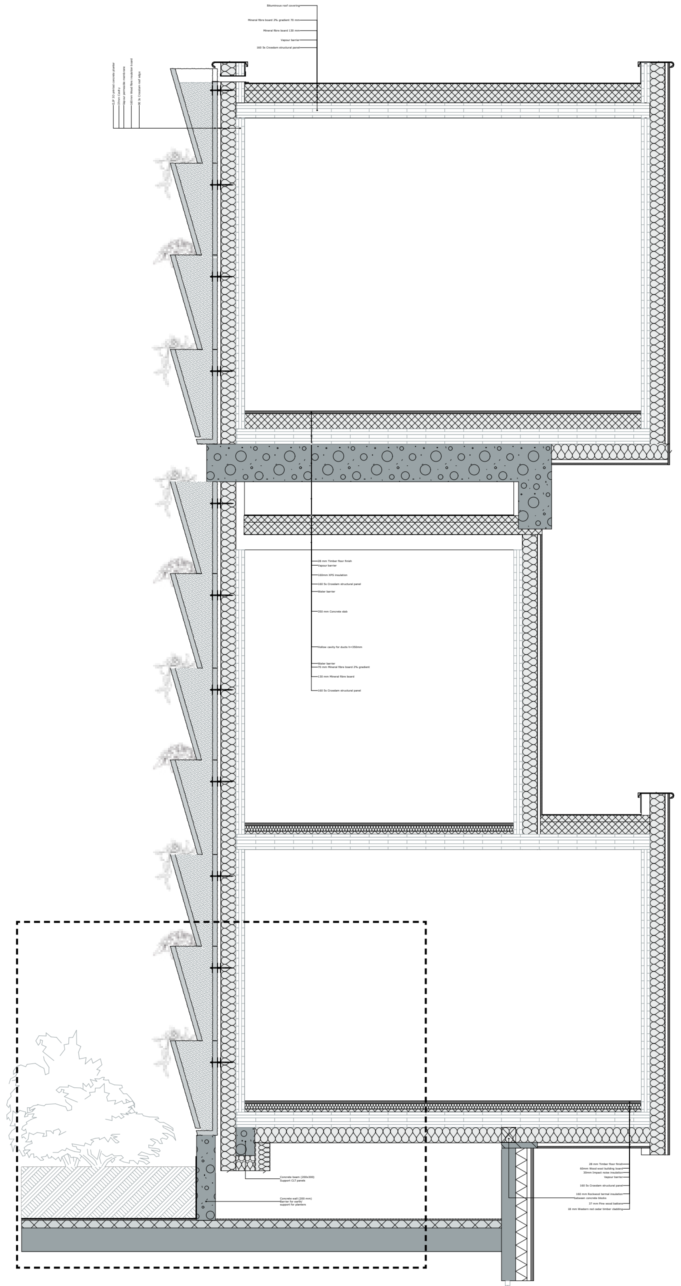
Drawing 5.58
Detail of green facade attached to a CLT dwelling units
Scale 1:20



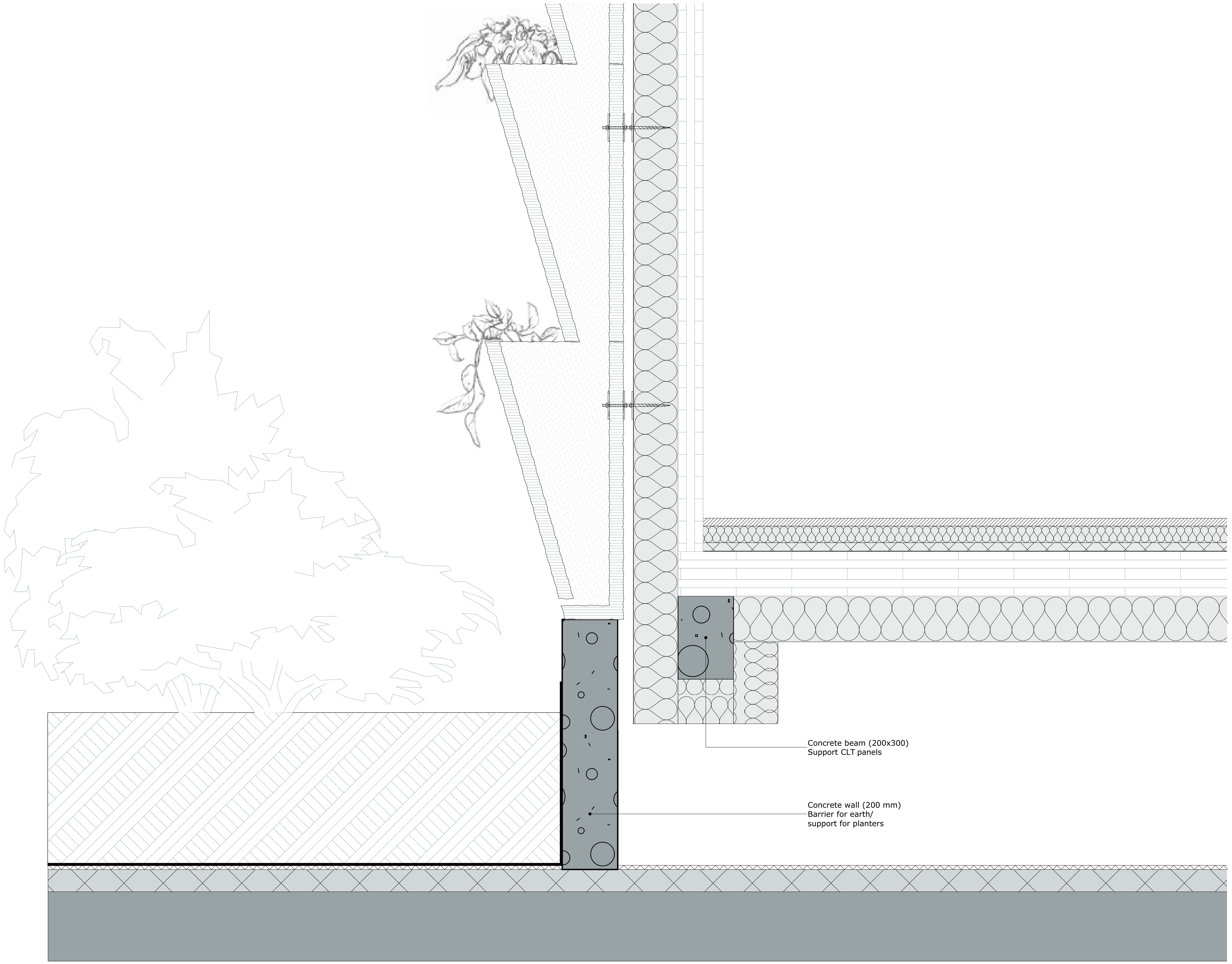
Drawing 5.59
Section over a green facade attached to a CLT dwelling units
Scale 1:100



Drawing 5.60
Detail of green facade attached to a CLT dwelling units
Scale 1:20



Drawing 5.61
Section over a green facade attached to a CLT dwelling units
Scale 1:100



Drawing 5.62
Detail of green facade attached to a CLT dwelling units
Scale 1:20

CONCLUSION AND DISCUSSION

CONCLUSIONS AND DISCUSSION

In this Graduation project four topics formed the basis for the research and design decisions:
Affordability of Housing, Densification of Cities, Urban Climate Resilience and Digital Manufacturing.

The presented design proposal implements those four topics in a building that provides a solution for future challenges in housing.

By following the principle of Optoppen (vertical extension of existing buildings) a strategy is provided to densify urban areas. Boundary conditions for a successful densification campaign are the provision of affordable housing for large groups in urban populations and the creation of a livable and ecological urban environment. In this way, a sustainable urban environment is created in which future generations can have a pleasant life.
According to Brundtland's definition of sustainable developments, the world (including the built environment) should offer a livable environment now, while ensuring future generations to have the same opportunities. (International Institute for Sustainable Development, n.d.)
In this report, a proposal is presented, which provides the ability for a large part of the population to live in the places they want to, even if this is located in dense and expensive urban areas. Many cities in the Netherlands have a large stock of buildings, which potentially are suitable for Optopping. Implementing this strategy on many rooftops would create a large increase in available housing space and would thereby solve the disrupted balance between demand and supply. Moreover, building on top of existing rooftops could potentially form a relatively cheap way of housing construction, as land prices make up an increasing share of construction expenditures. Occupying more land becomes unnecessary when building on top of existing buildings.

By densifying the cities using urban rooftops instead of the remaining open urban spaces, new opportunities for additional housing are created, while preserving a livable urban environment with green facilities. These facilities are vital for a livable urban environment as they provide possibilities for recreation and biodiversity. Moreover, green spaces are important for the urban climate as it provides cooling and rainwater absorption.
Rainwater management has been identified as a topic of special importance for this Graduation project. Within the design proposal, an ecological network has been implemented, which serves as a rainwater buffer and drainage. It provides the inhabitants of the building with a pleasant, green living environment and it contributes to a sustainable way to handle rainwater. For this specific location, it provides cooling and hydration during hot and dry summers and as a rainwater buffer during winters when rainfall peaks.
Implementing similar systems on multiple urban blocks could create a permanent solution to heat stress and flooding in cities.

To execute such custom-made, site-specific interventions, Digital Manufacturing offers a lot of possibilities. In this report, the contribution of Digital Manufacturing to the production of architectural elements in a quicker, cheaper, more reliable, and more differentiated way, is discussed. As a technique within Digital Manufacturing, Concrete Liquid Injection Printing (CLIP) was developed and tested. CLIP allows for the production of freeform geometries by 3D printing concrete into a supporting liquid. The topics of Urban Climate Resilience and Digital Manufacturing were combined by designing 3D printed concrete planters, which store and drain rainwater on the building.

Experiments with CLIP using the 3D concrete printer at the TU/e, show that freeform geometries that resemble the desired shape for the planters, are possible to manufacture. Also, a building system to assemble the planters to one structural façade is proposed and seems plausible to apply in this design. However, the limitations CLIP offers in terms of scalability of the objects, are expected to form an obstacle for large-scale implementation of this technique in this building scheme.

Nevertheless, many of the implemented design strategies seem promising to achieve the requirements that were set for the Big House in this Graduation project. The design provides an affordable housing facility, which could be repeated onto many buildings in cities. At the same time, the livability of cities is maintained and further improved by providing a new ecological rainwater network.

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Fig. 2.36
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Fig. 3.1-3.2
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Fig. 3.3
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Fig. 3.7
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Fig. 3.8-3.9-3.10
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Fig. 5.3
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Fig. 5.5
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Fig. 5.6
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Fig. 5.7
Mayr-Melnhof Holz. (2013). WHERE IDEAS CAN GROW.

TOP HOUSE

Appendix 1

BIG HOUSE

Research to the concept of the big house

Tutors

Prof. Ir. Arch. J.D. Bekkering
Ir. Z.Y. Ahmed
Ir. Arch. J.P.A. Schevers
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Date & place

April 2021
Eindhoven University of Technology

Introduction.

The starting point for this research was a very broad search for examples of Big Houses. Three topics were identified as searching criteria: Boundaries of the Big House, Social Issues and Emerging Technologies. This search resulted in a diverse collection of Big Houses, which gave new views on this theme.

In this paper the theme of Big House is approached as a concept which embodies a certain meaning. Through the different case studies different meanings have been discovered. Some examples mainly function as a representation of individual wealth and status, while others try to reduce their visual impact but still offer a lot of spatial quality and merge with their surroundings. Other projects have a meaning in terms of social structures, sustainability or flexibility. A common characteristic of these projects is their focus on improving or facilitating processes on the long term and short term for a large group. Examples are collective housing types to serve communities, expandable and adaptable housing types to serve different users or housing types with alternative energy and water supply to facilitate a more sustainable way of housing. These examples helped us to define our scope within the broad theme of Big House.

Introduction

01. Big House

Content.

Sources

1

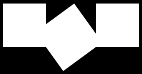
Exploring the boundaries of the Big House as a concept

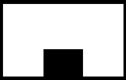
1.0

Introduction.

It is a dream for most architects to design a big house, preferably with a high amount of money. This first chapter shows different case studies of big houses and explores the boundaries of the big house. What can be called a big house? What is the smallest and biggest a big house can be? The houses are categorized by their size ranging from S (0-100m^2) to XXL (>5000m^2).

1.1





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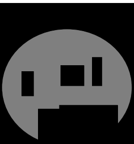

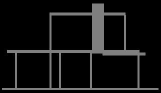

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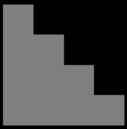

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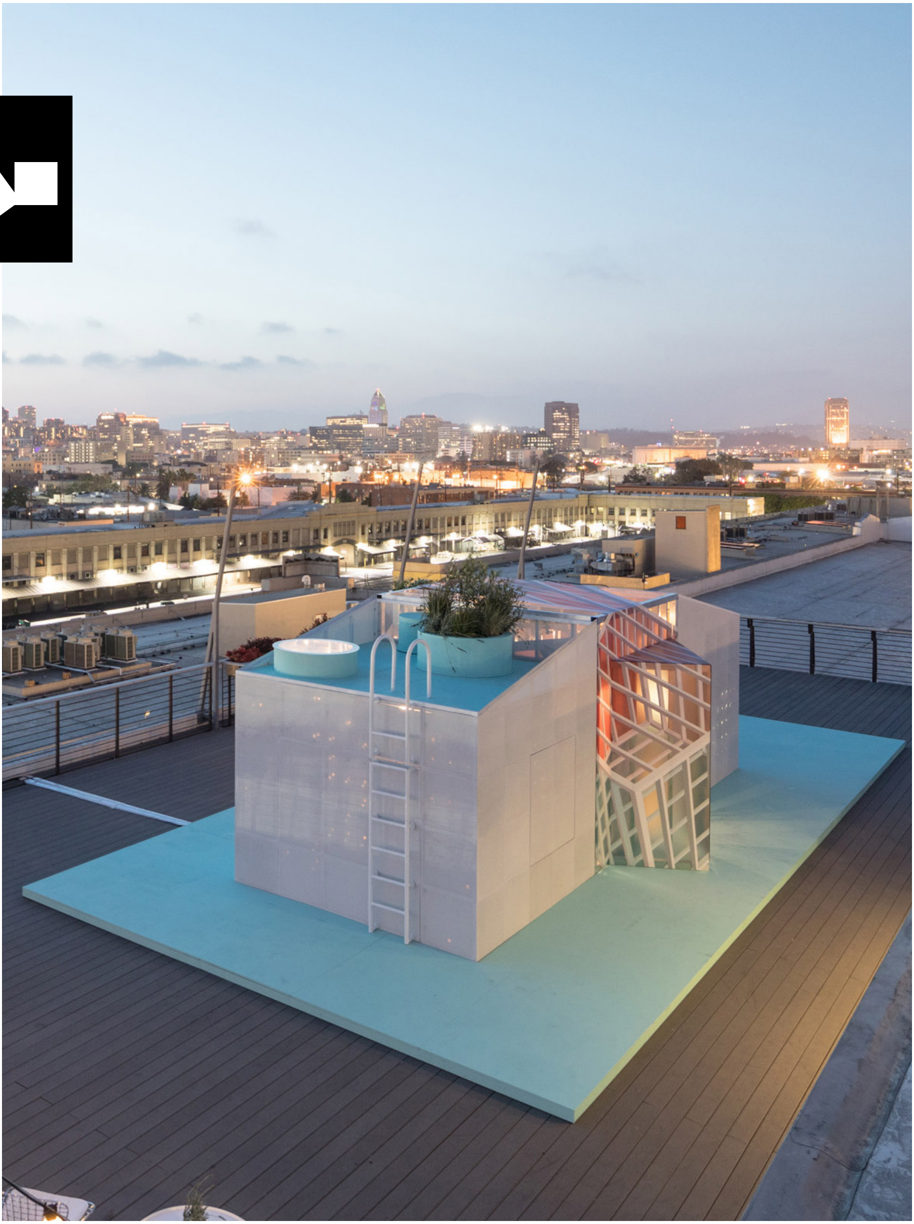

Fig. 1.1.1.1 Bird's eye view [Dezeen, n.d.]

1.1.1 MINI LIVING URBAN CABINS

Architect:	FreeLandBuck
Place:	Los Angeles, United States
Date of built:	2018
Floor area:	15 m^2

Why?
Dispite of the small scale, this building has the potential to daily solutions for bigger houses, and shows the smart technologies inside the building to comfort the needs.

This cabin was designed by the firm FreeLandBuck and was built on a roof of an apartment in Los Angeles. It was part of the global Village, presented at the 8th edition of Los Angeles Design Festival in 2018.

It was shown as a temporary home for the local people, and it provides alternatives and the flexibility on dealing daily based aspects on a 15 m^2 footprint.

Quotes from FreelandBuck on the MINI Living Urban Cabin:

“The structure is conventional metal stud framing, but instead of concealing it, we multiplied it, first adding a second rotated frame and then the image of a third frame projected through the layers of structure.”

“We’ve been making three-dimensional, building-scale drawings and illusions recently. In this case, the skin of pavilion is printed with a drawing of the same metal framing that encloses the central space. We are hoping to create an interplay between the layers of physical structure and the graphic that folds through them that will expand the small space of the interior perceptually.”

[FreeLandBuck - Archello, n.d.][1.1.1.1].

Fig. 1.1.1.2 Front view[Worldarchitecture, n.d.]

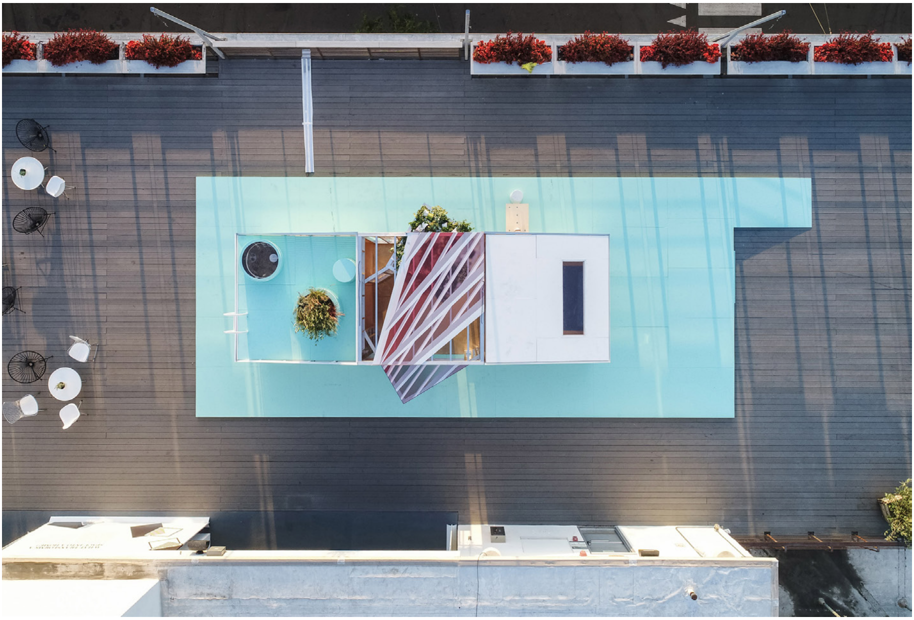

Fig. 1.1.1.3 Top view [Dezeen, n.d.]

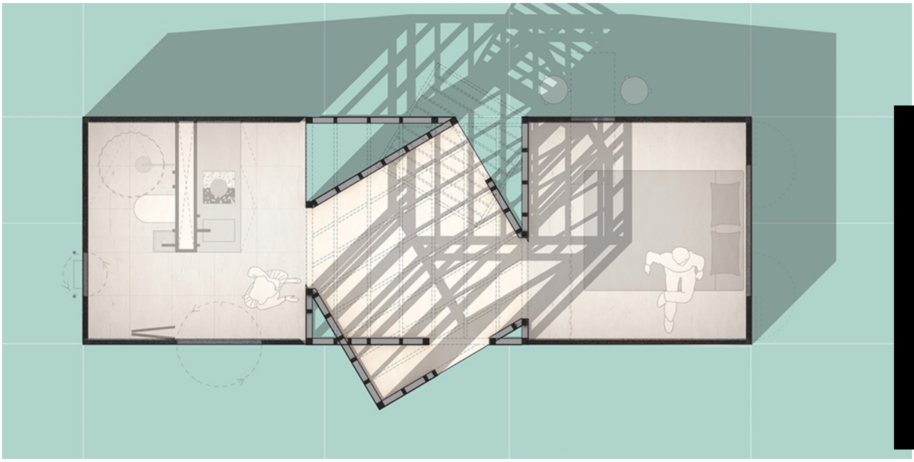

Fig. 1.1.1.4 The plan of the Global village [Worldarchitecture, n.d.]

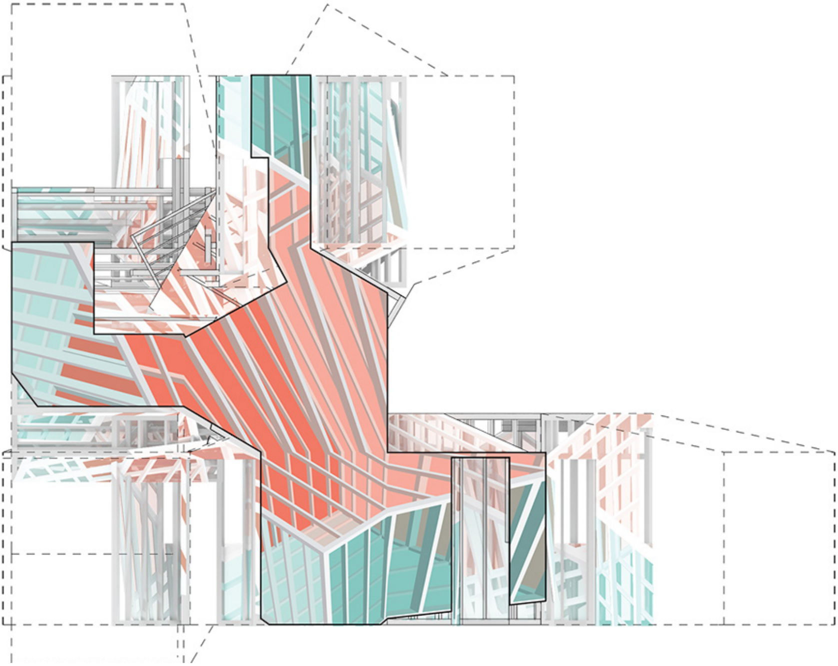

Fig. 1.1.1.5 The section plan [Worldarchitecture, n.d.]

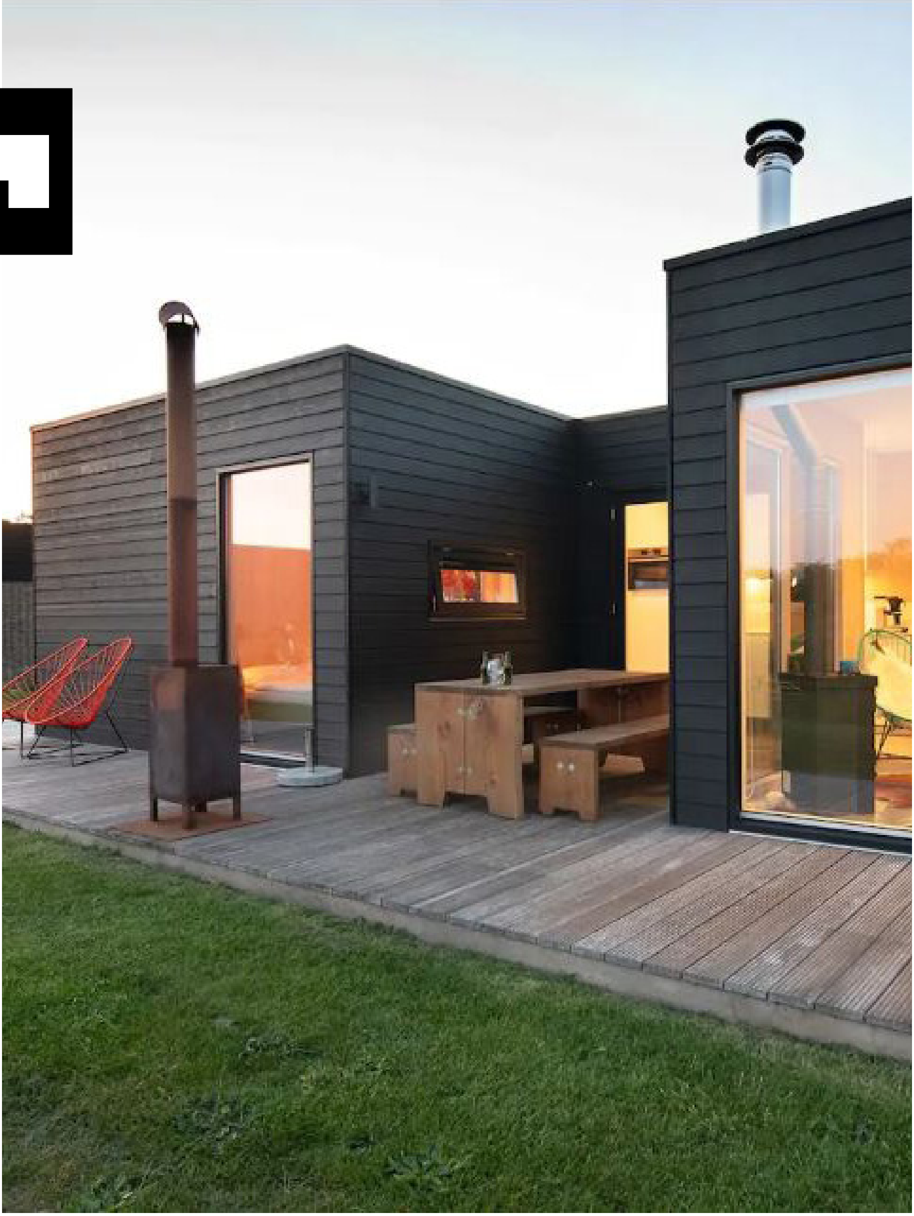

Fig. 1.1.2.1 Exterior [De Grote Beer, n.d.]

1.1.2 BUITENHUISJES

Architect:	Depot Rotterdam
Place:	Terschelling, Netherlands
Date of built:	2015
Floor area:	45 m^2

Why?
When looking at the different types of big houses and looking for the boundaries in them, one can also look at tiny houses. These can also be seen as big houses. The point is, however, from which context one looks at the word 'big house'.

For someone from a rich country, a big house is quickly associated with a house with a swimming pool, several bedrooms and bathrooms, a large garden, and so on. When one looks from someone from a third world country, a tiny house can already be seen as a big house.

This project contains tiny houses that are set up as holiday homes. It is a house of 45m^2 with sleeping accommodations for 4 to 5 people. In addition, the house is located on a plot of 235m^2. Smart solutions in the interior of the house will surprise people how much space there actually is. There is one bedroom with a double bed, a bedroom with both a double bed and a loft bed and then there is an extra bed under the glass roof. In fact, more than 4 to 5 people could sleep here. In addition, there is a kitchen, living room, dining area, bathroom, toilet, workplace and laundry in the tiny house. So a lot of functions in only 45m^2 [De Grote Beer, n.d.][1.1.2.1].

So looking from a different context a tiny house can also be a big house.

Fig. 1.1.2.2 Outdoor terrace [De Grote Beer, n.d.]

Fig. 1.1.2.3 Master bedroom [De Grote Beer, n.d.]

Fig. 1.1.2.4 Bedroom and workspace [De Grote Beer, n.d.]

Fig. 1.1.2.5 Plan [De Grote Beer, n.d.]

Fig. 1.1.2.6 Dining area [De Grote Beer, n.d.]

Fig. 1.1.2.7 In and outdoor space [De Grote Beer, n.d.]

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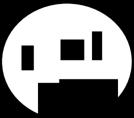

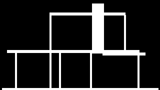

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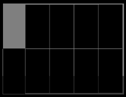

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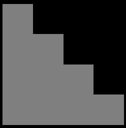

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Fig. 1.2.1.1 Villa Vals [SeARCH, n.d.]

1.2.1 VILLA VALS

Architect:	SeARCH
Place:	Vals, Switzerland
Date of built:	2009
Floor area:	225 m²

Why?
This project shows how a big house can be presented in a very subtle way. It has been very carefully integrated in the landscape and uses this landscape as a quality in the design. It represents a great building using small means.

This project was inspired by Peter Zumthor's famous Therme Vals, which is located nearby. The most important similarity is the embedding in the landscape. The surrounding nature was left intact as much as possible and was incorporated in the design. Both the characteristics of the landscape and local architecture were applied. For the latter local building types and techniques were interpreted for in this project. Local materials found during the excavation of the site, were used. A typical Swiss barn typology functions as the entrance to the villa and is connected to the rest of the building through a 22-meter underground tunnel.

The main part of the villa is organized around a patio, which provides the house with daylight and a stunning view over the Alpine landscape. The façade is used to express the interior organization of the building. The different rooms are shaped by concrete boxes at various levels. The façade openings indicate the locations of these rooms. The patio is literally incorporated in the landscape as it forms a kind of crater in the hill, which is also materialized with the natural stone of this area. Being in this patio and enjoying the view makes you feel part of the landscape as well.
The interior in materialized with local products like oak and natural stone. Also for the heating and electricity supply local sources are used, such as thermal heat and hydroelectric power from a nearby reservoir.
[SeARCH, n.d.][1.2.1.1]

Fig. 1.2.1.2 Project reference: Zumthor's Therme Vals [Fouillet, F., 2018]

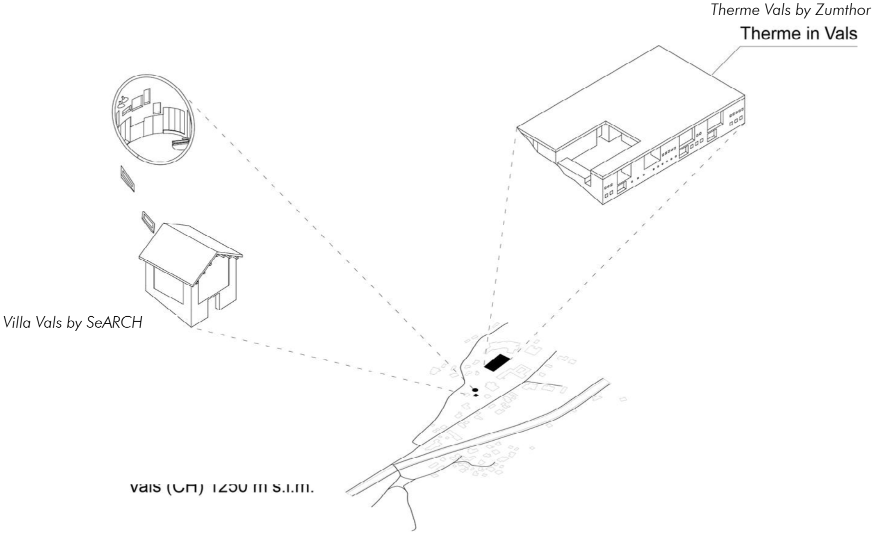

Fig. 1.2.1.3 Embedding in the landscape [SeARCH, n.d.]

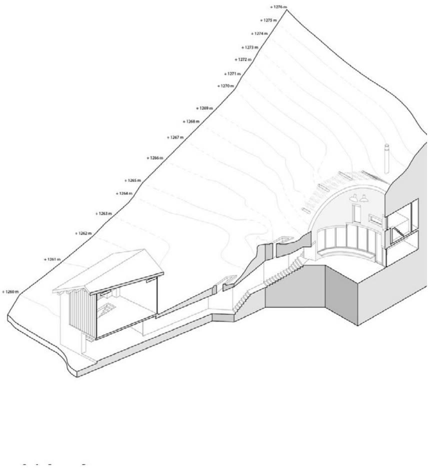

Fig. 1.2.1.4 Axonometric section [SeARCH, n.d.]

Fig. 1.2.1.5 Interior [SeARCH, n.d.]

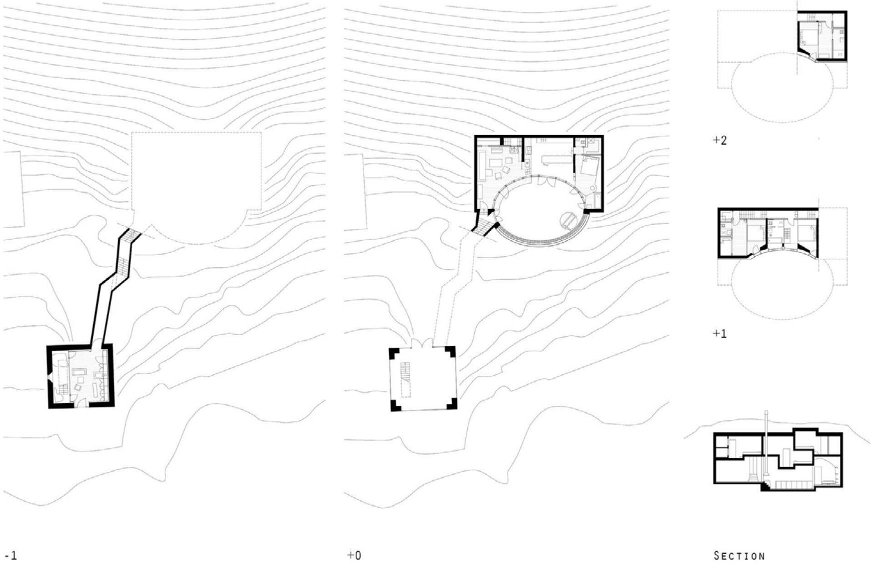

Fig. 1.2.1.6 Floorsplans and section [SeARCH, n.d.]

*Fig. 1.2.2.1 Exterior [*Kroll, A., *n.d.]*

1.2.2 KAUFMANN HOUSE

Architect:	Richard Neutra
Place:	Palmsprings, United States
Floor area:	300m²

Why?
The iconic vacation house is a modern house which can be addressed as a big house. It shows the charitaristics of a family house, where the spaces are orientated to the most functional and practical sides of the surroundings.

This big house was a vacation house designed for mr. Kaufmann by Richard Neutra.

The design of the house is quite simplistic; at the centre of the house is the living room and the dining room that is the heart of the house and the family activity. The rest of the house branches out like a pin wheel in each of the cardinal directions. From the centre of the house each wing that branches out has its own specific function; however, the most important aspects of the house are oriented east/west while the supporting features are oriented north/south.

The north and south wings are the most public parts of the house that connect to the central living area. The south wing consists of a covered walkway that leads from the centre of the house to the carport.

The house’s swimming pool is one of the most iconic and recognizable aspects of the Kaufmann House; however, it is not solely a photographic gem or simply a recreational feature. The swimming pool creates a compositional balance of the overall design of the house. The house alone is unbalanced and heavy as the wings are not equally proportioned, but with the addition and placement of the swimming pool there is a cohesive balance and harmony throughout the design.

[Kroll, A., n.d.][1.2.2.1].

*Fig. 1.2.2.2 Front entrance [*Kroll, A., *n.d.]*

*Fig. 1.2.2.3 Terrace [*Kroll, A., *n.d.]*

*Fig. 1.2.2.4 The vertical mullions [*Kroll, A.*, n.d.]*

Fig. 1.2.2.5 The family room [Kroll, A., *n.d.]*

Fig. 1.2.2.6 Interior facing the pool [Kroll, A., *n.d.]*

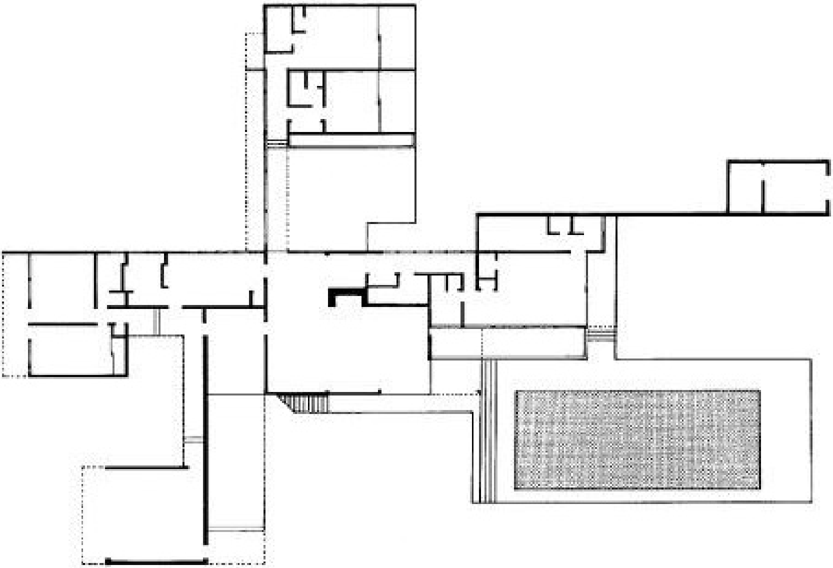

Fig. 1.2.2.7 The floorplan [Kroll, A., n.d.]

Fig. 1.2.2.8 The pool surrounded by the mountains [Kroll, A., n.d.]

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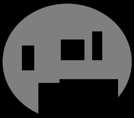

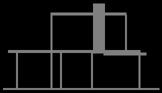

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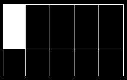

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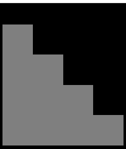

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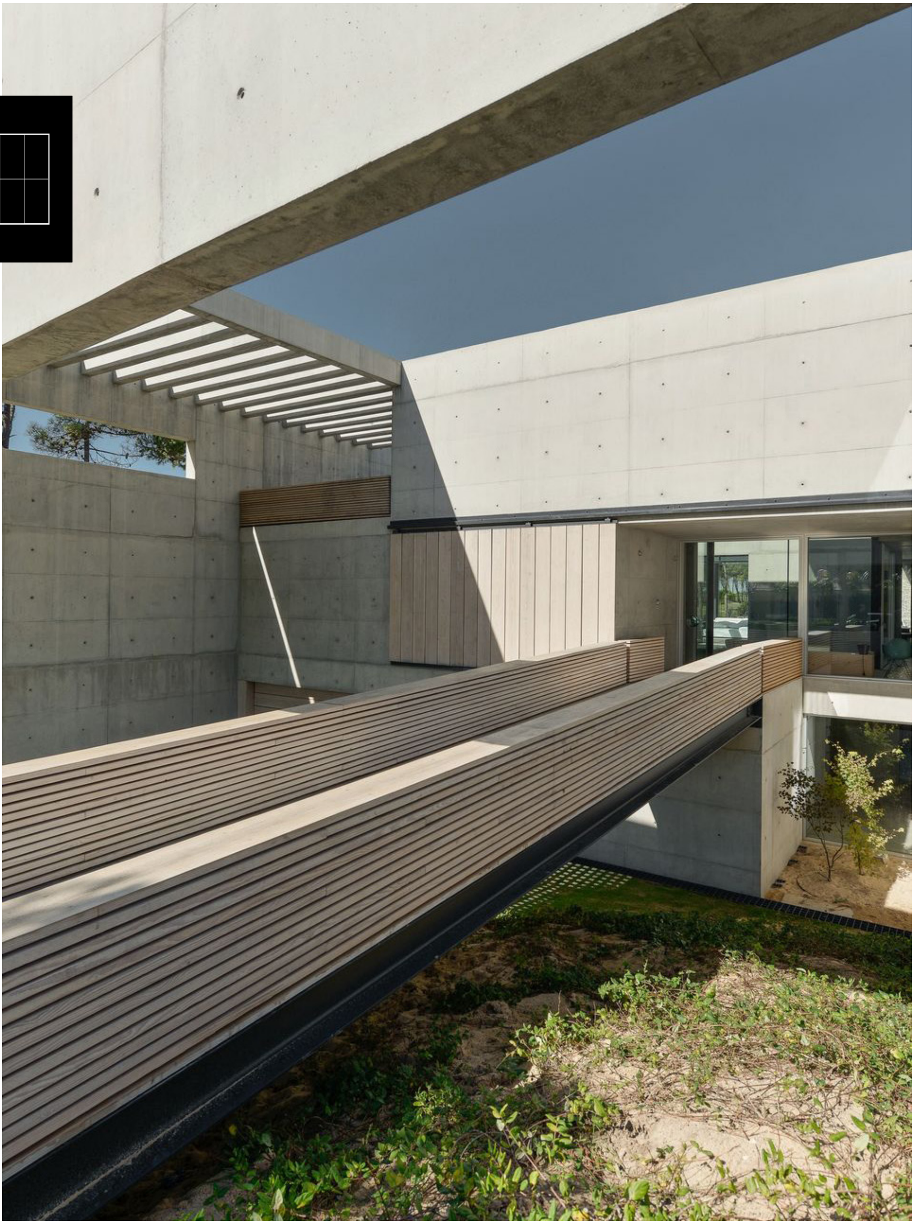

Fig. 1.3.1.1 Entrance of the house [Oliveira Alves, R., n.d.]

1.3.1 WALL HOUSE

Architect:	Guedes Cruz Arquitectos
Place:	Lisbon, Portugal
Date of built:	2013
Floor area:	1.100 m^2

Why?
This house we can really call a big house how would imagine it as we first think at it. The house is fully automated and has different luxury extras like two swimming pools, a big roof terrace and a beautiful view over the golf resort were it is located.

The house was designed inspired by the beauty of the surrounding. The house can be the best described by the description of the architect himself: *'Like a wall in a Castle not in stone, but in concrete, glass and wood. Not to for protection but because of the neighbours and the strong Atlantic Wind. A Patio house with a Mediterranean country culture in the hardness Atlantic Coast. A big Window opens to the golf and scenery sea views can be seen from the interior and exterior spaces. Two exterior pool's located in the patio crossing each other, one in the ground and the other in the air.' [Apers, J., 2017]*[1.3.1.1].

So the house consist of a block made out of concrete, glass and wood. The big glass facades and the wooden panels can open to let in fresh air from the Mediterranean Sea.
The most striking elements are the two pools, especially the pool on the first floor. The pool not only functions as a pool but also as a roof without losing light. The water also gives a nice contrast between dark and light in the building.

The house is designed for the weather. As the architect says: 'Nothing is designed for the appearance'. The house is designed for the climate were it is in. On a hot day, the glass walls can open to let in a breeze. There are no doors that open and close but walls which function like that. On a windy day the walls stop the wind [Press, S., 2019][1.3.1.2].

Fig. 1.3.1.2 Swimming pools [Oliveira Alves, R., n.d.]

Fig. 1.3.1.3 Back of the house [Oliveira Alves, R., n.d.]

Fig. 1.3.1.4 Outside space [Oliveira Alves, R., n.d.]

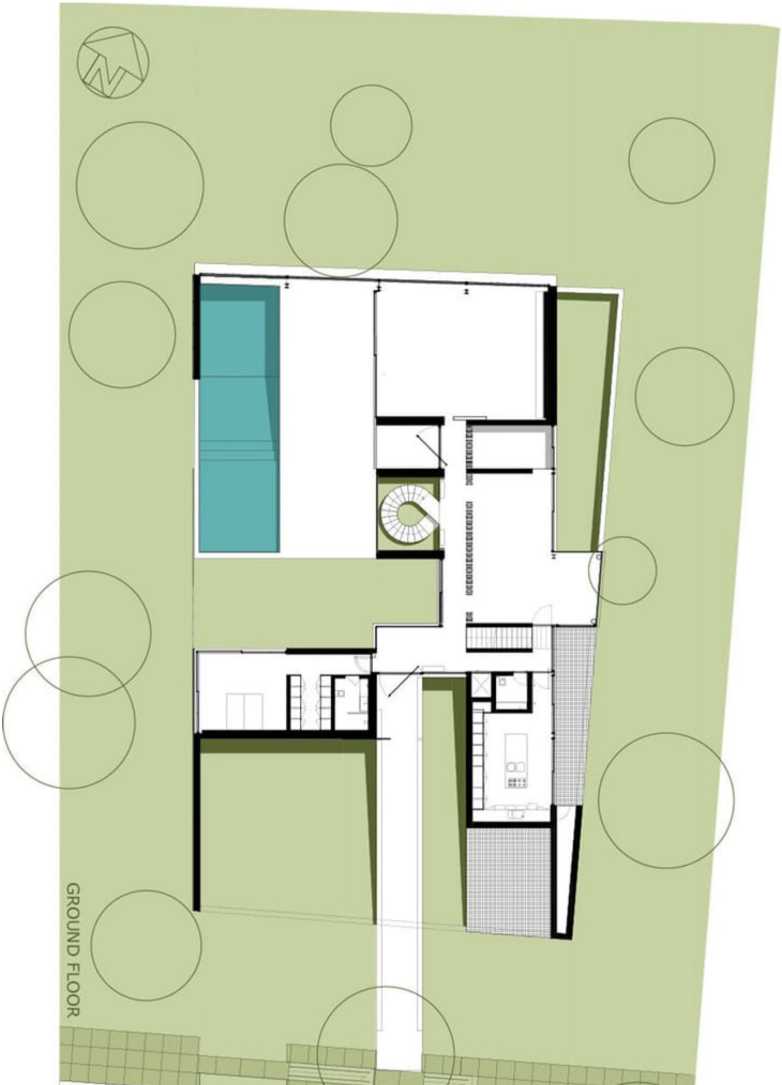

Fig. 1.3.1.5 Ground Floor [Guedes Cruz Arquitectos, n.d.]

Fig. 1.3.1.6 First Floor [Guedes Cruz Arquitectos, n.d.]

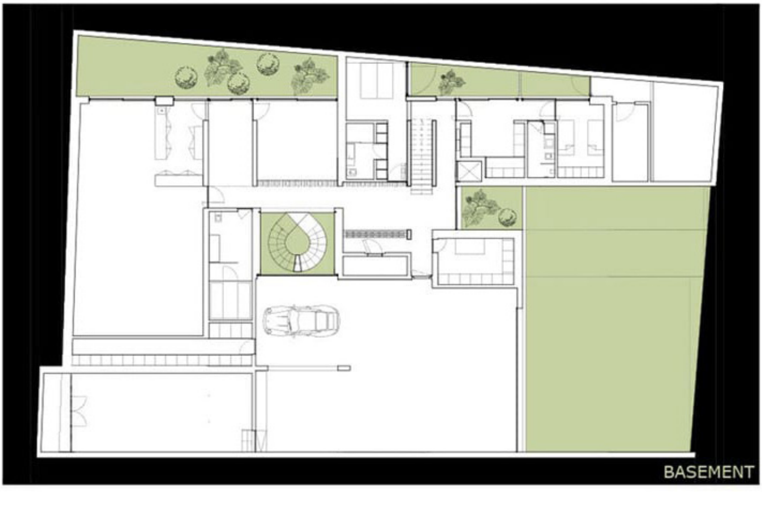

Fig. 1.3.1.7 Basement [Guedes Cruz Arquitectos, n.d.]

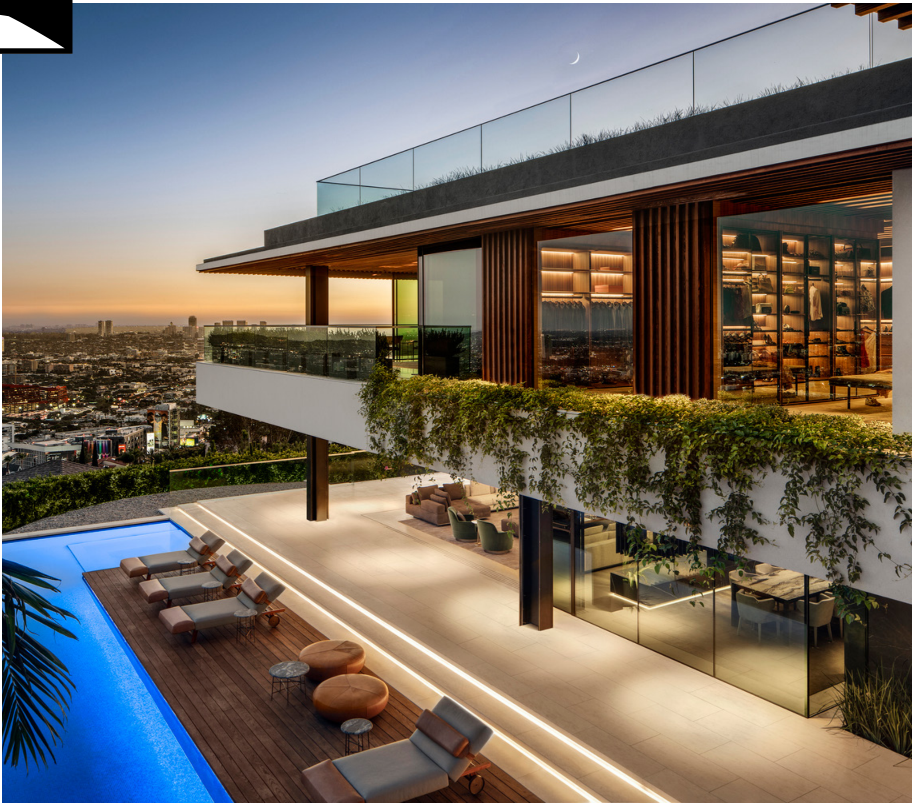

Fig. 1.3.2.1 Hillside House [Letch, A., n.d.]

1.3.2 HILLSIDE HOUSE

Architect:	SAOTA
Place:	Los Angeles, United States
Date of built:	2019
Floor area	1.687 m^2

Why?
This architect used the greatness of the location to create a great house. The view over Los Angeles is captured as much as possible in the design. The program and the construction of the building are adapted to ensure a strong connection with the landscape.

The most important element that makes this villa a Big House is the 300-degree panorama it provides over the Los Angeles area. The design consists of an east-west and a north-south orientated wing.
Roof planes were dimensioned relatively big to create covered outside spaces adjacent to the villa to incorporate the landscape and the view as much as possible into the building.

The floor plan shows a *free plan/ plan libre* where the different rooms and the surrounding landscape float into each other. The program is characterized by many living areas linked to the outdoor spaces around the building. This free plan is also visible in the vertical direction with atrium's and glass volumes penetrating the building and shifting volumes creating an airy facade.

To execute this almost modernistic open organization a structural solution on the outside of the project was needed. The floor slabs are carried by steel columns which are located on the perimeter of the building.
[Silva, V., 2020][1.3.2.1]

Fig. 1.3.2.2 Entrance in the basement level [Letch, A., n.d.]

Fig. 1.3.2.3 Section showing the open organization [SAOTA, n.d.]

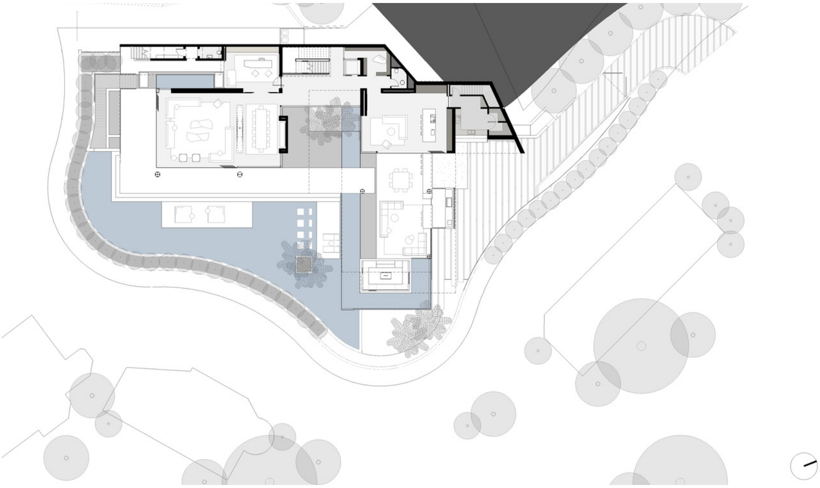

Fig. 1.3.2.4 Floorplan showing the open organization [SAOTA, n.d.]

Fig. 1.3.2.5 Spaces floating into each other [Letch, A., n.d.]

Fig. 1.3.2.6 Strong connection between inside and outside [Letch, A., n.d.]

Fig. 1.3.2.7 Panoramic view over Los Angeles [Letch, A., n.d.]

Fig. 1.3.2.8 Panoramic view over Los Angeles [Letch, A., n.d.]

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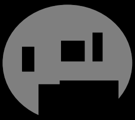

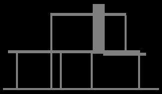

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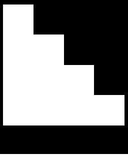

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Fig. 1.4.1.1 Roof terraces [Cuypers, P., n.d.]

1.4.1 SMILEY ZEEBURGEREILAND

Architect:	Studioninedots
Place:	Zeeburg, Netherlands
Date of built:	2016
Floor area:	± 7.500 m²

Why?
This building can be seen as a big house because it consists of several studio's which together form one big house. This can be compared to a normal house where everyone has their own bedroom but also shared functions such as a laundry room.

At a plot on Zeeburgereiland in Amsterdam Studioninedots created a housing block with 364 student apartments. The studio designed the apartment building in a way that the building can facilitate collective use of different functions. A good example are the shared roof terraces at the stepped roof were all the students of the apartment block can meet. The building is designed as a noise barrier for the residences behind the building.

In this building one has different studio's with their own kitchen, bathroom en bedroom/ living room. The shared facilities are the bicycle shed, laundry room, roof terraces, etc. It is one big block in which different persons live.

The complex is located on Zeeburgereiland, an area in Amsterdam that is developing at lightning speed.

The interior spaces are designed in such a way that a collective culture is created and the building can be used dynamically. By building the building with stairs, as it were, it provides variety in the urban silhouette. In addition, the building serves as a noise barrier for the houses behind [Mena, F., 2016][1.4.1.1].

Fig. 1.4.1.2 Roofterraces [Cuypers, P., n.d.]

Fig. 1.4.1.3 Front facade [Cuypers, P., n.d.]

Fig. 1.4.1.4 Back of the building [Cuypers, P., n.d.]

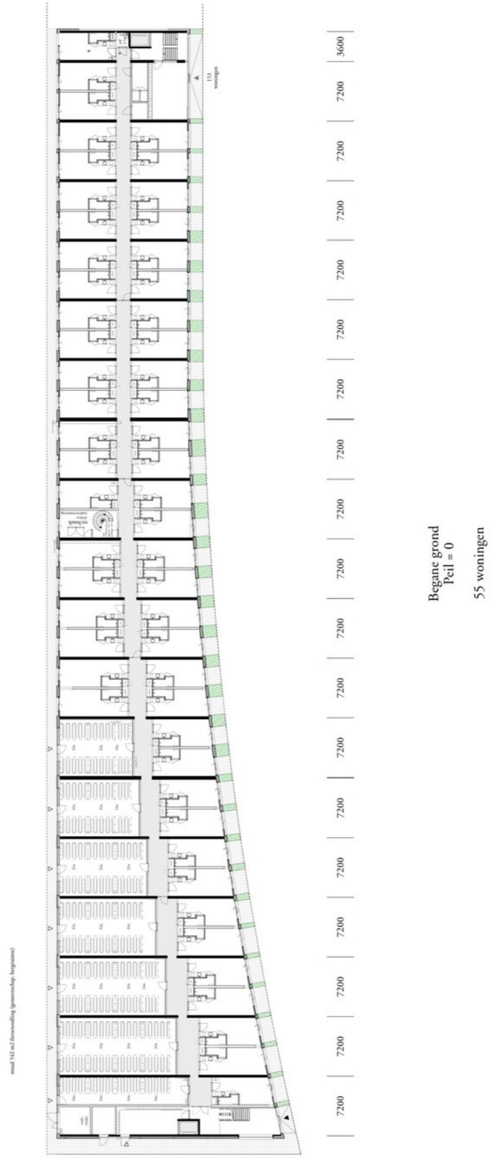

Fig. 1.4.1.5 Plan ground floor [Studioninedots, n.d.]

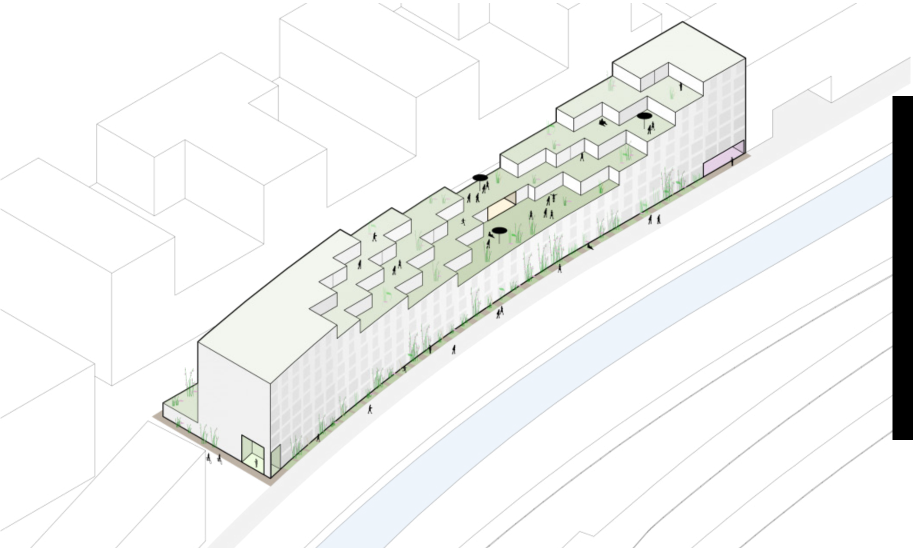

Fig. 1.4.1.6 Concept drawing [Studioninedots, n.d.]

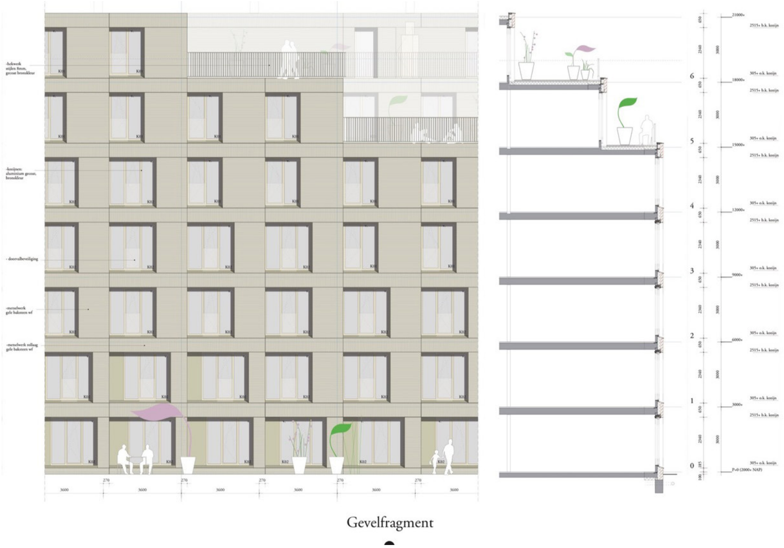

Fig. 1.4.1.7 Facade section [Studioninedots, n.d.]

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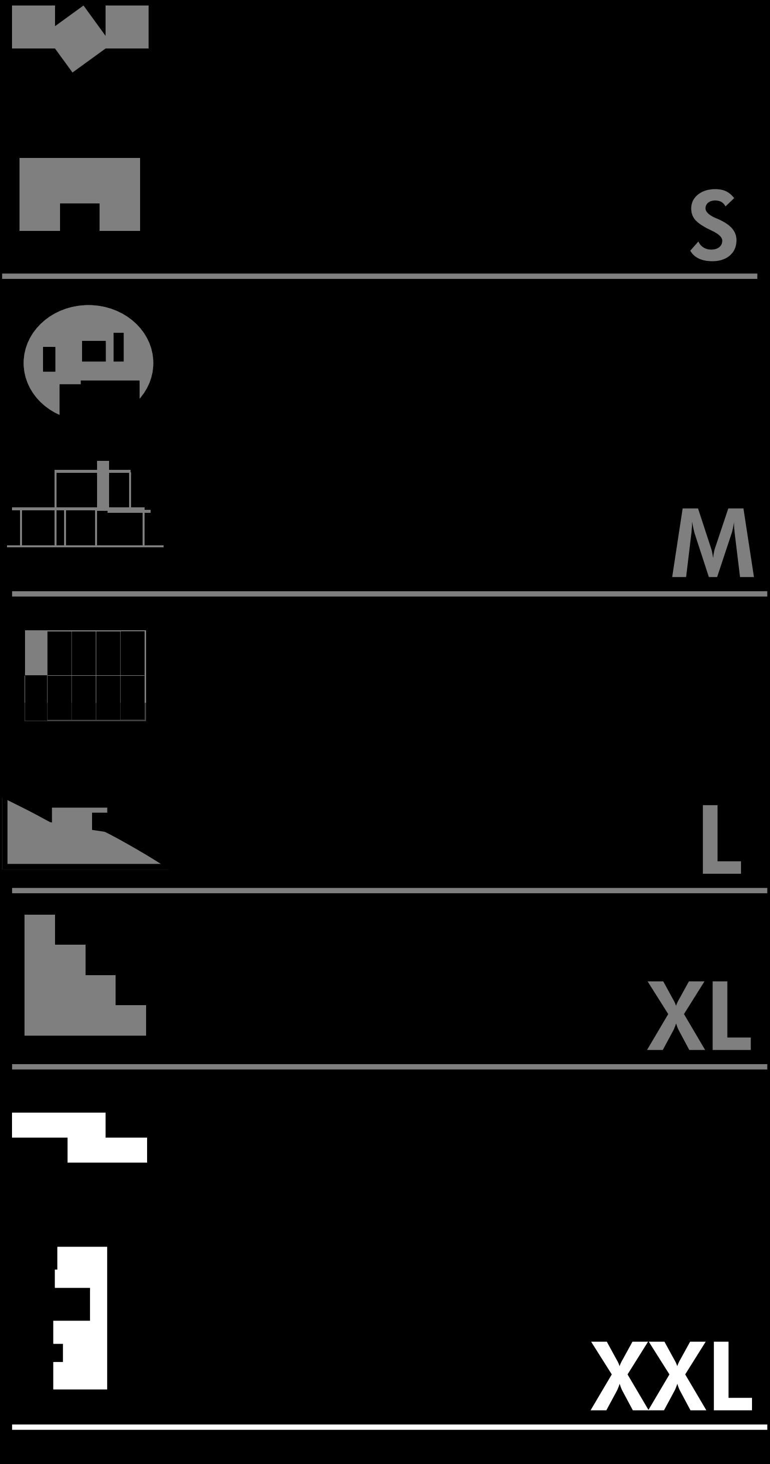
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Fig. 1.5.1.1 Exterior [De Architect, n.d.]

1.5.1 THE COLLECTIVE OLD OAK

Architect:	PLP architects
Place:	London, United Kingdom
Date of built:	2016
Floor area:	16.000 m^2

Why?
Despite of the large scale, this building has many sharing components that can be addressed as a big house with co-living units inside that harmonizes the atmosphere.

This project is the largest co-living building in the world, with 16.000 m2, redesigned by PLP architects. It was a former industrial building

At a micro scale, the building has conceived the privacy of the inhabitants and in the individual spaces, they allowed to have small clusters of people whom share in the communal spaces, like the kitchens, dining rooms, cafe and etc.
These clusterings, predicated on the one's feeling comfortable in their presence, are the key of success to forming a community within the building.

At a large scale, with the different moods in the various spaces, it comforts the inhabitants in their stay.

The Collective is about sharing these social spaces naturally, their layout of the units and distribution throughout the building, is the most important consideration of this concept of co-living.

The work & life components are a mix in this building.
The incubator for young start-ups, which is an boost to the communal activities and creative solutions in this building.

[PLP architecture, 2019][1.5.1.1].

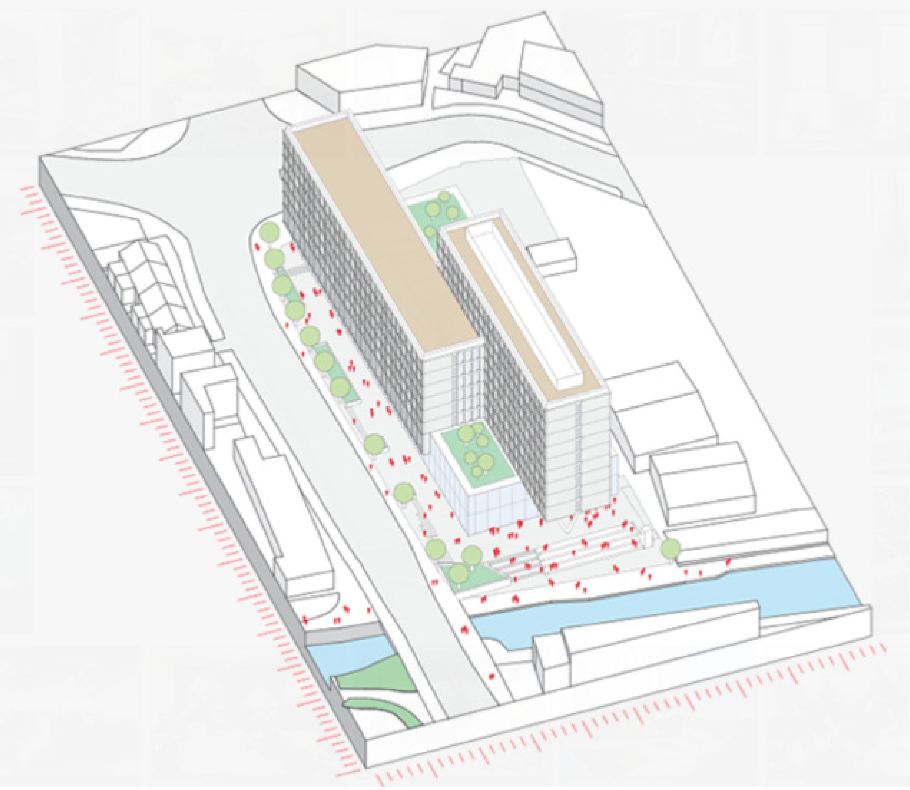


Fig. 1.5.1.2 Axonometry [PLP architects, n.d.]

Fig. 1.5.1.3 Workspaces [Mairs, J., n.d.]

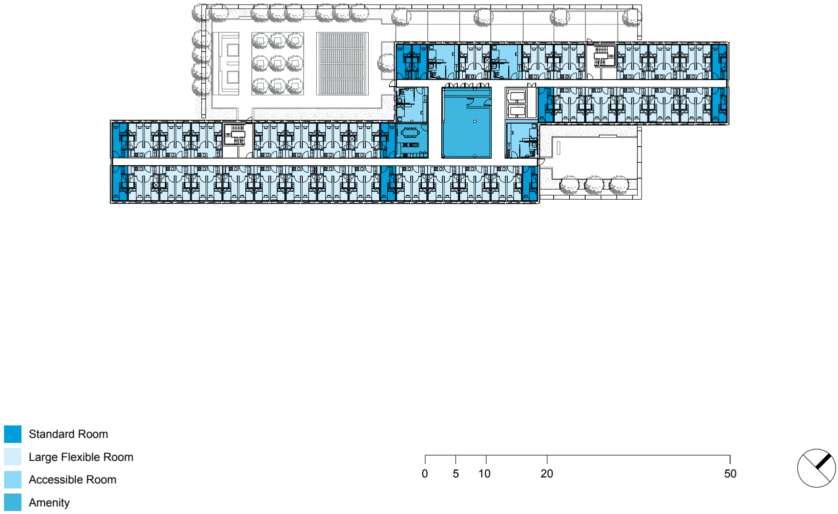


Fig. 1.5.1.4 The floorplan [Krabbendam, P., n.d.]

Fig. 1.5.1.5 The gaming room [Mairs, J., n.d.]

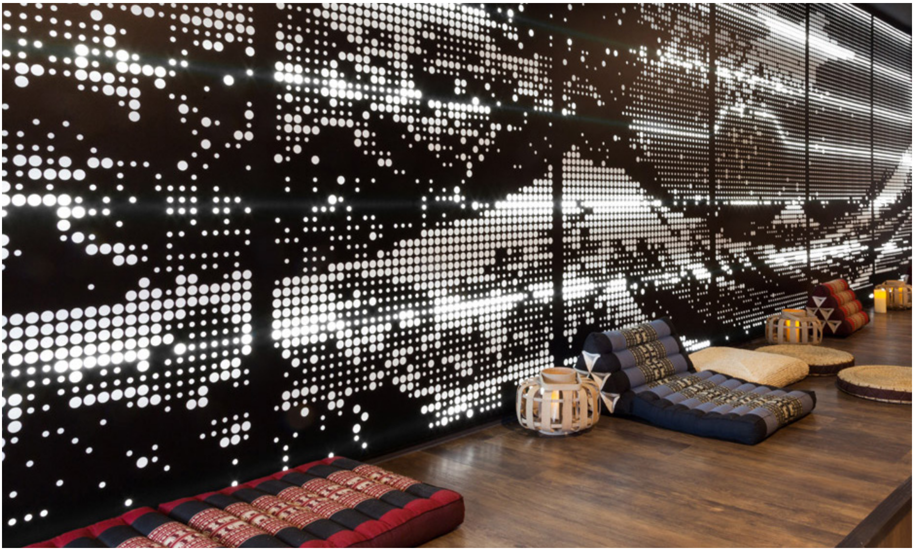


Fig. 1.5.1.6 Massage room [Mairs, J., n.d.]

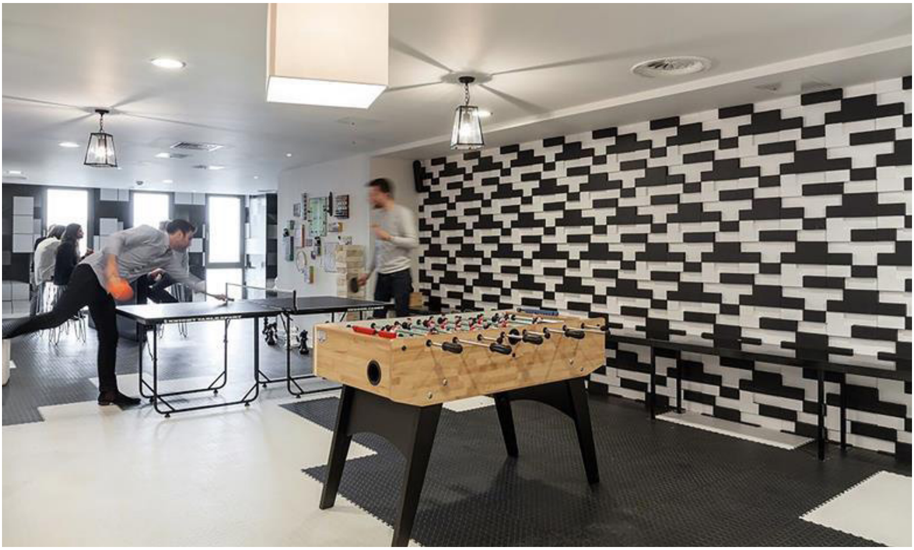


Fig. 1.5.1.7 Gaming room [Partington, S., n.d.]

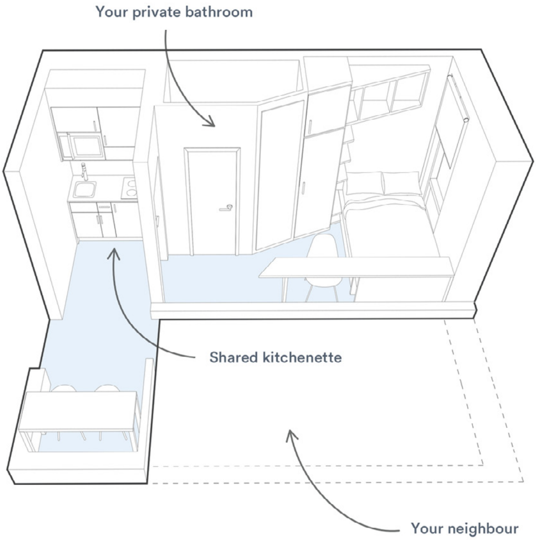


Fig. 1.5.1.8 The co-living studios [The Collective, n.d.]

Fig. 1.5.1.9 The shared kitchen hall [Trendiswitch, n.d.]

Fig. 1.5.2.1 Antilia [Becker, J., 2012]

1.5.2 ANTILIA

Architect:	Perkins & Will
Place:	Mumbai, India
Date of built:	2010
Floor area:	37.000 m^2

Why?
This project is an extreme and a slightly cynical example of a big house. One the one hand it is one the most expensive private houses in the house, on the other hand it is located in one of the poorest areas in the world.

This enormous residential project with office space is initiated by the Indian billionaire Mukesh Ambani. It is located in Mumbai, approximately 170 meters tall and costed 2 billion dollar to build. It is one of the most expensive private residences in the world. This project has seen a lot of controversy giving the poor living conditions of most inhabitants of Mumbai.
The top floors will be privately occupied by Ambani's family.
In the lower parts of the tower corporate facilities and parking space are located. Corporate and residential space are separated by an open green layer in the middle of the tower.
Much of the façade surface is covered with greenery to provide shelter against the heat stress. [Sokol, D., 2007][1.5.2.1]

Construction took four years and was completed in 2010.
It provides parking space for 168 cars. The residential part of the tower offers many facilities including a ballroom, swimming pools, theatre, spa etc. The building is topped off with a helipad and a panoramic view over the city. [AllThatsInteresting, 2011][1.5.2.2]

The tower was designed by the American office Perkins & Will, but curiously enough they do not advertise with their responsibility for this building on their website.

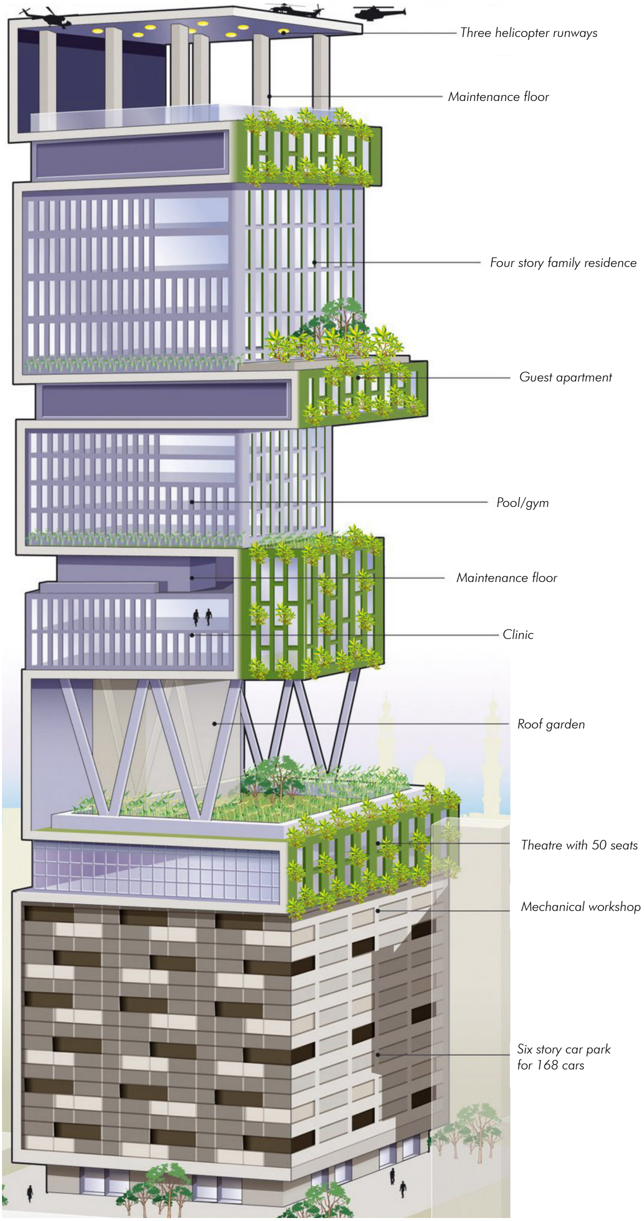


Fig. 1.5.2.2 Program of Antilia [Trincado , B., n.d.]

Fig. 1.5.2.3 Antilia in its context [Becker, J., 2012]

Fig. 1.5.2.4 Interior [Becker, J., 2012]

Fig. 1.5.2.5 Roof garden [Becker, J.,

1.6

Discussion.

In this chapter it becomes clear that a big house can be interpreted in different ways. Starting with the smallest big houses it immediately becomes clear that there are no strict boundaries of a big house. Whether or not a house is big depends to a large extent on the context from which one looks at it. Take, for example, the project 'Buitenhuisjes'. A project with a small floor space but by making clever use of the space it still looks large and contains many functions. In this chapter it also becomes visible that a house can be big in size but look not big and has a low impact on the appearance of the environment like we have seen at Villa Vals. In the paragraph 'XL' we see that a big house does not only have to be intended for a family. A combination of different studios with shared functions such as a bike shed, laundry room, etc. can also form a big house. The last category, XXL, shows that a big house can take on extreme forms. Not only a combination of several smaller living units together but also a single family house can take on extreme forms as we see in the Antilia project.

So in this chapter it becomes clear that there is no hard limit for a big house. It can be a house with a smaller surface area in which several people live as well as a very large surface area in which only one family lives. It is about multi-functionality, smart solutions and representation.

2

Connecting to real social issues and architectural discourse

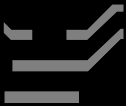
2.0

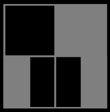
Introduction.

This section gives an overview of case studies which focus at various social issues. The case studies are divided using four typological groups: Social Housing, Co-living, Care and Emergency Housing. These groups are then ordered according to the severity of the social situation they deal with. Social Housing is considered the least severe, after that Co-living, and thirdly Care. Emergency Housing is considered the most severe social situation as they provide shelter for people in relatively harsh circumstances. The specific case studies were chosen for their exemplary approach within their typological group. They are examined to start a discussion about social issues, which are relevant for this graduation studio.

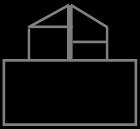
2.1

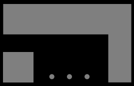
Social Housing



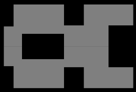


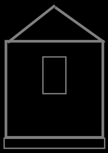
Co-living





Care





Emergency housing

Fig. 2.1.1.1 Quinta Monroy housing unit [Palma, C. , n.d.]

2.1.1 QUINTA MONROY

Architect:	ELEMENTAL
Place:	Iquique, Chile
Date of built:	2003
Function:	Social housing

Why?
This project illustrates a very unconventional approach to house 100 families in a location they have occupied since 30 years. The project allows for qualitative dwellings for a very limited budget in a relatively expensive location.

Important boundary conditions were the Housing Policy and a $7.500 subsidy for each dwelling (including land acquisition, infrastructure and building). Although the land prices are relatively high in this specific area, the goal of the project was to accommodate the 100 families in the same site and not in a cheaper area. Normally social housing projects in Chile are developed in very cheap and remote areas, far away from facilities such as work, transportation and healthcare. This leads to a very inefficient land use. Also a good location for the dwellings will allow for a constant of even rising value of the properties, which makes the investment more interesting.

Still, the high land prices and the limited budget made it very hard to house the 100 families. A $7.500 budget allows for a rough 30m2 of area to build on. Making very narrow dwellings with the width of one room seems logic. However when a family decides to enlarge the dwelling by building on the front or the back of the building, it will block daylight and fresh air in the existing rooms and it will create a linear organization in the building with multiple rooms in a sequence, which affects the privacy of each rooms.
A high-rise building could also be possible, but this would not allow the families to expand their dwellings in a later stage, which is something the architect considered important for this target group.

Four starting points were important for the design of this social housing project:

1. Create enough density to fit in the limited area while preventing overcrowding.
2. Create collective spaces, which is an intermediate between private and public spaces. It provides restricted access but also contributes to the social system in the families.
3. Create structures that can facilitate later expansions instead of limiting this. In this way later expansions will not negatively affect the value of the dwellings.
4. Create dwellings which will be delivered to the families unfinished to limit the buildings costs.

Especially this last point, to deliver half-finished buildings, seems very strange for an architect. Still this approach is expected to be very beneficial for the future property value. The architect provides the families with an expandable structure in which only the essential elements are present, such as kitchen, bathroom, stairs and carrying walls and floors. These elements will be executed within the $7.500 budget and the families themselves can later expand the dwellings to a maximum of 72m2 with functions like bedrooms and storage. In this way a qualitative core within a limited budget is delivered, which can be later be enlarged without affecting the spatial quality and value of the properties. [Fracalossi, I., 2008][2.1.1.1]

Fig. 2.1.1.2 Core housing units at delivery [Palma, C. , n.d.]

Fig. 2.1.1.3 Housing units after expansion by the residents [ELEMENTAL, n.d.]

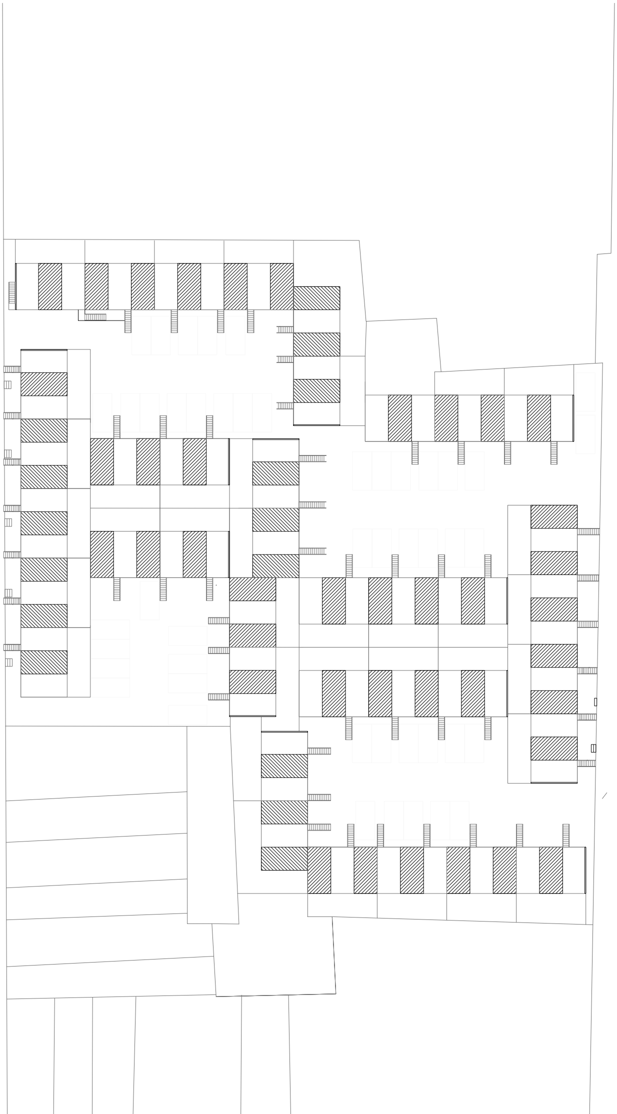


Fig. 2.1.1.4 Site plan [ELEMENTAL, n.d.]

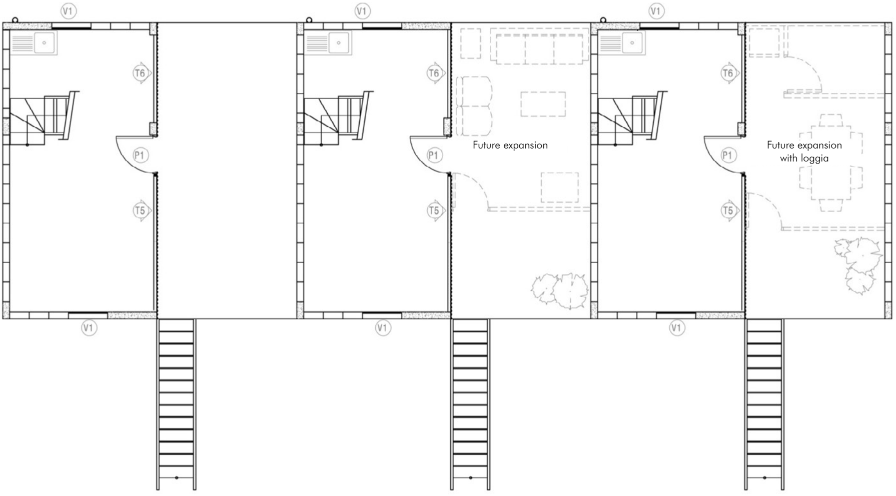


Fig. 2.1.1.5 Floorplan 2nd floor [ELEMENTAL, n.d.]

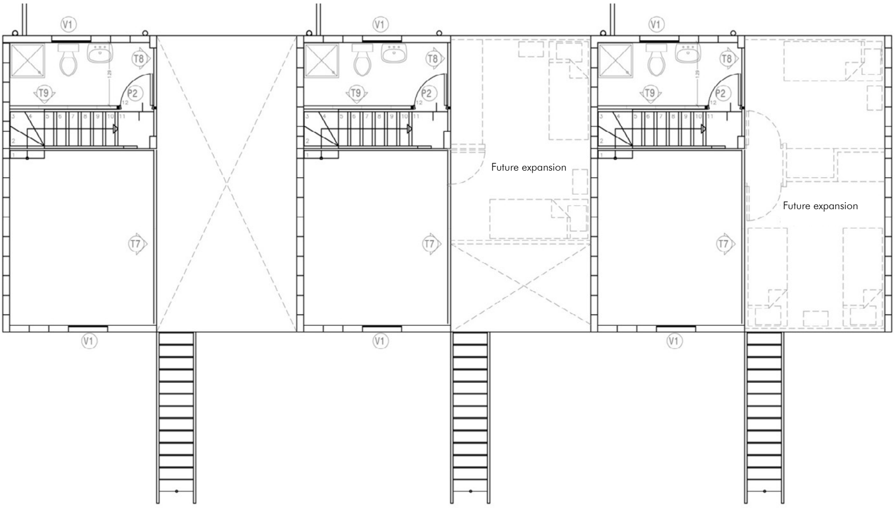
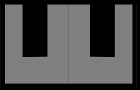
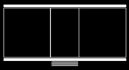


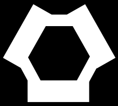
Fig. 2.1.1.6 Floorplan 3rd floor [ELEMENTAL, n.d.]

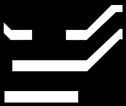
2.2

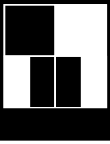


Social Housing

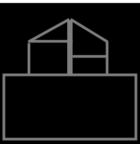


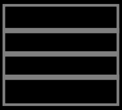


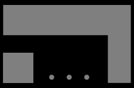




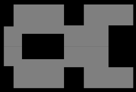
Co-living

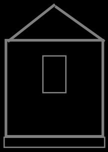






Care





Emergency housing

Fig. 2.2.1.1. Exterior [Dujardin,F., n.d.]

2.2.1 CO-LIVING COMPLEX

Architect:	bureau SLA
Place:	Almere, Netherlands
Date of built:	2017
Function:	Co-Living

Why?
This building shows that it is possible to design your own house with a small budget. You can build together with other people to reduce the costs and then everyone can live in their own designed home based on their own wishes.

A client of bureau SLA dreamed of an alternative way of living. He asked bureau SLA to design his dream house on a potato field from one hectare. But because the budget was limited it was not possible to build a free-standing villa. Then the architect came with the solution of finding friends who wanted to join the project. It is cheaper to build several houses at the same plot and time then one house. The client was able to find some friends and they started making plans for the different livings.

The limited budget was a key feature in the budget. The result of that is a 100 meter long building containing out of 9 livings. The positioning of the building on the plot leaves the greatest amount of space for creating a community garden.

The building was raised from the ground to make it seems like it is floating. The roof cantilevers to provide the residents for the sun. To make it easier to make contact with the neighbours the roof is cantilevering creating a huge porch.

Inside the building, everyone has been given 160 square meters of family space, which they could freely allocate.

The building is the winner of the Frame Award 2019 in the category Co-living Complex [Luco, A., 2019][2.2.1.1].

Fig. 2.2.1.2 Cantilevering roof [Dujardin,F., n.d.]

Fig. 2.2.1.3 *Overview of the complex [Dujardin,F., n.d.]*

Fig. 2.2.1.4 *Interior of one of the homes [Dujardin,F., n.d.]*

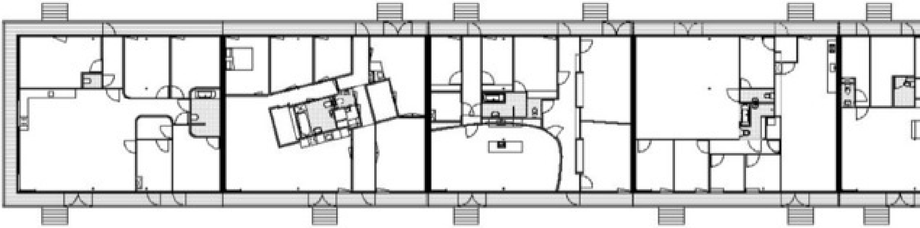


Fig. 2.2.1.5 Plan [bureau SLA, n.d.]

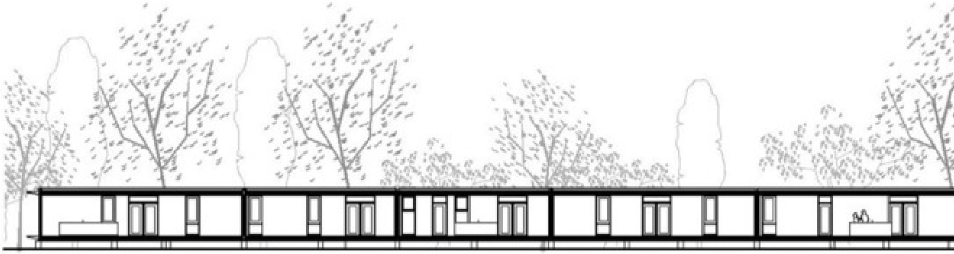
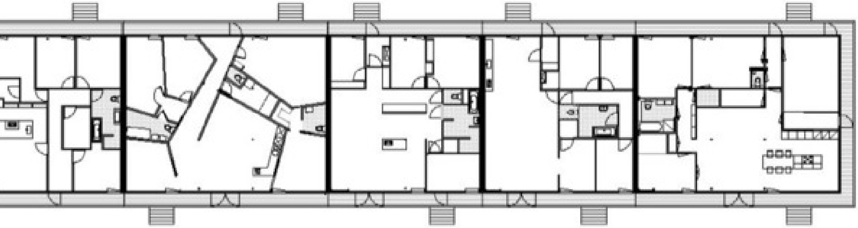


Fig. 2.2.1.6 Section [bureau SLA, n.d.]



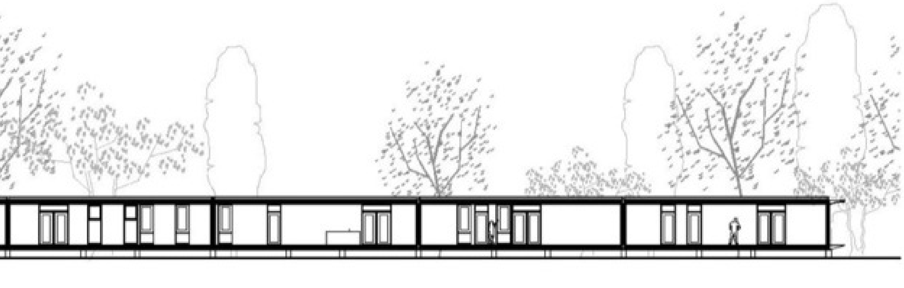


Fig. 2.2.2.1 Circle of containers [Urban Rigger, n.d.]

2.2.2 URBAN RIGGER

Architect:	BIG Architects
Place:	Copenhagen, Denmark
Date of built:	2016
Function:	Co-Living

Why?
Over the years, the number of students in Denmark has increased, and with it the demand for student housing. This project consist of student housing which can expand fast and meet the needs of the students.

Over the years, the number of students in Denmark has increased, and with it the demand for student housing. This number will continue grow and therefore additional student housing will be needed. A solution to this problem can be found in Copenhagen.

Here the port, an unused and underdeveloped place in the city, has been renamed a residential area for students. A building typology has been designed for them that is optimized for port cities. This typology ensures that students stay in the city.

A standardized container system has been developed that makes it possible to transport goods all over the world at very low costs. The use of containers makes it possible to create a flexible building typology.

The architect has placed the containers in a round shape. There are three container homes on the ground floor, and nine container homes on the first floor. In the middle of the houses is a winter garden where the students can come together.

The containers float in the water and all circles can be linked and form a whole. [BIG, 2016][2.2.2.1]

Fig. 2.2.2.2 Outside circle [Urban Rigger, n.d.]

Fig. 2.2.2.3 Wintergarden [Urban Rigger, n.d.]

Fig. 2.2.2.4 Interior [Urban Rigger, n.d.]

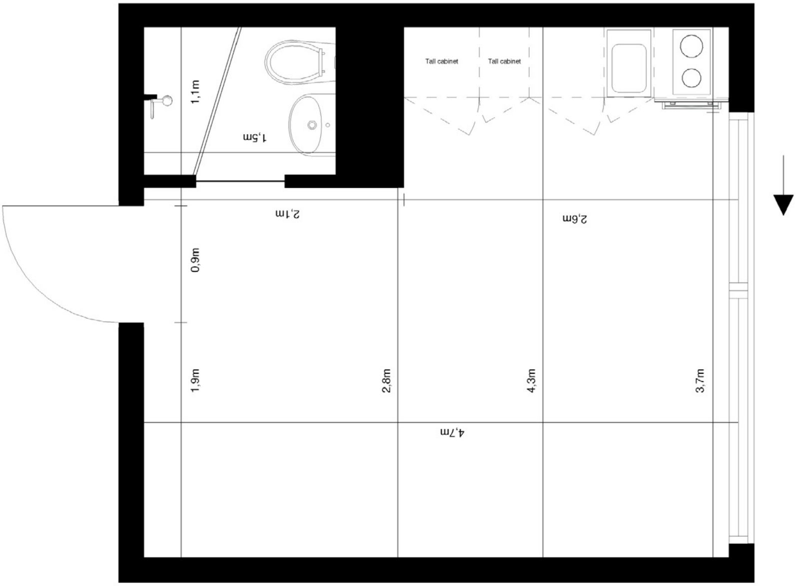


Fig. 2.2.2.5 Plan apartment number 8 [Urban Rigger, n.d.]

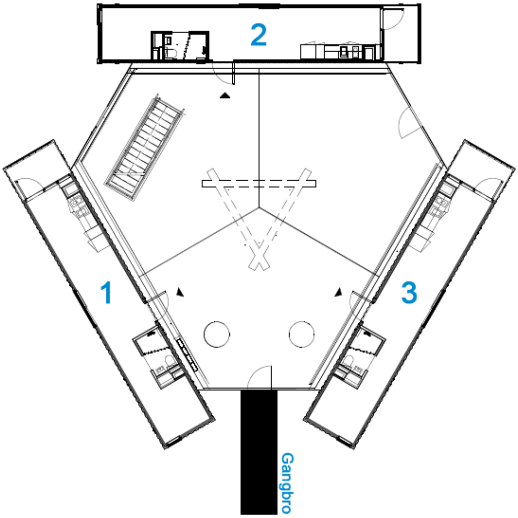


Fig. 2.2.2.6 Ground floor [Urban Rigger, n.d.]

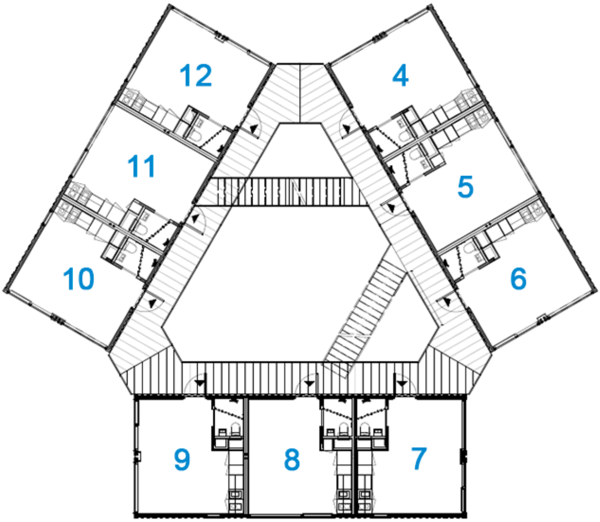


Fig. 2.2.2.7 First floor [Urban Rigger, n.d.]

Fig. 2.2.3.1 Facade [Van Capelleveen, E., n.d.]

2.2.3 SOCIAL BALCONIES

Architect:	Edwin van Capelleveen
Place:	Netherlands
Date of built:	2018
Function:	Co-Living

Why?
This project connects the problem of being on your own in your own apartment with architecture. The balconies stimulate social contact between the neighbours.

This project is a project designed by a product designer, Edwin van Capelleveen, for his graduation at the Design Academy Eindhoven.

The project is a concept for a modular balcony system that is designed to get more contact between neighbours. The concept consists of a set of modular components that can be placed between pre-existing elements in a way that they are connected and create a new shared space in-between. This should encourage neighbours for communal activity.

The modules consist of staircases to connect neighbours on different levels and bridges to connect neighbours next to each other. Besides the staircases and bridges the system also consists of planters to make the building comming more alive.

As the designer said: “This living concept places itself between co-housing and a private way of living. It offers a more delicate way of implementing social cohesion for the masses.” [Jordahn, S., 2019][2.2.3.1]

Fig. 2.2.3.2 Planter [Van Capelleveen, E., n.d.]

Fig.2.2.3.3 Facade [Van Capelleveen, E., n.d.]

Fig. 2.2.3.4 Facade [Van Capelleveen, E., n.d.]

Fig. 2.2.3.5 Facade [Van Capelleveen, E., n.d.]

Fig. 2.2.4.1 Impression of the Urban Village community [SPACE10, n.d.]

2.2.4 URBAN VILLAGE PROJECT

Architect:	SPACE10 and EFFEKT Architects
Place:	Under development
Date of built:	Under development
Function:	Co-living

Why?
Climate change, growing city populations, ageing populations and rising housing prices are big challenges for which urban populations need to formulate answers. This project proposes a solution.

This project still is in a conceptual phase and is being developed by SPACE10 and EFFEKT Architects. The Urban Village Project is a communal housing project which focusses on the topics of "Liveability", "Sustainability" and "Affordability". It rethinks how houses are being designed, built, financed and shared in the future cities.
Local water supply, renewable energy production, local food production and local waste processing are important elements for a more sustainable community. Apartments in different layouts for different individuals, couples or families are provided. They are built of Cross Laminated Timber, which reduces the environmental footprint compared to other building materials. Moreover the dwellings are modular and demountable, which allows for easy adaptations and recycling of building parts. The standardized building systems of the Urban Village Project can be prefabricated on a large scale. This allows for cheaper production and more control for the communities over their property. Also the share of resources leads to better affordable living conditions. People living in the communities together pay for and share for basic needs like rent, electricity, water, heating, maintenance etc. Additional needs like food, insurance, transportation and recreations could also be collectively arranged. Lastly people can buy real estate shares to become owner over time. [SPACE10, n.d.][2.2.4.1]

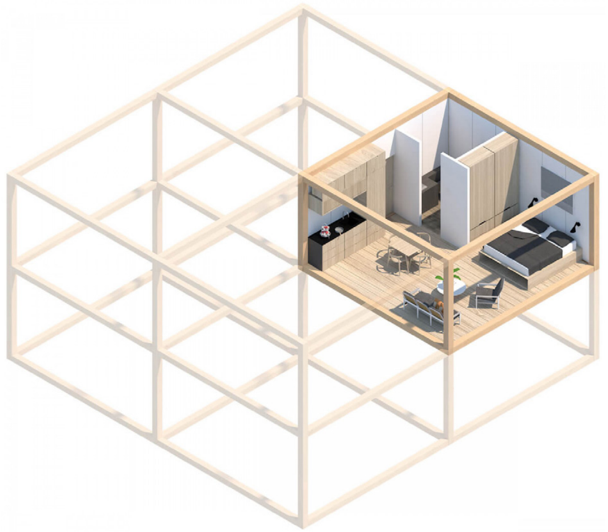


Fig. 2.2.4.2 Small housing module [SPACE10, n.d.]

Fig. 2.2.4.3 Large housing module [SPACE10, n.d.]

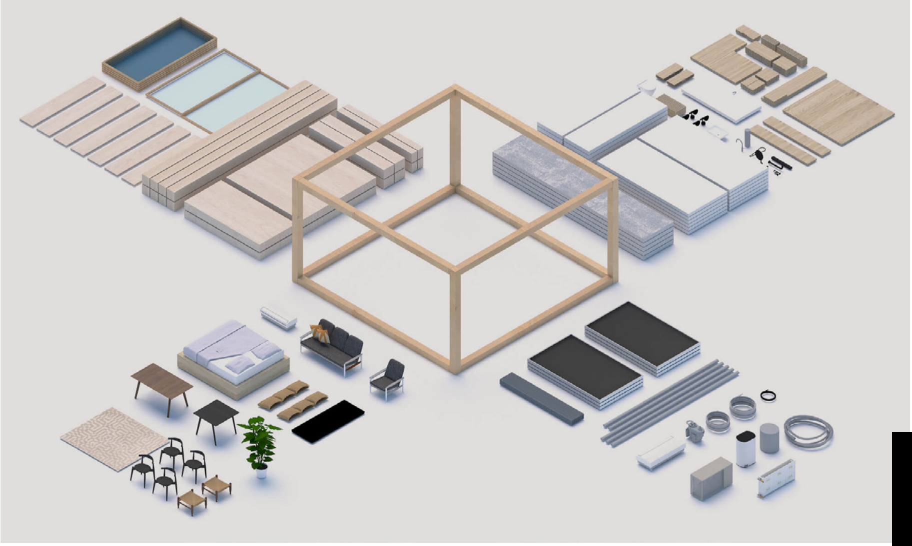
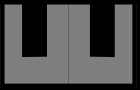


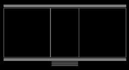
Fig. 2.2.4.4 Demountable module parts [SPACE10, n.d.]

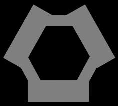
Fig. 2.2.4.4 Impression of urban embedding of Urban Village [SPACE10, n.d.]

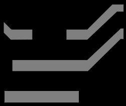
2.3

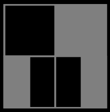


Social Housing

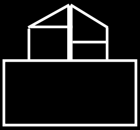


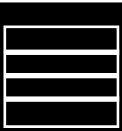




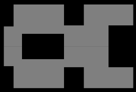


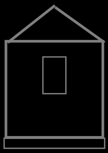
Co-living





Care





Emergency housing

Fig. 2.3.1.1 Exterior night view [EGM, n.d.]

2.3.1 RONALD MCDONALD HOUSE

Architect:	EGM
Place:	Utrecht, Netherlands
Date of built:	2011
Function:	Care

Why?
This Ronald McDonald Family Room is a place for families to retreat with their kids, away from the crowdedness in the city. This tree-house concept is strong in the way it has designed for the function in to give comfort to kids, away from any hospital treatment.

Safety, homeliness and comfort were important starting points for the design of the Ronald McDonald Living Room at the Wilhelmina Children's Hospital. A place where children, parents and siblings can escape the hospital, if only for a while.
A place without medical hustle and bustle, a place with a cosy and homely feel. A place to relax, read a book, play board games or computer games or watch television.

The Ronald McDonald Living Room is located on the roof of the entrance hall at the Wilhelmina Children's Hospital.

The wish to leave the medical environment behind was brought to life through a 'treehouse' design: a little free-standing house with a pointed roof, just like the one every child knows and draws.

The roof and exterior side elevations of the 'treehouse' are clad with slate in grey and orange hues. The north elevation consists entirely of glass in a robust wooden frame. This contrast continues inside. High ceilings are juxtaposed with snug corners. Room dividers made of wooden columns provide privacy or indeed subtle view lines. Natural materials such as wood and cork and warm colours create a homely atmosphere.

Ronald McDonald Living Room contributes to a pleasant stay in hospital and hopefully promotes a speedy recovery.

[EGM, 2011][2.3.1.1].

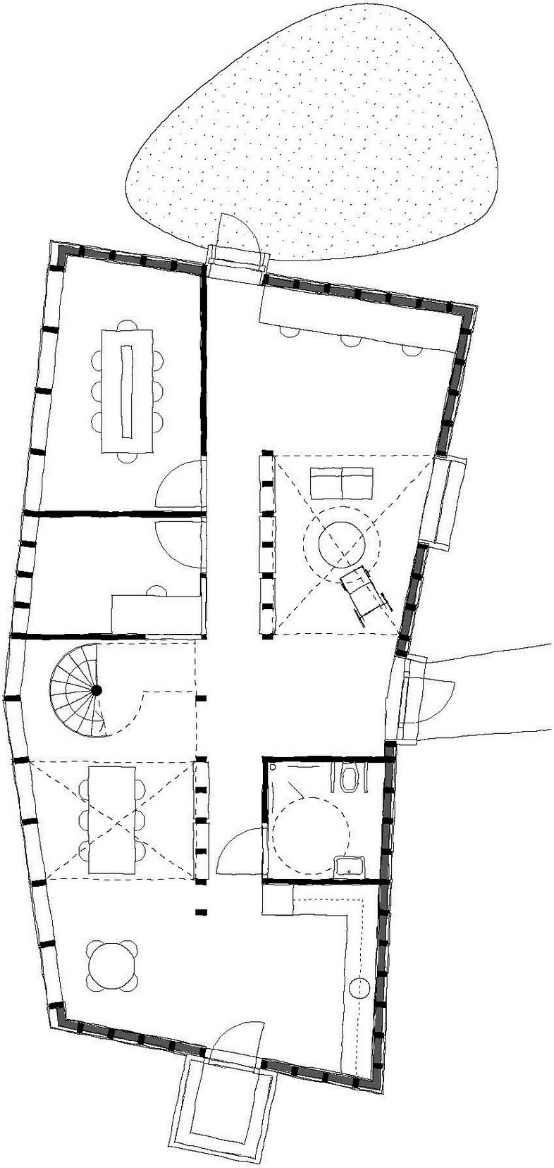


Fig. 2.3.1.2 Ground floor [Archdaily, n.d.]

Fig. 2.3.1.3 The hallway [EGM, n.d.]

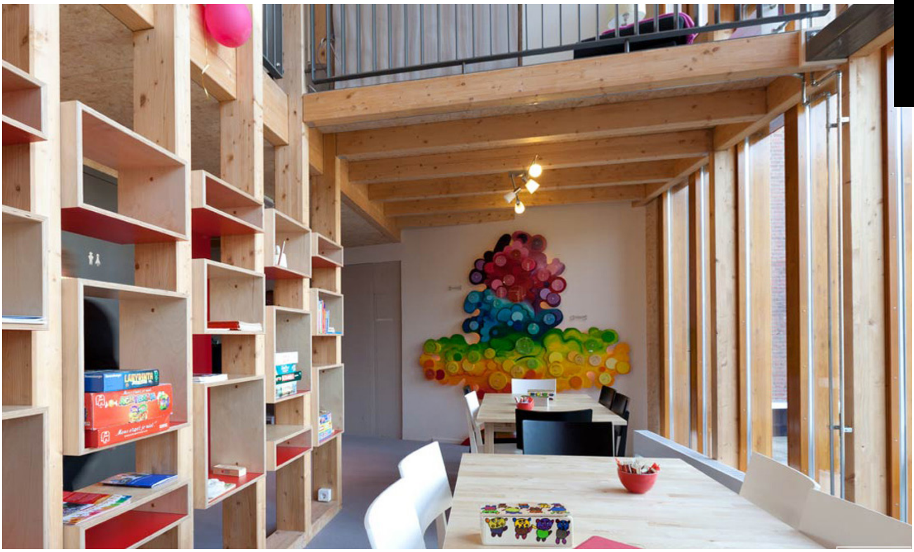


Fig. 2.3.1.4 Playing space [EGM, n.d.]

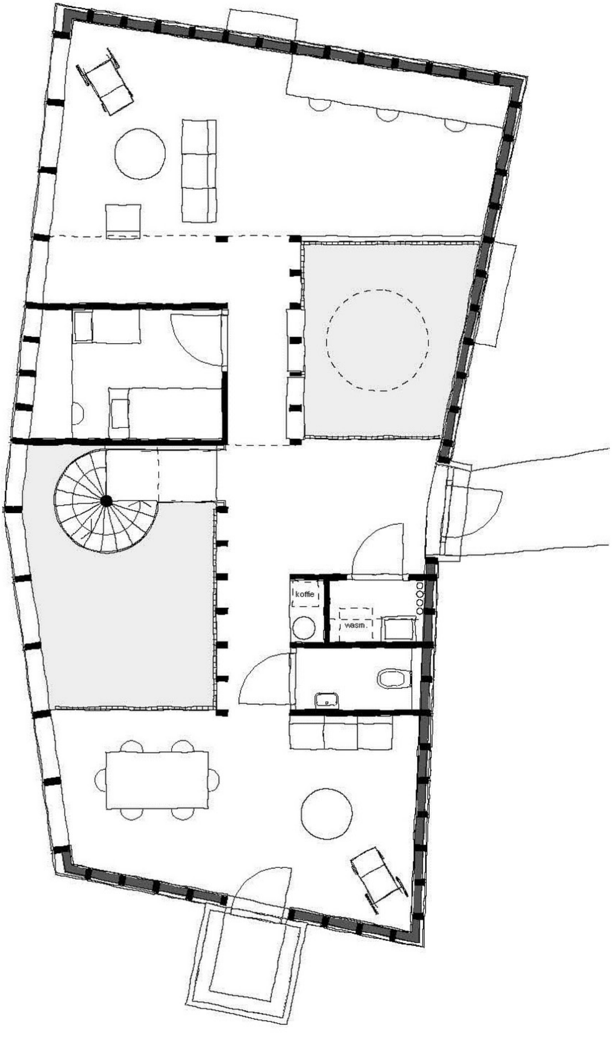


Fig. 2.3.1.5 First floor [Archdaily, n.d.]

Fig. 2.3.1.6 inside the tree [EGM, n.d.]

Fig. 2.3.1.7 Learning space [EGM, n.d.]

Fig. 2.3.2.1 Exterior [Archdaily., n.d.]

2.3.2 DRUG ADDICTS HOTEL

Architect:	Kempe Thill
Place:	Amsterdam, Netherlands
Date of built:	2012
Function:	Care

Why?
This building for drug addicts shows the social aspect the whole building is neutrally organised. The specific colours green and white suits the psychological atmosphere where the addicts are housed in.

The drug addicts hotel was designed by Kempe Thill architects in 2012. The simple building consists rooms and a communal space in the middle with activities for the addicts and serves as an atrium for the visitors.

The building is owned by a building society and has been rented by a foundation for a period of ten years. Yet unclear is whether the building will still be used as a "Drug Addicts' Hotel" after 2022, or whether it should be used for other programs down the road. In order to make it possible for the owner to make simple adaptations within the structure, Atelier Kempe Thill was, for the first time, faced with the challenge of creating a structure that is truly neutral in function.

Due to its compactness and its use, it is important that a considerable amount of natural daylight is available within the building. The façade was therefore generously glazed and allows significant light to penetrate the interior. The central atrium is illuminated by a skylight and receives additional light via the façade. Space-dividing walls are often executed in glass, which gives rise to expansive visual connections within the building that are necessary for facilitating an overview and for social interaction.

[Archdaily, 2012][2.1.1].

Fig. 2.3.2.2 The atrium [Archdaily, n.d.]

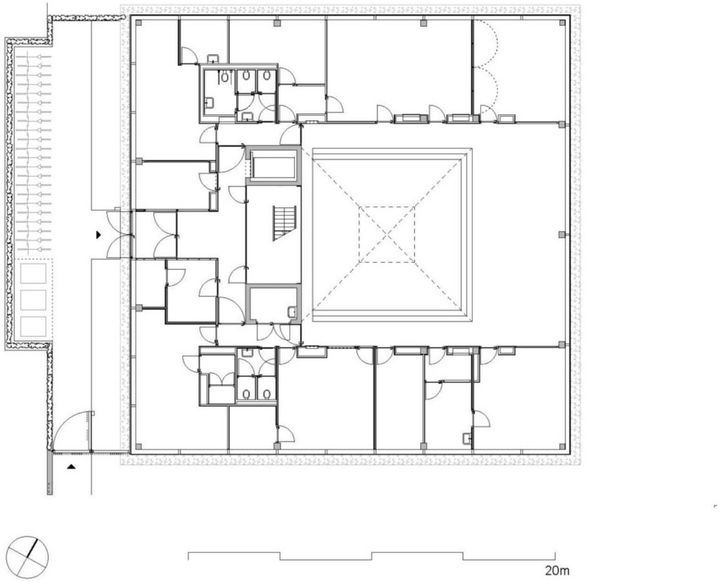


Fig. 2.3.1.3 The floorplan [Archdaily, n.d.]

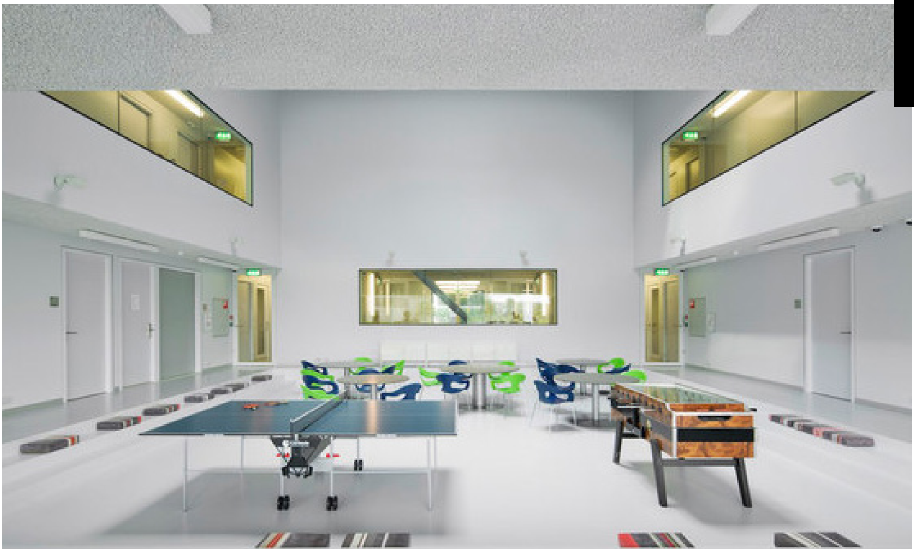


Fig. 2.3.2.4 communal space in the cavity [Archdaily, n.d.]

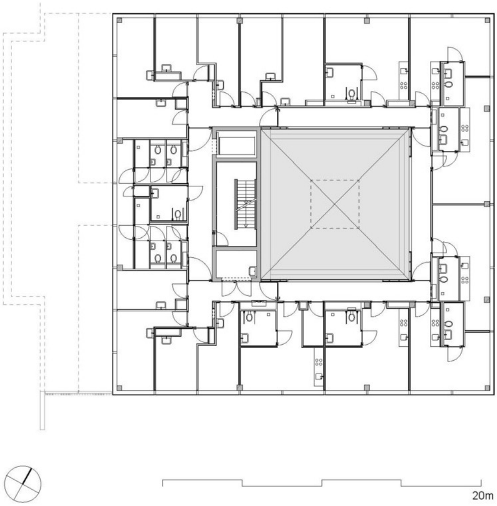


Fig. 2.3.2.5 the atrium floorplan [Archdaily, n.d.]

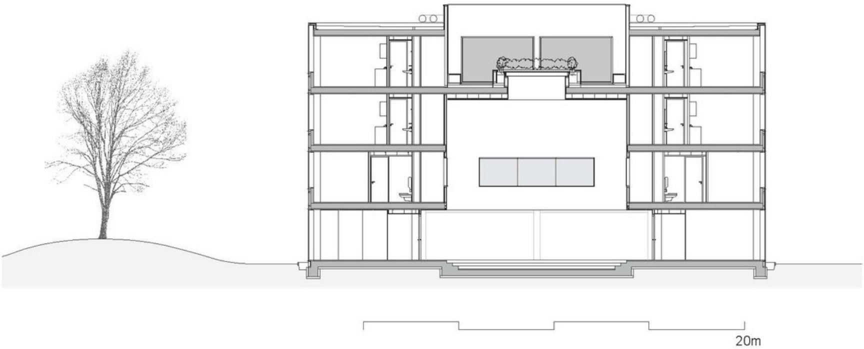


Fig. 2.3.2.6 Section [Archdaily, n.d.]

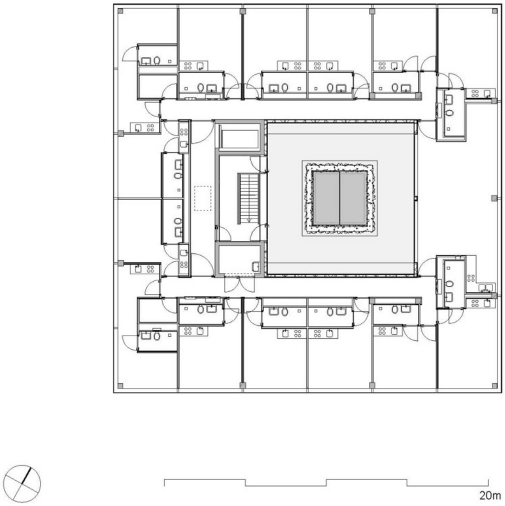


Fig. 2.3.2.7 roof floorplan [Archdaily, n.d.]

Fig. 2.3.2.8 Roof terrace [Archdaily, n.d.]

Fig. 2.3.3.1 Facade Children's Home [Calandra, F., n.d.]

2.3.3 CHILDREN’S HOME IN NOSY BE

Architect:	Aut Aut Architettura
Place:	Hell-Ville, Madagascar
Date of built:	2019
Function:	Care

Why?
This project is located in the context of extreme social conditions. Not only is it situated in one of the poorest regions on earth, it also aims at one of the most vulnerable groups in society: physically disabled children. This design responds to this situation.

This project was initiated by a Non-Profit Organization (NPO) which assists children with physical disabilities. Madagascar is characterized by poverty and limited healthcare and education. This building provides 36 vulnerable children with a place to eat and sleep and a place where they can study and meet each other. It has been realized next to an existing school building.
The building consists of two dormitories, sanitary rooms, nurse rooms, a kitchen, a dining room and a central covered outside space connecting to the school yard.

The roof has been detached from the underlying spaces to create an air layer. The upper roof provides shelter against the extreme sunlight and heavy precipitation while the lower roof is airier to allow for natural air circulation. [Silva, V., 2020][2.3.3.1]

This project was designed by Aut Aut Architettura, an office of four young architects in Rome. According to their description their strategy aims at ‘social enhancement’. They use architecture as a tool to ‘catalyse a discourse through new and even provocative spaces’. They also strive for a reduce ecological footprint of architecture.
[Aut Aut Architettura., n.d.][2.3.3.2]

Fig. 2.3.3.2 Roofed collective space [Calandra, F., n.d.]

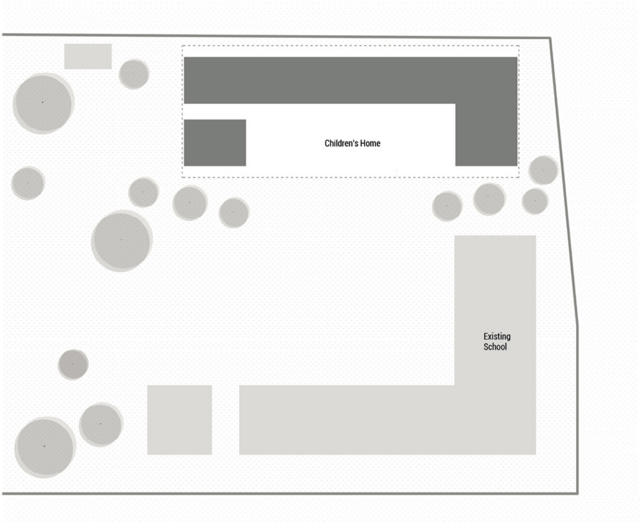


Fig. 2.3.3.3 Site plan [Calandra, F., n.d.]

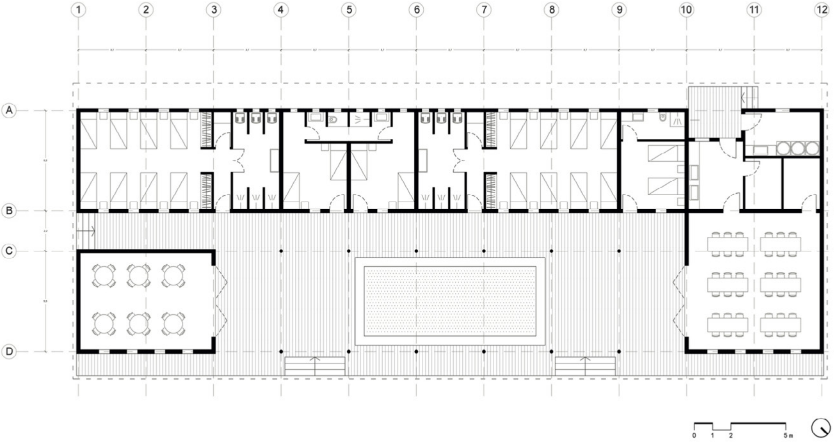
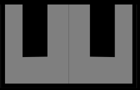
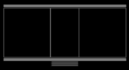


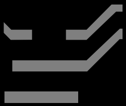
Fig. 2.3.3.4 Floorplan [Aut Aut Architettura., n.d.]

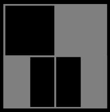
2.4



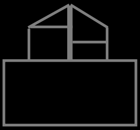
Social Housing

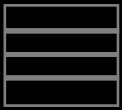


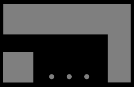




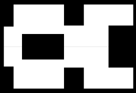
Co-living

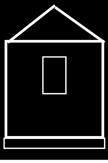






Care





Emergency housing

Fig. 2.4.1.1 Front facade of the shelter [One Light Studio, n.d.]

2.4.1 HOME FOR THE HOMELESS

Architect:	xystudio
Place:	Jankowice, Poland
Date of built:	2019
Function:	Emergency housing

Why?
This project provides an exclusively designed home for homeless people. It houses an extensive program for a very vulnerable group located in a very representative and idyllically located building.

This shelter was established for homeless people with physical disabilities who cannot apply for the regular care facilities in Poland. The project was initiated by nuns and the people living here have 24-hour care. The project is located in a remote area. The idyllic landscape plays an important role in the view from the rooms.

The front part of the building contains some public spaces. Here a chapel, offices and shared spaces such as the canteen are located. In the next part of the building the residences for the homeless people are found. There are 18 rooms with adapted bathrooms, which can be shared by multiple people. The rooms were designed very small to trigger the people to go out and rehabilitate among others.
In the centre of the building a courtyard provides the adjacent rooms with light and outside space. Many areas in and around the project are arranged in such a way to stimulate social interactions. Even the countless tobacco addicts are facilitated in order to help them to socialize.
In the back of the building the private rooms for the nurses are located. Four small apartments provide the people who care for the others with some privacy and the possibility to retreat from the hard reality in the house.
For the project cheap but ecological materials were used. For instance bricks from demolished buildings were recycled in this project. It is a very modern building but with very tangible, human character.
[Tapia, D. 2020][2.4.1.1]

Fig. 2.4.1.2 Recycled brickwork in the facade [One Light Studio, n.d.]

Fig. 2.4.1.3 Front garden with entrance [One Light Studio, n.d.]

Fig. 2.4.1.4 Aerial view with surrounding landscape [One Light Studio, n.d.]

Fig. 2.4.1.5 Floorplan [xystudio, n.d.]

Fig. 2.4.2.1 Paper Log Houses [Tadaima, n.d.]

2.4.2 PAPER LOG HOUSES

Architect:	Shigeru Ban
Place:	Kobe, Japan
Date of built:	2016
Function:	Emergency housing

Why?
This project provides shelter for the refugees of disasters in the Kobe region in Japan.

TThe Japanese architect Shigeru Ban is known for his innovative work with paper, particularly recycled cardboard tubes used to quickly and efficiently house disaster victims.

Kobe was the hardest hit city with 4,571 fatalities, more than 14,000 injured, and more than 120,000 damaged structures, more than half of which were fully collapsed. At the time a young Tokyo-based architect, Shigeru Ban responded to the urgent need for temporary relief shelter by designing the Kobe Paper Log House, which served to house thousands of displaced Kobe residents. Since its creation, Ban has been called on by such organizations as the United Nations to develop his innovative structures, regarded for their low cost, easy accessibility and simple application.

The foundation consists of donated beer crates loaded with sandbags. The walls are made from 106mm diameter, 4mm thick paper tubes, with tenting material for the roof. The 1.8m space between houses was used as a common area. For insulation, a waterproof sponge tape backed with adhesive is sandwiched between the paper tubes of the walls. The cost of materials for one 52 square meter unit is below $2000. The unit are easy to dismantle, and the materials easily disposed or recycled, as a result of this, Ban's DIY refugee shelters are used around the world.

[Michalarou, E., n.d.][2.4.2.1]

Fig. 2.4.2.2 Exterior view of the Log House [Tadaima, n.d.]

Fig.2.4.2.3 Inside the Log house [Tadaima, n.d.]

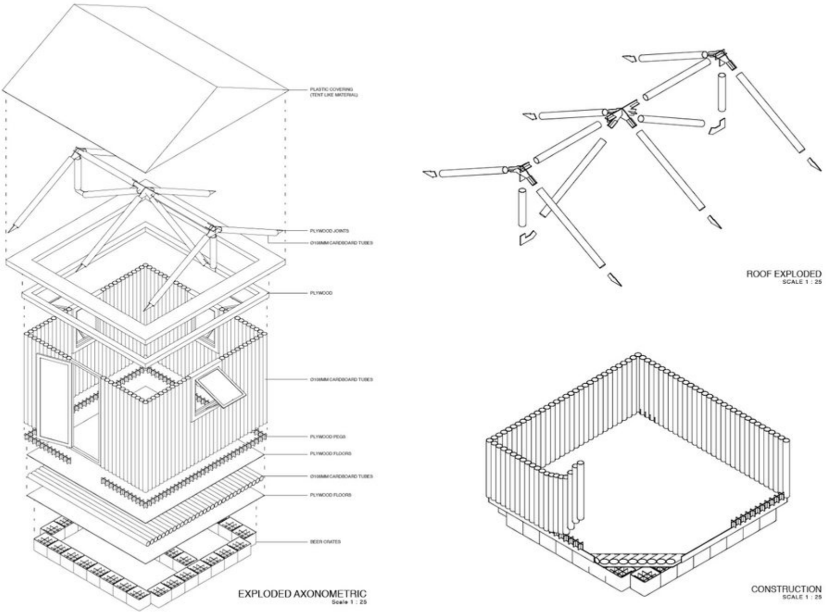


Fig. 2.4.2.4 The construction [Tadaima, n.d.]

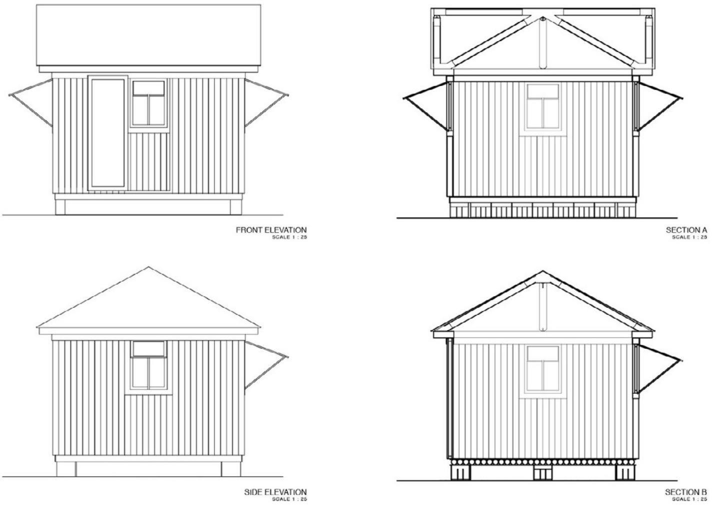


Fig. 2.4.2.5 Elevations & Sections [Tadaima, n.d.]

2.5

Discussion.

Multiple case studies, which deal with different social issues in different ways, have been discussed. They show a variety of short term emergency solutions for extraordinary situations to long term structural solutions for everyday life. Especially projects which formulate new approaches for everyday social questions, such as social housing and co-housing, appear to be very interesting. They offer alternative housing types for different locations in the world, with different circumstances and with different purposes. Some projects focus on creating affordable housing for low incomes, while others propose new housing types to allow for more social and ecological communities. Further research on new ways of designing, building and using our houses appears very relevant for many people in many places.

3

Incorporating the extensive use of emerging technologies

3.0

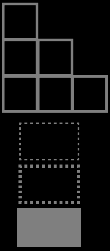
Introduction.

This chapter shows the emerging technologies used in housing today: Demountable, Expandable, Energy-efficient & 3d printing. The reason to arrange the different technologies types in this order from low-tech to high-tech is that we would like to put the low-tech technologies first that are most relevant to our social issues and constraints. According to our social issues of low costs, local materials, and off-grid housing, these specific case studies are chosen to showcase which advantages has on the productivity in the construction process.

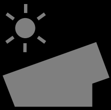
3.1

Off the grid

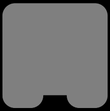
Demountable

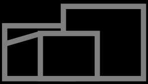


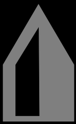
Expandable

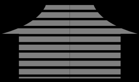


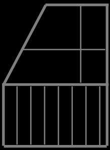
Energy efficient











3D printing

Fig. 3.1.1.1 Retreat in Finca Aguy [Finotti, L., n.d.]

3.1.1 RETREAT IN FINCA AGUY

Architect:	MAPA Architects
Place:	El Edén, Uruguay
Date of built:	2015
Technology:	Prefabrication/off-grid

Why?
This project shows the practical implementation of the off-grid housing concept. It proves the financial, ecological and architectural feasibility of building in remote areas without affecting the landscape.

This retreat provides living space in a remote environment with minimal impact on the landscape. It is located near the town of El Edén in Uruguay and was designed by MAPA Architects. This office is characterized by their aim to fit projects in remote areas. To reduce the impact on the landscape a prefabricated, off-grid (detached from central infrastructure grids) design was chosen. A steel frame and metal cladding were applied for little maintenance.

The placing of the house was primarily focused on optimal views over the landscape and optimal solar orientation. Although carefully embedded, the project as a whole forms a contrasting element in the landscape.
The projects expenditures were approximately $250.000. [Wang, L., 2017][3.1.1.1]

Fig. 3.1.1.2 Transportation of module [Finotti, L., n.d.]

Fig. 3.1.1.3 Placing of module [Finotti, L., n.d.]

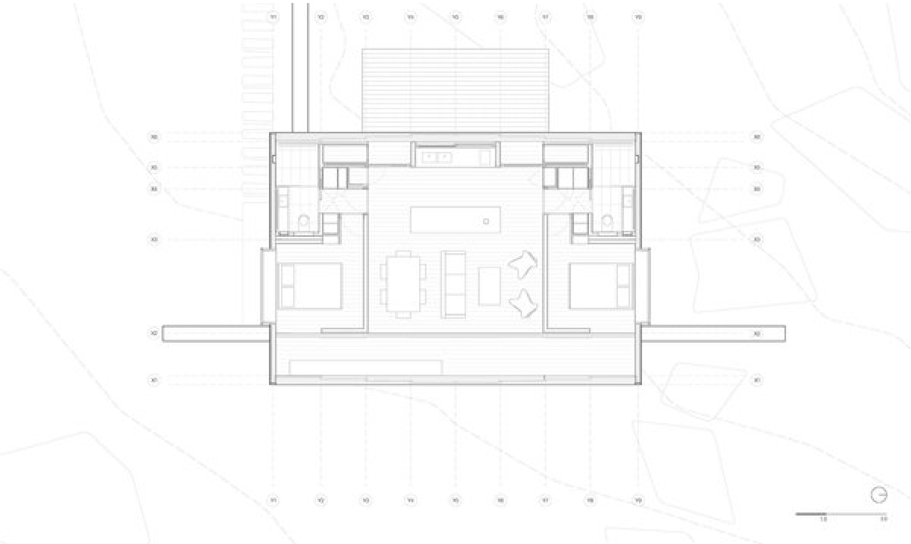


Fig. 3.1.1.4 Floorplan of retreat [MAPA Architects, n.d.]

Fig. 3.1.1.5 Context [Finotti, L., n.d.]

3.2

Off the grid

Demountable

Expandable

Energy efficient

3D printing

Fig. 3.2.1.1 The collective roof garden [GAAGAA, n.d.]

3.2.1 CIWOCO

Architect:	GAAGAA
Place:	Amsterdam, NL
Date of built:	2018/2019
Technology:	demountable

Why?
This project shows how you can build a demountable apartment complex. The project consists for 90% of materials that are recyclable and reusable. It is demountable so can be dismantled when needed.

A testing ground for circular construction is located in Buiksloterham (Amsterdam). One of the projects concerns the CiWoCo project by architectural firm GAAGAA. The architecture firm designed a demountable and adaptive project that can adapt to changing use in the future.

The building is built in two parts that are connected by a collective roof garden. The roof garden is located above the parking garage.

90% of the materials used in the building are recyclable and reusable. Demountable parts have been developed for the concrete structure in collaboration with the builder, Bestcon and Peikko. The shell of the building is therefore completely demountable. The piping, which is normally poured into the floors in residential construction, is included in secondary walls and false ceilings. This makes it possible to demountable the casco. Due to the lack of piping in the floors, the floor is also tinner which makes a difference in the amount of material that is needed.

In addition to the fact that the shell can be dismantled, the use of materials in the building is also sustainable. The facade is made from old sheet pile profiles.

The building is participating in the urban mining trend; the building is a repository of raw materials that can be mined for new use at the end of their life. [GAAGAA,n.d.][3.2.1.1]

Fig. 3.2.1.2 Front of the building [GAAWAA, n.d.]

Fig. 3.2.1.3 Facade [GAAWAA, n.d.]

Fig. 3.2.1.4 Construction site [GAAWAA, n.d.]

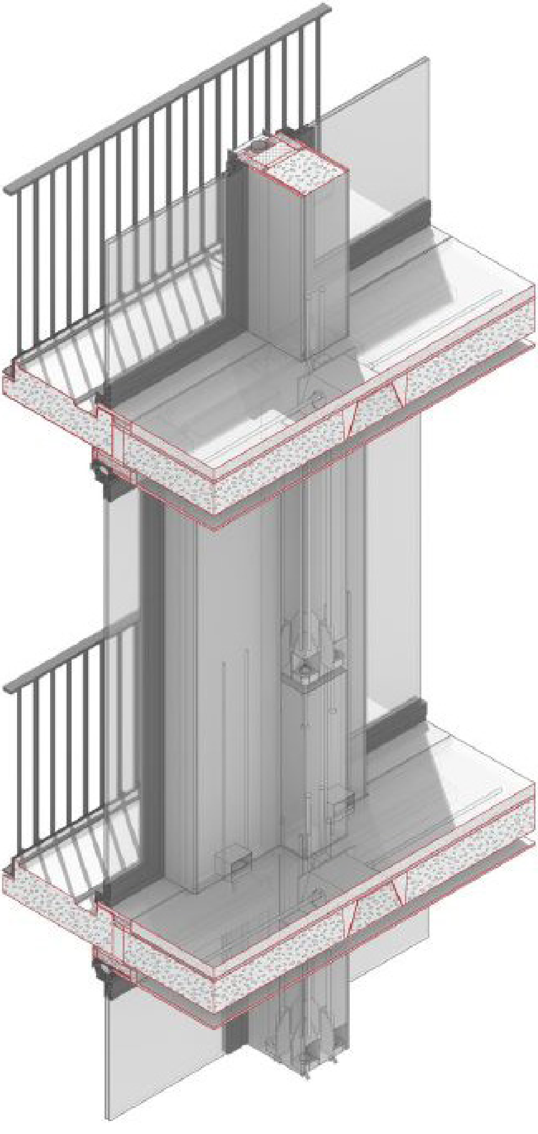


Fig. 3.2.1.5 Facade detail [GAAGAA, n.d.]

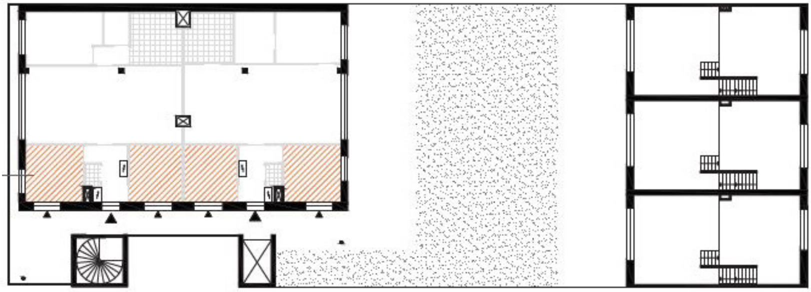


Fig. 3.2.1.6 Plan first floor [GAAGAA, n.d.]

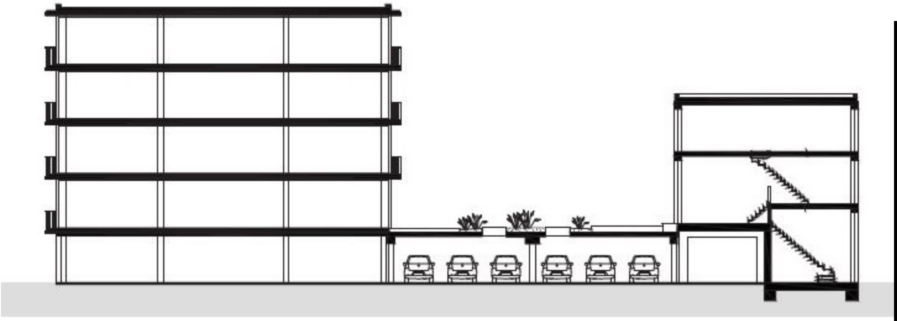


Fig. 3.2.1.7 Section [GAAGAA, n.d.]

3.3

Off the grid

Demountable

Expandable

Energy efficient

3D printing

Fig. 3.3.1.1 Modular stacking [Bartlett school of Architecture, n.d.]

3.3.1 BEYOND THE SHELL

Architect:	LianJie Wu Bartlett school graduate
Place:	UK
Date of built:	2019
Technology:	Expandable

Why?
This project is not a housing project but the innovation of modular stacking of spaces, by the wishes of the user. This technology uses a robot crane to stack the different volumes that fits the base of the structure.

The Modular project Beyong the Shell, designed by Bartlett school of Architecture graduate Lianjie Wu, gives a big overview of how living spaces can be shared and expanded in a modular way.

The concept was to rethink the traditional high-rise tower as a modular, multi-storey estate, with public and private spaces of different sizes stacked on top of each other to create a higher highrise.

Buyers then take ownership of the structural shells and adapt them to suit their needs of expansion and interior tastes.

Wu stated: “The unfinished shell helps to address the issue of over-finished but unaffordable housing supply,” the designer told Dezeen. “It provides a strategy to take advantage of residents’ labour to cut down the construction cost as a way to lower the price.”

Fabrication of the rudimentary structure would take place on site, using a transportable robotic arm crane that would carve blocks of foam into moulds for casting the components in concrete.

The Rebar steel rods would add structural reinforcement to the concrete modules, while built-in channels would allow panels of glass, sliding doors and additional insulation to be slotted into place upon assembling the load-bearing framework.

[Adey, S., 2019][3.3.1.1]

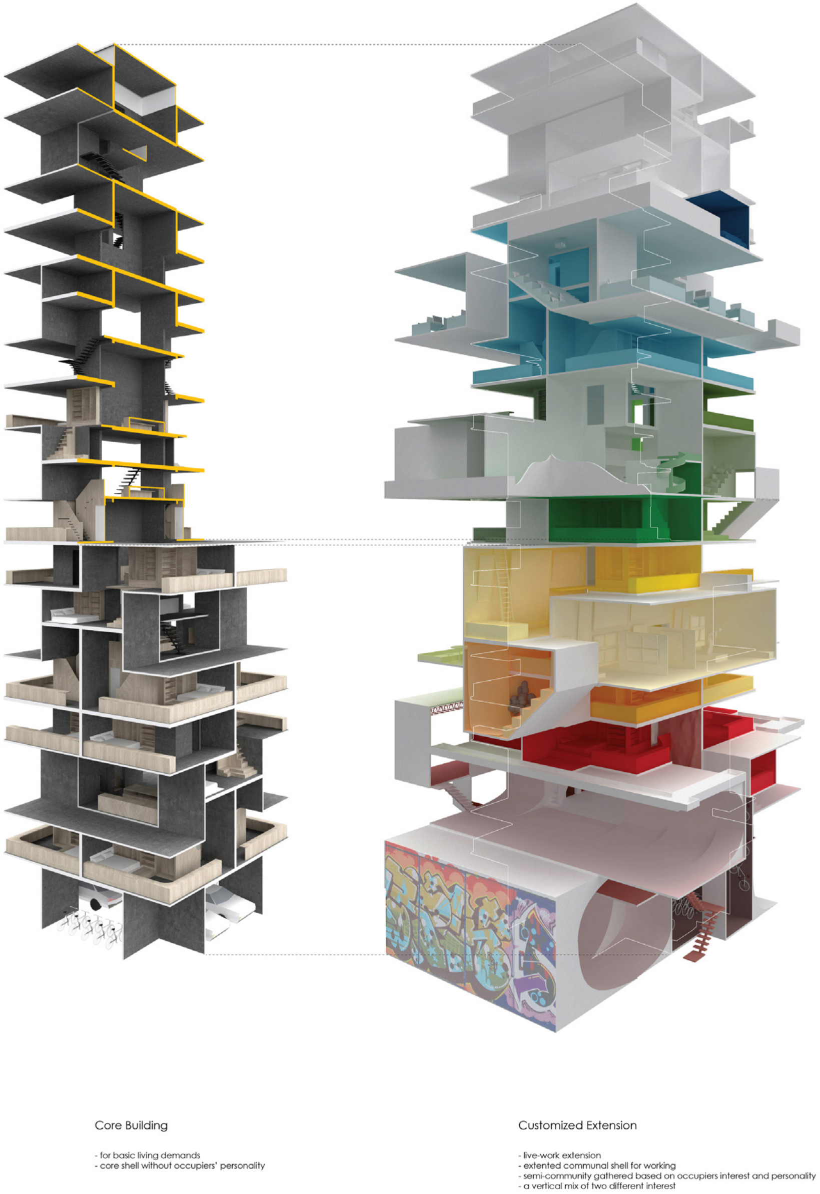


Fig. 3.3.1.2 The modular structure [Bartlett school of Architecture, n.d.]

Fig. 3.3.1.3 Space inside the living [Bartlett school of Architecture, n.d.]

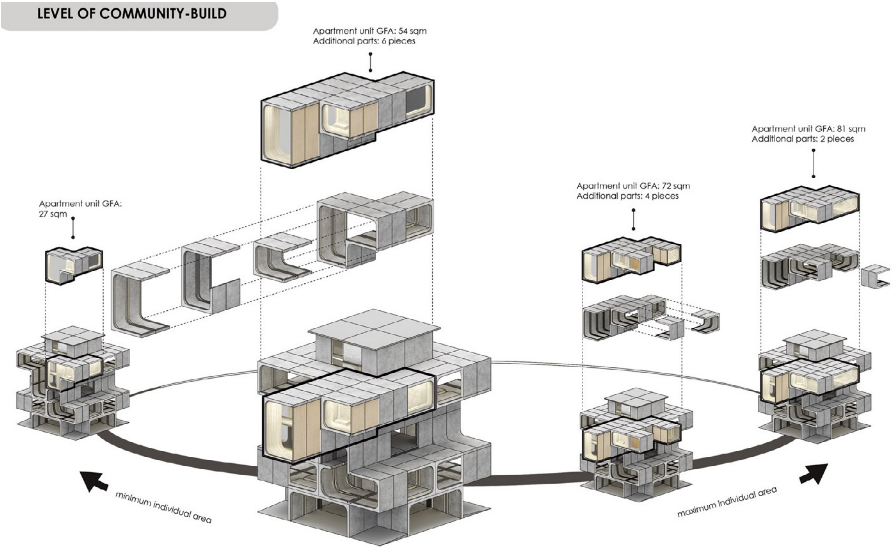


Fig. 3.3.1.4 Modular community in process [Bartlett school of Architecture, n.d.]

Fig. 3.3.2.1 Expandable House [Teteris, C., n.d.]

3.3.2 EXPANDABLE HOUSE

Architect:	Urban Rural Systems
Place:	Nongsa, Indonesia
Date of built:	2003
Technology:	Expandable

Why?
This project illustrates the application of very simple technologies to enhance living conditions in tropical settlements. The low tech solutions in this project allow for affordable building but also form a durable facility in this developing area.

The Expandable House provides affordable living space for the fast-growing population in Asian cities. It is based on the existing informal settlements in tropical areas and the changing dynamics in these areas. The construction is based on a so-called ‘Sandwich Section’: the developer or government provides the foundations, floors and roof (the bread) and the residents provide the infill based on their specific needs and budget. Other functions like shops or cafés are also possible. The roof can be manually hoisted to raise the building to a maximum of three floors. This vertical densification helps to reduce the area needed to house the ever-growing population and to spare land for agriculture. Collecting rainwater, generating solar energy and managing domestic waste on a local scale give a more reliable infrastructure than the centralized system for water, electricity and sewage. Manually hoisting the floors, rainwater and solar energy collection and managing domestic waste using septic tanks has been tested since 2018. The prototype has reached its maximum size of three floors and 108m2 floor space. Next step is testing this concept on a township level with public spaces, energy and water sharing and cooling. This is done with mockups. Developers work on acquiring sites for commercial implementation. The expandable house contains technologies that can be adapted to the local characteristics. It could therefore be applied in the development of many towns in tropical areas. [Abdel, H., 2020][3.3.2.1]

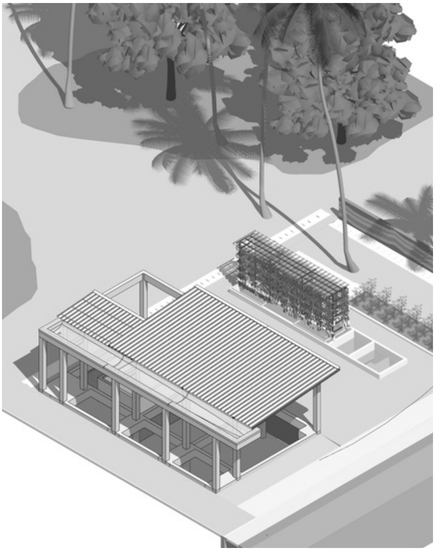


Fig. 3.3.2.2 Bare structure on ground floor [Urban Rural Systems, n.d.]

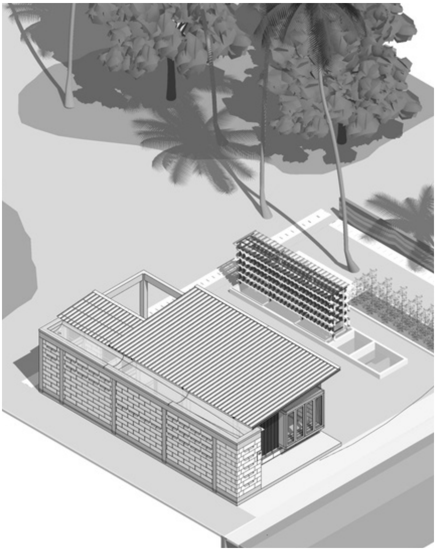


Fig. 3.3.2.3 Structure with infill on ground floor [Urban Rural Systems, n.d.]

Fig. 3.3.2.4 Two floors with infill [Urban Rural Systems, n.d.]

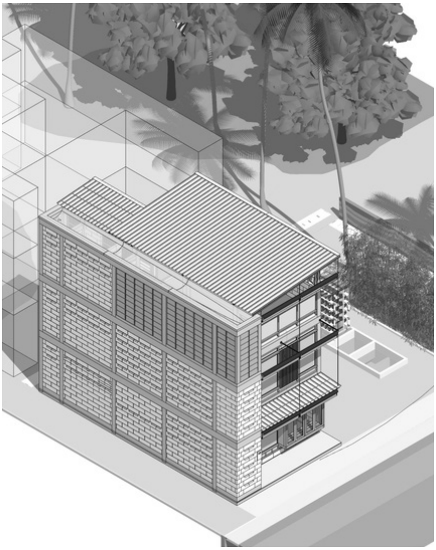


Fig. 3.3.2.5 Three floors with infill [Urban Rural Systems, n.d.]

Fig. 3.3.2.6 Interior view [Teteris, C., n.d.]   Fig. 1.1 figure text (Source)

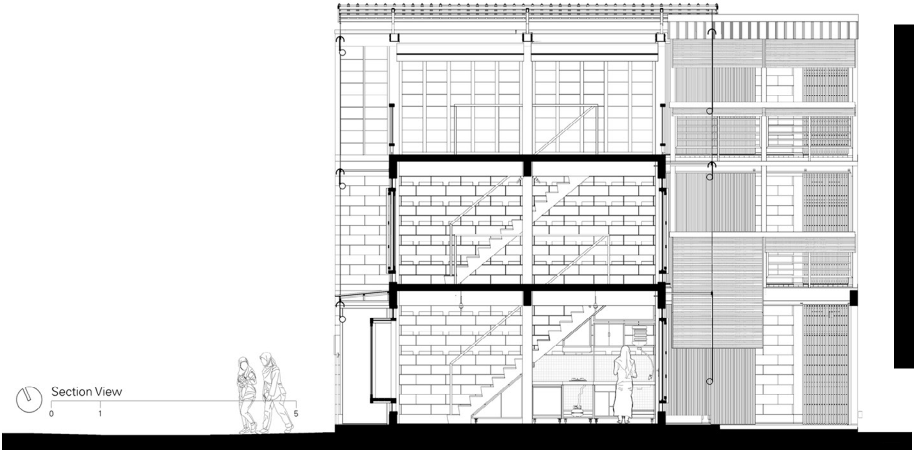


Fig. 3.3.2.7 Section [Urban Rural Systems, n.d.]

3.4

Off the grid

Demountable

Expandable

Energy efficient

3D printing

Fig. 3.4.1.1 ZEB Pilot House [Schwital, P. A., n.d.]

3.4.1 ZERO EMISSION BUILDING PILOT

Architect:	Snøhetta
Place:	Larvik, Norway
Date of built:	2014
Technology:	Energy efficiency

Why?
This project shows how an integrated multidisciplinary design approach can result in a building with neutral energy consumption and carbon emission and at the same time can create a pleasant living atmosphere.

This project comprises a family home, but it also functions as a demonstration for energy efficient building. The philosophy of the Zero Emission Building (ZEB) was to serve both the living and energy requirements of the client. The surplus energy generation of this project is enough to provide power to drive an electric car for one year.

The roof is covered with solar panels and collectors. Geothermal energy is used as well and together with the solar energy it provides the building with enough energy. Orientation of windows and the geometry of the building are adapted to the methods of passive warming and cooling. Despite the high-tech character of this building a warm and safe atmosphere was desired for this house.
Materials are applied based on their thermal characteristics, contribution to the air quality and their appearance.

The aim for a Zero Emission Building requires a very different design approach than traditional building. A multidisciplinary cooperation is necessary as well as strict documentation. Consciousness about the material use is vital from the start of the process. It must be integrated in the design and not be a mere cladding of the construction.
[Snøhetta, n.d.][3.4.1.1]

Fig. 3.4.1.2 Interior [Schwital, P. A., n.d.]

Fig. 3.4.1.3 Stacked firewood to enhance the homey atmosphere [Schwital, P. A., n.d.]

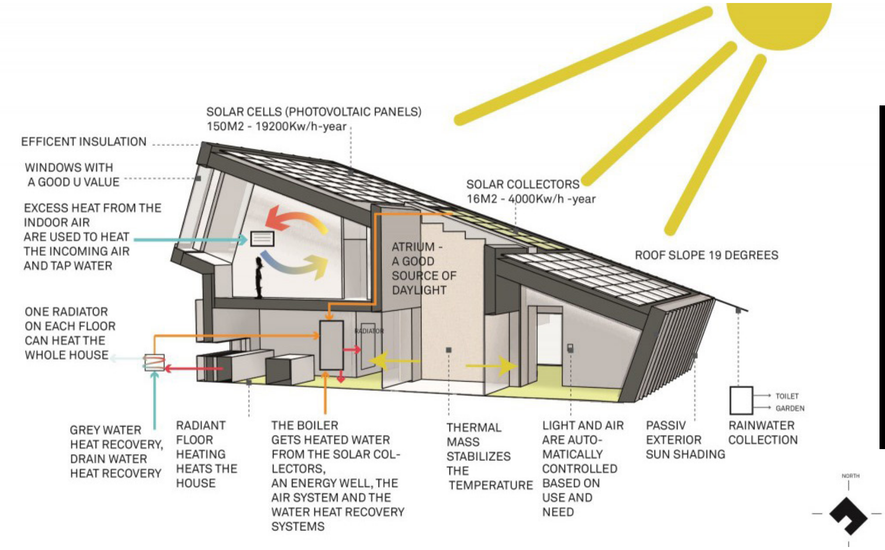


Fig. 3.4.1.4 Applied climate technologies in the ZEB [Snøhetta, n.d.]

3.5

Off the grid

Demountable

Expandable

Energy efficient

3D printing

Fig. 3.5.1.1 3D printed house [Perez, J., n.d.]

3.5.1 3D PRINTED COMMUNITY

Name:	3D printed community
Commisioning partner:	New Story
Place:	Tabasco, Mexico
Date of built:	2019/2020

Why?
This project is one of the first projects where 3D printing with concrete is used to construct several houses. Besides that it tackles the social issue of the homeless. The houses minimalise the homelessness and provide a safe home.

Mexico is working on the world's first 3D printed community. The 3d printed was used to create homes for the homeless. They want to offer them adequate shelter.

The client, New Story, aims to reduce the number of homeless people. After doing multiple projects in other countries with traditional building methods, they started researching innovative building solutions for a faster building process two years ago.

For the development of 3d printed houses in Tabasco, New Story collaborates with ICON, which is specialized in construction technologies.

The first two 3d printed houses are currently completed. The total number of houses that they want to realize are 50. The houses are printed on the construction site. The printer is made for quickly building multi-storey houses.
It has the capacity to build a house of 2000m^2. [Grace, K., 2019][3.5.1.1]

Fig. 3.5.1.2 Kitchen [Perez, J., n.d.]

Fig. 3.5.1.3 Printer on the side [Perez, J., n.d.]

Fig. 3.5.1.4 Exterior [Perez, J., n.d.]

Fig. 3.5.2.1 The front facade of the Dubai Municipality [Harrouk, C., n.d.]

3.5.2 DUBAI MUNICIPALITY

Concrete 3D printer:	Apis Cor
Place:	Dubai UAE
Date of built:	2019
Technology:	3d printing

Why?
This project shows the concrete possibilty of printing large buildings, with this technique, only 3 men was needed to complete the 3d printing, which shows the efficient use of labor through technology.

The Dubai Municipality wanted to have 3d printed the whole building at once. Apis Cor, an American company which was responsible for the concrete printing, has worked on the project with just three men to construct the building. the robot arm has been placed on site in phases, where the concrete columns and wall are poured layer by layer.

Once completed, the Dubai Municipality will become the world's largest 3D printed building, standing tall at 9.5 meters with an area of 640 square meters. Executed by Apis Cor, a U.S.-based company, the structure was directly built on-site.

Apis Cor, the first company to develop specialized equipment for 3D printing in the construction industry, completed the 3D printed wall structures of a two-story administrative building for the Dubai Municipality.
The innovative 3D printer used allowed the structure to be built directly in place, without any extra assembly works. Spread over 640 sq. meters, the total area of the edifice is "larger than the printing area accessible when the Apis Cor's 3D printer is stationary".

[Harrouk, C., 2020][2.5.2.1].

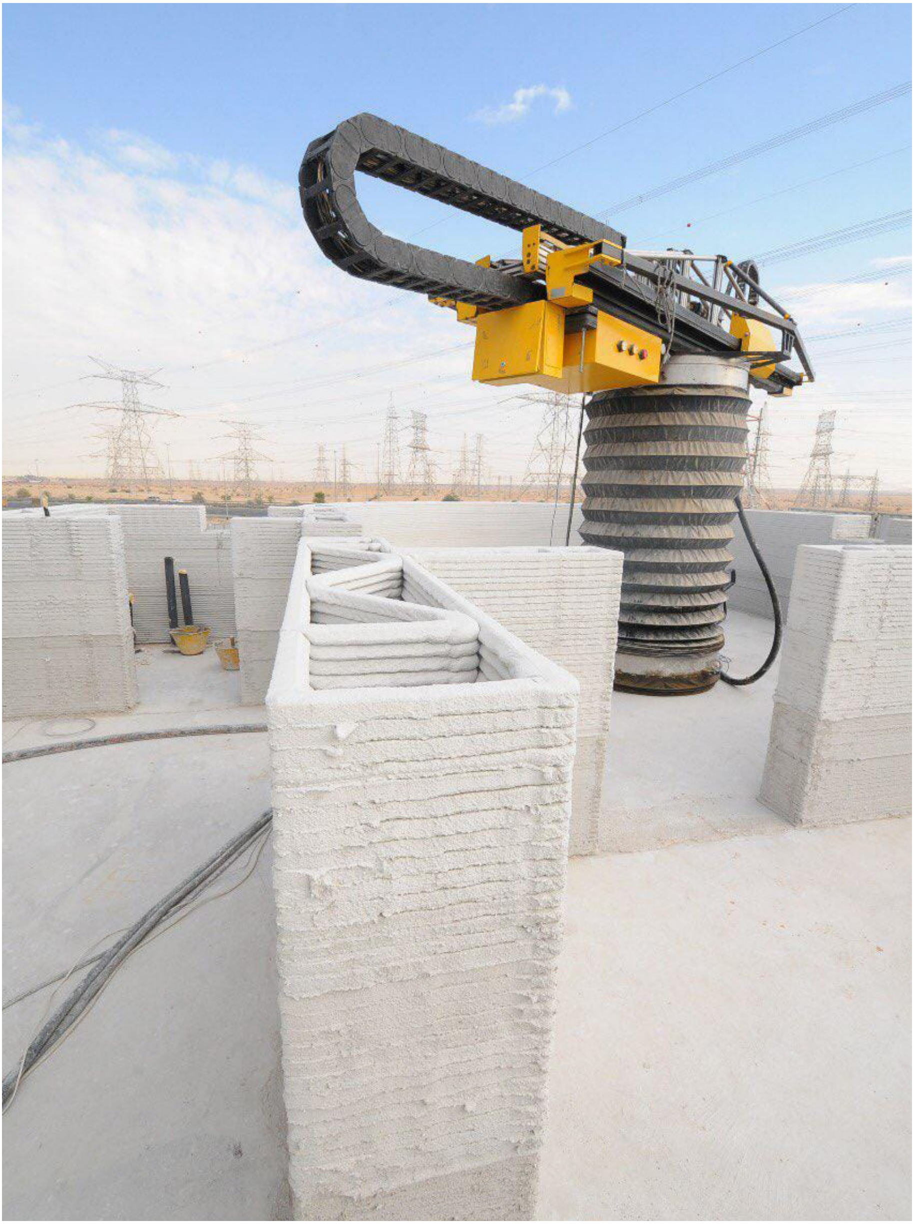


Fig. 3.5.2.2 Robot crane printing [Harrouk, C., n.d.]

Fig. 3.5.2.3 concrete printed walls with steel rebars [Harrouk, C., n.d.]

Fig. 3.5.2.4 Constructing walls [Harrouk, C., n.d.]

Fig. 3.5.2.5 bird's eye view [Harrouk, C., n.d.]

Fig. 3.5.2.6 Interior view [Harrouk, C., n.d.]

Fig. 3.5.2.7 Facade view [Harrouk, C., n.d.]

Fig. 3.5.3.1 3D printed micro home [Van den Hoek, S., n.d.]

3.5.3 3D PRINTED MICRO HOME

Name:	3D printed micro home
Architect:	DUS Architects
Place:	Amsterdam, NL
Date of built:	2015/2016

Why?
This project shows how we can build sustainable 3D printed homes. It is made out of bio-plastic which makes it possible to reuse the materials when the house gets destroyed. It is also a solution for fast growing cities around the world.

DUS architects created a 3D printed micro-home for staying overnight in Amsterdam. The micro-home is eight square metre and made out of sustainable bio-plastic [Frearson, A., 2016][3.5.3.1]. It is build through 'Design by Doing'. It is a first step in the process of using 3D print technology for developing sustainable housing solutions for fast growing cities around the world [DUS Architects, n.d.] [3.5.3.2]

The 3D printed micro home is made as a solution for temporary housing or disaster relief. It is eight square metre big and has a outside bathtub.

Because the house is made out of bio-plastic it can be destroyed when it is not needed anymore and the materials can be reused.

The walls are created with angular protrusions to create a three-dimensional surface which gave the structure of the building extra stability.

At one end of the building there is a big window, on the other end there is the entrance with a seating area.

Inside the house there is a bed which can be folded into a seat during the day. There is no bathroom but a 3D-printed bath outside the home.

It is not the first project of the architecture firm which is about 3D printing with bio-plastic. They also work on printing a canal house out of plastic and made a 3D-printed sculptural facade before. [Frearson, A., 2016] [3.5.3.3]

Fig. 3.5.3.2 Exterior with bathtub [Van den Hoek, S., n.d.]

Fig. 3.5.3.3 Pavilion on the site [Ossip, n.d.]

Fig. 3.5.3.4 Window frame [Heijmans, n.d.]

Fig. 3.5.4.1 Two 3D printed courtyard houses [Aldama, Z., 2017]

3.5.4 3D PRINTED COURTYARD HOUSE

Architect:	Winsun3D
Place:	Suzhou, China
Date of built:	2016
Technology:	3D printing

Why?
Winsun3D strives for the implementation of 3D printing building construction. They see many technical, economical and social benefits. This project was the first to combine traditional Chinese architecture with this new technology.

This 130m2 typical Chinese courtyard house has 3 bedrooms, 2 living rooms, 3 bathrooms and a kitchen. Decorative elements were printed in one whole.
The printed walls are hollow to allow insulation materials to be added. [Winsun 3D, n.d.][3.5.4.1]
The construction of this house took two days of printing and mounting. 3D printing of buildings means a revolution is traditional field of construction. 3D printing possibly reduces material use in construction with 30 to 60% and it may decrease construction time with 50 to 70%, according to Ma Yihe, founder of Winsun 3D in an interview with the South China Morning Post. [Aldama, Z., 2017][3.5.4.2]
The material used by Winsun 3D is 100%% recycled, it originates from industries, mining and demolitions. Ma also argues that the plasticity of the composites provides better structural properties to resist earthquakes and wind. It took some years since their first completed project in 2014 to improve the styling of 3D printed buildings. For this project Winsun3D developed a composite which has a natural stone look and makes the facades more appealing.
3D printed buildings also have a clearer construction budget than traditional projects. Cost estimates are relatively precise and reliable, which prevents corruption by officials involved. This occurs frequently in Chinese construction practices.

Fig. 3.5.4.2 First 3D printed project by Winsun3D [Winsun3D, n.d]

Fig. 3.5.4.3 Detail of printed wall [Aldama, Z., 2017]

Fig. 3.5.4.4 View of the courtyard [Aldama, Z., 2017]

Fig. 3.5.4.5 Aerial view of two courtyard houses [Winsun3D, n.d]

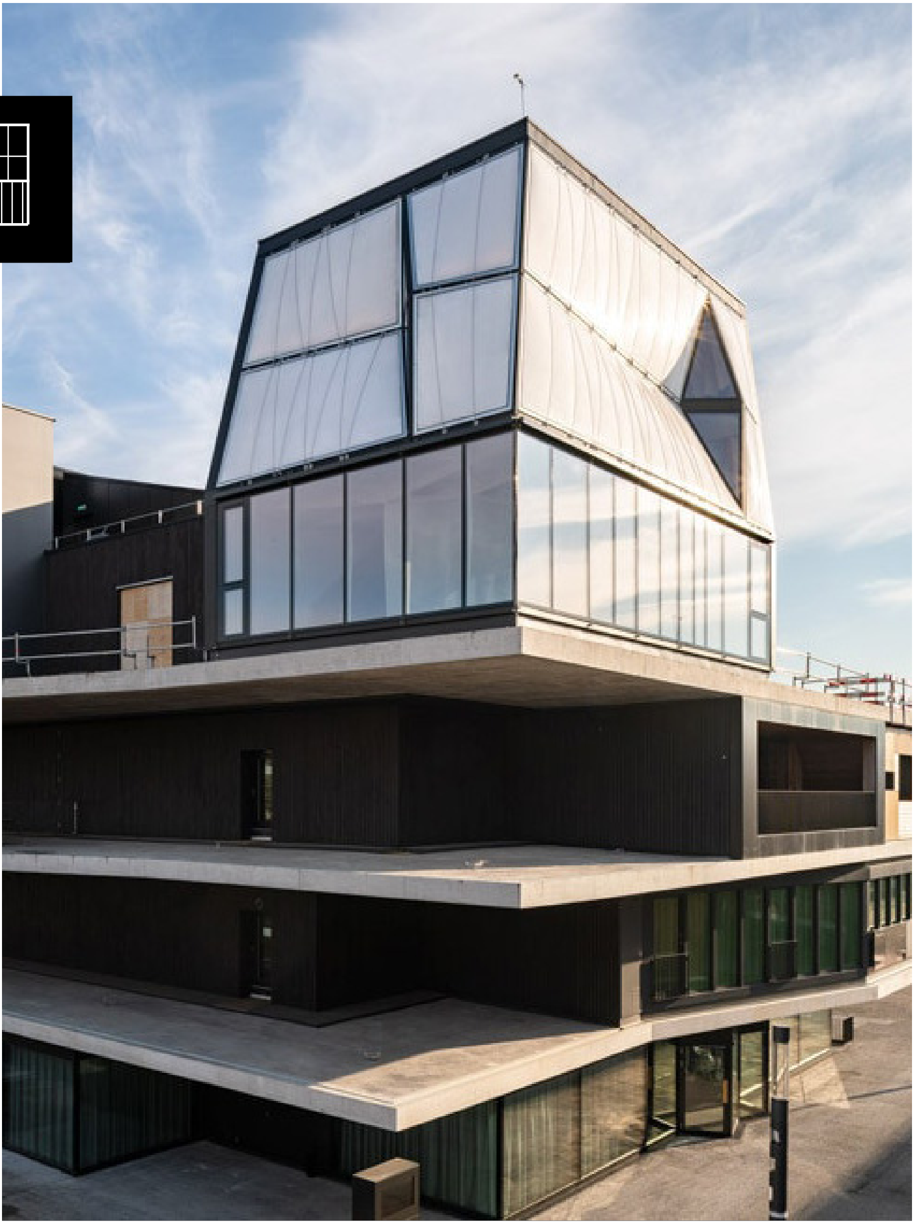


Fig. 3.5.5.1 3D printed house [ETH, n.d.]

3.5.5 DFAB HOUSE

Designers:	ETH
Place:	Zurich, Switzerland
Date of built:	2019
Technology:	3d printing

Why?
This project is one of the first projects where 3D printing technology has been used to construct the whole house with different 3d elements. A new technology has been introduced: Smart Slab.

This house is completely constructed with 3d printing modules.

The different design approach which the research has been applied into the building construction. By using the new technology of the smart slab, the efficiency can be achieved with rapid speed in casting steel reinforced concrete elements such as walls, floors and roof.

Smart Dynamic Casting (SDC) is a continuous robotic slip-forming process that enables the prefabrication of material-optimised load-bearing concrete structures using a formwork significantly smaller than the structure produced.

A slender, 12-m-long undulating Mesh Mould wall is the main load-bearing element of DFAB HOUSE. Instead of adding extra material, the undulations stiffen the wall against buckling, increasing its structural performance. The Mesh Mould Wall carries approximately 100 tons of load, coming from the concrete ceiling and the two-story timber unit above.

[Grifftihs, A., 2017][3.5.5.1]

*Fig. 3.5.5.2 The assembled fragment [*Griffiths, A., *n.d.]*

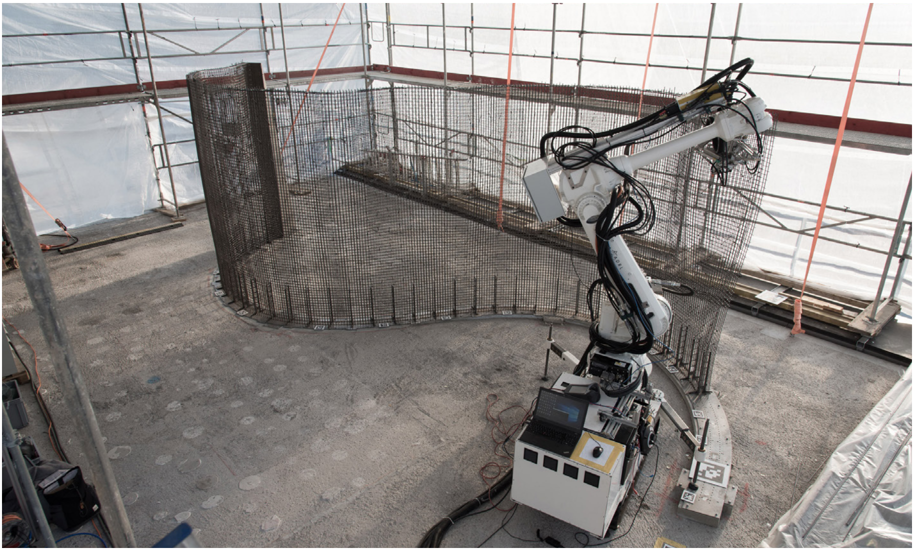


Fig. 3.5.5.3 Mesh mold printing process [Griffiths, A., n.d.]

Fig. 3.5.5.4 Exterior night view [Mac, D., n.d.]

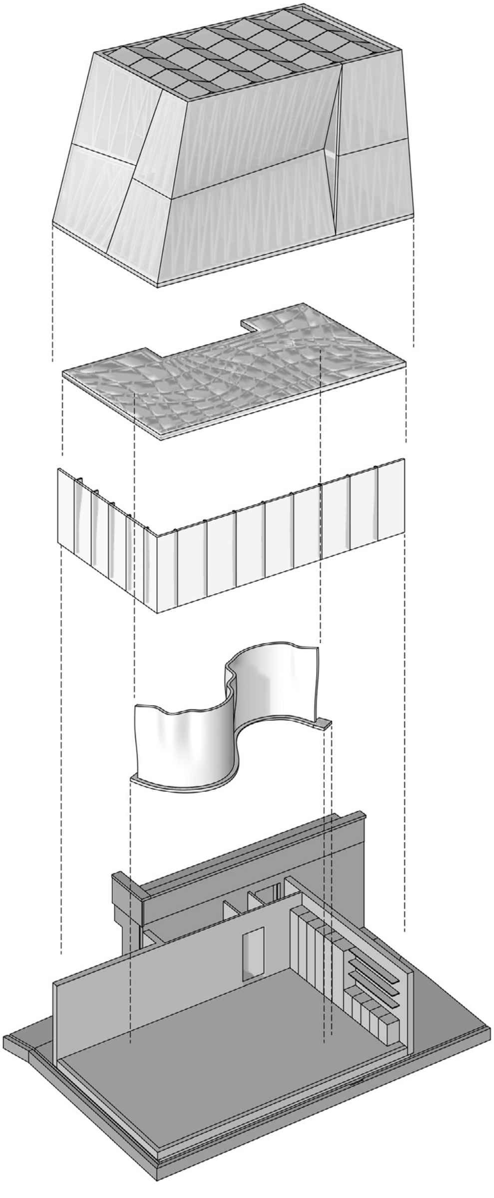


Fig. 3.5.5.5 The exploded view [Griffiths, A., *n.d.*]

Fig. 3.5.5.6 render [Griffiths, A., n.d.]

Fig. 3.5.5.7 Interior view [Mac, D., n.d.]

Fig. 3.5.5.8 The wooden structure [Mac, D., n.d.]

Fig. 3.5.5.9 wooden structure with double layered membrane [Mac, D., n.d.]

Fig. 3.5.5.10 The bedroom space [Mac, D., n.d.]

3.6

Discussion.

In this chapter, we discuss the different emerging technologies. Which technologies are important for the alternatives in the big house? It becomes clear about the different technologies that have consequences on the construction time and costs. New methods of constructing houses with low tech technologies, can bring new housing typologies. They can reduce housing prices and increase productivity in the construction process.

New creative ways of using techniques like the expandability of spaces. In terms of energy efficiency, where the integration of carbon emission and neutral energy consumption, can limit the impact on the environment.

Some of the emerging technology projects, that are related to social issues, become relevant and interesting projects to use for our graduation studio.

3d printing technologies like concrete printing, CLT & CNC milling projects in our Fabrication technologies booklet, are relevant for using different materials in the construction phase to increase the productivity, using fewer materials and reduce waste.

These are the solutions to reduce the construction costs, waste and to increase the productivity of the construction process, and on the ecological, sustainable and environmental aspects, that we can use and need to consider in our designs

4

Our scope for the Big House

OUR SCOPE FOR THE BIG HOUSE

Abstract

This paper and catalogue with case studies are built up around three topics: Boundaries of the Big House, Social Issues and Emerging Technologies.
The social questions involved, like the affordability of housing and the ecological footprint of housing, result in different architectural solutions focusing on specific groups. This approach is part of a larger trend in architecture, which is based on specific, differentiated solutions instead of general, uniform means. Differentiated solutions are based on local resources, cultural and social structures and applied technologies, either high-tech or low-tech. This way of designing is illustrated with examples and case studies from the catalogue. It leads to new housing typologies and technologies, which are based on new inventions like automated fabrication on the one hand, or revived centuries-old techniques on the other hand. These techniques have in common their aim to solve social issues by improving the affordability and/or reducing the ecological footprint of housing.
Lastly, the Boundaries of the Big House are not only characterized by size but more importantly by other parameters like functionality and technologies. In this paper size and the impact of houses are compared. It can be concluded that a Big House is much more defined by different social, functional and technological parameters rather than just size.

4.0 Introduction

4.0.1 General background

A lot of things are changing in the world of the built environment. Housing prices are rising, ecological issues play an increasingly important role and new techniques are emerging. What seems to have not hardly changed over the years is the design of big houses. There are opportunities to design new kinds of architecture which respond to the present and future wishes of mankind. This paper will focus on the current trends, challenges and solutions in housing and how they can be implemented in the big house of the future.

4.0.2 Setup

This paper starts with a description of the current trends and challenges in housing. It illustrates the development from uniform solutions for housing during Modernism to more differentiated, custom fit solutions since the 1970's. This differentiated approach forms the context for many contemporary housing projects, which aim at creating more social, more sustainable and more affordable living conditions. Also the current situation regarding increasing housing prices, exhausting resources and an increasing ecological footprint contribute to this context. In this essay multiple means and technologies are presented to create a big house for the future. They mainly focus on low-tech, affordable and locally resourced solutions. This paper tries to find an answer for the question; Which technologies and methods can be helpful to achieve more affordable and more sustainable housing types regarding the big house?

4.1 Historical approaches for housing

Architecture has always been closely linked to the way people life. Over time architects have tried many approaches to create liveable environments for everyone. Especially more vulnerable groups deserved attention in providing them with qualitative housing. During the 1960's and 70's new forces emerged to improve living environments. (Preiser et al, 2015) New design approaches contributed to a more effective way of achieving this. 'Differentiation' instead of 'uniformity' was one the starting points for this new approach. For example, the participation of vulnerable users, like disabled people, resulted in more social buildings. Procedures like Post-occupancy Evaluations and Environmental Impact Assessments have become common in most design approaches and so does the social impact of the built environment. Differentiated architecture aims at serving the needs of people in a differentiated way. Still miscommunication between the users needs and the architect's intentions occur, resulting in ineffective buildings. [Preiser, W. et al, 2015] People must be able to identify themselves in buildings. In order to create humane architecture an 'imaginable structure that offers rich possibilities for identification' is needed [Norberg-Schulz, C., 1986]. For a long time architects failed to create this differentiated architecture, leading to the anonymous modernist building blocks of the 1950's and 60's and the anticlimax being the demolition of the Pruitt-Igoe building in St. Louis in 1972. This event was symbolically considered to be the death of the modern movement and the rise of a new era in architecture. [Haddad, E., 2009] A new approach, which pays attention to local specifications instead of global conventions, evolved.

In this catalogue some case studies can be found that manage to adapt to local needs and traditions in order to formulate an answer to social questions. The social housing project in Iquique, Chile by ELEMENTAL for example focuses on the important family structures that are present in Chilean communities and the possibility to enlarge the dwellings if wished by the residents. [Fracalossi, I., 2008] Another project by

Urban Rural Systems in Nongsa, Indonesia has a similar approach for expansion possibilities, but this time aimed at communities in tropical areas. It allows the local people to build their own houses according to their budget and wishes, but within a structural frame to ensure a minimum level of safety and quality. [Abdel, H., 2020]

4.2 State of the art in housing

Currently the circumstances in the housing market are characterized by increasing housing prices, exhausted resources and a changing climate. At the same time new technologies and building methods are developed, which can provide a solution for those issues. Housing types like eco-housing, co-housing and off-grid housing get more and more attention, partly driven by the disapproval of the stress housing puts on its environment. People start to look for alternatives and architects need to find them.

4.2.1. Eco-housing

In many countries the trend of eco-housing is present, although still marginalized. To achieve ecological architecture the notion of cultural context, lifestyles, biodiversity, materials, climate, wind and sun conditions etc. is essential. And most importantly the relation between these element is crucial. Generally the functions of eco-houses are: minimize resource use and waste, maximize renewable energy and material use. The form in which this goal is achieved varies however from high-tech systems to low-tech natural approaches. High-tech solutions do help to increase the efficiency of eco-houses, but at the same time the big reliance on this forms a threat. As the social aspect of the functionality of eco-housing is often overlooked, the technological aspect cannot function optimally. For example when people leave their windows open, the climate system will not work efficiently. The same goes for low-tech measures which affect the usability. So more attention to the social aspect of eco-housing is crucial to make it a success. [Pickerill, J., 2017]

Urban Village Project [EFFEKT, 2019]

4.2.2 Co-housing

The demands and desires people have of a house are linked to the location, political and societal circumstances. But despite the changes in employment, technology, relations and quality of life over the years, houses have not changed a lot ever since. There also is the elements of continuity and nostalgia which seem to influence the feeling about home. [Heathcote, E., 2012] So there is a variation of fixed social norms, which have influenced housing for a long time, and more flexible norms, which change over time, and allow for different approaches regarding housing. A good example of this is the social norm of privacy. More informal relations within families and communities since the 1950's and the need to share space in order to reduce the need for space, infrastructure and resources, have resulted in more collective solutions for housing, for example co-housing. This way of living together allows people to share scarce space, resources and services. It results in a more efficient, more affordable and more sustainable living environment. [Leafe Christian, D., 2003] The Urban Village Project is good example of such a housing type in which both the building and the users strive for a sustainable way of living. The dwellings are built of renewable materials and offer flexibility to adapt to changing needs. The people share resources and other facilities and use renewable energy for their daily life.

4.2.3 Off-grid housing

So people's behaviour and their demands influence the way houses are built, but also the other way around. Self-build eco-homes therefore are suited to force a more ecological way of living. They can be adapted to a specific client with specific behaviour and demands. Also the location of a home can strongly influence the way a house is built and the way

Off-grid retreat in Finca Aguy [Finotti, L., n.d.]

people life in it.
Off-grid homes are a good example of homes in which people will have to adapt to the resources provided by the environment. Off-grid homes are detached from the conventional water and electricity grid and have their own supply. This demands from the users to build their own electricity, power and waste infrastructure and to life according to the constraints of this. It results in more consciousness and understanding of energy consumption. Off-grid building also allows to build in remote areas and it saves a lot of money as there is no need for centralized infrastructure. It is a type of building that provides more in-dependency from the traditional way we used to exhaust our environment. [Pickerill, J., 2017]

4.3 Current technologies in housing

Existing building technologies are continuing to develop new ways of building houses, and finding smarter, cheaper, and new techniques to improve the way of living.

The current problem is, in the way we build our houses with traditional technologies construction costs are too high and they are raising the housing prices. That is why low tech technologies can reduce construction costs, which is a big factor in reducing housing prices. It is found that about 26.11% and 22.68% of the construction cost can be saved by using low-cost housing technologies in comparison with the traditional construction methods in the case studies for walling and roofing respectively [Tam, V.W.Y. 2011].
New methods of constructing houses with low tech technologies, can bring new housing typologies, which can reduce the housing prices over time. When thinking about the low technologies and the low costs, the location is important to find local materials to build a house.

4.3.1 Technology in Eco-housing

This project Gaia House is highlighted for the use of local materials and the way they have used the materials in an ecological way, provided by nature and low cost in logistics. The mixture of soil, chopped straw, and rice husk, were all found nearby. Because the materials have been locally found, the logistics and material costs have already been reduced a lot. Although the robot crane is a high tech invention, it can be easily executed with just a small number of men and little materials needed, instead of many workers building it traditionally. This technology is sustainable and the material is fully biodegradable, according to the construction company WASP. They believe, if the building can't be maintained anymore, the materials can be turned into soil again and it can be reused. [Jordahn, S., 2019].

The Gaia House is 3d-printed with bio-based materials. [Jordahn, S., 2019]

4.3.2 Technology in off-grid housing

Off-grid housing is based on the way houses are designed for remote areas to reduce climate change, where the houses are completely independent of public resources, such as electricity, water and wind energy. The technologies, how these energy resources to be produced and stored, depends on the environment the user chooses to live in. The orientation and environment are important for producing enough energy to be consumed and stored for long term & short term. Therefore, to select a project which shows how to deal with these conditions, the Black barn house in Suffolk by Studio Bark is chosen as a case study where the orientation of the barn was the key to produce sufficient energy for the shared homes, which is fully powered by solar and bio-diesel, is designed to have a minimal environmental impact, with the bedrooms placed in the flint-structured ground floor. The orientation of the bedrooms and living rooms are the key to energy efficiency in the site. [Crook, L., 2019].

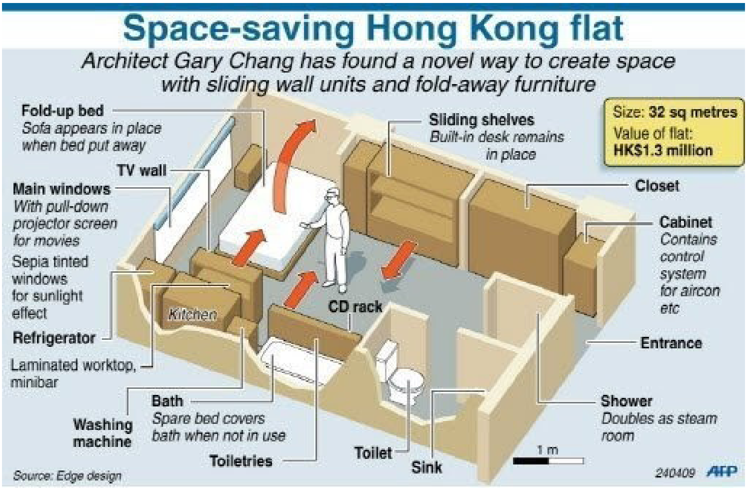
The offgrid Black Barn produces self-sufficient energy. [Crook, L., 2019]

4.3.3 Technology in Co-sharing

In the environment of big urban areas, where land is scarce and spaces have more and more limitations, it should be shared to make life comfortable for everyone. Co-sharing is becoming important where spaces can be shared in common. When the space is limited, it needs to be flexible in order to use it optimally.

The possibilities where spaces could be in the form of shareable spaces. The Domestic Transformer designed by Gary Lin is an apartment located in Hongkong in a complex residential block, where space is the biggest limitation in size, has found solutions to cope with the existing space for sharing. In terms of space co-sharing, the existing room can be maximized by using a sliding system to pull elements from the wall to extend the need for space for the moment. [Alter, L. 2009]

The main living room is the space where the activities for the guest will take place. All the functions are hidden behind the walls, and when the dining room is needed to fit in guests, the function can be pulled out from the wall



The Domestic Transformer with sliding wall units and fold-away furniture. [designswan.com, 2010] directly. The same system can be executed for the mini bar, TV, in total 24 different functions can be recalled for the moment of use.

These case studies show the advantages of technologies that relate to the social issues within our scope of research.
We can learn from the Gaia House to use biodegradable materials sustainably in our design, that can be reused and reduce the waste of materials due to climate change. From The Black barn off-grid project, we can learn that the orientation of the building is important to make optimized use of the sun to produce sufficient energy to use and store for the building. Using these techniques creates minimal impact on the environment.
The domestic transformer apartment case study shows the small space limitations can be maximized by smart solutions, like the sliding system of rails with separation walls that can be turned into a function when needed. We can learn from the sharing aspect to extend elements in the design of our big house.

4.4 Size vs impact

Besides the trends of the differentiated design approach, increasing housing prices, scarce resources, climate footprint, low-tech and cheap building we see the trend that we are, during the years, building more houses with a bigger floor area. Where, in the Netherlands, in 2013 the number of completed new-build homes of 150m2 and bigger was still 14 percent of the total of new-build homes, this percentage had risen to 22 percent in 2017 [Doodeman, 2018]. So we build more and more bigger houses. The question is, however, what can be understood under a big house? Is a big house only related to size, or can it also be something else? And is there a relation between big houses and the other trends we see in the built environment?

It is hard to explain what big exactly is. Rem Koolhaas writes that: "Beyond a critical mass, a building becomes a big building...". What

he’s not talking about is what the critical mass exactly is. There are several aspects that can fall under big such as length, height, width, volume, etc.
Arch2O (n.d.) summarized what Koolhaas said: “‘Bigness’ is not about the dimensions but rather the ‘parameters’ that the given Architecture stands for. The idea is to make Architecture stand for something ‘bigger’ than what the built form’s façade and interior speaks of, and everything ‘beyond’ – which one might not be able to see, but can always perceive. A large number of works in practice today are established at a scale, which, by virtue of its dimensions, can very well be categorized as Small or Medium Scale. But there is much beyond the dimensional aspects that define this ‘so-called scale”. So ‘Bigness’ is not only about measurements but about the parameters where the architecture stand for.

Jacob Hadler (2009) writes: “If we picture Notre Dame next to The Empire State Building, Notre Dame as a big building will not be apparent until we step inside, as we can no longer see the skyscraper. Can we then conclude that size is static while our perception of it is dynamic?”. If we look at those examples we can say that size is static if we look at square metres, volume, etc. while our perception of it is dynamic. It depends on the parameters that are there that decide whether something is big or not.

The definition of bigness as mentioned by Rem Koolhaas and Jacob Hadler is in line with the ambition of this research into low-tech, cheap, self-built housing which also tackle social issues. It is not about the exact size of a building in terms of dimensions, but the parameters that the architecture stands for. A larger goal than architecture in itself.

There is a close relation between those themes and the examples which are shown in this research paper and in the booklet. Not all of the buildings have a high amount of floor area or volume. Some projects can be called big because they used new techniques, are big but have a low impact on the landscape and there are also project which are big in their way of thinking about tackling social issues.

Take, for example, Quinta Monroy and the Expandable house by Urban Rural Systems. Both are based on low-tech technologies, low costs, expandable living and based on changing dynamics. They are at a first glance not big project because the size of the projects is small but looking at the parameters of those projects the projects are telling us more than just some measurements. They are built for the future with the perspective of a changing society. So the parameters tell us that they are big houses. The same follows for the project ‘Buitenhuisjes’. The floor area is not large but by using small solutions like a foldable table, foldable bed, etc. the house looks big although it is just 45 square metres. So important to note is that big stands for the parameters the building stands for and not just the amount of floor area.

4.5 Discussion

Working on this booklet helped us exploring the concept of the Big House. Multiple Big Houses and their parameters which make them 'big' are discussed. From those case studies we began to define our scope for this graduation studio. For this some case studies where selected and further analysed. The case studies try to formulate an answer to the following questions: how will we live in the future? How will our future-proof houses look like? And what parameters play a role? Those question relate to different social issues, the most important ones being affordability of housing and reducing the ecological footprint of housing.
Based on those question three different strategies for alternative housing will be executed during this graduation studio. Two strategies focus on developing new housing types which offer a long-term solution for economical issues at the one hand and ecological issues at the other hand. The economical solution will focus on developing affordable housing for starters on the housing market. More specifically, solutions will be investigated in unexplored urban areas, which require a different approach for the development of housing. The ecological solution will focus on alternatives of vertical farming that reduce the ecological footprint. The focus is on food production in areas with a limited amount of land. This concept is suitable for large scale buildings with a small footprint in urban areas.

The third strategy focusses on short-term housing solution for people with psychological problems. The chosen location is related to the specific target group. The location provides a healing environment.

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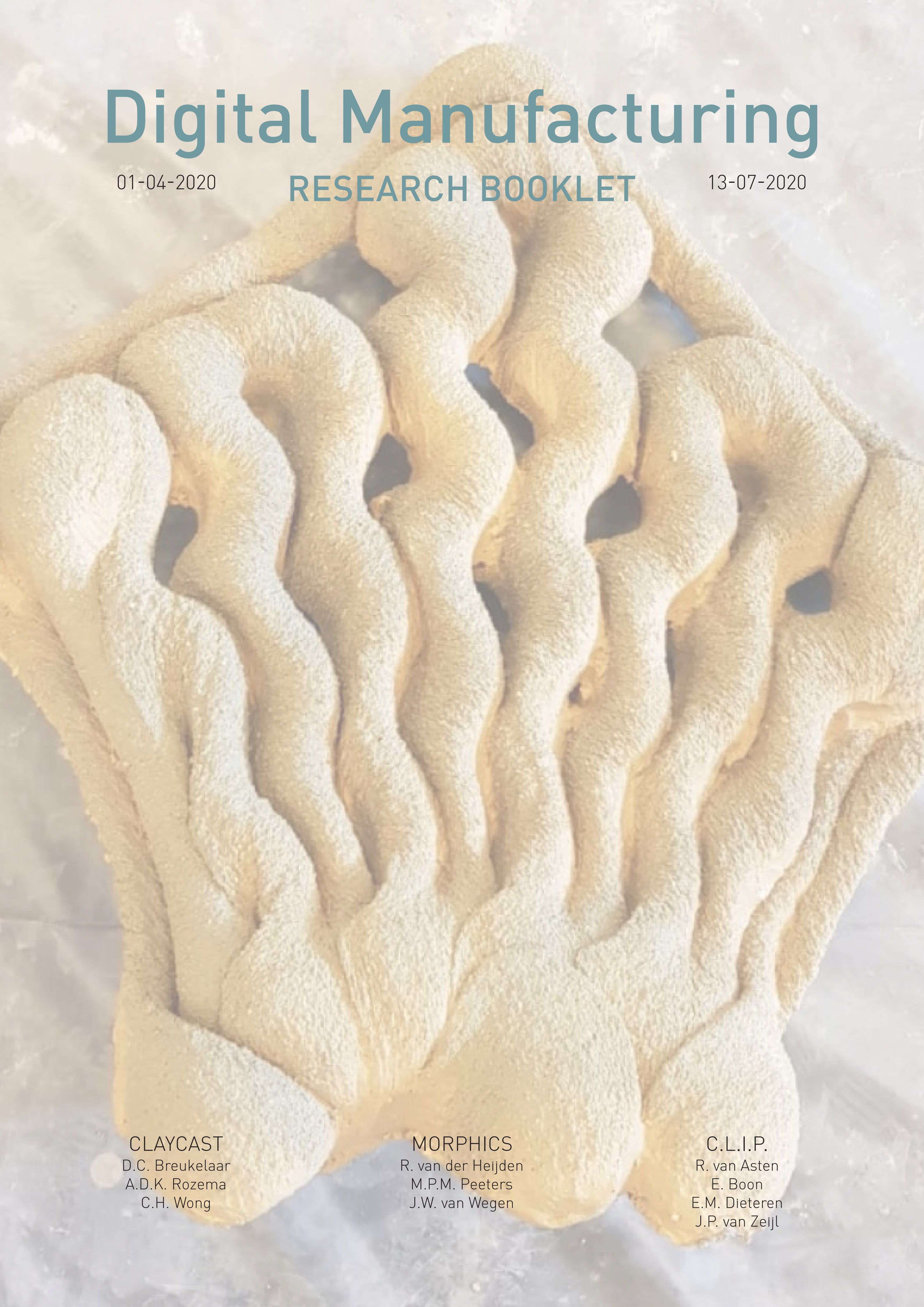
TOP HOUSE

Appendix 2



Digital Manufacturing

01-04-2020

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CONTENTS

1. PROBLEM STATEMENT

The Architecture, Engineering and Construction (AEC) Industry is trying to pursue digitisation and automation for a higher productivity. Advancements are being made regarding automation and robotics, but the industry is a long way from fulfilling its potential.

The problem is that the current state of the AEC industry shows a minimal growth in this digitisation and automation. Labour productivity is extremely low compared to other industries, and the supply chain of the AEC is too complex. This brings inefficiency between different parties in the construction process.

Automation in constructions can bring about solutions in digitisation for the construction process by using additive and subtractive manufacturing. These will improve the quality and productivity, but also safety and other factors, by adopting digital technologies in the industrial production. This will become important for speeding up the construction process with on-site automation, such as 3D printing with robots.

1.1 CONTEXT

The global population is estimated to increase with 81 million people per year [1]. Most of these people will live in urban areas, as currently, the world's urban area is increasing by 200,000 people per day. All of whom need comfortable housing, as well as transportation and utility infrastructure [2]. The entire population relies on the quality of the AEC industry to live comfortable lives [2].

This growing rate at which buildings are being constructed also has an increasing impact on the environment. With three billion tonnes of raw materials used to manufacture buildings worldwide, the AEC industry is the single largest consumer of resources and raw materials [2]. All these resources leave behind immense waste; about 40% of all solid waste derives from the construction and demolition of buildings [2]. Apart from material impact, the AEC industry also eagerly consumes other resources like oil and fuel for machinery, which accounts for approximately 20% of the total materials [3]. Consequently, the industry is responsible for 30% of the world greenhouse gas emissions [4].

The big impact of the AEC Industry on our lives also has a positive note. The AEC industry fuels global economic activity in a wide range of sectors [3], providing more than 100 million jobs worldwide [2]. Around $10 trillion a year is spent on the industry, which translates to around 13% of the global GDP, see figure 1.1 [2], [3], [5]. The spending is increasing with 3.6% since the end of the financial crisis and is expected to continue to at least 2025 [3].

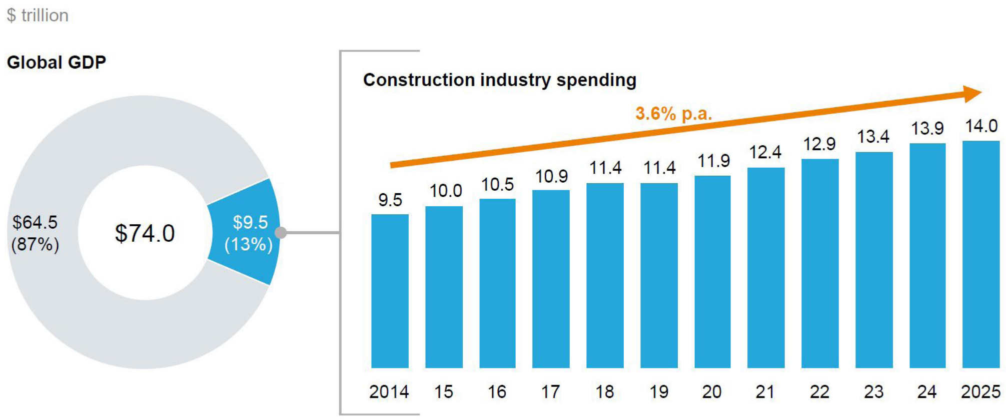


Fig 1.1: Construction Related Spending [3]

1.2 CURRENT STATE OF THE AEC INDUSTRY

In this rapidly advancing world, the AEC Industry faces some urgent problems. The biggest problem regards its labour productivity. The labour productivity of the construction industry over the past 70 years has only increased with factor 1.1x, see figure 1.2, whereas other comparable industries, such as manufacturing (8.6x) and agriculture (16.1x) have grown significantly.

The main reason for this low productivity is the manual labour required for construction projects. Whereas other sectors have mechanized, digitized or robotized, the construction industry is still considered low-tech [4]. Despite some highly technical and complex projects being undertaken, construction has largely continued to rely on traditional methods characterized by poor quality and performance [3], [4]. Little has changed over the past 800 years; pulleys have been substituted by cranes, but they work with the same principles: manual control, human operator visual feedback, big positioning error, etc [6]. Whereas other sectors have boosted productivity by innovations, the productivity within the construction industry has actually declined in some markets since the 1990s [7].

The poor labour productivity of the construction industry is pervasive. It is a long-term issue that affects virtually every economy, and which has not been tackled for decades [3]. It is estimated that a 1% increase in productivity could save around $100 billion in construction costs [2]. The cost to the industry is substantial, but therefore so is the opportunity [3].

Another problem is the complexity of the supply chain in the current AEC Industry. Building developments involve complex decision making [8], which is being fragmented into smaller firms. In total, around 2.7 million enterprises are currently involved in the industry [6], all of which have their expertise. This results in a highly complex system of relations. Xue et al. visualise this complex supply chain, as can be seen in figure 1.3 [9].

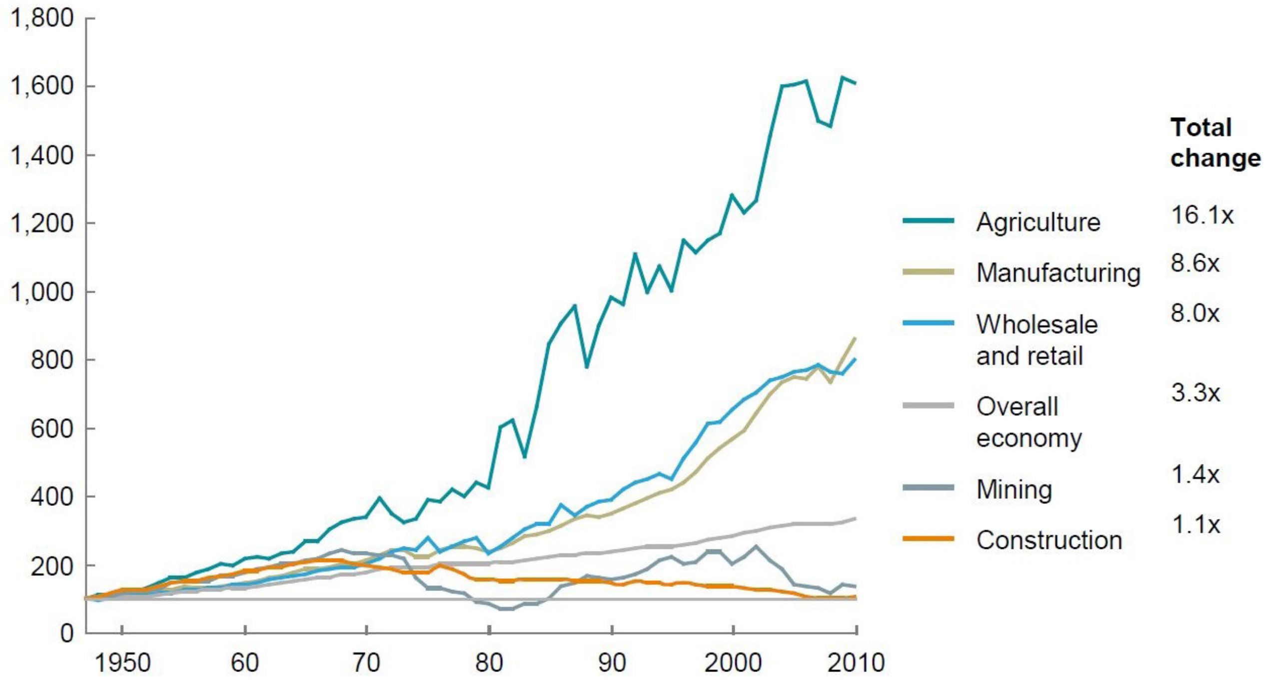


Fig 1.2: Labour Productivity: Value Added per Hour Worked [3]

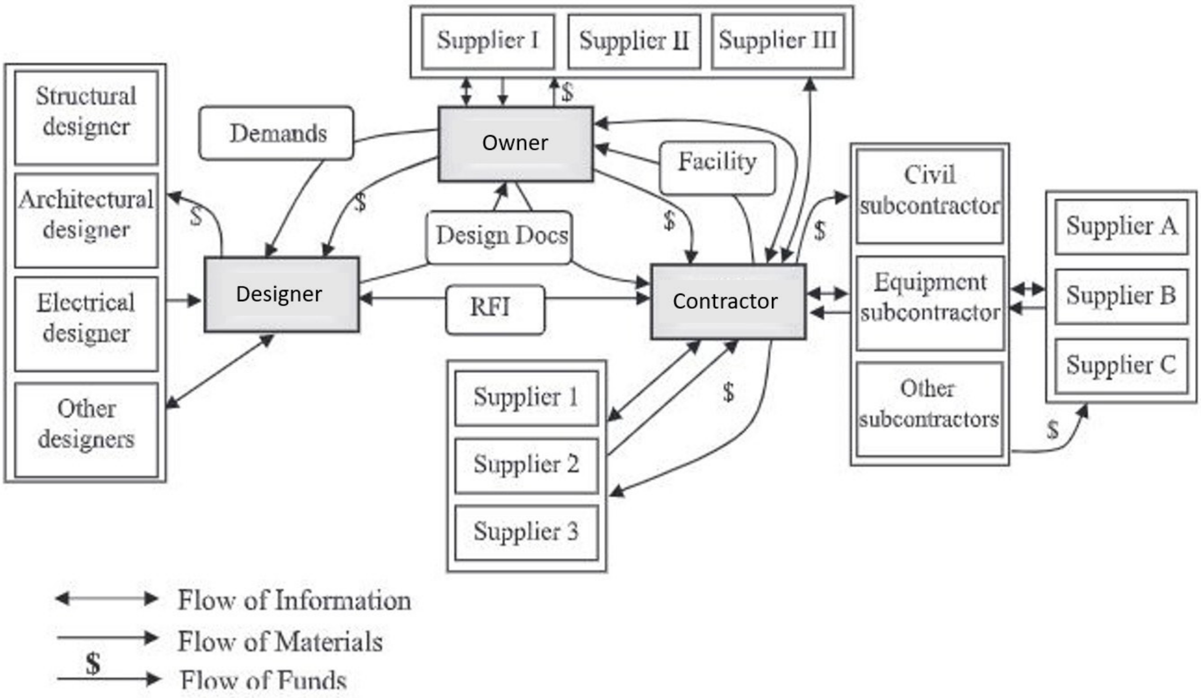


Fig 1.3: Complex Supply Chain in AEC Industry [9]

1.3 DIGITIZATION AND AUTOMATION

One of the solutions to countering these problems is to digitize the construction industry. Other industrial sectors, such as automotive, aeronautics and aerospace underwent radical process changes by adopting digital technologies to improve quality and productivity, these transformations are generally described as industry 4.0 [4], [6]. In contrast, the construction industry is one of the least digitized sectors, see figure 1.4, which indicates that a lot of improvement can be made in this field.

There have been advancements in digitization in the construction industry, but these have mainly been at the planning phase (planning, suppliers' relationships, etc.). Those advancements have not been translated to the production phase of the process (building erection, masonry, on-site automation) [6], [11]. The core of the problem will not be solved by these partial advancements; a digital solution should cover all phases of the construction process.

Digitization in the production phase can be achieved by Robotics and Automation in Construction (RAC). This brings some highly desirable advantages to the industry. First and foremost, RAC has the ability to improve the construction efficiency, and with that, increase labour productivity [3], [5], [6], [12]. This improvement will particularly be effective when elements are manufactured on-site. This is mainly due to the precision that the robotics can deliver [5], [6], [13]. Another factor is the quality of the product [5], [6], [12], [13]. Similarly to prefabricated elements that are more and more common on construction sites today, elements produced with RAC will be constructed under a controlled environment. This will guarantee products with similar high quality throughout. RAC will also greatly influence the impact of the AEC industry on the environment [14], [15]. The precision of the robotics provides a tool for the precise placement of material, therefore

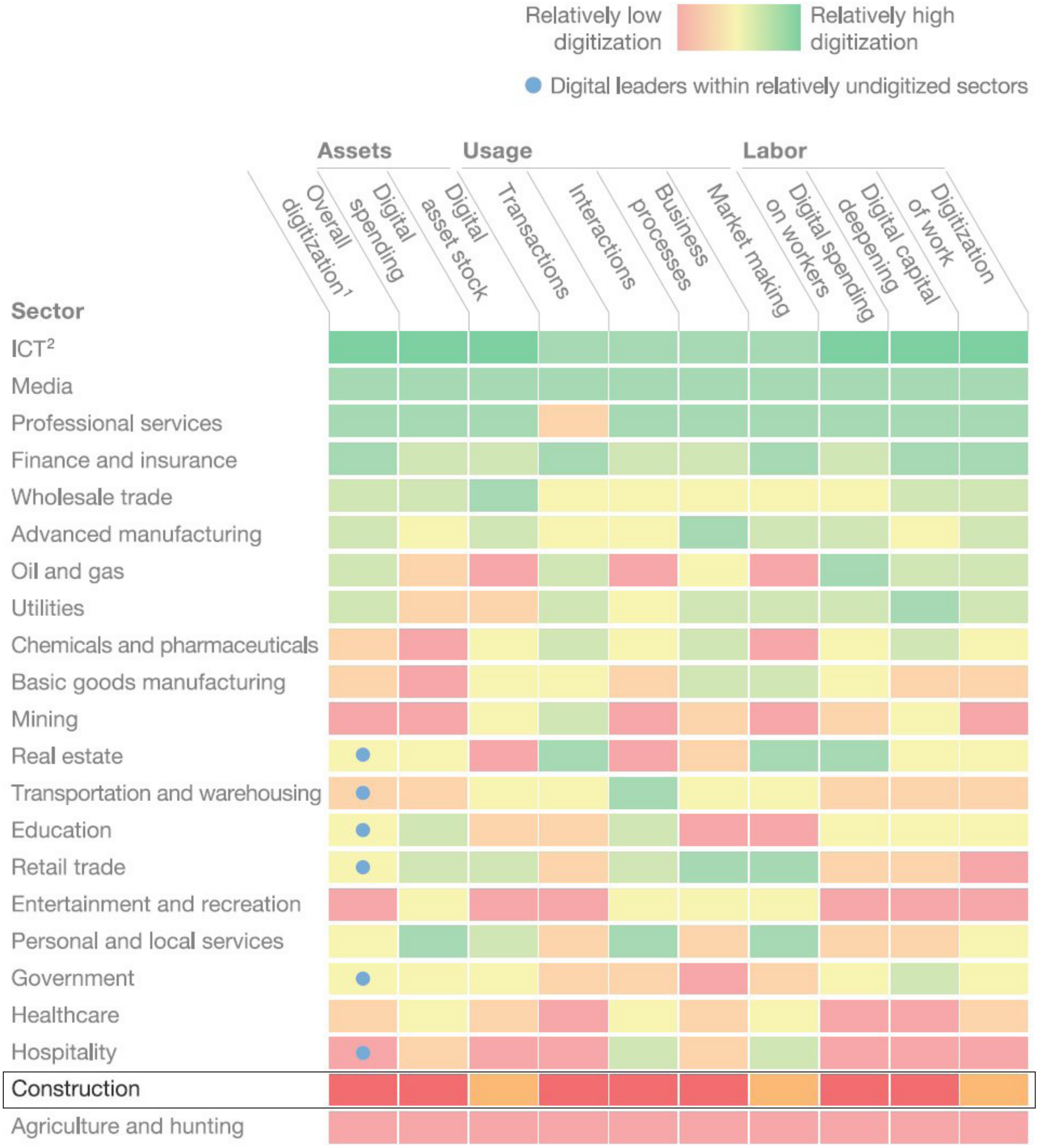


Fig 1.4: Industry Digitization Index; 2015 or latest available data [10]

reducing the overall material usage compared to tradition methods. Also the highly labour intensive and wasteful production of formwork is no longer needed [16], [17], which has a positive impact on the environment. Apart from the construction process, RAC is capable of simplifying the whole process, from design to manufacturing [3], [13]–[15]. This intergration of information can simplify the complex supply-chain of figure 1.3. Everything happens in one digital flow of information; a phenomenon from which the industry can learn from other sectors such as the automotive or aerospace industries. However, overall it should be noticed that RAC will not simply solve all these problems. It is a tool which can improve part of the problem. One of the more promising tools is additive manufacturing, which will be covered in the next chapter.

2. ADDITIVE MANUFACTURING

Additive Manufacturing (AM) is a technology that has transformed our perception on how products are designed and produced, AM is defined as; *''a process of joining materials to make objects from 3D model data, usually layer upon layer, as opposed to subtractive manufacturing (SM) and formative manufacturing methodologies''* [18]. The way AM operates is by creating a computer-aided design (CAD) model which will be digitally sliced in individual layers, the design will then be build up layer by layer [19]. The term AM was used to be called rapid prototyping (RP), which describes this 'rapid' process for creating a prototype etc. the most popular term for AM is called 3D Printing [20]. In contrast to AM, there is another type of manufacturing, namely subtractive manufacturing (SM). SM is removing material instead of adding material, like AM does, which is more a conventional technique of manufacturing, figure 2.1 shows the processes of both AM and SM.

2.1 ADVANTAGES OF AM OVER SM

Compared to traditional manufacturing methods and other methods, like SM, AM has several advantages as *''AM has now reached a point where it is ready to be implemented for industrial use''* [21]. Figure 2.2 summarises the advantages of AM as well as the challenges of this technique. The most characteristic of AM processes is that production is done by just one machine, this is why complex geometries are even more possible compared to the use of conventional methods, thus providing a lot of design freedom [20]. Unlike AM, SM is not as detailed when it comes to design freedom. This is caused by the fact that SM requires a cutting tool, producing parts is more difficult cutting into very thin material, for example, than it is to simply produce a layered part according to a CAD model [19].

Another advantage being that AM can make parts from start to finish, *''the only tooling involved is a single AM machine, so a constant tooling cost is eliminated''* [20]. Partly because AM can produce a part from start to finish, this also ensures that there is little material loss, this can lower the reduction of materials by 75% and lower the costs and production time by 50% [21]. This is in contrast to SM products, where a lot of material loss occurs because you remove material. However, the advantage of SM compared to AM according materials is that AM is developing its material use thus more high-end machines are required, while *''SM can make products out of almost any material. It is a proven and rugged technology, which has been using for ages''* [19]. Another advantage for AM to easy change the design and complexity of it,

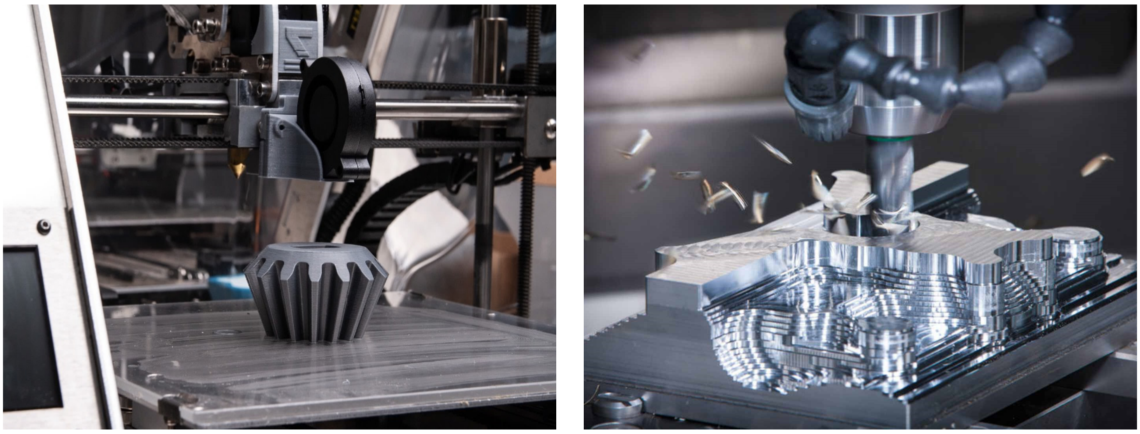
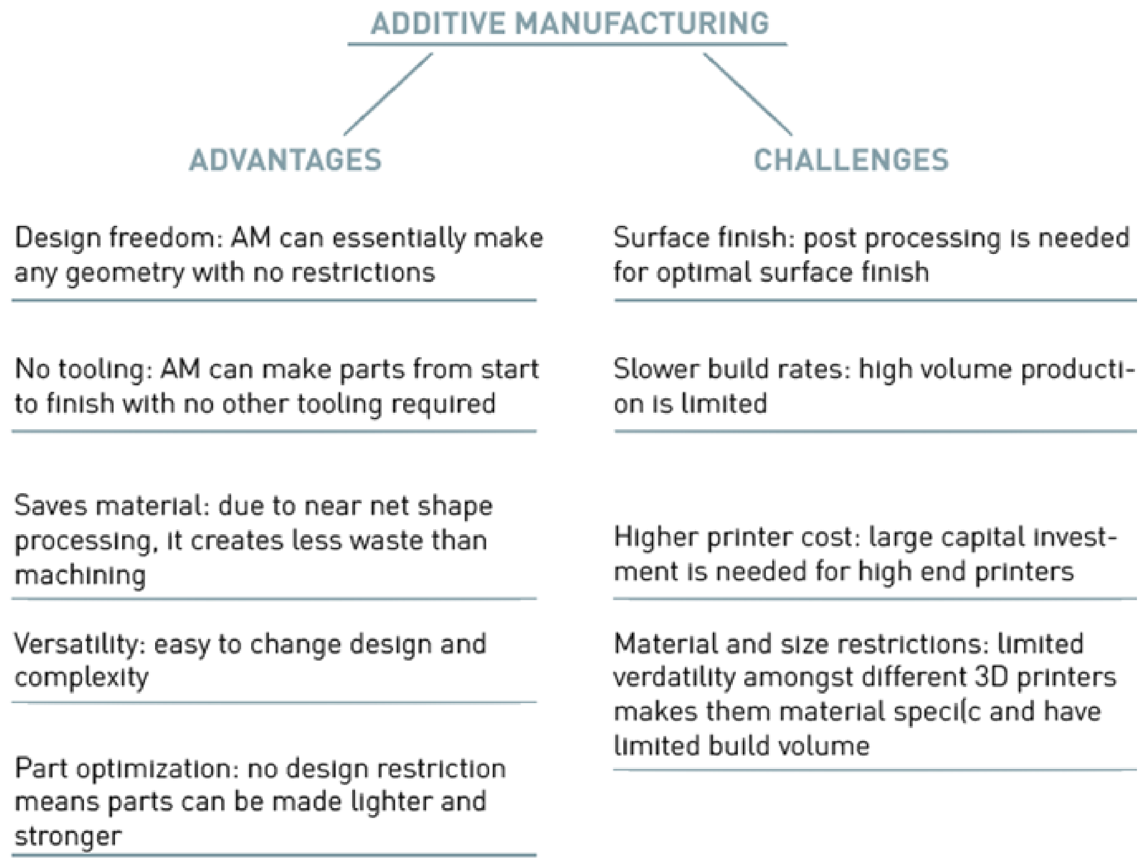


Fig 2.1: AM process (left) and SM process (right)

is the versatility. The Versatility of AM makes it easy to alter design decisions even during the production process. AM can offer this versatility due to digitization using CAD. Also, the advantage is that unique designs are more equal to standardized products now because the AM process can replace the specific crafts and/or equipment's to only using digital inputs. *''Thus the producing costs of customized product will be more or less the same with standardized ones, and individualized buildings will be promoted''* [13].

The 'final' benefit according to figure 2.2 is the part optimization, it states that there is no design restriction for optimize a design. This is similar as Topology optimization, which is according to [22] *''a computational material distribution method for synthesizing structures without any preconceived shape.''*

Not only are there advantages to using AM, but there are also some challenges worth mentioning. For example, the surface of AM products need post processing because of the layered effect this technique has. For SM it is possible to vary in surface finishes by choosing the optimal set of machining parameters, but this process of SM surface finishing costs a lot of energy [19]. The build rate for producing large quantities of AM products is limited, the process is expensive because of the high investment which is needed for example high end printers, and another challenge is the material and size restrictions which are limited because of the different 3D printers.



Design freedom: AM can essentially make any geometry with no restrictions

No tooling: AM can make parts from start to finish with no other tooling required

Saves material: due to near net shape processing, it creates less waste than machining

Versatility: easy to change design and complexity

Part optimization: no design restriction means parts can be made lighter and stronger

Surface finish: post processing is needed for optimal surface finish

Slower build rates: high volume production is limited

Higher printer cost: large capital investment is needed for high end printers

Material and size restrictions: limited verdatility amongst different 3D printers makes them material specific and have limited build volume

Fig 2.2: Advantages and challenges of AM [21]

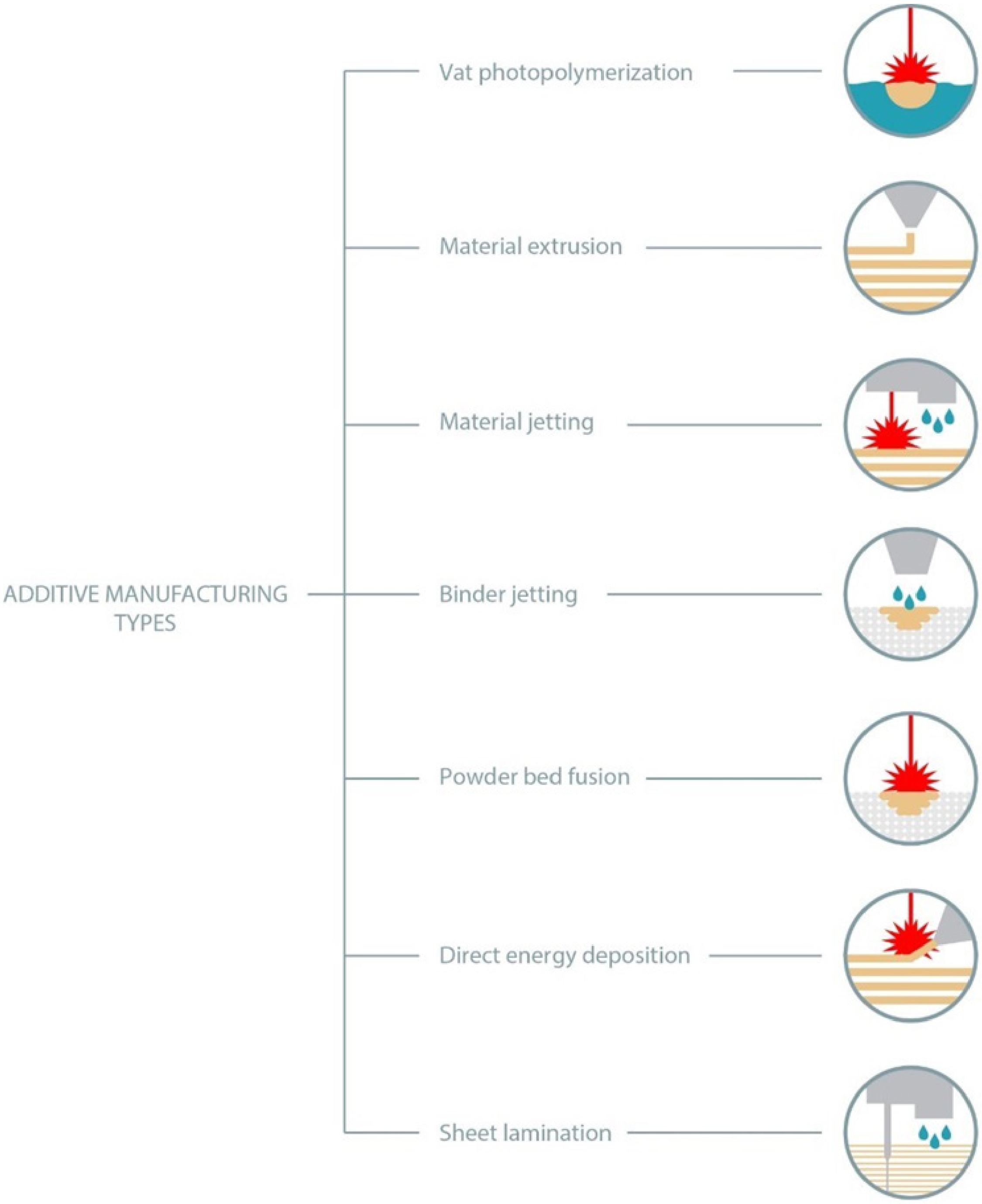


Fig 2.3: Different types of AM Technologies [21]

2.2 AM TECHNOLOGIES

AM has many different technologies. The different technologies are visible in figure 2.3 and will shortly be elaborated. All main technologies also consist of different types of additive manufacturing. These are not mentioned here. The pictures next to the technologies show the main concept of the additive manufacturing technologies.

2.2.1 Vat photopolymerization

Vat photopolymerization is a process in which UV light is shined onto a photopolymer resin. As a result, the resin cures and a hard layer of resin is formed. This process is repeated several times according to the geometry as drawn in the CAD model. After a layer is hardened the next layer can be produced until the model is completely realized [19].

2.2.2 Material extrusion

Material extrusion, also known as extrusion-based AM, is a very well-known way of additive manufacturing because of its cheaper set-up and hardware. In this process, a material raw material is extruded onto a plate by means of a nozzle. The model is formed according to the CAD model and built up layer by layer [19].

2.2.3 Material jetting

Material jetting can be compared to the technique used with 2D inkjet printers. A photosensitive polymer is applied by means of drops to a plate after which the polymer is cured by means of UV light. After this, the plate is taken down and this process is repeated. This creates an object layer by layer [19]

2.2.4 Binder jetting

The binder jetting process is characterised by the process of spraying a liquid binder onto a thin layer of powder through a print head. After the subsurface has been lowered and the next layer of powder has been sprayed, the overall model is gradually realised. When the work is finished it remains in the powder to harden and gain strength. After curing, the excess powder is removed by means of a jet of air [19].

2.2.5 Powder bed fusion

Powder bed fusion involves the process of sintering or melting a powdered material by means of a thermal energy source such as a laser or electron beam. The sintering takes place layer by layer in order to arrive at the final object. The spreading of the different layers of powder is done by a mechanism of a roller or a blade [19].

2.2.6 Direct energy deposition

Direct energy deposition refers to a method in which the building material, a powder or wire form is heated, melted and bonded. The energy is supplied by a laser or electron beam focused on the building material [19].

2.2.7 Sheet lamination

Sheet lamination is the layer by layer lamination of paper material that is cut by a CO2-laster. Each layer represents a cross-section of the CAD model of the part [20].

2.3 APPLICATIONS OF AM

According to Venekamp and Le Fever [22] the use of AM can be divided in two application areas: Finished Products (figure 2.4) and Parts (figure 2.5). AM offers a variety of advantages in terms of operational costs. For each application area a number of sub-areas and their interest in AM is discussed.

2.3.1 Finished Products

Prototypes is one of the oldest applications of Additive Manufacturing, which used to be called Rapid Prototyping. Prototypes are Finished Products which aim at an early evaluation of designs regarding the functionality. Traditionally prototyping used to take a lot of time and

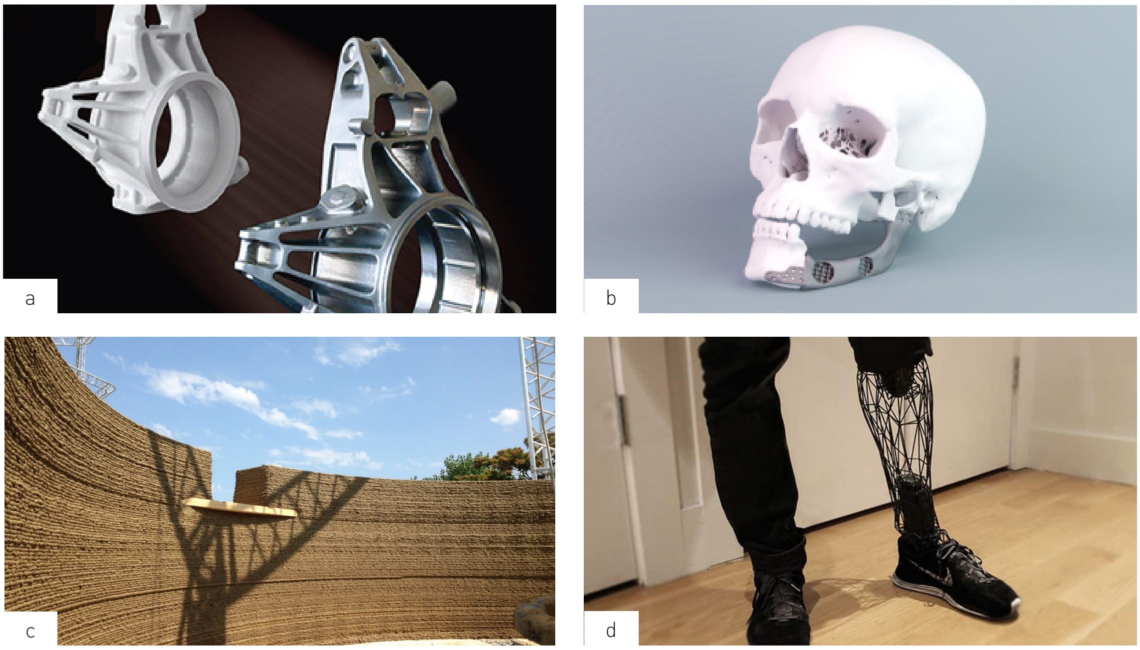


Fig 2.4: Application of AM in two categories [24]:
Finished products: a: Prototypes, b: Models, c: Consumer Goods, d: Biomedical products

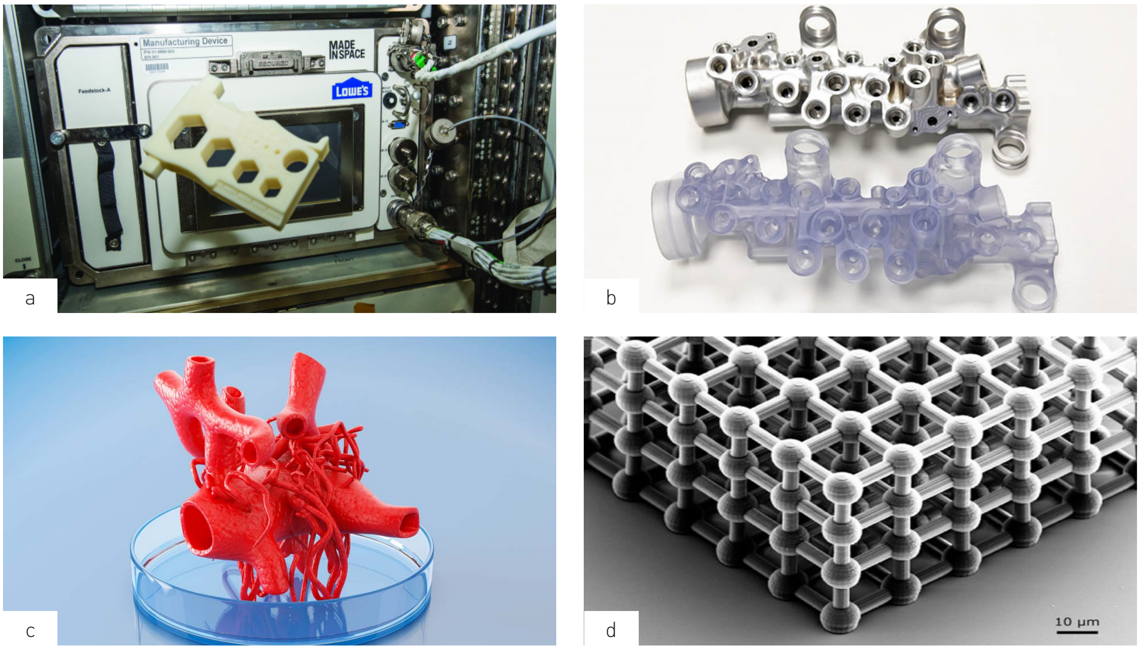


Fig 2.5: Application of AM in two categories [24]:
Parts: a: Spare parts, b: Singular parts, c: Bio constructs, d: Micro structures & electronics

craftmanship, but the application of AM can reduce the production time and thereby improve the design iterations [25].

Models are one of the Finished Products for which AM offers many opportunities. AM allows to make precise representations and visualizations for scientific and educational purposes. More specifically models in the medical field focus on mimicking anatomical structures for research, surgical planning and education. In this way AM contributes to more efficient health care [26].

Consumer goods form a broad range of Finished Products including replicas, custom fit equipment, and of course products for construction. Replicas and miniatures are being mass-produced using AM. Further development of AM devices and open source data provision will enable people to produce items themselves in the future [27].

A lot of research on AM produced Biomedical products is in progress. Biomedical products include both consumer goods such as hearing devices and medical protheses such as teeth and artificial joints [26].

2.3.2 Parts

Spare Parts are a type of parts for which AM offers a lot of opportunities. Spare parts can be quickly produced on demand instead of being stored until a client needs them for replacements, so it reduces storage space and costs. Furthermore the decentralized production of spare parts on location eliminates transportation costs and time, which again reduces the down time (time production is halted by mechanical failure) [28]. AM also reduces the ramp-up time (the time a producer needs to anticipate on future demand), it reduces the lead-time (the time between ordering and receiving parts) and it reduces material waste [24].

Space missions are an example of geographical isolated situations where AM can be very helpful in producing spare parts. Time isolation can occur when parts are not traditionally produced anymore because of changing procedures or because of discontinuation of the producing company after a bankruptcy or other events [29].

For the development of completely new or improved singular parts, AM offers opportunities. For example, in Formula 1 geometric design freedom and new material properties improved hydraulic flow with 250% compared to traditional manufacturing. In hydraulic components flow paths can be optimized resulting in less energy consumption and more efficient engines. At the same time AM allows a higher complexity of designs without an exponential rise of the production costs [30].

AM allows for the construction of biological structures, such as human tissues and organs. Different cells can be ordered along different axes to generate complex structures. This technique can be used to repair or produce tissues and organs but it also gives new knowledge about the anatomy and functioning of those tissues [31]. Also for the production of medicines AM can bring advantages. 3D printed oral drugs were developed which have a more complex release profile than conventionally produced drugs [32]. Lastly using AM in food production allows for new forms, textures, colors and flavors, whereas conventional robotic food production is only aiming at copying manual processes [33].

AM can also contribute to the production on micro scale. Rapid Prototyping (RP), a synonym for AM, was applied to print photomasks for the production of micro-electrodes and microlenses on photo-sensitive surfaces [34]. AM in combination with Direct Writing (DW) allows to directly print conductive patterns on a surface. The advantage of Direct Writing is the possibility to print on both flat and uneven surfaces. It is also possible to print conductive materials on prefabricated products [35].

In construction AM is used for the production of both Finished Products and Parts. Whole buildings manufactured at once using AM are considered Finished Products, whereas 3D printed walls and other elements are Parts. More on AM in the construction industry will be covered in the next chapter.

3.3D PRINTING IN CONSTRUCTION

Within the context of the AEC industry, the process of additive manufacturing is dominated by printing techniques that use concrete-like materials, and is therefore often referred to as 3DCP (3D Concrete Printing). A reason for the almost exclusive use of cementitious materials can be found in the fact that very little research has been done into the load-bearing capabilities of other materials in a context of additive construction [36]. From this point on, all AM techniques that are being discussed are related to the AEC industry and involve a nozzle of types, and will therefore be referred to as 3D printing techniques, or 3D printing techniques of cementitious materials, or 3DCP to narrow down the focus of the research.

In the AEC industry, not all 3D printing techniques are used to the same extent. The extrusion based process seems to be the most valuable printing process within the context of AEC. Followed by the powder bed fusion technique. On the other hand, a relatively new technique called spray printing is showing various interesting developments in the field of additive construction. These three 3D printing techniques will be briefly introduced in the context of AEC, after which we will explore the extrusion based printing process of cementitious materials in more detail to create a comprehensive overview of the state of the art of 3D printing within the field of construction.

3.1 SPRAY BASED PRINTING

The spray printing of concrete, or 'shotcrete printing' has only recently been researched in the context of 3D printing techniques. The technique of shotcrete itself has been around for more than a 100 years already. Applications for it can be found in the mining and construction industry [37]. However, relatively recent, the universities of Braunschweig, Clausthal and Hannover started looking at the possibilities of shotcrete as a 3D printing technique in the construction industry.

The process of spray printing concrete brings with it some advantages over other 3D concrete printing techniques. The first is the possibility to spray print on vertical surfaces. A useful application of that technique can be found in the double curved reinforced concrete wall that the university of Braunschweig developed in 2020. The wall is initially built up by depositing layers of concrete on top of each other, similar to how one would print a concrete wall using the extrusion based process. In between some of the layers, horizontal reinforcement is applied. Then, vertical reinforcement is placed against the wall, which is then vertically being spray printed over, to create a strong reinforced double curved concrete wall (figure 3.1). Other advantages include the excellent bonding of various layers, and the possibility to introduce additional accelerators to adjust the solidification times [37].

The spray printing of concrete is however a rather difficult process, with many parameters that influence all aspects of the outcome. Such aspects include the layer thickness, the early strength and the concrete quality. The many parameters that need to be taken into account are the spraying distance, the spraying angle, the concrete volume flow rate, the delivery pressure, the air volume flow rate, the air pressure, the concrete accelerator dosage and parameters related to the path planning such as the nozzle distance, velocities, layer spacing, application angle or times between layer applications [37].

Fig 3.1: Double Curved 3D Concrete Spray Printed Wall [38]

3.2 POWDER BASED PRINTING

Besides the extrusion based processes , the powder bed fusion based processes is currently the most valuable contributor to AEC in the field of 3D printing techniques. The process is based on the transformation of a material from a powder state to a solid state. This transformation might be achieved by sintering, melting, applying an energy source, or by means of a chemical reaction [36]. When the process is complete, the residual powder may be removed and reused in a next printing session.

The powder bed process in the AEC context makes use of a concrete-like powder, rather than the metals which are usually used in this process in other fields [36]. In AEC a powdered concrete mix is often used which is cured by means of hydrating the mix using an ink jet spray [39].

One of the things that makes the powder bed based process extremely beneficial to the construction industry, is the fact that there immediately is a supporting structure, which is the powder that in not used for the object that is printed at the time. This means that it is much easier to create objects with overhangs or arches [40].

On the other hand, however, the powder bed is much more vulnerable to exterior influences such as the weather [40]. This makes it difficult to apply this process to in situ constructions. Instead, most powder bed based objects are thus printed off-site. Making that an important constraining consideration during the design phase.

The most notable approach of powder based printing is the D-Shape, which was invented by Enrico Dini [41]. The D-Shape approach produced what is generally also considered to be the first large-scale additive manufactured structure, which is the Radiolaria Pavilion [36], which can be seen in figure 3.2. It was built in 2006, using the earliest version of Dini's D-Shape printer.

3.3 EXTRUSION BASED PRINTING

The most used 3D printing technique in construction at this point in time is extrusion based printing [36]. The process involves the deposition of a material in a liquid state by means of a printing nozzle [36]. Once the material is deposited, the curing of said material will result in a solidified whole. Examples of such processes are Fused Deposition Modelling, PolyJet and Inkjet.

Within the context of AEC, the extrusion based printing techniques can be roughly divided into two categories. The first category is the extrusion based printing of thermoplastics. There are no structural applications for this process in the construction industry, as it is mainly used for prototyping. We shall therefore not further discuss the topic of extrusion based printing of thermoplastics. The other category of extrusion based printing, is that of cementitious materials. This is by far the largest category that has any bearing in the AEC context. This 3D printing technique will be extensively covered in the next chapter.

Fig 3.2: Radiolaria Pavilion printed by Dini's D-Shape Printer [42]

Fig 3.3: Dini's D-Shape Printer [43]

4. EXTRUSION BASED PRINTING

As stated before, the extrusion based printing process of cementitious materials is currently the most valuable contributor in terms of 3D printing in the context of the AEC industry. It is based on the computer-controlled continuous extrusion of a cementitious material by means of a nozzle, while depositing various layer on top of each other to create an object in three dimensions [36]. Extrusion based printing offers a cheap and fast alternative to traditional construction. It has the potential to fully transform the AEC industry [44]. In order to understand the current state of the art of this 3D printing technique, this chapter will firstly cover the system engineering aspect of it. Then the material properties will be discussed. Thirdly, the importance of various design methodologies will be covered. And lastly, various applications of extrusion based printing will be elaborated.

4.1 SYSTEM ENGINEERING

The relevant hardware that needs to be discussed when talking about 3D concrete printing in the AEC context can be subdivided in the type of robot that is used, the printer head, and the delivery system. The extrusion based printing of cementitious materials is currently being executed by four different types of robots. These are the gantry system, the industrial robotic arm, swarm technology, and by means of cable suspended robots.

4.1.1 Gantry System

An example of the gantry system can be found at the university of Eindhoven (figure 4.1a). A gantry system operates on a structure, that allows the printhead to move in the X,Y and Z direction. It offers the advantages of being able to print relatively large structures, up to the size of a whole building. A gantry system generally has three, or sometimes four degrees of freedom. The first gantry system being developed for concrete extrusion was used for the Contour Crafting process, as invented by Khoshnevis from the university of South Carolina [36].

4.1.2 Industrial Robotic Arm

Another type of robot that is widely used in 3D concrete printing, is the industrial robotic arm (figure 4.1b). The robotic arm mostly offers six degrees of freedom. It is more precise and accurate than the gantry system and therefore, the robotic arm is thus often used for smaller objects with more detail present. The downside of such a robot is the limited printing area, due to the restrictions in the size of the arm. Another challenge that is posed by the robotic arm, is the fact that a deeper knowledge of the programming of such a robot is required in order to correctly operate it.

4.1.3 Robotic Swarm Technology

Robotic swarm technology might pose a future solution to some of the challenges that the industrial robotic arm faces. The idea of swarm robotics rejects the use of a single robotic entity, but instead, makes use of various smaller mobile robots (figure 4.1c). The swarm technology is especially interesting and practical for 3D printing in extra-terrestrial environments, where transportation is an important limiting factor on the size and weight of the robots [36]. The swarm robots can navigate their own way through a construction site, which again is very beneficial in extra-terrestrial environments, but also on harsh earthly environments [36]. One of the key aspects to get swarm technology to truly work, is to provide the robots with the ability to climb the structures they build. That way, they are not dependent on a large gantry system, or long robotic arms. One institution that made this a reality is the Institute of Advanced Architecture of Catalonia with their Minibuilders project.

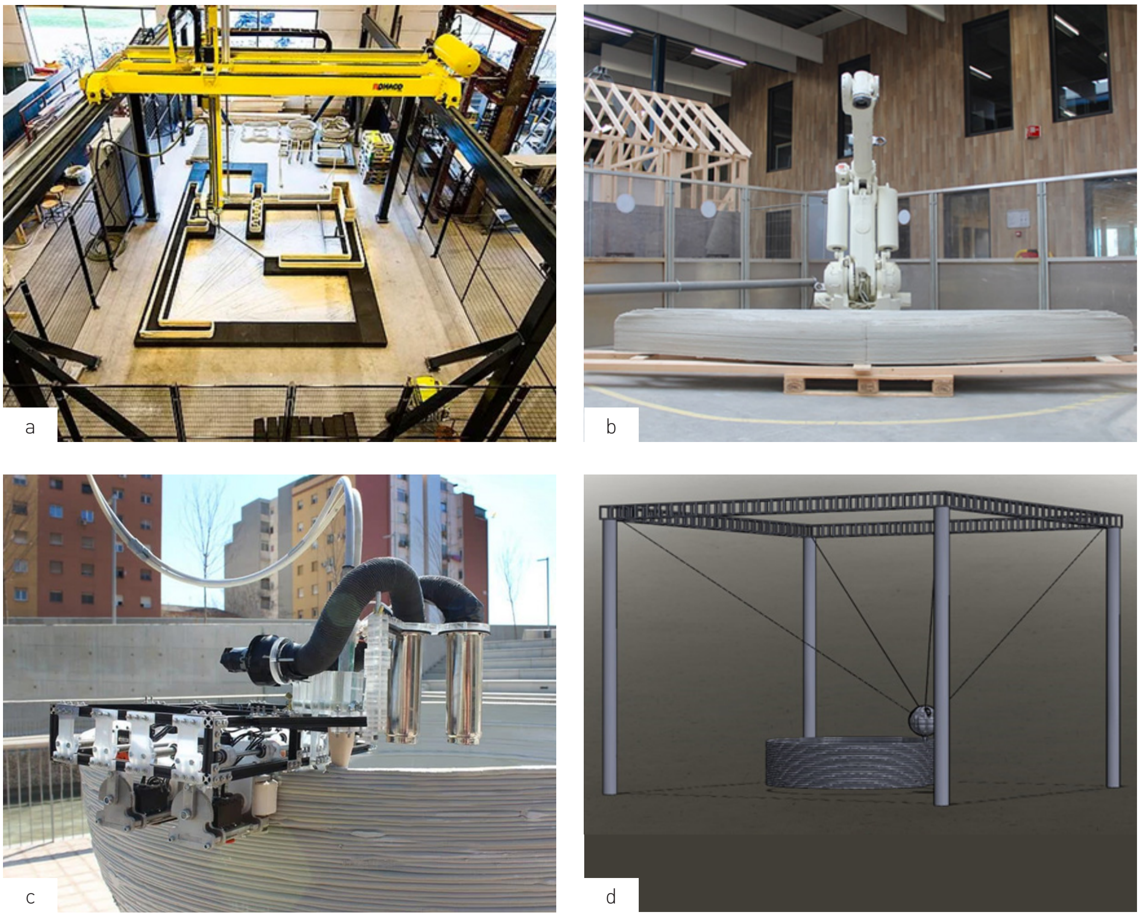


Fig 4.1: Types of extrusion based robots;
a: Gantry system at the TU/e [45], b: Industrial robotic arm at Vertico [46],
c: Robotic swarm technology by MINIBUILDERS [47], d: Cable suspended "spider bot" by MIT [48]

4.1.4 Cable Suspended Robots

The cable suspended platform, as is shown in figure 4.1d is rather similar to the gantry solution. However, it has various advantages over the gantry solution. The cable suspended printer has a structure that uses less material, which makes it easier to move around and thus making it easier to cast in place. Due to the fact that it consists of less parts, it is also much quicker in assembly and disassembly [36]. Another advantage that the cable suspended platform offers is the possibility of having a print head with six degrees of freedom, rather than the three or four that the gantry solution offers. The cable suspended platform is still in early development stages, but various institutions are investigating its possibilities and its potential at this point.

4.1.5 Print head and delivery system

Besides the type of robot, the print head itself of said robot has a huge impact on the 3D printing process. The print head usually consists of an extruder, a nozzle, possible side trowels, and a case with an Archimedean screw that forces the concrete out of the nozzle.

The nozzle may come in various shapes, which will help achieve the desired shape, size and buildability of any particular concrete layer [44]. Overall, it seems that the circular shape of the nozzle offers more freedom, as the angle does not need to be changed to correct for changing angles in the path [49]. The size of the nozzle may differ, depending on the desired width of the beads. The orientation of the nozzle must be applied tangent to the tool path [44].

The speed of the print head needs to be carefully calibrated, otherwise too much or too little material will be deposited, which might result in an increased or decreased bead dimension, which in turn will impact the finished object [49]. Some printer heads have trowels and the end of the nozzle, to help smoothen the surface of the concrete once it has been deposited. This also ensures a more consistent bead width.

In most cases the supply of the materials happens through a pump, which acts as the delivery system. Before the pump a mixing unit is located within this delivery system. The mixing unit provides the specified concrete mix, which is usually a high viscosity past like mix, to ensure the shape is retained when printing [49]. This also means that the pump needs to be relatively strong in terms of pressure, to transport said mix to the nozzle. Often, a variety of aggregates will be present within this mix, providing an extra difficulty to the pump. Alternatively, the concrete mix can be made with a higher viscosity, as long as additives in the nozzle are injected into the mix to make it quicker to cure [49].

The other half of system engineering consists of software engineering. An important consideration here is the toolpath. The toolpath is the path that the printer head needs to follow when extruding the concrete. It is important to realise that each 3D printer comes with its own software. On top of that, all software that was used during the design process, has to be able to work together with the software of the printer itself.

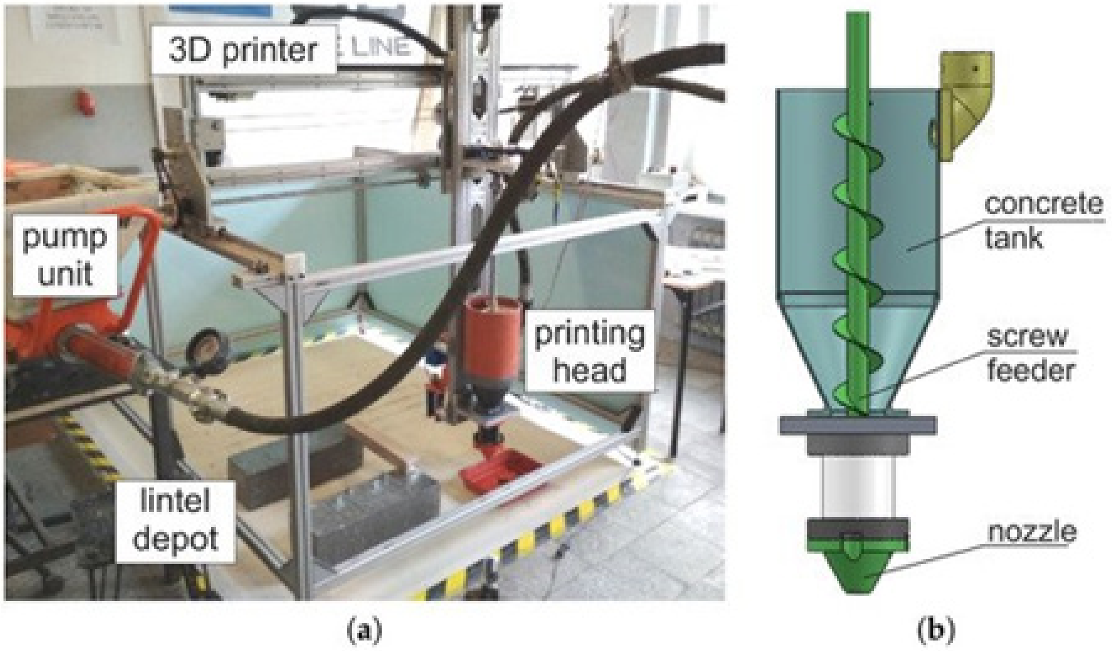


Fig 4.2: Printing Head and Delivery System [50]

4.2 MATERIAL ENGINEERING

Concrete is to the present day the most used building material in the world. The raw materials neccesary for producing concrete are cheap and commonly available in most areas. Its popularity is mainly due to its compressive strength, fire resistance and the fact that it can be applied in any shape because of its fluid state before setting. The actual composition in practice in general at least consists of a mixture of a cementitious material and water, together with a filler of sand, gravel or another granulate material. These are often complemented by additives like aggregates [44]. Regarding the 3DCP extrusion based process, the traditional concrete can't be applied instantly. The composition of the concrete is of high importance as there is an absence of formwork. In order to accomplish a consistent extrusion of material, research of the rheological properties of concrete in its fresh state is required. The influential factors of the material in its fresh state is defined by the characteristics of pumpability, extrudability, buildability, interlayer adhesion and open time. The latter concerns the time the fresh concrete needs to set. It defines the time between completing the mixing and the initial setting time of the material [49].

4.2.1 Pumpability and extrudability

Pumpability concerns the material's mobility and stability. In order to pump the material, a relatively soft mixture is required. When the concrete reaches the nozzle, a somehow more stiff material is desired so it does not slump while being extruded. The composition of the extruded concrete should be well-considered as it largely influences the pumpability [49].

As the material is being pumped over a distance, depending on the printer size and the desired working volume, the fresh concrete is less viscous when reaching the nozzle compared to traditional extrusions. The extrudability covers a proper and consistent extrusion of the material, where it should retain shape when extruded through the nozzle (figure 4.3a). Pressure differences may arise as the nozzle and pipe often differ in cross-sectional dimension. Material proportions should be carefully chosen and controlled, as a failure might lead to segregation of the mixture and possible material blocking in the pipe or nozzle [49].

4.2.2 Buildability and interlayer adhesion

Once extruded, the material's buildability refers to the printed layers being able to hold the subequent layers on top. It is of high importance that the material is self-supportive and it should be resistent to collapsing and deforming. Imperfection of layers could lead to instability as successive layers are added (figure 4.3b). A way to improve the buildability is to create a supporting filament [49]. These are printed adjacent to the actual structure to ensure a stable printing environment (figure 4.3c).

Additionally, when extruded, the material should set as fast as possible to remain shape. However, it should not dry too fast as it should still bond with the subsequent layer (figure 4.3d). This covers the parameter of interlayer adhesion. It is important that each printed layer is able to harden when poured and hold its self-weight. Although, it shouldn't become a separate entity [51]. All parameters are dependent on state parameters of concrete in its fresh state. The shear stress, viscosity and thixotropic behaviour of the concrete need to be researched [44].

As soon as the extrusion of the fresh material is successfully executed, the material properties in the hardened phase need to be researched. The structural properties of the hardened concrete are influenced by the strength (both compressive and tensile), shrinkage and ductility [52] [49]. The influence of these parameters may cause cracking of the concrete if not considered carefully. In order to control these parameters, and improve on the workability of the material, the printable mixture may be complemented with additives like aggregates, fibers, reinforcement and chemical additives (figure 4.3e). A better bonding by means of additives allows for achieving specific properties such as a high strength and a certain level of ductility [44]. If successfully executed, a concrete structure in its hardened state can have similar strength and density as cast concrete [53]. A successfully 3D printed concrete structure will remain a well-considered balance between all mentioned parameters in both the material's fresh state and hardened state.

Fig 4.3: a: Consistent extrusion, b: Buckling due to inappropriate buildability, c: Support structure to improve buildability, d: Bonding between layers, e: Addition of fibers

4.3 DESIGN METHODOLOGIES

4.3.1. Optimizing topologies

The method of optmizing topologies is opening new doors in relation to design, for example the 3D printed bridge by Vertico, shown in figure 4.4 is designed in accordance to the method of topology optimization which provides a freedom for structural designers who can now be more innovative with their structural lay-outs etc. A big advantage of this method is the way in which the material and weight can be reduced compared to how products would traditionally be designed. *"Arup claimed to have been able to reduce the weight of traditional steel nodes by 75%, resulting in an overall weight reduction of more than 40% for the considered structure. "* [36] see figure 4.5.

Fig 4.4: Topology optimized bridge by the University of Ghent [54]

Fig 4.5: Arup's stainless steel AM node with connecting threaded swaged ends to the cables. [55]

4.3.2 Complex geometries

"3-D printing is an additive manufacturing (AM) technique for fabricating a wide range of structures and complex geometries from three-dimensional (3D) model data."

For the construction industry extrusion based prosses could be extremely beneficial in the field of freeform constructions. The maintenance of high degrees of geometrical freedom, is a recurring theme. [36] By means of 3d printing, the complexity of a part is no longer determined by the production process but by the desired design and functionality of a product. Complex geometric parts that previously could not be produced with conventional techniques such as milling, turning and casting are possible with 3d printing.

With the possibility of 3d printing, any subject that can be constructed in a 3D CAD program can also be produced. There are hardly any limitations. It gives designers maximum design freedom

A project where freeform plays an important role is a project by XtreeE and Seaboost. They are doing research to the 3D printing of coral reefs. To construct the coral reefs they use a sand based concrete which imitates the natural composition of the coral reefs the best. The advantage of using 3D concrete printing is that they are able to replicate the intricate shapes of the coral reef

4.3.3 CAD to CAM

With the emergence of Computer Aided Design (CAD) systems, design and drawing processes of buildings have sped up [56]. This development allowed designers to draw in either 2D or 3D, with the use of computer software. However, the divergence between design and physical manufacturing has become more obvious by the emergence of Computer Aided Design (CAD) software [57] Computational design methods have produced architecture that is materially generic. [58].

The advent of Computer Aided Manufacturing (CAM) tends to fill the gap that exists between design and actual manufacturing. CAM refers to the use of computer software applications,

Fig 4.6: 3D printed coral reef

in order to automate and facilitate parts of the manufacturing process. Briefly, the CAD drawing is a model of what will be physically realized, due to the contribution of CAM. Whereas with CAD drawings, the gap between design and material became bigger, CAM combines the physical properties of materials with the virtual design.

This development enables us to move from the digital manifestation of physical form to its physical manifestation of digital form. [59]

The software respectively creates instructions, in order to steer a machine to the realization of desired manufacturing parts. [60] Data present in CAD drawings and models, can be extracted in order to realize the instructions. The choice of material and the form of the object can therefore be determined based on the information that is provided by simulations. Basically the design of form using CAD has changed to the design of algorithms using CAM. [61]

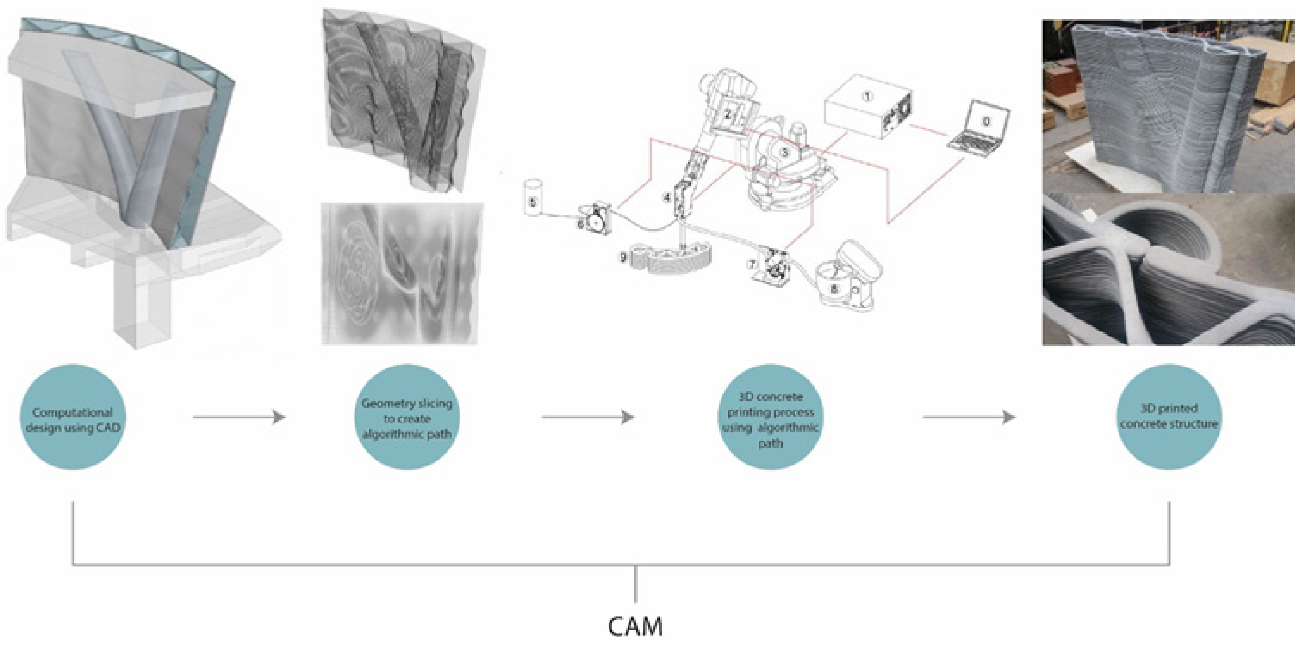


Fig 4.7: Manufacturing of concrete wall using CAM [62]

4.4 APPLICATION

4.4.1 Common Environment

There are different environments in the building construction where 3D printers are currently used. This could include, for example, the workshop where the printer is installed, or the construction site where the printer can be installed. The advantage of printing in a Common environment is, for example, that less material has to be used, because formwork is not necessary. The additive construction also allows for highly optimized construction processes and the production of highly optimized components.

The controlled environment makes this possible. when external factors occur, including wind, rain. etc, this can cause problems.

An example where the components are made in the workshop and transported in parts to the location is a project by the Eindhoven University of Technology, Project milestone figure 4.8. is a multi-level housing project, printed in concrete. This project is located in Meerhoven, a new district of Eindhoven. The Houses will be printed one by one, to learn from each printed house. The elements will be printed at the university, but the aim is to move the printer to the building site.

"The project is the world's first commercial housing project based on 3D-concrete printing. The houses will all be occupied, they will meet all modern comfort requirements, and they will be purchased and let out by a real estate company."

The following example (figure 4.9) uses a printer that can print on location. The example is a project by XtreeE using a 6-axis robotic arm. The wall element that is printed with this, is made of ultra-high performance concrete and was geometrically optimized, this ensures better thermal insulation. Production time was about 12 hours. [62]

Finally, an example from the Eindhoven University of Technology. The bicycle bridge has a span of 6.5 meters and a width of 3.5 meters. figure 4.10. The elements are printed by means of 3DCP. The upper part of the bridge consists of printed elements, interconnected by tendons installed later. In addition, some reinforcement cables have embedded layers during their deposition. All elements of the bridge are printed in 48 hours. [53]

In the following quote from Marinus Schimmel (director of BAM), indicates what advantages 3DCP has by printing bridges, after the success of the bridge of the TU/e;

"We have a world's first here," explains Marinus Schimmel, director of BAM. *"with 3D printing, you have more flexibility regarding the shape of the product. in addition, 3D printing a bridge is also incredibly efficient: you need less concrete, but there is also no need for shuttering where the concrete is normally poured in. you just use exactly what you need, and there is no release of CO2 emissions."*

Fig 4.8: Project Milestone

Fig 4.9: 3DCP pushes the limits of construction

Fig 4.10: 3DCP cycle bridge elements in the Netherlands

4.4.2 3D printing for Harsh Environments

The use of Additive manufacturing in a harsh environment can have advantages. A harsh environment is an environment that is difficult, impossible or even dangerous to reach for people. This category also includes areas affected by natural disasters or war zones. AM can offer a solution here by realizing first aid houses and repairing infrastructure, bridges, etc. in remote areas. [36]

Also underwater is currently being tested with 3D printing. As a research, a series of 3D-printed reef units for the Oyster Reef Recovery research project was placed in the North Sea in 2017. The reef figure 4.11. units are printed in Rotterdam by Boskalis with D-shape technology. The sizes vary from 50cm high to 120cm high. The effects of the salt water on the material will be monitored in the coming years. (reefdesignlab) This research is a basis for possible further research into underwater printing. An example of this is underwater by designoffice figure 4.12.

Another example of a harsh environment is for example on Mars. here too, studies are being carried out into whether it is possible to make 3D printed buildings. An example of one such project is AI SpaceFactory's habitat, figure 4.13. This egg-shaped designed building deals with the atmospheric pressure and is built from a material composed of a mixture of basalt fibre extracted from Martian rock, and renewable bioplastic derived from plants.

Fig 4.11: 3D printed Oyster Reef Recovery

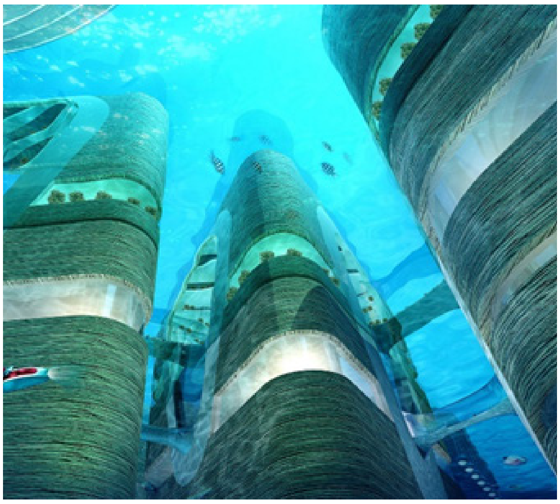


Fig 4.12: Design of a printed house underwater

Fig 4.13: AI SpaceFactory's building "3D printer"

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