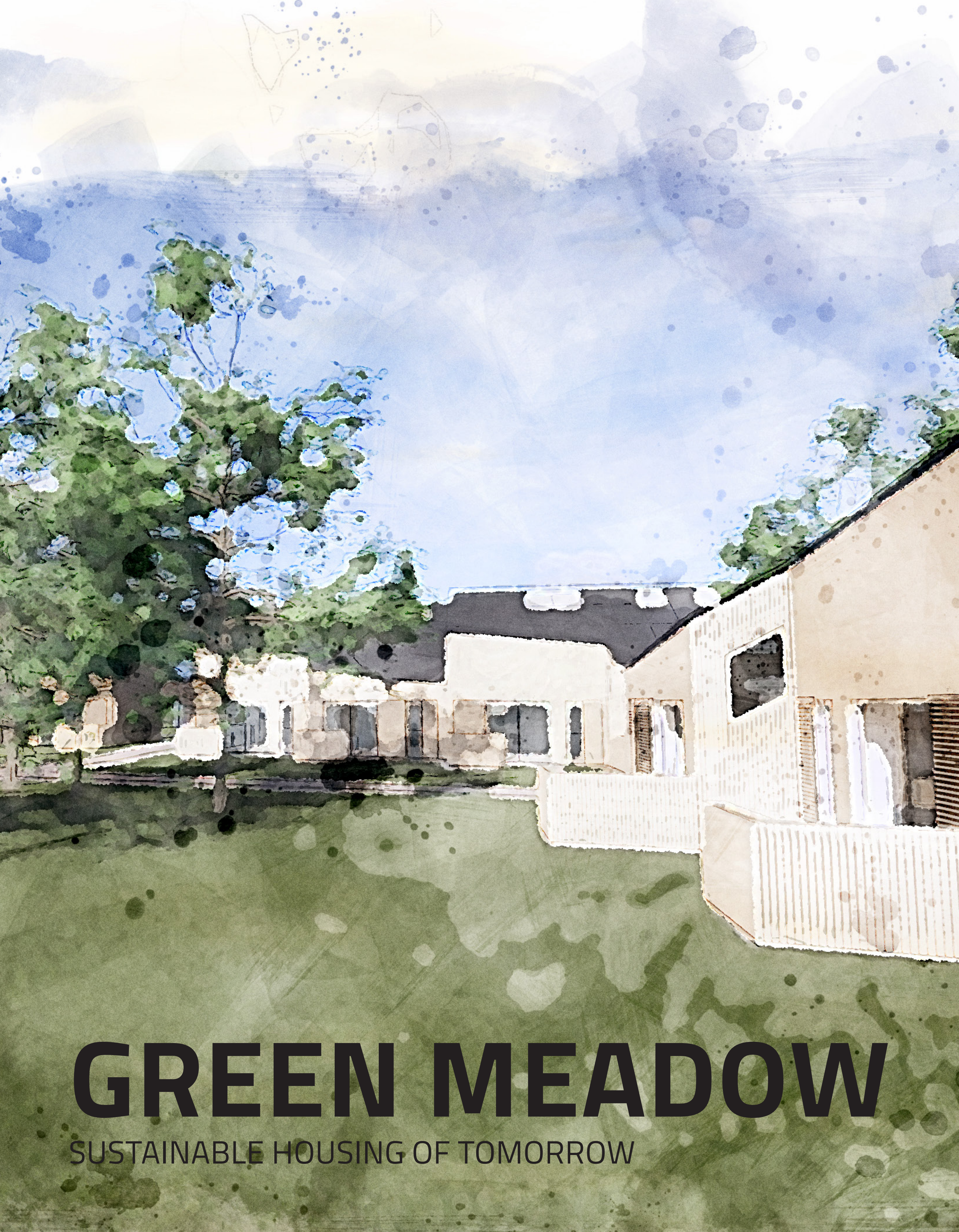

GREEN MEADOW

SUSTAINABLE HOUSING OF TOMORROW

TITEL PAGE

Project:	*MSc04 Architecture - Master Thesis*
Titel:	*Green Meadow: Sustainable Housing of Tomorrow*
Date:	*03.02-28.05.2020*
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Appendix:	*11*

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READING GUIDE

This thesis consists of one report with three main sections; Analyses, Sketching and Presentation. The report should be read from start to finish to get a complete understanding of the project and all its aspects. The project is displayed in a certain order, though it is important to state that the course have not been linear nor simple. Designing integrated is a repeating process, where everything happens at once. Moving back and foth between each phase is a natural development.

For references, the Harvard referencing method has been used. At the end of the report, a literature list can be found with, right after an illustration list, referencing all illustrations as well. By extension all appendix' are located. Here raw data, sketches and photos supplementing different parts of the thesis can be found.

The thesis follows 4,5 years of study at the University of Aalborg, and includes many of the methods and techniques learned throughout the years. This semester have varied from the others, as it unfolded during the crisis of Corona Virus. This have brough a few challenges and changes from what was expected at first, both regarding data collection and testing of specific concepts. Apart from this, the project havn't been affected.

Ill. 1. Skæring Bæk

ABSTRACT

The project takes offset in the issue of the ever continuing need for housing and an increase in size that renders the stricter building regulations almost indifferent. Through state-of-the-art research, the project works with the topic of small living and living in communities, while investigating how to ensure quality of living.

The project focuses on lowering life cycle energy, both through the energy used for materials and for opeating the building afterwards. Using LCA to examine materials in correlation to indoor environment and exspression, the project revolves around the use of passive and active strategies to develop the optimal design.

The result is realized on a site in Skæring, Denmark with 80 new homes, ranging from 73-91 m^2. The project is based upon ensuring the qualities of the single family home, into a smaller and more common housing unit, through built-in furniture, multifunctionality and flexibility. Furthermore, the units are optimized acording to energy use and leaves the total use of a life time, much smaller, than for the modern single family home.

CONTENT

PROLOGUE

Titel page	2
Reading guide	3
Abstract	5
Introduction	8
Methods and techniques	10

ANALYZES

When a house becomes a home	16
Qualities of the Danish home	17
Life cycle energy	20
Spacial dimension: Living small	22
Social dimension: Living together	24
Environmental dimension: Living comfortably	26
Site Location	28
Regulation and legislation	30
Topography	32
Microclimate	34
Access	40
Public functions	41
Typology/appearence	42
User group	44
Room program	46
Functions, activities and rooms	48
Design criteria	50
Vision	52

SKETCHING

Urban workshop	54
Urban qualities	56
Unit Grouping	58

Unit sketching 60
Interior strategies for downsizing 63
Detail workshop 64
Unit detailing 66
Siteplan 69
Common houses 71
Roof 72
Solar panels 73
Material choice 74
Window placement 80
Ventilation 82
Solar shading 83

PRESENTATION
Green Meadow 86
Common houses 98
Unit A 104
Unit B 108
Interior solutions 112
Construction and materials 116
Indoor environment 120
Energy use 123

EPILOGUE
Conclusion 126
Reflection 127
Illustrations 128
Literature 130

APPENDIX

INTRODUCTION

Since the beginning on the new millennial, temperatures have risen above what have ever been recorded. This have its roots in the way people live their daily lives. The construction sector and operations of buildings are a big part of the problem, as a third of all greenhouse gasses emitted comes from these. (Stephan & Crawford 2016)

The buildings keeps getting bigger and the greenhouse emission both for buildings but also for operations hereby increases. Since 2010 the built floor area has increased by almost 25% and both the energy use and emission have steadily climbed as well (IEA 2019). In order to slow down the emission and the load of the environment, the focus need to lie on how we build. The Danish building regulations have since 2008 had a high focus on lowering energy demands but it does not yet look into the embodied energy of the final building and therefor it is not yet possible to see or meassure the impact of these changes. (Nielsen 2018).

Low-rise buildings are one of the more popular living forms in Denmark and almost everybody have or will at one point in their life, live in this setting. The low-rise houses are also the house type with the second largest floor area. (Jensen 2008) This building form amongst others therefor needs a reduction in floor area to actually meet the increasing need for sustainability. Decreasing the home area can unfortunately also have a negative impact on human well-being. Generally the amount of space, either determined by rooms or floor area per person, is often used as an indicator for human well-being (Foye 2017).

Ill. 2. Site

PROBLEM

This project adresses the issues of the increase in life cycle energy due to larger build area by looking into the possibility of reducing residential area in low-rise buildings, without loosing the qualities, people search for, when choosing this form of living.

METHODS AND TECHNIQUES

Integrated Design Proces	During the past years, this **method** has been the most commonly used, as an overall structure of designing. This project uses it as a tool of organizing work but more importantly to ensure the integration of more technical solutions into the architeture from early on. One of the most central elements is its ability to move back and forth between different stages. (Knudstrup 2005)

ANALYZES

Mapping	Mapping is a **method** used to describe physical elements in a specific area. The method was described by Kevin Lynch (1960) but alterations have been made, as much more information can be described with this method, than originally intended in the method by Lynch. This project uses mapping to establish a base of information in form of potentials and challenges from sun, wind, access points and several more layers. This is a simple way to showcase otherwise complex information.
Case studies	Case studies can be an elaborate **method**, that studies real life cases from any angle. In this project, it is used to support specific themes and extract infromation, that can be used as inspiration later on. It can be seen as an elaborate trial-and-error method, where experiences from the existing cases can help set up the optimal starting point.
State-of-the-art research	This research **method** takes offset in scientific articles based on facts, experiments and/or studies. It is validated knowledge-based research, making it a more credible source of information.
Diagrams	Diagrams can be a **technique** that helps illustrate data in grafical and readable ways. There are many options to display the data, depending on what kind of information is most important. The diagram supersede a long explainatory text.
3D models	To help visualize volumes in the initial analyzes, simple 3D-modelling are being used as a **technique**. Software is used rather than physical models, to get direct results on the computer. This have been used e.g. to find sun and shadow on the site in specific conditions.

SKETCHING

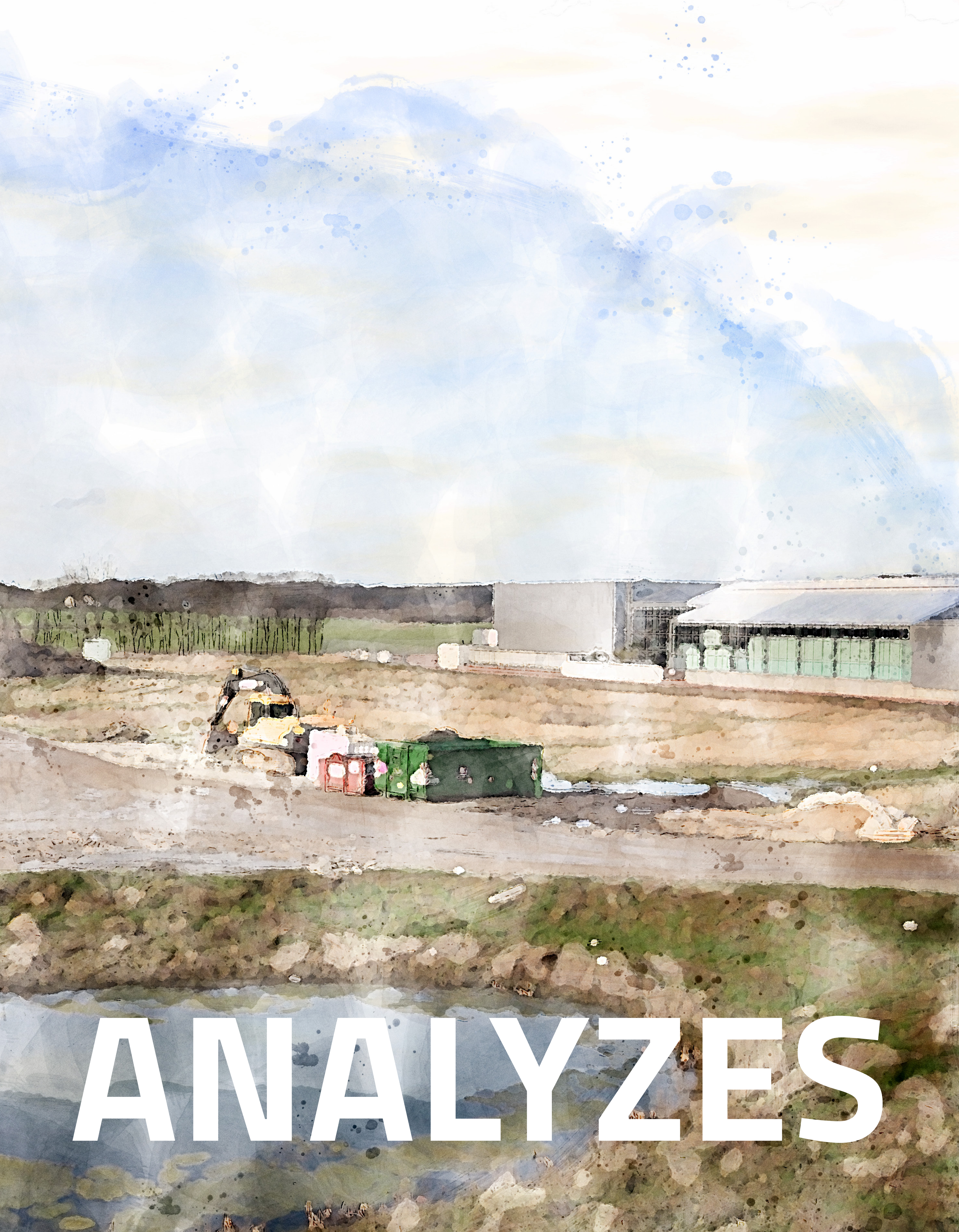
Mapping	This **method** can also be used during the initial design phase to easy visualize differences between several options. This comparison is simple to understand, as only the data result will differ between the options.
Hand skecthing	Hand sketching is a **technique** that connects the thoughts more directly with the paper. It is a quick way of expressing ideas and it can help ask questions, when somethings are missing. Using tracing paper can further speed up the process.
Weighted scoring model	When diciding between several options during the design phase, many factor can be in play. Here, the **method** of weigthed scoring is used (ProductPlan n.d.). Many have described this method in different ways, but the essence is to establish the qualification qualities and their weight before scoring each option to make it as objective as possible.
Physical models	Models are a simplification of shapes and volumes. Working with scaled physical models is a **technique** to obtain knowledge about the physical appearance and the spacial understading of different design proposals. This can also create random placements, that would take longer, modelling in a software.
3D modelling	The **technique** of using software to create volume studies can create different but in general more comparable results. It is also used to illustrate ideas in 3 dimensions, giving a better spacial understading.
Building drawings: Sections	Using sections can be a great **technique** to get an idea of room heights and how spaces relate to each other. As this project focuses on how to utilize spaces in more functional ways, it is even more important to look, not just in the plan, but also in the sections when designing.

SYNTHESIS

Simulation software	To investigate and ensure great indoor climate, simulations are run in BSim by the hour, to give a prediction of the building performance. Other software **techniques** are used as well, e.g. Be18 and Velux vizualizer, that calculates daylight on surfaces. In all simulation software, different sollutions will be tried out and evaluated.
Calculations	Some calculations needs to be made in hand to give an estimate result, either instead of or before working with the simulation software. Doing calculations in general by hand is an overall **technique**, but all the individual calculations are based on more specific **methods**.
Virtual Reality	Using virtual reality is a relativly new **technique**, that allows people to move within a fictional design. This will help determin when spaces move between livable and miniscule. Initially, accompanied by a small interview, unrelated subjects would be tested, but after the circomstances, this has been reduced in scale.

PRESENTATION

3D modeling	A 3D model can be an element containing a lot of information. From this type of model, both spacial renders and technical drawings can be extracted, which can be used as vizualizing elements of the project for clients etc. In this phase, it is a very versatile **technique**.
Diagrams	Diagrams will again be used as a **technique** of illustrating some of the more complex data results.



ANALYZES

WHEN A HOUSE BECOMES A HOME

When discussing the difference between a house and a home, it is important to figure out how the two notions are used and what defines them. The biggest difference found is, that a house is something one can buy. A material thing that does not correspond to special feelings nor emotions. Something to which, there is direct relation. The home, however, differs from the house by being a place where somebody lives. Talking about a home without inhabitants is not a possibility. Part of turning a house into a home, is adding personal belongings and mementos while deleting traces of earlier residents. A home is a psychological element and it is individual for everyone. (Vacher 2010)

'A house is part of the material structure of society, whereas a home is a phenomenon made by its residents'

(Gram-Hanssen & Bech-Danielsen 2004: p.25)

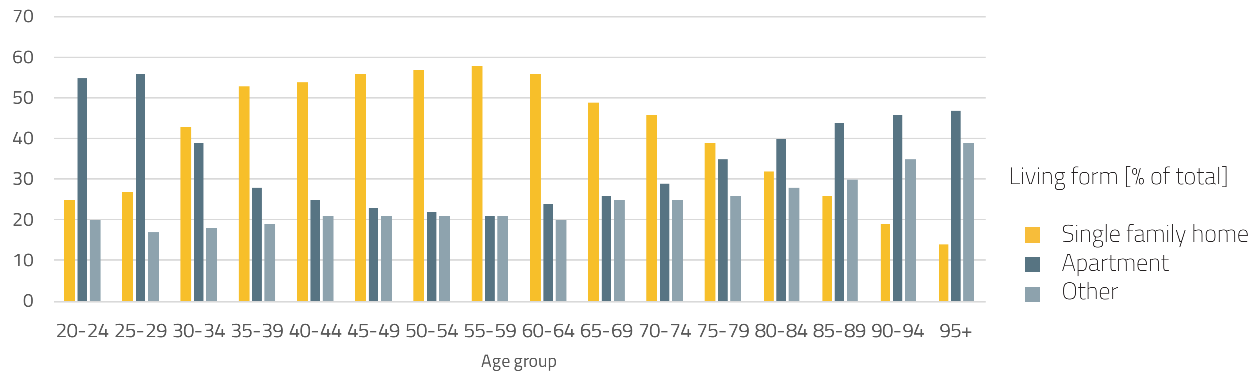
The word home is linked with feelings and emotions, that does not apear the first day, living in a house. The home also connects with the area, community and neighborhood which all provides an impact. Over time, the residents change the home to show who they are as people thus the house becomes an extension of their identity. The personal touches and the home bound feelings also reflect onto the residents. If elements are disrupted or lost, it can provide the feeling of missing parts of oneself. The home also provides people with a sense of safety and belonging which means that the home becomes a kind of sanctuary. (Carroll et al. 2009)

Narrowing down specific element that makes a home, can be diffucult. People have different personaities and the things they find important, as well as daily routines, varies. Some qualities though, can be used in general to get a sense of direction in how to design the best potential homes. This includes the importance of the neighbours or community. Wanting to feel included and belonging to a specific group of people, is human nature. As the feeling of home is unambiguously linked to comfort, it is important to find the sense of belonging at home. People are drawn to similarity, having things in common. This can be based on income, education, interest etc. Where some people see their neighbors as what binds them to the house, others find that personal improvement or changes in the house, turns it to a home. This feeling comes, when spending many hours, making the house special and unique for the residents. Some spend time crafting every detail themselves. Others simply decorate the house with things they own, that represents them. (Gram-Hanssen & Bech-Danielsen 2004)

CONCLUSION

To ensure the home feeling two qualities are found the most important. First, a place with the possibility of personalizing through styling and interior design. Second, creating an area of people with things in common, thus reinforce the sense of community and feeling of belonging.

QUALITIES OF THE DANISH HOME



Ill. 3. Current living form based on age. It is seen how the sing family home i the most common in a span of more than 50 years, starting around the age of 30. Data from Danmarks Statistik (2019c)

In Denmark the most dominant living form is the low-rise single family home, with more than half of the population living in this setting and more than one million of existing houses nationwide (see Ill. 3). The second most common is the high-rise apartment building and third is the row and duplexes. Together, these three building types cover more than 97% of the Danish population (Danmarks Statistik 2019b: Danmarks Statistik 2019d). In general, the single family low-rise building is the prefered setting between the ages of 30 and 79 years where the rest primarily lives in high-rise apartments. The row houses and duplexes maintain a steady level until the later ages where a small inclination is visible. (Danmarks Statistik 2019b)

People living in single family homes values their privacy in the sense of owning their own plot with distance to their neighbors. The suburban area associated with the single family home is further from the city noise and is often a very quiet neighborhood designed for kids to feel safe and be able to play on the road. One of the most important parts of the interior is the open floor plan which allows the family to be visually connected when using the most frequent facilities. (Jensen 2008b) Further qualities have been established as a combination of several existing interview results, to investigate why this typology is prefered by most (see Ill. 4 on page 18).

So the single family house is much prefered but it also posses problems, as it is one of the housing options with the largest floor area. In general the floor area is increasing in new build houses of all typologies, but for the single family home, the evolution has been extreme.

AVG. SINGLE FAMILY HOUSE: 152 M^2

PEOPLE >20 YEARS LIVING IN DETACHED SINGLE FAMILY HOUSE: 52 %

AVG. FLOOR AREA PR. PERSON: 60 M^2

INTERIOR QUALITIES

- ONE-STOREY HOUSE
- SEPARATED KIDS AND PARENTAL SECTION
- TWO BATHROOMS - ONE IN CONNECTION TO PARENTAL SECTION
- DIRECT ACCESS FROM LIVING SPACES TO THE EXTERIOR
- COMMON LIVING ROOM AS CENTRAL ELEMENT
- A MINIMUM OF HALLWAY SPACE
- STORAGE - THOUGH MORE IS COVETED
- UTILITY ROOM - THOUGH A BIGGER IS COVETED

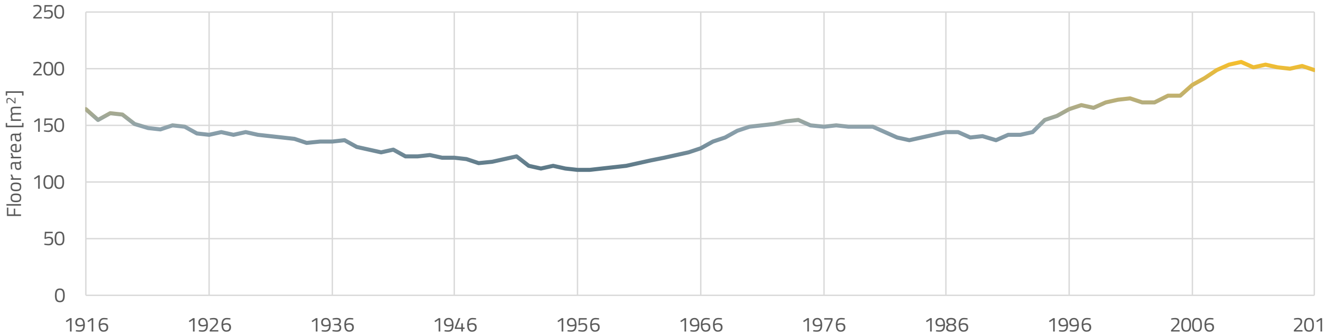
EXTERIOR QUALITIES

- LARGE GARDEN, WITH LOW MAINTAINANCE
- QUIET - NO DISTURBING NOISE FROM CLOSE NEIGHBOURS
- CHILD FRIENDLY AND SAFE NEIGHBORHOOD
- PROXIMITY TO NATURE
- BIG PLOTS - ABOVE 750 M^2

MISSING QUALITIES

- COMMON HOUSE FOR LARGER CELEBRATIONS ETC.

Ill. 4. Qualties of the single family home. The list is a combination of several results, translated from Danish (Valbjørn et al. 2006; Jensen 2008a).



Ill. 5. Floor area of new build single family houses throughout the last 100 years. From the lowest point of approx. 110 m², the average build floor area has increased around 80 % to more than 200 m². Data from Danmarks Statistik, interpreted by Bolius (Boding 2019)

During the last 60 years, a slow, but steady increase has lead to new houses being 80% bigger than they were during and after the war (see Ill. 5). (Boding 2019) Looking at the floor area more overall, the average single family house has increased 5 m² during just the last decade. In the same amount of time, row houses and duplexes have gone more than 1 m². The Danish population now lives in bigger homes, than ever before with an average size of a typical single family home on 152 m² and 93 m² for duplexes and row houses. (Danmarks Statistik 2019c) Claus Bech-Danielsen, professor at Statens Byggeforskningsinstitut (SBi), Aalborg Universitet interprets it as a result of prosperity in the Danish community, where new techniques have been tested and more rooms are being added. (Boding 2019) The results does thereby seem to come from a point of further pleasure rather than actual need. This is of cause important to take into considerations, how to implement the extra level of quality when trying to downsize the single family home.

In Japan they have minimum floor area requirements to ensure quality homes for everyone to live a healthy and good life. Besides this, they have set reccomendations around twice the size of the minimum requirements, depending on whether people live in the city or in the suburbs etc. (see Ill. 6). (MLIT n.d.) In Denmark, stadards likes this does not exist. Instead the Danish Building Regulations sets high standards for space in smaller scaled situations to ensure accessibility for all, which also challenges the posibilities to build as small as Japan requires. Instead the Japanese recommendations, for living in the city, can be a used as guidelines.

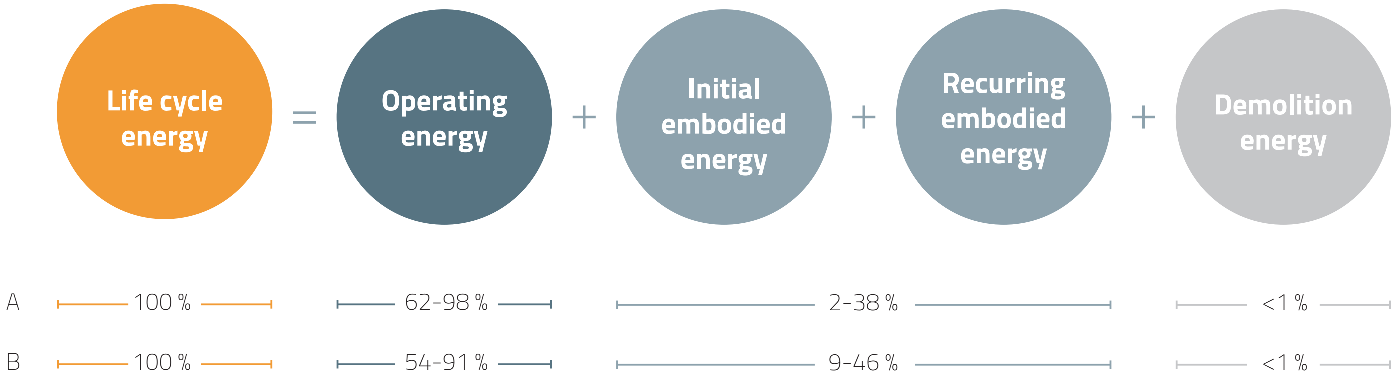
	Number of residents			
Floor area [m²]	1	2	3	4
Min. requirements	25	30 (30)	40 (35)	50 (45)
Recommendations in the city	40	55 (55)	75 (65)	95 (85)
Recommendations in the subburbs	55	75 (75)	100 (87,5)	125 (112,5)

Ill. 6. Japanese living area standards. (X) is for a child 3-5 years old. Data from MLIT (n.d.)

CONCLUSION

The build floor area is on a rise and seem to increase if noone addresses the issue. Most of the floor area lies in the low-rise single family house, which is also the most common housing typology for most age groups in Denmark. People have lived on less before and what is to say, that it can't happen again. Taking inspiration in the Japanese recommendations, a project goal can be set for the housing sizes. It is important to remember the various qualities from the popular single family home as well, which in the project will attept to preserve as much as possible whilst downsizing and optimizing.

LIFE CYCLE ENERGY



Ill. 7. Life Cycle Energy calculation, and share of the total LCE for A: Conventional housing, B: Low-energy housing (Ramesh et al. 2010) and (Sartori & Hestnes 2007)

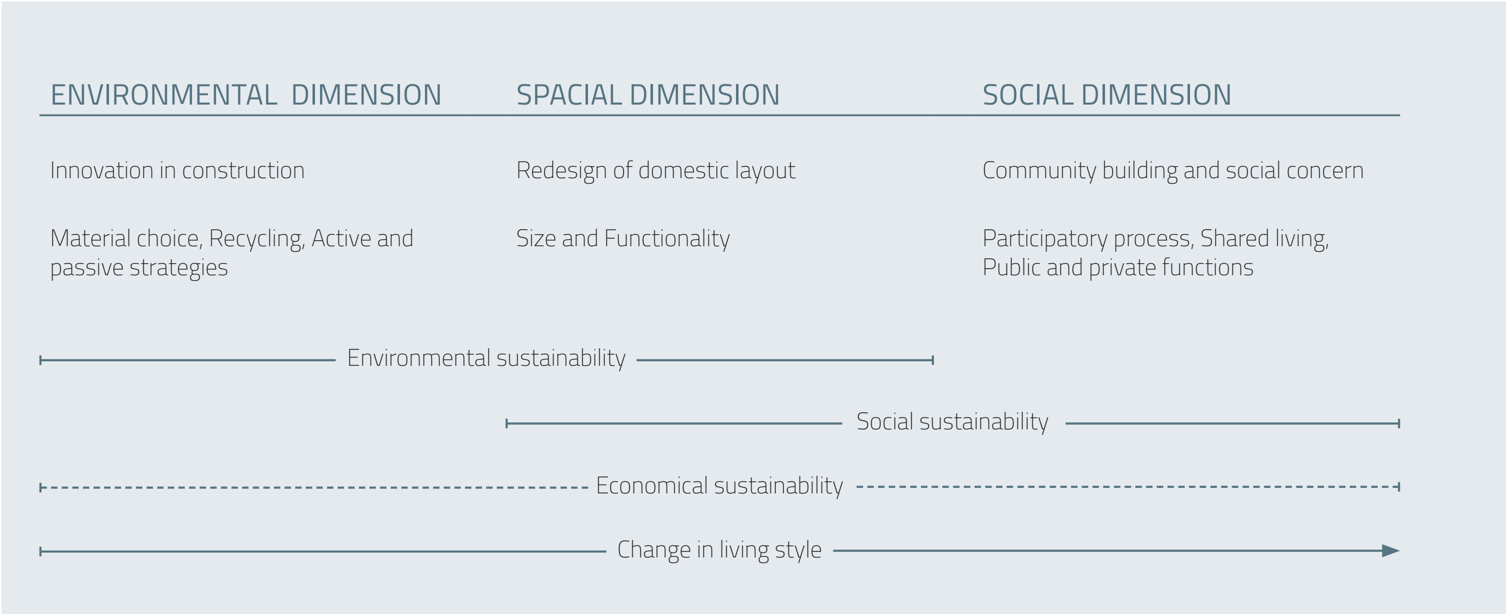
There are many different ways to determine performance of a building. One of these is looking into the life cycle energy (LCE), that describe the total amount of energy it cost for having a building – from raw materials to demolition (see Ill. 7). LCE consists of three parts during the life time of the building.

- Embodied energy (Manufacturing phase)
- Operation energy (Use phase)
- Demolition energy (Demolition phase)

The embodied energy can then again be divided into two, where initial embodied energy takes offset in the original installed materials and the recurring embodied energy comes from materials that needs replacing during the building's life span. (Ramesh et al. 2010) As the building sector is one of the biggest contributors in climate changes, and this partly comes from the amount of energy used in association with it, it makes sense to look into how to reduces the LCE in new constructions. (Stephan & Crawford 2016)

Studies have been made, in order to determine where in the process, the problems seems to lie and how to address them. In general, the biggest part of LCE derives from the operation of the building. Many have investigated the possibilities for lowering the operation cost and shown good results. It also shows though, that when designing for a lower operation energy (Low-energy housing), the amount of embodied energy rises (see Ill. 7 A and B). This can be seen as an investment in the long run but only until a certain level, as it has also been shown, that self-sufficient housing have had such a higher level of embodied energy, that it is not worthwhile compared to the low-energy housing. (Sartori & Hestnes 2007)

These studies have problematics to them, looking at the bigger picture though. All results are shown as a value pr. squaremeter and not as a total per building. Obviously, there needs to be considerations, when comparing residential housing and office etc. and this method works okay, when comparing the quality of the buildings. But looking only at residential units, it is important to also consider the size of each building compared to the number of occupants. Since the total material need is bigger in larger houses and the need for heating, lighting etc. is higher as well, the LCE will be



Ill. 8. Interpretation of contemporary principles of existenzminimum by Brysch (2019) with an additional layer of different types of sustainability.

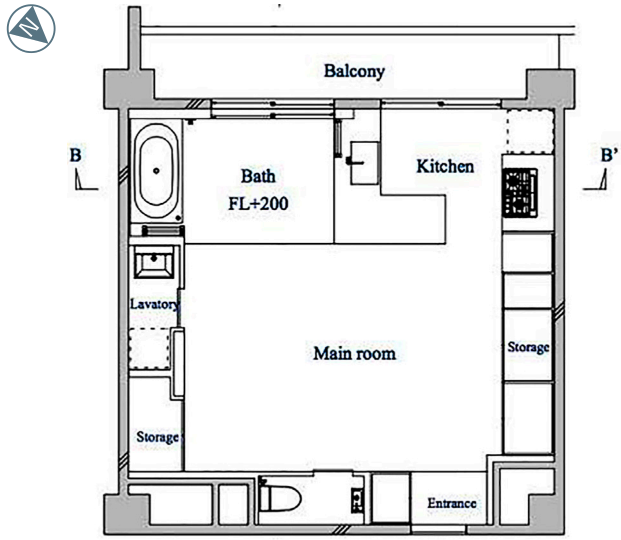
higher. Thus the energy use pr. m^2 is a very poor indicator to distinguish LCE between larger and smaller buildings. Also since the energy increases less, the bigger the floor area. This will give an impression of the largest houses performing best. When designing, this knowledge means, that detached housing will perform worse than combining units of the same floor area under one roof. The amount of occupants in the designated floor area also have an impact on the operating energy. Having several people living in the same space, will significantly reduce the energy use pr. person, compared to being fewer. (Stephan & Crawford 2016)

Looking into the term of existenzminimum, most of the contemporary principles of the small affordable housing typology can also be applied to research the concept of sustainability and the aim of reducing LCE. They investigate the reduction of cost, e.g. looking into a environmental (originally; technical), spacial and social dimensions (see Ill. 8). The dimensions may overlap but they each have significant aspects, that can be investigated further. Applying each dimension in the home can be more or less of a challenge, as they each demand something of the residents. The environmental dimension will have most effect when incorporated in the design phase as passive actions, where it will ensure a better indoor climate with a lower operational energy but many active strategies can also be applied to existing houses, giving the residents the responsibility of their primary energy sources. The spacial dimension sets demands for how to operate inside the house. It can be applied in existing houses when renovating, where the existing floor can be utilized better or flexibility added. Most of the time though, it requires the residents to want the tighter space to function well. The social dimension has the highest demand for its occupants. As it addresses how people can share space, reducing the total need, they would have to change their conception of how people normally live and adjust to another social construction. (Brysch 2019)

CONCLUSION

In order to reduce LCE, it is important to look at it both as divided types of energy but also as a whole. It is not enough to only address the operating energy, though this is typically where most energy is spend. Using the three dimensions of existenzminimum, further research can increase knowledge and serve as design principles for a more sustainable building performance in the future.

Ill. 9. The open plan is visually divided into niches by fixed furniture, difference in floor level and a large ceiling beam. ©Koichi Torimura



Ill. 10. Storage and plumbing are placed along the wall, leaving the rest an open floor plan.©Takeshi Shikauchi Architectural Office

Building smaller housing has always been seen in human societies but in the modern day society, living in larger accommodation is associated with status and wealth. The low-rise buildings in the suburban area are popular and over time, they becomes the cheapest way of living. (Jensen 2008) After World War One, Germany was on its lowest and the country damaged. In contrast to today, the people were extremely poor and living conditions even so. To rebuild affordable accommodation for everyone, the term existenzminimum was invented. It encouraged smaller housing that accommodated all the relevant facilities but at a lower cost. (Brysch 2019) This is rather similar, to what we today know as minimal housing, though the quality is often much better. (Kjær Christensen et al. 2000)

"Less space – just as high quality - less consumption in the same residential area and just as high comfort - The minimal housing"

(Graversen 2000: p.14)

This typology is seen in many forms around the world and for various reasons. Minimal housing focuses on optimizing area whilst sustaining the architectural qualities seen in larger housing (Kjær Christensen et al. 2000). The "Tiny House Movement" is keen on using sustainable and reused materials in their search of a sparse and affordable way of living. Also different types of co-living investigates the minimization of space but with a more social focus. (Brysch 2019)

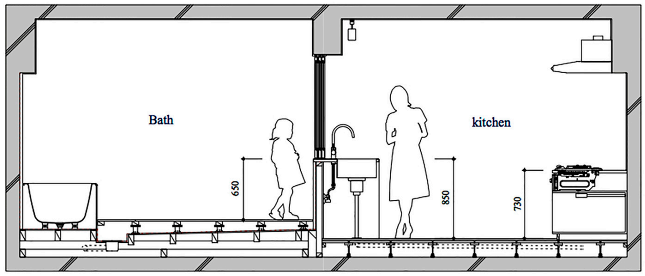
In Japan, the urban density has led to many small apartments, where the majority end up empty, due to the cost of refurbishment. As an experiment, architect Takeshi Shikauchi redesigned a 41 m^2 apartment located just east of Tokyo where he ended up taking residence, with his own family - Bath Kitchen House (see Ill. 9-Ill. 12). The floor area is a couple squaremeter short, of the current minimum Japanes requirements for a family of four, but the intent is to only stay there as long as the children are small and not in need of a room of their own - a span of ten years. The floor plan is open and very flexible. The space around the bathing area is also used for play, when not occupied and when needed, sliding doors close it off, from the rest of the apartment. The 6,5 m deep living area recives plenty of daylight through the large southern glazing, even when the sliding doors are closed, due to sheer frosted panels. As an extra quality, the apartment opens up directly from both bath and kitchen onto a narrow, yet functional balcony. The floor made with seamless transitions in teak runs through all rooms, making it feel bigger, as well as add a warm and natural contrast to the more rough industriel concrete structural elements. (Shikauchi 2014)

The concept of living small may reduce the high LCE and even more problematics but it also increase the

Ill. 11. The materials concrete, teak and stainless steel ties the home together. ©Koichi Torimura

awareness of others. Investigating why people want to live in larger houses, research has been made to find correlation between happiness and living space. Though subjective well-being only increase very little with larger living space, the housing satisfaction increases a lot, though not linear. (Foye 2017) Looking closer as to why this can be, several things can play a role. The issue may be due to the smaller homes, where the lack of space can mean the lack of certain facilities, wanted by the household. This may in extreme cases rise further problems involving relationships, education and even health. People search for specific qualities and some of the most sought after elements, when people live in smaller homes, are external space, room size and proximity to local services. Some of the issues in the smaller housing are lack of storage and flexibility. Both when it comes to socializing and privacy but also when changes occur in the household and the needs changes as a result hereof. (Roberts-Hughes 2011)

So designing optimized space, it needs to be functional as well, if people would want to live in them. The question is, when is it too small and when are the relevant qualities neglected? It is important to remember, that both tiny houses and some co-housing options are made by the people who are going to live there afterwards. Thus the quality minimum and residential demands are specifically decided by the end-users. (Brysch 2019) It is assumed, that this helps reduce the floor area



Ill. 12. Section BB. The bath can functions as a play area, and a raised floor makes the kitchen more child friendly. The kitchen also offers full view of the entire apartment, so an eye can be kept on children at all times. ©Takeshi Shikauchi Architectural Office

PREPARING AND EATING FOOD

DEALING WITH WASTE AND RECYCLING

STORAGE AND THE APPEARANCE HEREOF

ACTIVITIES AND USAGE OF FURNITURE

SOSIALIZATION AND ENTERTAINMENT

PRIVACY AND PUBLIC DISPLAY

FLEXIBILITY FOR FUTURE CHANGES

Ill. 13. Basic human housing needs. Text edited and shortened (Roberts-Hughes 2011)

significantly which might not be entirely possible in this project. Instead, general functions and facilities are illustrated in order accomodated the basic human being and its housing needs (see Ill. 13) and general guidelines are follow with inspiration from the Japanese when it comes to floor area (see Ill. 6 on page 19)

CONCLUSION

There is a limitation as to how small, it makes sense to build, in order to still be able to fulfill the basic human needs for a house. The more narrow a user group, the more customization, leading to better use of every cubic meter. It is important to understand the space fully and though the project design may not be as personalized as seen in many tiny houses, many elements can still function as inspiration for the design, in order to optimize the space.

SOCIAL DIMENSION: LIVING TOGETHER

Ground floor plan

1 Common house
2 Storage
3 Laundry
4 Wood workshop
5 Craft and sewing room
S Supplementary room
■ Family units (A, B, C, D, E)
■ Covered Street
■ Common facilities

Three sizes of co-housing communities defined from existing European cases that have proven successful.

Size	Households	Qualities
Small	8-15	Intense connections Requires Easier to establish More expensive to buy
Medium	16-25	Great balance between social and private Small enough to know everyone Formal but easy decisionmaking
Large	26-35	Allows greater diversity Requires experienced developer Higher chance of government subsidies

Ill. 14. Plan, Jystrup Savværk 1:500. © Tegnestuen Vanskunsten

Living several people on less space i another way of reducing the LCE. As stated earlier, when several people live together, their combined operating energy is lower pr. person. (Stephan & Crawford 2016) The term co-living is one of the more common types of complex social living forms, also including college halls and multigenerational housing. It distinguishes between shared and private zones and the importance of these serves as foundation for a succeding co-living society. (McCamant & Durret 2011)

Co-living started in Denmark around mid 60's when Jan Gudmand-Høyer and five of his friends started looking into creating a community with shared values. This kind of movement started as a counter response to the industrial period and focuses more on the needs of the individual. The housing deviate from the already known suburban family home and the multi-story apartment buildings, as both of these alternatives were lacking the fundamental principles of community, they searched to achieve. The size of the community was one of the more important elements. It could not exceed a higher amount, than that the occupants could all get to know eachother. Furthermore, to encourage the use of shared space and facilities, more space would be assigned here and less to the individual family homes. The common room should then be seen as an extension of the individual living areas and invite people to interact with one another across ages and households. Designing co-housing sollutions, the placement of public and private space plays a large role in the functionality. Placing the individual units far apart will lessen the feeling of living in a shared community and clustering them too close will take away the privacy associated with the common co-housing principles. (Ibid)

A Danish examples of a successful co-housing project is Jystrup Savværk, a settlement built in 1982 (A/B Jystrup Savværk 2017) in Jystrup where a former sawmill was located . The project is constructed as a single building where a glass roof covers the area between the housing units in order to keep the area useable during cold and otherwise unpleasent times. The building is consisting of two 90° angled wings, where the common room is placed in the joint. From the end of each wing it is possible to see all the way to the common room which has become a social interaction point (see Ill. 14). The building is made with many common facilities placed along the building mass and covers shared washing machines, workshops, storage and shared apartments for guest or for one family to rent if the apartments gets too small. Outside, an existing building have been transformed into a repair shop for cars and other mechanics. The apartments ranges in size from 63-97 m^2, where the one storeys are oriented toward the center of the site and the two storeys towards the site exterior. (McCamant & Durret 2011)

Problematics compared to LCE includes the gross area of each appartment, that also includes a part of the 1200 m^2 common area (Ibid). The average gross unit size ends up being 146 m^2 wich compared to the average detached single family home of 152 m^2 (Danmarks Statistik 2019c), is not much of an improvement.

One of the biggest differences in co-living is the change in the family structure compared to the nuclear family living in the single family homes. Some might see this as a benefit, as people will be more likely to help each other, seeing the entire co-housing structure as their family. The whole small community will then rely on each other rather than only their own household. Some residents might have kids, some might not and it is important that the buildings provide the option for diversity. (Ibid) Others may not find, that the social difference is for them, as the norm of family structure is rather set i Denmark. In human history though, it is not uncommon, that people work together in smaller communities, helping each other and alloparent the younger ones (Emmott & Page 2019).

CONCLUSION

Co-housing contains some qualities, very relevant to the project. It implements a focus on social interactions where the size and density serves as important factors in order to be successful. Concerns needs to be on the total build area, where common facilities should not be a compensation for lost area in the individual units but instead be reduced to the necessities in order to sustain the social qualities. The projact also needs to address the community sizes, where the medium seems like the best choice which will result in 4-5 different co-living clusters.

ENVIRONMENTAL DIMENSION: LIVING COMFORTABLY

Ill. 15. Integration of climatic design. Design method by Heiselberg (2006)

The technical aspect of building smaller, while keeping the same amount of occupants, brings up many challenges, where both the construction techniques, material sources and dimensions, application of passive strategies and many others can be addressed. Though, to lower the LCE, it is not the development of new technologies but the combination and optimal dimensioning of existing ones, that has the biggest impact (Andresen et al. 2019). Designing the building, the order of when to apply specific strategies have a huge influence on the effect. Looking at Ill. 15 it shows, that the design of the building envelope comes first, in order to minimize any internal needs. This e.g. includes the material choice and thermal mass for lowering heating needs and minimizing fluctuations, and openings as well as interior finish to lower the need for daylight. Afterwards, passive solutions are investigated and applied to benefit from the existing microclimatic conditions. This can be cooling by natural ventilation or using a trombe wall to heat up air. Lastly, if the passive strategies cannot supply the needs completely, further active strategies and mechanical systems can ensure indoor environment, using solar panels, heat pumps etc. These three steps are also known as the Energetica Pyramid. (Heiselberg 2006: Ramesh et al. 2010)

HEAT BALANCE

When addressing the lowering of LCA by building more compact, some of the interior environmental factors poses a greater challenge than others. Many elements have an effect on the heating and cooling (see Ill. 16) and this can be both good and bad, depending on what result is wanted. During winter, more heat is needed, where in the summer, high temperatures can be a big problem. (Steen-Thøde 1997b) Compared to the average single family home of 152 m^2 (see "Qualities of the Danish home" on page 17), this project aims to keep the same number of people and possibly appliances in a smaller space. This means the same amount of internal gains in a smaller volume and will result in higher temperatures all year. Though it might be beneficial during winter, the internal temperatures during summer needs to be kept below a certain level.

When investigating non-stationary systems as well, it becomes clear that the specific materials also plays a role. While the external temperatures change during the day, it is desired to maintain a more steady temperature on the inside. Heat accumulation occurs in a greater extent when the materials exposed to the surfaces of the room has a higher thermal capacity. This is also known as thermal mass, as it depends on the total mass of the material. The thickness partly decides how much heat can be accumulated, though less would be preferred from an embodied energy perspective. It is usually the heavy organic materials, like stone and earth, that possesses the higher heat capacities, which also drives up the thermal mass. (Steen-Thøde 1997b)

$$\Phi_H + \Phi_S + \Phi_B + \Phi_M = \Phi_{Tr} + \Phi_V$$

Φ_H= Heating surfaces (Radiator, floor heating etc.)
Φ_S= Solar gains through glazing
Φ_B= Excess heat from lighting and appliances
Φ_M= Excess heat from people
Φ_T= Transmission loss through surfaces
Φ_V= Loss through ventilation

Ill. 16. Heat balance

ATMOSPHERIC COMFORT

Other elements that needs to be addressed can be found within the atmospheric comfort. This can be both smells, pollution, moisture etc. where these also need to be kept below certain values at all times. Taking pollution as an examples, it is shown how the factors of volume and ventilation rate affect the concentration (see Ill. 17). (Steen-Thøde 1997a) When lowering the floor area and keeping the same ceiling height, the volume will decrease thus enlarging the concentration. To counteract this, the ceiling height can be adjusted accordingly, though higher walls also increases the amount of build material, thus the embodied energy. When the ventilation rate stays the same in a smaller room, less ventilation is needed though, compared to a larger room. Ventilation can therefor also be adjusted to even out the concentration, though this can heighten the operational energy, if using a ventilation system.

$$c = \frac{q}{n \cdot V} + c_i$$

c= Equilibrium concentration of pollution
q= Consentration of pollution in room
n= Air change
V= Room volume
ci= Consentration of pollution in inlet air

Ill. 17. Equilibrium concentration of pollution

NATURAL VENTILATION

To avoid the rise in operational energy, natural ventilation may be the better solution. Using the potential of natural existing elements, like solar heating, daylight and wind driving forces, will provide energy for operating, free of charge. The challenges of natural ventilation, when building smaller occur in the facades, where cross ventilation is not always an option. Instead the project should look into optimizing the single sided ventilation by using several openings or take advantage of the stack effect, that uses the principles of thermal buoyancy as a driving force. This will require openings in the top of the building as well, where more room height will help drive the hot polluted air away from the occupancy zone. (Heiselberg 2006)

CONCLUSION

To lower LCE, the design must be optimized according to lowering the operational needs. Afterwards, the challenges of building small must be addressed by investigating the possibilities of natural gains while keeping in mind the problematics that comes with it. It will be important to find the right balance of lowering the operational energy without increasing the embodied energy too much.

SITE LOCATION

Ill. 18. Location

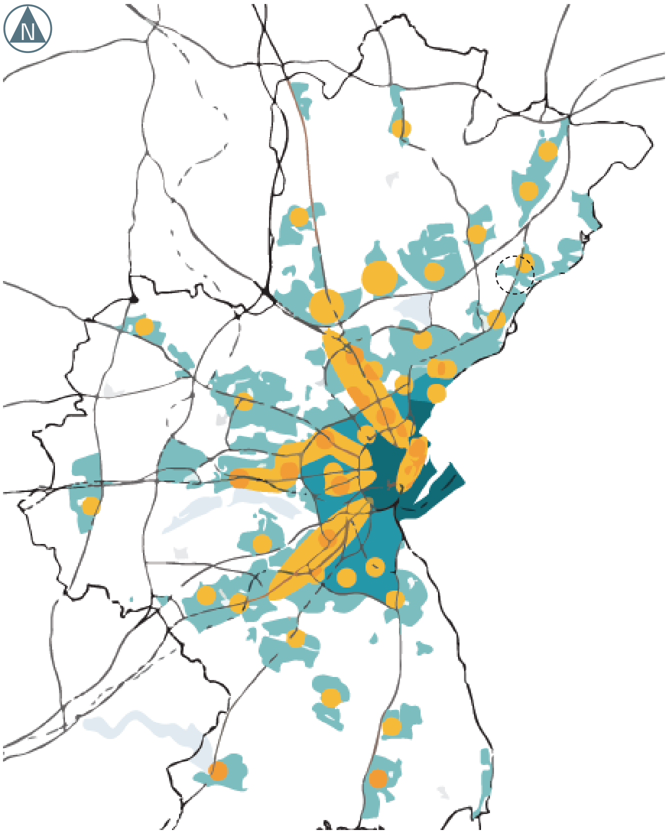
Ill. 19. Skæring

The project site is located in the small town of Skæring, a suburban area 10 km north of Aarhus, placed along one of the main gateways. Furthermore the city is situated between rural areas with farmlands and the waters of Kalø Vig. The town is mainly dominated by low-rise and detached residential buildings but social, more dense housing is also seen around, thus sharing the characteristics of other smaller suburbs.

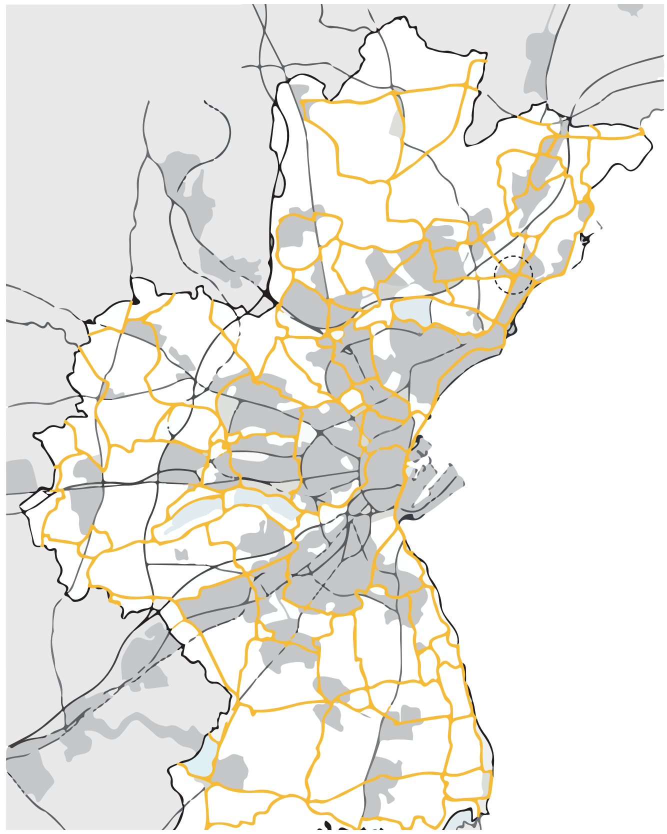
In 2016 Arbejdernes Andels Boligforening issued a competition on the site in Skæring, alligned with Skæring Bæk. The aim for the contest has been to design more sustainable housing on a conceptual level. The design must work to incorporate the benefits and characteristics of the area. The first stage is already under construction, leaving the second stage where the project site is located. The project must then be designed with a coherent apperance and encourage the future direction of housing development in Aarhus. (Arkitektforeningen 2019)

This project takes offset in this particular site, due to the suburban context and obvious need for housing but will not be complying with all the competition directions thus not entering the competition, which has anyway already been settled.

REGULATION AND LEGISLATION



Ill. 20. Development plan (finger system). Data from Aarhus Kommune (1027)



Ill. 21. Recreative bike routes. Data from Aarhus Kommune (1027)

MUNICIPALITY PLAN

The municipality of Aarhus is in growth. Every year the municipality gets around 4.000 new inhabitants and 2.000 new workplaces and residences. To keep the city expanding, the municipality have set goal a of reaching 450.000 citizens by 2050 compared to the 335.000 in 2017. The development of the city is based on the finger principal (see Ill. 20) with axes going out from the dense city center, with a clear division between city and rural area to ensure proximity to green and recreational areas for everyone. The new housing developments in the suburban areas placed along the development axes must focus on families and diversity. Especially the coastal areas have higher development value. These places are great for living and the benefits and recreational values of the water and beach are many. (Aarhus Kommune 2017)

The municipality of Aarhus have a grand focus on the connection between the different suburban settlements in order to provide great infrastructure and a feeling of a united municipality. The plan is to also create green connections between and along the fingers to create access for the people to the green areas between the settlement axes. These green zones are part of breaking down the physical and mental barriers between different cities and areas. (Ibid)

Affecting Skæring, is also the development of the infrastructure. Traffical oars should meet in key locations, creating infrastructural junctions and work as informal meeting spaces. This also calls for having a well established bicycle system (see Ill. 21) and other infrastructure being connected or close to these spaces. (Ibid)

DISTRICT PLAN

The district plan describes an area of 60.600 m^2 which is parted in two. The first, which is currently under costuction is 32.700 m^2 and the project site, which is 27.900 m^2. The district plan encourages the possibility of making a low-rise residential area, including a common

ATMOSPHERIC	VISUAL	THERMAL	ACOUSTIC
CO_2 must be maximum 500 ppm above outdoor level.	Average daylight factor >2.1%	Maximum 100 hours above 27°C and 25 hours above 28°C.	Sound transmission between rooms ≤58 dB
Air change rate = 0.42 l/s/m²	View to surroundings	Temperature range winter: 20 - 25 °C	Impact sound ≤48 dB
Air inlet Living- and bedroom: 1 l/s/m²		Temperature range summer: 23 - 26 °C.	Noise from traffic ≤25 dB
Exhaust air flow Kitchen: 20 l/s Bathroom: 15 l/s Toilet: 10 l/s			Reverberation time ≤0.6 s
(Dansk standard 2019)	(Dansk Standard 2018a)	(Dansk standard 2019)	(Dansk Standard 2018b)

Ill. 22. Indoor environment requirements.

space for the residents. The sites must provide a range of housing units in order to attract a variety of people. The district plan dictates that the housing must have a common architectural exspression with materials being either wood or brick. The buildings must have a total floor area of maximum of 7.590 m², and additional 20 m² pr unit of unheated small sheds, carports etc. (Aarhus Kommune 2011)

Officiallly, the project should comply with the parking standards of Aarhus, which dictates that low-rise housing must be provided at least two parking spaces at each unit. As the project wants to lower the amount of cars and promote the use of alternative transportation, an aims at a total og 1,1 car pr. unit can be made instead. For bicycles the parking standards only requires the area around the house to be available for possible parking. (Aarhus Kommune 2018)

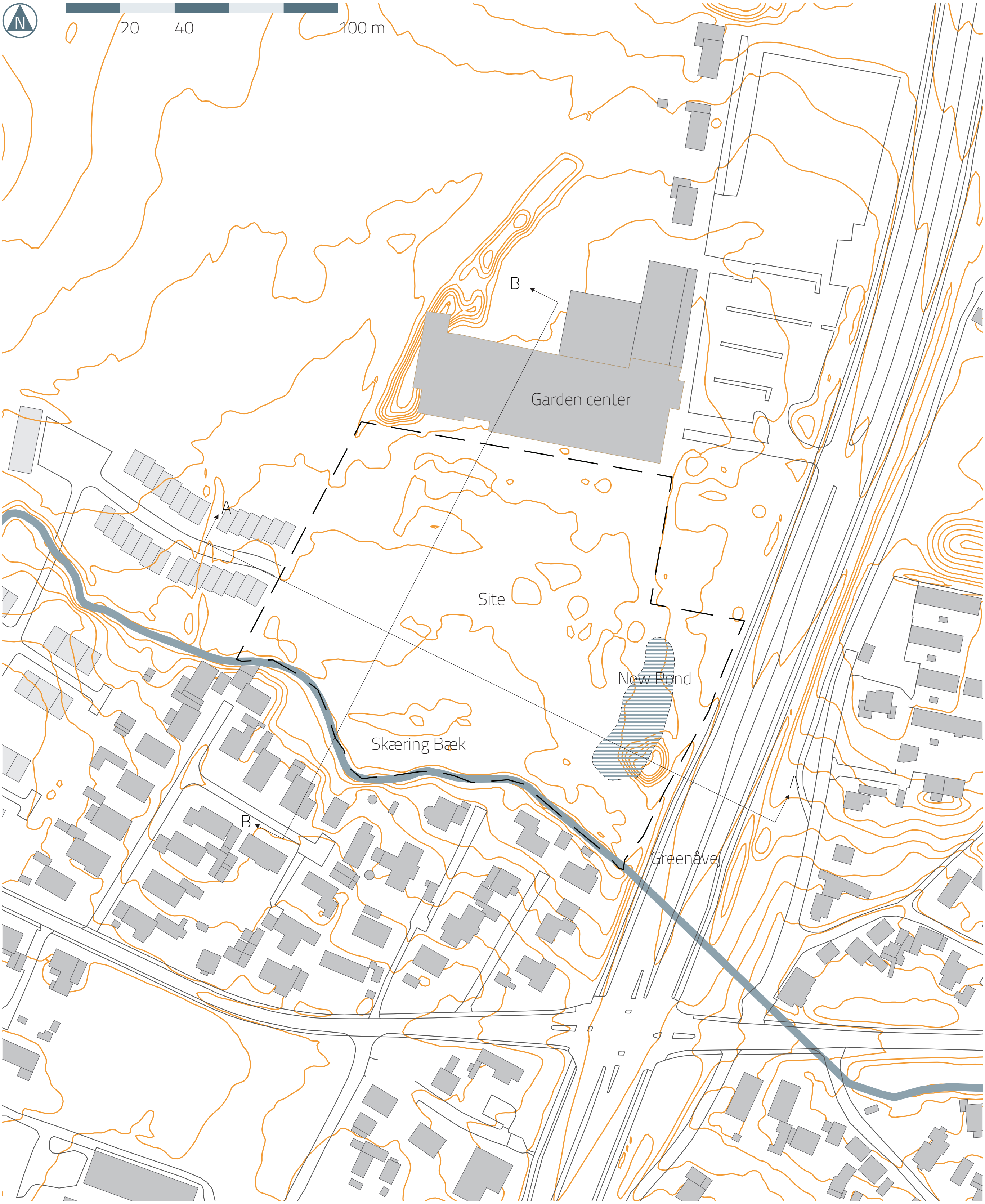
BUILDING REGULATION

The building regulations provide framework, that every building must comply with at the time of construction. The Danish building regulations provide a minimum class to uphold for all building types regardless of function but does also give the opportunity to aim for a higher level. The project aims to minimize the size of the buildings which might make it difficult to comply with the energy frame, as the same installations will be present at a smaller area. The regulations from 2018 (BR18), takes the size into consideration by setting a higher maximum energy frame, the smaller the building (Trafik- Bygge- og Boligstyrelsen 2020).

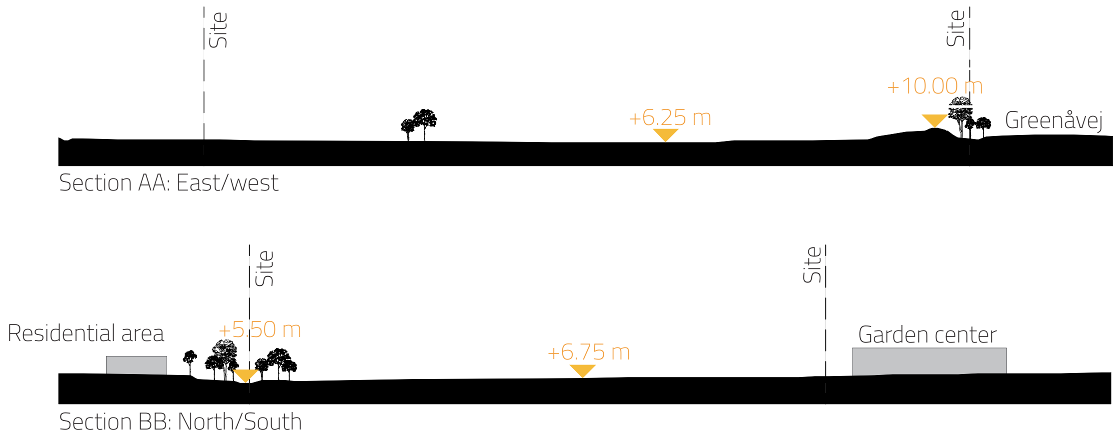
No matter the end result, the buildings will still have an energy use of both heating and electricity. To ensure self-sufficiency, the low-rise project will work with renewable energy sources. The project must aim to lower its energy use as much as possible, before adding the active strategies though, by investigating and incorporating passive ones. Indoor environment is also important to consider. When reaching for category II in the Danish Standard for interior comfort, the project will ensure a healthy atmosphere (Dansk Standard 2007).

The Danish building regulations, for now, does not focus a lot on the building lifecycle. As this project will look into how to reduce the amount of embodied energy, other demands might be set, as the project moves along.

TOPOGRAPHY



Ill. 23. Topography 1:2000, equidistance 0,5 m. Data from Kortforsyningen (2020a)



Ill. 24. Topography sections 1:2000. Data from Kortforsyningen (2020a)

Ill. 25. Current earthwork and pond on site

Having an empty building site, it is important to gain understading of the topography to know the movement and natural flow. It is also important when investigating building placement and heights, in order to fully utilize the area and natural occuring elements as sun and wind. Looking at the map (see Ill. 23) and the sections (see Ill. 24) the site is very flat. Some natural barriers are created in the form of the creek and the road but other than that, there is not much variation in heights.

Topography can be difficult to understand and show in complete detail, as it is rather complex and may change over time. The site visit gave an insight as to how the site was very different, from what is seen on the map. When arriving to the site from Greenåvej, a large earthwork was located as a long barrier between the site and the road and a small pond was to be found on the other side (see Ill. 25). A small hill of soil was also found in the middle of the site. These things may have changed from the map in accordance to the construction happening on the adjacent building site as well as the preparation for this particular site.

The flat land makes it easier to build, but also makes the area seem less natural. The new found elements may be a positive aspect and preserving these can add some different qualities to the project.

MICROCLIMATE

SUN AND SHADOW

Sun and shadow plays a large role in everyday life. Both in bringing light and energy to the human body but also the potential in utilizing the physical energy of both active and passive solar power. Daylight is neccesary in order for the human body to function correctly and different areas both in- and outdoor need a different level of direct or indirect light. In order to get an understanding of where to place volumes, functions and spaces on the site, as well as how to harvest the power of the sun for energy, solar diagrams are made on the site. The diagrams show four times during the day, to represent different times, where people might be home. During winter, the day is shorter, and the hours have been adjusted accordingly.

Looking at the shadows being cast on the site from the excisting context, the site is primarily affected along the edges and especially towards the south where Skæring Bæk is enclosed by trees (See Ill. 26 and Ill. 27). Around the creek, the district plan currently dictates a distance of at least 15 meters. This way, the trees won't affect the site as much, except during winter, where a third of the site will be shaded the entire day (see Ill. 28).
Besides the excisting context shadow studies, initial volume studies are made to analyze the impact buildings would have on shading and how the direction create different possibilities. The focus is based on shadows on the exterior surfaces and areas. They take offset in the typology and built area mentioned in the district plan, distributed equally on the site. The buildings are two stories with an angled roof. A total of 8,5 m heigh.

For recreational use in the evening, when most people are home, the results show larger useable areas to the west, when the building mass is located further from the tress and rotated east/west (see Ill. 29) In this case, the roofs facing south will be completely exposed between 08.00 and 17.00, making them ideal for harvesting solar power. This also leaves the northern facade without direct sun almost at all times. When the building mass is oriented north/south the sun hits both facades during the day, and the solar power can be utilized on more surfaces (see Ill. 30) Both options have the possibility of creating useful spaces inbetween, but where the east/west oriented building mass create great sun bathed spaces near the southern facades and completely shaded areas near the northern ones, the north/south oriented building mass creates spaces with both sun and shade during different times in the day. Depending on the needs of different rooms, the orientation can help place and organize functions within each unit and to place all units on the site.

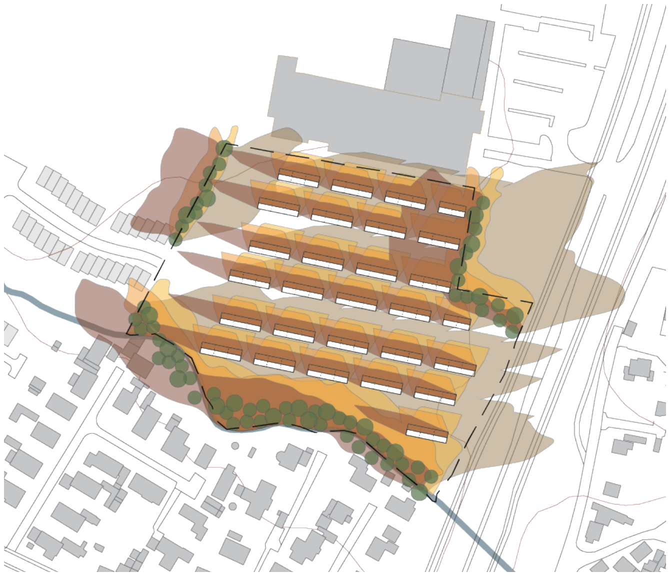
2020	Sunrise	Sunset
Equinox spring	06.23	18.32
Summer solstice	04.31	22.11
Equinox fall	07.05	19.17
Winter solstice	08.50	15.44

Ill. 26. Summer solstice (20/06)

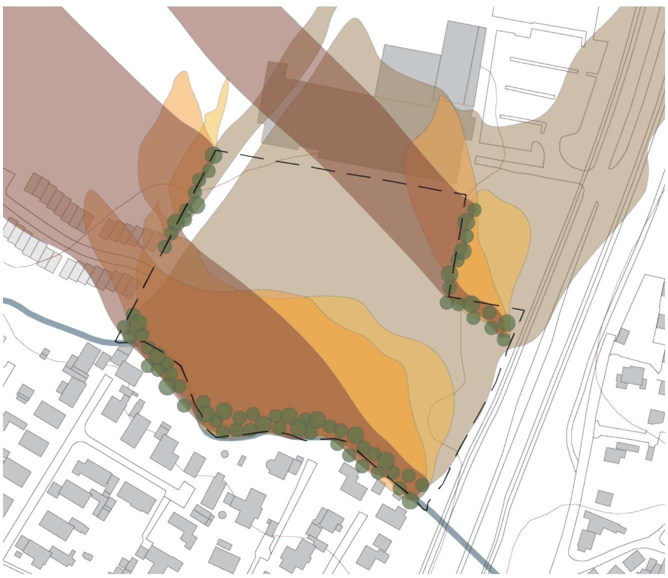
Shadow at hour

	Summer/equinox		Winter
	8.00		9.00
	11.00		11.00
	14.00		13.00
	17.00		15.00

Ill. 27. Equinox(20/03and22/09)



Ill. 29. Equinox - Volume study east/west oriented

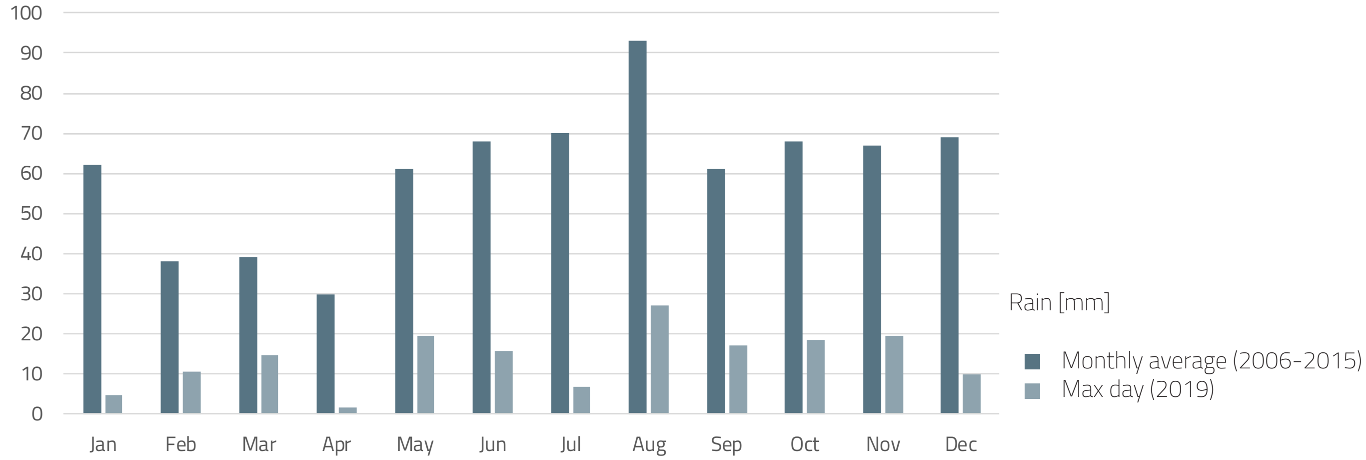


Ill. 28. Winter solstice (21/12)

Ill. 30. Equinox - Volume study north/south oriented

Ill. 31. The site after multiple days of rain

Ill. 32. Smaller swamps occuring temporary on site



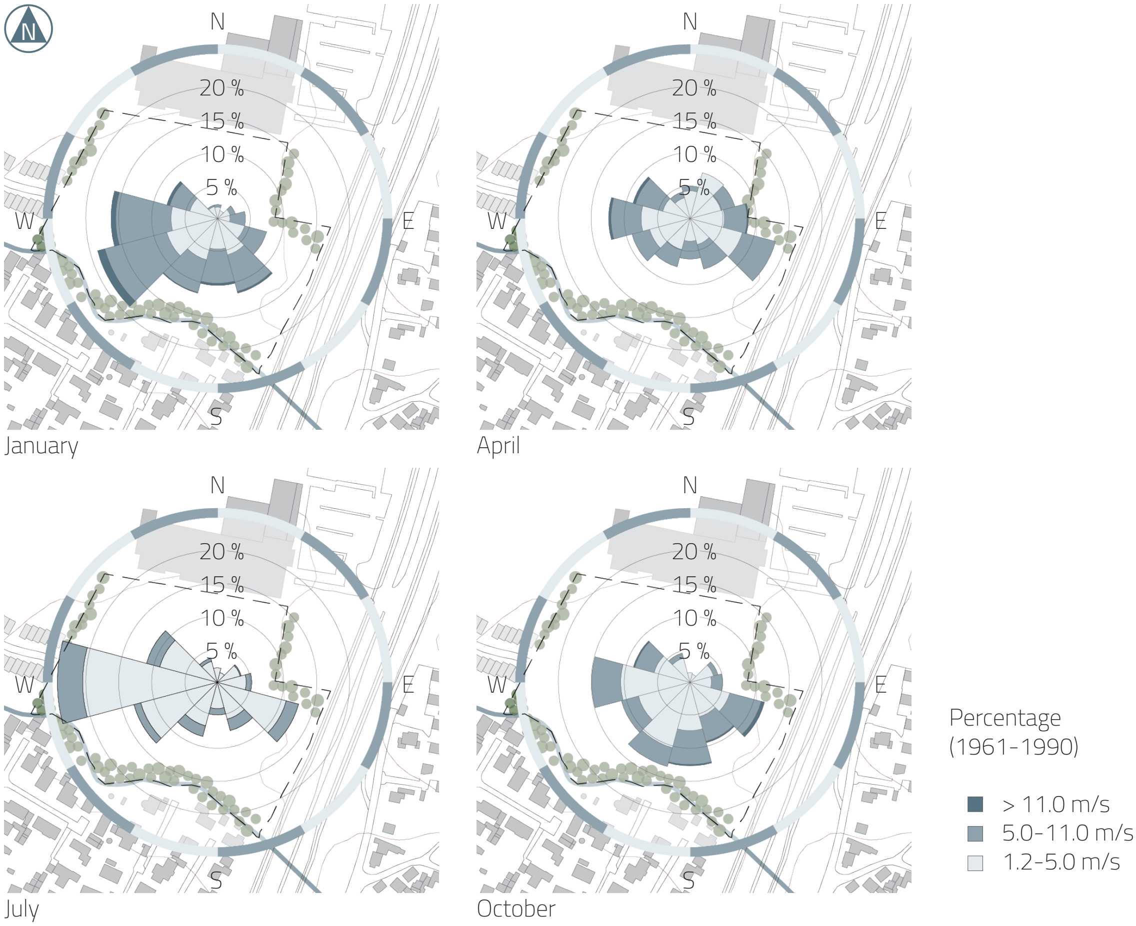
Ill. 33. Precipitation Aarhus. Data from DMI (2020)

PRECIPITATION

In Denmark, rain and snow is very common and can at points cause flooding. This happens when the water rises too high from the neutral water level or when too much pressure is put on the sewage system. When looking at the average amount of precepitation during the year, it is found that spring is usually the dryest time of the year but every month have a high probability of around 40 mm or more falling (see Ill. 33). The average rainfall gives an indication of the potential amount of water which can be harvested for residential grey water needs, as toilet flushing, laudry and watering of plant.

The graph also show the amount of rain or snow fallen on the worst day in each month. This can variate a lot between years and this is only showing the worst days of 2019. These numbers gives an idea of what to expect in the worst cases, so the housing area will be prepared for episodes with exessive rain. Looking at 2019, it is not uncommon to find days with up to 30 mm precipitation.

Heavy rain in shorter time is one of the reasons for smaller floddings and swamped area. Flodding won't be an issue on the site until the water rises four meter above current level (Miljøstyrelsen 2020). As it is rather flat, low laying land, enclosed by Skæring Bæk, it can happen though. The water may create undesireble muddy areas on occasions as well. Visiting the site, after a couple of rainy days it was covered in water (see Ill. 31 and Ill. 32) and it became difficult to move around freely on the site. To avoid this, the design needs to consider sollutions which can delay the water to both the creek and the sewage system. This can both happen via rain water collection and different integrated systems such as green roofs, drainage and rainwater basins.



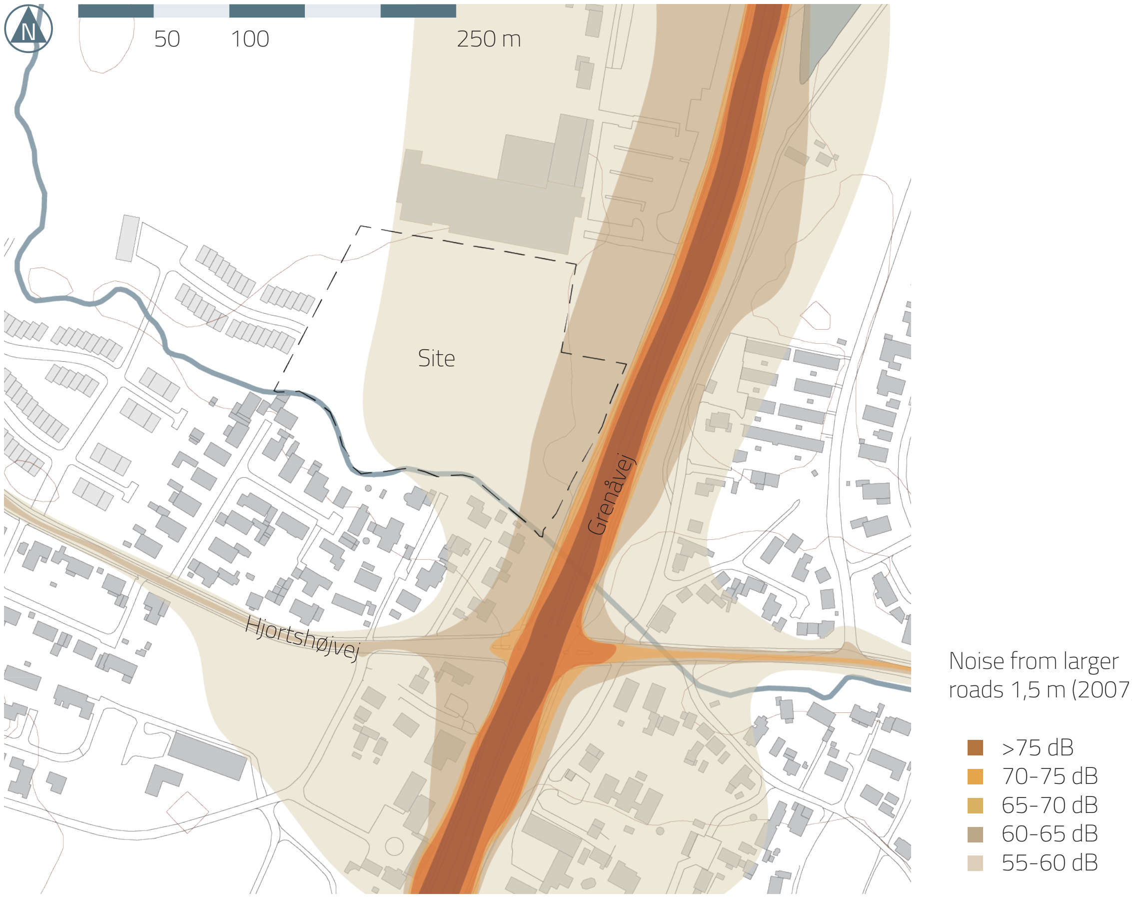
Ill. 34. Wind on site. Data from Cappelen & Jørgensen (1999)

WIND

The four wind roses show the primary wind directions as well as the intensity during the four seasons (see Ill. 34). In general, the dominant wind direction is west, but during spring and autum it is more unforeseeable. The least dominant direction is north, from where the wind almost never arrives. The intensity is strongest in the colder months and milder during summer.

In relation to the site, it is covered by trees and housing to the south and the west is currently under constrution, where new housing will soon be finished as well. This creates a natural barrier towards the primary wind directions. The landscape around north west is relatively open and the surroundings are in general low-rise. This needs to be considered as well, as the wind may move over or around the barriers reaching the site.

Skæring is located right down to the water, whereas the meassurements are made in Ørum, located further from the coast. In general, the wind can get more intense near the coast i Denmark but it can be assumed that the dirrections are correlating to the wind roses shown. The wind roses were made over 30 years, between 1961 and 1990. They are somewhat still relevant, as the wind does not change much in either direction nor intensity, which is shown in the archives of danish institute of meteorology. (DMI 2020)



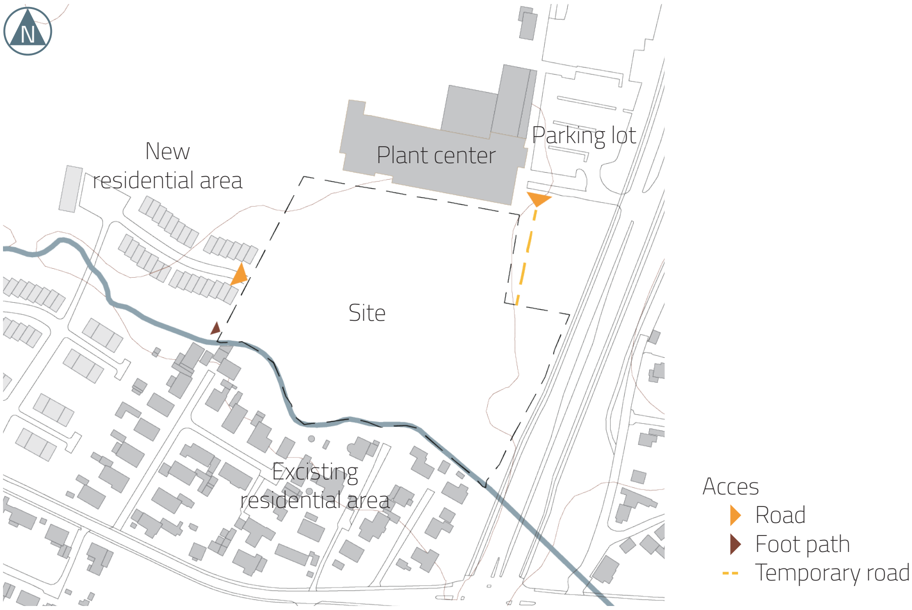
Ill. 35. Noise on site (2007) 1:5.000. Data from Miljøstyrrelsen (2020)

NOISE

The map shows the trafical noise experienced primarily due to the large road, Grenåvej, running parallel to the site. As the district plan states, the level of noise should be reduced to 58 dB at all exterior recreational areas (Aarhus Kommune 2011). The level meassured in 2007 lies on up to 65 dB around 50 m from Grenåvej and up to 60 dB almost the entire site (see Ill. 35). This needs to be adressed in the urban planning of the area, to ensure an acceptable level of noise. This can be handled with e.g. screens, landscaping and natural element as trees and water. This can create a natural buffer zone between the road and the site and make the site seem more enclosed.

After visiting the site, it was found that a few of those elements were already present (see Ill. 25) The earthwork along the road are around four meters high and the pond pushes back the remaining site from the noise. The noise level is thereby currently reduced.

ACCESS



Ill. 36. Acces to the project site, 1:5.000.

The site is currently rather sheltered and getting in, requires some knowledge of its conditions. The large earth work (see Ill. 25 on page 33) covers the site from direct access from the large road, and the steep slope makes it almost imposible to cross by foot as well. As the adjacent site is currently under construction, it is not possible to get in from the west side until they are finished. A road has been planned from that direction, but as it moves through the entire new residential area, it might not be the best acces way, as it will create more disturbance for the residents (se Ill. 36). The road might be ideal for bicycle traffic, as it connects with the large bicycle grid, created by the Municipality of Aarhus (see Ill. 21 on page 30) and thereby encourage pedestrian and biking culture in the area. A foot path will be available as well, which creates the oppotunity for utilizing the nature beyond the project site. It will also create larger freedom for moving around, while being safe, as there will be no cars.

From the north, the district plan encurages another option for access. This will be through the parking lot associated with the plant center. This will be closer to the large road and won't be a nuisance to other residents by adding preassure to the excisting roads.

As the site is currently being used to help with constrution on the adjacent site, a temporary road has been made already, going parallel to the site. This might be an oppotunity to get cars further into the site if, this is wanted.

The site lies very close to the large road, which leads directly to Århus. Bus stops are placed less than 200 m from the site (see Ill. 37) and living on the site, the residents will therefor easily be able to use public transportation to get to larger cities. Getting around in Skæring, the site is close to the ceter, making the entire city in walking distance (approx. 1-1.5 km)

Transport to Århus (11 km)	Time [min]
Bike	35
Bus	26
Car	19

Placement from site	Distance [km]	Time by foot [min]
School	0.9	11
Large Market	0.8	10
Gas station	0.75	10
Beach	1.1	14
Church	1.0	13

PUBLIC FUNCTIONS

Ill. 37. Functions, 1:5.000

TYPOLOGY/APPEARENCE

Ill. 38. Detached single family houses

Ill. 39. New build detached single family houses

Most of Skæring cosists of older single family homes buildt more than 20 years ago (see Ill. 38 and Ill. 42). These houses are mainly in one level, with brick or plastered facades and tiled pitched roof. They express a strong sence of privacy with hedges that forms a natural barrier between the plots and the street. As part of the municipality plan, Skæring is a city in development (see Ill. 20 on page 30) which can also be seen in the newer residential areas in the outskirts of the town (see Ill. 39). These houses have a larger variety in appearence where materials as both brick, wood and metal is seen. They seem less private as they have larger openings in the facade, making glass a dominant material as well, and for now lower hedges. The new housing area south of the project site was developed in 2015 and new buidlings is still being added.

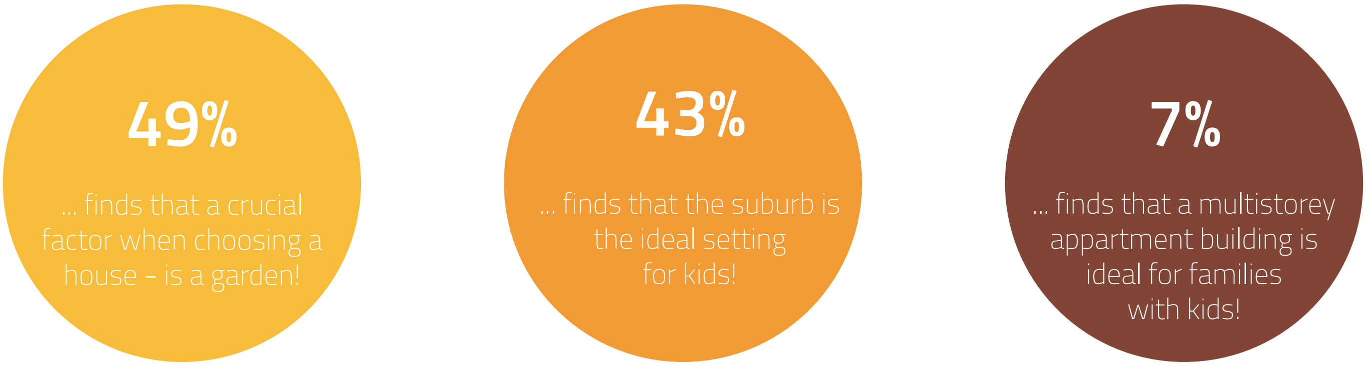
Skæring also contains several 1-2 storey row house areas (see Ill. 40). Most are located a bit further from the site and many are very private with high hedges along the boundary of the plot. Most of these settlements share a communal house which promotes community. One of these areas is the new build on the adjacent site covered by the same district plan as the project site. When finished with construction, it will have row houses in two levels intended for families and a communal house as well. These rows are less private than otherwise seen and instead they use shared space to promote social encounters and safe fare on the roads.

Ill. 40. Row houses

Ill. 41. New row houses on adjacent site. © Rubow Arkitekter.

Ill. 42. Typologies

USER GROUP



Ill. 43. Keynumbers (Dieckmann 2020)

In the municipality of Aarhus, the amount of families with children have inclined during the last decade. The typical family lives in a suburban area like Skæring, which is still close to the larger city. The family structure of people with two children is the most common setting in Aarhus, covering around 46% but having more or less, is not uncommon (Danmarks Statistik 2020). Skæring has a lot to offer for children as well, where the city both have a school several daycare facilities and an activity hall. Furthermore the city and project site is placed in close relation to nature and water (see Ill. 37 on page 41).

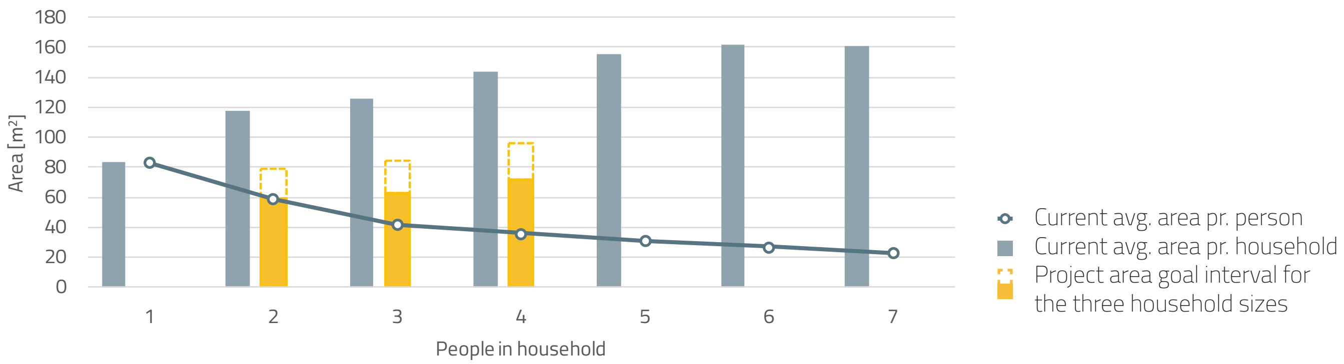
More families find that the need of their children is one of the biggest factors when determining where and in which setting to live. The typical family generally wishes to live in the suburban area in a one-storey house. Children keep becoming a bigger part of the family lifestyle and more than 75% of the Danish families finds that every child needs to have their own bedroom. Due to children being a big parameter for the families, an understanding of childrens requirements is needed to fully understand the user group. The children generally focus on the space where they can play and be with their peers. Other children are often one of the things they long for, when living in an area with vast distances to their neighbors. In an interview made by Bolius with a child living in a small appartment, they found the common playground and outdoor space as a big quality. (Dieckmann 2020)

To reach the target user group before they settle in to the larger single family homes, the project will look into the younger segment before and in the beginning of establishing their family. At the age of 25-35, after finishing their education, the money may be sparse but these people seek to build a safe future for their children. This can be both in form of a quality home but also by looking at more sustainable solutions, to secure the future, as the youger generation is also a bit more environmentally conscious than the older ones (Arla 2018).

Taking the user group into consideration, the household sizes can be narrowed down to 2-4 people which should be able to be accommodated in two different unit types. As earlier stated, the size of the units will take offset in the Japanese recomendation for living in the city (see Ill. 6 on page 19). When looking at the average floor area in different household sizes in Denmark, this fits well with an attempted minimization of a third to half of the average area (see Ill. 44 and Ill. 45).

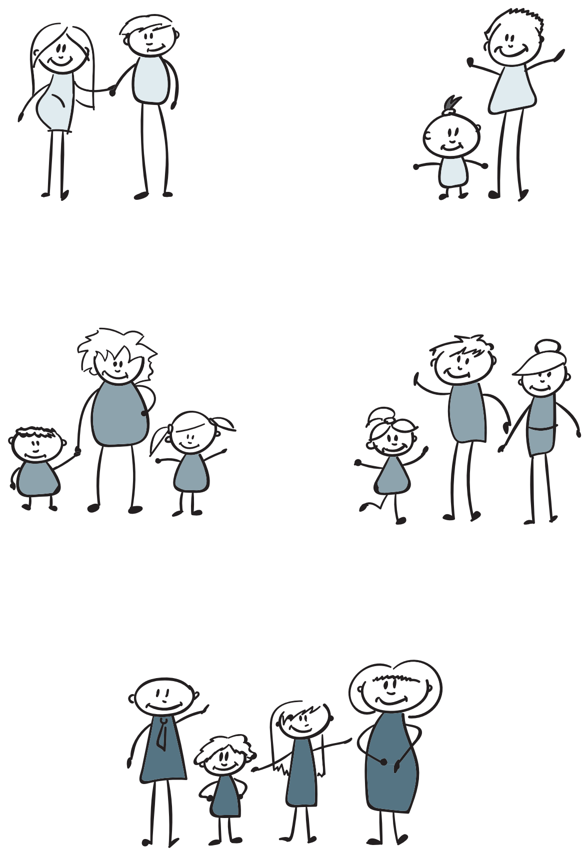
CONCLUSION

The project will target a user group of upcomming families with adults from 25-35 and 0-2 young kids at the time of moving in. It will be important to address children in all units, as this is a priority for the parents but also to adress the flexibility that is needed for changing family structures throughout the time they live there. As it is the age group that would usually consider moving into detatched single family homes, the qualities of these needs to be addressed as well.



Ill. 44. Average floor area in different household sizes (Danmarks Statistik 2016) concluding with a project goal interval between 1/2 and a 2/3 of the average size pr. household for 2-4 prople.

2 Bedrooms
~63-84 m^2
30 units



3 Bedrooms
~72-96 m^2
50 units

Ill. 45. Family structures in project units

ROOM PROGRAM

UNIT A ROOM	SIZE [M²]
Communal part (9%)	6
Living space	33
Kitchen	10
Bathroom	6
Entrance/Utility room	5
Bedroom	12
Room	8
Total	80

40 UNITS = 3200 M^2

UNIT B ROOM	SIZE [M²]
Communal part (9%)	7
Living space	38
Kitchen	10
Bathroom	6
Entrance/Utility room	8
Bedroom	10
Room x2	8
Total	95

40 UNITS = 3800 M^2

ROOM	ARCHITECTURAL QUALITIES	FUNCTIONAL QUALITIES
Living space	Ceiling height above 2,5 m	Manual or partial control of solar shading
	Direct access to exterior	Possibility for flexibility in decoration for different scenarios
	View to kitchen	Social gathering place
Kitchen	Seamless spacial trasition in between kitchen and dining table	Durable materials for easy maintenance
	Contact to living space	Min. 7 kitchen units for storage and preparation
Bathroom	Neutral colors and materials	Durable materials for easy maintenance
Bedroom	Modern and clear built-in furniture	Built-in storage
	Light materials with possibility for personalizing	Possibility for flexibility in decoration for different scenarios
	Ceiling height above 2,5 m	Privacy between rooms and common areas
Entrance	Can be used ad both mud-room and official entrance when entertaining guests	Storage for outerwear
		Table area for work space

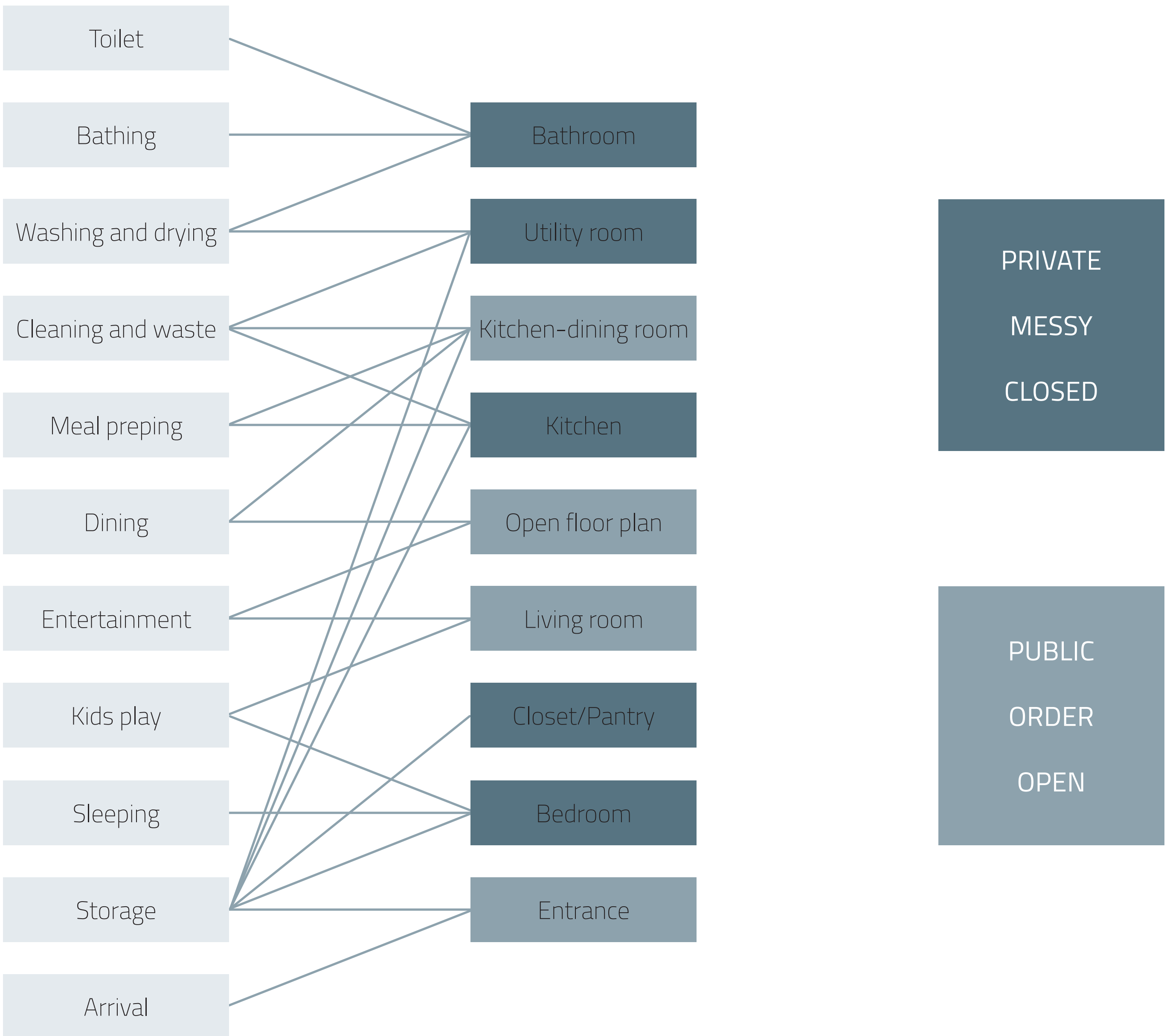
Further technical requirements for indoor environment etc. can be found in "Regulation and legislation" on page 30.

COMMON HOUSE ROOM	1 SIZE [M²]	ARCHITECTURAL QUALITIES	FUNCTIONAL QUALITIES
Open space	150	Open and embracing Ceiling height above 2,5 m	Seat 120 people
Kitchen	10		Min. 10 kitchen units for storage and preparation Can be closed off from common area
Bathroom x2	4		
Entrance	10	Spacious	Racks for coat hanging
Wardrobe	8		Can be closed of
Depot	14		Easy storage
Technical room	10		
Guest room x2	20	Similar furnishment as the homes	Separation from common area Including bathrooms
	= 250 M²		

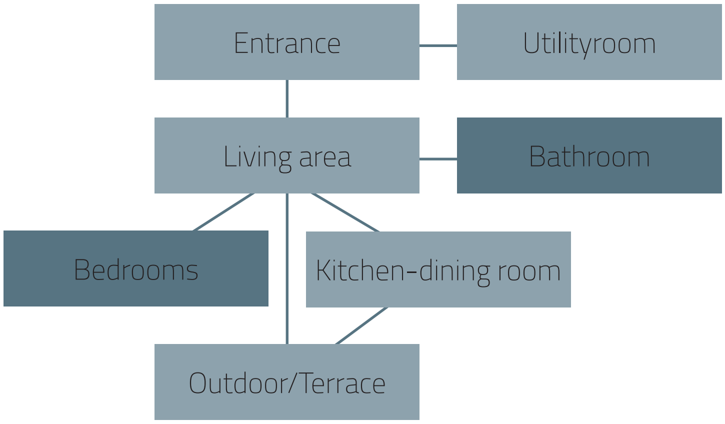
COMMON HOUSE ROOM	2 SIZE [M²]	ARCHITECTURAL QUALITIES	FUNCTIONAL QUALITIES
Open space	85	View over field	Flexible layout
Toilet x2	5		
Entrance	15	Spacious and leading towards the common area	
Wardrobe	10		Can be closed of
Techical room	5		
Wood workshop	35	View towards fields	Direct acces from outside
	= 160 M²		

COMMON HOUSE ROOM	3 SIZE [M²]	ARCHITECTURAL QUALITIES	FUNCTIONAL QUALITIES
Lounge	45	Unformal	Flexible layout
Dinning area	45	Seamless spacial trasition in between kitchen and dinning space	Min. 8 kitchen units for storage and preparation
Toilet x2	5		
Entrance	10	Spacious and leading towards the common area	
Wardrobe	10		Can be closed of
Technical room	5		
Covered terrace	65	View towards pond	Privacy towards homes
	= 125 M²		

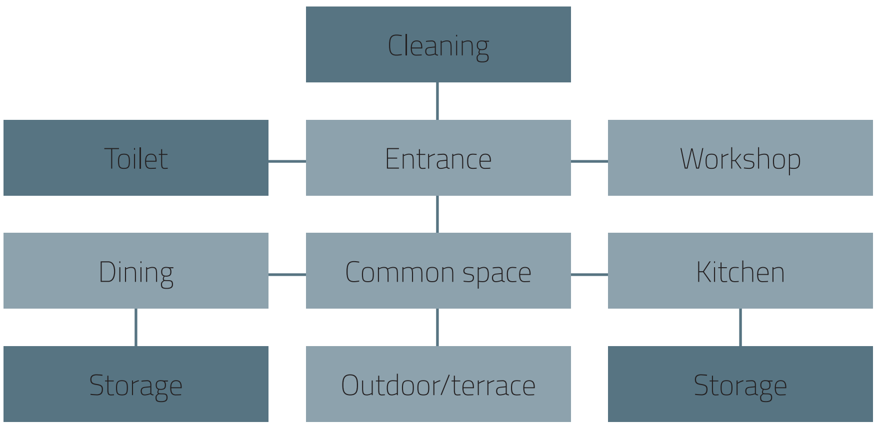
FUNCTIONS, ACTIVITIES AND ROOMS



Ill. 46. Basic function needs in a house and combinations into rooms



Ill. 47. Room connections in a residential unit



Ill. 48. Room connections in a communal unit

Based of the basic human housing needs (see Ill. 13 on page 23) and the qualities of the single family home (Ill. 4 on page 18) and the user group, different functions have been combined into typical room structures. Combining several functions will lessen the number of rooms and help build smaller, but it is also important to remember that different personalities and family structures call for a variety in layout and use of space.

The functions can be combined in many different ways, and some functions can also be a room on its own. Storage is the function that draws the most connections, where almost every room has a specific storage need of clothes, kitchen appliences, service, textiles, cleaning supplies, toys, books, hobbies etc. As the house often is divided into the more private and more public parts, considerations needs to be made about how the room structure can accomodate this, in the best way possible when connecting them.

DESIGN CRITERIA

PRIMARY

- LCE must carry a central role by:
  - Optimizing room sizes according to specified activities and functions
  - Informed material choices and LCA comparisons
  - Lowering operational energy with passive solutions
- Incorporate qualities of the detached single family house while keeping room for personalization
- Use the principles of flexibility, multifunctionality and built-in furniture to utilize the three dimensional space
- Operate within the existing microclimate conditions to lower operational energy through passive and active strategies

SECONDARY

- Create optimal daylight conditions both internally and for external communal spaces throughout the year
- Maintain and expand the natural barrier to prevent high levels of traffic noise
- preserve existing pond and earthwork to minimize physical impact on existing nature
- Solve the threatening and current issue of water stagnation on the site
- Architectural design must correspond or relate to the surrounding buildings in form of typology, materials and uban density
- Operational energy generation on site using renewable energy sources
- Encourage social interactions with common facilities and shared spaces
- Design a society that promotes common values but ensures room for diverse family structures

VISION

This project aims to create a residential housing project with focus on changing the trend of increasing area in housing and by providing communal houses the project will work with applying benefits of co-living as part of the house minimization. For the house design a grand aspect will be to apply sustainable solutions for minimizing the LCE. This includes both lowering the use of operational energy, improving the different phases of material life and gaining energy from alternative more environmental sustainable sources. Meanwhile trying to create a new housing type the project must have in mind that minimization and lowering of LCE must still provide the desired qulities a home.


Teknisk

SKETCHING

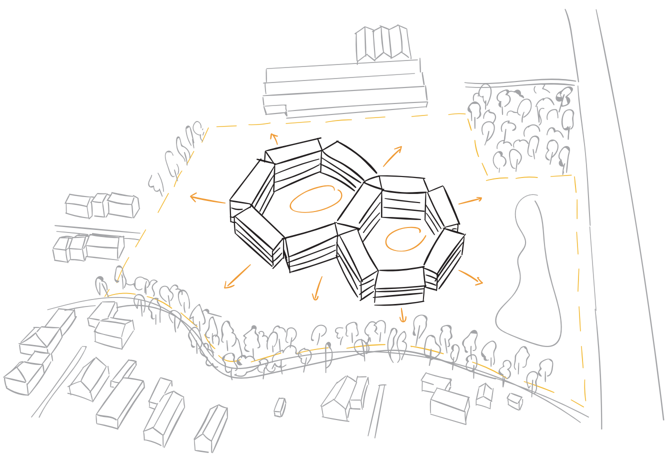
URBAN WORKSHOP

To get an understanding of the site area and context, a physical model was created with a map and existing housing in foam. Small foam bricks of different sizes representing the individual units were created and placed around, bringing out different ideas for the urban layout. Along with conceptual hand sketching, different themes were explored in a fast paced workshop. The themes each represents parts of the design criteria, that seem relevant for the urban layout as well as being able to initiate creative thinking by being understood in different ways. For the worksop, the themes where picked in random order, to challenge the mindset, with a time frame of 5 minutes to create several ideas. On these pages, the themes are described as they were thought of during the workshop, most of them along with an illustration of one of the ideas. All the sketches and model photos can be found in "Appendix 1: Urban workshop".

From this workshop, certain qualities were found more important, and gave good insight, in how to move forward with the urban scape. Each idea also had its own set of demands from the units used to build it, which also needed to be taken into consideration, when deciding which direction to move in the smaller scale.

DEFINITION OF PRIVATE AND PUBLIC

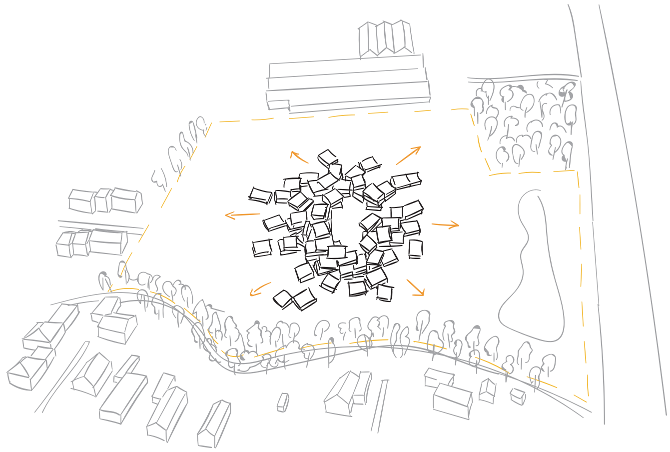
To ensure privacy in the units, having a private and a public side, can help arrange the rooms inside. Here, the residents have a completely private side in the courtyard while they open up to their sourroundings. Some of these qualities have been taken further in the project.



Ill. 50. Definition of private and public

OPEN COMMUNITY

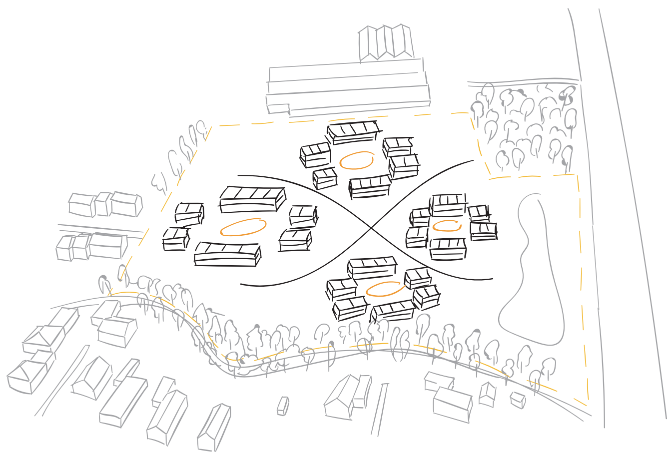
Here, the aim was to pull people onto the site. This idea opens up, creating a more central mass and welcoming everyone on to the site. The gradual rise in height keeps it dense without intimidating bypassers.



Ill. 51. Open community

DEFINED COMMUNITY

With inspiration from the co-living societies, smaller groups were formed, creating distinguished areas with their own private sense of community. Here without closing anyone out.



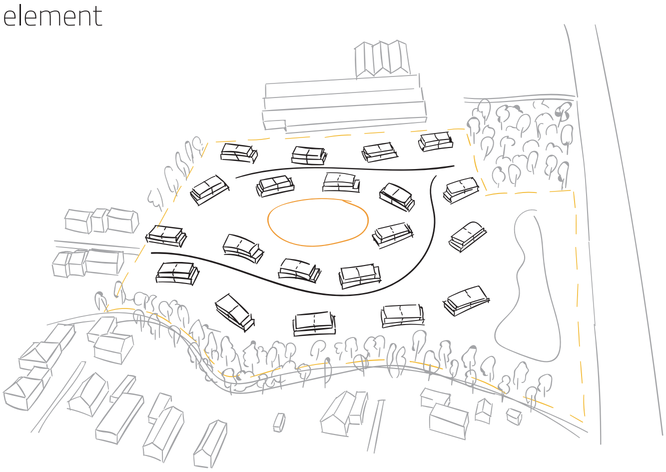
Ill. 52. Defined community

COMPACT FORM

Here, the ideas included gathering the building mass to larger and taller buildings. Most of them leaves no air right around them, but the rest of the site, is often left more open. It is something, that needs to be considered, in order to minimize the LCE.

SAFE SPACE

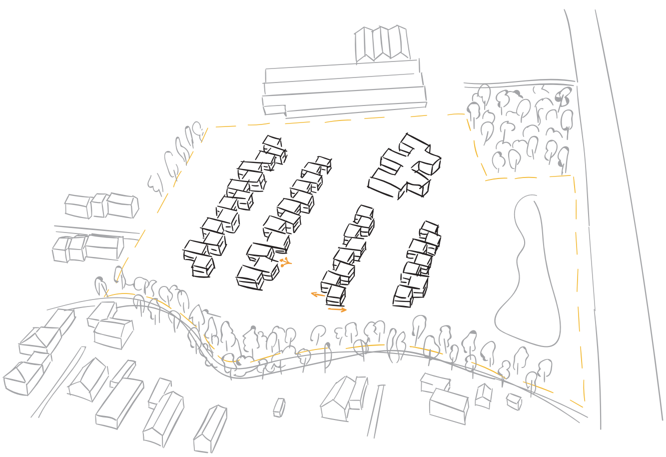
Looking more into how the residents can feel secure and away from sudden traffic, roads were located on one side, and safe zones on the other. This can also be translated to a back yard and a front yard, which the project also continues to work with as a significant element



Ill. 53. Safe space

DIRECT SUNLIGHT INSIDE

The ideas here were to arrange the units in such a way, they all had a lot of free facade, without shading too much. Here, the displacement gives all the units the possibility of following the sun during the day.



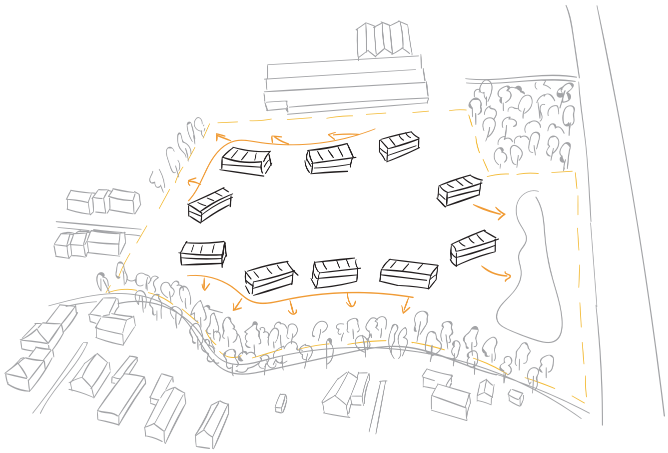
Ill. 54. Direct sunlight inside

SUN IN RECREATIONAL SPACES

Most suggestions were about opening up towards the south, with a distance between buildings that could secure sunlight onto the ground, even during winter.

VIEWS

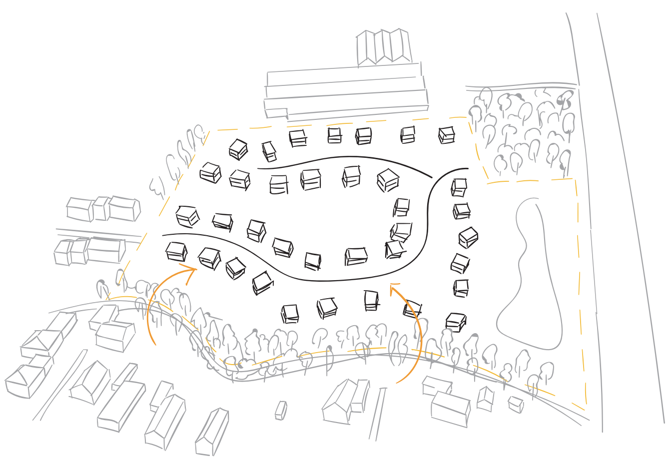
The site provides many possibilities from great views, which these ideas wanted to accomodate. Here, three different views were used to create different identities; The field, the pond and the creek. All of them also look upon the large grass field in the middle. These views turn into themes for the further development.



Ill. 55. Views

CONTINUATION OF CONTEXT

As the site is located in the middle of three different building types, many suggestions here took ofset in each of those. Here, it is the single family home, as it is the quality of those, the project pursuits. This was also one of the ideas, the project continues to work with, as it provides many qualities, not seen in all the other ideas. One of the bigger problematics here though, were the number of units located on the site and the amount of envelope.



Ill. 56. Contiuation of context

URBAN QUALITIES

After the urban workshop, though along the design proces of the individual units, several urban qualities where decides on, to guide the project's further development.

ZONES

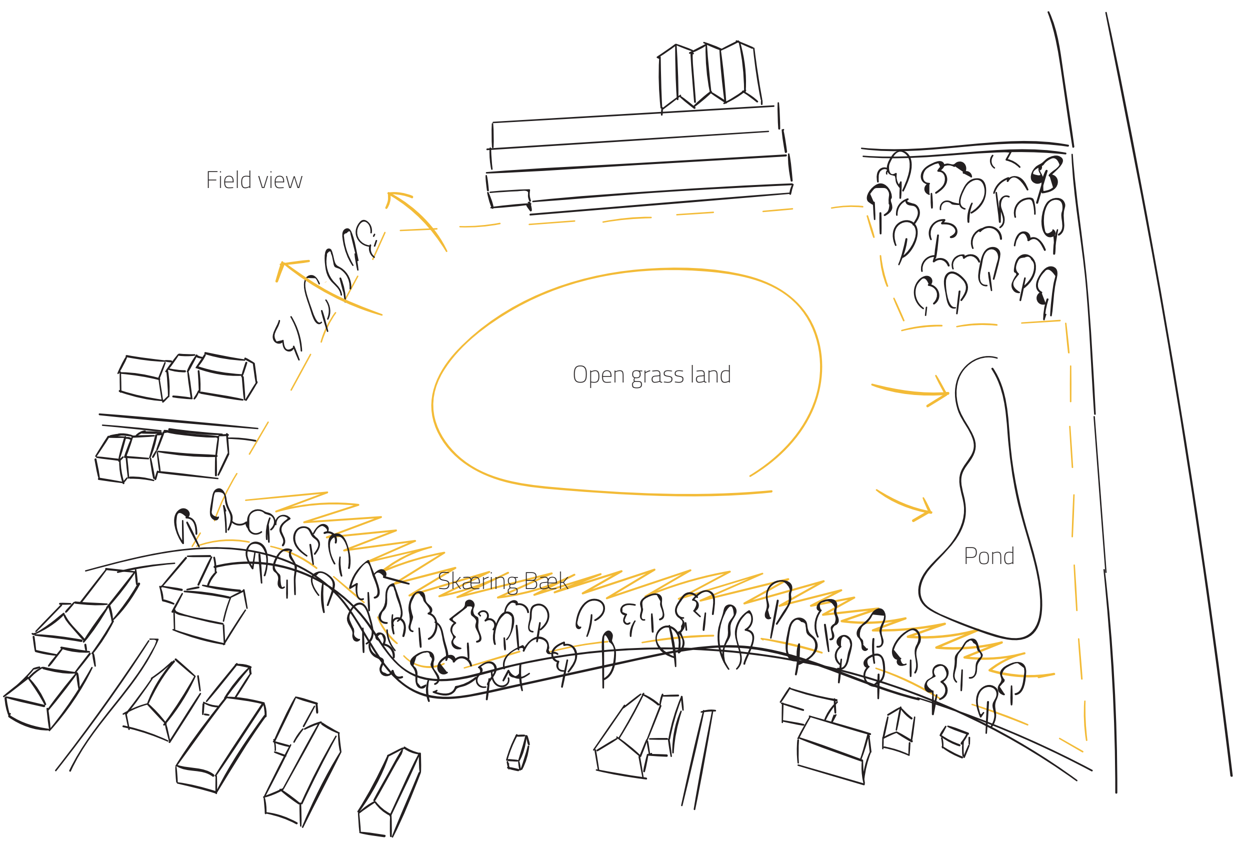
The site has a relatively large size with many different things happening. The location is on the outskirts of town, with view over the large fields covering the land but it is surrounded by buildings of different typology and a large road as well, as seen on Ill. 57. This combined with the groups of trees puts the site in its own little corner. The views towards the south have the nice creek and to the east, a small pond lies. These differences have been decided to be used in the projects, when locating the dwellings on the site. This can help give different identities as well as developing different activities in the area.

FRONT AND BACK YARDS

After a while of sketching the individual units, it became clear that the principles we found in the urban workshop revolving privacy and safety was the best way to design the dwellings (see Ill. 58). The clear division of a front and a back helps arrange the rooms on the inside, as a desire for the residents of the single family home is direct acces from living space to the outdoors. As a big part of the recreational areas on the outside will be common, it was found natural, that the living area that gathers the whole family would be in relation to this. The front side of the houses also help locate the roads, where fewer is needed, than if arrival could happen on both sides.

TRANSPORTATION

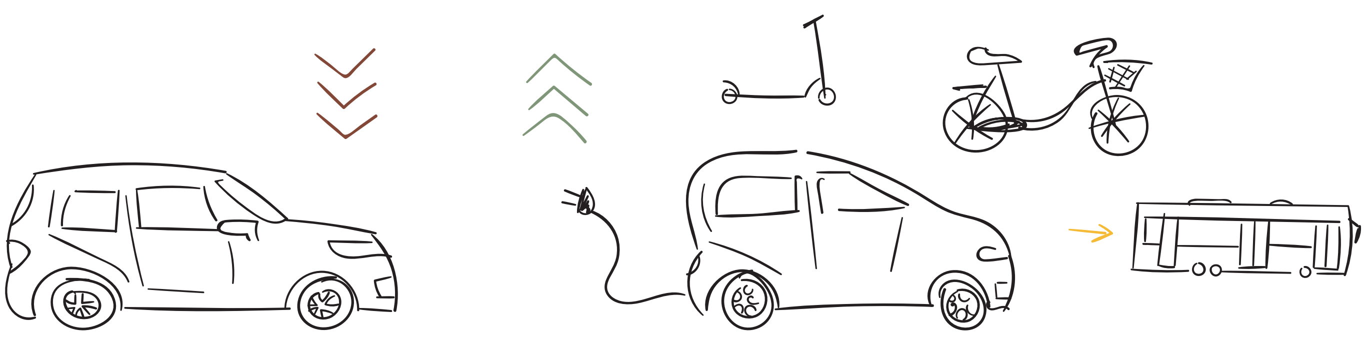
The project focusses a lot on sustainability and how to design dwellings better suited for the furture. Cars have for a long time been an issue, as it pollutes a lot but does not yet have a completely functional alternative. Most families have their own car, and the location of the site is rather far from the city, for some to use alternative transportation. But the town of Skæring



Ill. 57. The site offers many qualities in different areas. These can offer variation and differences between the individual units

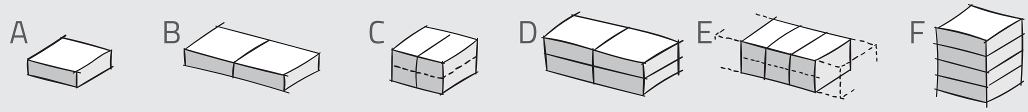
is actually very well connected to Aarhus, both by bus and with the biking routes (see Ill. 21 on page 30). Therefor the project should try to encourage the use of these alternative transportation methods, as well as opting electrical cars over petrol cars (see Ill. 59).

Ill. 58. To create a distinction between areas, the units will have a front and a back side. This creates safe and more private areas for the residents in the back, as well as more formal and easy to navigate side towards the front. This arrangment with front and back yards is also very common in regular single family homes.



Ill. 59. Promoting environmentally friendly vehichles over regular cars, have been a priority, when looking at transportation. These vehicles can be electrical cars, bikes, electric scooters and the existing busses connecting Skæring to Aarhus.

UNIT GROUPING



QUALITY (FACTOR)	A	B	C	D	E	F
Entrance (3)	4	4	4	2	4	1
Accessability around the house (2)	4	4	2	3	2	3
Privacy from direct neighbors (2)	4	3	3	2	2	2
Openings in facade (1)	4	3	3	2	2	3
Natural ventilation possibilities (2)	2	2	4	2	3	2
Envelope (3)	1	2	3	3	4	4
Impact on nature/ Footprint (1)	1	1	2	2	2	4
TOTAL	~~40~~	~~41~~	45	34	43	~~36~~

WEIGHTED SCORING MODEL

Different grouping options have been explored by several parameters to ensure both enough units on site as well as lowering the LCE and keep the qualities of the detachend single family home.

Scores

1 Unacceptable (Knock out = /)
2 Non-optimal
3 Good
4 Great

ENTRANCE

How easy one accesses their home is important in several ways. The optimal sollution here is entering at ground level, as seen in A,B,C and E, to easy the transition between inside and out. The exclusion occurs when having to install an elevator due to building regulations, when accessing on 2nd floor or above as in option F. This quality is found very important because having an elevator requires additional energy for operation.

ACCESSABILITY

In prolonging of entering the dwelling, moving around inside and towards the exterior areas also affects the flow. A quality of the single family home (A) is for many, that it is a one-storey home, and having internal staircases (C and E) can be problematic with small children if not solved properly. D and F are both one-storey, but conceptually have no direct access to the exterior.

PRIVACY

Living in a single family home (A) the neighbors are always further away, providing much more privacy. This is both when it comes to noise and visuals, that privacy is apreciated. The number of directly adjacent neighbors determine the score for this quality.

OPENINGS

Moving towards the internal environment, the amount of dayligt corelate with the facade, where openings may be located. Having several facades with openings also provides two option of better following the light during the day. This is considered a less important quality, looking at the factor. Because of the small sizes of the units, it is not found problematic to obtain a good level of daylight in either grouping.

VENTILATION

As discussed in "Environmental dimension: Living comfortably" on page 26, natural ventilation is an excellent way of facing the challenges of high temperatures and air pollution. Option C here gets the highest score, as possibilities of both stack, single-sided and cross ventilation are found.

ENVELOPE

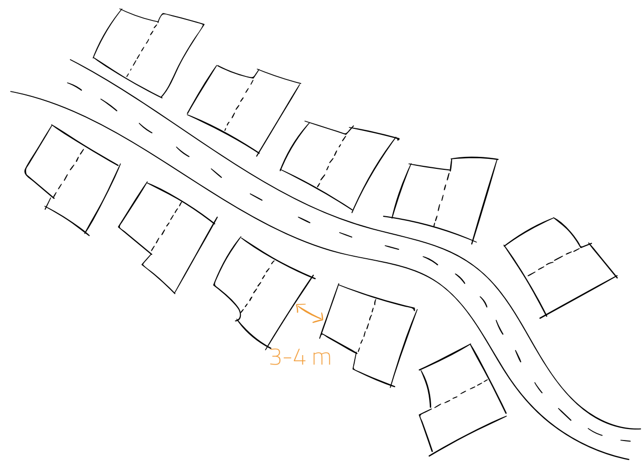
Taking a broader perspective of the different ways of grouping the units, the amount of envelope is very important as it is directly linked with the embodied energy of the building. Grouping several units together will save a great amount, which is also why E and F scores so high. These values have been estimated on a basis of "Appendix 2: Unit grouping - Envelope".

IMPACT

Lastly, the units are being located on a new building site, of a certain size. This quality both determines how much of the site can be spared as well as if the goal of 80 units may actually fit into the area. Again, grouping several units help utilizing the area in between, but the only thing, that truely affects the impact, is placing the units in several layers. Having just two-storeys reduce the impact roughly 50% compared to only one, though stairs etc. need to be considered in these cases too (C, D, E and F). Having all units in just one storey is not an option though, due to the footprint it would have on the entire site, where there wouldn't be room enough.

COMPARISON

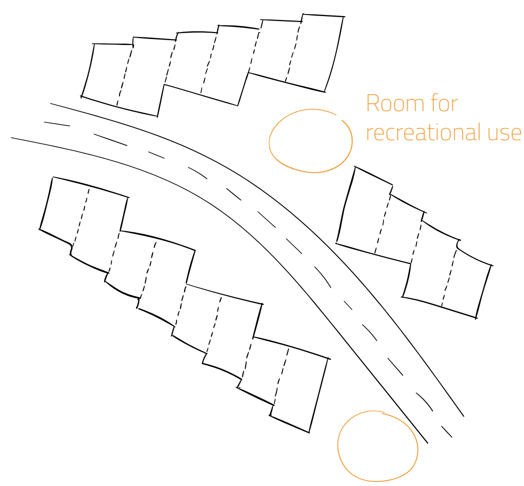
The different ways of grouping the units all have their own posibilities and can be good or bad for different things. In this case, with the specific qualities chosen to evaluate from, it is found, that option C (the double two-storey) scores the highest, closely followed by



Ill. 60. Small plan section of the placement of unit grouping C. The units fits on the site but leaves little room in between, creating passages instead of recreational areas.

E (rows), which can be seen as an extension hereoff. Using this method keeps the result more objective, but its still needs to be tested in order to validate, whether it makes sense.

After placing and moving the groups around the site, it is found, that some of the qualities does not have the best foundation for functioning optimal as well as the site does not seem to be fully utilized (see Ill. 60). Instead, the projects moves forward with a combination between option C and E, where the units are put together but displaced. This takes some of the good qualities from each, as the envelope minimizes but the units have several facades for openings as well as less shared wall with the neighboring unit (see Ill. 61).



Ill. 61. Small plan section of the placement of a combination of C and E.

UNIT SKETCHING

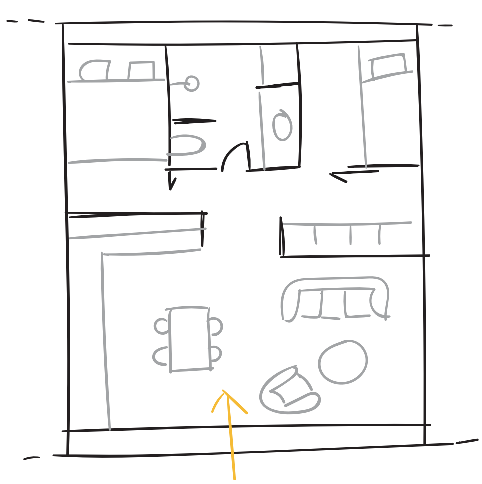
The development of the units have been a long proces determined by the functionality, the potential of lowering the energy use, the arrangement on the masterplan etc. Many ideas have been tested in order to figure out, what could actually work, in the small amount of space. Things needed to be considered while designing included the size, flexibel sollutions, one or two stories, and the number of people going to live there. Parts of the design journey have been shown here, but for further sketches and unit development ideas, see "Appendix 3: Unit sketching".

INITIAL SKETCHING

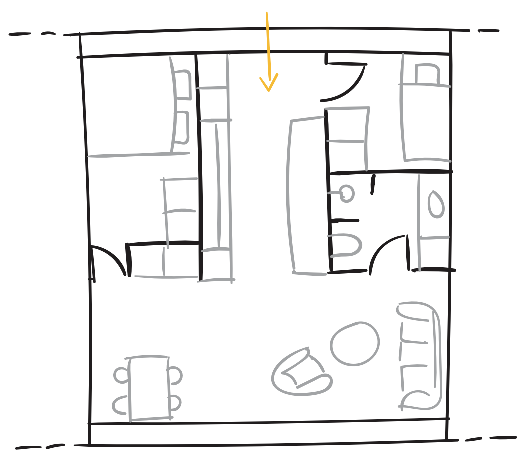
The first round of skecthing primarily focused on how to fit all function into the small size of 60 and 70 m^2. The designs started with one-story units in drawings by hand and simplified 3D models on the computer, mostly looking at the planar view. This stage had a lot of research on furniture sizes and dimensions in and between different functions. The building size limited the option of any design, making it very challenging to design anything completely functional in the spirit of the detached single family home.

Ill. 62. Closed room towards north, open space towards south. An entrance on the side gives small displacements in the facade.

Ill. 63. This unit is designed to be at the end of a row, with the entrance towards east, and rooms on both north and south facades demanding views outside.



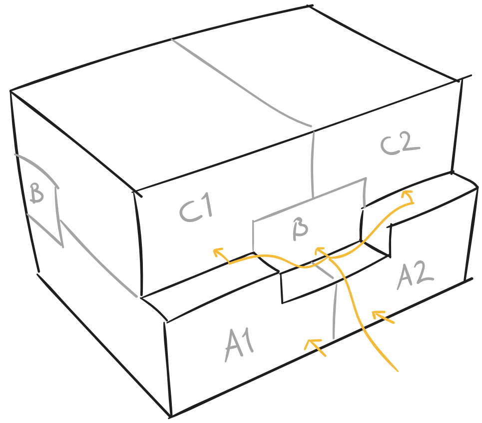
Ill. 64. This unit provides very small sleeping areas and a common closet for everyone's storage. This gives great space for the living area, but an entrance will be located directly in there.



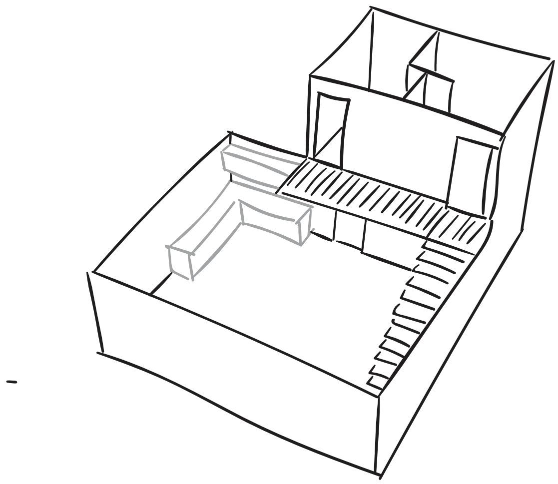
Ill. 65. With an entryway down the middle, directly into the kitchen, a good separation of the bedrooms appear. It also leaves room for a spacious living area and plenty of storage.

INTEGRATED DESIGN APPROACHES

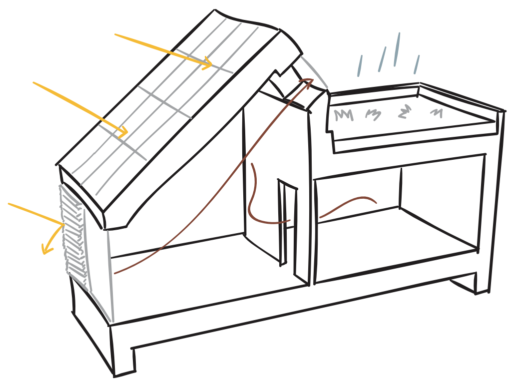
Trying to design from a more holistic approach, the 3rd dimension was added looking more into ceiling heights, sustainable sollutions and space saving furniture on the specific walls.



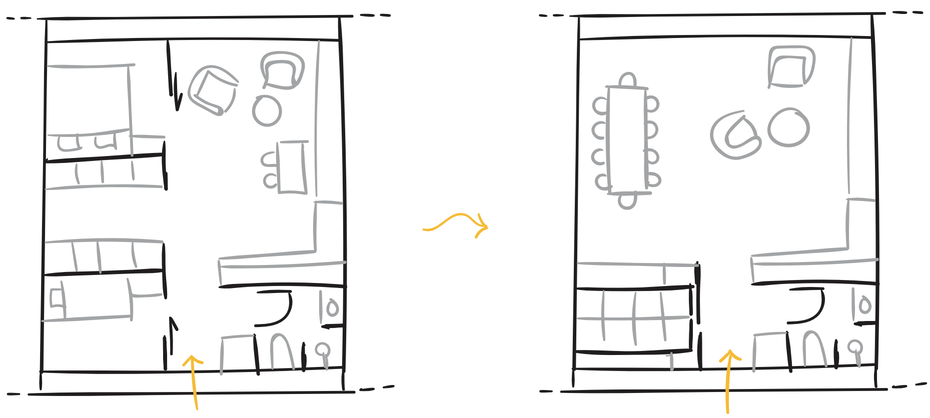
Ill. 66. A combination of five units, where the ceiling heights differs in each room.



Ill. 67. One of the earlier attempts working with two-storey units. Having the smaller rooms on the second floor provides privacy, and the living area is free above, potentially adding volumen and therefor more air with better quality.



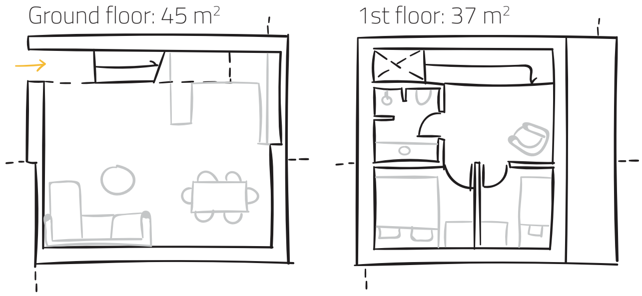
Ill. 68. When working with only one-storey builds, this was the principles tried incorporated. A larger volume towards the south, with and angled roof for solar energy and high placed windows for ventilation with a stack effect. A flat part of the roof could be used for rain water collection.



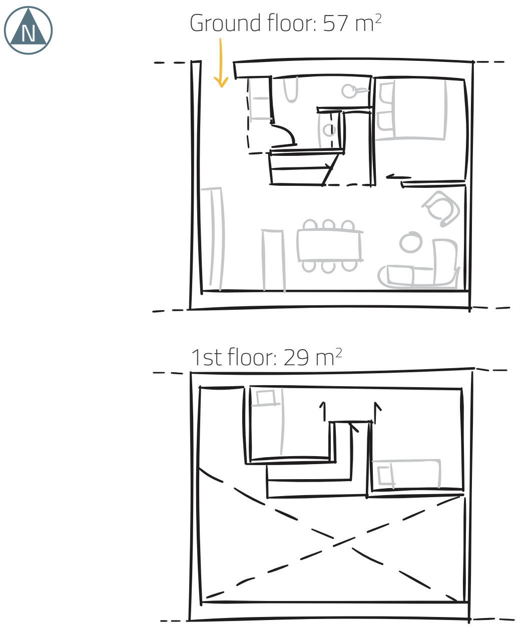
Ill. 69. This design works with flexible wall systems, where entire walls can be moved, and the smaller rooms disappered. It also incorporates some built-in furniture, like the murphy bed, to help utilize the space even better.

FURTHER DEVELOPMENT

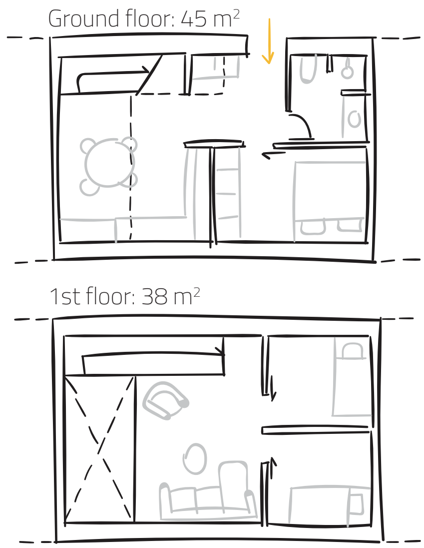
While simultanious figuring out how to group the units together, it became clear that the design needed to consist of two story units, that could somehow fit together on a row of sorts, as well as work together on its own. The two different size units went on to have the same room arrangments, making them similar, but fitting to their own size and needs.



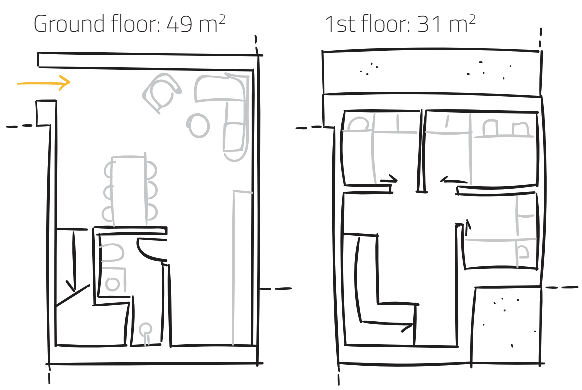
Ill. 70. Initial though by having two storeys, was to divide the area equally between them. It is not possible to have a bathroom on the first floor only, according the the building regulations, though, and the first floor is still smaller in area, but not in amount of envelope.



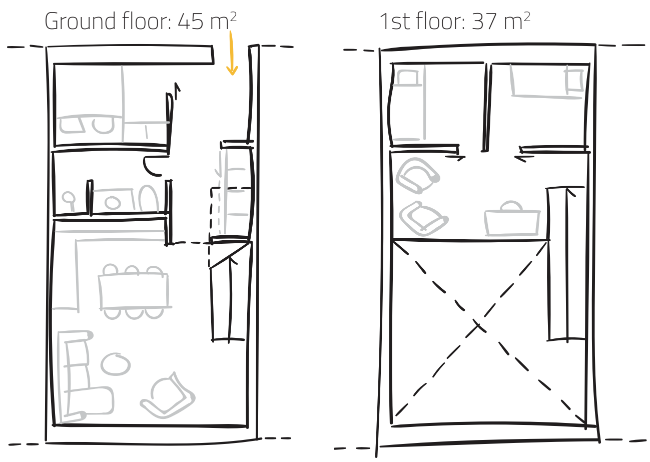
Ill. 71. Minimizing the cildrens rooms, but still making them flexible and open. The amount of double high rooms becomes too much, when looking in 3D.



Ill. 72. Another idea was to divide the living area into two with a visual connection. This functions well but lowers the range of personalizing the furnishing.



Ill. 73. Working with different sizes on the two floors can work, if also incoporating some displacements in the connection between the units. Having all rooms right next to each other gives no privacy.



Ill. 74. Dividing the floors into zones, making the upstairs primarily for the children, but having the visual connection from the shared living area. It also provides good amounts of space for choosing personalized furniture in the living area.

INTERIOR STRATEGIES FOR DOWNSIZING

When aiming on building smaller, the interior furnishing will also have an impact. Implementing different strategies of design can help this, in their own ways. The project looks into flexibility, multifunctionality and built-in furniture and self-defines them to figure out which works best for this particular project as well as designing small in general. The three may overlap but these clear boundaries will help distinguish them from one another to get a better understanding of their different potential.

FLEXIBILITY – SPACE

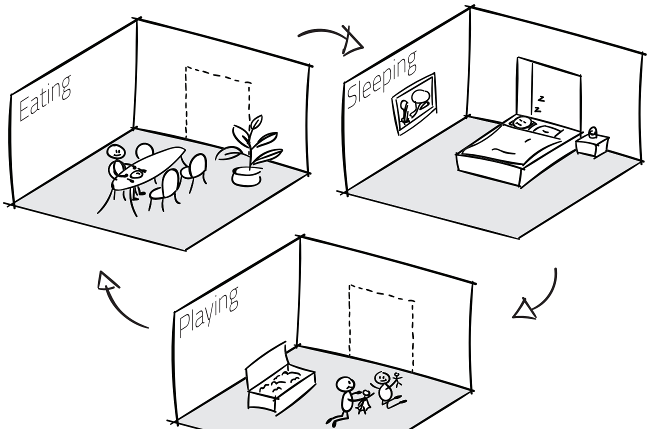
This aspect addressed how a room can vary over time, both during the day and during different stages of life. This can be a great way of using space for several activities at different times, but it requires something from the occupants, as it is a transformation of the space. Though not describes as a quality of the single-family low-rise house (see Ill. 4 on page 18), having the occupants moving heavy furniture or even wall sections around every day cannot be expected. What is a quality in the low rise though, is the possibility for flexibility on fewer occasions or during life changes. Using this strategy can also be a great way of embracing the different family types and personalities, expected to live in the houses.

MULTIFUNCTIONALITY – OBJECTS

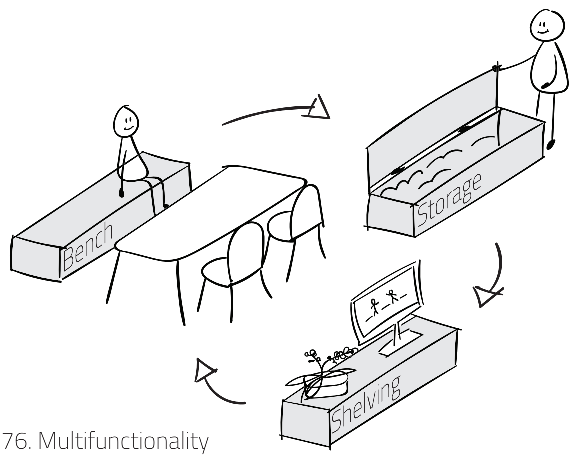
This is when a single item has several functions incorporated. One thing can then be used in many different ways and the need for different objects then decreases and frees up space. Problematics with this tactic can be the specific products, that may need more intense designing and can become more complicated to use. It also removes the possibility of the designated actions to happen at the same time. The more people sharing the multifunctional items, the bigger the challenge.

BUILT-IN FURNITURE – PLACEMENT

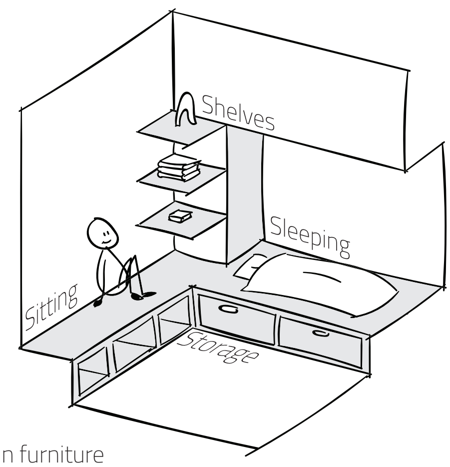
Built-in furniture is a part of the building layout the same way the kitchen and bathrooms are. It is fixed furniture that fits in an exact space, where it otherwise might not. This is great for utilizing every square meter in the house and can help give it an overall identity, though it limits the layout of the furniture as specific elements are placed beforehand. This limitation can be problematic when looking at the home feeling, as it leaves less room for choosing furniture as well as overall personalization of the space.



Ill. 75. Flexibility



Ill. 76. Multifunctionality



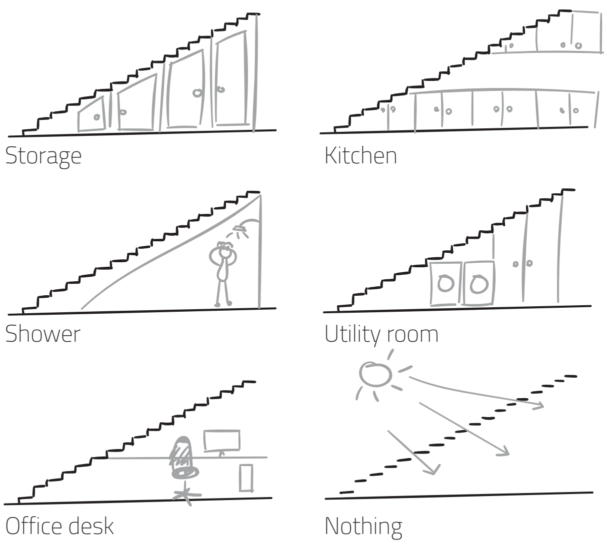
Ill. 77. Built-in furniture

DETAIL WORKSHOP

Along the design proces, smaller sketching sessions were made, when found nessesarry. The themes varies and more could easily have been added but they worked as a way of kickstarting the proces, when facing bigger challenges or lacking ideas. The individual sketches also serves as a way of comparing different sollutions to each other.

STAIRS

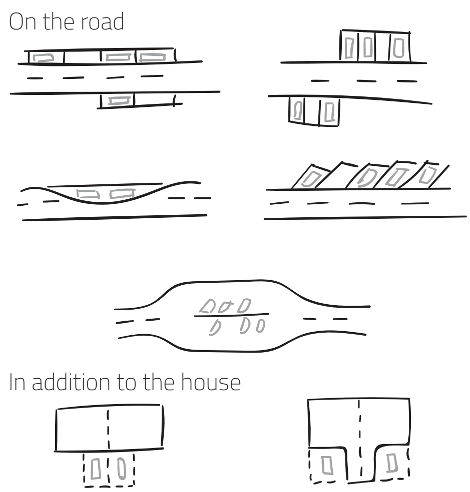
When deciding to work with two-storey units, the incorporation of an internal staircase was inevitable. To get at comfortable and safe staircase, it takes up approx. 4 m^2, which in the big picture, is a lot, working with small homes. To make sure the space doesn't go unused, different ideas where thought of, to utilize the space underneith (see Ill. 78). Some elements, like the kitchen, unfortunatly have a smaller depth than the stairs, meaning it doesn't work very well, when stading in the low end. It is suited for other storage, that can somehow be pulled out, in spite of the depth. It was also found that a set of stairs with full storage takes a lot of space and light visually. Having the stairs open can do the opposite, making the rest of the room seem bigger, even if the space isn't being used.



Ill. 78. Stairs

PARKING

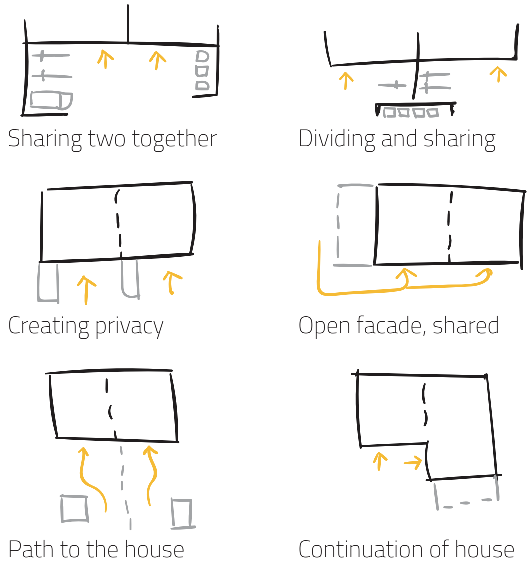
Before having the final masterplan and unit layout, car and parking was considered. Even if the project encourages the use of other transportation forms, there is a parking norm as well as a common understanding, of having a car. Thus, it cannot be completely neglected. Having the cars parked as a part of the house was also considered. When designing parking, the space for movement also needs to be considered.



Ill. 79. Parking

EXTERNAL STORAGE AND WASTE

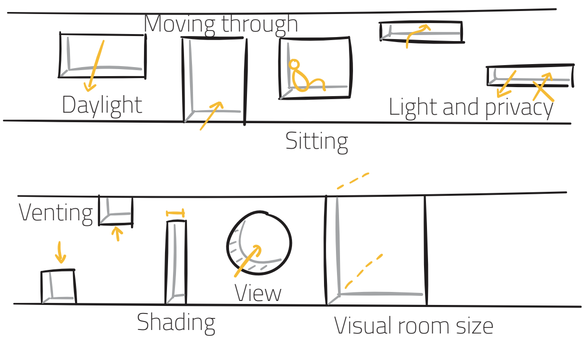
To encourage the use of bikes, as well as fulfill the funtion of handling waste, external storage and waste needed considerations as well. It was found to work well as a divider for privacy, between the neighbors.



Ill. 80. External storage and waste

WINDOW PLACEMENT

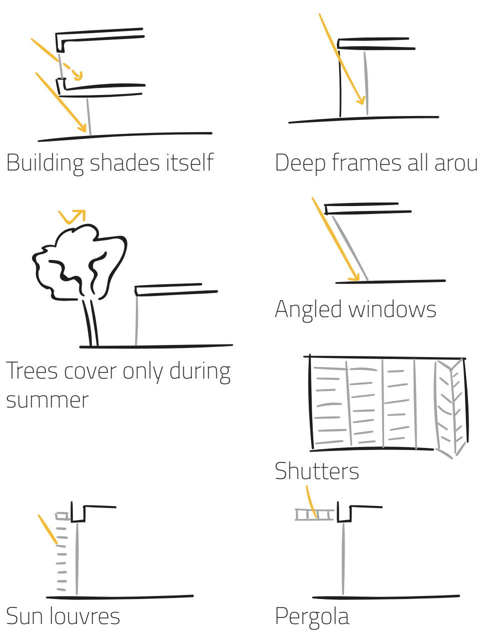
Windows have many different functions including gathering solar energy, opening for venting and viewing the outside. They can also serve other function such as sitting, moving through and storage. Sometimes the windows are needed for one function, such as venting, but privacy is also important. The opening needs to be able to provide both.



Ill. 81. Windows

SOLAR SHADING

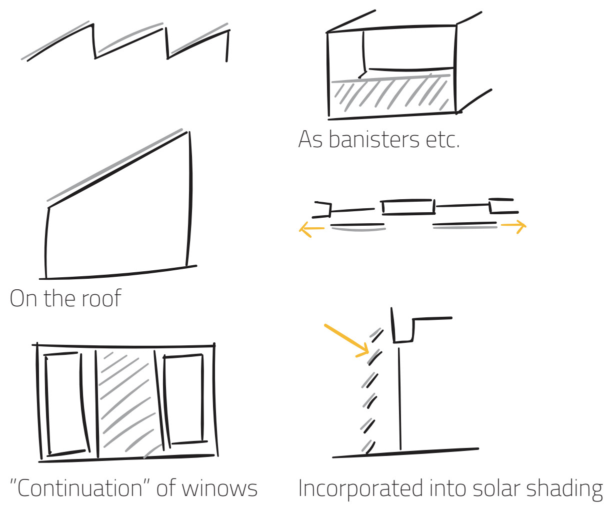
To prevent too much solar energy during summer, but still get enough during winter to use as passive heating, solar shading needs to be considered. It can be as a part of the building shape or added afterwards as shades or vegetation. This element plays a huge role, when lowering the operational energy throughout the year.



Ill. 82. Solar shading

SOLAR ENERGY HARVESTING

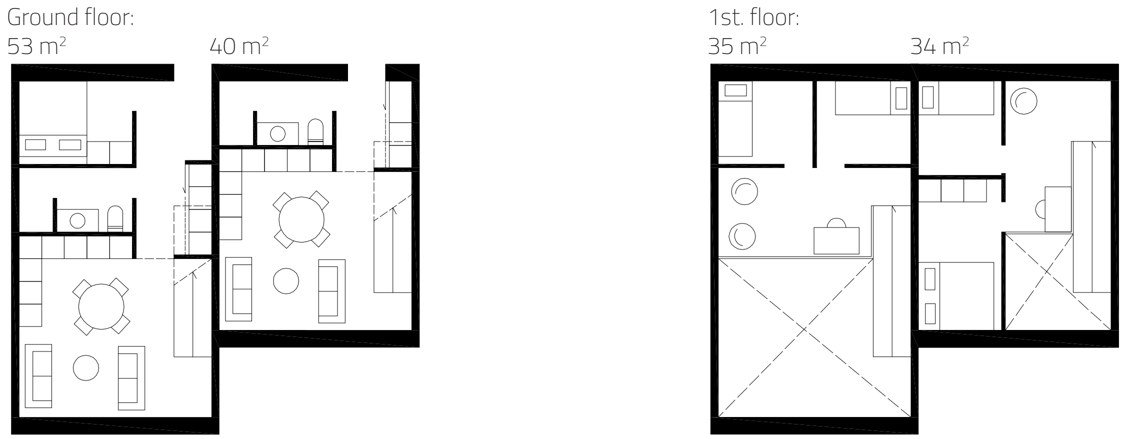
To ensure energy on site, PV-cells have been chosen as the best sollution. They need to be placed on an element hit by the sun, preferable all day. Some systems have been developed to follow the sun, but most are stationary in its position. Instead the specific location and form can vary. It is rather common to place them on the roof, but they are often placed after the building is already stading. Instead they need to be incorporated from the start, also ensuring optimal conditions while designing the roof shape. Other sollutions can be to make them as part of the facade and incorporate them into other element of the building. The problem here can be the small amount of surface available compared to the expensive technology it takes to place them there.



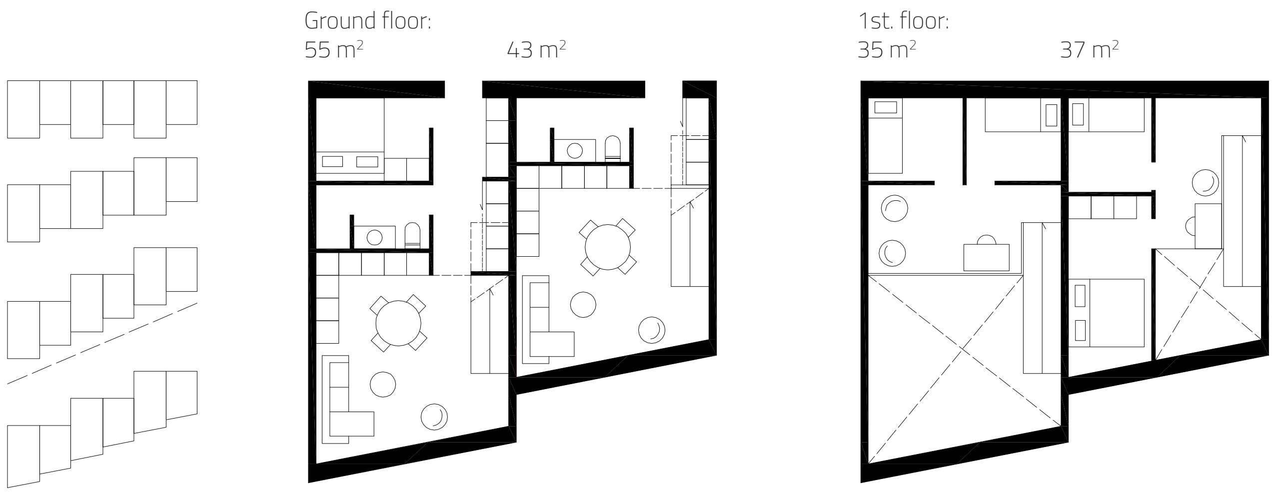
Ill. 83. Solar enegy harvesting

UNIT DETAILING

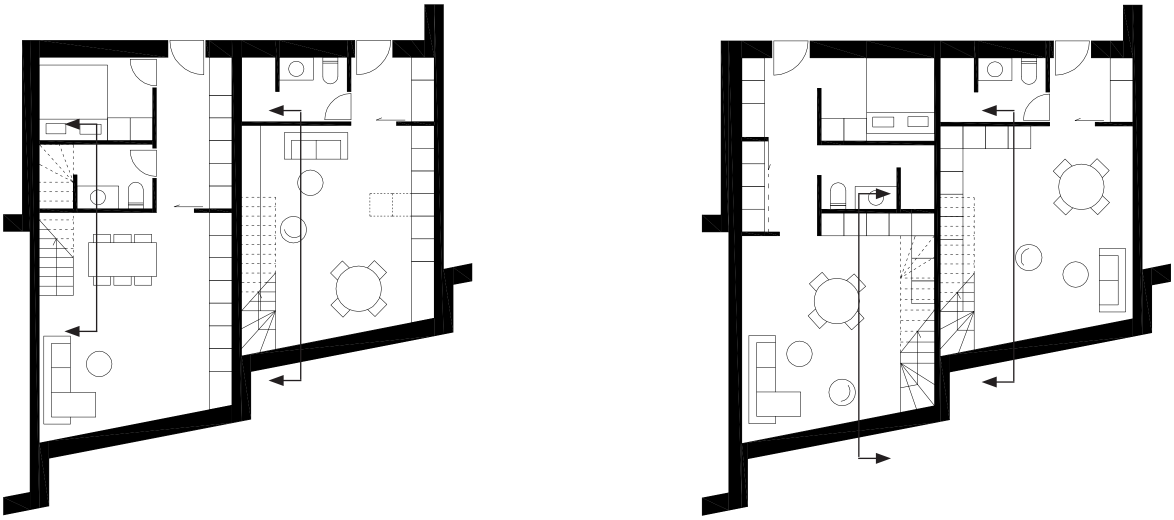
After all initial skecthing in different scales, more detail could be implemented, also acording to analysis made along the way. The most time have been spent detailing the individual units of both sizes, having them work together and work well on the site. With offset in the unit shown in Ill. 74 on page 62, further itterations have been made.



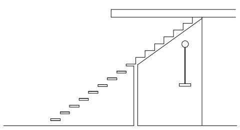
Ill. 84. From earlier sketching, the large unit was initiated, and a smaller unit have been created afterwards in the same spirit. Quite bedrooms upstairs with a visual connection, a large living area downstairs with direct acces outside and a entrance + utility + bath zone combined.



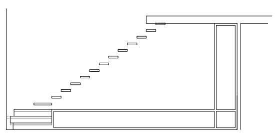
Ill. 85. The different depths of the units was utilized to creat a smoother facade, but maintain the privacy it gives. It also allows for windows in more facades at different orientations, than if they were placed in straight rows.



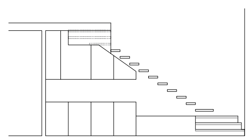
Ill. 86. Different arrangements were tried to ensure the best use of the living area. Both were investigated, having the kitchen area unterneath the stairs. Though it can work with the heigh of the stairs theopen layout is harder to furnish, than having the kitchen on the opposite side. The unit with the shower underneath the stairs saves some space, but the shower will be less roomy, and the opposite wall will be a long continuing element.



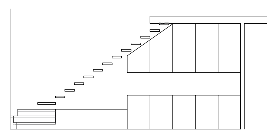
Ill. 87. Large unit. Shower.



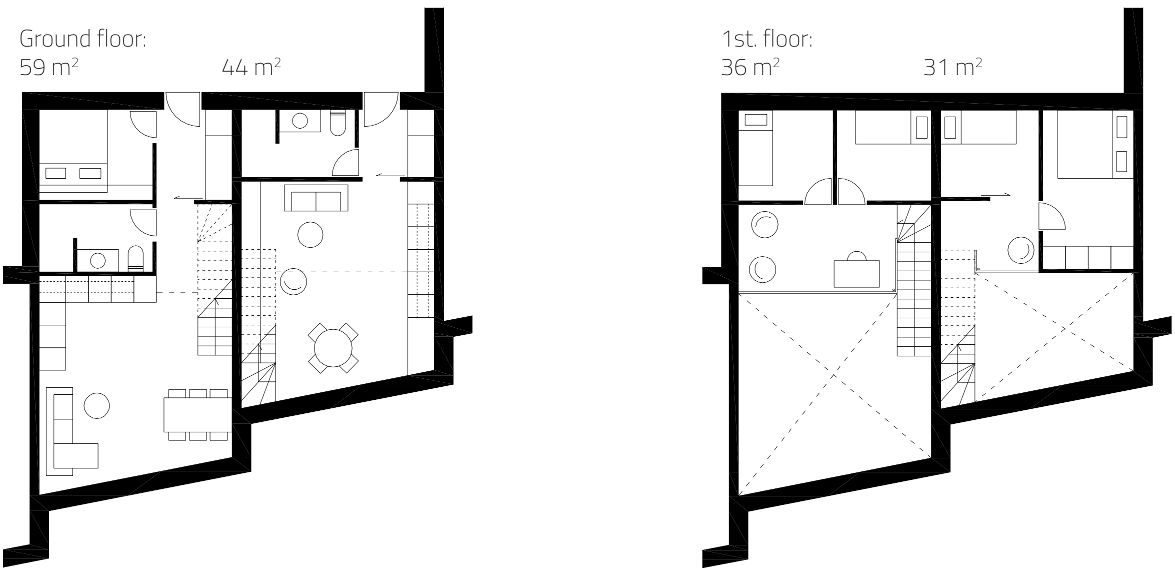
Ill. 88. Small unit. Built-in multifunctional furniture.



Ill. 89. Large unit. Kitchen.



Ill. 90. Small unit. Kitchen.



Ill. 91. The living area was expaned a little, as the VR-experience gave an impression of more space needed to not have things cramped together. More floor area gives more space for family time and adds volume to the room, which also have indoor climatic benifits. On the first floor, the rooms in the small unit have been rotated to the upper facade only, as the stairs could be moved further away on the ground floor.

VIRTUAL REALITY

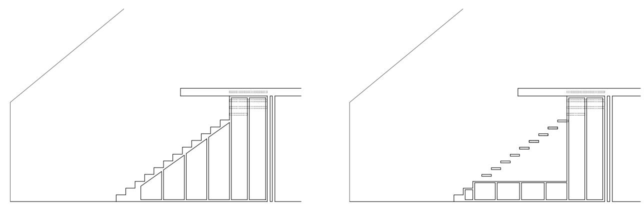
One of the methods initially expexted used in the project was virtual reality. This have been limited from having several people test it out, to only one. It has still proven a very effective tool in order to test more detailed decisions in the interior. It is diffucult to show in pictures or even regular video, so it will rely on the impressions left on the test person. The method have been valueable, especially looking at the rooms, and entryway, which have been minimized a lot, compared to the detached single family home. It has also been used to determin ceiling height vs. floor area.

Ill. 92. Low ceiling. Working with minimizing, the floor area vs. celing height was tested in the living area. The volumen stays the same.

Ill. 93. Medium ceiling. This works well, as the height fits the room size. It is eaqually nice to stay in as the low ceiling.

Ill. 94. High ceiling. The proportions of the room change, and does no longer provide the atvantages it did with the medium ceiling height.

Ill. 95. Example of a room seen in VR. The rooms ranging from 6-10 m^2 were all though plenty spacious using VR.

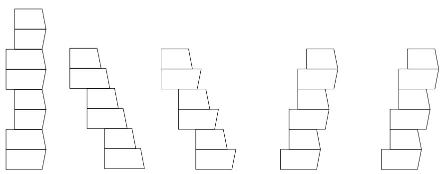


Ill. 97. Section towards stairs - two diferent options. The first poviding more storage, the second a seating or shelfin area.

Ill. 96. Using VR, walking through the entryway help determine the visual qualities of each suggestion. The first option with the closed set of stairs takes more light, and gives a feeling of a narrow hallway. The second option works better for this , making the living area feel bigger.

SITEPLAN

On the site, different patterns were tested on the site, both acording to the dwellings but also the roads and. The site should be connected to adjacent sites to both east and west but other than that, much traffic by cars have not been wanted. Due to the parking norms, cars have to be considered though, and for this project, the dictated amount of cars will go from 1,5 pr. unit to 1,1, which is the same parking norm, as seen in many high rise buildings.



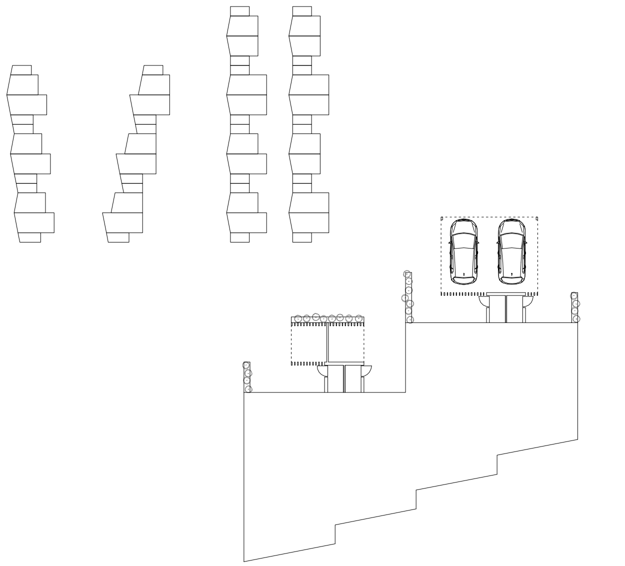
Ill. 98. Different arrangement of the units were considered, but the original til seemed as the best basis for both privacy, facade exspression and roof shape.

Ill. 99. The initial siteplan made with inspiration from the urban workshop and the suggestion in Ill. 53 and Ill. 56 on page 55. After developing the units, they no longer fit in that specific constellation. After this, new setups were tried, also in order to have better ground for using the roof for solar energy. This was though to be on the slanted facade in the living area, which would be higher ceiling or double height.

Ill. 100. Instead of having any towards the north, they were tried all turning east and west. This divides the large open area into two long grass belts instead of a large common area.

Ill. 101. Moving the roads around from the privious two options, having them follow the road better, gives a much better outdoor area. The challenge of the orientations of the unit still havn't been solved.

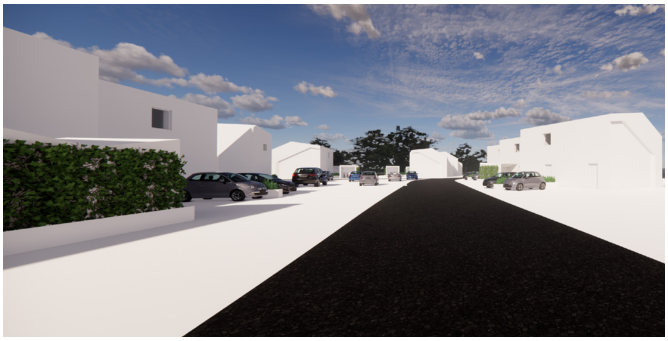
Ill. 102. Keeping the road layout and adding the idea of not having any units facing north, but stil south, east and west took the masterplan to a much more fucntional arrangement. This way, the different themes on site can also be utilized better.



Ill. 103. After deciding to add the external storage and car/bike parking outside the house, the density of cars needed to be evaluated. Could all cars be placed together and houses with bike parking the same, or should it be more mixed.

Ill. 104. Every unit have a car parkig in this area. This takes a lot of the open visual green society, that should bee created.

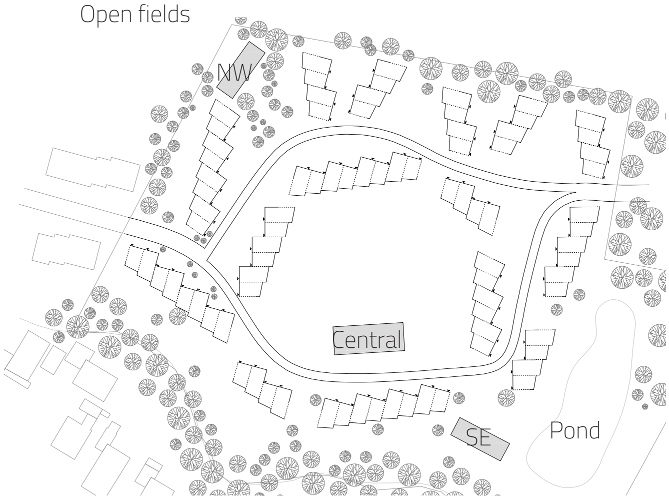
Ill. 105. Bike parking only for every unit. This seems open, safe and comfortable to move through, but it is not realistic with no cars at all.



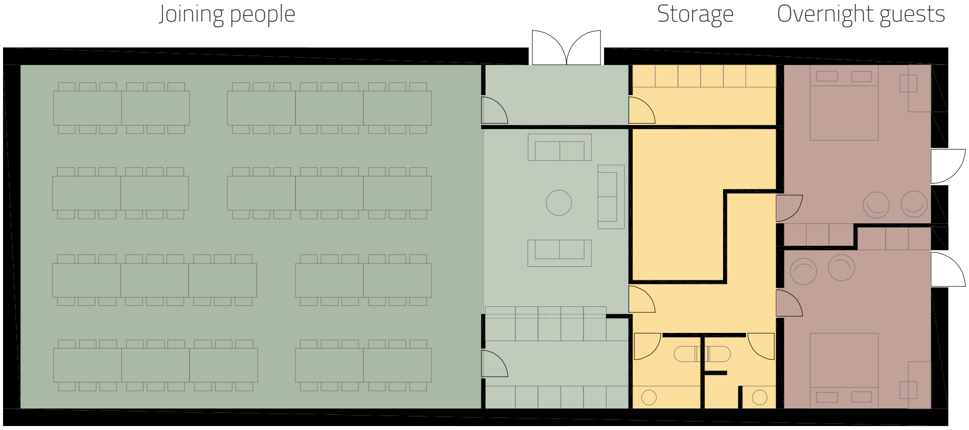
Ill. 106. A mixture, where every second have parking for cars and for bikes. Additional parking can be created around site in smaller groups, to ensure enough parking of 1,1 spots

COMMON HOUSES

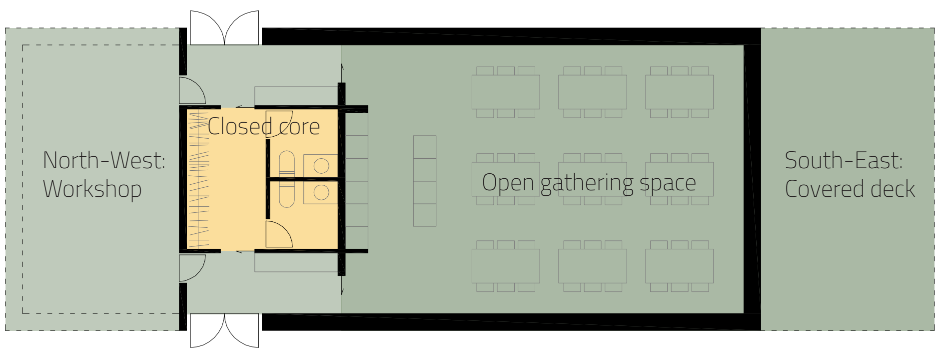
As a part of minimizing the individual units and researching co-living, additional space have been created for every resident on the site to use. This have been represented by three common houses, to fulfill functions, that can't happen at home due to the smaller size.



Ill. 107. Common houses on site



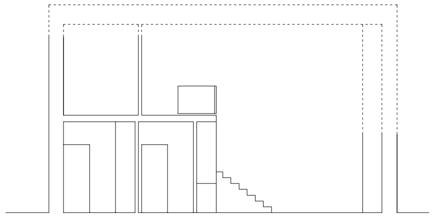
Ill. 108. The main principle of the larger common house, located in the center of the site, consists in joining many people and residents being able to have guest over. The functions in this suggestion can be difficult to decode, and as many people can come from outside, it was found, that the layout need to be a little more clear for better wayfinding. There is a lot of wasted space, that can still be optimized.



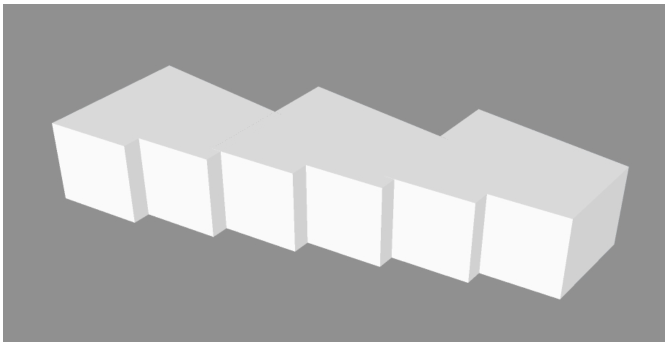
Ill. 109. The two small common houses started with a similar layout, that would only differ in each end, depending on the location. After this, it was found that they needed to distinguish themselves more, both from each other but also from the bigger one. Thinking even further about different functions, they can accomodate, while having flexible floor plans to work in several occasions.

ROOF

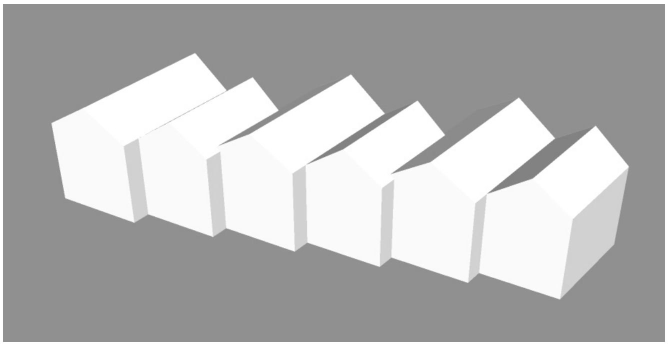
The room arrangement of the individual units gives the option, of trying very different thing with the roof. According to the initial solar analysis made on site (see Ill. 29 and Ill. 30 on page 35) the southern facing roofs were most efficient, but having faces to east and west stil gather a high amount of solar energy, if sloped correctly.



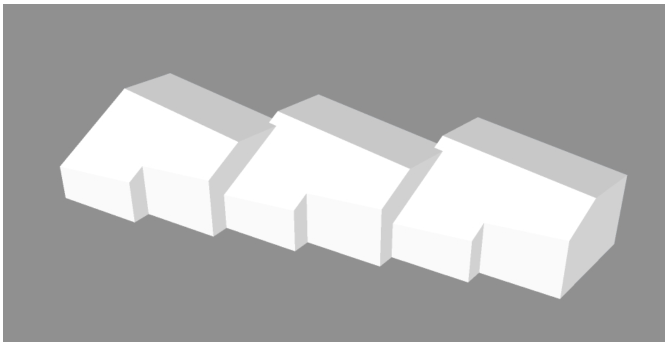
Ill. 110. Section showing the walls where they need to be to ensure enough ceiling height. The dotted lines represent a flat roof.



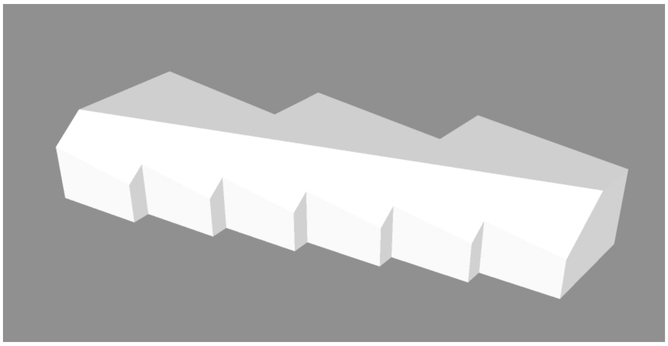
Ill. 111. The flat roof is efficient for solar energy all day and all year, but it give much height to the living area, which isn't needed.



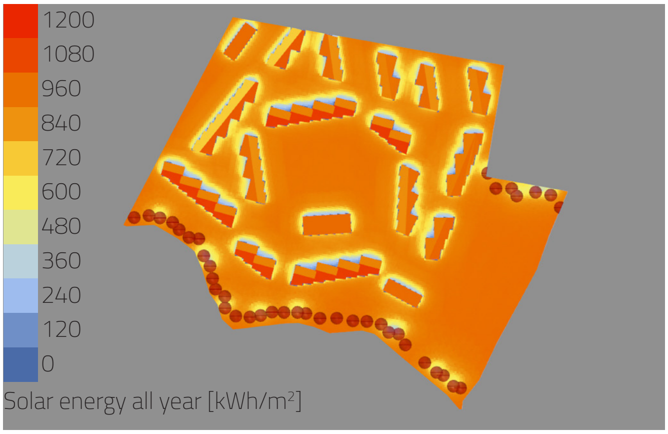
Ill. 112. This roof adds even more envelope. The slope can be altered to fit perfectly, but may shade itself during low sun e.g. during winter.



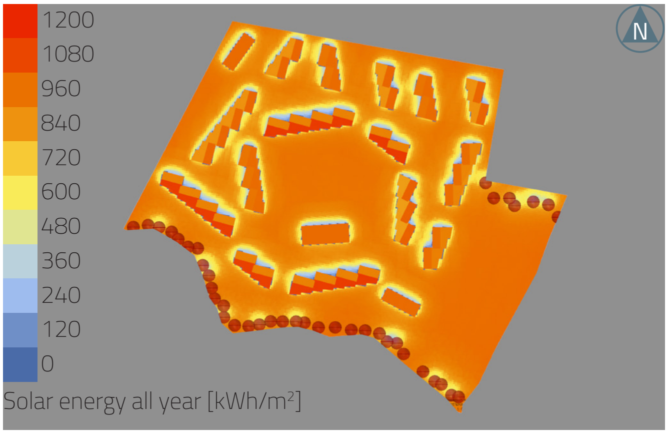
Ill. 113. Creating a sloped roof pr. 2 units utilizes the rooms inside and basicly do well collecting solar energy. The large roof face have an inclination of 30°, where the smaller is 7°. Only the big is intended for gathering solar energy.



Ill. 114. This option is an alternative suggestion for the east and west turned units, which is tested as well. It gives less variation in the facade.



Ill. 115. The sloped roof for every second units performs great on almost all groups.



Ill. 116. The option of having collected roof surfaces for the entire groups have been tested here, but does not indicate a succes for the 30° inclination side.

SOLAR PANELS

As part of the sustainable strategy, solar panels are being placed on the roof of all dwellings. The roof shape have been formed acordingly, so the large roof face has an inclination of 30°, which is the optimal for PV-panels. A demand have been estimated to approx. 286 MWh/year for the entire site, which can be coved over different areas, depending on the type of panel. As the shape of the roof is a little odd, they need to be able to fit into an odd shape. Usually, thin-film panels are used for this purpose, as they can bend and cover more difficult shapes, but they are not very efficient and expenssive to produce. Instead, a newer technology based on monychrystaline panels have been developed by SolarLab on glass, that combines a higher efficiency with the versatility of the thin film cells. Usually monochrystaline panels can utilize 15-20 % of the solar energy, and due to the aestetics in the patterned glass, the SolarLab panels have a decreased efficiency of 90-75 %, but the total efficiency still exceeds the thinfilm. (SolarLab, no date). Combining the efficiency with the available roof on the large and inclined surfaces, more than enough energy was produced. To reduce the amounts of solar panels, 17 roof faces could be swiched to the smaller surface (see Ill. 117), where it was more efficient, and the total production of electricity would still suffice, leaving an excess 300 kWh/year pr. unit, which could be assumed to cover the expenses in the common houses. For calculations see "Appendix 4: Solar Energy production".

Estimations of energy balance:
Total energy demand: 286 MWh/year
Total energy production: 310 MWh/year
Excess energy: 300 kWh/year pr. unit.

As the solar analysis have been made throughout the year, it is important to understand, that the average amount of energy won't be produced every day, even if it is used. The solar panels also only produces electricity during the day, and certain times therefor needs to be covered another way. By connecting the energy production to the common electricity grid, a trade can be made, where excess electricity is send there and the residensts then can recieve their electricity in deficit times.

Estimation of energy need

Unit A: 3.800 kWh/year x40 units
Unit B: 3.350 kWh/year x 40 units

Total energy demand: ~286 MWh/year
(Energistyrelsen, no date)

Ill. 117. solar panel placement on site

MATERIAL CHOICE

Choosing the right material is a big part of the architecture and plays a large role in many of its aspects. It is important to look at them all differently, depending on where, they are being used. A wall in the envelope can be either simple, without additional material, as the loadbearing structure also provides the desired facade expresion and indoor environment. Other times, all the different layers needs to be considered carefully, for each of them to fully accomplish their goals.

For all parts of the structure, it is important for this project, to evaluate them using an LCA. All of the embodied energy lies in the materials used for building and a lot of energy can be saved, when choosing wisely. Especially the internal cladding and sometimes even the loadbearing structure also affects the operational energy. This is mostly due to the energy need for heating affected by the thermal mass and electricity for light affected by the reflectance of the surface and the trasparency throughout the building layout and furnishment. The LCA has many outputs, but as this project is concerned about the energy, the result comparison will be based on the PEtot (Total primary energy)

The comparison here are parted in three; The loadbearing structure, interior-, and exterior cladding, where different materials will be evaluated in different ways.

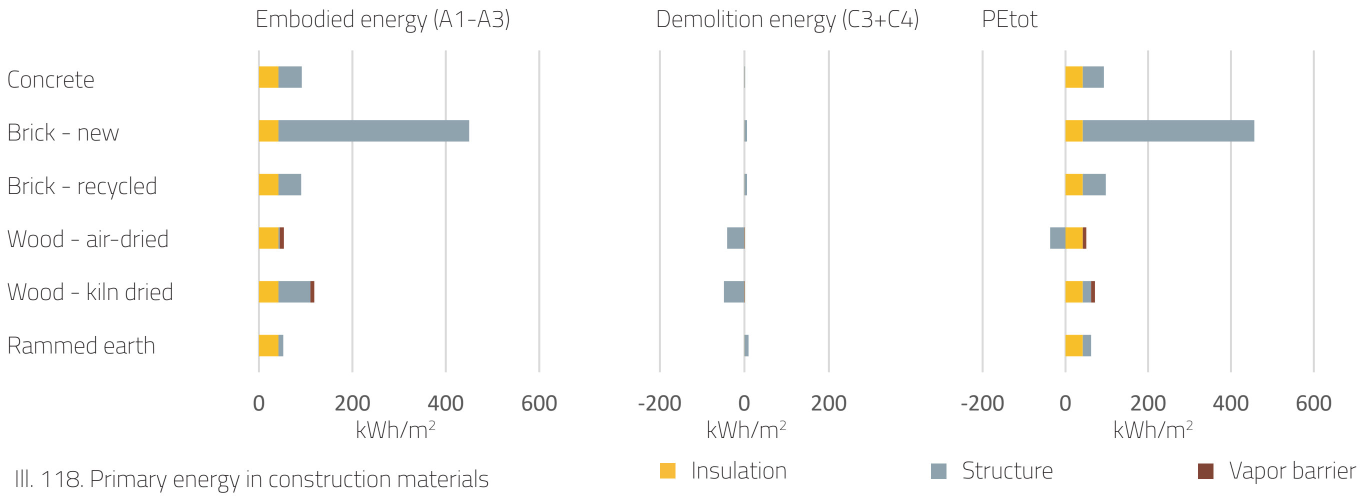
STRUCTURAL MATERIALS

There are many ways to construct a building, depending on the specific building material. This project looks into the most commonly used structures, as well as one more alternative, yet ancient method. They are all being compared by the different amounts of all the elements needed for that structure to function.

For insulation, the commonly known mineral wool have been chosen. It can be a thin layer and a more superficial LCA evaluation have been made quickly, to find the most energy efficient. These results show, that regular mineral wool demands the least energy for the entire lifetime. Other materials investigated are woodfibre, seaweed and straw.

As the same material have been used as insulation in all structure analyzes in almost the same amount, this is not were the big differenses lie looking at the energy use. The results show, that the best performing

STRUCTURE	MATERIALS	QUALITIES
Concrete plate	Concrete: 0,1 m Insulation: 0,275 m Concrete: 0,07 m = 0,445 m	Can be prefabricated creap, at brought directly to the building site for easy assembly. Cannot be recycled.
Masonry	Brick: 0,108 m Insulation: 0,275 m Brick: 0,108 m =0,491 m	Vernacular Danish building style, that can be done i many variations.
Wooden frame	Wooden posts: 0,275x0,045 m C/C 0,6 m = 0,026 m^3/m^2 Insulation: 0,275 m^3/m^2 - 0,026 m^3/m^2 = 0,249 m^3/m^2 Vapour retarder: 0,002 m =0,277 m	Needs additional cladding both in and out to cover insulation. Not fireresistant.
Rammed earth	Rammed earth: 0,3 m Insulation: 0,275 m =0,575 m	Cheap but labor-intensive building method. The earth has many qualities for indoor environment, but needs additional external cladding.



Ill. 118. Primary energy in construction materials

materials in general is the wooden structures and the rammed earth (see Ill. 118).

Challenges with using rammed earth is the thickness of the construction, which even is without additional external cladding, that also needs to be added, to protect the insulation and give a different architectural expression. Though the construction may be too thick to ensure proper daylight, when insulation is also needed, it may still work as a seperating structural element between the units.

We see a big difference in the methods used to aquire and produce the materials. A lot of energy can be saved, when using brick, if recycled brick is considered. The same differences is seen in wood. Looking at the different methods of producing wood, the most common is the kiln dried. This proces is faster and cheaper, but the naturally dried method uses a lot less energy. Problems here may be the availability and cost, as it takes a long time (up to two years), for wood to dry naturally.

As expected from the theory presented in Ill. 7 on page 20, the demolition energy is rather low compared to the total. For the wood it is even negative, which makes it even better in the total energy comparison. As this is in the demolition phase, it doesn't depend on the method of provision, but on the weight.

The project aims to use wood, both as it is a natural material, but also as it performs well in the LCA. As air dried wood may be harder to come by, it is not the obvious choice, but is prefered due to the great gain compared to kiln dried wood.

The LCA input comes from the program LCAByg except for the air-dried wood and the recycled brick. Here, the production method differs, and the phases A1-A3 are taken from respectively (Puettmann & Wilson 2005) and (Gamle Mursten ApS 2017). To see the results separated into renewable and non-renewable energy, see "Appendix 5: LCA for structural elements".

INTERIOR CLADDING

The concrete, masonry and rammed earth walls all have great rough finishes, that can also function as the interior cladding. If doing so, installations needs to be carefully considered before the build, to fully integrate them, though they will not be flexible over time. With the wooden frame, it is common to divide the frame, where the internal part becomes a layer for installation. This layer can also be added on top of the other constructions but gives an even thicker wall as an end result. Other things also needs to be considered, when chosing this surface. One aspect is the arcitectural expression and the way it looks. Another is all its physical properties and how it functions. Also remembering, when adding further material, it will contribute to the LCE calculations. All detailed calculations for interior environment and value sources can be found in "Appendix 7: Materials - Indoor environment"

The table shows data for raw untreated surfaces, though all surfaces can be treated with paint, varnish etc. to increase reflectance and alter color or/and expression. It is also the finish that determines the atmospheric properties of absorping moisture, where vapor diffusion open finishes are to prefer.

An LCA have also been conducted for the materials potentially added, and the additional material they each need for setup (see Ill. 119). Unlike the analyzes made for the structural elements, some of these needs to be changed at some point during their lifespan of 80 years. therefor another category have been added, the recurring embodied energy. From this LCA, it is found that gypsum and clay brick are the better options, but all the wooden materials aren't far from.

For the living area in the large unit, where the analyzes have been made, different material combinations have been tried, to see, if it still makes sense, to use the wooden structure, and what additional cladding could be used on all surfaces.

Combination A takes offset in a concrete structure, covered with gypsum on all surfaces except the floor

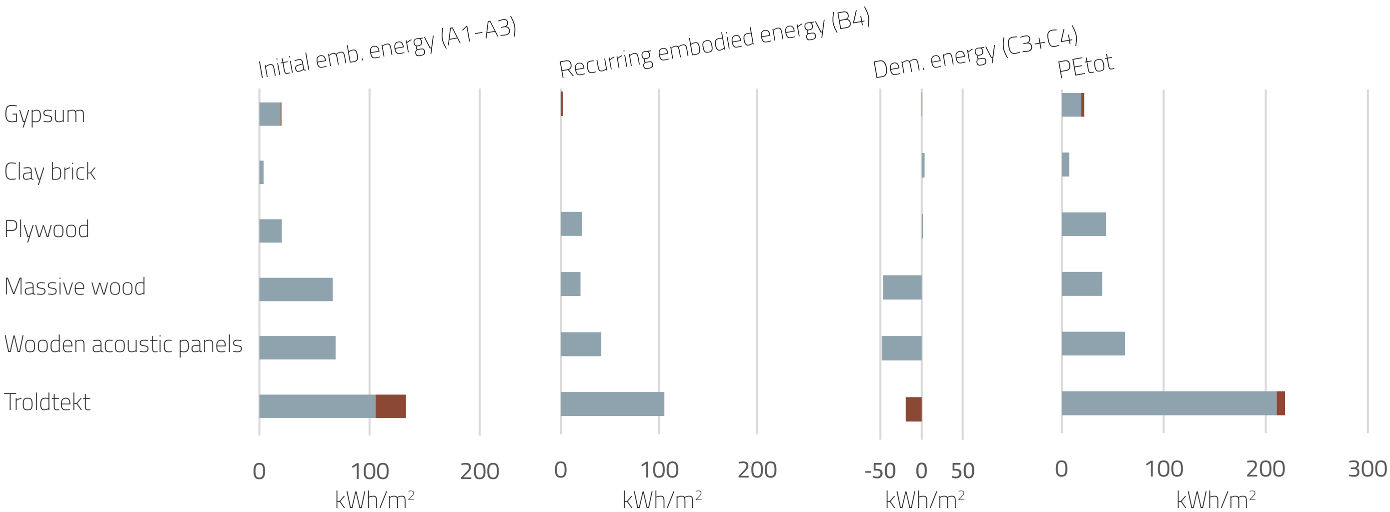
MATERIAL	THERMAL (HEAT CAPACITY)	ACOUSTIC (ABSORPTION COEFFICIENT [125;4000 HZ])	VISUAL (REFLECTANCE)
Concrete (exposed)	10 cm = 64 kWh/°C·m^2	0,02-0,05	0,25-0,45
Brick (exposed)	10 cm = 44 kWh/°C·m^2	0,02-0,05	0,25
Rammed earth (exposed)	10 cm = 89 kWh/°C·m^2	0,02-0,05	0,3-0,45
Gypsum with glass felt	2,5 cm = 6 kWh/°C·m^2	0,04-0,29	0,85
Clay brick	10 cm = 89 kWh/°C·m^2	0,02-0,05	0,05-0,15
Plywood	2 cm = 6 kWh/°C·m^2	0,06-0,14	0,3-0,45
Solid wood	2 cm = 4 kWh/°C·m^2	0,06-0,14	0,3-0,45
Wooden acoustic panels directly on the insulation	2,5x2,5 cm C/C 3 cm = 5 kWh/°C·m^2	0,43-1.0	0,3-0,45
Troldtekt on 25 x 100 mm lathing directly on the insulation	2,5 cm = Estimated around 3 kWh/°C·m^2	0,43-1.0	Unkown

(see Ill. 120) It obtains a high heat capacity for the room the reverberation time is unacceptable. It becomes very high due to the hard surfaces. Visually, it is light and unpersonal - like a blank canvas.

Combination B is a wooden structure closed off by wooden plates, a wooden floor and wooden acoustic panels in the ceiling (see Ill. 121). Having only darker materials on all surfaces takes a lot of light. This could be avoided by painting them over with a bright vapor diffusion open paint. The heat capacity is very low though, as no heavy materials are being used. An upside is the low reverberation time, where it performs the best This option seems more warm and embracing than option A.

Combination C is made mostly from brick covering all walls, rammed earth floor and Troldtekt panels on the ceiling (see Ill. 122). All these natural materials may come of as dirty and problematic to clean, but do have great properties. The heat capacity is high and the reverberation time is low, though this is mostly due to Troldtekt panels, that doesn't score very well in the energy calculations.

Combination D is an optimization of the three others, taking the great aspects of each ones into consideration. A wooden construction in the external surfaces and interior walls covered with white gypsum for better daylight, unit dividing walls of rammed earth for higher heat capacity, wooden floor on joists for warm feel, clean look and together with the wooden acoustic panels giving a low reverberation time (see Ill. 123 on page 78). Visually it looks honest and warm, but with some clean surfaces, where the residents can add personal touches.



Ill. 119. Primary energy in interior cladding materials

Ill. 120. Interior materials A: A concrete build, with gypsum on the surfaces and raw concrete floor.

Avg. reverberation time: 2,29 s
Total heat capacity: 10.522 kWh/°C

Ill. 121. Interior materials B: A wooden structure, with wooden acoustic panels on the ceiling and hardwood surfaces.

Avg. reverberation time: 0,45 s
Total heat capacity: 1.082 kWh/°C

Ill. 122. Interior materials C: Brick as a loadbearing structure that covers all walls. Floor of rammed earth and Troldtekt in the ceiling.

Avg. reverberation time: 0,55 s
Total heat capacity: 7.929 kWh/°C

Ill. 123. Interior materials D: Optimization. Unit dividing walls of rammed earth and other walls in gypsum directly on insulation. The ceiling with wooden acoustic panels and a parquet floor on joists.

Avg. reverberation time: 0,57 s
Total heat capacity: 6.557 kWh/°C

EXTERIOR CLADDING

To determine the exterior cladding, the structural material again plays a big role. Using either brick or concrete, an exterior would already be present. But as wood have be found to be the better choise energy-wise and combined with the internal cladding as well, the structure needs further protection from the weather. Using the knowledge of the previous LCA, no more were found necessary. As the exterior cladding also depends on architectural expression, visualizations have been made, to determine the expression of the whole neighborhood, while standing in the street. The concrete facade is found monotonous and dark and does not seem like a pleasant place to be. The facades in brick are nice and gives a vivid and sturdy surface and it doesn't require any maintenance. The yellow brick is lighter and may help reflect the light a little better. The wooden facade also offers some life and can be done in many variation. It also offers a small sense of personality, as it can be treated differently and in that way help create variations as well as offer the residents som orientation, moving around the site.


Ill. 124. Exterior materials A: Concrete


Ill. 125. Exterior materials B: Brick - Red


Ill. 126. Exterior materials C: Brick - Yellow


Ill. 127. Exterior materials D: Wood - Horisontal


Ill. 128. Exterior materials E: Wood - Vertical

WINDOW PLACEMENT

Figuring out the placement of windows need to be determined by many different factors both when it comes to design and when aproaching internal environment. This mainly includes the following:

- Visual - View: Investigating the visual impact of the windows and their placements and ensuring a balance between outlook and direct look in.
- Visual - Daylight: Adding windows and working with placement to provide sufficient daylight.
- Thermal: Arranging windows for optimal solar gains.
- Venting: Including window placement in venting strategy for natural ventilation.

The window placement is decided after the initial shape of each unit. Some parameters were already known prior to placing the windows, e.g. that the ventilations strategy has been determined to be thermal buoyancy. To get an understanding of how much glazing area should be in each direction to optimize solar gains, hand calculations have been made. These help estimate the temperature in a specific room, during the summer and winter, with different amounts of glazing. As all tests have been made with a glazing area above 10% of the floor area, no daylight analyzes have been found necessary at this level (Trafik- Bygge- og Boligstyrelsen, 2018, §379 stk. 2).

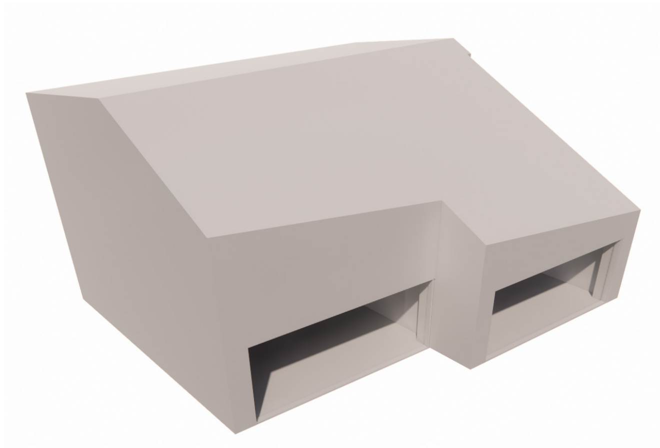
To determine the glazing area, the day average was calculated for the living area with five different window layouts for both a small and a big unit (see Ill. 130-Ill. 134). The results of the initial calculations showed a difference between the southern faced facade and the east/west faced facades. The east and west show almost identical result in all tests. The analyzis was made with focus on keeping a low temperature in the summer and achieving a high temperature during winter.

The results have only small variations but show a general tendency of smaller amounts of glazing having the best effect. For further Day Average values see "Appendix 8: Day Average". As the size of the openings also affect the other mentioned parameters, they need to be investigated further. Using BSim, the natural ventilation can be measured automatically on the basis of window size and placement while also measuring the temperature throughout the day. The views are based on placement principles as well as whether the chosen solar shading can provide the balance between privacy and views outwards.

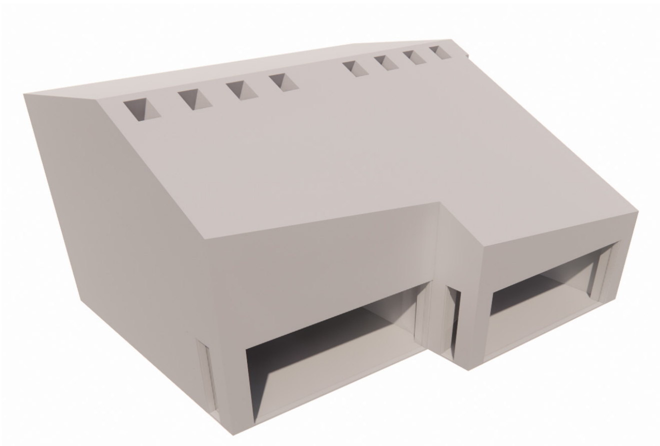
AVG. OPERATIONAL TEMPERATURE

[°C]	South facing living area		East/West facing living area	
	Unit A	Unit B	Unit A	Unit B
A - 10 m^2 of glazing	22,4 (15,6)	23 (14,6)	22,4 (15,4)	23 (14,4)
B - 12,2 m^2 of glazing	22,4 (15,4)	23 (14,4)	22,4 (15,2)	23 (14,2)
C - 10 m^2 of glazing	22,3 (15,5)	22,9 (14,4)	22,3 (15,4)	22,9 (14,3)
D - 11 m^2 of glazing	22,3 (15,4)	22,9 (14,4)	22,3 (15,3)	22,9 (14,2)
E - 7,5 m^2 of glazing	22,3 (15,6)	22,8 (14,6)	22,3 (15,5)	22,9 (14,5)

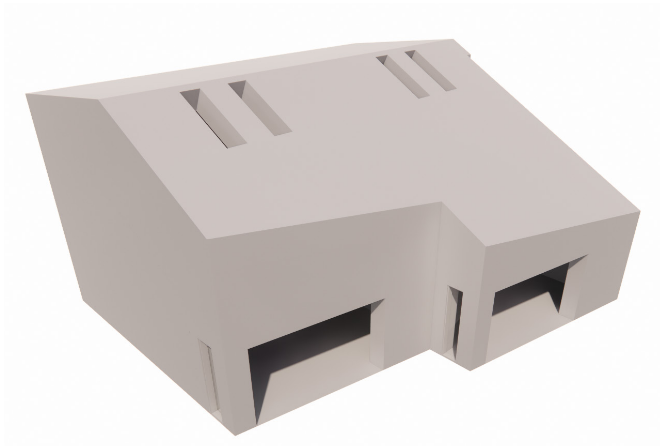
Ill. 129. Day average temperature



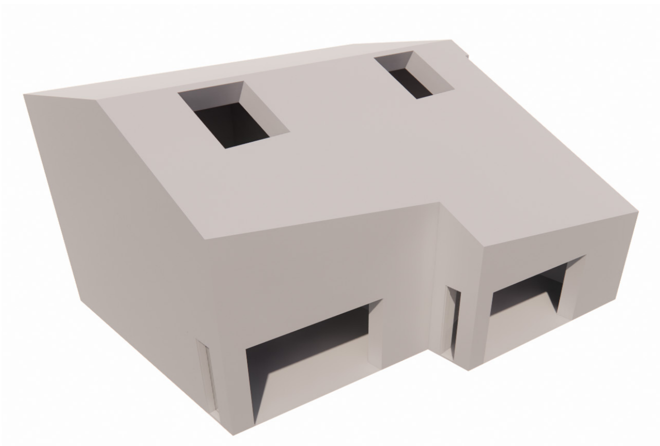
Ill. 130. A - Glazing area 32/24% of floor area



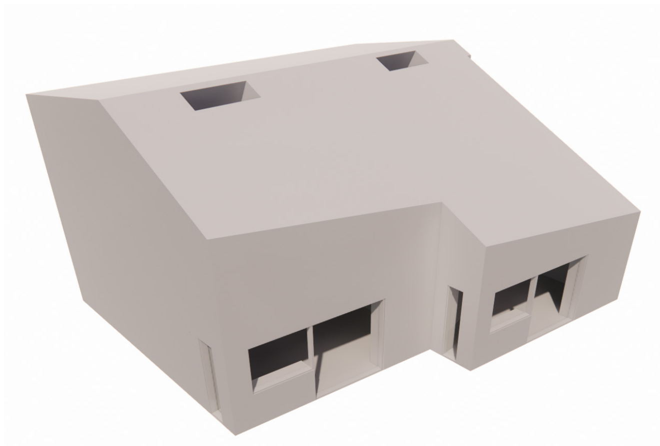
Ill. 131. B - Glazing area 38/29% of floor area



Ill. 132. C - Glazing area 31/24% of floor area



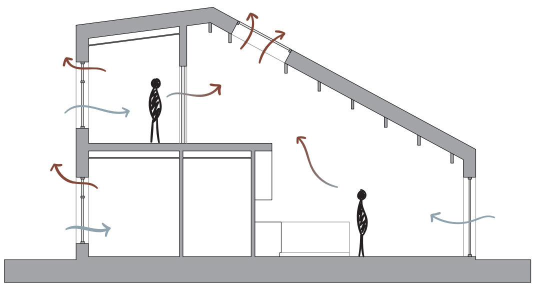
Ill. 133. D - Glazing area 34/26% of floor area



Ill. 134. E - Glazing area 23/18% of floor area

VENTILATION

At all times, the idea of working with hybrid ventilation has guided the design and layout of the units. Having a living space with a higher ceiling and openings in the top, serves as a way of enforcing thermal buoyance, as warmer air is lighter and therefor moves upwards (see Ill. 135). This is especially usefull in the summer, where it works together with the thermal capacity to ensure a more stable temperature. During the day, the heat will be absorbed into the construction, then relieved again during the night, where it can be ejected out the top windows.

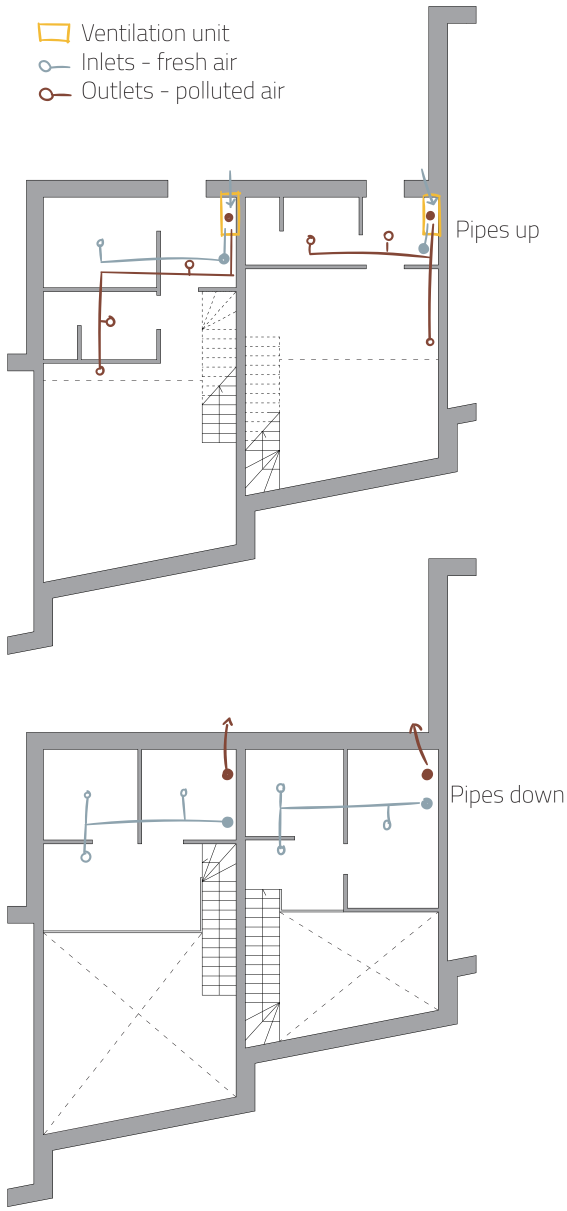


Ill. 135. Natural ventilation principles.

The smaller rooms may not always be able to be connected to the top windows, if doors are closed. Thus, to ensure the posibility of natural ventilation there, single sided priciples have been implemented. By applying two openings, the ventilation becomes more effective, as well as it provides several venting posibilities, depending on user needs.

Due to low temperatures in Denmark and regulations demanding a constant minimum air flow, natural ventilation cannot be used as the only strategy. Too much energy would exit the dwellings with the air and in this case increasing the heating demand from 7 kWh/m^2 to 23,2 kWh/m^2. Instead, hybrid ventilation can be used as an overall strategy, using the best of both ways. The mechanical ventilation strategy is based on pipes running in existing closets and under suspended ceilings. This happens in one half of the unit, where the rooms are located, leaving an open living space with visible construction. the inlet here is located on a wall on the repos, where the exhaust is located in the kitchen hood (see Ill. 136).

The air intake should be in the facade, close to the ventilation unit. The outlet should be located away from the intake to prevent polluting the fresh air. This can instead happen higher on the facade or on the roof, depending on the specific piping options.



Ill. 136. Mechanical ventilation principles.

SOLAR SHADING

Testing the building in early Be18 and the southern facing living area in BSim, overall results were okay, but problems with overheating occured. This was expected as no passive shading have specifically been incorporated into the building shape. Both softwares were used to gain knowledge of the severety and if the challenge would be too great for solar shading to handle. The two programs does not always agree when the values are acceptable, which is why both were used. This is likely due to the difference in method used for calculating, where Be18 calculates pr. day and BSim pr. hour. The results from BSim can therefor also become more precise, but as it has many more parameter to adjust, it also have a bigger risk of not being correct.

Different types of solar shading have been considered and as it shows in the table below, so have the operating control. Be18 doesn't tell apart different types of shading but only concerns about the shading coefficient. It does however take different passive shadings into considerations, as typing in angles of all shading elements in different orientations. Using BSim, different types of shading devices have been specified to also help calculate daylight, but it is still the shading coefficient that determined the most regarding operational temperature.

Having a light piece of curtain on every window does not help enough, but it does make a small difference. A factor, that higtens the coefficient can be the placement, where shutters can be located on the external face of the southern windows. This proves more effective, but not enough. Another aspect is if they are made automatically controled, where the results show acceptable values. This takes away the user control, and neglects the function of the doors. Instead, manually controlled shutters can be complemented by automatic internal shading on the skylights, where they help a lot.

SHADING TYPE	SHADING COEFFICIENT	ENERGY (BE18)	HOURS (BSIM)	
Combinations	0-1 0= complete shading 1=No shading (Andersen, Heiselberg and Aggerholm, 2002)	Energy used to remove excess heat [kWh/m^2]	Hours > 27° pr. year Should be below 100h	Hours > 28° pr. year Should be below 25h
No shading	1	2,4	107	54
Light curtains on all windows - Manually	(1+0,8)/2=0,9	2,1	86	41
External shutters on southern windows - Manually	(1+0,15)/2=0,6	2	89	46
External shutters on southern windows - Automatic	0,15	0	44	13
External shutters on southern windows - Manually + Internal curtains on skylights - Automatic	(1+0,15)/2=0,6 0,75	0	44	15

PRESENTATION

GREEN MEADOW

Welcome to Green Meadow, the sustainable choice of living for the new family. With the site, located just 20 km north of Aarhus between open fields and the meandering Skæring Bæk, nature is right outside, while the city is still close. Green Meadow cosists of 80 new homes ranging between 73 and 91 m^2 with 2-3 bedrooms and the site also includes 3 large common houses free to use for all resident. Besides this, Green Meadow is a safe environment for kids, in the grand exterior that also offers a, pond for fishing, playgrounds and pathways all around for long walks in the wild nature.

Ill. 137. Masterplan 1:1000

Site area: 27.900 m²

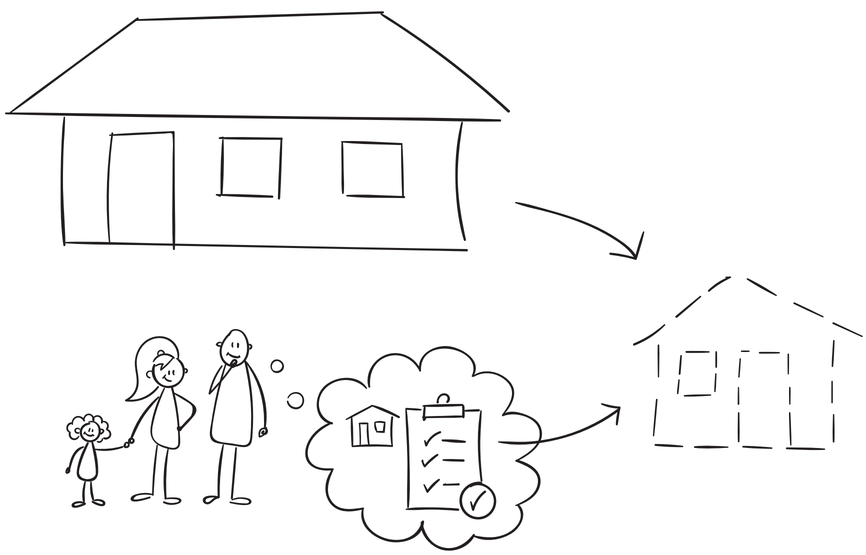
Unit A: 73-76 m² x40
Unit B: 88-91 m² x40

Total residential area: 6680 m²
Total common house area: 535 m²

Total built area: 7.215 m²

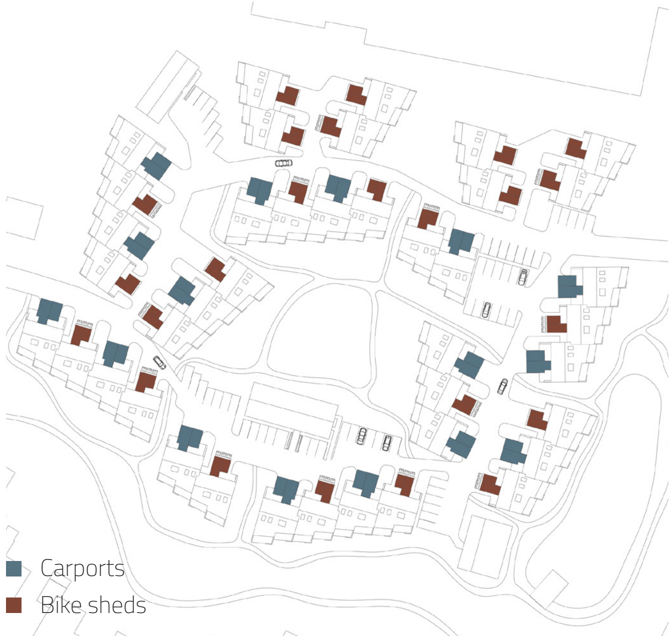
Plot ratio: 25,9 %

The project of Green Meadow have investigated the issues of building large private homes and spending energy on materials as well as the operation of it. It has uncovered the qualities people seek in the larger dwellings and attempted to apply these in smaller more environmentally sustainable dwelling. The final masterplan arranges the buildings scattered around the site with equality in mind. Every unit has a private entrance and direct acces to nature from their private terrace. The entire settlements layout is heavily influenced by plants and nature growing wilder than usually to make the area need less care and have a greater biodiversity. Along the edge of the site larger trees are kept, ensuring the sites preexisting nature. Furthermore, the roads around the site is made with a focus on slowing down the speed of cars with gravel pavement, that also provides a feeling of being in nature.



Ill. 138. Reducing the size while maintaining the qualities of the typical detached single family home

Ill. 139. Roads and pathways on site. The roads are one-way, creating a more predictable and safe flow.



Ill. 140. Parking options. 32 units have a private parking space that also accommodates electrical vehicals. 48 units have designated bike parking.

Ill. 141. Public zones. Almost all exterior is common for everyone. The private terraces create a buffer zone between the private interior and the public exterior.

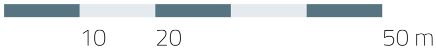
Ill. 142. The site offers many wonders, and houses located in different areas can enjoy different views and access directly from their living room.

Ill. 143. In the center of the site a natural playground with old logs is made to provide outside activities for kids and playful souls. The long grass invites residents to investigate or relax as they explore the wonders of Green Meadow.

Ill. 144. Site section plan, 1:2.000


Ill. 146. Site section AA 1:1.000


Ill. 145. Site section BB 1:1.000



Ill. 148. The roads on the site is made from gravel and works as main access for all dwellings. Each units is equipped with either a carport or an open shed for bicycles, baby strollers etc.. Further more, small depots provides every home with additional storage.

Ill. 147. Towards the larger road, Greenåvej, an earthwork and a local pond lies and functions as a transfer zone. Here one of three common houses is also located. The existing pond is kept on the site as a sustainable urban drainage system in combination with the already existing stream.

Ill. 149. Facade - North1:100

Ill. 150. Facade - South1:100


1
2
5 m

Ill. 151. Facade - East:100

Ill. 152. Facade - West:100


1
2
5 m

COMMON HOUSES

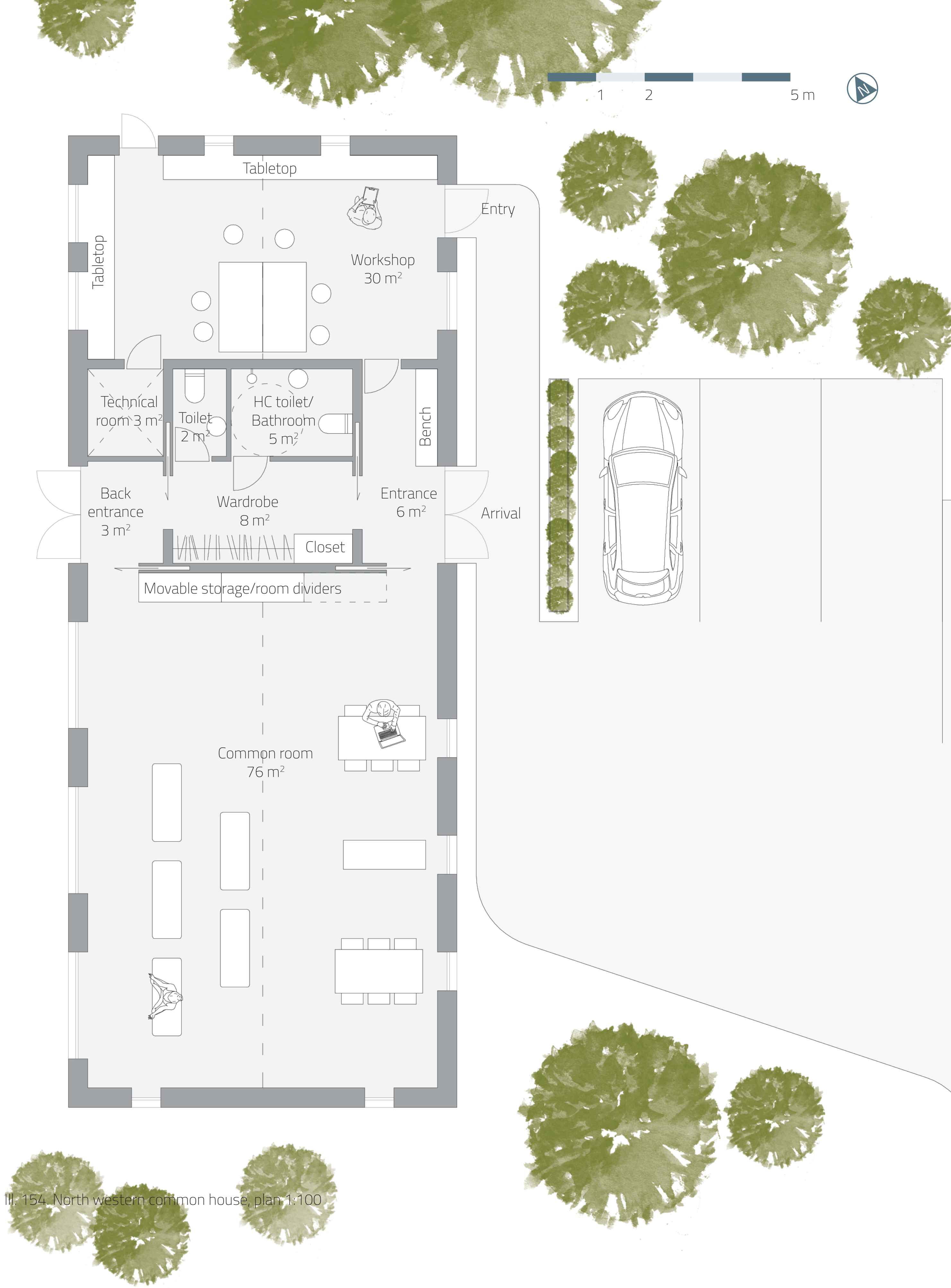
Around the site three common houses are located. They provide additional area for the residents, when the need for more space occurs. The common houses are all design with pitched roofs with lamellas in a darker color than the rest of the settlement. This makes them easier to navigate after, while they still fit in with the dwelling. The three buildings each provides different options for acitivties and number of residents.

Ill. 153. Location of north western common house

NORTH WESTERN COMMON HOUSE

Common house:	North west
Rooms:	2
Toilets:	2
Gross area:	160 m^2
Workshop area:	30 m^2

In the upper corner, with a view over the open fields, the first common room, with more practical functions, is placed. This common house is fitted for smaller groups or individuals and offers the possibility of working with different hobbies. It provides a workshop area for more practical and dirty work but also a larger and flexible room with moveable furniture to create smaller zones within. This supply the options for several groups being in the room at the same time, without too much disturbance. When all cabinets are placed along the wall, it opens up the room for more space consuming activities like yoga, where the view also helps provide focus.



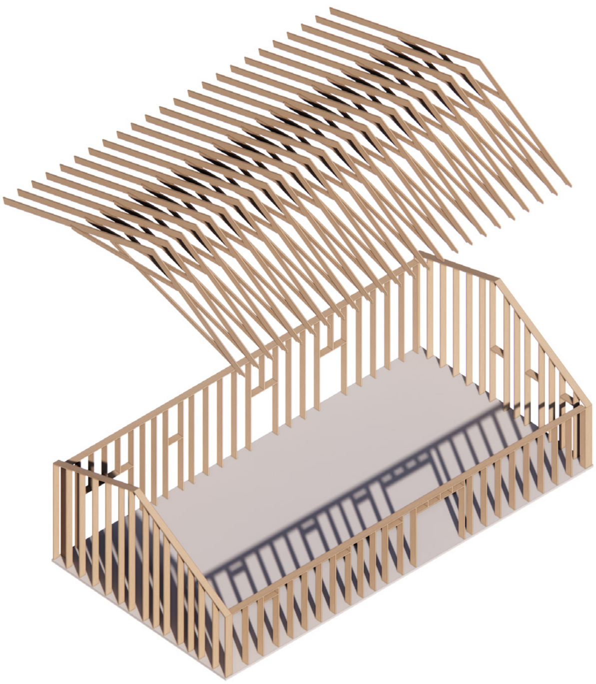
Ill. 154. North western common house, plan 1:100

CENTRAL COMMON HOUSE

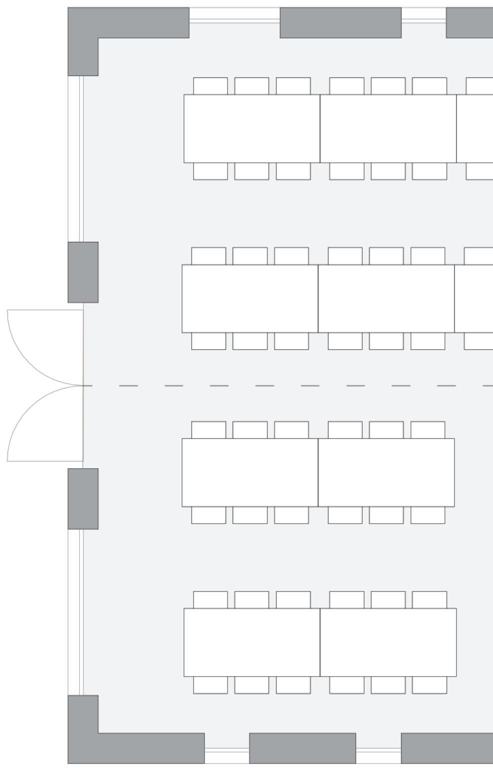
Common house:	Central
Rooms:	1
Compl. rooms:	2
Toliets:	4
Gross area:	250 m^2

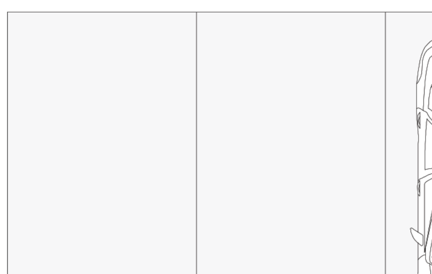
In the center of the site the largest common house is placed. With its 250 m^2 and, it is perfect for larger gatherings such as parties or arrangements with many participants. The house is also fitted with two small rooms for guests to stay over night, either in connection to an arrangement in the common house or if people are having guest from far away in their own homes. The facilities also includes a kitchen with openable dividers to either open it up or close it off, depending on the function.

Ill. 156. Location of central common house



Ill. 155. Construction principle of common houses





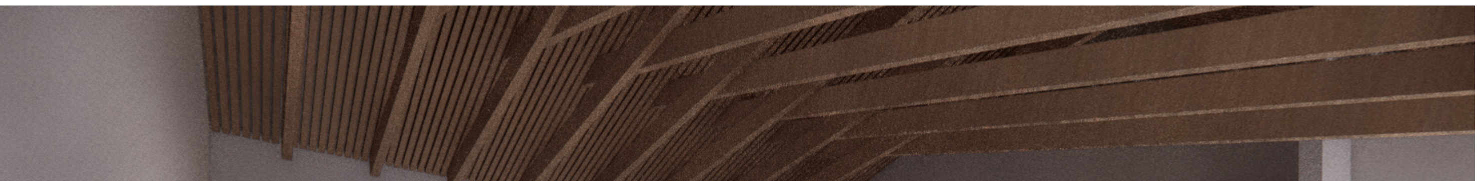
Ill. 157. Central common house, plan 1:100

SOUTH EASTERN COMMON HOUSE

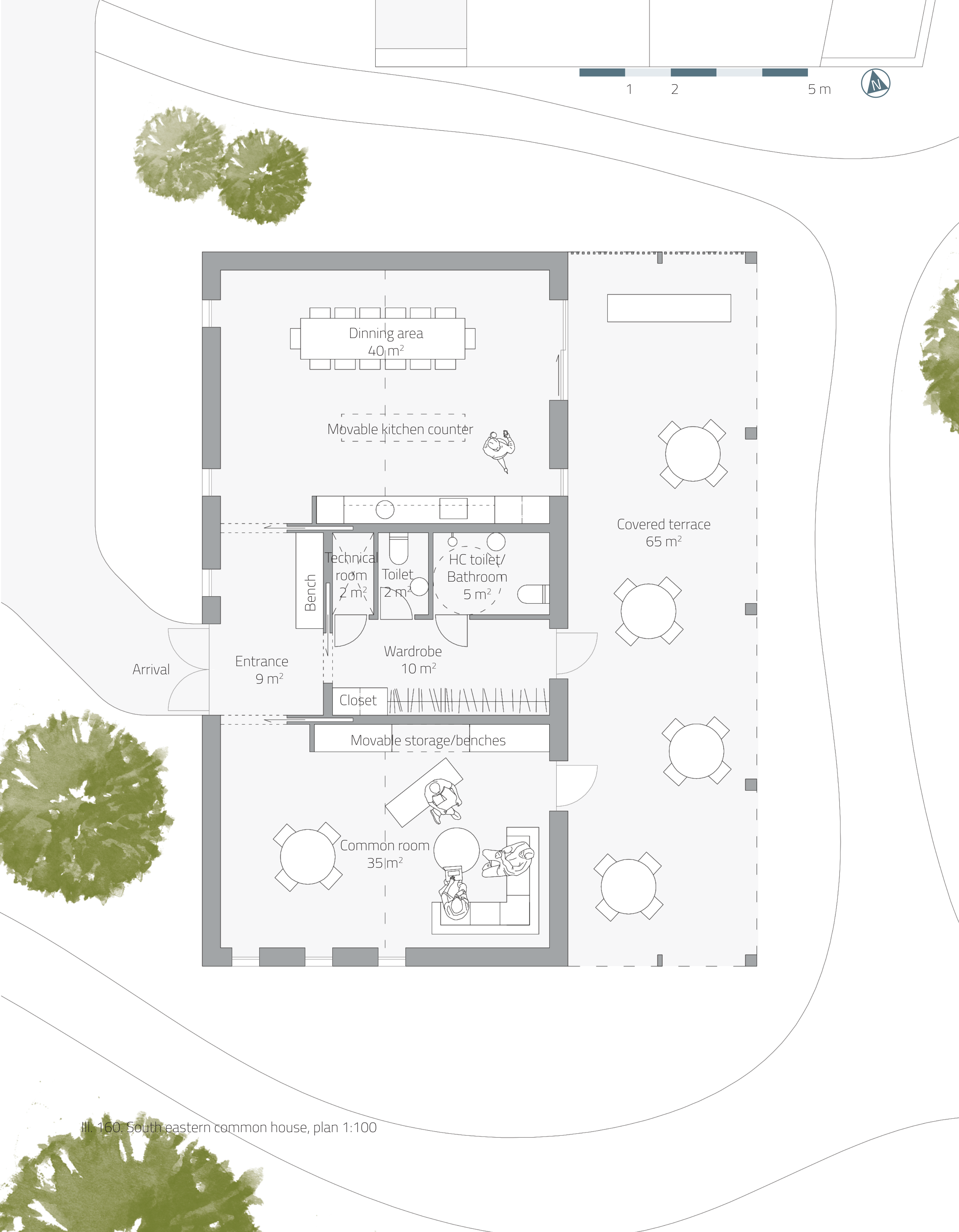
Common house:	South east
Rooms:	2
Toilets:	2
Gross area:	125 m^2
Covered terrace:	65 m^2

The third and last common house is located next to the pond and is equipped with a common dining area that extends out onto a large patio facing the water. In the middle of the room a kitchen island is located on wheels to move it around for use elsewhere. The southern end of the common house has a more lounge like setting. It provides the perfect setting for movie night and hanging out with friends. Moveable storage benches opts for a variety of arrangements and help store stuff like games and blankets, when not in use.

Ill. 158. Location of south eastern common house



Ill. 159. Dinning area in the common house. The kitchen island can be moved oround, including outside to work as exstra table space when grilling or as a buffet, when serving many people.

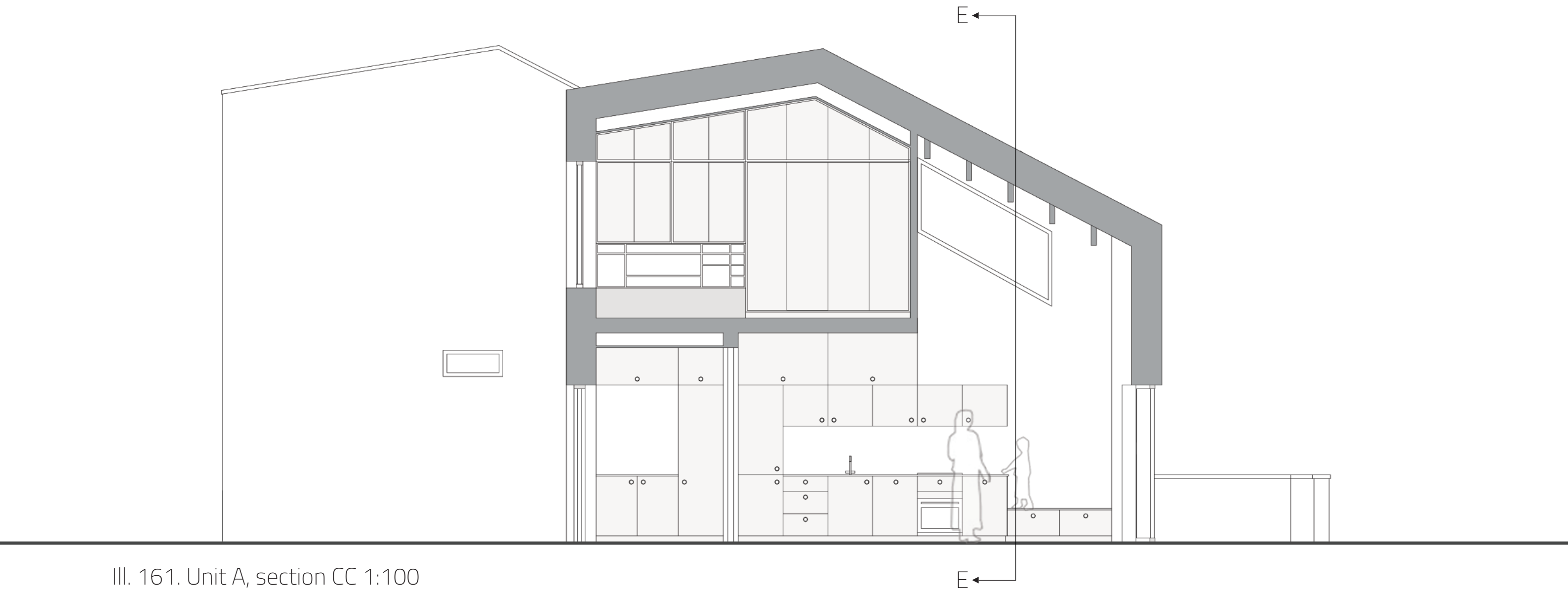


Ill. 160. South eastern common house, plan 1:100

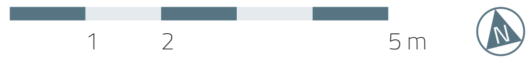
UNIT A

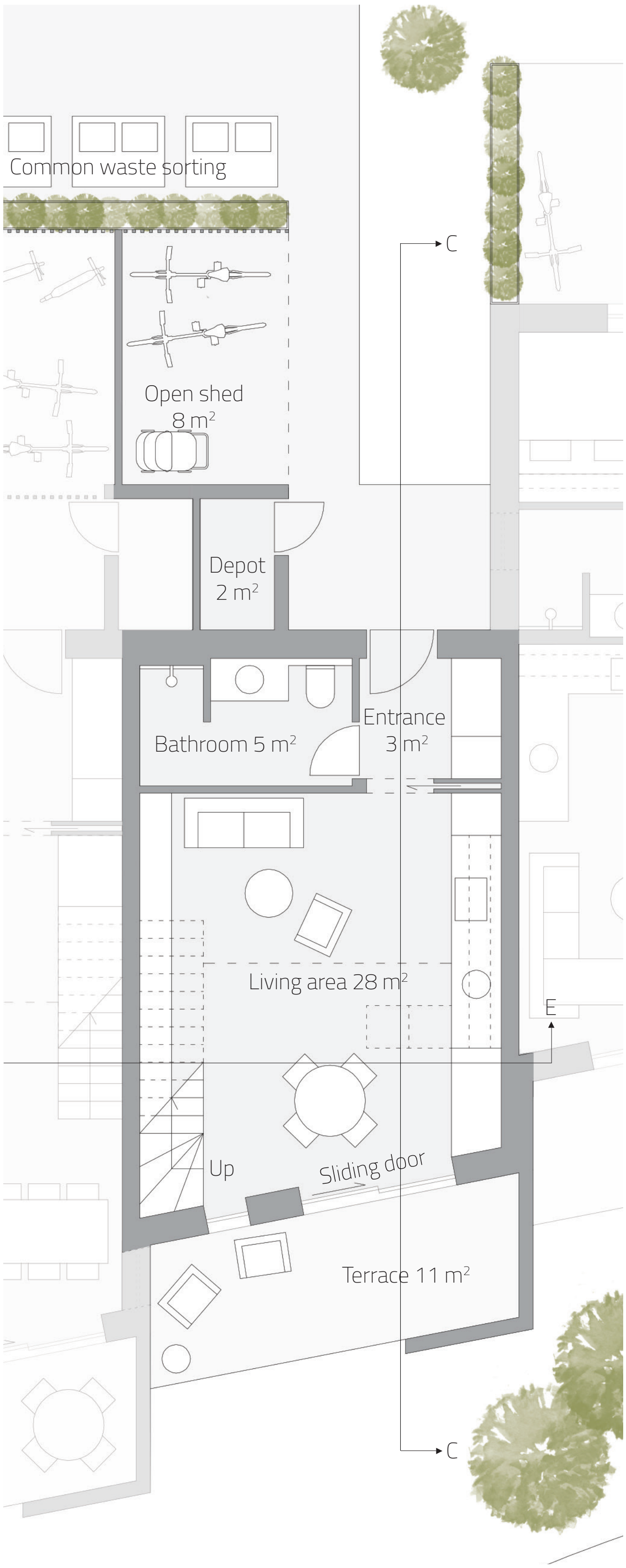
Unit A is the smaller unit around 73 m². It is entered in a functional utility room, with plenty of storage, where all appliances can be closed away. From here, an open living area is accessed with a flexible kitchen sollution to maximize the tabletop area when needed, and minimize at other times. Built-in furniture ensures the best use of all squaremeter and adds storage for all situations. Moving further, direct access to a private terrace invites the nature all the way in and serves as the perfect setting for a lunch with the family. The common garden work as a social meeting point and the wild growth is without maintenance for the residents. Upstairs, two bedrooms are accessed from a small repos, that creates visual contact with the living area and works as a functional buffer for the smaller room. This can be opened up with a sliding door, making the room feel bigger and adding floor space to play on. The unit furthermore includes a spacious bathroom with room for the entire family.

Unit type:	A
Bedrooms:	2
Bathrooms:	1
Gross area (common):	73-76 m² + (6 m²)
Terrace:	11 m²
Depot:	2 m²
Bike shed / Carport:	9 m² / 17 m²
Total number of units:	40

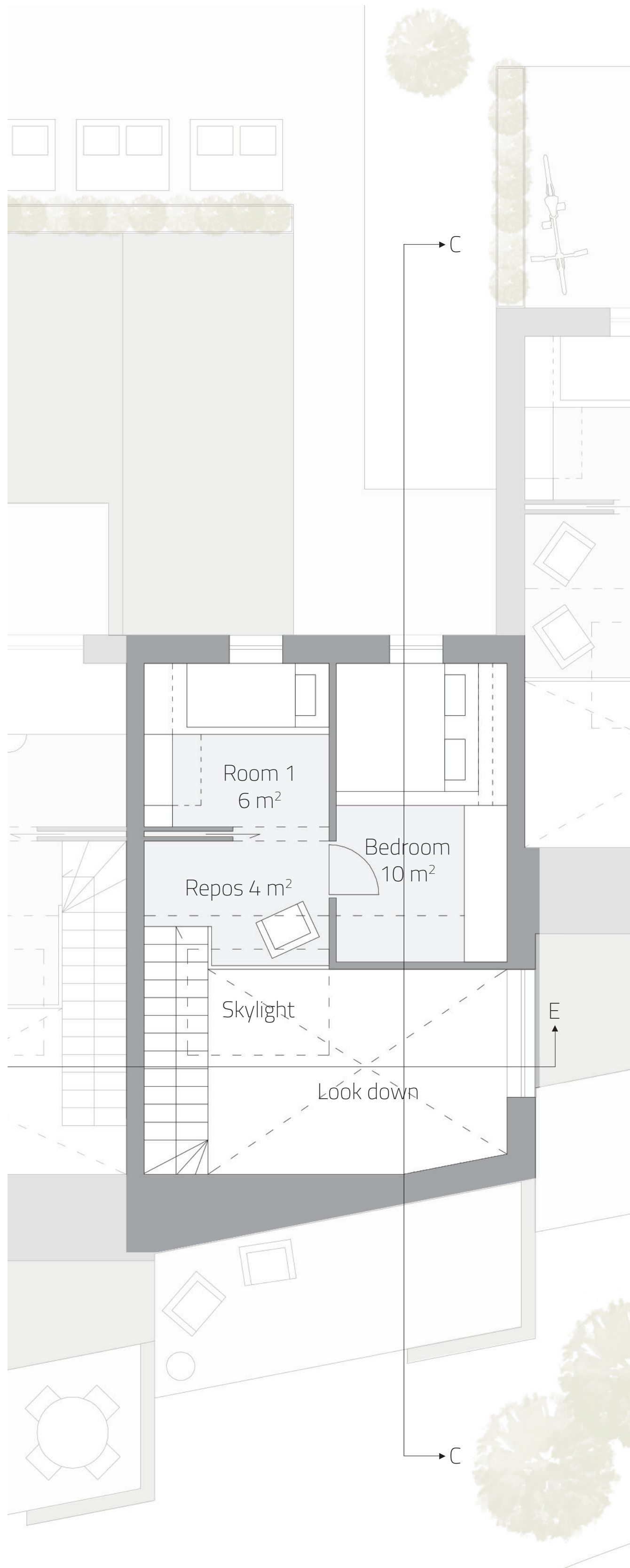


Ill. 161. Unit A, section CC 1:100





Ill. 162. Unit A, plan 1:100 - Ground floor 44-46 m^2



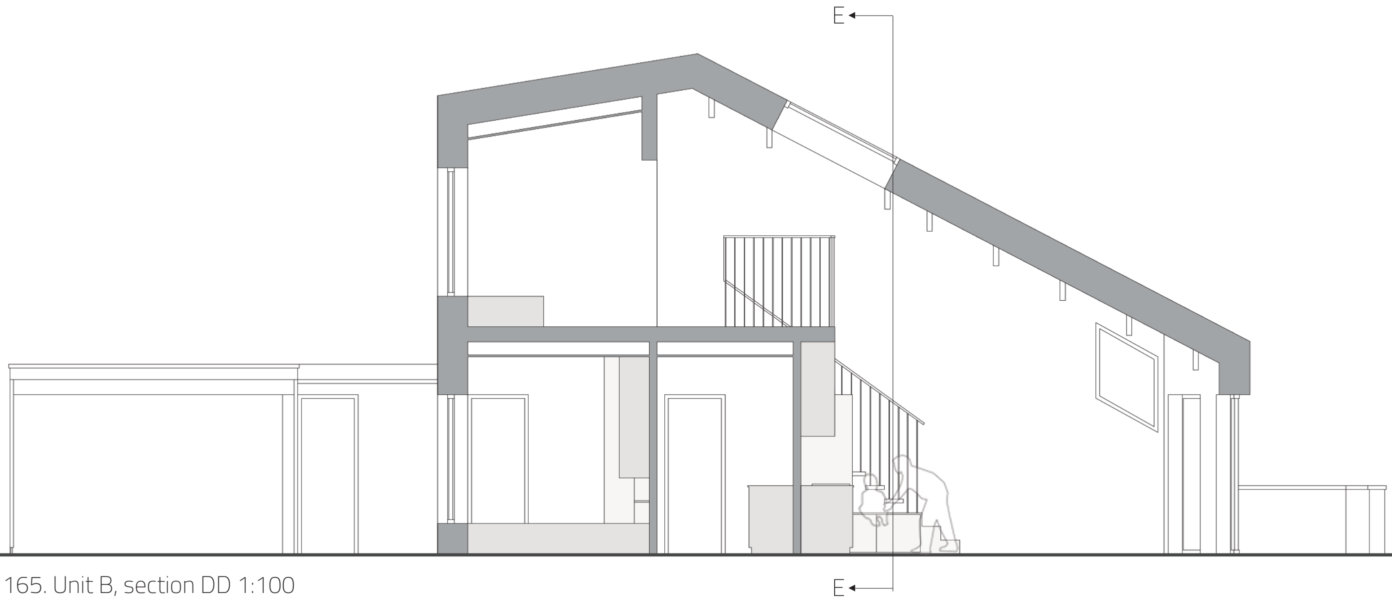
Ill. 163. Unit A, plan 1:100 - First floor 29-30 m^2

Ill. 164. Unit A, Living area. The built-in furnitue under the stairs can be used as a seating area, saving floor space from more furniture

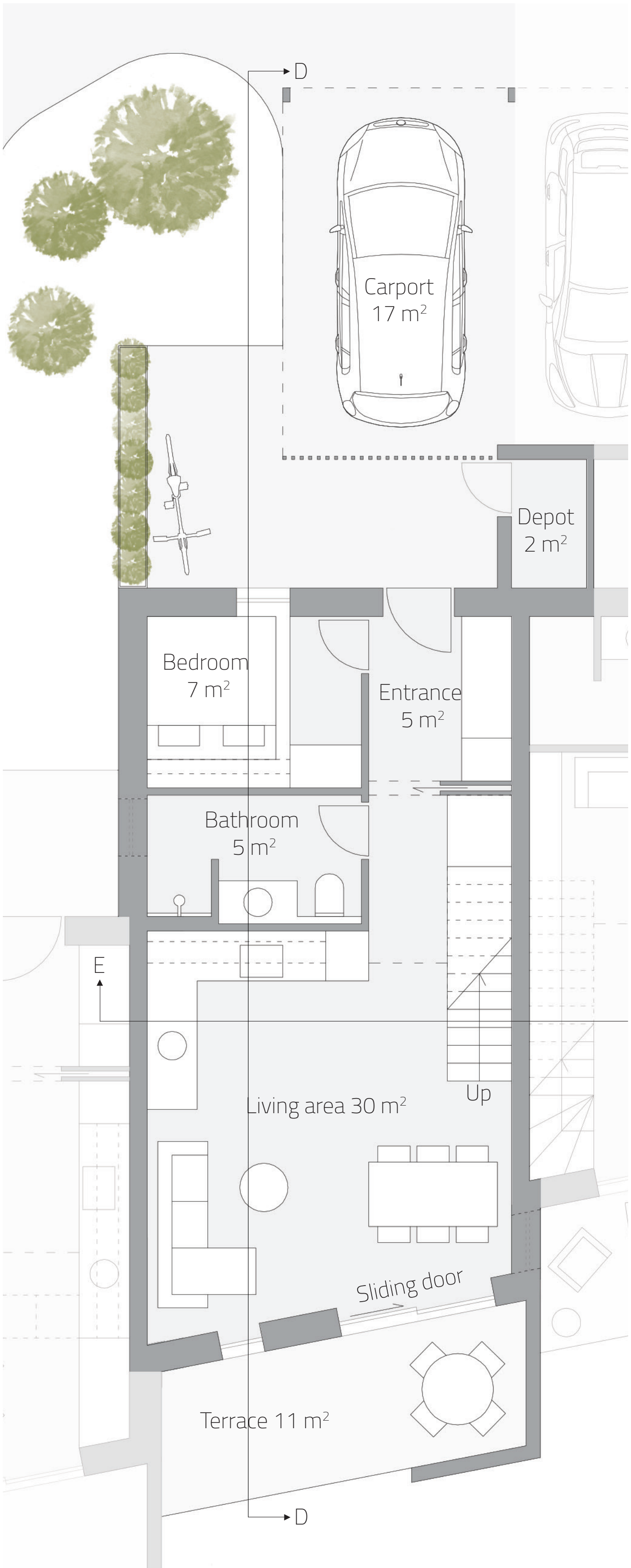
UNIT B

The larger option, unit B, have 3 bedrooms and adds up to around 88 m^2. It is entered in a functional utility room, with plenty of storage, where all appliances can be closed away. Here the first bedroom is also located, providing the possibility of seperating the sleeping areas between kids and adults. From the entrance, the voluminous living area is accessed introducing a large kitchen, maximizing all space for additional storage. Built-in furniture ensures the best use of all squaremeter and adds storage where needed. Moving further, direct access to a private terrace invites the nature all the way in and gives parents better views of the exterior, when the kids are out playing. The common garden work as a social meeting point and the wild growth is without maintenance for the residents. Upstairs, two bedrooms are accessed from a large repos, that creates visual contact with the living area and works as a functional buffer. The rooms can open up with a sliding doors, making them feel bigger and adding floor space to play on. The repos also adds space for a home office, with a nice view to the sky. The unit furthermore includes a spacious bathroom with room for the entire family.

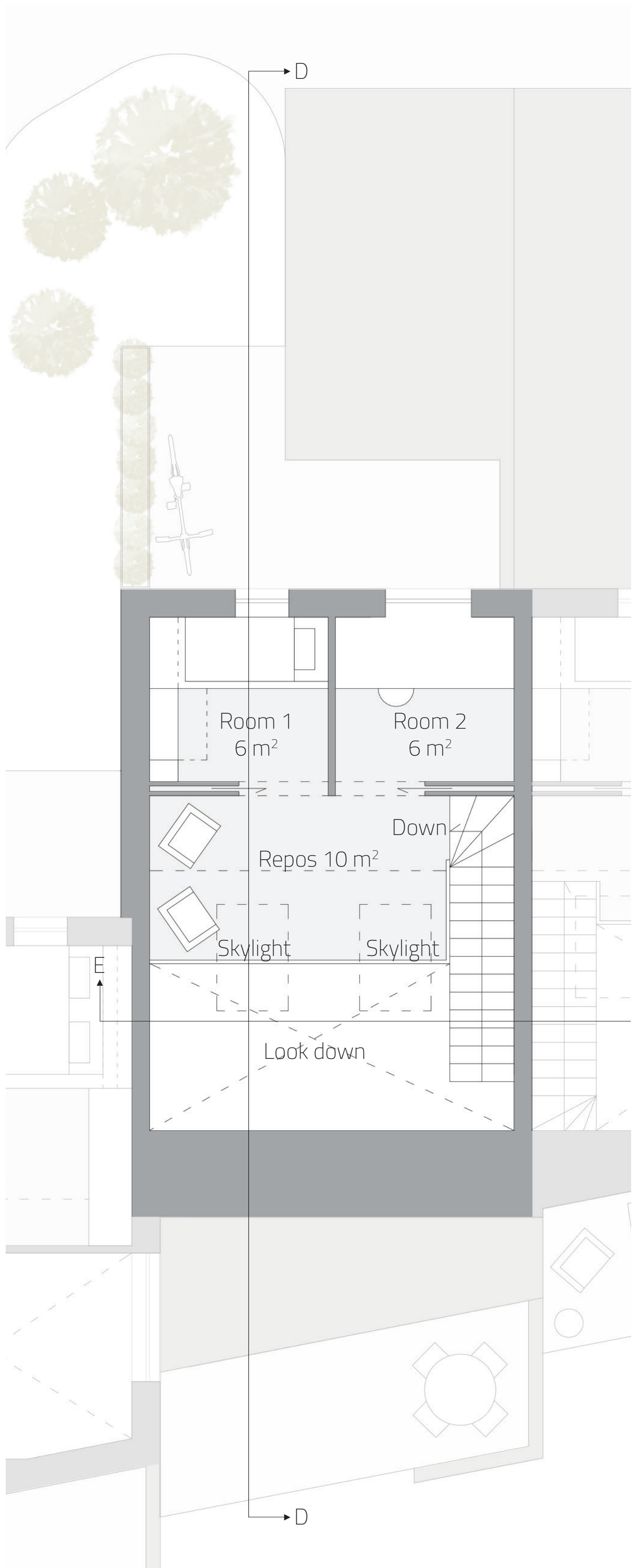
Unit type:	B
Bedrooms:	3
Bathrooms:	1
Gross area (common):	88-91 m^2 (+ 7 m^2)
Terrace:	11 m^2
Depot:	2 m^2
Bike shed / Carport:	9 m^2 / 17 m^2
Total number of units:	40



Ill. 165. Unit B, section DD 1:100



Ill. 166. Unit B, plan 1:100 - Ground floor

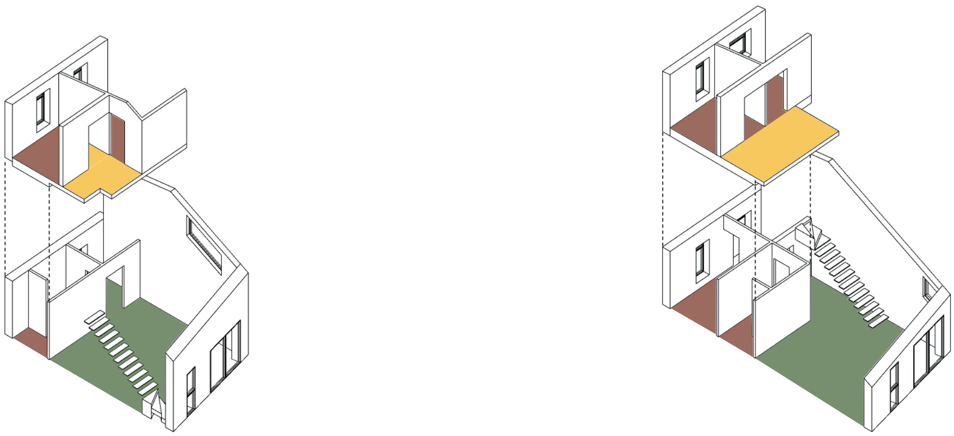


Ill. 167. Unit B, plan 1:100 - First floor

Ill. 168. Unit B, Living area. The visual connection between the storeys ties the home together.

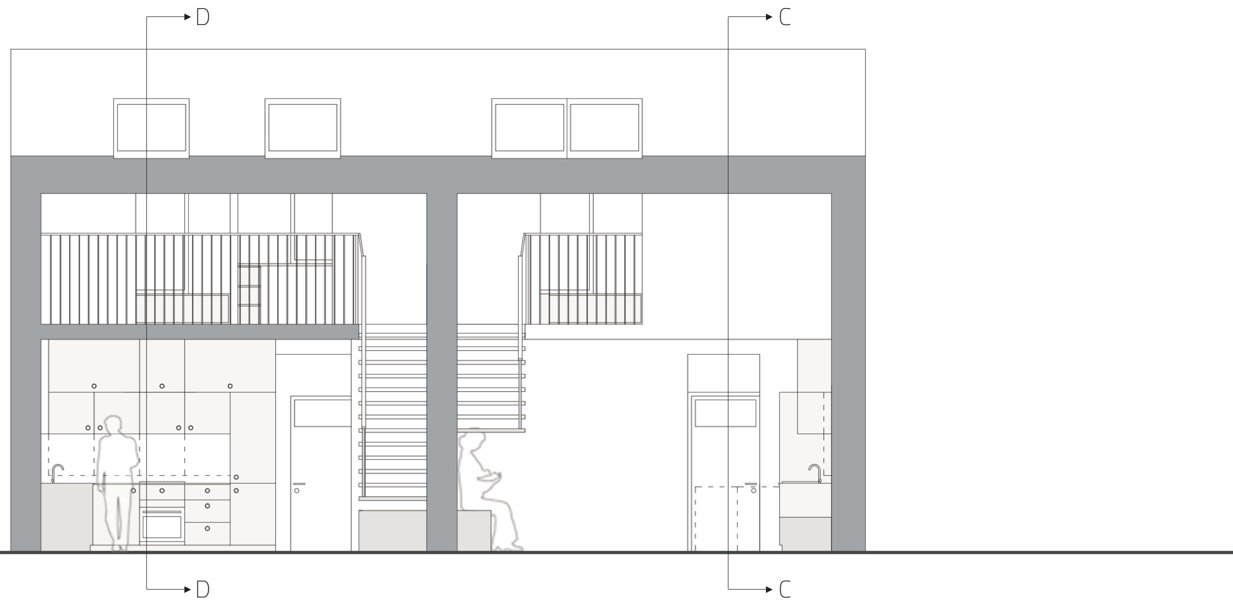
INTERIOR SOLUTIONS

Inside, many choises have been made to accommodate the qualities seen in the detached single family home. Though both units are arranged on two storeys, all main functions are located on the ground floor, making it unnecessary to move upstairs as a guest or for some during the day. The moving up and down stairs work as a tranfer zone, creating a more private area upstairs, unbothered by others at home. As the main focus have been to minimize the floor space, it have also demanded focus on optimizing everything else. Where larger homes may have hallways guiding towards every room, all flow space can be used for other activities than just moving, thus eliminating hallways completely. Plenty of storage have been added, and the ceiling height is being completely utilized over all cabinets for even more storage. The built-in furniture also secures additional storage as well as creating smaller niches within the living space, that can be used for numerous thing, like sitting or playing. The rooms have been minimized in order to maximize the space in the living area, providing the option for personalizing the house with own furniture. The rooms have therefor been designed more detailed to ensure a good use of each of them.



■ Private ■ Semi-private ■ Common

Ill. 169. The apartments natural is separated into zones of different privacy ranging from private in the bedrooms to common in the living room and entrance. The repos is a zone in between which is a semi private zone.



Ill. 170. Section EE 1:100. The repos creates a visual and autitorial contacts between the two storeys. Space above regular kitchen top cabinets is also used for additional storage.

1 2 5 m

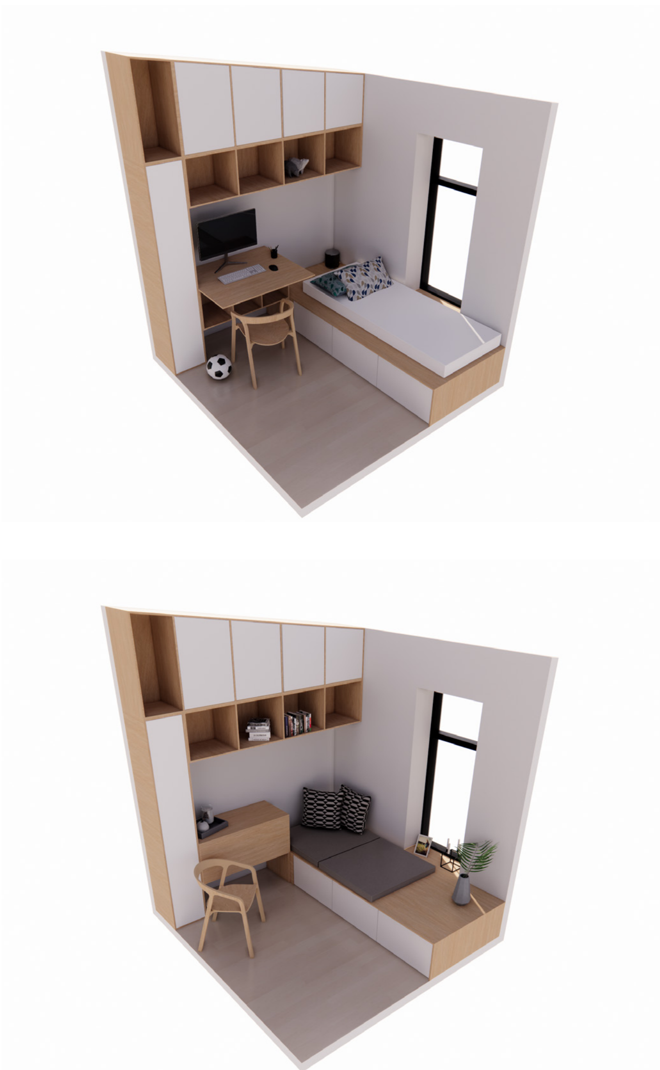
Ill. 172. Bedroom

BEDROOM

The bedroom is made with the most fixed design and is ment to act as the main bedroom for parents, as it is the only one, that can fit a bed for two. Below the bed, drawers can be opened for emidiate storage but the large dept also opts for a door placed below the mattrass for the storage of rarely used things. Above the bed, less deep cabinets are located and next to, regular fittet cabinets ensures storage for everyday clothes. In unit B, additional storage can be found under the stairs, where in unit A, a larger room and ceiling height gives more storage within the room.

ROOM 1

The layout of room 1 can be found in both unit A and B. This room ensure plenty of storage for both clothes and toys, as it also includes drawers under the bed as well as a storage system build up on the wall utilizing the entire ceiling height. The height of the bed continues into the window sill, functioning as a bed side table, with a great view. A small desk can also be unfolded and have the room used as an office, if not a childrens room. This adds the flexibility aspect over time, as the room can be used differently, depending on current needs.



Ill. 171. Room 1

ROOM 2

The second smaller room is made as a multifunctional experience, again with flexible solution to accomodate for the different stages of life. The built-in furniture gives the possibility to use the wooden desk as either a desktop, an elevated bed or a working station. Under the wooden plate, cabinets can relocate, adding additional storage behinde them, or creating more leg room underneath the table top. The cabinets can also be stacked next up the wall to act as a more regular cabinet setup. The sliding staircase allowing for access to the top of the desk, is made with integrated drawers to fully use the construction and provide for additional storage. Using the stairs, the platform can be used as a bed, even for younger children. This room layout can only be found in unit B, but funtions great for different needs.

Ill. 173. Room 2

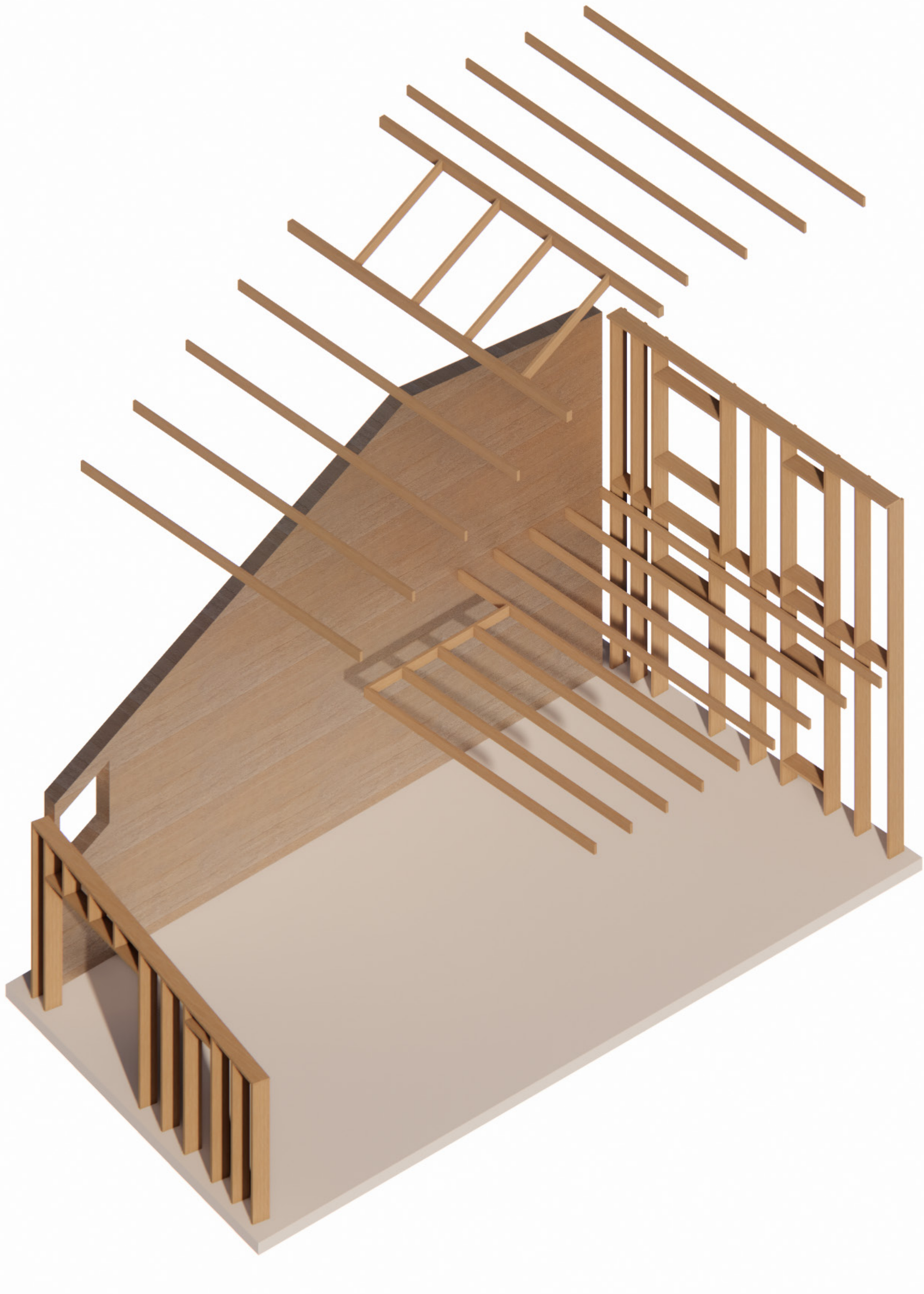
ENTRANCE AND UTILITY ROOM

Most people appreciate the possibility of dealing with dirty clothes from home. Here, the entrance converts to a utility room when needed, and back at all other times. Sliding cabinet doors makes it easy to quickly acces and hide the appliances, making it a more formal space when inviting guests. In the top cabinet the ventilation unit is located, providing fresh air for the entire unite. The high placement allocates it from everyday situations, but still makes it accessable when repairs etc. are needed.

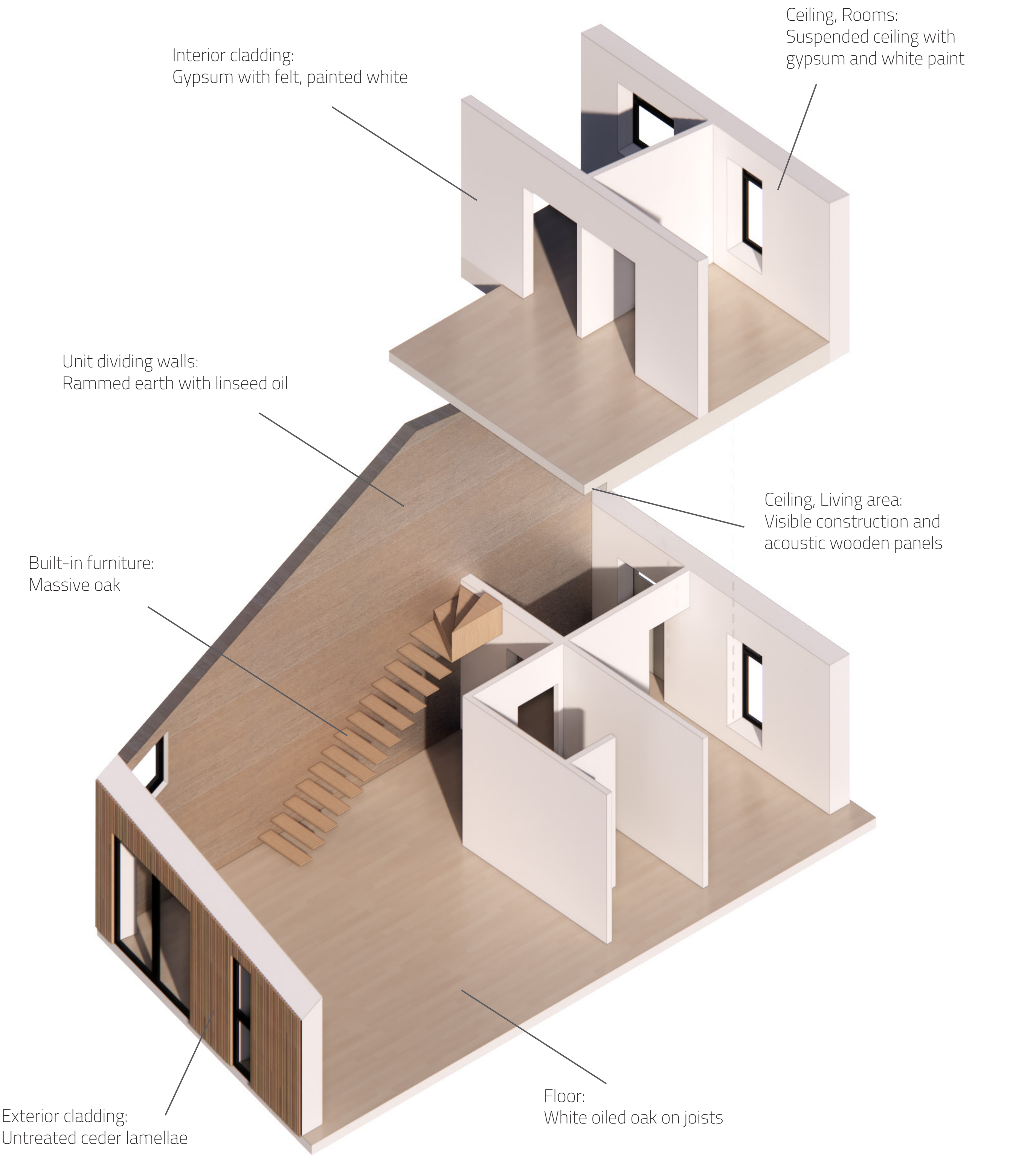
Ill. 174. Entrance and utility room

CONSTRUCTION AND MATERIALS

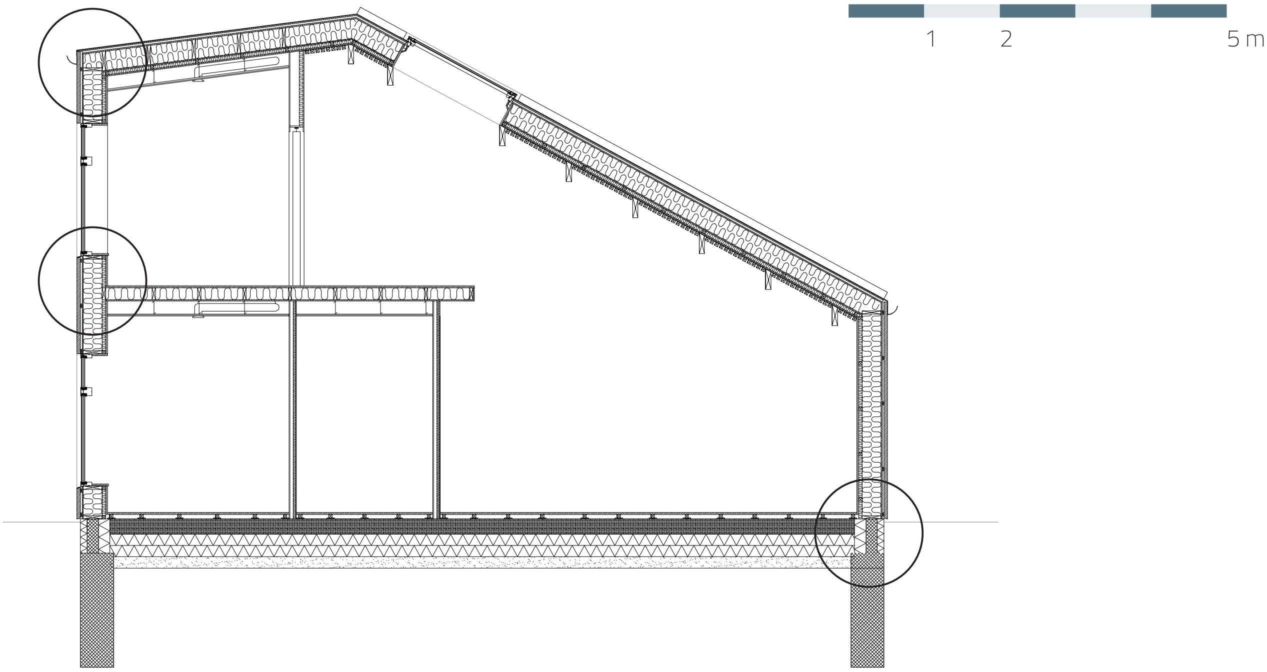
The dwellings are build up by a wooden balloon frame, fixed to a rammed earth disc on the two long sides, creating more spacial stability. Metal crosses are used to ensure total stability in the wooden part.



Ill. 175. Construction principle



Ill. 176. Materials



Ill. 177. Detail section 1:100

ROOF (FROM TOP)
Roofing felt 5 mm
OSB-board 15 mm
Air gap with horizontal battens 25x45 mm CC 600 mm - as ventilatin layer
OSB-board 15 mm - as wind barrier
Rock wool insulation 255 mm with wooden construction of 255x45 mm CC 600 mm
OSB-board 15 mm - as vapor barrier
Rock wool insulation 45 mm with battens of 45x45 mm CC 600 mm - as installation layer
OSB-board 15 mm
Air gap 170 mm with metal hangers - for installation and ventilation
Gypsum board 2x12,5 mm

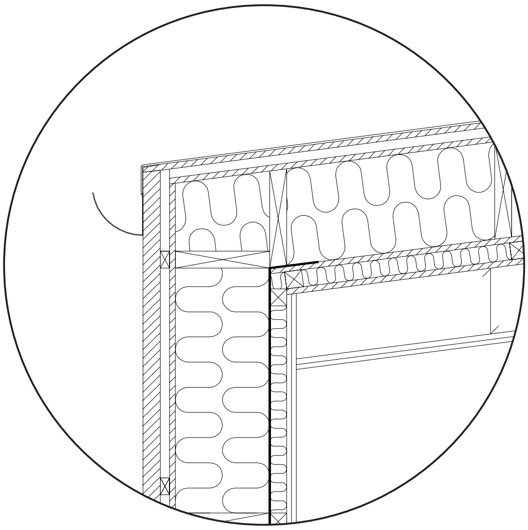
OUTER WALL (FROM OUTSIDE)
Vertical siding ceder battens 45x45 mm - CC 60 mm.
Air gap with horizontal battens 25x45 mm CC 600 mm - as ventilatin layer
OSB-Board 15 mm
Rock wool insulation 250 mm with wooden construction of 255x45 mm CC 600 mm
Vapor barrier 2 mm
Rock wool insulation 45 mm with battens of 45x45 mm CC 600 mm - as installation layer
Gypsum board 2x12,5 mm

UNIT DIVIDING WALL
Rammed earth 100 mm
Air gap 50 mm with metal ties
Rammed earth 100 mm

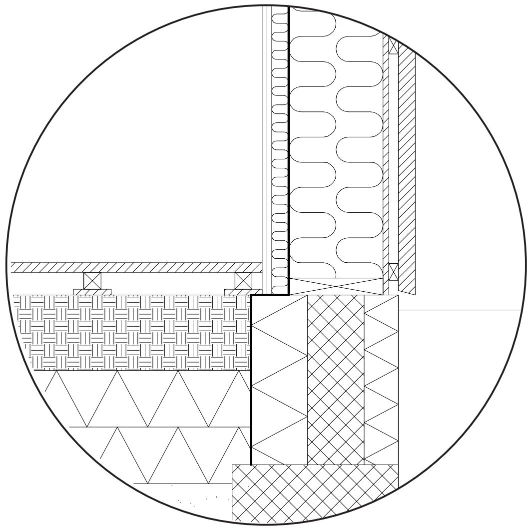
FLOOR SLAB (FROM TOP)
Flooring boards 25 mm
Rock wool insulation 160 mm with wooden construction of 160x45 mm CC 600 mm
15mm OSB board
Air gap 170 mm with metal hangers - for installation and ventilation
Gypsum board 2x12,5 mm

GROUND SLAB (FROM TOP)
Flooring boards 25 mm
Joist construction 45x45 mm joists placed on 70x15 mm OSB-plates CC 400-500 mm
Earth slab 200 mm
Pressure firm insulation of 2x150 mm
Sand 150 mm

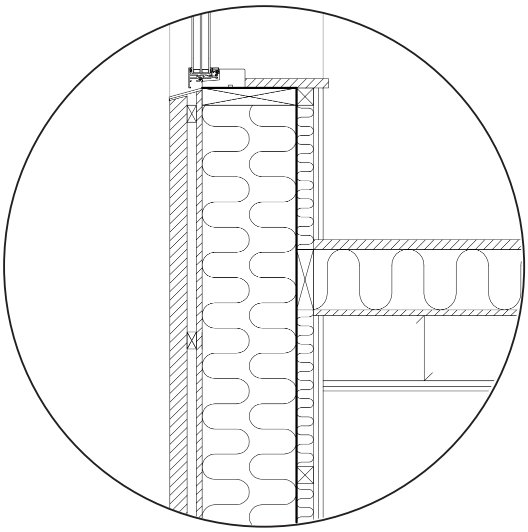
FOUNDATION BASE (FROM OUTSIDE)
Lime plaster 2 mm
Pressure firm insulation 100x450 mm
Strip of concrete with a depth of 150x450 mm
Pressure firm insulation 150x450 mm



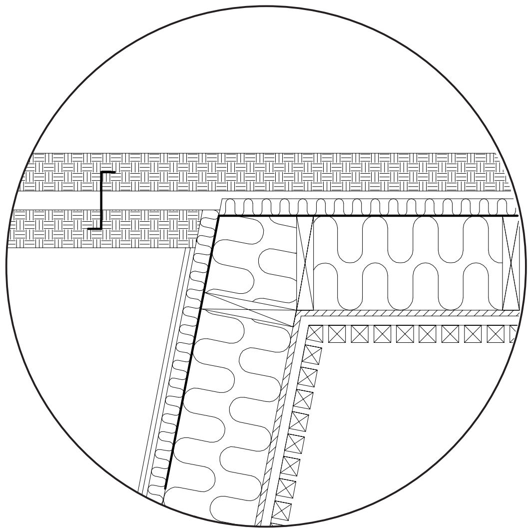
Ill. 178. Section 1:20. Roof meets outer wall. A zinc flashing covers the exterior cladding grain ends and leads rain into the gutter.



Ill. 181. Section 1:20. Gound slab meets outer wall. The outer construction stands on a bottom plate to lead the loads to the foundation. It also helps stabilize the construction.



Ill. 180. Section 1:20. Outer wall meets floor slab and wiindow. The window is located on top of the insulation to prevent large cold bridges. On the outside, a zinc outer sill covers the cladding end grain and on the inside a wooden window sill covers the construction, making the sill usefull.



Ill. 179. Plan 1:20. Unit dividing wall meets outer wall. The rammed earth continues along the exterior construction to keep the earth surface.

INDOOR ENVIRONMENT

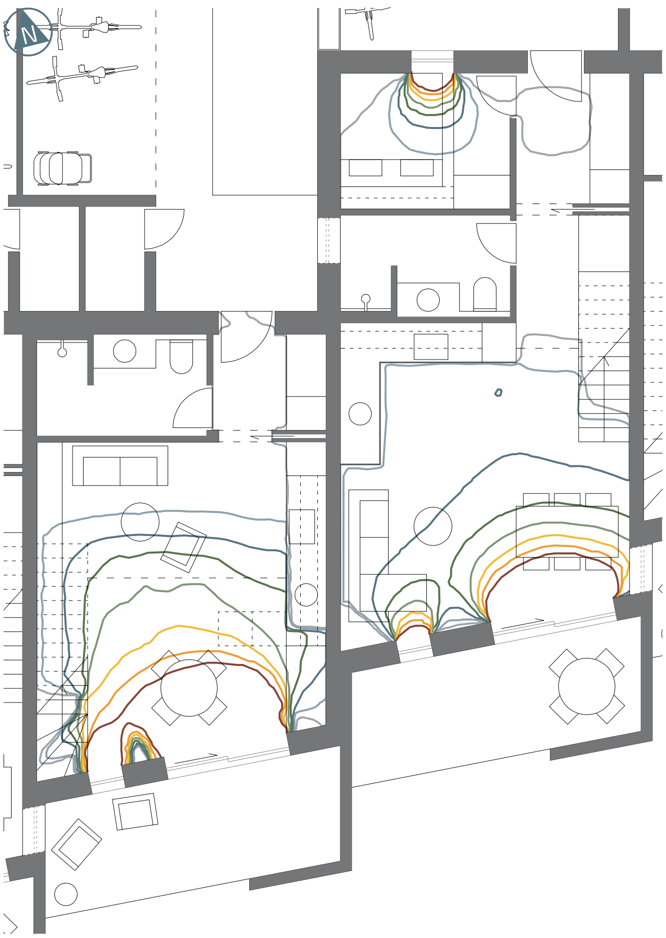
Many factors are in play, when designing the great home, here under the indoor environment, which contributes to well-being on both short and long term. This project have investigated the following four types of indoor environment; Acoustic, Visual, Atmospheric and Thermal.

VISUAL

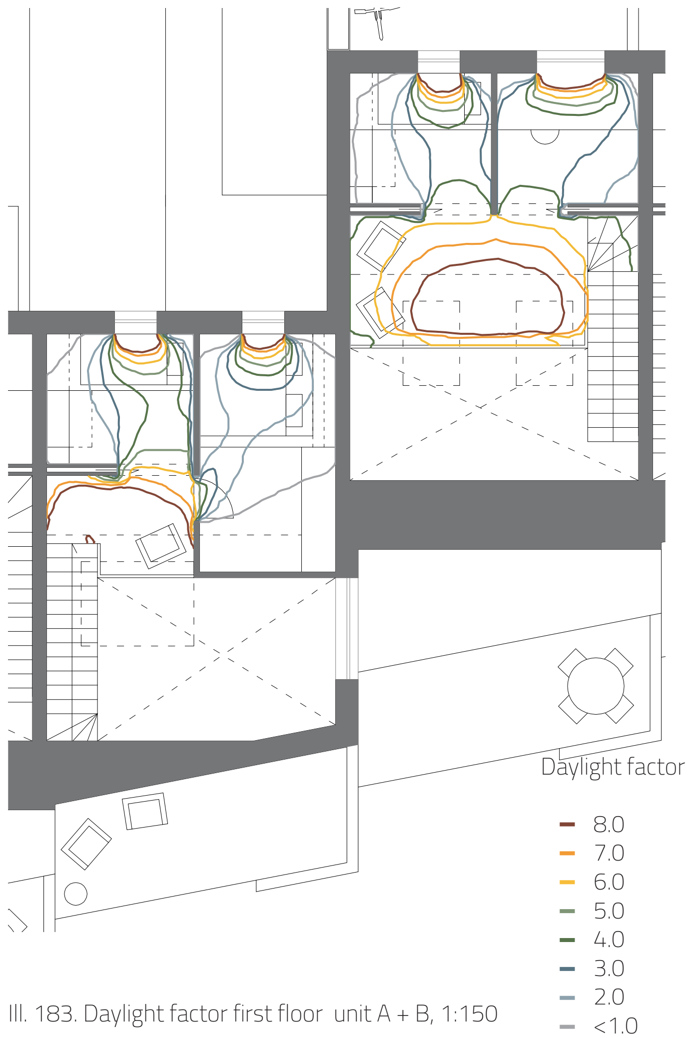
The daylight factor needs to be above 2% as an average for all rooms except the bathroom in order to accommodate a pleasant visual environment . The light colored walls and large openings ensures more than enough daylight all over as seen in Ill. 182 and Ill. 183. The entrance can become a little dark, but by having a window in the entry door, light can always find its way, as well as it creates a visual connection alle the way through the house. Having higher placed windows in the living area in a different facade also enhance the sense of orientation and time of day, while it creates beautiful light play on the surfaces further in.

ACOUSTIC

The acoustic environment is easily forgotten, but this is what can create an echo, if not designed properly. To avoid to much noise pollution, the reverberation time for the main living area have been calculated as seen in Ill. 186. The reveberation time ends on an average 0,57 s, which is below the 0,6 s, that is the general limit. It is based on a set of different frequencies, where the lowest on 125 Hz, the bass, can be more difficult to avoid. The good acoustics are due to the acoustic panels in the ceiling, wooden floor on joists and gypsum on laths.



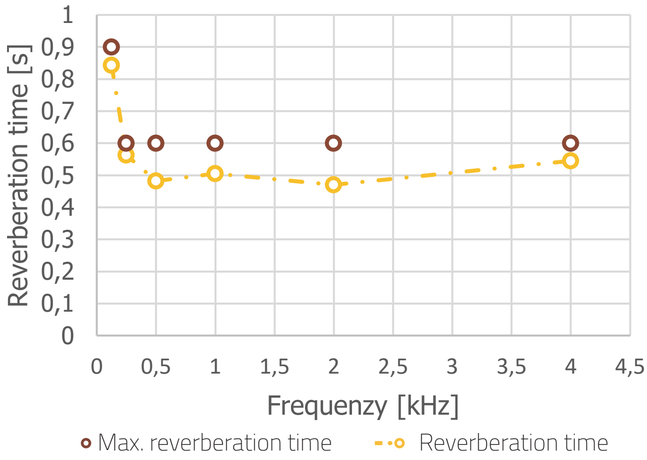
Ill. 182. Daylight factor ground floor unit A + B,1:150



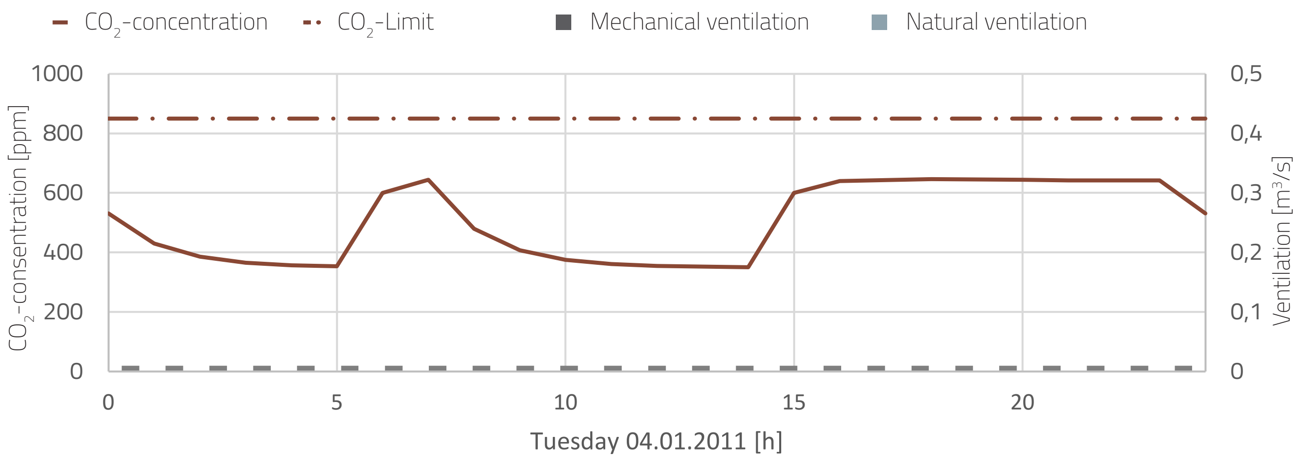
Ill. 183. Daylight factor first floor unit A + B, 1:150

ATMOSPHERIC

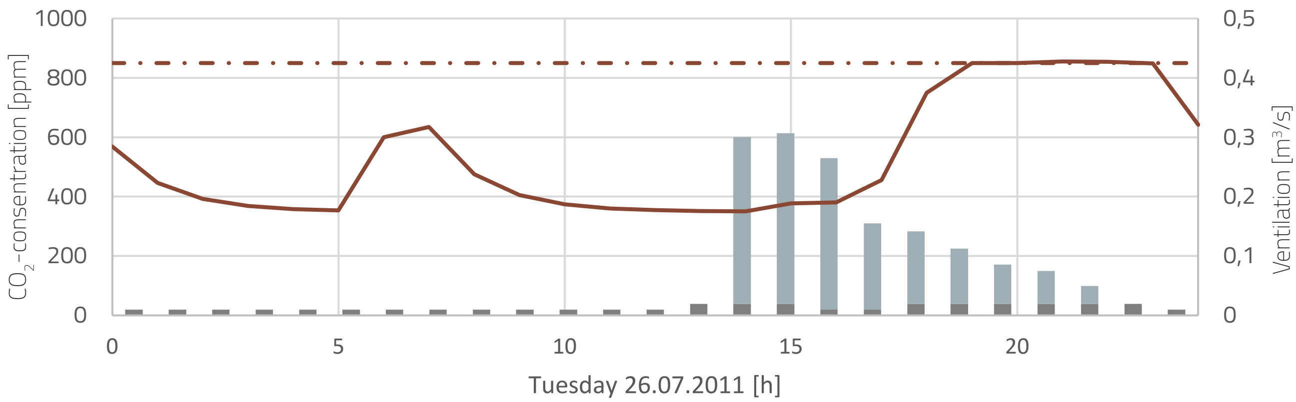
The atmospheric comfort entails the amount of CO_2 in the air. A lower consentration is always better, and due to a large volume in the living area, the consentration never ecxeeds the limit, when three people are in there as seen on Ill. 184 and Ill. 185 on page 121, around 6-8 and 14-23 o'clock. The ventilation system is adjusted to the lowest setting out of three, and when people leave the room around 8 and 23, the consentration slowly recedes to a normal consentration of 350 ppm. In the summer, when natural ventilation is assisting the mechanical unit, the concentration rises more slow in the afternoon, as the fresh air from directly outside dilutes the polluted air inside.



Ill. 186. Reverberation time



Ill. 184. CO_2-concentration during a typical winter week day.



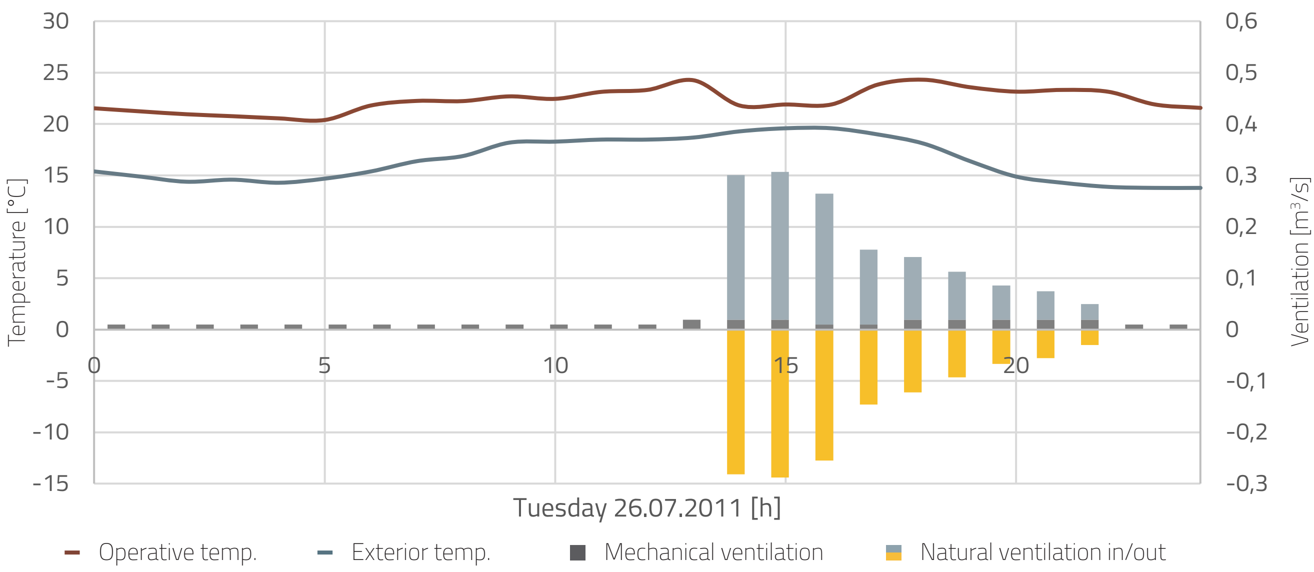
Ill. 185. CO_2-concentration during a typical summer week day.

THERMAL

The thermal environment is also important to consider, especially during summer, where excess heat can be an issue for well being. The machanical ventilation, always running on at least 0,3 l/s/m^2, can handle some of it, but the mechanical air flow can be a lot smaller, when initiating with natural ventilation. Several openings in all rooms ensure that a functional single sided ventilation is always an option. Windows placed in the ceiling top, improves the effect with the priciples of stack ventilation. Here, the warmer air rises up, and escapes out the top windows, creating a pressure difference inside and thus a natural air flow. The large openings between the rooms and the common areas, where these windows are placed, also enables the effect in there.

The use of hybrid ventilation isn't always enough, when the external temperature exceeds the wanted internal temperature. Here, solar shading and a high heat capacity is another way to ensure a cooler temperature. The heat capacity lowers all temperature fluctuations, creating a more constant room temperature. The heavy rammed earth walls enhances this effect, and proves extra potens, as direct sun hits their surface. On all the large windows, facing the terrace in the living area, manual shading in form of shutters have been implemented, for residents to both create shadow, but also a visual distancing from by-walkers outside. The top windows have been equipped with automatic solar shading, that can be overwritten by the residents, to ensure the pleasantness of user operation.

All these initiatives wind up the total amount of hours above 27 and 28 °C respectively 60 and 19.



Ill. 187. Operative temperature on a typical summer week day.

ENERGY USE

To conclude the project, the energy use throughout the building have been calculated, to make an estimated comparison with newly built typical single family homes. first, reference values have been applied, using the results of the recent LCA comparison by Zimmermann et al. (2020). The average values for ten single family homes (ENF1-10) have been used when comparing both operation and materials, looking only at the total primary energy use. These houses all comply with at least BR15, and serves as a realistic measure to uphold this project against.

The operational energy use have been calculated using Be18 and complies with the low-energy class BR20 with at total use of 9,4 kWh/m²/year. This is about half of the single family home (see Ill. 188). For more further Be18 information, see "Appendix 10: Be18 - Inputs and results".

The use for materials including embodied, recurring and demolition energy have been estimated using LCA and reveals a collective use of 508 kWh/m². This is around a third of the reference buildings (see Ill. 189). For more detailed LCA results, see "Appendix 11: LCA results".

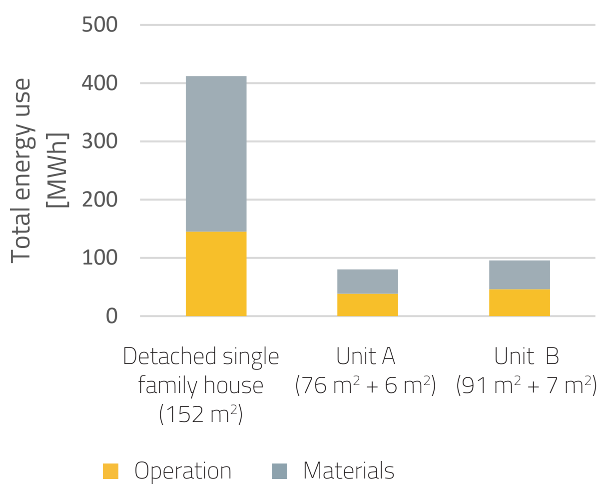
Gathering all results multiplying them up by the total floor area, Unit A and B uses around 75-90 MWh in a life time of 50 years, an estimated 80 % less than the 400 MWh, the single family house on 152 m² uses (see Ill. 190).

Operational energy [kWh/m²/year]		Primary energy factors		Energy requirement		Reference value
		BR18	BR20	BR18	BR20	
Heating	7,0	0,85	0,6	6,0	4,2	
Electricity	2,9	1,9	1,8	5,5	5,2	
Total	9,9			11,5	9,4	19,1

Ill. 188. Operational energy use based on Be18 calculations compared to the reference value. Reference values from Zimmermann et al. (2020)

Energy use in a life span of 50 years [kWh/m²]	Project	Reference values
Materials		
Embodied energy	1.058	-
Recured embodied energy	56	-
Demolition energy	-606	-
	=508	=1.756
Operation		
Operational energy	470	955
Total	978	2.711

Ill. 189. Comparison of building quality acording to energy use. The project of Green Meadow have a lower energy use pr. m² over time, meaning that the principles may be applicable to larger homes as well. Reference values from Zimmermann et al. (2020).



Ill. 190. Comparison of total energy use over a life span of 50 years. The energy use is around 75-80% smaller than a newly build detached single family home.

EPILOGUE

CONCLUSION

The project aim has been to investigate sustainable housing, focusing on changing the way people live, by minimizing and optimizing space. The project has focused on more flexible and multifunctional layouts with an offset in the single family home, combining the principles of smaller living with cleaver use of materials. This have contributed to a unit in the final project using around 80% less life cyckle energy over a life span of 50 years, than a typical single family home.

The project is mainly constructed in wood. A resource that, when used correctly, proves much more sutainable than other conventional building materials. Wood is a natural resource, that keeps the atmosphere clean while growing on its own. When its life ends, energy can be released from the material and used for other purposes. Its diversity and beautiful structure, is also the reason it has been chosen as cladding for several surfaces in and outside.

Though building with more sustainable materials, the size still makes up a large part of the problem. People tend to chose the single family home, due to specific qualities. This projects have embraced many of these, as it have become clear, that many of the qualities doesn't depend on having a larger floor area. Instead, it depends on clever design and managing every squaremeter available correctly. The new homes in Green Meadow contains both a utility room, plenty of storage, a central living space and a parental and kids section. The possibility for personalization is achieved by reducing the room sizes and adding more space to the living area. The residents can then decorate it in their own style, focusing on what they find important. Direct access to the outdoors happens via a private terrace and the wild nature reduces both stress level and maintanance for all residents, though providing an enormous garden. All of this takes place in a quiet naborhood, safe and exciting for kids to move around. Though the homes are reduces to half the size, the qualities are not.

The project of Green Meadow is the perfect place to start a family, both for the environmantally conscious, but also for the people, searching for a great community in beautiful surroundings.

REFLECTION

Though the conclusion shows a great result, the road there have been entangled. It will also always be difficult to be content with every single aspect of a project of this scale. Many things can be wished differently, but only further work, can actually get it there.

A larger focus could have been placed on the common facilities, whose current design is based on principles from the dwellings. The plan layout is what have undergone the most significant iterations, where the identities and funtionalities of each have played a large role. For the site as well, especially regarding cars and parking, the project could have benifitted from diving deeper into the sustainable aspect, completely ignoring the requirement from the municipality instead of landing on a middle way. Though there is a possibility of reducing the realistic aspect when disregarding cars, it could add a new and exciting angle to the project.

Moving through several stages of detail, when designing integrated solutions such as window size and placement or solar shading seem like the obvious road to follow. Issues have occured though, where the more detailed software concludes much differently than the initial hand calculations have, making them obsolete. The projects have gained much more from knowledge of basic principles, rather than actual early calculations. Whether it means the software needs more inputs or the calculations are made different is unknown, but it does add the pressure of upgrading software like BSim to a more design-based tool, rather than only analyzing final results.

Another software to reflect upon, is LCA-Byg and the entire concept of Life-cycle assessment. The software is definitly a step in the right direction, when it comes to evaluationg materials. Energy use and emission of greenhous gasses have become a huge topic, and for obvious reasons. The knowledge of each individual material is not, however, fully developed. The EPD's used for analysing each material can vary a lot, depending on where they are found. The existing materials in the program makes a good base, but the readability of each material is poor. E.g. There can be a lot of confusion trying to understand why organic materials score so high in primary energy compared to non-organics. Exactly where the energy etc. in each phase comes from, cannot be found. This limits the method, as the basic knowledge gets lost. Instead, this projects have demanded looking outwards, in articles not made as official EPD's to gain understandable results. This is a shame, as the software and analyzing methods shows great potential.

The thesis has gone through a quit different proccess than initially expected due to the pandemic of Corona Virus. This have made the physical group work obsolete and urged creative thinking in new ways. Early planed things had to be rescheduled and done differently. This for instance applies to the testing and questioning of people moving through the minimized design, using virtual reality. As an alternative to this, the tests were still carried out using a single member and instead more 3D modeling was done to understand and communicate the project internally. In general has much more of the project been carried out as digital media as the hand sketches provides some issues in communication through a camera. This have benefitte the project by elevating the quality of the 3D models, which have gone through several more iterations.

A final thing, that could have gotten some more time, and as seen as a natural next step, is the variation in design across the site. Enhancing the qualities of each single unit acording to its placement and connections to its nabors can create even further variety in choises, for the people moving there. At the same time, giving each house a uniqe identity e.g. in the external cladding could add even more personality to the different houses instead of being another house in the row. This would also utilize the diversity in the wooden cladding, as it offers many options regarding exterior cladding.

To summarize, the project have been great, challenging current societal issues, that needs solving within a short time span. Further work can still be done, but the project shows great potential as a stepping stone for building more sustainable in the future.

ILLUSTRATIONS

Unless other is stated, the illustration is our own.

Ill. 3. Data from Danmarks Statistik (2019c)

Ill. 4. Data from Valbjørn et al. (2006) and Jensen (2008a), Translated from Danish

Ill. 5. Data from Danmarks Statistik, interpreted by Bolius (Boding 2019)

Ill. 6. Data from MLIT (n.d.)

Ill. 7.Data from Ramesh et al. (2010) and Sartori & Hestnes (2007)

Ill. 8. Interpretation of data from Brysch (2019)

Ill. 9. Photo by Koichi Torimura, from MINI Clubman (2014)

Ill. 10. Plan by Takeshi Shikauchi Architectural Office, from MINI Clubman (2014)

Ill. 11. Photo by Koichi Torimura, from MINI Clubman (2014)

Ill. 12. Section by Takeshi Shikauchi Architectural Office, from (MINI Clubman, 2014)

Ill. 13. Data from Roberts-Hughes (2011), edited and shortened

Ill. 14. Plan by Tegnestuen Vanskunsten, scan of original drawing, edited

Ill. 15. Data from Heiselberg (2006)

Ill. 16. Data from Steen-Thøde (1997b)

Ill. 17. Data from Steen-Thøde (1997a)

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Ill. 20-21. Illustration from Aarhus Kommune (2017), edited

Ill. 22. Data from Dansk standard (2019), Dansk Standard (2018a), and Dansk Standard (2018b)

Ill. 23-24. Data from Kortforsyningen (2020a)

Ill. 26-30. Data from Sketchup Pro, 2020, shadows [Accessed February 18, 2020]

Ill. 33. Data from DMI (2020)

Ill. 34. Illustrations from Cappelen & Jørgensen (1999), edited

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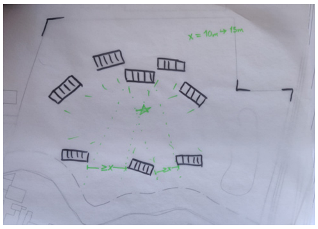
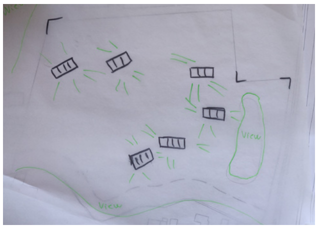
APPENDIX

Appendix 1: Urban workshop
Appendix 2: Unit grouping - Envelope
Appendix 3: Unit sketching
Appendix 4: Solar Energy production
Appendix 5: LCA for structural elements
Appendix 6: LCA for interior cladding
Appendix 7: Materials - Indoor environment
Appendix 8: Day Average
Appendix 9: Solar shading
Appendix 10: Be18 - Inputs and results
Appendix 11: LCA results

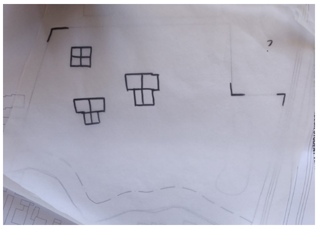
APPENDIX 1: URBAN WORKSHOP

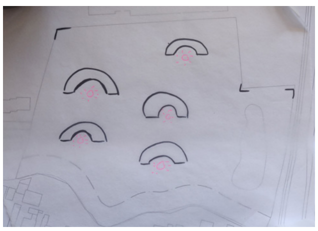
VIEWS

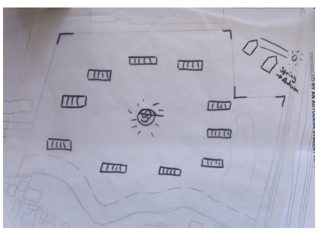
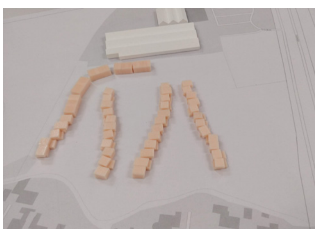
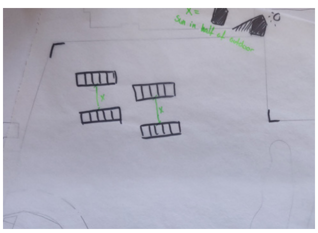


DIRECT SUNLIGHT INSIDE



SUN IN RECREATIONAL SPACES

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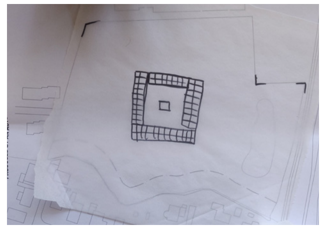

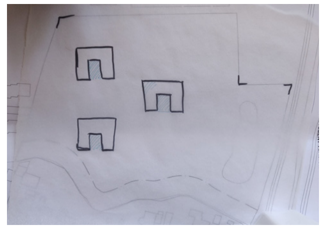


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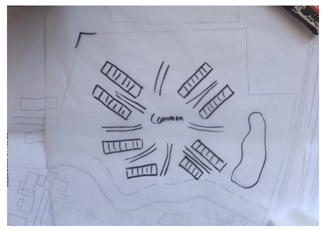
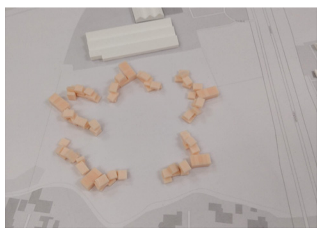
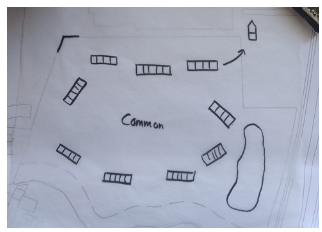

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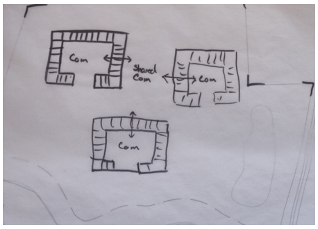
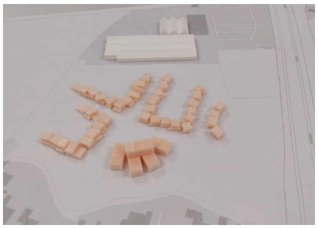
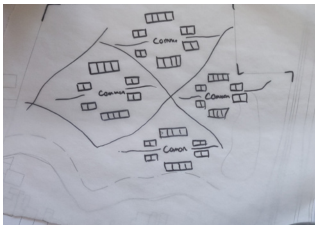
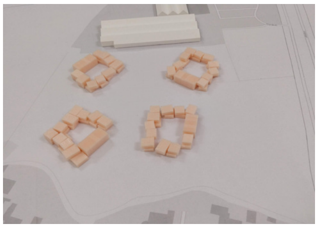
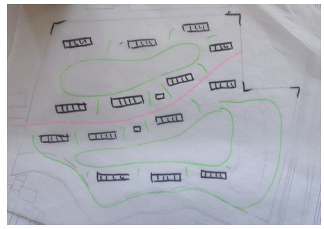
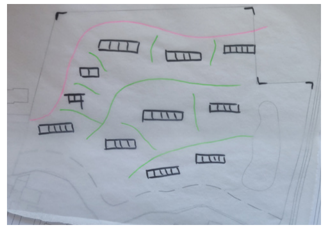


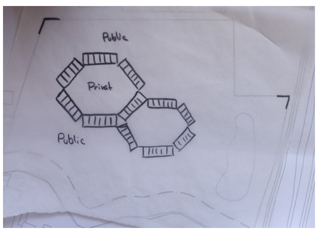




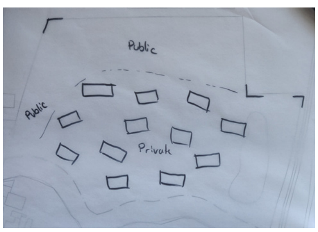
SAFE SPACE

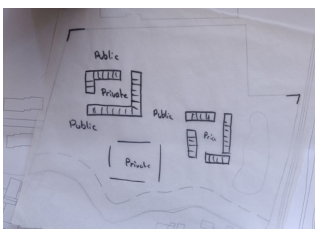





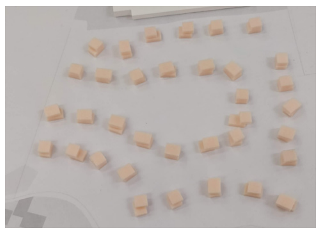
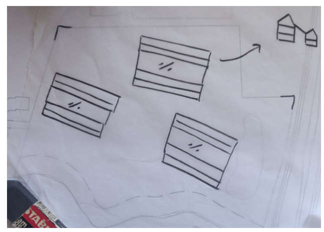
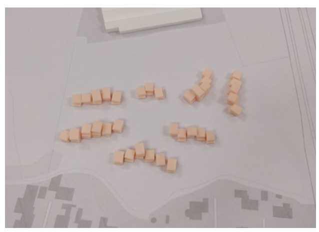
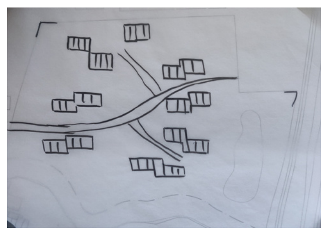

DEFINITION OF PRIVATE AND PUBLIC

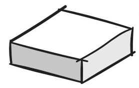



CONTINUATION OF CONTEXT

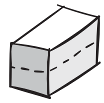






APPENDIX 2: UNIT GROUPING - ENVELOPE

In order to help investigate the different unit groupings, a comparison have been made for the quality of the envelope. To help evaluate, each have been analyszed using Be18, where only the envelope have been typed in and changed between the options. No openings, heating systems etc. have been entered in the program, thus the results are not final, but instead a way of comparing the different solutions.



One-storey unit



Two-storey unit

A

Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	36,8
Renoveringsklasse 1	52,8	0,0	52,8	36,8
Energiramme BR 2018	30,2	0,0	30,2	36,8
Energiramme lavenergi	27,0	0,0	27,0	36,8

Bidrag til energibehovet		Netto behov	
Varme	36,8	Rumopvarmning	36,8
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

B

Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	33,4
Renoveringsklasse 1	52,8	0,0	52,8	33,4
Energiramme BR 2018	30,2	0,0	30,2	33,4
Energiramme lavenergi	27,0	0,0	27,0	33,4

Bidrag til energibehovet		Netto behov	
Varme	33,4	Rumopvarmning	33,4
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

C

Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	26,2
Renoveringsklasse 1	52,8	0,0	52,8	26,2
Energiramme BR 2018	30,2	0,0	30,2	26,2
Energiramme lavenergi	27,0	0,0	27,0	26,2

Bidrag til energibehovet		Netto behov	
Varme	26,2	Rumopvarmning	26,2
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

D

Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	22,8
Renoveringsklasse 1	52,8	0,0	52,8	22,8
Energiramme BR 2018	30,2	0,0	30,2	22,8
Energiramme lavenergi	27,0	0,0	27,0	22,8

Bidrag til energibehovet		Netto behov	
Varme	22,8	Rumopvarmning	22,8
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

E

Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	21,0
Renoveringsklasse 1	52,8	0,0	52,8	21,0
Energiramme BR 2018	30,2	0,0	30,2	21,0
Energiramme lavenergi	27,0	0,0	27,0	21,0

Bidrag til energibehovet		Netto behov	
Varme	21,0	Rumopvarmning	21,0
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

F

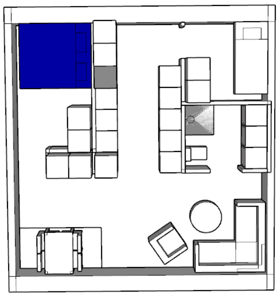
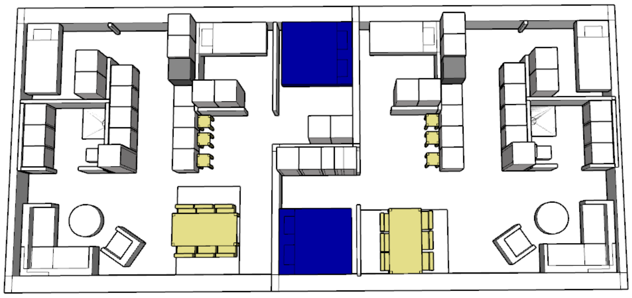
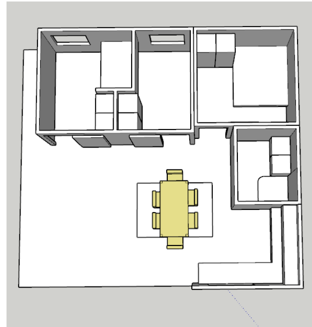
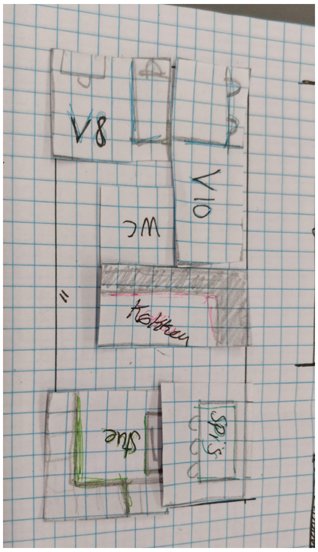
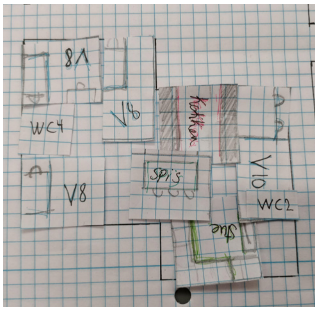
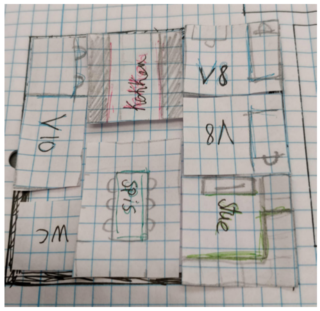
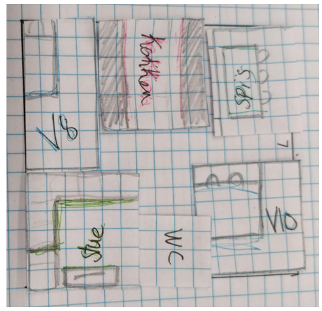
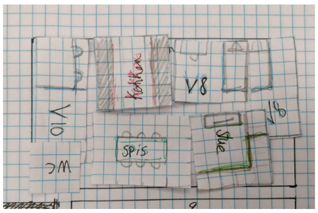
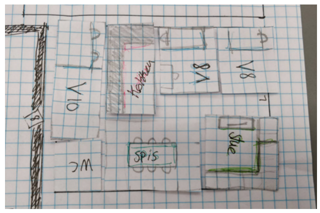
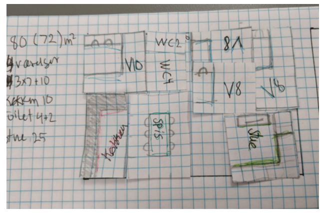
Nøgletal, kWh/m² år	Uden tillæg	Tillæg for særlige betingelser	Samlet energiramme	Samlet energibehov
Renoveringsklasse 2	70,3	0,0	70,3	20,9
Renoveringsklasse 1	52,8	0,0	52,8	20,9
Energiramme BR 2018	30,2	0,0	30,2	20,9
Energiramme lavenergi	27,0	0,0	27,0	20,9

Bidrag til energibehovet		Netto behov	
Varme	20,9	Rumopvarmning	20,9
El til bygningsdrift	0,0	Varmt brugsvand	0,0
Overtemp. i rum	0,0	Køling	0,0

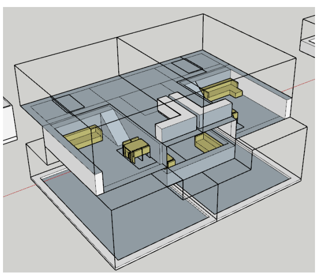
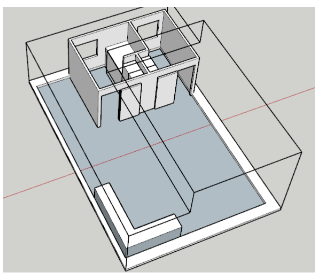
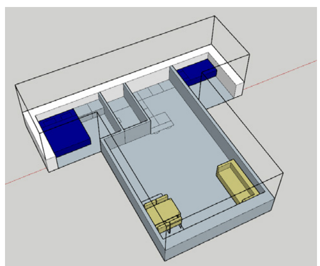
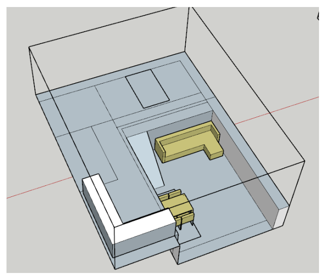
Udvalgte elbehov		Varmetab fra installationer	
Belysning	0,0	Rumopvarmning	0,0
Opvarmning af rum	0,0	Varmt brugsvand	0,0
Opvarmning af vbv	0,0	**Ydelse fra særlige kilder**	
Varmepumpe	0,0	Solvarme	0,0
Ventilatorer	0,0	Varmepumpe	0,0
Pumper	0,0	Solceller	0,0
Køling	0,0	Vindmøller	0,0
Totalt elforbrug	0,0		

	A	B	C	D	E	F
Total energy demand [kWh/m²]	36,8	33,4	26,2	22,8	21	20,9
Total envelope area [m²]	21.440	19.520	15.040	13.120	12.160	11.840
Score	=1	=2	=3	=3	=4	=4

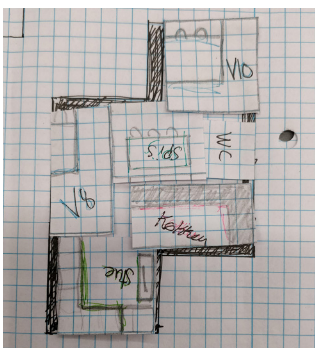
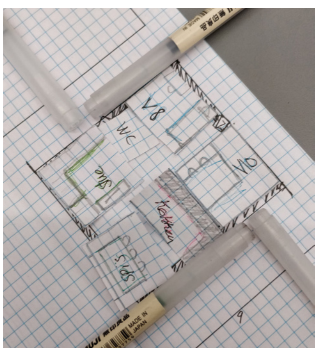
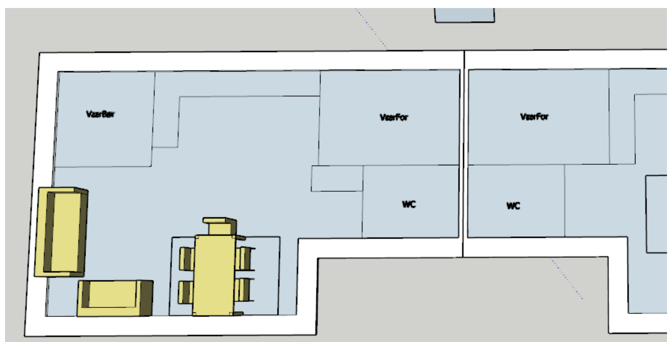
APPENDIX 3: UNIT SKETCHING

WORKING WITH CEILING HEIGHT

DISPLACEMENTS IN FACADE AND UNITS

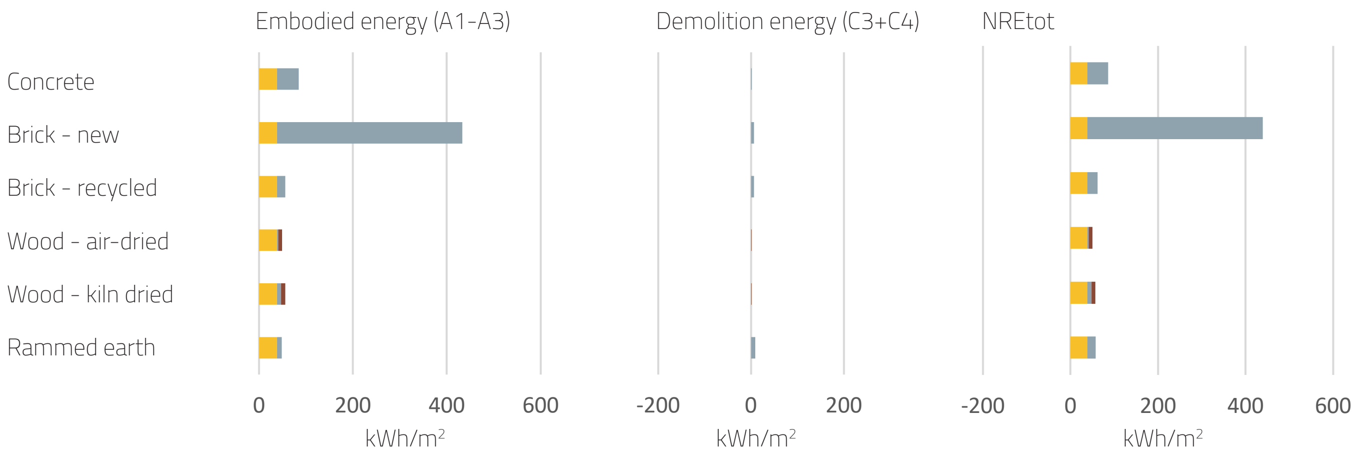
APPENDIX 4: SOLAR ENERGY PRODUCTION

ENERGY PRODUCTION

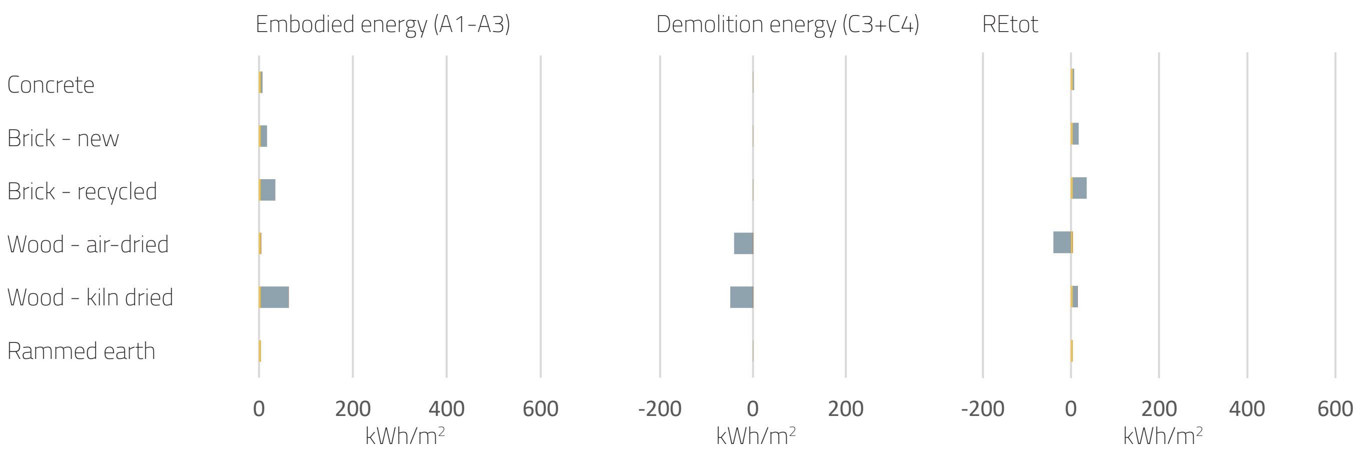
Surfaces with specific gain	Large roof surface (62,5 m^2)	Small roof surface (50 m^2)	Solar gain [MWh]
1200 kWh	6	0	450
1080 kWh	10	0	675
960 kWh	7	17	1.236
Efficiency of monocristaline pv-panels			~17,5%
Efficiency of SolarLab pv-panel compared to standard modules (SolarLab, no date)			>75%
Total energy production			310

APPENDIX 5: LCA FOR STRUCTURAL ELEMENTS

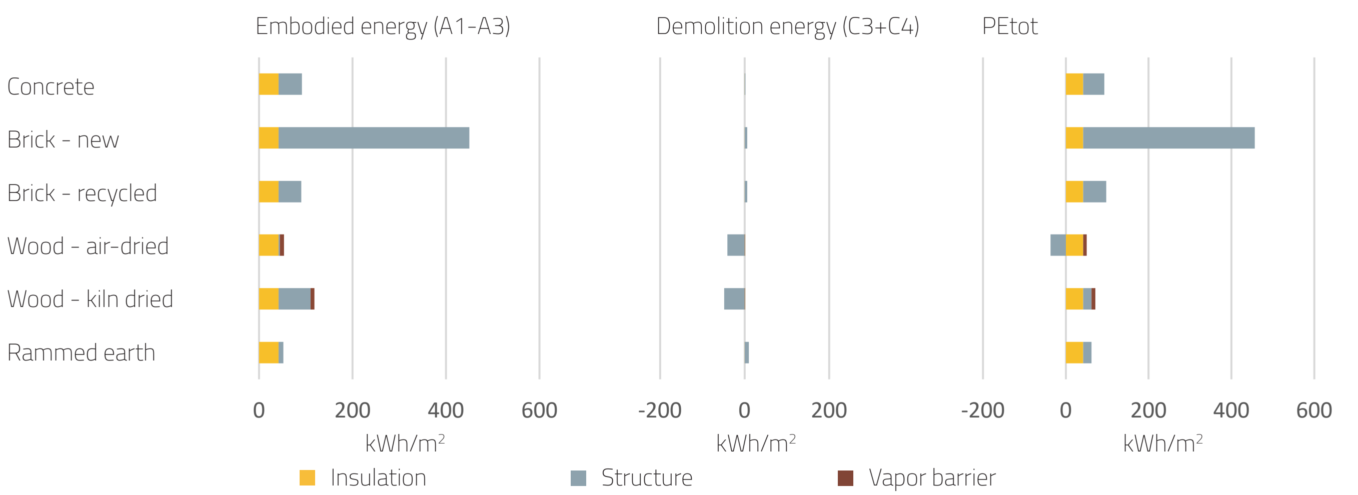
NON-RENEWABLE ENERGY USE



RENEWABLE ENERGY USE

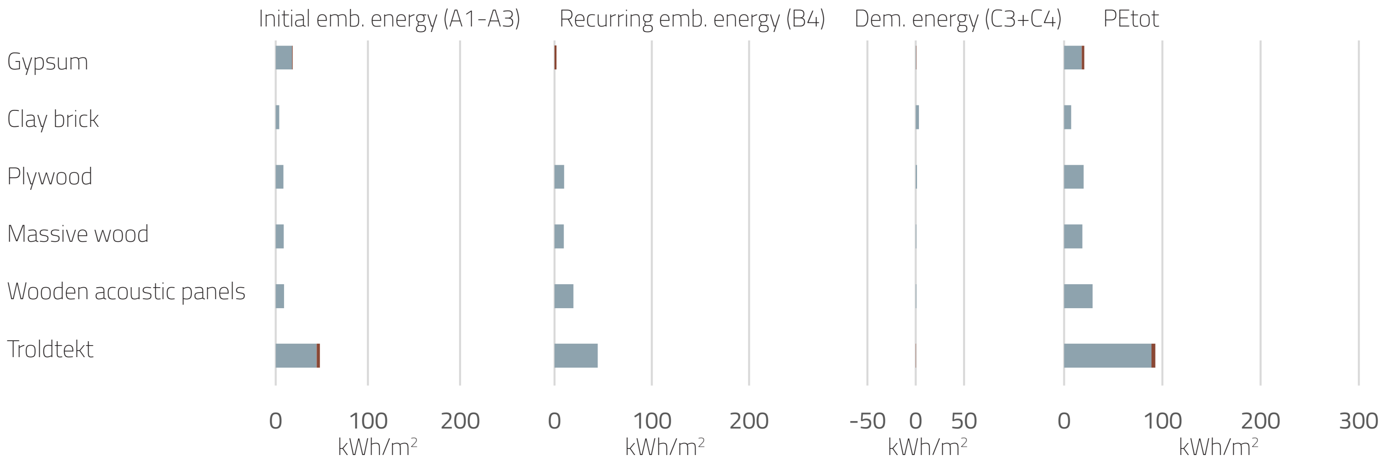


TOTAL PRIMARY ENERGY USE

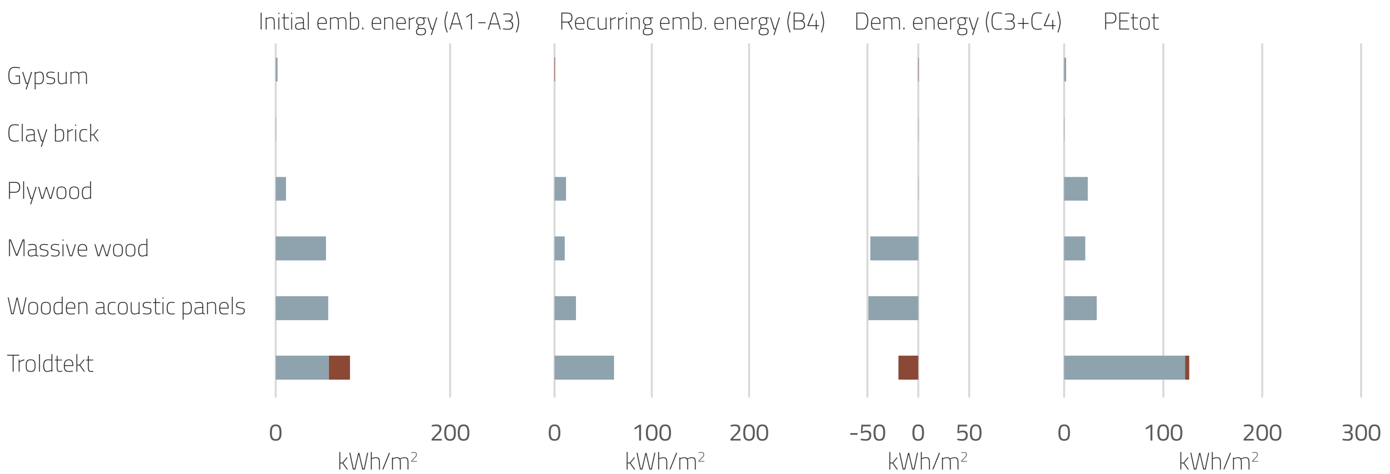


APPENDIX 6: LCA FOR INTERIOR CLADDING

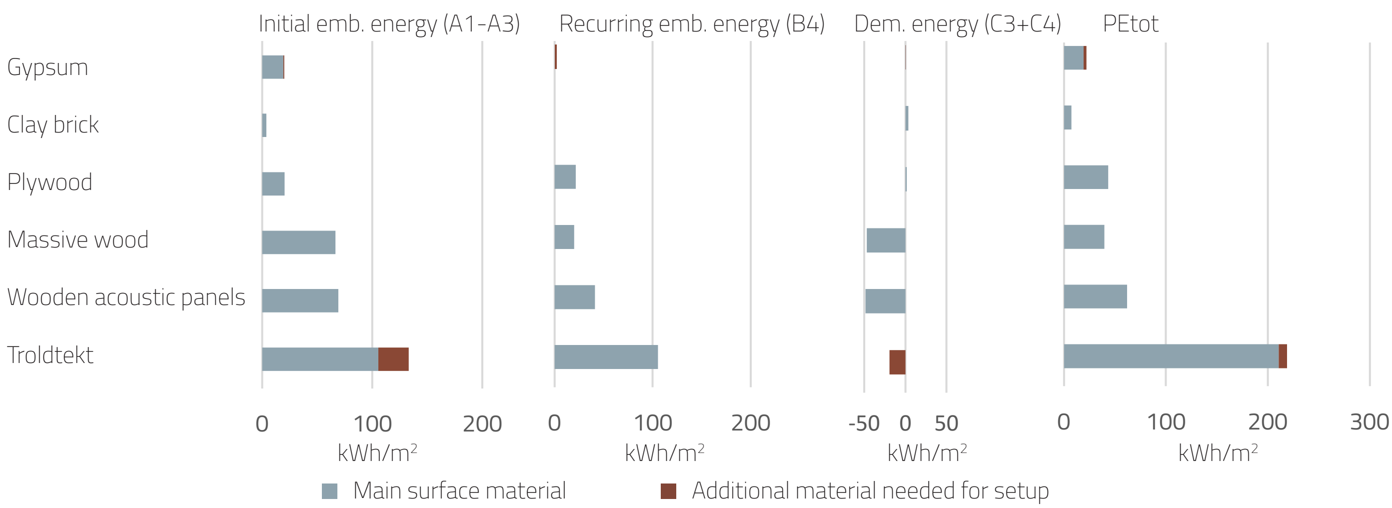
NON-RENEWABLE ENERGY USE



RENEWABLE ENERGY USE



TOTAL PRIMARY ENERGY USE



APPENDIX 7: MATERIALS - INDOOR ENVIRONMENT

To evaluate the different options of interior cladding, each material must analyzed in several dimensions. To help with the indoor environment, 3 categories are used; Thermal, Acoustic, and Visual.

THERMAL PROPERTIES

The thermal properties lies in the ability to attract heat into the material during the day, and release it again during the night. For a specific surface, this ability depends on the material and the volume heroff. The heat capacity is thus relying on the thickness of the layer, as well as it only effectivly can use the outer 10 cm of each layer (Steen-Thøde 1997b).

$S = c \cdot \rho \cdot V$

Using the apropriate units, a heat capacity can be found for a square meter of the wall. To calculate the heat capacity on an entire room, find the sum of all areas of each surface multiplied by their respective heat capacity.

The specific heat capacities and the desity of each material are design values from Dansk Standard (2008). Only the troldtekt density is from a specific data sheet (Troldtekt 2020).

ACOUSTIC PROPERTIES

The acoustic properties are also important to consider. In larger rooms with hard surfaces, the reverberation time can be several seconds. This is not desirable in a dwelling, where the reveberation time should be no more than 0,6 s in general.

Each material has an absorption, that lowers the reverberation time. The more surface, the more absorption. Softer materials absorp more, where harder

MATERIAL	SPECIFIC HEAT CAPACITY	DENSITY	VOLUMEN	HEAT CAPACITY
	c, [J/kg·°C]	ρ, [kg/m³]	V, [m³/m²]	S, [kWh/°C·m²]
Concrete (exposed)	1000	2300	0,	64
Brick (exposed)	1000	1600	0,1	44
Rammed earth (exposed)	2000	1600	0,1	89
Gypsum with glass felt	1000	900	0,025	6
Clay brick	2000	1600	0,1	89
Plywood	1600	700	0,02	6
Solid wood	1600	500	0,02	4
Wooden acoustic panels directly on the insulation	1600	500	2,5x2,5 cm C/C 3 cm = 0,021	5
Troldtekt on 25 x 100 mm lathing directly on the insulation	1300	378	0,025	3
Glass	750	2200	0,01 m³/m²	5

surfaces reflect it. this can cause an echo. To calculate the reveberation time in a room, all the surfaces must be known. It it normal to calculate for several frequenzies, as materials absorp differently in different wave lengths.

First, a table of the absorption of different materials are presented, to get an understanding of which materials are better. As the final material choice also depends on other factors, this makes for an easier way to find single substitutes, if a surface performs bad. The values comes from Bies & Hansen (2009).

The rooms' equivalente absorption area
$A = \Sigma(\alpha_i \cdot S_i + n_p \cdot A_p) + 4 \cdot m \cdot V$

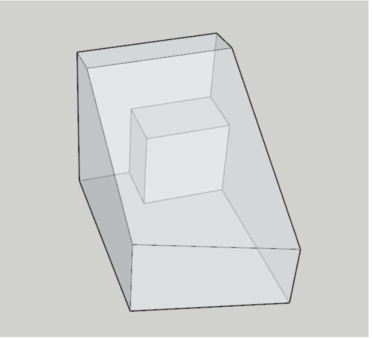
Rverberation time
$T=0{,}16 \cdot V/A$

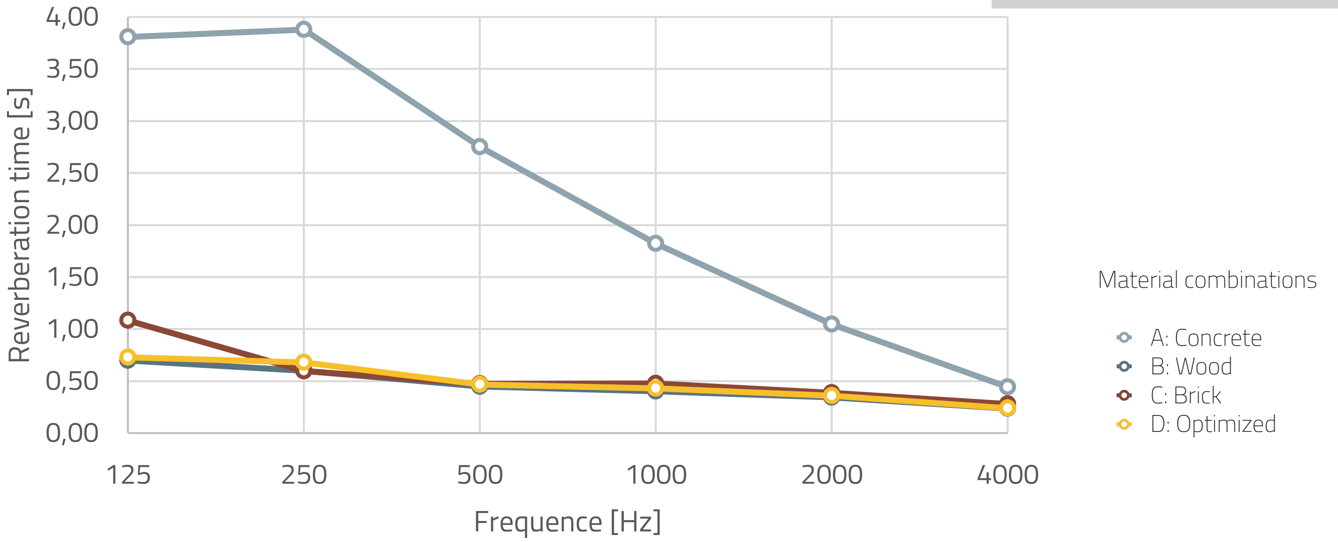
MATERIAL, S_i	125 HZ	250 HZ	500 HZ	1000 HZ	2000HZ	4000 HZ
Concrete	0,01	0,01	0,01	0,02	0,02	0,02
Brick	0,01	0,01	0,01	0,02	0,02	0,02
Rammed earth	0,02	0,02	0,03	0,04	0,07	0,09
Gypsum on hard surface	0,013	0,015	0,02	0,03	0,04	0,04
Gypsum on laths (50x100 mm)	0,29	0,1	0,05	0,04	0,07	0,09
Plywood	0,14	0,1	0,06	0,08	0,1	0,1
Troldtekt	0,4	0,85	1,05	0,95	1	0,8
Wooden acoustic panels on fiberglass/rockwool (50 mm thick)	0,27	0,54	0,94	1	1	1
Windows	0,35	0,25	0,18	0,12	0,07	0,04
Cork floor tiles (8-10 cm thick)	0,08	0,02	0,08	0,19	0,21	0,22
Parquet floor on joists	0,15	0,12	0,1	0,07	0,06	0,07

MATERIAL COMBINATIONS

Using different combinations of these materials, the reverberation time have been analyzed in the critical room, in the large unit - the living area.

The intermediate calculations are only being shown for the optimized cobination, but the others have been made in the same way.





WALL FACES	QUANTITY	CONCRETE	WOOD	BRICK	OPTIMIZED
	[m²]				
Back walls, interior (North)	34,8	Gypsum on hard surface	Plywood	Brick	Gypsum on laths (50x100 mm)
Unit dividing wall (East)	29	Gypsum on hard surface	Plywood	Brick	Rammed earth
Unit dividing wall (West)	31	Gypsum on hard surface	Plywood	Brick	Rammed earth
Outer wall (south)	9,6	Gypsum on hard surface	Plywood	Brick	Gypsum on laths (50x100 mm)
Floor	37,2	Concrete	Parquet floor on joists	Rammed earth	Parquet floor on joists
Ceiling	38,8	Gypsum on hard surface	Wooden acoustic panels on fiberglass/ rockwool (50 mm thick)	Troldtekt	Wooden acoustic panels on fiberglass/ rockwool (50 mm thick)

WALL FACES	QUANTITY	MATERIAL	125 HZ	250 HZ	500 HZ	1 KHZ	2 KHZ	4 KHZ	HEAT CAPACITY	
	α_i, [m²]								[kWh/°C·m²]	[kWh/°C]
Back walls, interior (North)	34,8	Gypsum on laths (50x100 mm)	0,01	0,01	0,01	0,02	0,02	0,02	6,3	219
Unit dividing wall (East)	29	Rammed earth	0,01	0,01	0,01	0,02	0,02	0,02	88,9	2578
Unit dividing wall (West)	31	Rammed earth	0,02	0,02	0,03	0,04	0,07	0,09	88,9	2756
Outer wall (south)	9,8	Gypsum on laths (50x100 mm)	0,013	0,015	0,02	0,03	0,04	0,04	57,4	559
Windows	9,6	Windows	0,29	0,1	0,05	0,04	0,07	0,09	4,6	44
Floor	37,2	Parquet floor on joists	0,14	0,1	0,06	0,08	0,1	0,1	6,2	231
Ceiling	38,8	Wooden acoustic panels on fiberglass/ rockwool (50 mm thick)	0,4	0,85	1,05	0,95	1	0,8	4,4	171
People, n_p	4		0,27	0,54	0,94	1	1	1		
Chairs, n_p	8		0,35	0,25	0,18	0,12	0,07	0,04		
Air absoption at RF50%, 4·m·V [m⁻¹]			0,08	0,02	0,08	0,19	0,21	0,22		
The rooms' equivalente absorption area, A			28,84	43,21	50,45	48,14	51,76	44,59		
Volumen, V [m³]	152									
		Reverberation time, T [s]	0,84	0,56	0,48	0,51	0,47	0,55	Total heat capacity, S	6557

APPENDIX 8: DAY AVERAGE

GLAZING AREA

[m^2]	Roof	Other facades
A	0	10
B	1,2	11
D	2	8
D	3	8
E	1	6,5

SOUTH FACING LIVING AREA

[°C]	Avg. op. temperature		Fluctuations		Max. op. temperature	
	Unit A	Unit B	Unit A	Unit B	Unit A	Unit B
A	22,4 (15,6)	23 (14,6)	2,9 (/2)	3,5 (2,5)	23,8 (16,6)	24,8 (15,8)
B	22,4 (15,4)	23 (14,4)	3 (2,1)	3,5 (2,5)	23,9 (16,4)	24,7 (15,6)
D	22,3 (15,5)	22,9 (14,4)	2,8 (1,9)	3,4 (2,4)	23,7 (16,4)	24,6 (15,6)
D	22,3 (15,4)	22,9 (14,4)	2,9 (1,9)	3,4 (2,4)	23,8/ (16,4)	24,6 (15,6)
E	22,3 (15,6)	22,8 (14,6)	2,7 (1,9)	3,2 (2,3)	23,7 (16,6)	24,5 (15,8)

EAST/WEST FACING LIVING AREA

[°C]	Avg. op. temperature		Fluctuations		Max. op. temperature	
	Unit A	Unit B	Unit A	Unit B	Unit A	Unit B
A	22,4 (15,4)	23 (14,4)	2,9 (1,9)	3,5 (2,4)	23,9 (16,3)	24,8 (15,5)
B	22,4 (15,2)	23 (14,2)	3 (1,9)	3,6 (2,4)	23,9 (16,1)	24,8 (15,4)
D	22,3 (15,4)	22,9 (14,3)	2,9 (1,8)	3,4 (2,3)	23,8 (16,3)	24,6 (15,5)
D	22,3 (15,3)	22,9 (14,2)	2,9 (1,8)	3,5 (2,3)	23,8 (16,2)	24,6 (15,4)
E	22,3 (15,5)	22,9 (14,5)	2,7 (1,8)	3,3 (2,2)	23,7 (16,4)	24,5 (15,6)

APPENDIX 9: SOLAR SHADING

NO SHUTTERS

Hours > 21	1651	1651
Hours > 27	107	107
Hours > 28	54	54

Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total ene
76,6	0,0	
Total energy requirement		

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
57,4	0,0	57,4
Total energy requirement		13,6

Energy frame BR 2018

Without supplement	Supplement for special conditions	Total energy frame
33,0	0,0	33,0
Total energy requirement		13,6

Energy frame low energy

Without supplement	Supplement for special conditions	Total energy frame
27,0	0,0	27,0
Total energy requirement		13,6

Contribution to energy requirement		Net requirement	
Heat	6,7	Room heating	6,7
El. for operation of bulding	2,9	Domestic hot water	13,1
Excessive in rooms	2,4	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	0,0	Room heating	0,0
Heating of rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	2,9	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	33,6	Wind mills	0,0

LIGHT CURTAINS

Hours > 21	1611	1611
Hours > 27	86	86
Hours > 28	41	41

Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total ene
76,6	0,0	
Total energy requirement		

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
57,4	0,0	57,4
Total energy requirement		13,4

Energy frame BR 2018

Without supplement	Supplement for special conditions	Total energy frame
33,0	0,0	33,0
Total energy requirement		13,4

Energy frame low energy

Without supplement	Supplement for special conditions	Total energy frame
27,0	0,0	27,0
Total energy requirement		13,4

Contribution to energy requirement		Net requirement	
Heat	6,8	Room heating	6,8
El. for operation of bulding	2,9	Domestic hot water	13,1
Excessive in rooms	2,1	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	0,0	Room heating	0,0
Heating of rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	2,9	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	33,6	Wind mills	0,0

SHUTTERS - MANUAL

Hours > 21	1573	1573
Hours > 27	89	89
Hours > 28	46	46

Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total ene
76,6	0,0	
Total energy requirement		

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
57,4	0,0	57,4
Total energy requirement		11,5

Energy frame BR 2018

Without supplement	Supplement for special conditions	Total energy frame
33,0	0,0	33,0
Total energy requirement		11,5

Energy frame low energy

Without supplement	Supplement for special conditions	Total energy frame
27,0	0,0	27,0
Total energy requirement		11,5

Contribution to energy requirement		Net requirement	
Heat	7,1	Room heating	7,1
El. for operation of bulding	2,9	Domestic hot water	13,1
Excessive in rooms	0,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	0,0	Room heating	0,0
Heating of rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	2,9	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	33,5	Wind mills	0,0

SHUTTERS - AUTOMATIC

Hours > 21	1355	1355
Hours > 27	44	44
Hours > 28	13	13

Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total ene
76,6	0,0	
Total energy requirement		

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
57,4	0,0	57,4
Total energy requirement		11,4

Energy frame BR 2018

Without supplement	Supplement for special conditions	Total energy frame
33,0	0,0	33,0
Total energy requirement		11,4

Energy frame low energy

Without supplement	Supplement for special conditions	Total energy frame
27,0	0,0	27,0
Total energy requirement		11,4

Contribution to energy requirement		Net requirement	
Heat	7,0	Room heating	7,0
El. for operation of bulding	2,9	Domestic hot water	13,1
Excessive in rooms	0,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	0,0	Room heating	0,0
Heating of rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	2,9	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	33,5	Wind mills	0,0

SHUTTERS AND CURTAINS

Hours > 21	1405	1405
Hours > 27	44	44
Hours > 28	15	15

Key numbers, kWh/m² year

Renovation class 2

Without supplement	Supplement for special conditions	Total ener
76,6	0,0	
Total energy requirement		

Renovation class 1

Without supplement	Supplement for special conditions	Total energy frame
57,4	0,0	57,4
Total energy requirement		13,3

Energy frame BR 2018

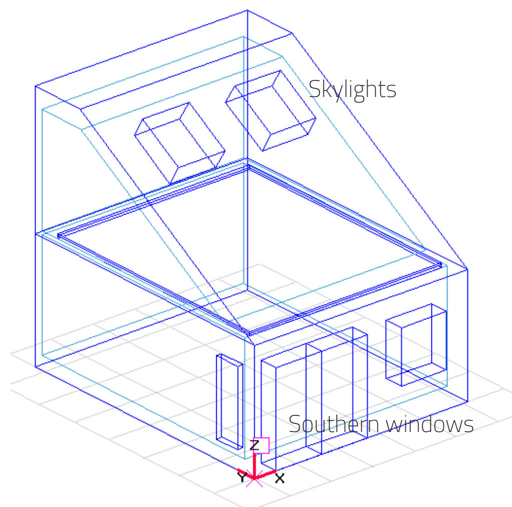
Without supplement	Supplement for special conditions	Total energy frame
33,0	0,0	33,0
Total energy requirement		13,3

Energy frame low energy

Without supplement	Supplement for special conditions	Total energy frame
27,0	0,0	27,0
Total energy requirement		13,3

Contribution to energy requirement		Net requirement	
Heat	6,9	Room heating	6,9
El. for operation of bulding	2,9	Domestic hot water	13,1
Excessive in rooms	2,0	Cooling	0,0

Selected electricity requirements		Heat loss from installations	
Lighting	0,0	Room heating	0,0
Heating of rooms	0,0	Domestic hot water	0,0
Heating of DHW	0,0		
Heat pump	0,0	Output from special sources	
Ventilators	2,9	Solar heat	0,0
Pumps	0,0	Heat pump	0,0
Cooling	0,0	Solar cells	0,0
Total el. consumption	33,6	Wind mills	0,0



APPENDIX 10: BE18 - INPUTS AND RESULTS

Be18 model: Be18 - Small southern gorup		Dato 25.05.2020 21.51			
Klima: Denmark					
Skæring Bæk - Masterprojekt					
Bygningen					
Bygningstype	Sammenbyggede boliger				
Antal boligenheder for sammenbyggede boliger	1				
Rotation	16,0 deg				
Opvarmet bruttoareal	334,0 m²				
Areal opvarmet kælder	0,0 m²				
Areal eksisterende / anden anvendelse	0,0 m²				
Opvarmet bruttoareal inkl. kælderandel	334,0 m²				
Varmekapacitet	80,0 Wh/K m²				
Normal brugstid	168 timer/uge				
Brugstid, start - slut, kl	0 - 24				
Beregningsbetingelser					
Beregningsbetingelser	BR: Aktuelle forhold				
Tillæg til energirammen	0,0 kWh/m² år				
Varmeforsyning og køling					
Grundvarmeforsyning	Fjernvarme				
Elradiatorer	Nej				
Brændeovne, gasstrålevarmere etc.	Nej				
Solvarmeanlæg	Nej				
Varmepumper	Nej				
Solceller	Nej				
Vindmøller	Nej				
Mekanisk køling	Nej				
Rumtemperaturer, setpunkter					
Opvarmning	20,0 °C				
Ønsket	23,0 °C				
Naturlig ventilation	24,0 °C				
Mekanisk køling	25,0 °C				
Opvarmning lager	15,0 °C				
Dimensionerende temperaturer					
Rumtemp.	20,0 °C				

Udetemp.	-12,0 °C				
Rumtemp. lager	15,0 °C				
Ydervægge, tage og gulve					
Bygningsdel	Areal (m²)	U (W/m²K)	b	Dim.Inde (C)	Dim.Ude (C)
Foundation	211	0,09	1		10
Roof	217	0,09	1		
Walls	216	0,12	1		
Walls to shed	12	0,12	1		0
Ialt	656	-	-	-	-
Fundamenter mv.					
Bygningsdel	l (m)	Tab (W/mK)	b	Dim.Inde (C)	Dim.Ude (C)
Foundation line	72	0,04	1		
Vinduer	191,4	0,04	1		
Ialt	263,4	-	-	-	-

Vinduer og yderdøre													
Bygningsdel	Antal	Orient	Hældn.	Areal (m²)	U (W/m²K)	b	Ff (-)	g (-)	Skygger	Fc (-)	Dim. Inde (C)	Dim. Ude (C)	Ot
Syd åbent	1	191	90	17,4	0,8	1	0,8	0,63	A	0,6			0
Syd skygge	1	191	90	5,8	0,8	1	0,8	0,63	B	0,6			0
Vest stue	1	270	90	1	0,8	1	0,7	0,63	C	1			0
vest 1. sal	1	270	90	1,8	0,8	1	0,7	0,63		1			0
Nord dør	1	0	90	8,4	0,8	1	0	0,63		1			0
Nord stue ude	1	0	90	4,2	0,8	1	0,7	0,63	E	1			0
Nord stue hjørne	1	0	90	0	0,8	1	0,7	0,63	F	1			0
Nord 1. sal fri	1	0	90	8,4	0,8	1	0,7	0,63		1			0
Nord 1. sal hjørne	1	0	90	2,8	0,8	1	0,7	0,63	G	1			0
Øst stue skygge	1	90	90	0,3	0,8	1	0,7	0,63	H	1			0
Øst stue fri	1	90	90	0,3	0,8	1	0,7	0,63		1			0
Øst 1. sal fri	1	90	90	0	0,8	1	0,7	0,63		1			0
Øst 1. sal hjørne	1	90	90	0	0,8	1	0,7	0,63	I	1			0
Roof Nord	1	0	7	0	0,8	1	0,7	0,63		0,75			0
Roof syd	1	180	30	13	0,8	1	0,7	0,63		0,75			0
Ialt	15	-	-	63,4	-	-	-	-	-	-	-	-	

Skygger					
Beskrivelse	Horisont (°)	Udhæng (°)	Venstre (°)	Højre (°)	Vindueshul (%)
Default	15	0	0	0	10
A	15	0	25	0	10
B	37	0	0	0	10
C	30	0	0	0	10
E	15	0	75	0	10
F	15	0	75	70	10
G	15	0	40	0	10
H	15	0	0	80	10
I	15	0	80	0	10
Sommerkomfort					
Gulvareal	0,0 m²				
Ventilation, vinter	0,3 l/s m²				
Ventilation, sommer, 9-16	0,9 l/s m²				
Ventlation, sommer, 17-24	0,9 l/s m²				
Ventilation, sommer, 0-8	0,6 l/s m²				
Internt varmetilskud					
Zone	Areal (m²)	Personer (W/m²)	App. (W/m²)	App,nat (W/m²)	
Beboelse	334	1,5	3,5	0	

Ventilation													
Zone	Areal (m²)	Fo, -	qm (l/s m²), Vinter	n vgv (-)	ti (°C)	El-VF	qn (l/s m²), Vinter	qi,n (l/s m²), Vinter	SEL (kJ/m³)	qm,s (l/s m²), Sommer	qn,s (l/s m²), Sommer	qm,n (l/s m²), Nat	qn,n (l/s m²), Nat
4* Lejligheder Gennemsnit ifl BSim	266	1	0,3	0,9	20	Nej	0,03	0	0,8	0,7	2,36	0	0

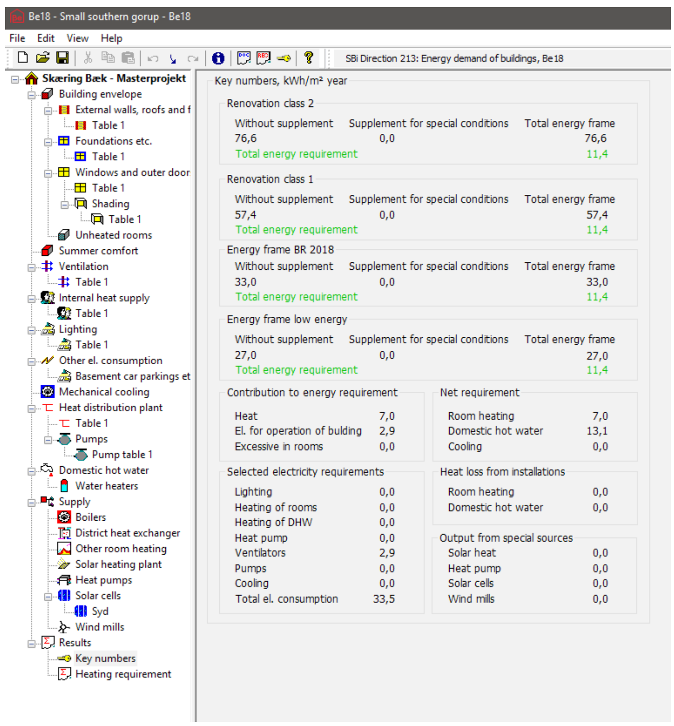
Mekanisk køling					
Beskrivelse	Mekanisk køling				
Andel af etageareal	0				
El-behov	0,00 kWh-el/kWh-køl				

Belysning											
Zone	Areal (m²)	Almen (W/ m²)	Almen (W/ m²)	Belys. (lux)	DF (%)	Styring (U, M, A, K)	Fo (-)	Arb. (W/ m²)	Andet (W/ m²)	Stand-by (W/ m²)	Nat (W/ m²)
Andet elforbrug											
Udebelysning	0,0 W										
Særligt apperatur, brugstid	0,0 W										
Særligt apperatur, altid i brug	0,0 W										
Parkeringskældre mv.											
Zone	Areal (m²)	Almen (W/ m²)	Almen (W/ m²)	Belys. (lux)	DF (%)	Styring (U, M, A, K)	Fo (-)	Arb. (W/ m²)	Andet (W/ m²)	Stand-by (W/ m²)	Nat (W/ m²)

Varme-behov	0,00 kWh-varme/ kWh-køl				
Belastningsfaktor	1,2				
Varmekap. faseskift (køling)	0 Wh/m²				
Forøgelsesfaktor	1,5				
Dokumentation					
Varmefordelingsanlæg					
Opbygning og temperaturer					
Fremløbstemperatur	55,0 °C				
Returløbstemperatur	40,0 °C				
Anlægstype	2-streng	Anlægstype			
Pumper					
Pumpetype	Beskrivelse	Antal	Pnom	Fp	
Konstant drift året rundt	Vand	0	50,0 W	0	
Konstant drift året rundt	Varme	0	90,0 W	0	
Varmerør					
Rørstrækninger i fremløb og returløb	l (m)	Tab (W/mK)	b	Udekomp (J/N)	Afb. sommer (J/N)
Vandrør	0	0,17	1	N	N
Varmt brugsvand					
Beskrivelse	Varmt brugsvand				
Varmtvandsforbrug, gennemsnit for bygningen	250,0 liter/år pr. m²-etageareal				
Varmt brugsvand temperatur	55,0 °C				

Vandvarmere					
Elvandvarmer					
Beskrivelse	Elvandvarmer				
Andel af VBV i separate el-vandvarmere	0				
Varmetab fra varmtvandsbeholder	0,0 W/K				
Temperaturfaktor for opstillingsrum	1				
Gasvandvarmer					
Beskrivelse	Gasvandvarmer				
Andel af VBV i separate gasvandvarmere	0				
Varmetab fra varmtvandsbeholder	0,0 W/K				
Virkningsgrad	0,5				
Pilotflamme	50,0 W				
Temperaturfaktor for opstillingsrum	1				
Fjernvarmeveksler					
Beskrivelse	Ny fjernvarmeveksler				
Nominel effekt	0,0 kW				
Varmetab	0,0 W/K				
VBV opvarmning gennem veksler	Nej				
Vekslertemperatur, min	0,0 °C				
Temperaturfaktor for opstillingsrum	0				
Automatik, stand-by	0,0 W				
Anden rumopvarmning					
Direkte el til rumopvarmning					
Beskrivelse	Supplerende direkte rumopvarmning				
Andel af etageareal	0				
Brændeovne, gasstrålevarmere etc.					
Beskrivelse					
Andel af etageareal	0				
Virkningsgrad	0,4				
Luftstrømsbehov	0,1 m³/s				
Solvarmeanlæg					
Beskrivelse	Nyt solvarmeanlæg				
Type	Kombineret				
Solfanger					
Areal 230,0 m²	Start effektivitet 0,8	-			

Varmetabskoefficient a1 3,5 W/m²K	Varmetabskoefficient a2 0,0 W/m²K	Vinkelafhængighed 0,9			
Orientering S	Hældning 20,0 °	-			
Horisont 10,0 °	Venstre 0,0 °	Højre 0,0 °			
Rør til solfanger					
Længde 0,0 m	Varmetab 0,00 W/mK	Veksler 0,8			
El					
Pumpe i solfangerkreds 50,0 W	Automatik, stand-by 5,0 W				
Solceller					
Beskrivelse	Syd				
Solceller					
Areal 117,0 m²	Orientering s	Hældning 30,0 °			
Horisont 10,0 °	Venstre 5,0 °	Højre 0,0 °			
Diverse					
Peak power 0,175 kW/m²	Virkningsgrad 0,75				



APPENDIX 11: LCA RESULTS

To be able to compare the project and figure out, what have been gained by optimizing structures in LCAByg, every construction par have been analyzed. It is important to state, that this is merely an estimate and a complete Life cycle analyzis would most likely give different values. The analyzis have also been made without solar panelse, which can add a considerable amount of energy as well.

The LCA have been made on the same building group as the Be18 calculations, and are therefore for 4 units with a total floor area of 334 m^2.

LCA-ESTIMATES FOR THE ENTIRE CONSTRUCTION

	Non-renewable [kWh/m^2]			Renewable energy			Total primary energy		
	A1-3	B4	C3+4	A1-3	B4	C3+4	A1-3	B4	C3+4
Outer walls	106,9	0,0	0,6	57,6	0,0	-168,7	164,5	0,0	-168,1
Unit dividing walls	7,0	0,0	5,9	0,2	0,0	0,4	7,2	0,0	6,3
Internal walls	60,9	0,0	6,1	11,3	0,0	-593,7	72,2	0,0	-587,6
Ceiling - lowered	71,6	0,0	2,5	378,3	0,0	-23,5	449,9	0,0	-21,0
Ceiling - visible structure	216,2	75,1	2,3	189,9	1,8	-267,9	406,1	76,9	-265,6
Floor slab	217,1	75,1	1,7	93,1	1,8	-179,8	310,3	76,9	-178,0
Ground slab	269,0	0,0	9,3	382,7	0,0	-9,7	651,7	0,0	-0,5
Line foundation [m]	615,0	0,0	8,8	35,3	0,0	0,9	650,3	0,0	9,7

	Area [m²]	Embodied energy (A1-3) [kWh]	Recurring embodied energy (B4) [kWh]	Demolition energy (C3+4) [kWh]
Outer walls	228	37499	0	-38324
Unit dividing walls	135	966	0	851
Internal walls	182	13148	0	-106941
Ceiling - lowered	58	26093	0	-1217
Ceiling - visible structure	159	64567	12233	-42226
Floor slab	86	26682	6617	-15310
Ground slab	211	137500	0	-101
Line foundation [m]	72	46823	0	699
Total		353278	18850	-202568
Total floor area [m²]	334			
Total energy use [kWh/m²]		1058	56	-606