CLIMATE RESILIENCE IN ARCHITECTURE

IIDA SIPONMAA A MASTER'S THESIS

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Iida Siponmaa

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EXAMINER

Assistant professor Sofie Pelsmakers, Tampere University

SUPERVISORS

Assistant professor Sofie Pelsmakers, Tampere University

University instructor Teemu Hirvilammi, Tampere University

ABSTRACT

Iida Siponmaa: Climate resilience in Architecture
Tampere University
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Climate resilience addresses climate adaptation with an outlook that change is a natural state of matters and a system can adapt to them while maintaining a capacity for further transformation and adaptation (Nelson & al. 2007). The goal of climate resilience is written in the Paris Agreement alongside emission mitigation and climate adaptation (United Nations 2015). In this thesis the understanding of the meaning of this goal for architectural design is studied by cutting across different scales of predictions of impacts, risks they pose, and responding policy and design. The aim is to form a comprehensive idea on relevant information on the ecological impacts of climate change and resilient design measures to gain understanding on improvement of the climate resilience of current residential architecture in Helsinki, Finland.

The background for understanding the impacts and risks related to the climate crisis is based on current climatic research knowledge reported by IPCC (International panel on climate change) and several meteorological studies specific to Finland. This information is discussed in relation to current institutional climate action to analyse how the regulative parties on different levels are responding to the crisis. The risks posed to the built environment by the ecological impacts of climate change, such as rising temperatures, increasing precipitation and flooding are studied. Responding urban and building design measures, such as green and blue structures, are speculated and analysed further, before the presentation of a conceptual design of a residential area. The design concept is an effort to express resilient building design aspects and is located in a typical coastal new residential area in Helsinki. The research aims to understand what are the ecological climatic impacts in Helsinki, Finland that create risk to our built environment and what kind of design solutions could respond to these changes in a resilient manner.

Key words: climate resilience, climate change, climate adaptation, sustainability, architecture

TIIVISTELMÄ

Iida Siponmaa: Ilmastojoustavuus arkkitehtuurissa
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Ilmastoresilienssi käsittelee sopeutumista ilmastonmuutokseen lähtökohdasta, jossa muutos on luonnollinen olotila ja näihin muutoksiin on mahdollista sopetua samalla säilyttäen kyky muutokseen ja sopeutumiseen myös jatkossa (Nelson & al. 2007). Ilmastoresilienssi on kirjattu tavoitteeksi Pariisin ilmastosopimukseen päästöjen vähentämisen ja erityisesti ilmastosopeutumisen ohella (United Nations 2015). Ilmastoresilienssin merkitystä arkkitehtuurille pohditaan tässä työssä leikaten eri mittakaavojen ilmastovaikutusten ja -ennusteiden läpi. Huomioon otetaan ilmastonmuutoksen vaikutuksien aiheuttamat riskit ja niihin vastaavat toimet ja suunnitelmat. Tavoitteena on muodostaa kokonaisvaltainen käsitys oleellisesta tiedosta ilmaston ekologisista vaikutuksista ja joustavista sunnitteluratkaisuista, ja saavuttaa ymmärrys asuinrakentamisen ilmastoresilienssin parantamisesta nykyarkkitehtuurin keinoin, keskittyen sijaintina Helsinkiin.

Ilmastokriisin vaikutuksia ja riskien ymmärrystä on taustoitettu tämänhetkisen Suomeen keskittyneen ilmastotutkimustiedon ja IPCC:n (International panel on climate change) uusimpien saatavien raporttien avulla. Tätä taustatietoa verrataan tämänhetkisiin ilmastotoimiin, jotta saavutetaan kokonaiskuva, millaiset toimet ohjaavat suunnittelua eri tasoilla. Ilmastonmuutoksen ekologiset vaikutukset, kuten nousevat lämpötilat, lisääntyvät sateet ja tulvat, sekä niiden aiheuttamat oleelliset riskit käydään läpi. Näihin muutoksiin vastaavia kaupunki- ja rakennussuunnitteluratkaisuja spekuloidaan ja niiden joustavuutta analysoidaan, ennen viimeisen osion asuinalueen konseptisuunnitelmaa. Konseptisuunnitelman pyrkimys on esitellä joustavia suunnitteluratkaisuja ja se sijoittuu paikalliseen kontekstiin tyypilliselle uudelle asuinalueelle rannikon tuntumaan Helsingissä. Tutkimus tähtää laajentamaan ymmärrystä ilmastonmuutoksen ekologisista vaikutuksista, jotka muodostavat riskejä rakennetussa ympäristössä Helsingissä ja millaisilla suunnittelukeinoilla näihin muutoksiin voitaisiin vastata ilmastojoustavasti.

Avainsanat: ilmastojoustavuus, ilmastoresilienssi, ilmastonmuutos, sopeutuminen, kestävä kehitys, arkkitehtuuri

GLOSSARY

ADAPTATION	Actions that increase capacity to adjust to or absorb the impacts of climate change
ANTHROPOGENIC	Caused by humans
CCA	Climate change adaptation
CLT	Cross-laminated timber
GHG	Greenhouse gas
MITIGATION	Actions that lower emissions to reduce the resulting environmental impacts
RCP	Representative concentration pathways (pitoisuuksien kehityskulun skenaariot)
UHI	Urban heat island (lämpösaareke)
PLUVIAL FLOODING	Temporary flooding due to a heavy rainfall event/a cloudburst
FLUVIAL FLOODING	Flooding due to overflowing of an existing watershed

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PREFACE

Our atmosphere is warming up and causing a global climate change. The impacts vary locally, and in order to mitigate emissions and lower future temperature rise, the effects of inevitable changes in our climate need to be considered (see Ch.2). As humans are responsible for this phenomenon, we need to protect the natural environment and all ecosystems, but also our own environment to avoid economic, social and further environmental impacts (see Ch.4).

Building use and their construction combined are responsible for a significant 38% of emissions in Finland, but the emissions from construction can be decreased. The mitigative value of retrofitting and renovation of existing buildings is evident. Building anything new will always release some emissions. Increasing the efficiency of utilization of an existing building, repairing an old building or modification of an existing one, and reusing parts from an old building are all good options to mitigate the emissions of the construction sector. (RT 2020) While the use of these measures is furthered, new construction occurs.

In addition to being a source of emissions, buildings are also our shelter from their impact on our climate. Climatic changes will increasingly threaten our habitation in the future if they are not designed to adapt. Predictions for future climate conditions become more uncertain the further we look into the future, but as the lifetime of a new building should exceed the time span of the more certain, nearby scenarios, we need to be able to design for an uncertain future.

International, national and local climate goals are guiding our climate action with targets, such as emission reduction of 80% in Helsinki by 2035 (Helsinki 2018). Nevertheless, mitigation alone is not enough to avoid the entirety of the impending climate crisis and adaptation plans are initiated to reduce further damage. However, the ultimate goal is to mitigate and adapt while maintaining the capacity to continue to do so in the future as well.

IPCC (2014) definition for resilience is ”the capacity of social, economic and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation”.

Within this definition, climate resilience in architecture can be specified here to include coping with disastrous events, trends and disturbances, such as floods, temperature and sea-level rise and increasing precipitation, resulting from climate change. Urban and building design measures are defined to act as the responsive and reorganizable factors of environmental systems such as cities and buildings to help them preserve their essential function, identity and structure while maintaining the capacity for adaptation, learning and transformation.

Notably, the definition of climate adaptation is limited here to actions that help these systems absorb and adjust to changes that are occurring or will probably occur due to climate change, and is accordingly included in climate resilience. Climate resilience includes adaptation to change while maintaining essential function, but resilience additionally maintains the capacity for self-renewal and transformation as well, and considers occurring change as the natural state. (Nelson & al. 2007)

SCOPE AND STRUCTURE

In this thesis, climate resilience in architecture is studied with a focus on climate adaptive design measures. The matter is studied in its temporal and regional context to comprehensively improve understanding of climate resilience in current and local architecture.

To build sustainably, the building sector needs to simultaneously mitigate emissions, adapt to known and unknown changes, and to improve resilience. Emission mitigation could be done by reducing construction overall, or by repairing existing buildings, but previous inconsideration of circularity and resilience in construction, and megatrends such as urbanisation, are challenging to these manners of approach. Meanwhile, new construction in growing areas such as Helsinki keeps on getting built (discussed further in Ch. 1). Climate adaptation and resilience in new construction are secondary in their urgency compared to emission mitigation, but still need to be addressed alongside mitigation to reduce negative impacts of climate change and ease future mitigation and adaptation. The focus of this thesis is therefore on climate resilience properties of current and future construction, as this allows for an opportunity to improve understanding on the relationship of the climatic future and resilient and adaptive measures in architecture.

As resilience enhancing measures in architecture vary locally according to specific climatic conditions and the initial function that is to be maintained, designing a resilient environmental system requires risk and vulnerability assessment to support the justification of these measures.

Climate change and climatic future, its local impacts, and institutional action responding to climate change are all assessed through a literature review in the first part, with a scope of specifically looking into climatic changes in the future of the Finnish climate, their impacts and posed risks to built environment and its users in order to create a framework for the thesis. In the second part, the relationship between architecture and climate resilience is reflected and architectural design solutions are examined and analysed through case studies from the point of view of climate resilience. Lastly, a concept of a residential building in an area with a typical climate for Helsinki is designed, focusing on climate resilient design aspects to study how research translates to design.

PART ONE

1 INTRODUCTION

In this chapter, I will go through the definition of climate resilience in the context of current Finnish construction, its place among other climate action and sustainability goals and how it is studied in this thesis.

My research problem is essentially to discover and design responsive and reorganizable factors to specific environmental systems. In this case, the environmental systems in question are apartment buildings in Helsinki to be designed for housing as their initial purpose. The scope is limited to new housing buildings in Helsinki intentionally, as predictions by Vuori & Kaasila (2019) show that population of Helsinki is expected to grow over 25% in the next 30 years, and several new housing areas are under development. Average production of new apartments was 4500 per year in Helsinki during 2014-2018, only 10% of which was due to modification of use. Moreover, the goal for 2019-2021 has been to construct 7000 new apartments per year.

In the light of these numbers, climate resilience issues of new construction specifically in Helsinki are currently relevant. The fundamental question is if this amount of new construction is actually needed in Helsinki area, or could it possibly be replaced by modification of use and retrofitting and renovating, remains. Meanwhile, by studying how resilience can be increased in building design of new construction, the demand of future research on retrofitting buildings can be decreased, closing a loop where we design non-resilient buildings and spend future resources to adapt them. Additionally, adaptive measures can be studied broadly and possibly applied in renovation projects to enhance adaptivity and resilience.

As outlined above, the main problems, or threats, addressed in this work include disastrous events, trends and disturbances resulting from climate change. To cover these, a comprehensive study on the background of climate change, its impacts, and risks specific to Finland and Helsinki is necessary and will be discussed in the following chapters. The preservation of the essential function, identity and structure of the buildings, as well as maintaining the capacity for adaptation, learning and transformation will be handled further in the chapter seven.

The overall sustainability of the scope and its position among all climate action requires some further elaboration. Climate action is often divided to mitigation and adaptation with a goal of climate resilience, e.g. in the Paris Agreement (United Nations 2015).

Mitigation is more urgent and currently the primary concern, whereas adaptation is considered as the means to respond to future impacts. These definitions help define the aspects of climate change and help analyze relationship between the causes and impacts of climate change and responsive methods in the construction sector. As the lifetime of new buildings could and should exceed a human lifetime, resilience needs to be emphasized as it links climate adaptation, defined here as absorption of or adaptation to change, to maintenance of the capacity for further adaptation and transformation. This could possibly increase the lifespan of a building regardless of the adaptive measures taken to improve resilience towards current ecological change. Resilience furthermore helps with mitigating future emissions as well as current ones.

As climate adaptation is adjustment to and absorption of change, climate resilience includes a dual function of this climate adaptation and the maintenance of capacity for self-renewal, re-organization, transformation and profit from known and yet unknown changes. (Nelson & al. 2007) Adaptation currently in the context of Finnish urban planning (see Ch. 6) is mainly responsive to known climatic changes. Even though some design measures that are considered climate adaptive improve the climate resilience of a building, by absorbing climate impact, not all of them improve resilience. For example, some climate adaptive building design measures, may decrease resilience as their further modification or repair is more complicated, thus lowering the capacity for further transformation.

In such cases the relevance of these measures needs assessment in their context. Could the climatic threat in this location be responded to in some other way? (see part two).

Temporally and regionally aware climate resilience, inclusive of comprehensive sustainability, such as the relevant aspects of mitigation, adaptation and circularity, should therefore be the goal in sustainable building design. To clarify, urban planning level of design and institutional policy have the capacity to respond to larger scale trends, such as avoiding construction on flooding risk areas or addressing demolition trends in growing areas, and responding to them according to evaluations of vulnerability and exposure. Building design instead, needs to recognize the local circumstances and the future conditions as well as the different aspects of sustainability related to those conditions. For example, focusing simply on adaptive measures without mitigation would create a cycle where a building prepares to adapt to a change it is assisting to create. A narrow focus on mitigation may lead to buildings that emit less but fail in their ability to adapt or transform possibly resulting in less durability. High focus on circularity would be unnecessary in an area with low expectations of change.

When considering the sustainability of a building, the lifespan is important, yet a very uncertain factor. A study by Huuhka & Lahdensivu (2016) shows that 80% of demolished building area between 2000 and 2012 was in under 60-year-old buildings and the demolition of these buildings was more linked to their function and size rather than their age or materials. Non-residential buildings built of durable materials such as concrete or steel, were shown to be demolished at a younger age than residential buildings. In the light of this statistic, the durability of the building material has less influence over the length of the lifespan of a building than some of its other aspects.

Yet, the choice of building materials and the way they are used influences the emissions of the construction phase, the use phase and eventually the demolition through their potential for reuse. While their durability may not be of the primary importance in the length of a building's lifespan, well thought choices can increase ecological adaptivity and improve resilience in changing climate conditions.

As climate resilience responds to climatic changes that may be a trend developing over time, such as temperature rise or sudden extreme weather event, like a pluvial flood, climate resilient measures need to be selected accordingly already in the design phase to respond to these threats when they occur. This is crucial as buildings we build today, should endure changes and last several decades to the future. In this sense, a climate resilient design needs to, not only consider the emissions and potential benefits of certain materials or measures during any phase of the lifespan, but they also cannot reduce the overall resilience of the design and allow for transformation in a shorter timeframe. (Pelsmakers et al. 2020, 269) As climate change impacts are just beginning to show, adaptation measures' justification also relies on future predictions and their potential risk. Furthermore, climate impacts appear differently around the world, and risks need to be studied locally and understood and implemented on different levels.

To summarize, this thesis is an effort to comprehensively contemplate aspects of building design that affect its climate resilience. The emphasis is on adaptation to those climatic changes that are highly possible in the near future to the specific location of Helsinki in the environmental systems of residential buildings, favouring the solutions that create less emissions now and in the future, create flexibility, and allow for transformation to create more resilience towards any changing condition.

2 CLIMATE CHANGE

Excessive anthropogenic pressure on our environment during the last century has raised concerns of the limits of our planetary systems. To assess global impacts of human activity comprehensively, a concept of nine planetary boundaries and their estimated quantified limits, was proposed by Rockström et al. (2009). Consequences of crossing any of these boundaries may result in global climatic changes, effects on the other systems' balance and irreversible environmental events. Climate change is one of the earth-system processes with a quantified boundary that humans have already transgressed with anthropogenic greenhouse gas (GHG) emissions. This has caused the atmosphere and the ocean to warm, moving us to a zone of uncertainty and increased risk (Rockström et al. 2009; IPCC, 2014).

2.1 CLIMATE ACTION AND THE FUTURE

To predict the climatic changes, projections for the future are studied with climate models. An internationally used method presented by van Vuuren et al. (2011), presents originally four representative concentration pathway (RCP) scenarios to be used for assessment of possible climate change impacts in a comparable way. These scenarios take a number of variables into account, such as GHG - and air-pollutant emissions, land and energy use, and socio-economic and technological change to better predict future conditions. The four pathways, RCP2.6, RCP4.5, RCP6.0, and RCP8.5, describe the future climate as radiative forcing values (W/m2), and present plausible scenarios for the end of the 21st century. The scenarios are numbered according to the predicted radiative forcing values, which relate to the

intensity of the greenhouse effect. RCP2.6 depicts a scenario where emissions are successfully mitigated during the next century, RCPs 4.5 and 6.0 are intermediate ones, and RCP 8.5 depicts a worst-case scenario (figure 1). If we were to continue without an effort to mitigate emissions, pathways would lead somewhere around RCPs 6.0 and 8.5. (Van Vuuren et al. 2011; IPCC 2014)

The international goal for global warming limit was set in 2015 in the United Nations' Paris Agreement to 2°C with ambitions to remain at 1,5 °C above pre-industrial levels. The Paris Agreement is a legally binding treaty within the United Nations Framework Convention on Climate Change that was agreed upon to address climate change. (United Nations 2015). The RCP2.6 scenario is likely to reach the goal of staying under 2°C, but this pathway's yearly CO_2 emissions still place us over the planetary boundary of climate change for a significant period of time. The planetary boundary of climate change was set to a concentration of 350 ppm of atmospheric CO_2 and we've been transgressing this since the last century (figure 1). To perceive the current situation, the annual average atmospheric CO_2 concentration in the end of 2020 was 413.95 ppm (NOAA 2021). Because of this, climate change induced extreme weather phenomena, such as heat waves, heavy precipitation, storms, flooding and sea-level rise will affect natural and human systems globally (IPCC 2014). Climate related risks for these systems are higher depending on the rate, peak, and the duration of warming. The amount of these risks depends on location, level of development and vulnerability, and the implementation of adaptation and mitigation options. If the warming continues its current increasing rate, we are likely to reach 1,5 °C between 2030 and 2052. (IPCC 2018)

Therefore, the main three targets of the Paris Agreement are to limit the global warming to preferably 1.5 °C above pre-industrial levels, to increase the ability to adapt to climate change impacts and add climate resilience, further low-GHG emission development and to guide financial flows towards low-GHG emissions and climate-resilient development. Implementation of the agreement is to be carried out with consideration of different national circumstances. (United Nations 2015).

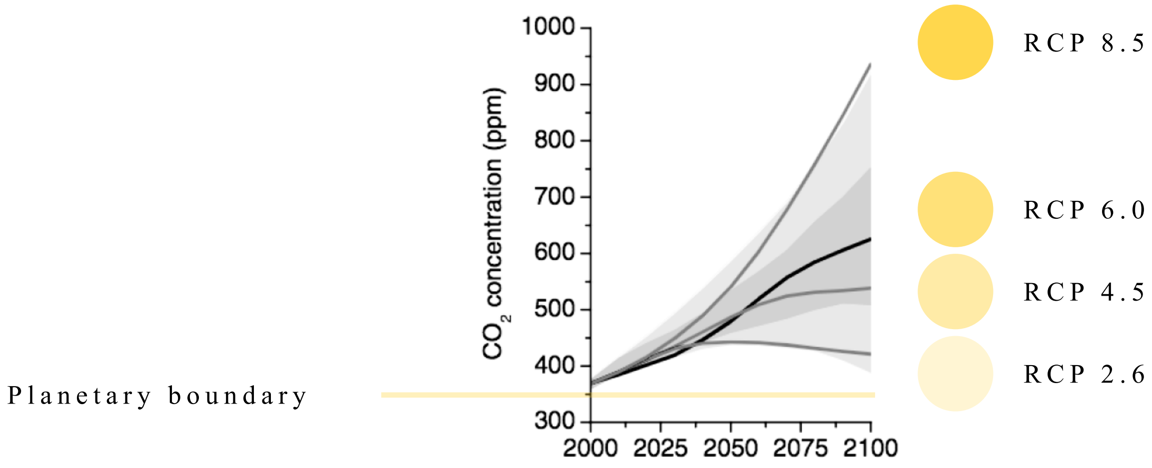


Figure 1. Trends in GHG consentrations and representative consentration pathways adapted from Van Vuuren et al. (2011)

The European Union, responsible for 8,6% (with UK) of the world's GHG emissions in 2020 (UNEP 2020), aims to carbon neutrality by 2050 with the European Green Deal. Building and renovating strategy according to the Green Deal is to further renovation, energy-efficiency, circular economy, digitalization and climate proofing and to enforce rules on energy performance (European Commission 2020). In 2013 the EU adopted an EU adaptation strategy, which will be renewed in 2021. Objectives in the current version are to promote action by member states, for example by encouraging national adaptation plans, climate-proofing at EU level, and furthering better informed decision-making. (European Union 2013)

National climate policy in Finland follows the Climate change act from 2015, with goals to reduce GHG emissions by 80 % by 2050 and to reach goals of mitigation and adaptation of climate change. (Ministry of the Environment 2015) This was evaluated to be inadequate by the Finnish Climate Change Panel in regard to the Paris Agreement 1.5 °C goal (Ollikainen et al. 2019). The current government of Finland has set a goal of carbon neutrality by 2035 in their Programme from 2019, exceeding the speed required at EU level. To achieve this target, medium-term climate change policy is set to be updated in 2021. The aim is to reach nearly emission-free electricity and heat production by the end of 2030's, reduce carbon footprint of construction and advance circular economy and climate friendly sustenance policies. (Ministry of the Environment n.d.)

Disastrous events, trends or disturbances deriving from the climate change, are a result of the greenhouse gas effect and the temperature rise. It can be concluded that the amount of atmospheric greenhouse gas furthering climate change has reached a critical point, and this will impact our environment regardless of climate action. The future climate will evidently be different from today's climate, but the amount of this change is however dependent on the success of climate action. Institutional climate action signals motivation towards emission reduction and ambitious goals have been set to limit global warming. Also, the need for climate adaptation has been recognized and, at least in Finland, the goals have been made even more ambitious than before to mitigate possible further impacts. The imminent and the possible impacts of climate change to the Finnish climate will be handled further in the next chapter.

3

CLIMATE CHANGE IMPACTS IN FINLAND

The impacts of climate change to the climate of Finland are examined in this chapter. The risk they pose to our built environment and people are examined in the following chapter.

Impacts of climate change occur differently around the world, influenced by specific local conditions. Since the 1980s, global warming has accelerated in the Northern Hemisphere, mainly due to the ratio of land to ocean, which is higher north of the equator (Friedman et al. 2013). Finland is also proximate to the arctic, the reflecting value of which is decreasing as it is melting. For these reasons, we can expect above global mean temperature rises sooner in the North. Humidity is also higher in a warmed atmosphere and its condensing releases extra warmth in arctic areas. Ice cover for the sea will appear later in winter, which allows warmth and moisture to transfer to the lower atmosphere. Cloudiness will increase, and this further constrains loss of heat from atmosphere to space, adding to the temperature rise. (Mäkelä et al. 2016)

While RCP scenarios' temperature rise estimations for the end of the century have much variation, changes in the nearby future in all scenarios are similar. According to Ruosteenoja et al. (2016), after the mid-century, temperatures remain highly dependent on GHG emissions, but regardless of scenario, temperatures in Finland are rising faster than globally. The ratio of annual mean temperature increase in Finland compared to the global mean increase is estimated somewhere between 1.6 to 1.9 relative to years 1981-2010. Therefore, our annual mean temperature rise could vary from over 1,5 times greater to almost double the global mean temperature increase by 2100. As a result, the estimated mean temperature rise in Finland spans from 2°C to 7 °C depending on the future scenario. More specifically, our winters are warming up faster than our summers, and getting even darker, due to increasing cloudiness. The winter-time temperature rise is estimated higher than that of summer with a similar ratio of 1.6 to 1.7. Additionally, we will be losing approximately ten percent of the current wintertime solar radiation.

According to Mäkelä et al. (2016), extreme low temperatures will become notably rarer. Diurnal temperature range is also predicted to decrease significantly, as general cloudiness increases. This results in less variation between day- and night-time temperatures. In the future warm climate, frequent hot temperature extremes are likely to become more common and heat waves will predictably occur more often and last longer (IPCC, 2014). In Finland, summertime hot temperature extremes rise according to mean temperature rise, and thermal discomfort may especially increase in city areas (Mäkelä et al. 2016).

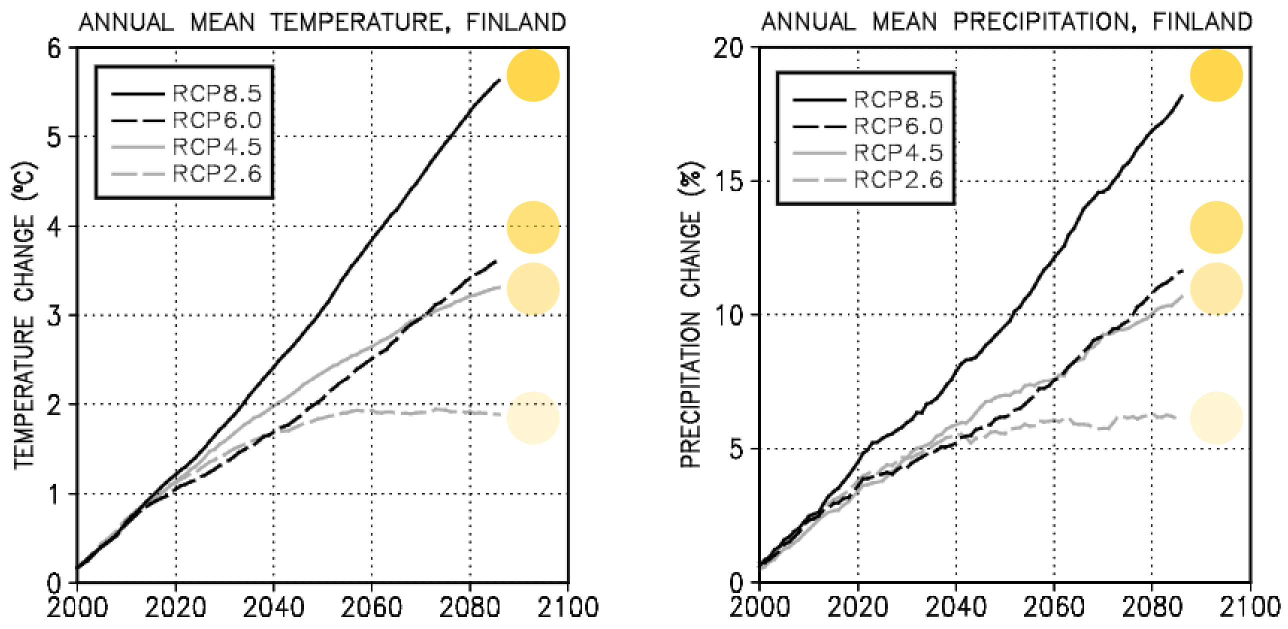


Figure 2. Changes in mean temperature and precipitation adapted from Ruosteenoja et al. (2016)

The urban heat island effect (UHI) is a phenomenon, where temperature is warmer in a dense city compared to its surroundings. The UHI effect has clear seasonal characteristics, as it's caused by solar radiation during summer and anthropogenically through heating of buildings, traffic and industry in winter. Its intensity is defined by thermal properties of city structure as they reserve and release heat. (Drebs 2011)

Climate change may impact these characteristics, as winters get warmer, there will be less need for heating resulting in a less clear UHI effect. In contrast, as temperatures rise and diurnal temperature ranges decrease, summertime UHI phenomenon may intensify as a result of decreasing heat release during cooler night-times. Warmer summers in addition to heatwaves and the urban heat island effect may contribute to thermal discomfort in cities.

Precipitation, like temperature, will also increase throughout the century depending on the scenario after the mid-century. Estimated annual mean precipitation change is nearly linear in the worst-case scenario with a possibility of 30% increase by the end of the century. In case the highly ambitious RCP 2.6 scenario is realized, precipitation increase would even out the mid-century somewhere over a mean 5% change (figure 2). (Ruosteenoja et al. 2016)

Furthermore, it will rain more during winter, or more of the snowfall will land as water. High intensity precipitation events will be more likely than long-duration precipitation events, increasing the possibility of flash floods in cities. Due to intensifying precipitation, extreme snowfall events are possible as well. (Groenemeijer et al. 2016)

Summertime precipitation increase will not be as high as that of wintertime, but heavy precipitation events will occur more often (Mäkelä et al. 2016).

Mean change for surface wind speed in Finland in the future is close to none (Ruosteenoja et al. 2016). However, storm winds are supposed to intensify especially over sea and coastal areas, but there is some uncertainty concerning wind and storm predictions as it is a difficult variable to predict, and the range of results in studies has been large (Groenemeijer et al. 2016; Ruosteenoja et al. 2016).

Global warming causes ice to melt, resulting in sea-level rise, which is imminent even if mitigation policies succeed at stabilizing the temperature rise. This puts all coastal and low-lying areas at risk. (IPCC 2019) However, the geographical distribution of sea-level rise is not even. The geographic position of the Baltic Sea, divided from the North Atlantic Ocean by the Danish Straits, has an impact on how the sea-level will actually change in the Finnish coast. Ocean dynamics, annual and decadal changes, thermal expansion, local meteorology and postglacial rebound all affect the future scenarios. (Johansson et al. 2004) Taking these into consideration the sea-level rise will probably be 24-33 cm for the Gulf of Finland during this century, whereas the Bothnian Bay, more affected by the postglacial rebound, has the average sea-level decline of 24-30 cm. Nevertheless, the uncertainty concerning the sea-level rise in different scenarios result in a large range of possible outcomes for end of the century, e.g. the range for Helsinki is from five cm to over a meter (See figure 3). (Johansson et al. 2014)

Overall, in a global comparison, the geographical location and the postglacial rebound effect lower risks related to sea-level rise in the coast of Finland. According to Pellikka et al. (2018) regional differences in the probability of coastal floods in Finland in the future are expected. Results on flooding correlate to some extent with those of the sea-level rise, indicating diminishing flooding risks for the Bothnian Bay until 2050, due to land uplift and weaker sea-level rise. After that, the risk goes back to current day levels in 2100. In the Gulf of Finland however, probability of a major coastal flood, where the sea-level exceeds 170cm, goes up to fifty floods per century from the current probability of three floods per century. As the study in question was optimized to produce estimates for decision makers to define safe building heights and for climate change adaptation estimates for structures of high importance or value (e.g., hospitals, power plants),

	Change 2000–2100 (cm)			Sea level in 2100 (cm, N2000)		
Tide gauge	Low	Average	High	Low	Average	High
Kemi	−69	−26	25	−49	−6	46
Oulu	−66	−24	28	−46	−3	49
Raahe	−69	−27	25	−49	−7	45
Pietarsaari	−70	−28	24	−51	−9	43
Vaasa	−72	−30	22	−53	−10	41
Kaskinen	−66	−21	35	−46	−2	54
Mäntyluoto	−57	−13	43	−38	6	62
Rauma	−49	−4	52	−30	14	70
Turku	−36	9	65	−17	27	83
Degerby	−38	6	62	−22	22	78
Hanko	−22	24	82	−3	42	100
Helsinki	−15	30	89	5	50	109
Hamina	−12	33	92	8	54	113

Figure 3. Sea level scenarios (Johansson et al. 2014)

it therefore assesses the probability of events instead of providing multiple measures according to the RCP scenarios. The latest recommendations for regular buildings are by Kahma et al. (2014) from a report by the Finnish Meteorological Institute and the set values (280 cm in Helsinki) are based on a probability of one flood per 250 years estimation in 2100 to be safe. Risks from possible wave-action in addition to recommendation height for buildings is assessed separately in each location.

Results of a national scale assessment of climate change impacts on flooding show variation according to location and its watershed characteristics, and dependance on the climate scenario. In general, seasonal variation correlates with climate change impacts to some extent, as springtime flooding should decrease due to diminishing snow accumulation especially in central and southern Finland, and autumn and wintertime flooding risk increases with temperature and precipitation. Signs of increased flooding in central lakes and their outflow rivers were found, yet local characteristics should always be studied independently as climate change impacts do not scale nationally in flooding predictions. (Veijalainen et al. 2010)

In summary, climate change will impact our mean temperatures by increasing wintertime temperature more than summertime temperature. Extreme low temperatures will get rarer. Heatwaves will occur more often, and extreme hot temperatures will be higher than today, and urban heat island effect may intensify this temperature rise in cities during summer.

Winters are getting even darker with cloudiness and more humid. Especially the amount of precipitation will change in the future, following with pluvial and fluvial flooding according to location and season. The global sea-level rise may also cause flooding, overtaking land area more permanently. Because of these changes, all water management will require further consideration as well as preparedness for temperature changes. The combined impacts and their potential environmental, social and economic risks are discussed next.

4

CLIMATE RISK IN FINLAND

The volume of risks, related to climate change, is elevated with exposure and vulnerability of environmental systems. The geographical location of Finland defines much of the severity of climate change impacts, as presented in the previous chapter. Subsequently, the risk that these impacts pose to existing environment in Finland requires some evaluation. Climate change induced threat, in addition to vulnerability, creates environmental, social, and economic risks. Vulnerability is defined by IPCC (2014) as ”predisposition to be adversely affected”. It may consist of a variety of elements, including exposure to harm and lack of capacity to cope and adapt. According to ND-GAIN (2018), the vulnerability of Finland, is overall low in a global comparison, considering human habitat and health, food and water, and ecosystem service and infrastructure. Adaptation challenges exist, e.g. in projected changes in flooding hazard and agriculture capacity, but globally Finland is relatively well equipped to adapt.

Nevertheless, in this chapter, I will look into the reasons for concern listed by IPCC (2018) created to elaborate main impacts and risks across sectors and regions. As the regional climatic impacts of climate change were addressed previously, the possible social, environmental and economic risks related to them and relevant to the construction sector will be discussed here. Positive outcomes and benefit from the climate change will also be addressed.

The three main reasons for concern relevant to climate resilience in cities are extreme weather events and the uneven distribution of impacts, as well as the global aggregate harm i.e., economic, social, and environmental damage, and loss across sectors (IPCC 2018). In the context of built environment these can be diverse. Assessment of the impacts of climatic change in relation to exposure and vulnerability and increasing crisis preparedness accordingly helps in preparation for risk and creating climate resilience posed by climate crisis.

A picture of the future of the Finnish climate is painted in the book Suomen luonto 2100 (the Finnish Nature 2100) by Kerttu Kotakorpi (2021) and the diverse impacts on our various environments are speculated based on research on the climatic development of Finland. The following speculation on the risks posed to built environment by climate change impacts are either presented in, or largely based on the view of the future in this book.

The decreasing solar radiation between December and February will make winters feel like an endless November, and this has health impacts on a national level. Seasonal depression may have the economic impact of millions of euros per year as work efficiency decreases, and suicide rates may go up. (Kotakorpi 2021) Light reflecting snow will arrive later every year. This can be assumed to increase the use of artificial lighting as opposed to natural light and could potentially be addressed in window and spatial design as well as on the reflectiveness in the material choices in buildings and other infrastructure in cities.

The increasing precipitation in wintertime poses multiple risks and challenges to buildings. The load bearing capacity of the ground decreases as it gets moist and the resulting land movement can damage foundations in buildings, which is especially threatening to stone based buildings. While this may influence the choice of construction materials, it also emphasizes the choice of the type of ground we build on. The location and the structural members proximate to the ground should be chosen based on knowledge of exposure to flooding or sliding in landmass. (Kotakorpi 2021)

The nearby future of Southern Finland will experience wintertime temperatures that go frequently below and over zero degrees, creating ice that erodes streets and the ground, as well as buildings facades (Kotakorpi 2021). Stone-based materials that are susceptible to the freeze-thaw cycles, especially in older building stock will be more vulnerable. In Southern Finland, as cold winters become a distant memory, the risk of freeze damage decreases. However, a significant amount of our building stock is in coastal areas of Southern Finland and the increasing precipitation will have an increasing impact on the facades. (Pakkala 2020)

While current requirements for stone-based facades may be sufficient, the question is if materials that are currently considered durable, such as concrete and brick façades, are actually future proof or whether they should be covered more to avoid for example aesthetic damage and should they be replaced with other cladding materials.

Temperature variation may also increase wintertime load on top of the flatter roof structures, as ice is heavier than snow, and furthermore the snow that we get in the future will be moister. The increasing heavy raining events mean snow loads will come suddenly and intensively. This increases the risk to all roof structures. Metal as cladding, for example metal roofs, will also experience increasing corrosion. (Kotakorpi 2021)

As winter rains become more common, the combination of wind and rain becomes more likely and this will become a more severe problem. Wind direction may also increasingly vary and come from any direction as opposed to the currently prevailing South-West winds. Wind driven rain potentially keeps the façade materials damp for longer periods of time and the moisture gets below overhangs more easily, if such structures are designed. Yet, South-facing facades will still be most exposed to climate stress (Pakkala 2020). Wind driven rain is threatening to structures if they are not covered and ventilated sufficiently to allow for drying. Additionally, wood may lose its structural capacity if moisture damage is vast enough. This may also lead to worse indoor air quality and health issues. The changes in wintertime weather will affect the durability of building materials as well as create aesthetic damage.

However, milder winters also have a positive impact. The need for heating will decrease, which is a significant source of emissions in buildings. Seasonal temperatures may become also more suited for passive ventilation in the future, as cooler seasons warm up faster than the summertime temperatures increase. This would lower possible heat loss during cool seasons. Health-related risks from cold weather reduce, but they may also change in their nature. Sleeting becomes more common, and the environment will be icier, resulting in various safety hazards to health.

While rain amounts increase in winter, drought may also occur during other seasons. Especially spring and early summer can be very dry, and strain the groundwater reserves. Furthermore, drought may deteriorate the air quality especially in cities, worsening health issues in airways and allergies (Kotakorpi 2021), which may make it difficult to differentiate them from air quality issues in buildings.

As temperatures rise, warm season will become longer. This provides more efficient growth for the typical conifer favored forests in Finland and ensures and adds to the local resources of wood (Kotakorpi 2021). For resource security, wood may be considered to be favored as a local building material in the future.

A notable reason for concern in addition to weather impacts is the distribution of impact. Uneven distribution of impacts is included in climate risk, for instance due to an aging population, impoverishment or geographical exposure, as these increase vulnerability and predispose to more severe consequences. (IPCC 2018) As the Finnish population is aging, vulnerability to rising summertime temperatures increases (Pilli-sihvola et al. 2018). Rising temperatures in summertime pose a threat to human health, as estimations show, excess deaths related to heatwaves will increase significantly in the latter half of the century (Guo et al. 2018).

This risk can be either decreased or increased by the construction sector in the design of buildings. As noticed by Sukanen (2020) cooling energy consumption may go up in the future if passive and adaptive measures are not utilized to mitigate overheating. Effective mitigation to overheating includes the opportunity for adaptive use of natural ventilation through windows or better yet, larger balcony doors and the use of blinds, and passive methods such as fixed shading and orientation.

The climate risk index of Finland, measuring vulnerability to extreme weather events is nevertheless, relatively low (Germanwatch 2020). Yet, the fact that we are more equipped to cope with climate change, does not mean we can ignore the existing climate risks and possible increasing vulnerability, but highlights our responsibility to mitigate emissions, as the more severe consequences may be endured somewhere else.

One extra concern that can be addressed for positive impact, is ecological and human systems, that are unique and threatened. These are systems that are confined by climate-related conditions and have distinctive properties. For example, in Finland some heritage environments that host endangered species, such as meadows, are endangered themselves (IPCC 2018; WWF n.d.). When planning urban vegetation, this risk can be addressed, by planting endangered species to make an effort to create disappearing environments on e.g., green roofs, parks and courtyards.

The final concern listed by IPCC (2018) is large-scale singular events such as melting of Greenland, which reminds us that while some climatic impacts may be predicted quite accurately, singular sudden events have the potential to tip the climate impacts to an unpredictable direction or intensity.

In summary, climate impacts' threat that could be addressed through design are various, including economic and environmental harm as well as deteriorated living conditions for building users and a threat to their health.

5

CLIMATE ADAPTATION

Climate change adaptation (CCA) is adjustment to expected climate change impacts. Changes in processes, practices and structures are required to mitigate potential economic, ecological and social damage, to adjust to new conditions and furthermore to benefit from emerged opportunities. (UNFCCC n.d.) One of the main goals of the Paris Agreement is that countries and cities develop adaptation solutions and implement them to add resilience and prepare for future. (United Nations 2015) The response to climate impacts and the risks they pose will be discussed in this chapter.

As climatical impacts can be hazardous, abrupt events, such as flash flooding, or slowly increasing, like temperature and sea-level rise, adaptation measures need to include disaster preparedness as well comprehensive resilience.

Sendai framework for disaster risk reduction (2015-2030), endorsed by the UN General Assembly following the 2015 Third UN World Conference on Disaster Risk Reduction (WCDRR) prioritizes understanding ”disaster risks, strengthening governance to manage them, investing in disaster risk reduction for resilience and enhancing disaster preparedness for effective response risk recovery”. Global targets of the framework include addressing vulnerability through ”reduction of global disaster mortality, number of people affected, direct economic loss, disaster damage to critical infrastructure and disruption of basic services”. To improve preparedness, the goal is to e.g. increase availability of early warning systems, which is a so-called soft adaptation measure. These measures include raising awareness on risks across different parties or enabling innovation and may include e.g. informing citizens how to react in case of a flood or a heatwave (European Environment Agency, 2012). Also, for example, setting a level for safe construction is legislative guidance towards disaster risk reduction. While this effectively reduces disaster risk and increases climate adaptive capacity, it can increase emissions due to land use modification, and lower the potential for innovation.

Implementation of the framework on EU level, is addressed in an action plan by the European Commission (2016), which also highlights risk knowledge, overall approach across sectors, risk informed investment and supporting a holistic risk management approach according to the framework. Actions are listed according to these key areas and "disaster risk management in policies" category specifically mentions developing guidance on green infrastructure, ecosystem-based adaptation, and disaster risk reduction, which are also known as nature-based adaptation solutions.

Adaptive measures in city planning can be classified in different ways, such as according to scale, the risk they address, or their character e.g. nature-based solutions which are divided further into green, blue and grey structures. Green and blue infrastructure are measures, such as green roofs and urban water features meant for rainwater retention and evaporation to cool down city areas or prepare for flooding. Grey structures include the more common engineering measures to deal with runoff water, such as sewer systems. Use of blue and green infrastructures lowers the reliance on only grey structure, and may provide multiple benefits, such as solar shading, improved air quality or biophilia. Additional soft measures refer to modification of behaviour to for example lower vulnerability or further knowledge. (European Environment Agency, 2012)

In response on a national level, Finland updated its National Climate Change adaptation plan by the Ministry of Agriculture and Forestry in 2014 and it is included in the Climate act. The updated plan includes the implementation of the EU strategy on adaptation to climate change. The aim of the adaptation plan is that the Finnish society "has the capacity to manage the risks associated with climate change and adapt to changes in the climate". Objectives set until 2022 include such outcomes as ”adaptation being integrated into the activities of various sectors and their actors, climate change assessment and management methods have become accessible, and research development work and communication have enhanced the adaptive capacity of the society, developed innovative solutions and improved awareness on CCA". The importance of climate resilience is recognized in the plan, and solutions, mitigating risk, and benefitting from opportunities through e.g. land use planning and legislative steering are mentioned.

Internationally and nationally the risk of climate change impacts is recognized and climate adaptation, disaster risk reduction, addressing vulnerability and improving resilience are included in policies. But how does this translate to a national and regional level for different sectors? Midterm evaluation of implementation of the National Adaptation plan (Mäkinen et al. 2020) shows that the land use and construction sector has a slightly above average awareness on adaptation. Research knowledge, normative guidance, region specific and economic information and training was called for by respondents in the sector and long-term and short-term operational recommendations should be established. Recognition of climatic risks and climate adaptive measures that are initiated in a city policy level concerning Helsinki will be handled further in the next chapter, and climate adaptation measures in architecture further in the part two.

6

HELSINKI

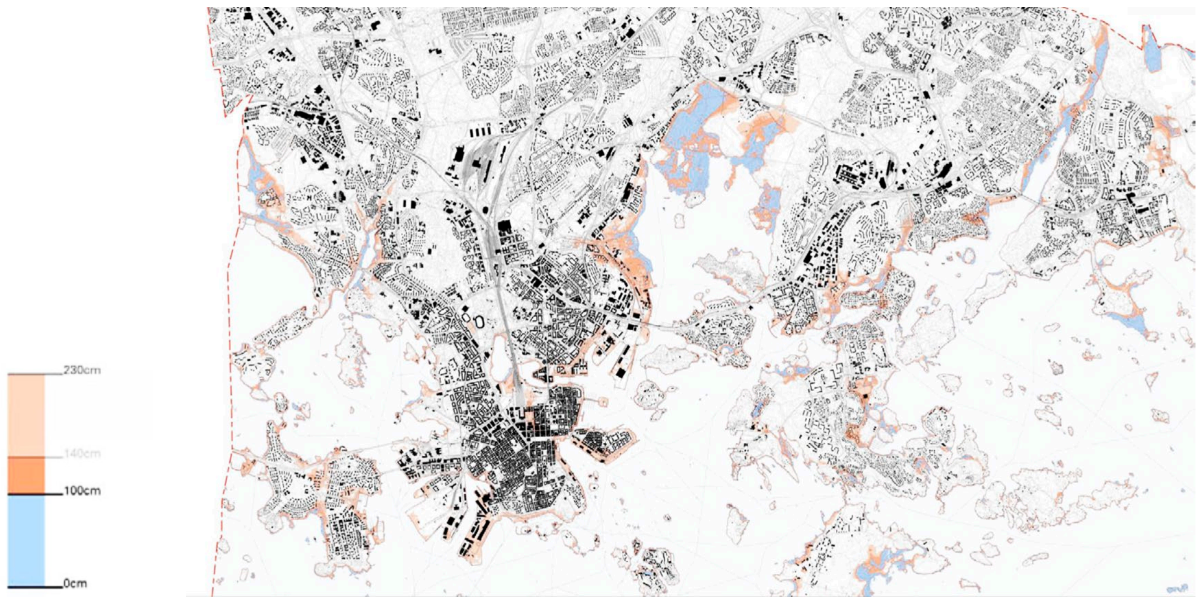


Figure 4. Coastal ground levels in Helsinki, NN (+305mm in N2000), 2004-2007, (Helsinki 2010)

Local awareness, policy and action on climate chande adaptation varies locally and is dependent on the activity of cities. Climate change impacts, vulnerability and adaptive preparedness of Helsinki are examined in this chapter.

A fifth of Finns live in the capital area. Helsinki, the largest city of Finland by population with 648 042 inhabitants in 2019, houses a tenth of the population (SVT 2020). The city is projected to grow up to 820 000 by the mid-century. The majority of the citizen growth is from national and international migration and its percentage is expected to grow. Climate measures of Helsinki affect a large number of the people of Finland and its coastal position as a city puts urban areas at risk of flooding due to sea-level rise. According to Helsinki, its most important growing areas are the large developing areas, such as Kalasatama area, Jätkäsaari, Hernesaari, Kruunuvuorenranta, Laajasalo, Vuosaari and Pasila, almost all of which are coastal. (Vuori & Kaasila 2019)

Climate change impacts in Helsinki are much like those described in the previous chapter concerning the whole of Finland. A thorough report on local risks to Helsinki by Pilli-sihvola et al. (2018) particularly mentions flooding relative to sea-levels, runoff water and watersheds. Pluvial floods in Helsinki will also occur mainly due to heavy precipitation events, and especially events with long duration. Winters will face most change as they get warmer, wetter, and darker, yet nevertheless heavy snowfall events and sleeting will become more probable, also creating safety hazards. Dark winters predispose to seasonal depression, which can be predicted to increase due to less solar radiation. Heat-related risks and UHI effect have not been researched thoroughly in Helsinki, but health risk posed by temperature rise will increase. The changing climate also creates a risk to biodiversity, as new species and diseases arrive, and endemic species may not adapt to a changed climate.

Same report by Pilli-Sihvola et al. (2018) addresses the researched vulnerability to increased flooding due to heavy precipitation events in areas that are already densely built-up such as the inner city. Amount of non-permeable areas will increase with densification and add to the risk. Inner city of Helsinki is susceptible to flooding as underground spaces and functions are vast, e.g., public transport, shelter and energy maintenance. Aggregate risks and supply security in a possible exceptional flooding situation are high. Even though there is exposure to flooding risk in central city area, social vulnerability to pluvial flooding risk is higher in Etelä-Vuosaari, Länsi-Herttoniemi, Roihuvuori, Viikki, Vallila/Itä-Pasila, Maunula-Suursuo and Pohjois-Meilahti areas. Vulnerability to climate change in Helsinki relates also to supply security and secondary impacts, like the arrival of climate refugees in the future. Similarly, the exposure to heat is very high in Helsinki overall (figure 8), yet social vulnerability to heat is emphasized in Northern and Eastern Helsinki as seen on figure 7.

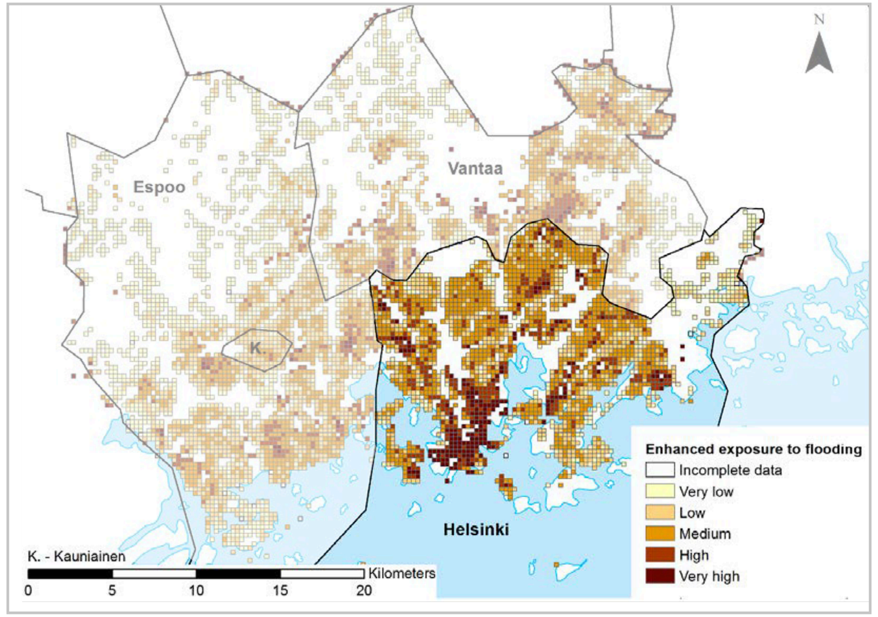


Figure 5. Exposure to flooding in Helsinki (Kazmierczak & Kankaanpää 2016)

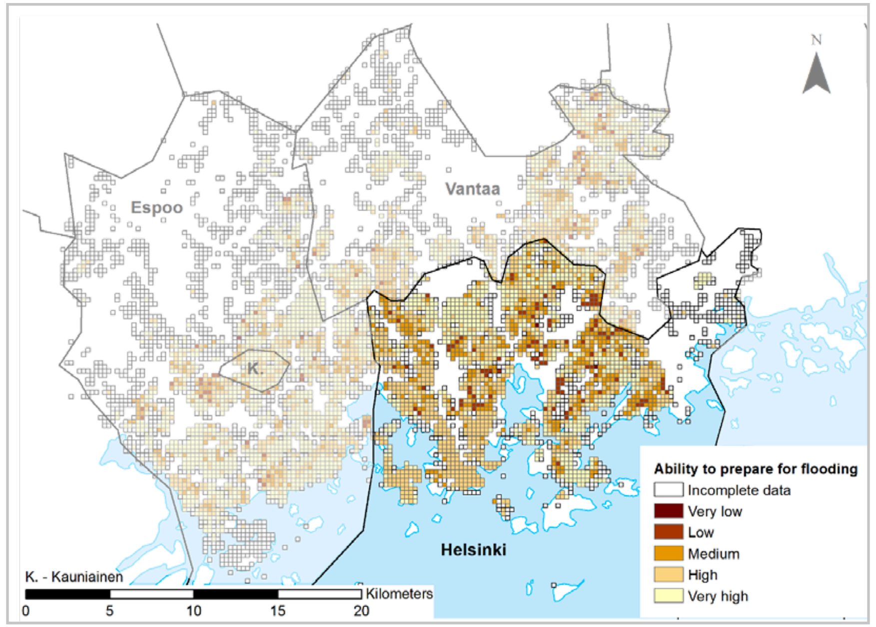


Figure 6. Preparedness for flooding in Helsinki (Kazmierczak & Kankaanpää 2016)

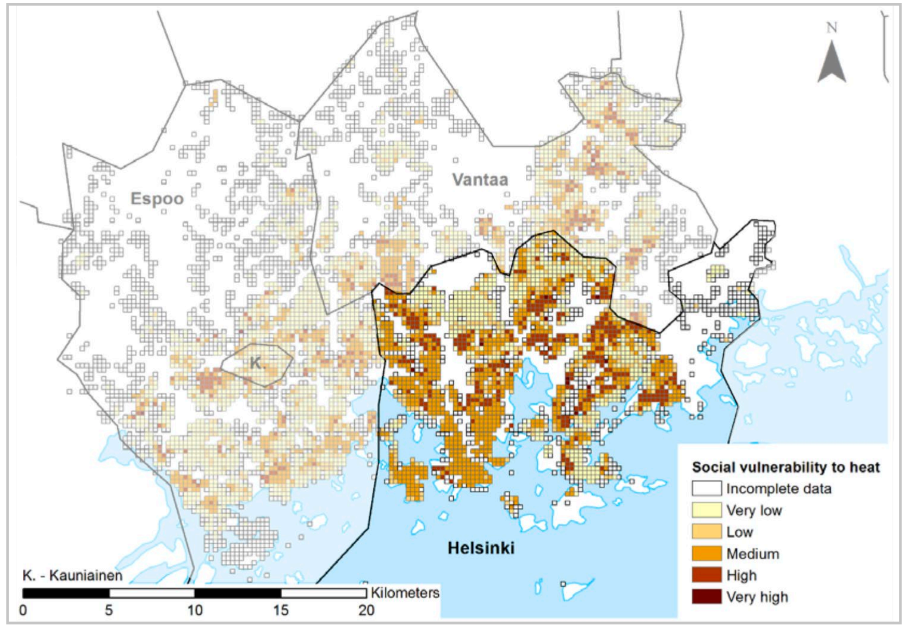


Figure 7. Vulnerability to heat in Helsinki (Kazmierczak & Kankaanpää 2016)

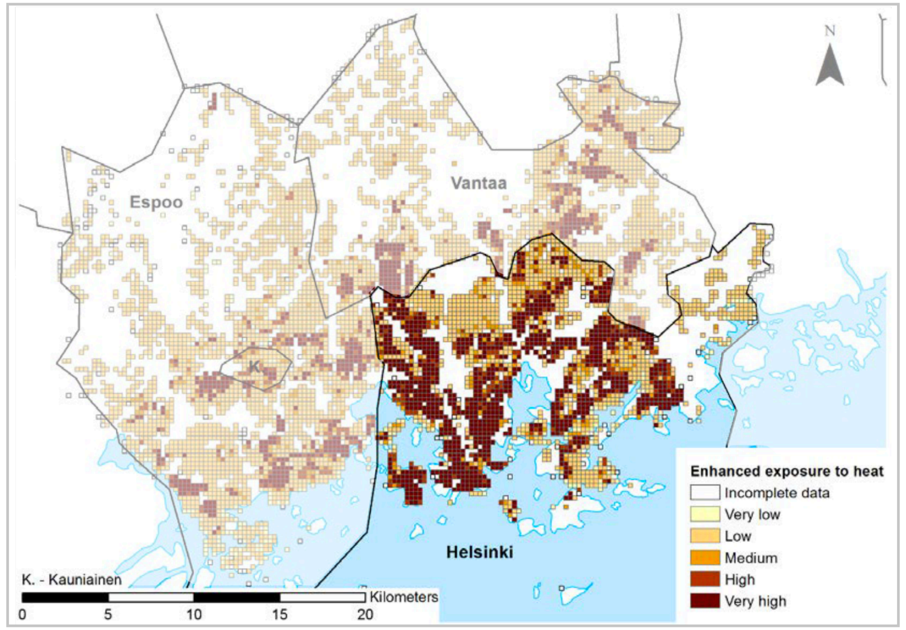


Figure 8. Exposure to heat in Helsinki (Kazmierczak & Kankaanpää 2016)

To further understand the policy and regional response in Helsinki concerning adaptation, different strategies and programs need analysis. The Helsinki climate plan for a climate resilient city includes adaptability measures preparing for a 4°C temperature rise. These include building new infrastructure for a changing climate, and citizen awareness on how to prepare for global change, flooding events and increased amount of rainwater. Sea-level rise and need for cooling is taken into account in construction policy. Urban vegetation is also being considered in order to maintain biodiversity, and to avoid flooding, and for its cooling effect during heatwaves. In the climate change adaptation policy 2019-2025 of Helsinki, tangible measures mentioned are runoff water and flooding programmes, green roof policy, and green factor. (Helsinki 2019)

In the runoff water plan of Helsinki, which follows the land use and construction law, goals are defined to develop the planned control over runoff water in areas with a city plan, to delay and soak runoff water on their accumulation location, to prevent damage to the environment and buildings from pluvial flooding considering climate change and to further giving up on leading rainwater to sewers. (Helsinki n.d.)

Helsinki city flooding strategy emphasizes furthering knowledge, building protective structures in response to potential flooding, updating the information on construction heights and wave action, and mapping out exposed underground spaces adding cooperation between city organizations. (Helsinki 2010)

Green roof policy of Helsinki furthers construction of green roofs e.g. through city planning and pilot projects. The policy defines that new buildings with a lower roof angle than 20 degrees should be the primary option in city plans and building design. Non-heated maintenance buildings should primarily have a green roof. Biodiversity should also be furthered, and resource efficiency considered. Knowledge on green roofs advantages, costs and structural advice is handed out by the city. (Helsinki n.d.)

The green roof policy, while taking into account the type of roof structure that is well suited for a green roof structure, does not emphasize the addition of such structures in especially exposed, formerly built areas as seen on figures 5 and 6. This certainly furthers the adaptive capacity and preparedness for flooding in new areas as well as reduces the urban heat island effect. It may however be considered that new areas preparedness for flooding and overheating could be realized through other measures, such as cool roofs, permeable pavements, sufficient green areas on ground level, or blue and retention structures rather than through building design. Exposed areas on the other hand do not have the luxury of redefining the space for green areas and parks, to change their pavements or to increase the height of their ground floor as easily, and therefore retention measures, such as green roofs, may be considered. Also, the exposed, the newly built, and the most vulnerable areas for flooding should have some influence over the priorities of the measures taken to ensure the adaptive capacity of the city, as these areas are potentially not the same.

Green factor is a tool that describes the amount of water retaining solutions on site such as vegetation, permeable surface, water retention pools, rain gardens and green roofs. The tool is mainly aimed for landscaping and city planning, but is largely based on the goal to increase the adaptive capacity in a city. The tool takes into the account various green and permeable solutions, but also for example proposes to consider a significant amount of green roof if over 50 % of the site is covered with a courtyard parking structure. (Helsinki n.d.)

Even though the green factor tool is considerate over runoff water management, it fails to assess the impacts of the choices made as a result of using the tool. The choice to design a green roof may lead to the choice of a stone based structural material, which is less of a low carbon choice than for example wood, on top of which it may not be preferable to construct a water retention structure. The sustainability of the combined result of the adaptive capacity and the mitigative potential of a system would be more in line with e.g., the Paris agreement.

Information on exposure and vulnerability in Helsinki have been carried out and is available. While much has been done in Helsinki to ensure crisis preparedness and to guide construction through city planning, further consideration might be paid towards where adaptive measures are actually urgently needed, how this could be made through innovative solutions. Furthermore, it could be reconsidered in which scale of planning e.g., flooding needs to be addressed in new areas, and which sort of measures are less emissive. For example, land use modification may lead to high emissions in raising ground levels in preparedness for flooding, whereas floating buildings would essentially be resilient towards sea-level changes and pluvial flooding. Ground floors can also be made flooding proof or be built on stilts and construction near watersheds could be avoided altogether. City planning is a fast and efficient tool to guide construction and careful consideration of the aspects of climate adaptation is needed to further resilient choices.

CONCLUSION
PART ONE

In summary of the first part of this thesis, it can be concluded that climate resilience comprises of the two functions of adapting and absorbing climate change impacts and the maintenance of transformability, learning and further adaptation. Aiming towards climate resilience rather than climate adaptation, while fostering innovation, should be the ultimate goal.

Ecological impacts of climate change are inevitable and need to be addressed on different scales of action. These impacts include changes in temperatures, humidity, the amount of precipitation and the amount of solar radiation. The risk they pose to buildings and health are various and potentially severe. These include structural damages due to flooding or increased moisture, as well as thermal discomfort and heat-related death, seasonal depression, and reduced indoor air quality. Especially risks that pose threat to health or environment should be addressed through architectural means, rather than focusing on the damage through their potential economical risks, altough they may easily be seen as more severe and addressed sooner. For instance flooding may easily pose primarily economic risk and be seen as a severe threat, while health issues related to overheating and increasing vulnerability seem unlikely in the current cooler climate.

In response, design measures should be guided through normative legislation or city planning more consistently, in order to address exposure and vulnerability. To further understand how climate adaptation measures respond to climate impacts and create resilience in built environment, climate resilient architecture in both urban and building design scales are studied and analyzed in the next parts of this thesis through reflection of the role of architecture as the means to respond to climate change and to advance resilience. This is achieved through the analysis of case studies that present some design aspects in preparedness of the climatic future.

PART TWO

7

CLIMATE RESILIENT ARCHITECTURE

Elaboration on the definition on climate resilient architecture and the state of the policy concerning it will be covered further in this chapter. Case studies and an analysis elaborating their adaptive capacity and climate resilient design aspects are presented after.

The beforementioned definition of climate resilience entails preservation of the essential function, identity and structure of environmental systems in a way that maintains capacity for adaptation, learning and transformation. In this case, the environmental systems are dwellings in Helsinki. For climate resilience purposes, we can define the essential function of a residential building to just a building here, as possible future modification of use is almost as desirable as continuance of the original purpose in constantly changing cities. This follows the definition of resilience, where change is the natural state of a system. Flexible buildings have the capacity to allow for this adaptation and transformation that may happen over time.

The identity of a building can be linked more closely to the architecture the building presents and its value. An identity of a building can be formed through its design concept, its architect and architectural style or it can be formed and changed over time. To be able to design a building that can maintain an identity, a certain appreciation needs to be achieved for the building, yet the transformation of this identity is not necessarily for the worse. In this case, the resilience comes from consideration of the building to be worthy of repair to keep its function and value as a building. In the Shape of green (2012, 5-7) Hosey argues that aesthetics should not be separated from sustainable design although attractiveness has not been previously considered significant to sustainability. According to him, beautiful design discourages us from abandoning things and therefore creates sustainability. An example of this could be found in the infamous marble cladding of the Finlandia Hall, where aesthetics and architecture have evidently been valued higher than durability of the material and maintained for decades, although with some debate. Neither beautiful architecture without durability nor a durable building that is not attractive is a desirable result.

As mentioned in the first chapter, building type influences its demolition age as residential buildings are demolished older compared to non-residential ones (Huuhka & Lahdensivu 2016). Residents' attachment to their habitation and their will to repair it and protect their environment and investment from weather and age can have an influence on how resilient a building eventually is. Design of the building, as well as a changing climate can both affect the frequency in which repairs are required.

The structure of a building is of high importance in maintaining the capacity for adaptation, learning and transformation. All of these are responsive or reorganizable measures that absorb or adapt the building according to change and they require some flexibility from the design, i.e., how easily the building can be repaired, retrofitted or modified. This includes both design for spatial flexibility and structural means to allow for transformation. Climate adaptation is design for a future with a different climate and can be realized in measures that increase durability to future weather or allow for absorption of impacts or adaptation to them. Certain design measures may also increase the capacity of the building user to adapt their environment according to changed needs.

Architectural guidelines and policy are currently updated to address climate issues and megatrends in Finland as well. A proposal for an Architectural Policy Program (Apoli) was submitted in January 2021. It addresses five main themes: climate change, equality, economy, purpose and education. Climate measures in the program include furthering ecological sustainability in construction, climate, and biodiversity informed land-use, low-carbon and circular planning, and spatial and structural resilience. Resilience related goals for 2035 in the program include e.g. lengthening the age of new construction and building blocks by addressing transformability and repairability in design and execution. Circularity would be addressed in the design of reuse and disassembly with aims to use natural resources as long and efficiently as possible. (Ministry of Education and Culture & Ministry of the Environment 2020)

While climate change is prioritized in the policy proposal as it is addressed in the first chapter, and adaptation is in the first sentence of that chapter, only mitigation and circularity are addressed thoroughly in its goals and proceedings. Climate adaptation is only mentioned briefly in context of land-use only to be addressed with urban vegetation and landscaping. While the policy addresses largely mitigation and circularity as they urgently should, it seems to emphasize mitigation, renovation, and flexible spatial design as essential measures and seems to overlook the means architecture has in the context of building design to create innovative solutions to combat climate impacts with adaptive design and even benefit from it. It seems, enabling and promoting innovation concerning adaptation has not to trickled down to Finnish policy.

In the following chapters I will go through some case studies to analyse different properties that architectural design has in different scales to address climate resilience innovatively. First case study is a residential building in Helsinki that uses green structures as an adaptive response to climate change. The second one is an urban scale blue "climate park" in Denmark that addresses exposure to flooding in urban design level. The following two cases are residential buildings in Helsinki and in Denmark that express some future-proof aspects in their building design.

CASE STUDIES

7.1

GREEN

CASE: Vihreistä Vihrein, Helsinki, Talli arkkitehdit

Urban vegetation in response to climate change and increasing adaptive capacity through building design

Figure 9. Green structures create the architectural and adaptive identity of Vihreistä vihrein by Talli Architecture & design (Archinfo n.d.)

Helsinki is leading the development of apartment buildings through co-operation with the construction sector to create innovative pilot projects. Kehittyvä kerrostalo (the developing apartment building) project is an answer to development of design and construction of future-oriented buildings focusing on technical, functional, aesthetical, social and housing political aspects and the construction process. Themes for the project are housing solutions and building types, lifespan, technical solutions and reasonable pricing. (Helsinki n.d.)

In this case study I will focus on a particular pilot project by Talli architects, Vihreistä vihrein, which is located in Jätkäsaari, Helsinki as an example of urban green construction and a nature-based solution to climate change adaptation. Vihreistä Vihrein is also a research case as a part of Sogreen project in collaboration with Tampere and Helsinki Universities that aims to track the performance and survival of the type of vegetation chosen especially for a Nordic climate (Nessling 2018). Green facades are supposed to provide protection from e.g. wind driven rain for the wall structure behind in a humid location. (TA n.d.) In laboratory conditions the moisture safety of green facades in a Nordic setting has been studied e.g. by Edelman et al. (2019).

Different wooden and metal surfaces on the facade provide a platform for growth of creeper plants and a distinctive exterior architecture that develops over time (figure 9). Leafy plants help shade the apartments to avoid overheating in summer, while letting light in during winter. Green planting boxes increase the number of different plants on the façade, advancing biodiversity. The rooftop of the building is also in the use of urban green with a greenhouse, planting boxes and meadow and forest type vegetation areas. The green structures provide rainwater retention and purify the city air as well as add self-sufficiency in food production. Urban vegetation and light-colored façade surfaces defend the building from overheating and reduce UHI-effect.

Vihreistä Vihrein succeeds at addressing several climate issues with just a couple of nature-based solutions such as biodiversity, pluvial flooding and

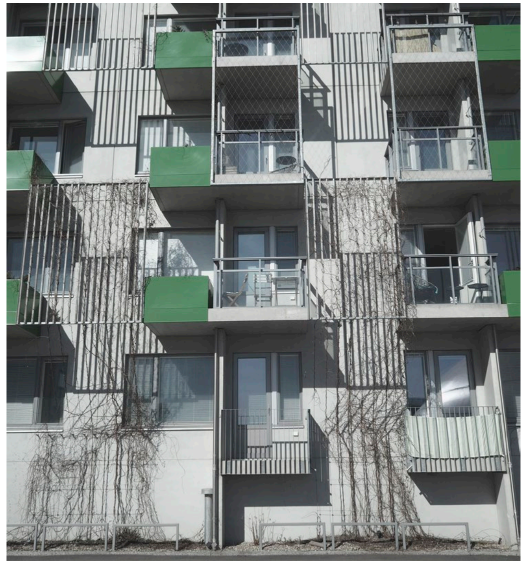


Figure 10. Green facade in April 2021

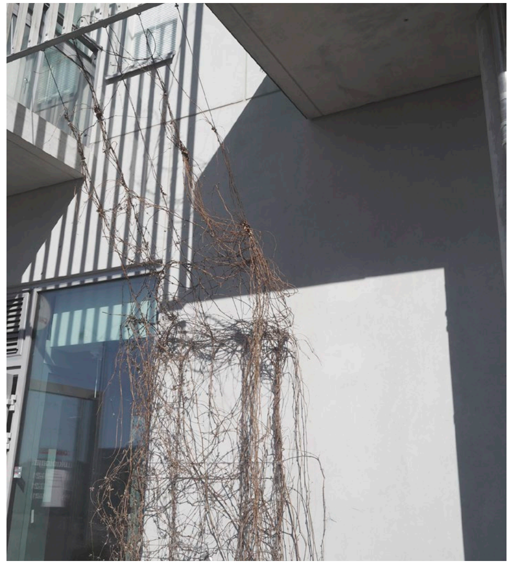


Figure 11. Progress of vegetation varies according to orientation, April 2021

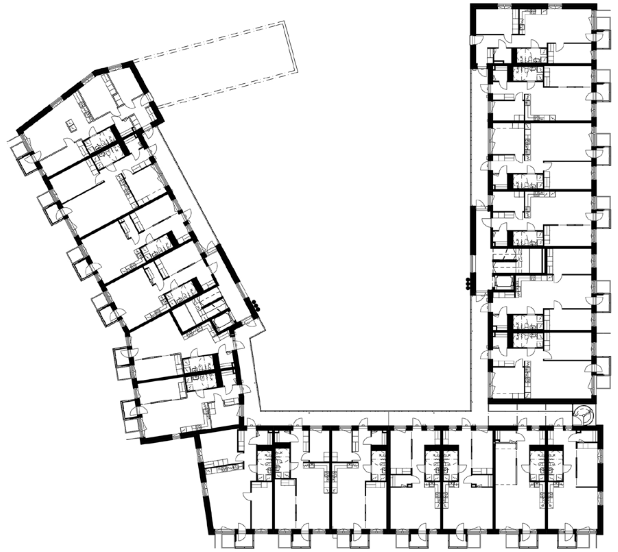


Figure 12.Spatial layout of Vihreistä vihrein provides opportunities for natural ventilation, Talli Architecture & design (Archinfo n.d.)

wind driven rain as well as overheating. The flat roof allows for its use by residents and rainwater retention on top of the building. The building form provides a lot of façade area towards the South, West and East whereas the positioning of corridors outside the building on the inner court side allow for apartments to extend through the depth of the building. This lowers the amount of heated space and encourages to ventilate in response to overheating, which can be regarded as desired design for climate change adaptation to temperature rise. Capacity for further modification of the building, or addressing changes in solar radiation in this case, is, however, reduced due to load bearing walls that are repeated throughout the deep building form to create quite narrow apartments.

Green roofs are a common nature-based solution in building design scale that retain some water during a cloudburst, but their structure defines much of their potential for delaying water. An intensive green roof, like a roof garden retains more water than a steeper angled extensive roof (RT 2016). A green structure is a valid solution in a dense and impervious environment, and these properties can be recognized in the future of the residential area of Jätkäsaari. Although rainwater retention may be necessary in this location, it raises a question why the moisture safety of a building is compromised with a complex structure that delays water on top of the structure in a newly built area. Has the responsibility of rainwater management been transferred to building design level as opposed to being addressed already through city planning by e.g. sufficient area of surrounding parks and other vegetation?

Interesting aspects of the roof choice in Vihreistä Vihrein are the multiple functions of the green roof and its accessibility to users, where the adaptive measure has been further benefitted from and its function is more than only water retention. While there are potential benefits to liveability, green roofs add stress to the structures below them, increasing the load on the roof as snow, ice, water and people may strain the structure below. Heavier load increases the sturdiness of load bearing structures, further increasing material use. As green roofs are not an optimal choice to wooden buildings, this choice of structure essentially may lead to stone-based materials,

increasing the embodied carbon content. Wooden buildings can be realised with a low angle pitched green roof, but the effect on rainwater retention and moisture safety has to be balanced carefully. Non-heated spaces, like parking garages and low buildings are safer choices for this combination, as snow or ice loads may increase in the nearby future and pose risk to the structural capacity and moisture safety of the building.

Extending the urban green to facades helps to protect the building and its users from overheating in an adaptive way, where the plant cover grows over time. During summer, the light façade colour reflects light, but also creates contrast to highlight the vegetation growing over it. In a humid and windy location, protection of the structural walls provided by the green layer may be even more important of a function than the solar shading. The facade is also under-designed in a sense that nature and time modify the exterior aesthetic of the building and create transformative adaptation. The vegetation also adds to the value of the building, as it is not just a building, but also a park, a plantation and a forest. The identity of the architecture is therefore intertwined to the adaptive measure and potentially elevating its value. Yet, the beauty of the design can only be seen after an explanation or later when the plants have grown. The way the building is perceived for a large amount of the year and the beginning of its lifetime is without the plant cover (figures 10 and 11) and these seasons and parts of its life should be paid attention to.

What can be learned from the case study, is critical contemplation on whether green roofs are the perfect multi-beneficial adaptive measure, or if they pose a risk of moisture damage themselves, or at least decrease material efficiency and guide towards high carbon materials. Furthermore, the question remains if run-off water should be retained in some other way, and possibly not on top of structures that should essentially stay dry. The areal relevancy of a green structure is also a significant matter. Some older areas that are more exposed to pluvial flooding than new areas, may have less options to solve this risk. In this case I might further consider green roofs. However, in a newly built area, the possibilities to solve pluvial flooding through city planning remain more diverse.

7.2

BLUE

CASE: Enghaveparken, Denmark, Tredje Natur

Rainwater delay structure and a reservoir in response to pluvial flooding

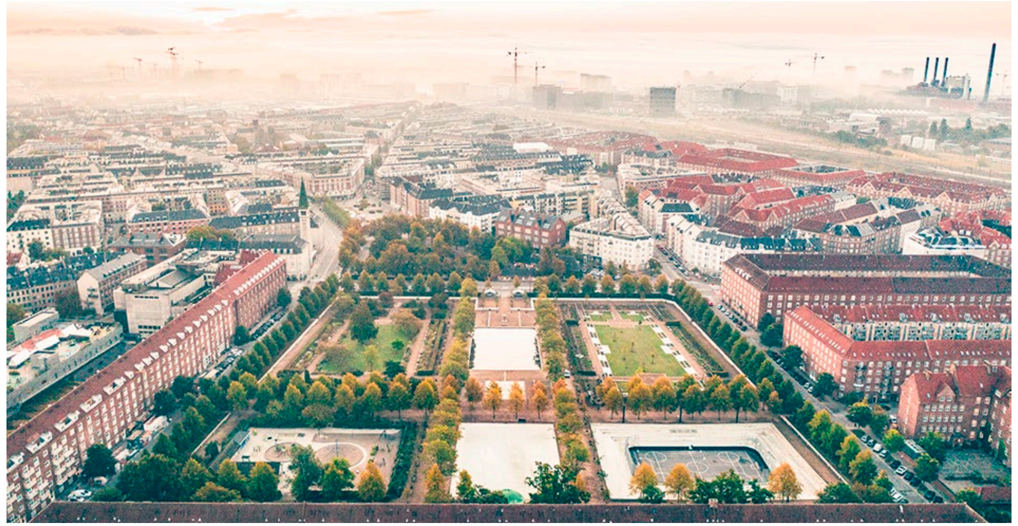


Figure 13. Enghaveparken is a climate part in an area exposed to pluvial flooding (tredje natur n.d.)

Crisis preparedness is a key aspect of climate adaptation. As flooding and overheating are potential threats in Helsinki, foreseeable ecological impacts can be prepared for and tracked by designing blue structures i.e. water features for delaying the access of rainwater to sewer systems. Water retention in urban design and cities can already be found in Malmö, Sweden, or Kuninkaantammi and Eko-Viikki in Helsinki, but an example of a large-scale solution that widely benefits from pluvial flooding in an area exposed to flooding, has been realised in Copenhagen.

The large-scale adaptive blue structure of this case study, Enghaveparken, was designed by Tredje Natur. It is a transformation project of a park turned into a water delay and detention area with a capacity to store 22 600 m^3 of rainwater. The design aims to gather runoff water from surrounding areas and store it in a basin and reuse it for a fountain park and watering vegetation. The design of the whole park allows for its flooding in a heavy raining event, but also adapts to benefit from the water in different recreational use over time. A dam circulates the whole park to protect the surrounding areas in a flooding event. (Tredje natur n.d.)

The project absorbs climate impacts by the retention of runoff-water and reduces the risk of pluvial flooding. Furthermore, it benefits greatly from the possible flooding by providing different recreational activities for a variety of users. The identity of the park can further knowledge of the climatic situation by notifying of the increasing frequency or volume of flooding, functioning subtly as a soft measure. The project has an adaptive nature, as it currently still functions as a regular park with trees and playgrounds as opposed to its potential future as a water park. Pergolas and trees provide solar shade, and together with a fountain park, they provide an area for nearby residents to escape summertime overheating. Existing winter conditions are still included as the park functions as an ice rink in wintertime adding to recreational nature of the park.

Enghaveparken utilises adaptive design measures that absorb climatic change in an exposed area, while maintaining its essential function as a recreational park and can therefore be considered to be climate resilient design within this definition.

Blue structure solutions to crisis preparedness have more often been introduced in Finland in urban design scale and in new housing areas, such as in Kuninkaantammi, Helsinki. While blue structures are easier to implement in new areas, Enghaveparken is exemplary due to its large scale on a pre-existing area, where raising ground floor levels or enhancing sewer capacity is more difficult. Exposure to flooding in densely built central areas may be high, as can be seen in figure 5 for Helsinki. Even though the

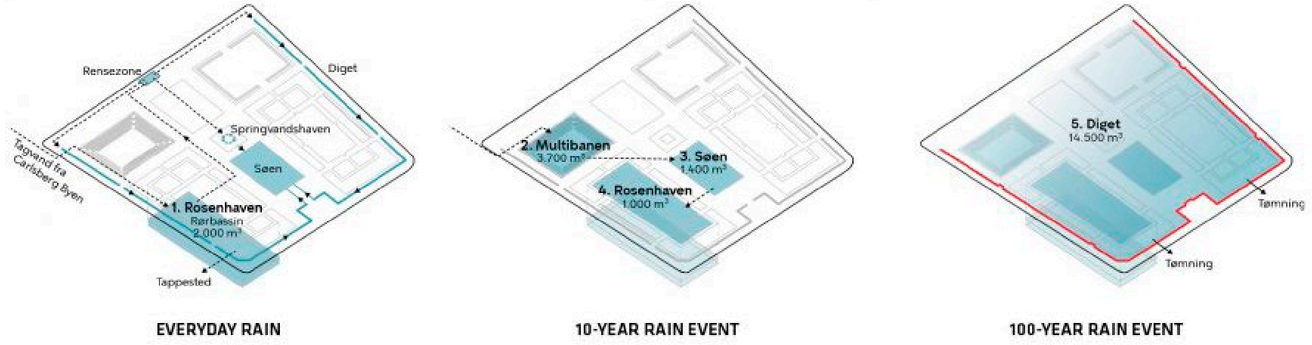


Figure 14. Enghaveparken will gradually fill up with water over time (Tredje natur n.d.)

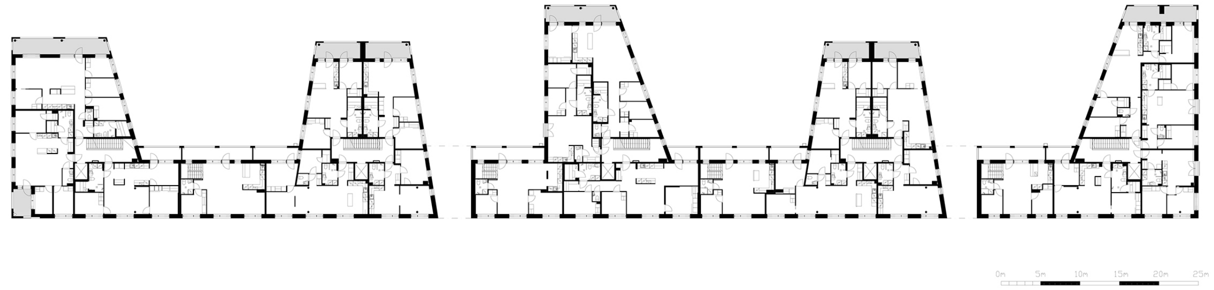
project mainly addresses the exposure of existing built areas, and the solution is of urban scale design, it showcases how an innovative blue structure design solution improves crisis preparedness and how investing in it may benefit communities. Including landscaping and blue solutions into residential building design already in the concept phase could amount to similar improvements. However, some waterproof structures required may be high carbon materials, and the sustainability of the equipment needed for filtration and reuse has to be considered. Blue structures, compared to green ones, have often more capacity to restore large amounts of water and provide information on the progress of frequency of heavy raining events, as well as provide the opportunity to use the collected water during dry seasons. However, an innovative approach is required to connect a blue structure to its environment, if it is aimed to function as more than a tank. A combination of green and blue measures could provide multiple benefits. In existing areas, an assessment on the pre-existing conditions, such as exposure and vulnerability should be analysed and responsive adaptive measures realised accordingly in consideration of the local conditions.

7.3

RESIDENTIAL

CASE: Aleksis Kiven katu 19, Helsinki, Anttinen Oiva Arkkitehdit

Addressing overheating and access to light and the aesthetic expression of robust architecture



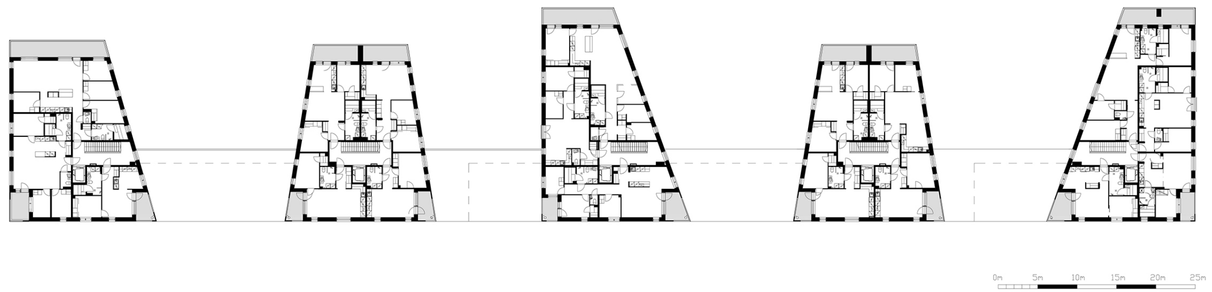


Figure 15. The spatial layout of Aleksis Kiven katu 19 allows for access to sunlight and natural ventilation through windows (Archinfo n.d.)

Aleksis Kiven katu 19 is mainly a residential building in Helsinki designed by Anttinen Oiva Architects. The project has qualities that address the existing climatic conditions, as well as those of the future. In the project, access to light and ventilation through windows towards more than one direction has been carried out thoroughly and the possibility for such is increased with the form and mass of the building block. The structural depth and the spatial design together with larger sized apartments allow for windows and balconies that face in different directions.

Furthermore, the South-West facing facade will be more shaded by trees in the future during summer, but the top floors are slightly exposed to the sun currently and during springtime (figure 16). In the future external blinds could passively ease the thermal comfort in the apartments facing in this direction. Many of them fortunately extend through the building and allow for cross ventilation. Some smaller apartments face directly towards South-West on some floors, which is not ideal for preventing overheating, but a balcony provides some shade and the West side windows of these apartments are quite narrow as well. Balconies are otherwise mostly pointed towards North-East, which provides cooler spaces for most residents during summer, but are less agreeable in spring and autumn.

Architectural expression is based on a robust brick footing close to the ground, but the look is only utilised aesthetically, and the structural material throughout the building is concrete. If the expressed look presented the actualities of the structural materials, this could potentially be used as a resilience measure. Ground floor is more exposed to moisture or flooding and massive stone-based material could endure climate change impacts while maintaining its essential function and structure. This ground floor could then protect low-carbon structural materials, such as wood used as structural material on higher floors.

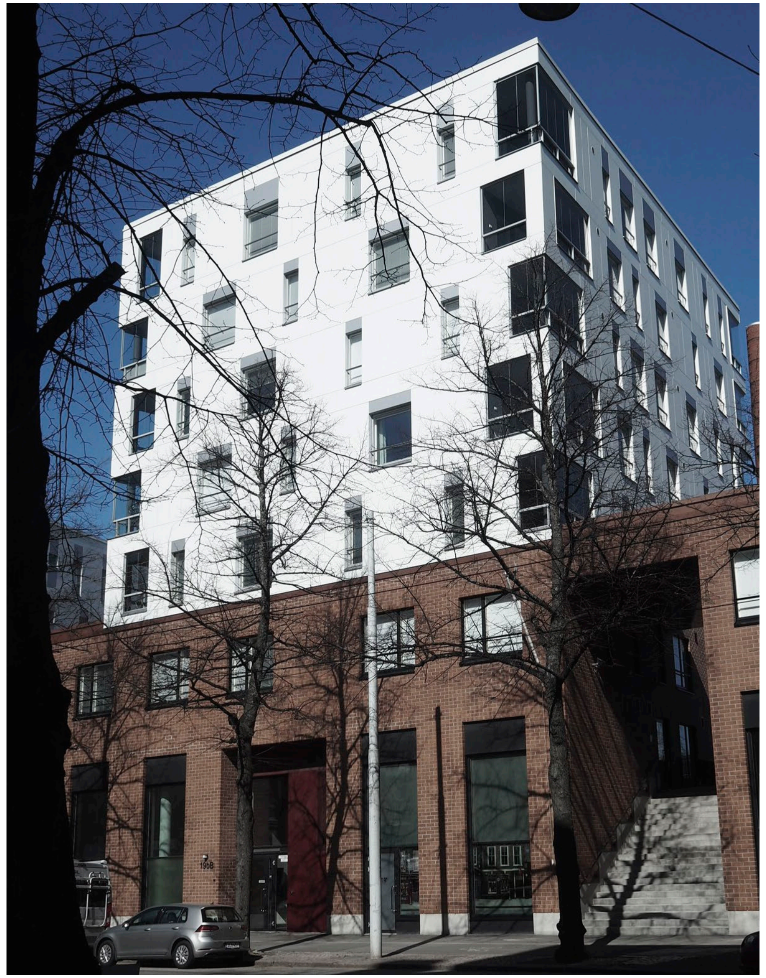


Figure 16: Many internal blinds are drawn down on South-West facing façade in Aleksis Kiven katu 19 on a sunny day in April 2021.

7.4

HYBRID

CASE: Lisbjerg hill, Aarhus, Denmark, Vandkunsten Architects

Durability and capacity for further transformation

Figure 17. Wooden cladding is protected by overhangs and flashings, Lisbjerg hill, Vandkunsten (Mikkelsen 2021)

Lisbjerg hill is a residential project, finished in 2018 in Arhus, Denmark and designed by Vandkunsten. The project represents hybrid construction with wood as the main structural material, steel connectors and concrete in staircases and slabs. The structural system is based on a post and beam structure, which allows for flexibility in spatial design. The spaces also have good access to daylight and ventilation opportunities. Walls are prefabricated cavity wall elements. The building design aims for durability, which can be seen as moisture safety in the form of pitched roofs, eaves and flashings and drip edges on the façade. (Dalgaard 2019)

The building has a rough look controlled by untreated metal and wood. The architectural expression is defined by aspects increasing durability, such as eaves and a pitched roof, and the end result is quite industrial rather than refined. The initial design by the architects shows balconies that might have improved the finished look and the resilience of the building. Also, the weathering turning the façades grey improves the final look, as the grey shades of the natural tone of the weathered wood are repeated in the metal parts (figure 17).

The building's design is low in embodied carbon, as the structure is mainly wood. Other materials like concrete and steel are only used where they provide further benefit in comparison to using low carbon materials. For example, the concrete used provides acoustic properties. (Dalgaard 2019)

The solid wood elements have been designed to be disassembled and reused. (Mikkelsen 2021) Many of the wooden post to steel connections in the building are made with bolts (figure 18). This is preferable to those connections that have been realised as screw connections, as the wood would break if disassembled and reassembled multiple times. The slabs are cast in concrete on site for acoustics, limiting the reuse of the materials used in the rest of the slab. Also, most of the wooden members are of glue laminated wood, which does not age as gracefully as solid timber, and the lack of aesthetic value may lower the will to reuse the members.

Figure 18. Gluelaminated wood posts have been connected with steel, Lisbjerg hill, Vandkunsten (Dalgaard 2019)

Many design aspects of Lisbjerg hill make it all in all quite a climate resilient design. The building is low carbon, addresses increased amount of rain and the access to light and ventilation and furthers transformation through structural choices. However, as a project it raises questions connected to the reuse of the building in the future. When and why is it expected to be disassembled and where are the structural members aimed to be reused? Should the building be reused in a similar way to the initial design to maintain its identity, or rather, should it be aimed to be used for parts for environmental benefit and to further circularity? Is the essential identity of the expressed architecture the aspect that needs maintaining over time or is it the embodied carbon in its structure that only temporary expresses architecture on its way to becoming a new arrangement. And should the aging process of the structural members be considered if they are wished to be reused. Can, for example, the glue laminated timber maintain its value over time?

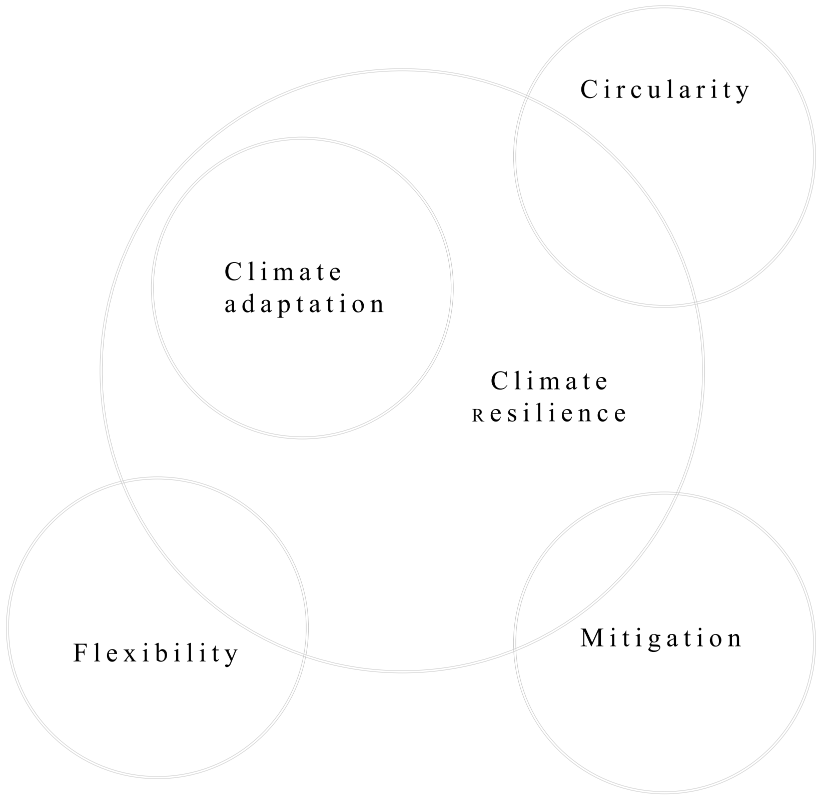
PART THREE

8

DESIGN

CLIMATE AWARE DESIGN

Concepts linked to sustainable design like circularity, mitigation and flexibility, have qualities that may improve climate resilience, but some may also be contradictory towards each other or decrease climate resilience. To improve climate resilience of a design, these measures have to be selectively looked through a climate resilient point of view and their impacts assessed and those measures that benefit climate resilience are chosen. For example, some emission mitigation could be compromised in favor of structural flexibility in choice of materials if this provides a more resilient design. Climate adaptation is entirely included in climate resilience as the main focus of climate resilience is to adapt to, and absorb shock from climate change. The overall resilience of a design may, however be reduced by adaptive design measures. Mitigative design measures may not directly add or reduce resilience, yet the success of mitigation has a direct influence on the severity of climate change impacts over a long period of time, even though some impacts will happen regardless of mitigation.



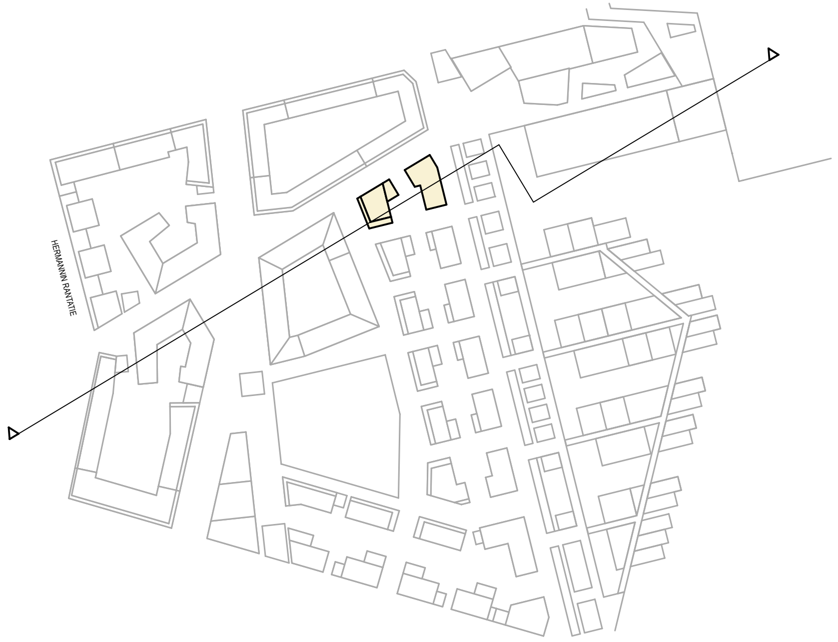
DESIGN FRAME

Design part of this thesis is based on a student competition “Affordable Community Living Design in Kalasatama Smart City” by EFL/ city of Helsinki.

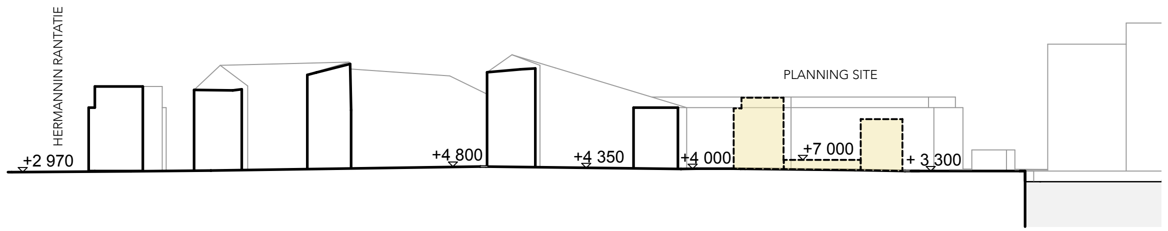
Objective is not to follow the competition goals to create a complete architectural design for a competition proposal, but to study climate resilient design measures in the form of an architectural concept. The design is used as a tool to reflect on, and to present those design measures that increase resilience. Aim is also to see how the environmental preconditions in a typical new housing area in Helsinki, where new construction is produced in volumes, and the frame of a city plan exists, guide these building design measures.

The design area is situated in North-Verkkosaari in Kalasatama area, in the north end of building site 10658.

In the design it is assumed as stated in the competition brief that no spaces are to be built under street level and soil investigations and groundwork are assumed to be complete.

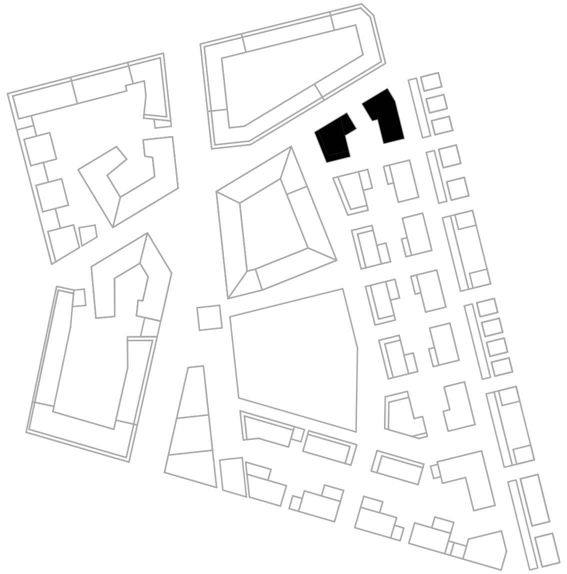


Site location in Northern Verkkosaari 1:5000



Site section 1:2500

SITE ANALYSIS



Site location in North Verkkosaari 1:5000

CLIMATE RESILIENCE OF THE VERKKOSAARI CITY PLAN

The basis for the city plan (asemakaavaselostus) of Verkkosaari defines the planning area as situated entirely on sea-flooding risk area. It is also notified that the steel and reinforced concrete foundations and landmass changes and fills increase CO_2 emissions and energy use in the construction phase. From a "future-proof" and climatic point of view, when multiple resources are invested and emissions created in an area, it may be preferable to construct such in a more stable location in the future, as opposed to one that is in a flooding risk. As stated in chapter three, a flooding safe building height was defined as 280 cm in Helsinki, and this is followed in the city plan which states that adaptation to climate change impacts in sea-levels and increasing storms and heavy precipitation has been prepared for in construction heights and municipal infrastructure. This reduces possible future risks significantly, but as mentioned, increases construction phase emissions due to the required landmass fills and foundations. Therefore, it can be concluded that interests to build the area and its disaster risk reduction have been valued above mitigation. In the future, the new Apoli proposal (Ministry of Education and Culture & Ministry of the Environment 2020) would address this in the chapter 1, section B, where climate and biodiversity aware land use is encouraged e.g., through city planning. In the interests of sustainable city development new residential areas would address climate issues more thouroughly.

Desirably new construction would be built in an area safe from climate change impacts, but with less emissions in the construction phase. Preparedness for sea-level rise flooding in a central or desired area, in the interest of climate resilience, should work with the nature adaptively, possibly in the form of floating buildings or urban design blue structures that absorb changes in sea-levels such as presented in the second case study. This would mitigate emissions from foundation work and allow for innovative climate adaptation. Some floating construction has been planned on the shore of Verkkosaari, but it's small scale and minority type in the area.

Other sustainability aspects in the plan list accessibility to public transport and furthering sustainable transportation-based lifestyle. The plan determines solar panels to be used for local energy production. Possible future overheating is paid attention to with a demand of energy-efficient central cooling system for residential buildings. Pluvial flooding, agreeable living and self-sufficiency are considered with a regulation that defines roof surfaces to be green roofs, terraces or in solar panel use.

To increase resilience and respond to the ecological impacts of climate change, furthering passive measures might be primarily encouraged rather than those that use energy, even if efficiently. External solarshading or furthering natural ventilation through windows to mitigate overheating could be such solutions. As the foundation work is already highly emissive, some other retention measures than green roofs could be considered as they encourage to use stone based materials, essentially heavier in their embodied carbon than, for example, wood.

AREAL RESILIENCE

The city plan follows a municipal engineering plan for the area which is to include normal networks for maintenance of urban infrastructure. Northern square, the largest one on the map, has a reservation for a pluvial flooding pump station and barricade system. The area has some spatial reservations for possible needs of maintenance of urban infrastructure, especially for water management. Level of Hermannin rantatie will be lower than the areas surrounding it, and runoff water from these areas is guided through a separate drainage to the flooding pump station. All sites east from Hermannin rantatie and their street areas form “a flooding embankment”. Runoff water east from this embankment is guided directly to the sea. The middle blocks of site 10658 include flooding routes that are to be left open for water streams.

Regardless of the grey adaptation measures extensiveness, some urban scale green or blue retention measures may have been considered for the area to ensure preparedness for pluvial flooding and further benefit from climatic change. The only mention of this is the city plan suggestion to favor green roofs. Potentially, the pedestrian areas (see page 101) could be permiable, include stormwater retention structures or have green areas for water retention.

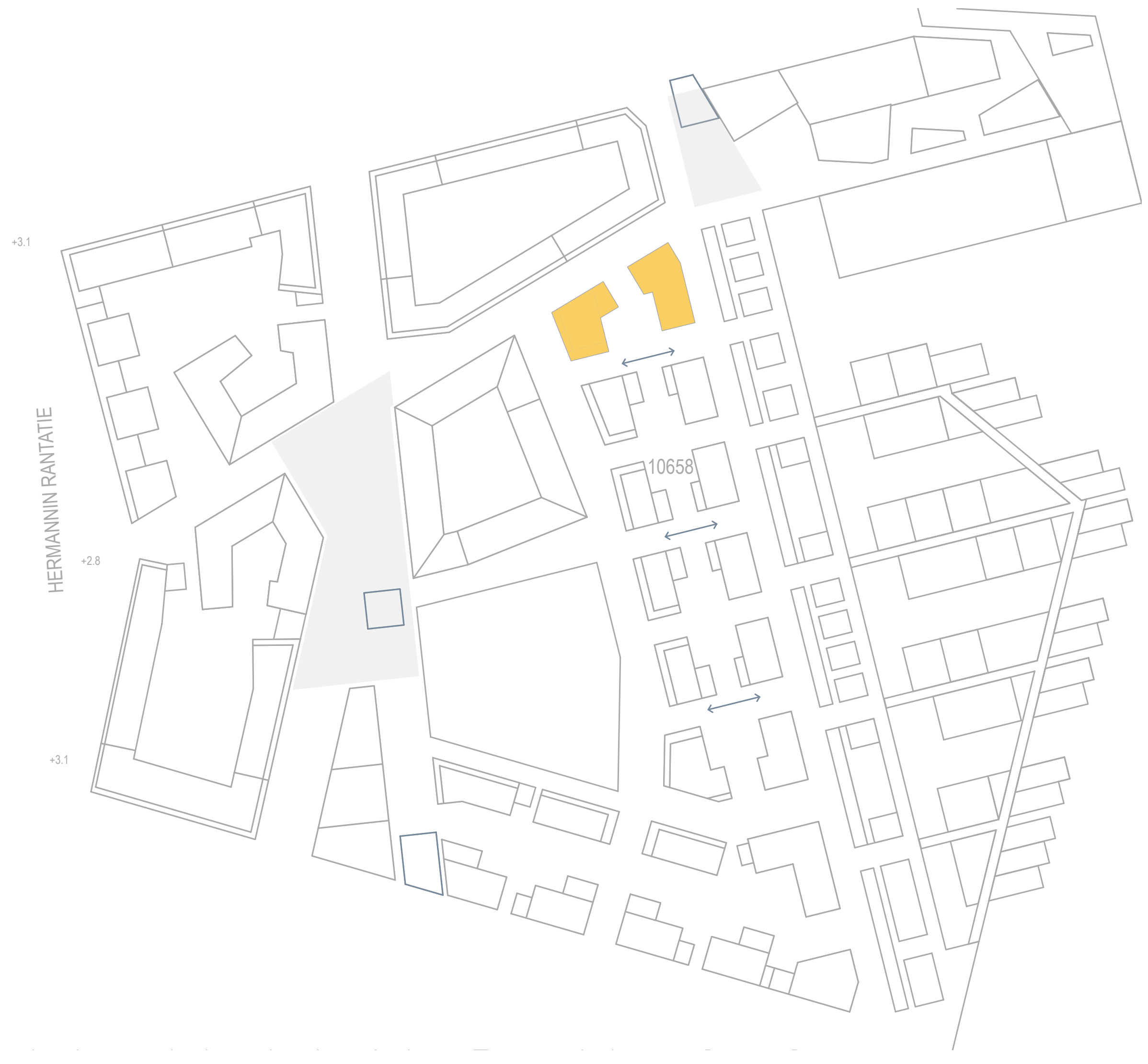
10658 Site area

Reservation for infrastr.

Planning site

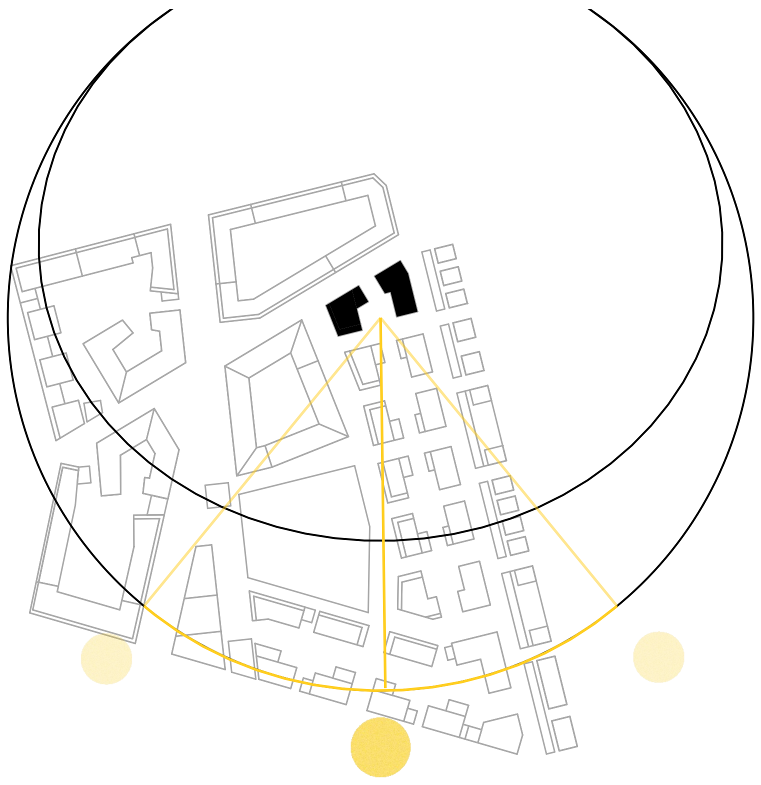
Square

Flooding route

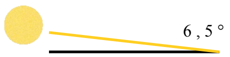


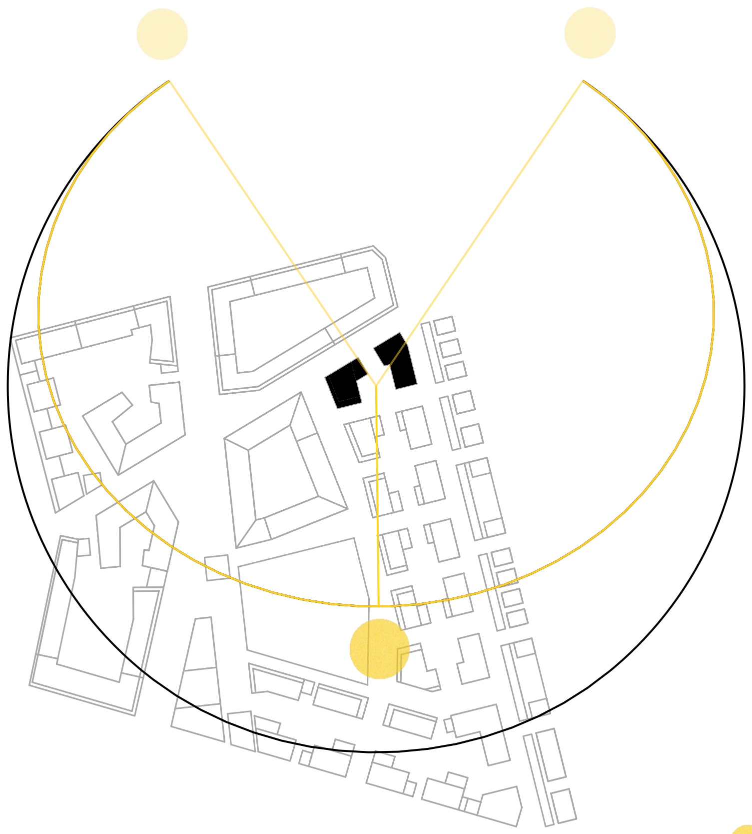
NORTH VERKKOSAARI 1:3000

SUN

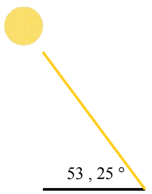


WINTER SOLSTICE

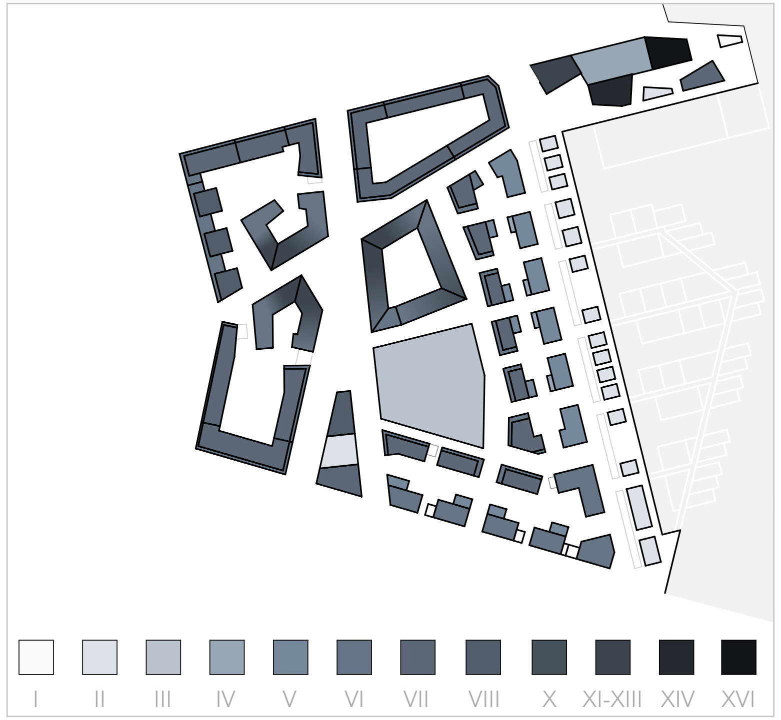




SUMMER SOLSTICE



SHADE



1:5000

The direction and angle of the sun are constant climatic conditions, even though solar radiation will decrease in the future due to increasing cloudiness. The ground of the new area is relatively flat, and the surrounding buildings and structure mainly influence the lighting conditions on site. North Verkkosaari has been planned to create a versatile but dense, characteristically central typology. This typology shades especially the lower floors of buildings throughout the year. As seen on right, the large building masses West and South of the site shade it throughout the year.

GREEN

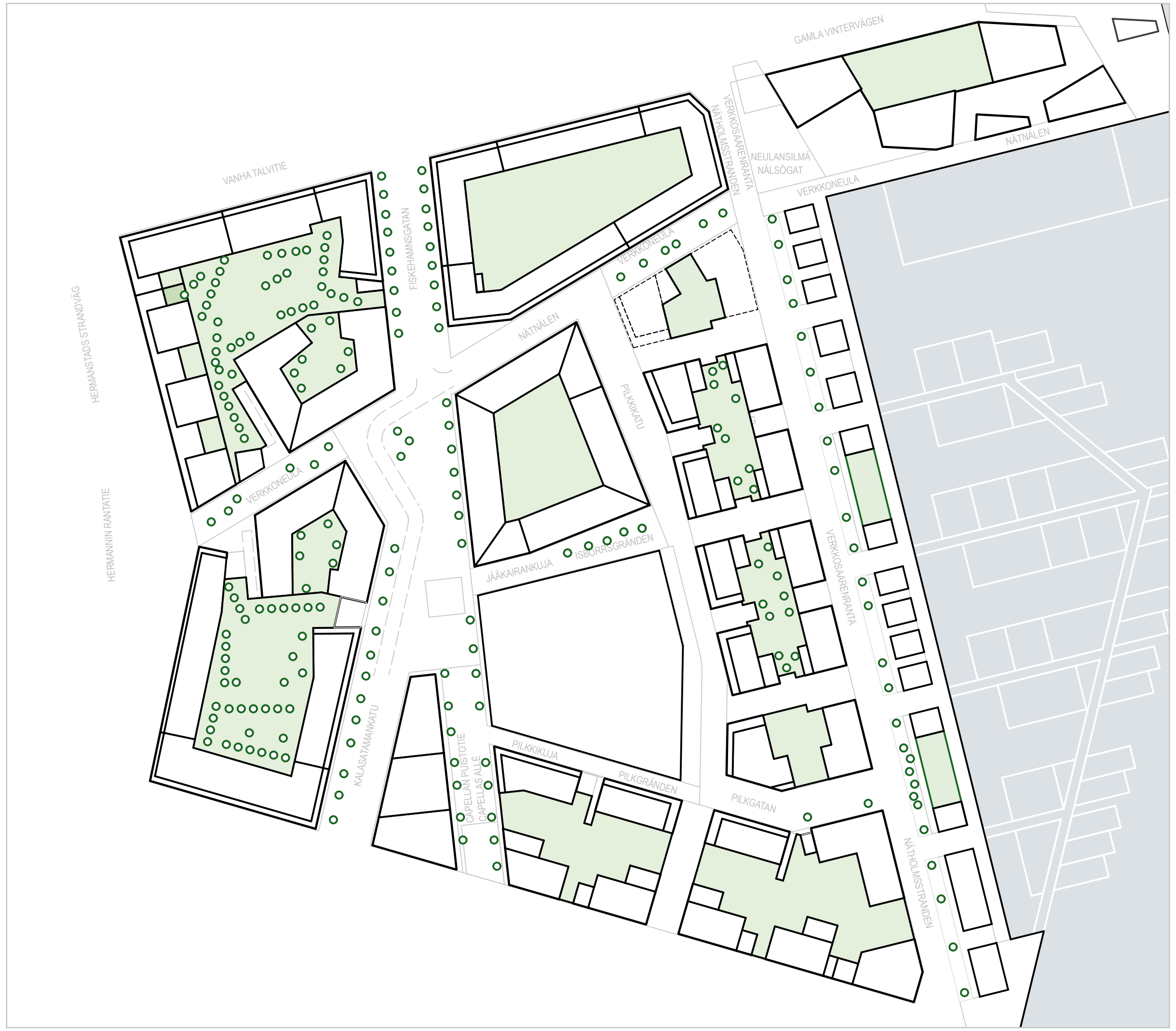
Most vegetation in the area has been limited to the inner courtyards of the bulding blocks and some additional green areas may develop as green roofs are built. Three larger public squares exist in the area, but they are reserved for pedestrians and market use rather than vegetation. Trees along streets may decrease windiness but will have a larger impact on microclimate when they reach sufficient size. Nevertheless, they provide a possibility for runoff water retention. In a coastal area, prone to sea breeze, smaller bushes and different scale vegetation could be beneficial to influence microclimatic conditions in different scales further and to accumulate and keep snow from piling against buildings in winter. A large recreational park area is planned north from Verkkosaari, which adds to public green areas proximate to the neighbourhood.

On the site, the court yard is a parking structure, so the green factor tool would recommend a green roof for the buildings. This would not work well together with wooden construction and other permiable and water retention measures should be considered.

○ Tree to be planted

Vegetation

– – Site



North Verkkosaari 1:3000

SERVICES AND CONNECTIONS

Coastal identity is highlighted in the area, with sites reserved for recreational water use, harbor for smaller boats and a yacht club. A bulevard for pedestrians and bikes follows the coastline. Services include a building for a daycare center and primary schooling, small scale service buildings alongside the coast and reservations for commercial spaces in first two floors of the residential buildings. A 50 m² commercial space is required in the East side building on the competition site as well. Biking routes and pedestrian areas are emphasized.

Small services

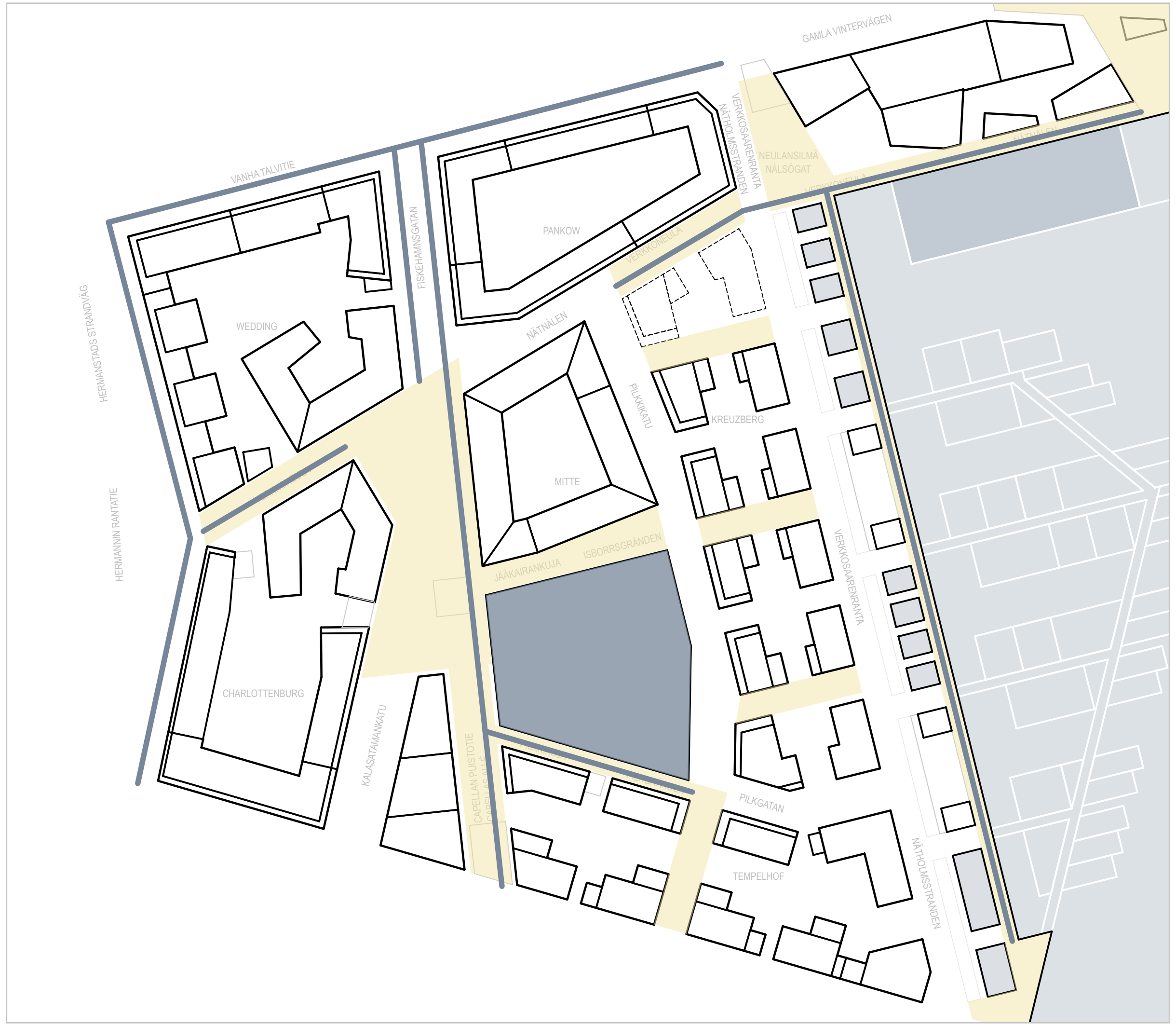
Small harbor/ Water recreation

Daycare centre and primary school

Pedestrians

Bikes

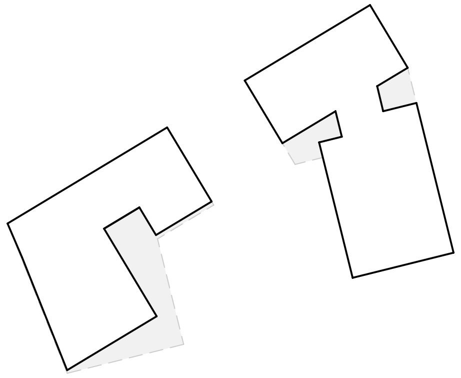
Site



North Verkkosaari 1:3000

THE CLIMATE RESILIENT DESIGN CONCEPT

THE CITY PLAN INFLUENCE ON THE RESILIENCE OF THE BUILDING DESIGN



1:1000

Building right defined by the city plan

Buildings in this design

The city plan signals towards choosing stone based building materials by presenting the site covered with flat roofs in the visualization of the area. This choice would increase the embodied carbon of the design. Building right, allowing a deep building mass is visible in the city plan. The irregular shape of the building site leaves much of the facade pointed towards North-West and the deep frame, in combination with a design including small apartments would decrease the climate resilience by leaving small apartments less equipped to allow for natural light and ventilation possibilities. The building masses in the design, presented in the scheme, have been cut out from the building right area, to allow for more light to enter the courtyard, as well as the apartments.

City plan visualization of the Northern Verkkosaari

City plan for the site 1:1000

SITE

PITCHED ROOFS

RUNOFF WATER RETENTION

SITE AND LANDSCAPE PLAN 1:500

As visible in the site plan, the buildings do not have a flat roof in the interest of providing the opportunity to use wood, a low embodied carbon material, for the structure. The pitched roofs also guide the increasing amount of rainwater away from the load bearing structures, that essentially need to stay dry. The water is then retained over the parking space with a green structure and eventually collected in a water reservoir on site. After filtration it may be used for non-potable purposes for potential benefit and an increase in self-sufficiency.

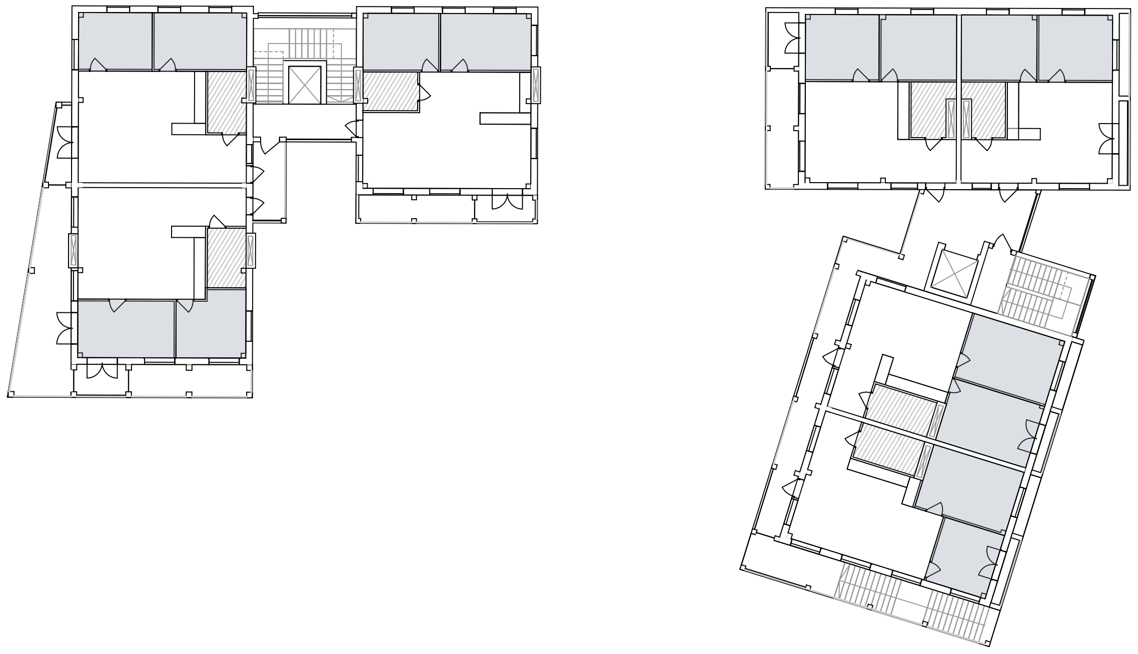
The building A is six storeys high and B and C building, that share a staircase, are both five storeys. One typical floor plan (on the next page) comprises of seven housing units, three of which are in the building A and two each in B and C. Size of the apartments varies from 70 m^2 to 82 m^2, with an average of 76,5 m^2. Altogether the design includes approximately 35 apartments and uses 650 m^2 of building right per floor.

The competition, which this design is based on, asks for 70 to 100 apartments on this site, which would lead to an average size of 35 to 50 m^2. This design, however is made to ensure transformability in the interest of allowing different living arrangements inside housing units, to further communal living, increase resource efficiency and respond to increased need for additional space during a crisis situation. The same number of people, about a hundred or even more, if apartments are in family use, can be calculated to fit the site regardless of this choice.

The top floor of the building A is reserved for a communal multipurpose space for e.g., distance office or gatherings to provide a space with nice views for all building users. Maintenance spaces, storage etc. are situated on the ground floor as well as 50 m^2 commercial space in the building B, looking at the sea. Sauna facilities are located on the ground floor of building C as this provides sea views, but also locates the humid or moist space to the ground floor away from the main wooden structures to minimize risk of moisture damage.

The fire safety regulations concerning this building are not discussed extensively in this design, as this is a concept, created to illustrate the written part of this thesis through architectural drawings and to provide a tangible example of climate resilient design measures. The amount of storeys and the function of the building would, however, point towards a fire safety class of P2, and would require a fire sprinkler system as well as necessary fireproofing according to fire compartments in addition to other standard fire safety measures. In this class, under 20% of wood element surface may be left visible if the structures have a classification of REI60, and more with a higher classification. Non-loadbearing walls may be left visible.

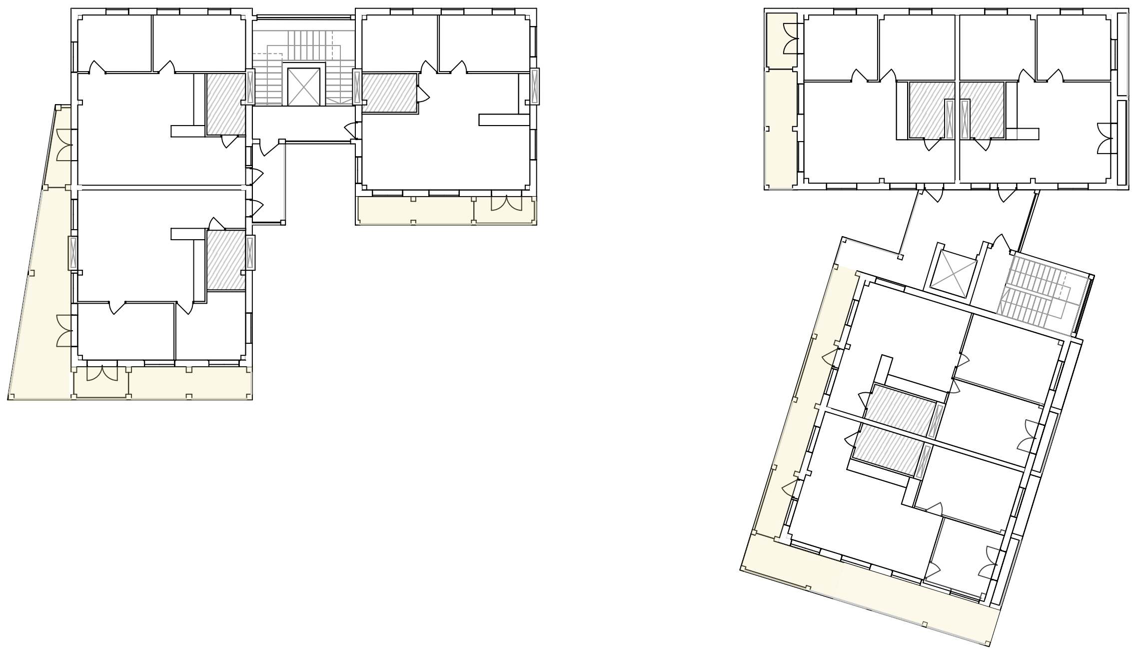
SPATIAL DESIGN



BEDROOM BATHROOM

FLOOR PLAN 1:250

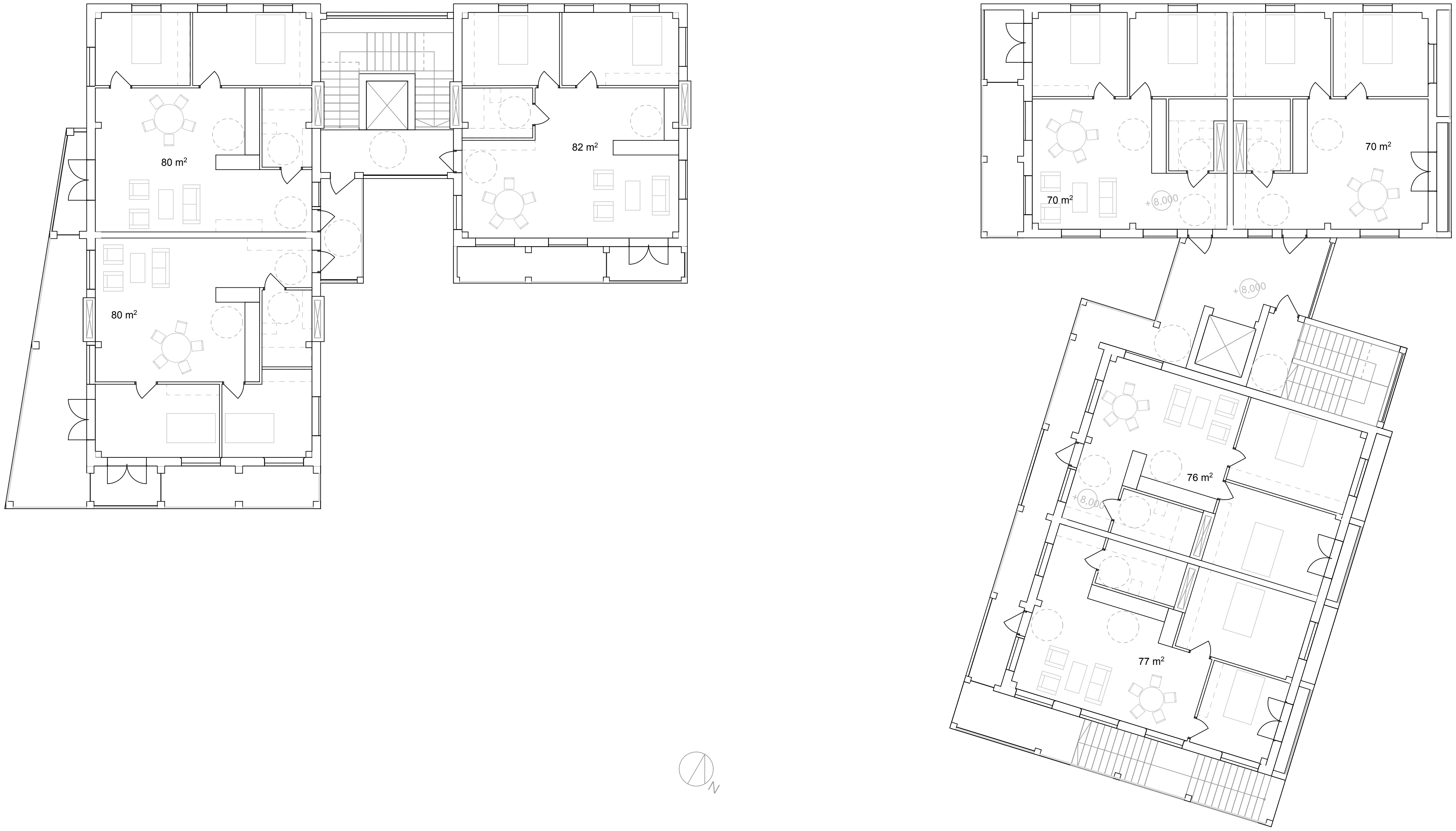
Floor plans are designed initially in a way that the bedrooms face North-West and North-East where possible. This choice is made to ensure cooler sleeping areas during warm seasons as thermal comfort is especially important for resting. This measure also takes advantage of the wide facade area pointed towards North-West. The larger units provide an opportunity to seek for a cooler space and cross ventilate in case of a heatwave. The apartments also allow for natural light to enter from different directions.



BALCONY

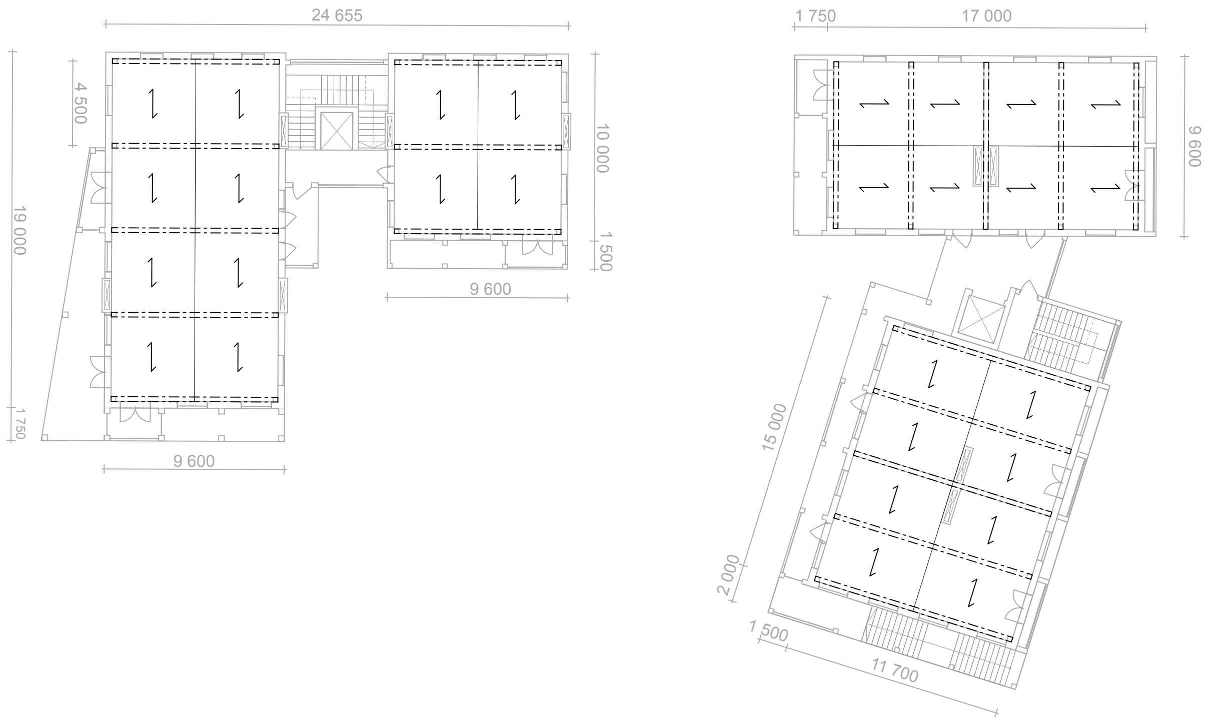
FLOOR PLAN 1:250

The primary function of the rows of balconies is to provide solar shading in the Southern directions, where it is most needed and to cover spaces potentially exposed to midday sun. The balconies also provide shelter for the structural members from other weather impacts, such as increased precipitation, that may raise the risk of moisture damage on the side that is most under the impact of wind driven rain.



A TYPICAL FLOOR PLAN 1:200

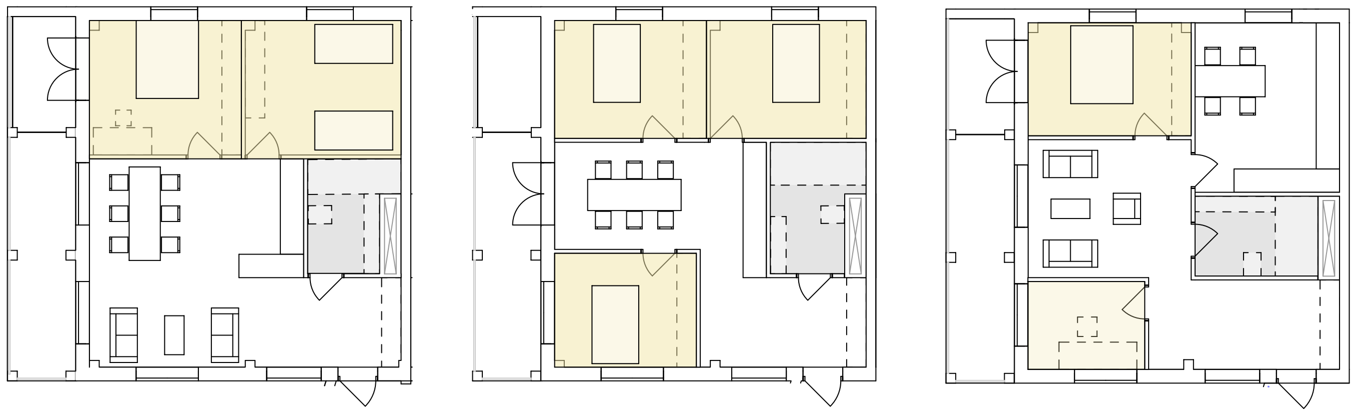
STRUCTURAL SYSTEM



STRUCTURE 1:250

To allow for spatial flexibility, the structural system has to support the modification of spaces. In this design, the primary structure is an open plan, created with a post and beam structural system. The structure is completed with massive wood slabs and non-loadbearing massive wood wall elements for rigidity together with shafts and elevator shafts. This way inner walls are not loadbearing and may be situated more freely.

FLEXIBILITY

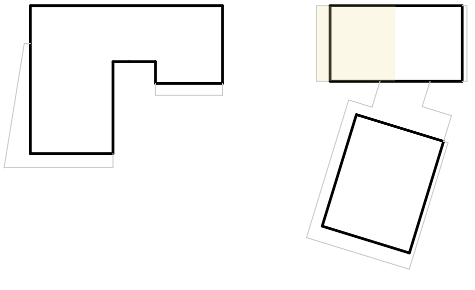


FAMILY ARRANGEMENT 1:200

COMMUNAL LIVING 1:200

SEPARATE FUNCTIONS 1:200

Units are spatially flexible towards versatile room arrengemets to accommodate different living arrangements inside an apartment. The floorplan may also be opened up further to create larger spaces for modification of use.



In the climate resilient design concept, the materials chosen for cladding, do not only endure a changing weather and time, but also represent the materials of the wall structure beneath. Both wall cladding materials, that are exposed to weather, have a rough finish to begin with, to absorb the visual impacts of the weather and time.

Larch endures humidity changes well and was chosen for cladding for its durability in humid weather conditions. Many available materials break down eventually in outdoor conditions, yet wood was chosen as it has a low carbon footprint and mitigation in this case is prioritized. The shades chosen for the facade are colors that naturally occur in wood.

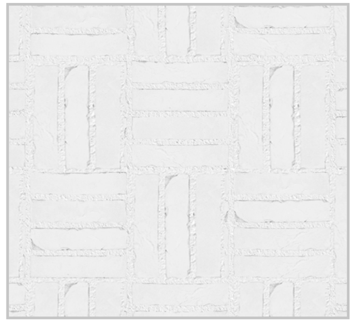
Lightly charred and brushed larch is used in the more exposed North and East facades as well as for the structural elements of the balconies. The wood is preserved by charring the surface. Heat treatment reduces absorption and release of moisture and the moisture movement that results from this, yet it makes the wood more brittle. By heat treating only the surface, the cladding endures weather where it’s needed, but keeps its structural properties. Preserving the wood with fire reduces need for additional chemicals. Brushing the finished surface makes the grain pattern visible and releases any loose burnt material.

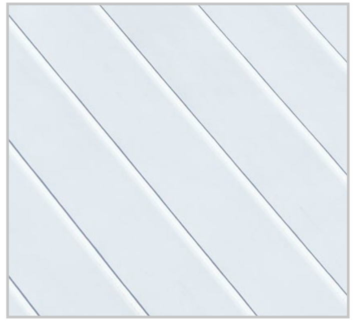
The walls, that are more sheltered by balcony structures, towards West and South are clad with larch treated with ferrous sulfate (rautavihtrilli), that speeds up the process of the wood turning grey and evens out the color development, which is necessary to avoid years of uneven surface colors due to uneven shadowing and moisture. The lighter colored wood is chosen for the façade and the floor surfaces on these sides of the buildings to reflect solar radiation and keep the surfaces cooler. Grey is also the natural color of aged wood.

Brick cladding protects the massive brick structure of the ground floor. Brick endures humid weather and splash back from the ground with less visual damage than wooden cladding and the rough finish absorbs possible visual impacts from freeze-thaw erosion.

The facade cladding materials aim for durability to protect the structure below. While this is true for the roof material as well, its key function is preparedness for overheating. The white sheet metal roof cladding has a high albedo and reflects light, reducing overheating in summertime. This may also reduce solar gains during cool seasons but as wintertime is losing some of the current solar radiation, solar gains will be reduced anyway. Also, the building is heavily shaded by other buildings on South and West sides and this blocks the lower rays of sunlight during cool seasons.

MATERIAL CHOICES





ELEVATIONS

SOUTH-EAST FACADE 1:400

NORTH-WEST FACADE 1:400

Southern side facades are covered with rows of balconies to shade the spaces facing this direction from summertime midday sun. Glazed areas create pleasent spaces for late spring and early autumn, while open balcony area is increasingly more usable in the future as the warm season will become longer. Exterior balcony structure shelters the main structure of the building towards the prevailing wind direction and potential wind driven rain. Overhangs protect the wall to roof connection from the weather impacts. East facade is protected similarly from weather impacts as it is facing the sea, and humid sea breeze may damage surface materials as well.

Windows on the Northern side of the building are smaller to minimize heat loss during cold seasons. Charred larch facade endures the impacts of weather, yet is situated over the brick ground floor to minimize possible moisture damage due to splash back during heavy raining events.

INDOORS CONDITIONS

As wintertime solar radiation will further decrease, enabling sufficient light to enter inside gets increasingly important. Large windows aimed towards South-east let in early, lower rays of sun from the open seaside whereas balconies shade the windows from midday sun.

Solar radiation won't be reflected much by the decreasing snow covers during future winters. This is compensated with light colored floor and wall surfaces to reflect natural light and to create a lighter atmosphere inside. Untreated exposed CLT works as a moisture buffer and balances indoor humidity.

SECTION 1:250

COOL ROOF

A roof with a high albedo refelcts solar radiation and reduces overheating during summer. A pitched roof guides rain and snow away from structural members to reduce risk of moisture damage and maintains a possibility for installation of solar panels. A green structure is situated over non-heated parking spaces to retain runoff water which is eventually stored in a water reservoir.

PASSIVE & NATURAL VENTILATION

Passive ventilation requires thorough planning. On this site there is potential for its use, as as the large motorway is quite far and therefore the location is acoustically less problematic. Cars only pass on two sides of the site and this leaves multiple facades for fresh air intake. In this design, it is organised through windows situated over balcony doors that are equipped with an intake system. The block is proximite to the sea and therefore windy conditions can be expected. This provides a possibility to ease thermal discomfort passively with natural ventilation through windows and balcony doors during warm seasons. Passive ventilation together with exposed wooden surfaces keeps indoor air humidity on a natural level.

While passive ventilation works well most of the year, a mechanical exhaust and heat recovery may be necessary during some winters in the near future. Eventually exterme low temperatures will decrease significantly and heat recovery is required less. The aim of the passive ventilation system is essentially to provide transformability for the design, as the most well suited system can be utilised according to the climatic situation. In the future, winters may become less problematic to the ventilation system as opposed to overheating. Therefore having capacity to adapt accordingly is essential.

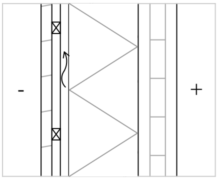
STRUCTURAL CLIMATE RESILIENCE

The pitched roof allows for the passive ventilation of the upper floors, as the exhaust shafts can be taken further away from the ventilated space through the cold attic. The attic space also allows for easier discovery and repair of any possible leaks in the roof.

The ground floor is realised with a massive brick structure to create robustness to withstand a flood due to either sea-level rise or hevy raining events. Upper floors are made with wood to mitigate emissions, but raised from ground level for their protection from weather impacts, flooding or fire. The floor height is 3 600 mm in order to allow for transformation.

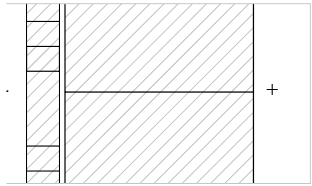
STRUCTURE

EW2



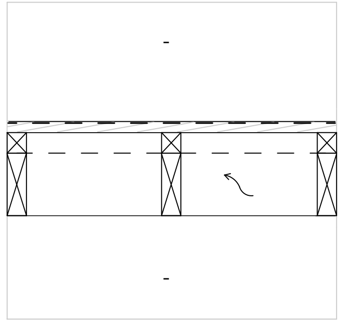
CLT	100 mm
Rigid wood fiber insulation	180 mm
wind tight, weatherproof	
e.g. Steico special dry	
Battens, ventilation	22 mm
Battens	22 mm
Cladding, larch, lightly charred	28 mm
U-value: 0,17 W/m^{2}K	352 mm

EW1



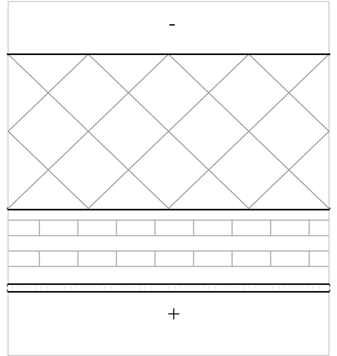
Massive brick	490 mm
e.g. Wienerberger Proton S8 490	
Air gap	15 mm
Cladding brick, white, rustic finish	85 mm
U-value: 0,16 W/m^{2}K	590 mm

R1



High albedo cool roof coating, white	
Metal sheet roofing	0,5 mm
Roof battens	25 mm
Battens, ventilation	50 mm
Underlayment	1 mm
Rafters, ventilation	150 mm

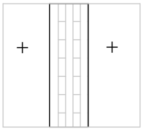
R2



Rigid wood fiber insulation panel	400 mm
CLT	200 mm
Gypsum board	13 mm
Clay plaster, off-white	

STRUCTURE

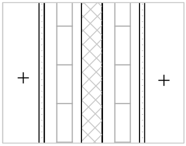
IW1



CLT	100 mm

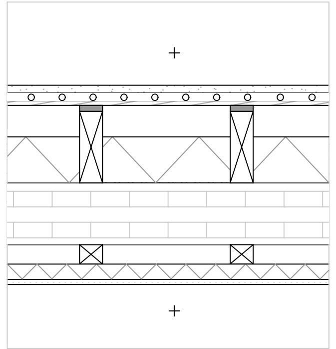
IW2

Wall between apt.



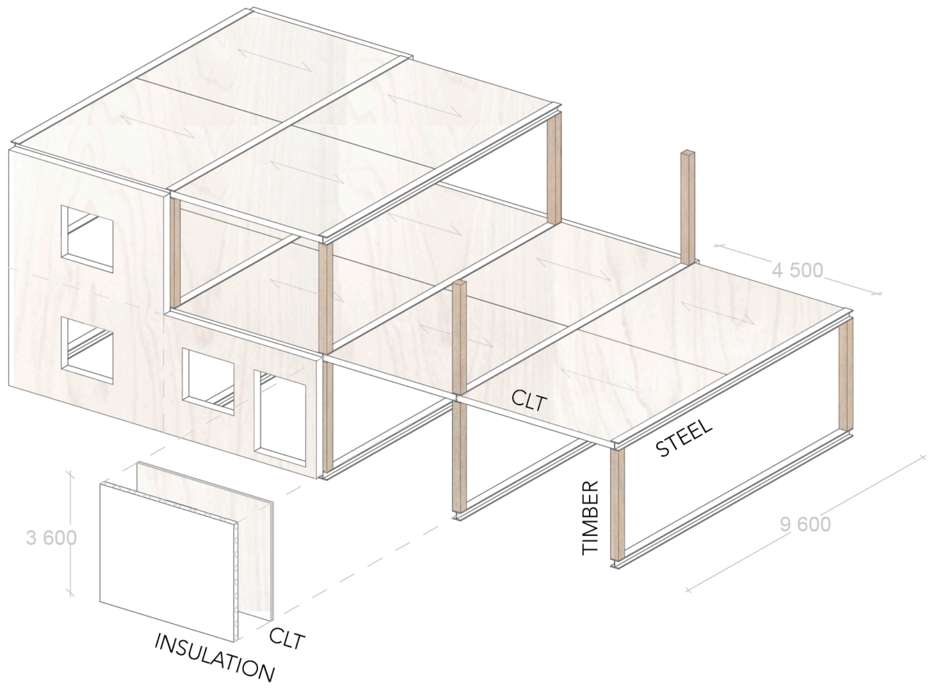
Gypsum board, clay plaster, off-white	13 mm
CLT	100 mm
Wood fiber insulation panel, fireproofing	50 mm
CLT	100 mm
Gypsum board, clay plaster, off-white	13 mm

S1



Ceramic floor tiles, matt white, 60 x 60	10 mm
Heat transfer plates,	
Hydronic floor heating and cooling	25 mm
Plywood, spruce	18 mm
Vibration isolation	
Sawn timber beams, acoustic insulation	200 mm
CLT	160 mm
Sawn timber, installations	40 mm
Additional acoustic layer insulation	50 mm
Gypsum board	13 mm
Clay plaster, off-white	
	516 mm

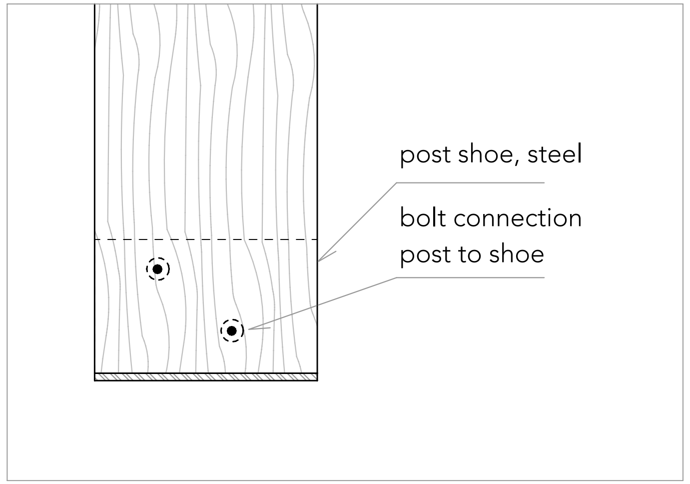
STRUCTURAL SYSTEM PRINCIPLES



The structural system of the project is not aimed to be modular, as this would serve a future vision where the building is relocated and reused as such. It is rather designed so as to enable the reuse of its structural members in other projects and the maintenance of the embodied carbon in circulation, after this building can no longer serve its original purpose. This choice is made as the demand for residential building in the centre of Helsinki can be expected to stay high in the future, and transformation of the building and its durability are prioritised to enable a long lifespan, rather than a quick relocation. However, dissassembly and reuse of the structural members is encouraged with connections that can be repeated multiple times and in the choice of the materials used. This choice is made as the reclaim and reuse of building materials can be expected to be more common in the future.

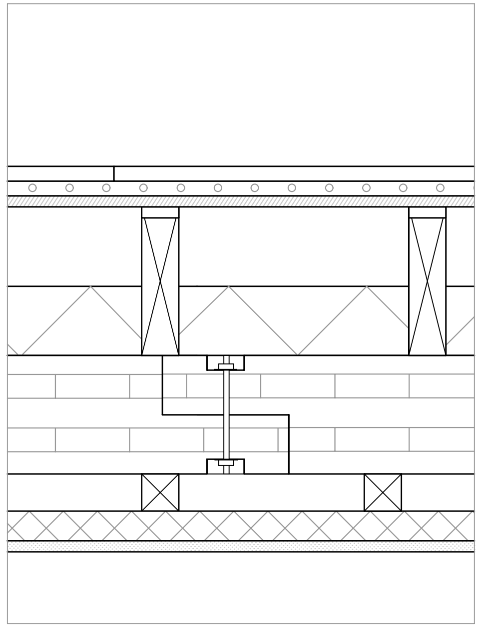
According to these preconditions, resilient structural design would aim to maintain the structural capacity of the structural members as long as possible. In this design, this leads to a choice of solid timber posts to bear vertical loads. Solid timber can be reused as a structural material in the form of a post, a beam or for a more traditional log house. Steel beams allow for a larger span and create flexibility for spatial design and maintain their structural capacity throughout assembly and dissassembly cycles and are suited for various building types. As steel is heavy in its embodied carbon but makes a versatile structural material, its reclaim and reuse should be encouraged. CLT slabs and wall elements may be more difficult to reuse as such, but chosen anyway to create the surfaces for the building. This is because most of the area is covered with the wall and floor elements and low-carbon properties of CLT are desirable. The slabs are of even size throughout a building and they are cut in the middle for easier logistics in a dense city area. CLT elements help brace the building with notched connections. The reuse of the CLT is encouraged, but the windows may make the reuse of the wall elements more difficult, and the value as a structrual material may not endure time. The floor slabs are more suited for reuse as they may function as either walls or floor slabs.

ASSEMBLY AND DISASSEMBLY PRINCIPLES



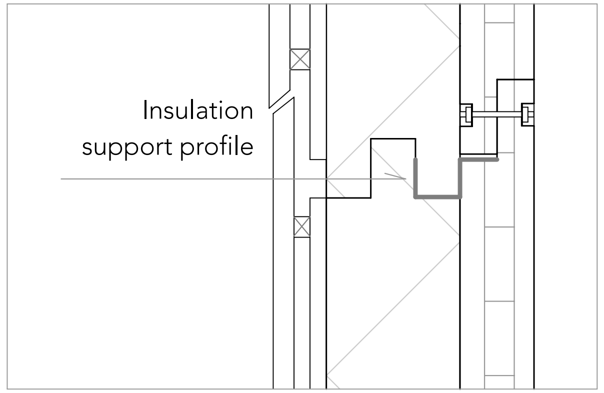
POST CONNECTION 1:10

Connections between sturctural members are carried out mainly with bolts, for example in post connections and between CLT elements through an overlap in order to enable potential repetition of the joint.



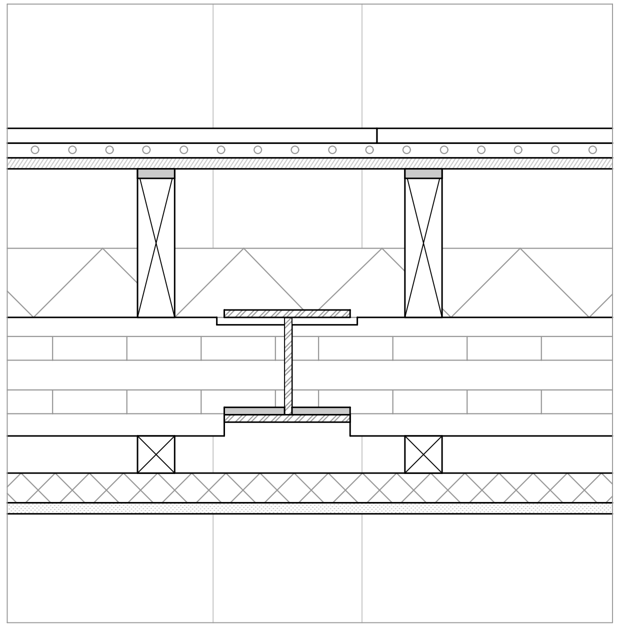
SLAB CONNECTION 1:10

Slab structure does not include cast layers to encourage disassembly.



EXTERIOR WALL 1:10

Rigid insulation panels are installed with supporting metal profiles to minimize screw connections made to the CLT elements.



SLAB TO BEAM 1:10

CLT slabs are notched in their connection to the steel beams. Installations of e.g. electrical systems are made in the cavity between the CLT and the additional acoustic insulation on the ceiling.

CONCLUSION
PARTS TWO AND THREE

Increasing resilience towards the ecological impacts of climate change in the built environment can be done with nature-based solutions, such as green and blue structures that often may provide further benefit in addition to increased adaptive capacity. However, their implementation requires some effort in existing areas which may be especially exposed to the impacts of climate change. Consideration of resilience should be inherently embedded in the city planning of new areas, but also paid attention to in those areas that already exist.

As trends, such as urbanisation and densification of city structure further increase the amount of non-permeable surfaces in cities, the combined result with climate change impacts amounts to increased exposure to pluvial flooding. A dense city may also shade apartments situated on lower floors while wintertime solar radiation further decreases. Intensifying urban heat island effect with temperature rise and an aging population will increase exposure and vulnerability to overheating during summers. All of these aspects can be addressed through architectural means, for example with weatherproofing and retention measures, spatial layouts that enable sufficient natural light to apartments and passive measures to ease thermal comfort. These design measures could be realised in more beneficial configurations, if carried out in co-operation between city planning and building design. A resilient city should not only rely on building design scale measures to absorb the impacts of climate change, but to address them on the first possible design phase so as to avoid a situation where different climate actions contradict each other or create unnecessary risk. City plan also influences largely on the climate resilience of any building design through the form, orientation and depth of the frame. These might be defined so as to encourage sufficient access to natural light and natural ventilation in spatial design and to guide for passive adaptation solutions primarily.

Sufficient solar shading, spatial flexibility and structural means to allow for it may, however, be addressed in building design scale. Furthermore, to create resilience in building design, the identity, function and structure are essential in defining which aspects of a building are aimed to be maintained according to the expected change. Moreover, any change needs to be responded to in a way that the building maintains capacity for further adaptation, transformation or potentially a new organization that is more beneficial. This could mean, for example, choosing structural members that are aimed to be used circularly in many buildings, or modularity so that a building is used in many locations.

In the future, a new area may be located away from flooding risk areas, and rainwater retention could be realised with sufficient green and blue structures. Permeable surfaces would surround buildings, that endure weather impacts while maintaining their essential structure and function. People using these buildings would live in a healthy environment and would have the opportunity to adapt their behaviour and environment according to climatic change as well as any other change. If these people decided to move out of the city, the buildings could be taken along.

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