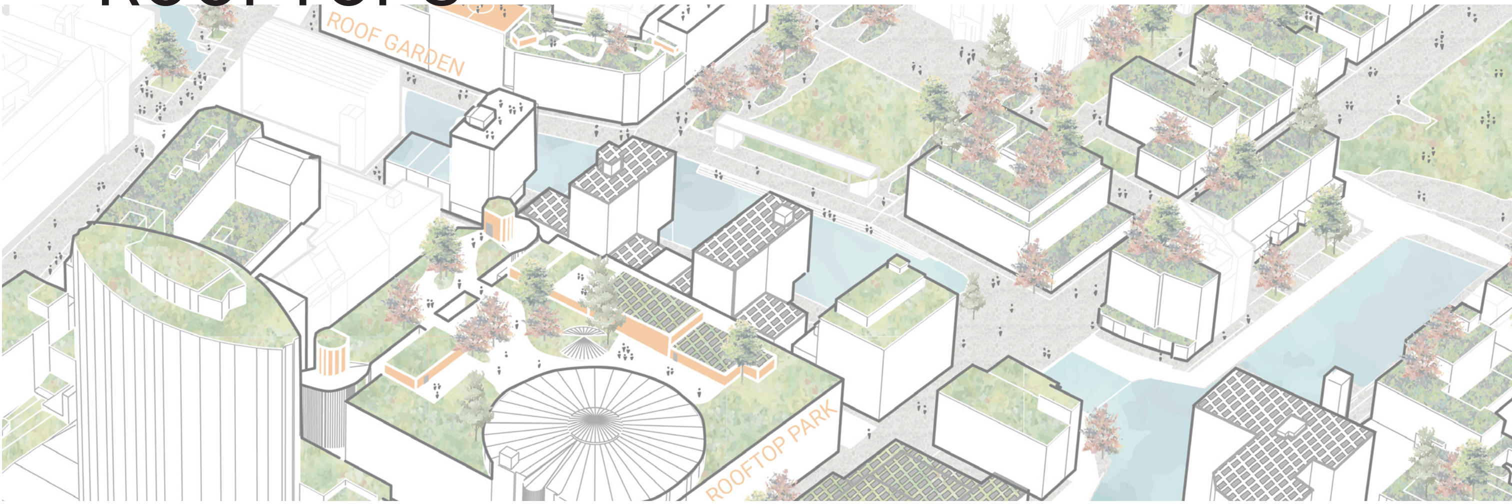
RETHINKING ROOFTOPS



Exploration of the potential and (re)development of Rotterdam's flat roofs to contribute to a sustainable and resilient city in the future

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COLOFON

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Figure 1. Bridge Rotterdam Rooftop Walk

ABSTRACT

Rotterdam's almost untapped roofscape offers an exceptional chance to solve large urban, and environmental problems cities are facing nowadays. Take for instance, climate change, energy transition, loss of biodiversity, and the shortage of public places. Therefore we should rethink flat roofs, and expose their potential. In many different ways, they could contribute to the development of a sustainable and resilient city in the future. Especially, multifunctional, green roofs are able to reduce heat stress, store (temporarily) water, purify the air, enrich biodiversity, and accommodate social functions, especially when there is a possibility to connect all those 'hidden', unused spaces in the city. There are already a lot of initiatives in Rotterdam, that come up with all different ideas to fill in the 18 square kilometers of flat roofs we have at our disposal. However, this is mostly about the (re)development of a single plot, a building block, or a street. If we really want to tackle those large urban challenges, we should not only see the potential of a single roof but zoom out and see how at a city scale the roofs could be transformed into a liveable roofscape.

This thesis explores the potential and redevelopment of flat roofs in the city center of Rotterdam and aims for a whole new flat rooftop network above the existing city. The main research question is: How can the (re)development of Rotterdam's flat roofs be guided to achieve significant progress towards a sustainable and resilient Rotterdam? By analysing the existing urban fabric, investigating possible functions flat roofs could accommodate in relation to large urban scale problems, and seeing the technical implications and possible limitations, a proposal for a rooftop toolkit and strategy for the city of Rotterdam is formulated. The main research method is research by design. This all to support the growth of Rotterdam in the upcoming years and make the city even more sustainable, resilient and liveable in the future.

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- Sustainable development goals
- Project lay-out

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This chapter gives an introduction to the type of place and location of this research, and what the ambitions of the municipality are regarding the type of place concerning the sustainable development of future cities.

1.1 TYPE OF PLACE

1.1.1 Flat roofs in Rotterdam

In the past few decades, many scientific researchers focused on the potentials of (flat) roofs in the sustainable development of urban environments. Take for example green roofs and their benefits towards the surrounding environments, in terms of appearance, solar radiation, biodiversity, and cooling performances (Li&Yeung, 2014). Rooftops are also widely used for installing solar panels (Porcaro et al., 2021). Next to these two possible functions of roofs, there is an enormous amount of other ways to redevelop roofs, ways that not only make a city more sustainable but also enrich it. And probably even enable cities to add a whole new (city) layer on the existing underlying structure. A layer that is completely self-contained, having all the functions a city needs.

The type of place this research will focus on are flat roofs. Rotterdam has 18,2 square kilometers of flat roofs in total. This is an enormous surface area, especially, when one of cities biggest problems these days is space scarcity. As there is such an amount of space, there also is a potential to not only focus on 1 specific function for these type of place, but investigating all possible functions, and see what function fits the best on a specific building.

MVRDV (2021), in collaboration with the municipality of Rotterdam already came up with the idea to assess the possibilities of flat roofs. They have formulated 130 different possible functions of rooftops, from green roofs to water storages, event sites, train stations, and housing.

In short, Rotterdam's flat roofs are a type of place, located throughout the city, that has a huge, unused space at its disposal with a great potential.

Figure 4. Flat roofs >500m2 in Rotterdam (RIVM, 2018)

1.1.2 Amount of space

To get a feeling of the available amount of space on flat roofs, it is desirable to compare it with other urban design projects or types of places. However, it is difficult to come up with other projects that occupy such a large area. Therefore, 18km2 of flat roofs in Rotterdam is compared with other land uses in Rotterdam. The municipality of Rotterdam is about 319km2. 113km2 consists of water (35%), and 206km2 of the mainland (65%). Rotterdam's mainland is used for all different kinds of functions. 24km2 (12%) of the 206km2 is covered with greenery. The green structures are mainly located on the outskirts of the city. Interesting is that all buildings in Rotterdam, take up 24km2 (12%) as well. This means that the land used for green and buildings is equally divided. However, the largest area, 158km2 (76%) is paved and is used for infrastructure for instance.

So, 24km2 of Rotterdam's land is build-up. This means that there is also 24km2 of roofs in Rotterdamx. 18km2 (75%) are flat roofs, and 6km2 (25%) are sloping roofs. This strong presence of flat roofs has especially to do with all the port warehouses and the bombardment of Rotterdam in 1940. There are barely any other cities in The Netherlands with such a high proportion of flat roofs.

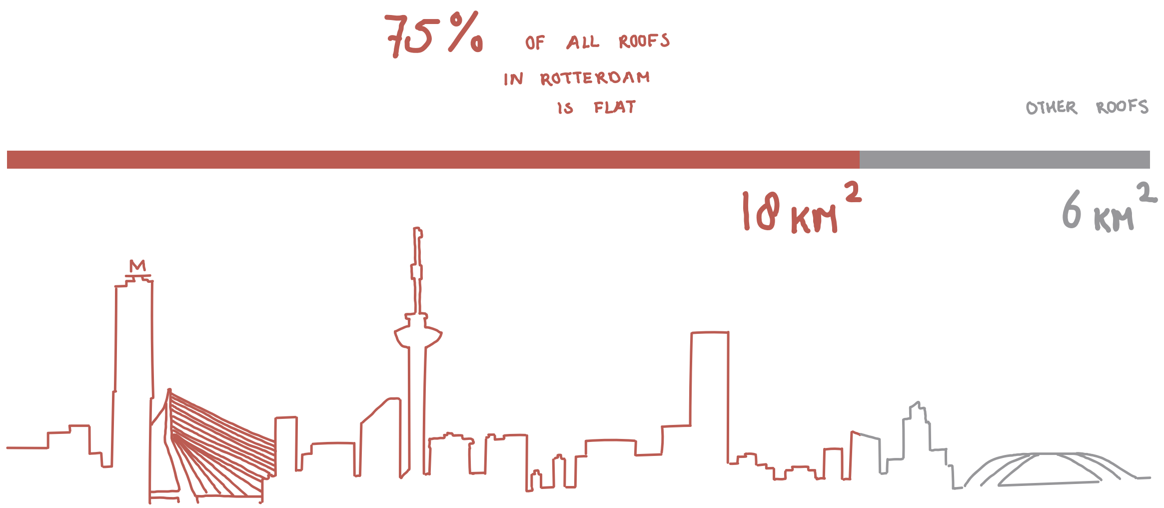


Figure 5. Percentage of flat roofs in Rotterdam

1.1.3 The ambition of the project

Even though there are many ideas about the way we could develop rooftops, it is mainly based on one single plot. For instance, a whole neighborhood rooftop structure is not realised yet. Neither in The Netherlands nor foreign countries. But why is that? Why do cities still only use a limited number of rooftops, when there is a whole new world to be explored? Has it to do with policies? Are the supporting structures of buildings unsuitable? In other words, many questions remain unanswered and are convenient for further research. Besides, how can rooftops be developed to become really a part of a city? A part of an already existing neighborhood? A rooftop for the community, private or public use? What functions should it have in a specific neighborhood? What are the needs and wishes of a certain area? How can we come up with a 'new city layer' and engage local residents in the design process and make the rooftops part of their city? In other words, how to take advantage of the potential of Rotterdam's rooftops to contribute to a sustainable and resilient city in the future?

This research project will focus on how rooftops can be used to make cities, such as Rotterdam, more sustainable and resilient in the future. The research tries to answer multiple questions, such as: how can rooftops tackle urban challenges such as climate change, lack of green, and population growth. What elements are needed? How are we going to (re)design those roofs? Do we have to combine functions that are crucial to combat those urgencies? Who is going to transform those roofs? Which roofs are possible to transform (regarding roof structures)? And for who are roofs accessible? Is it also desirable to add a social function to those roofs?

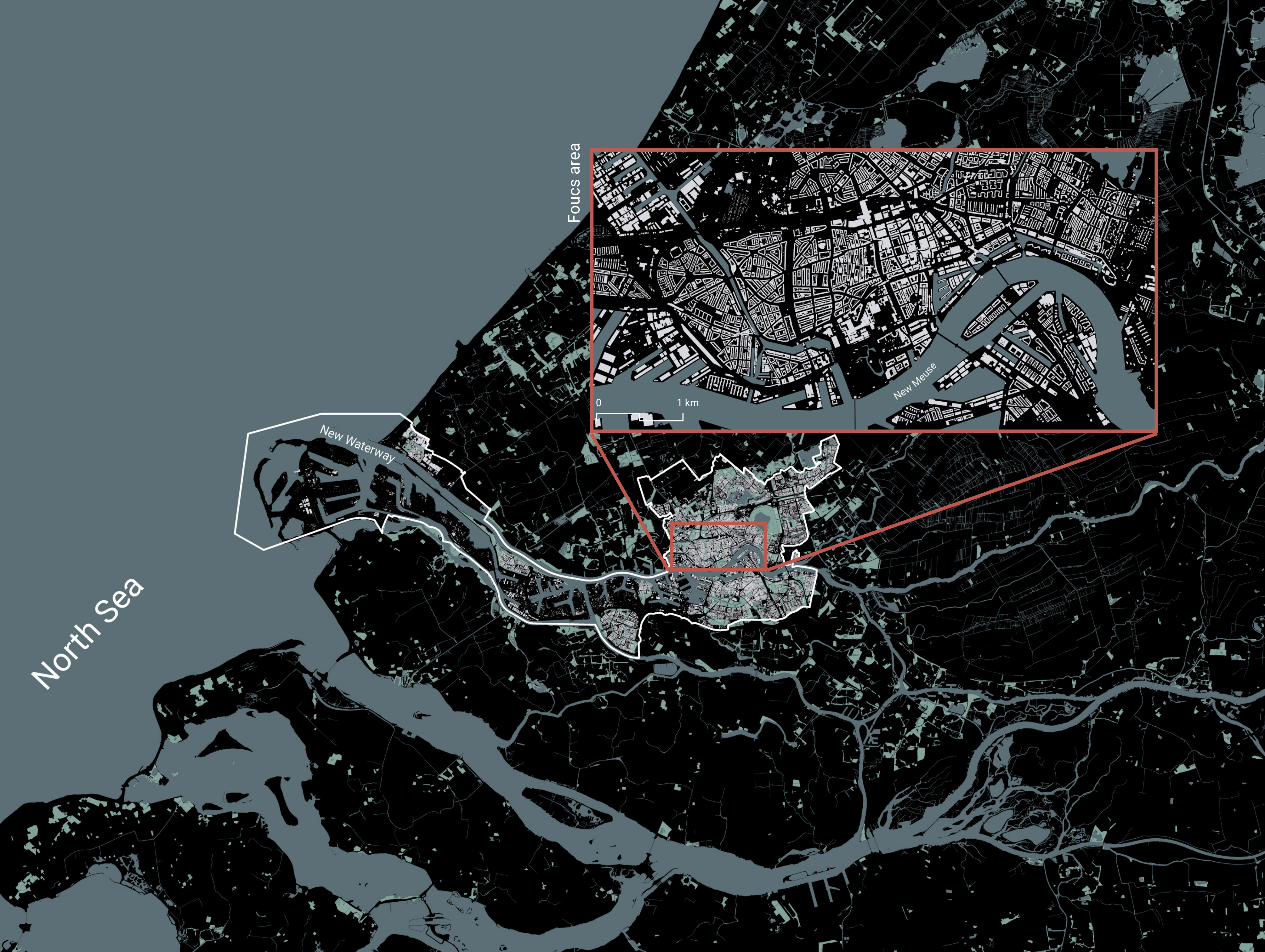
The ambitions of the project are to go beyond existing rooftop projects and initiatives in Rotterdam, as most of them occupy one single plot. To be able to deal with big, societal, environmental, and climate-related problems, we need more, larger, interconnected spaces. Spaces that form together a network and become 'strong' enough to make a change in the future. In other words, thinking on a large scale and trying to see the connections between different spaces or areas on roofs in a city, to make a significant step toward a more sustainable and resilient city in the future.

1.2 RESEARCH LOCATION

1.2.1 Project location and focus area

Rotterdam is located in the southern part of the province of South Holland in The Netherlands. It is the second-largest city in the Netherlands and a major European port. The city center is located in the eastern part, which lies 30km from the North Sea. The New Waterway links the city center with the North Sea. The city center itself lies along both banks of the New Meuse, in Dutch the Nieuwe Maas.

This research project will focus on the old city center of Rotterdam (as shown in the figure). This is because the city center suffers to most from climate change and other urban challenges (this will be elaborated further in the next chapter). Next to that, it has the highest density tasks, while it is already completely build-up, so innovative and new solutions need to be found to deal with all the different problems the city is facing and see how the existing structures can be transformed in the future.



LEGEND

Rotterdam
land
water
recreational green
buildings

0 7 14 km

Figure 6. Project location and focus area (RIVM, 2018) (CBS, 2015)

1.2.2 History of the place

On 14 May 1940, in less than a quarter of an hour, a German bombardment destroyed the center of Rotterdam, Kralingen, and the north of Rotterdam. The city burned for days. As a result of the shootings and bombardments that took place between 10 to 14th May, 30.000 buildings, 1 square kilometer of streets, and open spaces, 1,58 square kilometers of the built-on area were demolished (Stadsarchief Rotterdam, 2018). This meant that 79.600 persons, who represented 12,8% of the population, were left homeless (Multifunctional Roofs Programme Team, 2019).

Due to the bombardment and the reconstruction work in the years afterward, Rotterdam has gotten a unique roof landscape in the city center. Many buildings have large flat roofs, and there is a high degree of vertical layering. Next to that, Rotterdam is a high densification rate, and almost all surface is covered by paving, which makes space for water and greening scarce at street level. With more than 18 square kilometers of flat roofs in Rotterdam, there is a unique opportunity for developing a second 'city layer', on the top floors for densification, new landscapes, and attractive public places. In other words, a new way of place-making on top of the city (Multifunctional Roofs Programme Team, 2019).

Figure 7. Fire boundary Rotterdam (Stadsarchief Rotterdam, 2008)

1.3 A GOOD CITY GROWTH

1.3.1 Municipal vision of Rotterdam

To see how Rotterdam's roofs can be transformed, the municipal vision that is published in 2021 is one of the most important leading documents. This document is about the city goals for the upcoming years and elaborates on how Rotterdam will have good growth towards a sustainable society.

It starts with the fact that the city of today will have a different look in 15 years. Rotterdam changes and grows super fast, while the territory of the city will not expand. Besides, several, big tasks such as the energy transition, and climate adaptation are coming our way. To keep the city strong and guide this development in the upcoming years, the municipality formulates a vision and so prepares and leads the growth of the city using five different perspectives to remain an attractive city for everyone. The five perspectives are the healthy city, compact city, productive city, circular city, and inclusive city. This thesis responds especially to the compact, healthy and sustainable city perspectives (see drawings and explanations on these pages).

One of the focus areas of the city's vision is the city center. The main task in the city center is to densify and thereby increase the attractiveness of living, working, and recreation. In the center, the car must make space for cyclists, and pedestrians on several boulevards and green. The city will strive for a balance between tranquillity and activity, as it should remain an area where everyone can meet each other.

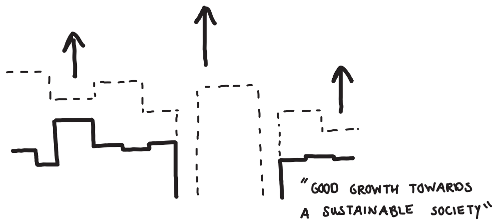
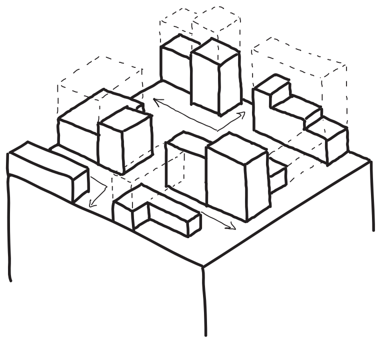
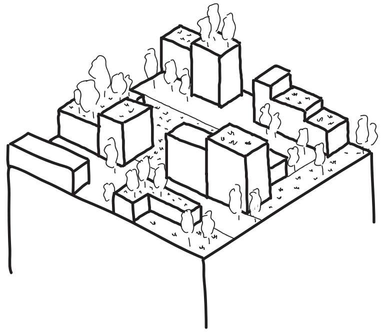


Figure 8. Vertical city growth (Municipality of Rotterdam, 2021)



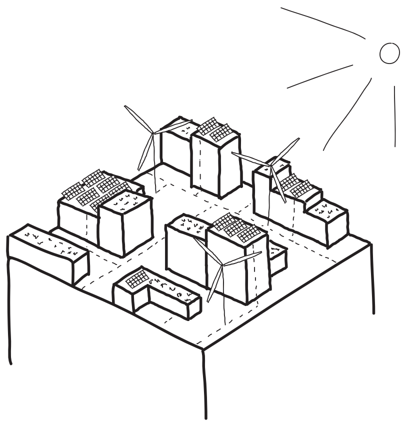
COMPACT CITY

The compact city is about enforcing the city, especially nearby/around new or existing high quality public transport centres/points. By adding housing, there will be greater support to add amenities as well in the same area. Therefore, transport, living, and working will be in the close environment. Finally, it will create a new network of complementary urban centers.



HEALTHY CITY

The healthy city is about Rotterdam which will be a healthy, green, and appealing city to live, work and recreate in. A city structure wherein blue-green structures are important. New green structures will be realised by adding parks and greening boulevards. More important is that those green structures will be connected to magnify biodiversity in the city. Next to that, all these added green spaces will serve as a sponge during heavy rainfall and reduce the urban heat island effect. Besides, those green areas will make the city more attractive for its citizens and make the open-air more accessible. There will be less place for the car, and more for the cyclist and the pedestrian.



SUSTAINABLE CITY

The sustainable city is about the implementation of renewable energy sources. In the coming years, we will be going to generate more and more renewable energy, distribute it differently and reduce the demand. The materials loops will be narrowed down, to get a fully recycled system. For instance, residual heat from port industries will be used for our heat demand. Besides, the urban mobility and transport in the harbor will be more sustainable.

Figure 9. Three of the five city models for a good growth of the city of Rotterdam (Municipality of Rotterdam, 2021)

1.4 ROOFTOP PROGRAM

1.4.1 Multifunctional rooftop program for Rotterdam

While the municipal, and environmental vision focuses on the city as a whole, the National Rooftop Program (2021) and the Multifunctional Roofs Programme of Rotterdam (2019) elaborate specifically on the (re)development of roofs in the upcoming years. A future-proof rooftop landscape (roofscape) in The Netherlands, is what the 'Nationale dakenplan' is about. Their vision is as follows: the roof is not the closing piece of a building, but it is the starting point for a green roofscape with a diversity of societal functions. Their ambition is that cities can benefit from roofs in terms of health and well-being, biodiversity, climate adaptation, and sustainable energy.

Whereas the National Rooftop Program argues only for what urban challenges roofs could serve. The Multifunctional Roofs Program of Rotterdam, focuses fully on Rotterdam and elaborates more extensively on what specific functions roofs could accommodate in the future. The multifunctional roof program formulates seven different ways to redevelop bare plat roofs in the city of Rotterdam. And this is all to make from multifunctional roofs a roof landscape (figure 10).

Since 2008, Rotterdam has been a frontrunner in the development and encouragement of the construction of green roofs. Currently, there are 400.000m2 of green roofs, and 168.0m2 of solar panels already released on Rotterdam's roofs (Municipality of Rotterdam, 2022). Over the years, Rotterdam is slowly moving from a monofunctional roof structure to a multifunctional roof structure nowadays, and a sustainable roofscape in the future. "We can create added value for the quality of life in Rotterdam citizens' immediate living environment by combining various roof functions (Municipality of Rotterdam, 2019)."

Since most of Rotterdam's roofs are privately owned, the municipality has very little say in the development of the roofs. The dependency on the willingness of citizens forms a blockade in the completion of the sustainable goals and the potential of the roofs that are for the taking. The expectation is that it will take 15 to 25, or even more, years before all roof owners are informed, inspired, stimulated, and eventually establish a multifunctional roof.

Nowadays, residents of Rotterdam are increasingly discovering the potential and benefits of the use of roofs. Especially in terms of energy generation in combination with a green surface, which makes the roof more attractive as an outdoor area, keeps the building cooler during heatwaves, and ensures a longer life of the roof. They see an optimal combination of different functions on one rooftop. Also, investors and entrepreneurs acknowledge the opportunities of rooftops and try to combine green, solar panels, water storage, and social functions on the same surface. Apart from rooftop owners, cultural institutions such as Rotterdam Roof Days (organized since 2015) show the willingness and enthusiasm to get up on roofs and use them for (temporal) cultural functions as well.

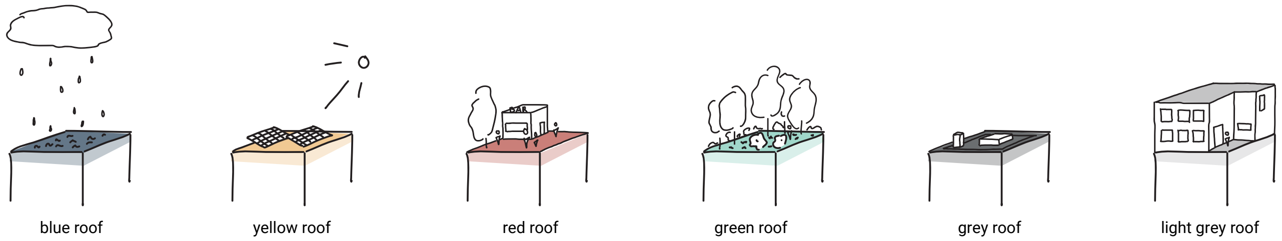


Figure 10. Rooftop program (Municipality of Rotterdam, 2019)

1.5 SUSTAINABLE DEVELOPMENT GOALS

1.5.1 Contribution of roofs to a sustainable city

The United Nations formulated seventeen Sustainable Development Goals (SDGs), which are for all countries over the world an urgent call for action. The goals will stimulate action on all different topics of critical importance for the planet and humanity from 2015 to 2030 (United Nations, 2015). With the redevelopment of rooftops in the future, the municipality of Rotterdam aims to respond to seven of them (MVRDV & Municipality of Rotterdam, 2021). Each goal is related to specific rooftop features. It depends on the rooftop function and the location of the roof in the city, which SDGs can be addressed. In the functional analysis, these goals will be applied to more specific rooftop functions (see page 57).

Green roofs can contribute to more green spaces to purify air, cool air, and reduce sound pollution, and calm spaces as an escape from the busy city

Blue roofs can retain water, delay drainage of rainwater, and collect water for irrigation or reuse of 'grey'

Yellow roofs can generate renewable energy by the use of solar panels, while green roofs can improve insulation of buildings and so reduce energy consumption.

Red roofs can accommodate more public space, provide more diversity of functions, and a more inclusive program

Green roofs can contribute to local food production by urban farms. Next to that it is possible to use circular building constructions of roofs, and make use of existing materials.

Especially green (cool air), blue (store water), and yellow roofs (generate renewable energy) can play a part in climate adaptation.

Green roofs can be new spaces for flora and fauna, and so increase biodiversity (especially native species).

Figure 11. Seven Sustainable Development Goals (United Nations, 2015) (MVRDV & Municipality of Rotterdam, 2021)

1.6 PROJECT LAY OUT

1.6.1 Phases of the project

After the introduction including the type of place, the project ambition, research location, and existing city visions and programs, the thesis will focus and elaborate further on many other topics. The thesis could be divided into four different phases: orientation and exploration phase, research phase, design and implementation phase, and the finalisation phase.

The introduction is together with the problem definition part of the orientation and exploration phase (see figure 12). The problem definition will be followed by the methodology, theoretical framework, and spatial analysis. These three chapters belong to the research phase. Subsequently, the design and implementation phase will follow, concerning the design of the base layer, the design of the social layer, the toolkit design, and the implementation. The implementation will together with the concluding remarks be part of the last phase of this research, the finalisation phase.

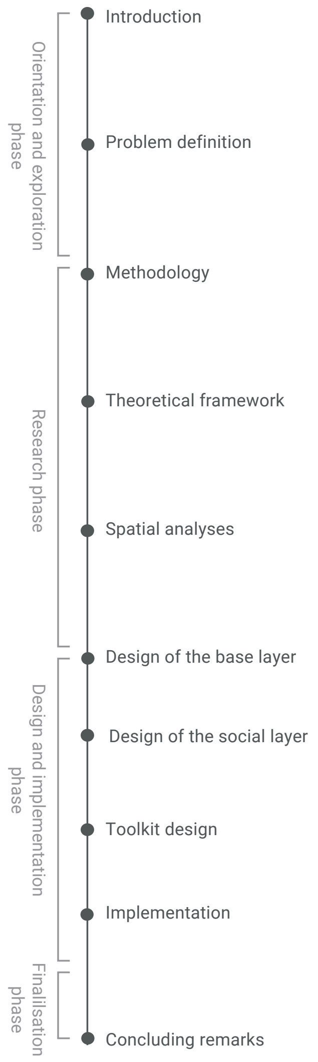


Figure 12. Phases of the project

Figure 13. View on Coolsingel from Rooftop Walk

PROBLEM DEFINITION

- Drivers of change
- Urban challenges
- Problem statement
- Relevance

This chapter introduces the drivers of change of this project, and so the five large-scale urban challenges the project addresses and tries to tackle.

2

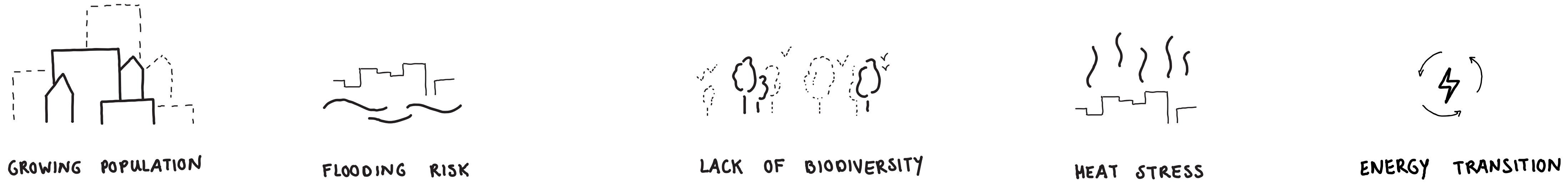
2.1 DRIVERS OF CHANGE

2.1.1 Main urban challenges that will be addressed

Rotterdam needs to combat various different (climate) challenges over the forthcoming decades. The city needs to become more resilient to cope with these challenges. There is growing pressure on every square meter, especially in the city center. Therefore, Rotterdam is forced to come up with a solution and search for new places in the city where there is a potential to extent the city. Since there are 18 km2 of flat roofs in the city, there is an enormous amount of space that can be developed in order to tackle all those challenges (Municipality of Rotterdam, 2019).

The project shows how rooftops can deal with several urban challenges (at the same time). Take for instance the capacity of green roofs to store water, cool the city, purify the air, enrich biodiversity and improve the appearance of our living environment. Besides, (green) roofs could simultaneously serve as attractive (public) spaces.

Nowadays, in The Netherlands, 0.5% of all roofs are green, while four years ago it was only a little less, 0,45%. This means that if we continue like this, it will take 2.000 years more until all flat roofs are green (Rotterdamse Dakendagen, 2022). The interesting thing is that even though we have those huge (environmental) problems, and the enormous amount of unused space in cities, it is still not implemented (fast) enough on the roofs.



- city needs to grow in a vertical way, instead of in a horizontal way

- city as a 'sponge city', to absorb and store (temporarily) rain water

- city should have more green areas to strengthen the desired green corridors

- make the city less stony and more energy efficient

- city has to get rid of gas, and has to become energy neutral in 2050
- less (air) pollution

Figure 14. Urban challenges

2.2 URBAN CHALLENGES

2.2.1 Growing population

The first urban challenge is the growing population, in other words, urbanization, and the attractiveness of the city, while preserving the public realm (Gemeente Rotterdam, 2021). Worldwide, more and more people are moving to cities. The global migration of people to the city or metropolitan regions is being propelled by the large presence of jobs, facilities, and educational facilities that are concentrated in these places. At this moment, Rotterdam counts 651.631 residents. Compared to last year, it is an increase of 9%, so 58.647 new residents (Municipality of Rotterdam, 2021). It is expected that in the coming years it will continue like this.

To cope with this growing population Rotterdam indicated areas all over the city where there is a potential to densify. These areas are mainly connected to important public transport points. In the map on this page, these areas are visualised in red dots.

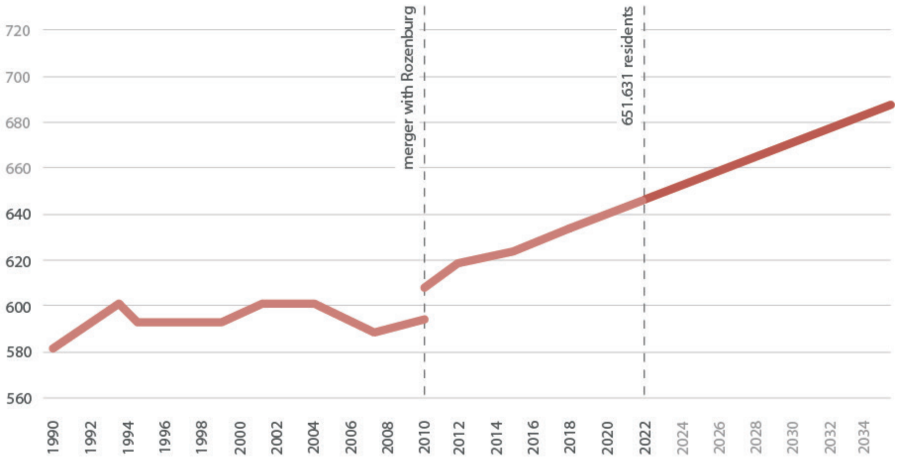


Figure 16. Omgevingsvisie (Municipality of Rotterdam, 2021)

Figure 15. Hoogbouwvisie (B&W, 2019)

2.2.2 Climate change

Another very present urban challenge Rotterdam is facing is climate change. Climate change refers to long-term shifts in weather patterns and temperatures. Those shifts can be caused by natural events. But since 1800, humans and their activities have been the main driver of climate change. From 2019 to 2035 there will be an increase of 65.000 inhabitants in Rotterdam. More people living and working in a city, means also more (community) traffic, while CO2 emissions have to reduce significantly, to improve air quality and thereby the living environment (Multifunctional Roofs Programme Team, 2019).

The most visible effects of climate change are flooding, the urban heat island effect (UHI-effect), and air and sound pollution (in other words, environmental health risks).

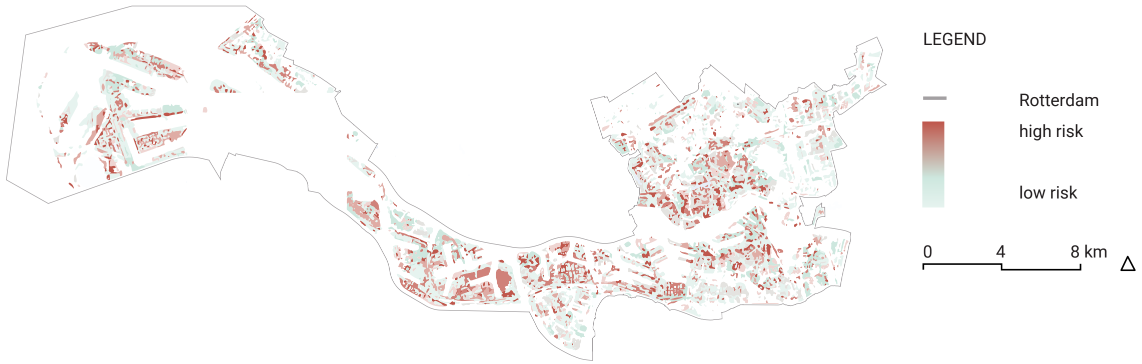


Figure 17. Water level after heavy rain | 140mm/2h (Klimaateffectatlas, 2021)

In figure 17, the effect after heavy rain (140mm/2h) is visible. This is almost unimaginable, given that an ‘extreme wet day’ in The Netherlands is defined as a day with 50mm of rain in 1 hour (KNMI, 2021). However, this extreme scenario shows perfectly where water does not easily runoff in the city.

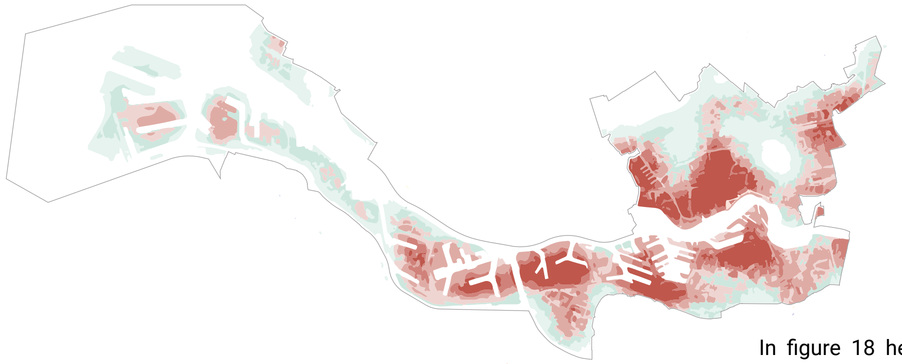


Figure 18. Urban heat island effect (Klimaateffectatlas, 2021)

In figure 18 heat stress in Rotterdam is visualised. Heat stress happens in urban heat islands that experience higher temperatures than rural areas. In urbanized areas structures such as roads, buildings, and pavement absorb the sun’s heat. When there is not an equal distribution of materials that absorb heat and materials that have a cooling effect, such as water and green, these areas become an island of relatively higher temperatures. In figure 20 the differences in temperature between rural areas and dense areas in cities are visible.

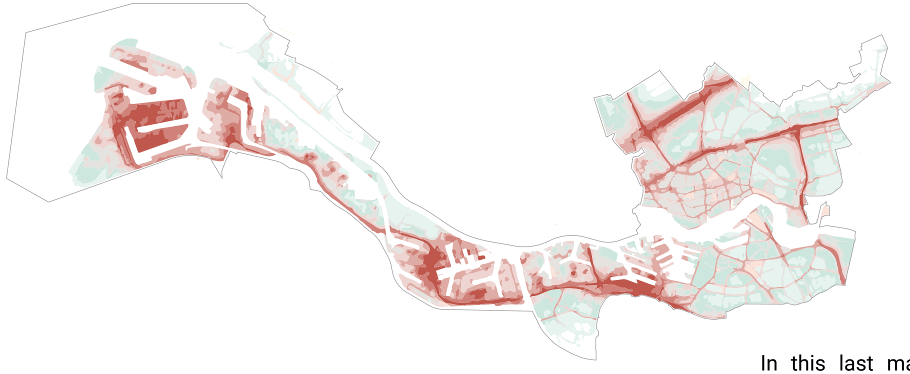


Figure 19. Environmental health risk (Klimaateffectatlas, 2021)

In this last map, the environmental health risk is depicted. The environmental health risk is a scoring instrument that can express risks from various local environmental factors, such as air pollution and sound pollution (Klimaateffectatlas, 2021). One of the main tasks for the city is to improve quality of life, especially by reducing air pollution. 50% of Rotterdam’s air pollution is caused by car traffic.

2.2.3 Lack of green (in relation to heat stress)

Rotterdam experiences a lack of green space. Due to rapid urbanization, natural areas are replaced by build-up areas. Even residents are tiling their gardens. In this way, green (completely) disappears in the city and 'moves' to the edges of the city. As visible on the map on the right page, there are some green spaces in Rotterdam, but they are mostly located on the northwest side, away from the crowded areas. Especially in the city center, the only large urban green area is around the Kralingse Plas.

However, people need rest and quiet spaces, there is a need for biodiversity in a dense city, cities have to 'cool down', water storage needs to be ensured (in a natural way), and air quality needs to improve. One overall solution for all these problems is greenery. Therefore, we have to make urban spaces greener again.

In figure 21, potential ecological connections are visualised in red. These connections are based on existing green-blue structures and form the connections between all-natural areas in the city. This is to bring flora and fauna back to the city, and so enrich and strengthen the city's biodiversity.

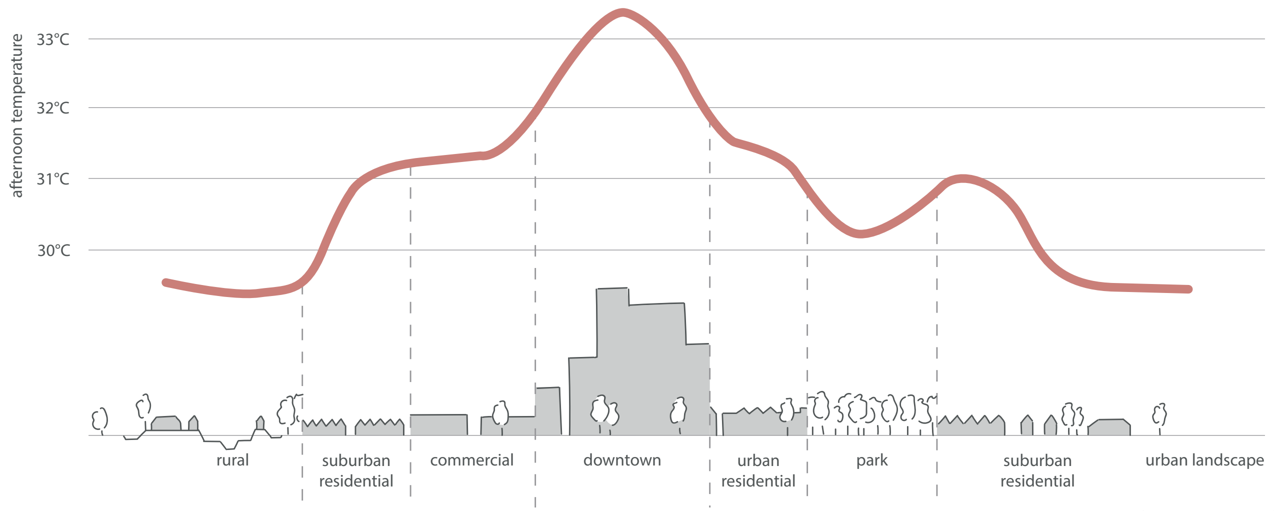


Figure 20. Urban heat island (UHI Basics, 2008)

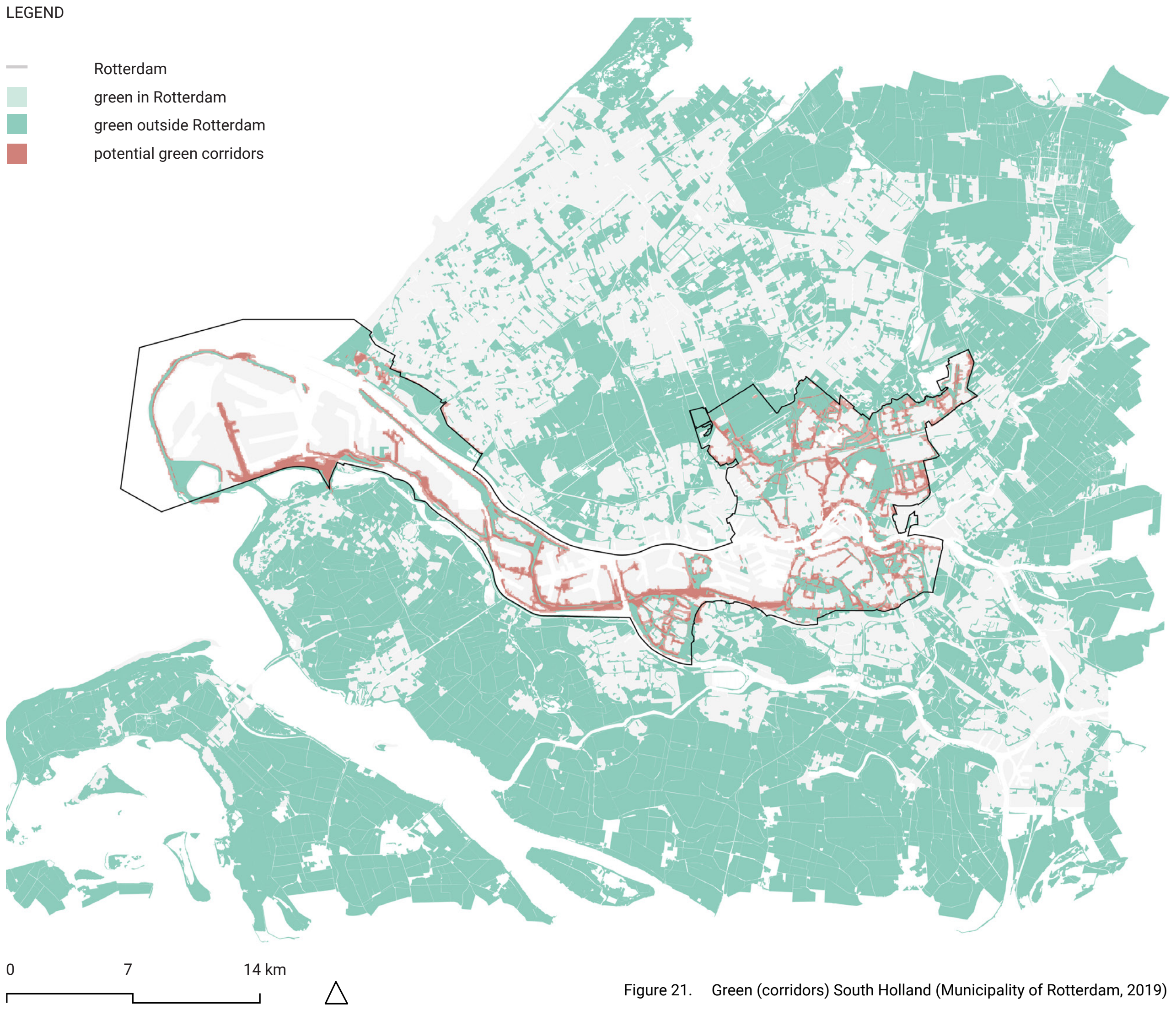


Figure 21. Green (corridors) South Holland (Municipality of Rotterdam, 2019)

2.3 PROBLEM STATEMENT

2.3.1 Urgency map

In short, Rotterdam has to cope with many (different) urban challenges. To deal with all those problems, an urgency map is made. This map shows only the high urgent areas based on all discussed urban challenges. So, only the red areas of all individual maps are visualised. This is to make even more explicit which areas in the eastern part of the city, and especially in the focus area, need full attention in the next years.

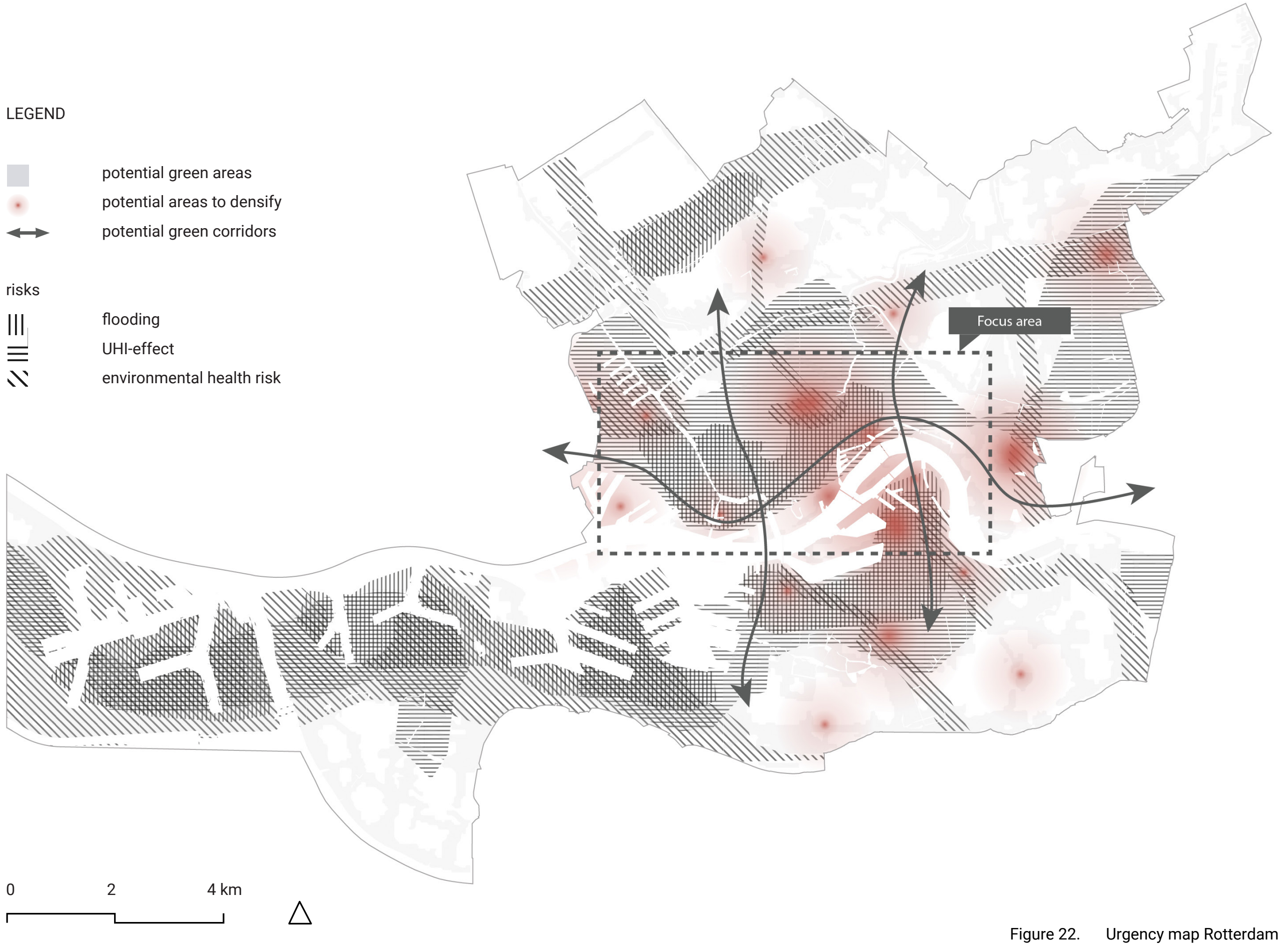


Figure 22. Urgency map Rotterdam

Figure 23. Groot Handelsgebouw - Rotterdam Rooftop Days 2022

2.4 RELEVANCE

2.4.1 Societal relevance

By developing a strategy to rethink roofs in the city of Rotterdam, the project gives insight into how society can in collaboration with residents and local initiatives be able to transform rooftops into a new sustainable city layer. It unfolds a way of how public and private can work together in this process. The relationship between society and residents is important because at this moment most of the roofs in Rotterdam are (re)developed independently from each other, and in this way, the whole process of redeveloping rooftops will take extremely long and will not be sufficient to contribute to a more resilient city. And given that climate change is happening now and we have to do something about it now, there is a need to come up with a strategy to redevelop roofs in a short period of time, as there is so much potential in the use of rooftops to combat climate change.

2.4.2 Scientific relevance

A source of the environmental problems we are facing today is due to the form of contemporary cities (Alberti et al. 2003; Beatley and Manning 1997; U.S. Environmental Protection Agency [EPA] 2001). Urban developments directly affect water quality, ecosystems, travel behavior, air quality, soil pollution, noise, and the loss of natural landscapes (Cervero 1998, 43-48) Urban planners, governments, scholars, and local and international NGOs have been induced to tackle this problem and tried to come up with sustainable ways to (re)develop urban forms. They have been making use of different spatial levels to address sustainable urban forms on different scales. However, there is no common conceptual (rooftop) framework that can be applied on every scale in different cities. Concepts, policies, and approaches for planning propositions differ.

Next to that, many scientific researchers focused on the potential of roofs in the sustainable development of urban environments. Take for example green roofs and their benefits to the surrounding environments, in terms of appearance, solar radiation, biodiversity, and cooling performances (Li&Yeung, 2014). Rooftops are also widely used for installing solar panels (Porcaro et al., 2021).

In other words, many researchers try to come up with models of sustainable city forms, however, a generic one is not there yet, especially not with rooftops included. This research can contribute to this by focussing on one specific type of place, rooftops, and see how these urban places can be (re)developed to contribute to a sustainable, resilient, and future-proof city and neighbourhood model. By defining different functions of rooftops and their relations, and investigating the amount of space that is needed to make a difference, this thesis will also contribute to the functionality and potential of rooftops in cities. Not only in terms of green (vegetation), blue (water storage), and yellow (solar panels) roofs but also in terms of how those functions can at the same time accommodate public functions to enrich public life in cities and make the city more liveable. And most important, the synergies of these different roof types. To my knowledge, few scientific papers focus on the potential of roofs in cities concerning our society in combination with the environment. It is mostly about the effectiveness of green roofs or solar panels on roofs.

2.4.3 Ethical considerations

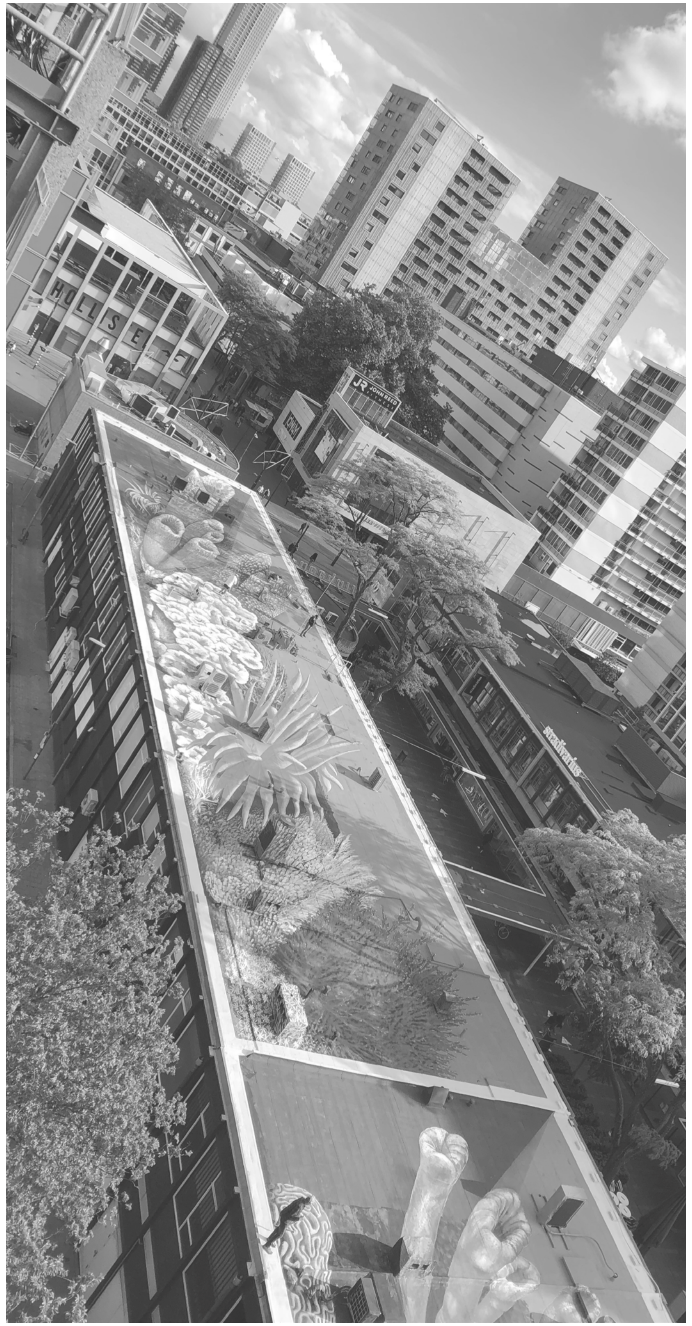
There are five different ethical issues that will be considered in this thesis (MyPeer, 2021): validity, voluntary participation, confidentiality, anonymity, and only assess relevant components.

Validity is about the research question – methods used- results – conclusions that must relate to each other's. The methods have to be appropriate to the research questions and the kind of outcomes you foresee.

Voluntary participation (not harm) is relevant when doing interviews, and exploring perceptions and experiences it is important that the people I want to analyse or want to speak to, volunteer. The participant or the person that will be interviewed, have to make explicit that he or she want to collaborate and participate in the study.

Confidentiality is about identifying information that should not be made public, or accessible by anyone but the first and second mentor. It is not possible to publish confidential information, so it has to be excluded in the report.

Anonymity concerns all people that participate in the process. They should be asked if they want to stay anonymous or not. Next to that, all personal information about the participants should be kept anonymous, for instance educational level, background, income and profession, unless the participant permits to share it in the research. Only assess relevant components means that the focus will be on elements that are interesting for your project, leave out all redundant information/methods/theories.



METHODOLOGY

- Research questions
- Research approach and methods
- Expected outcomes
- Time working schedule

This chapter focuses on the research questions, the research approach, methods, expected outcomes, and it elaborates on the work planning of this year, the time working schedule.

3

3.1 RESEARCH QUESTIONS

3.1.1 Main and subquestions

As mentioned in the abstract the main question is as follows: How can the (re)development of Rotterdam's flat roofs be guided to achieve a significant progress towards a sustainable and resilient Rotterdam? (figure 24)

To be able to provide the most complete answer to this question, five sub-questions have been drawn up (see figure 24). Every subquestion is related to a specific part of the main question (see image below). Subquestions 1 and 2 will focus on defining the main concepts in the project, and the potential of roofs in general. Whereas subquestions 3 to 5 will address Rotterdam's roofs specifically and will look into the way those roofs should be (re) developed to achieve the ambitions of the project.

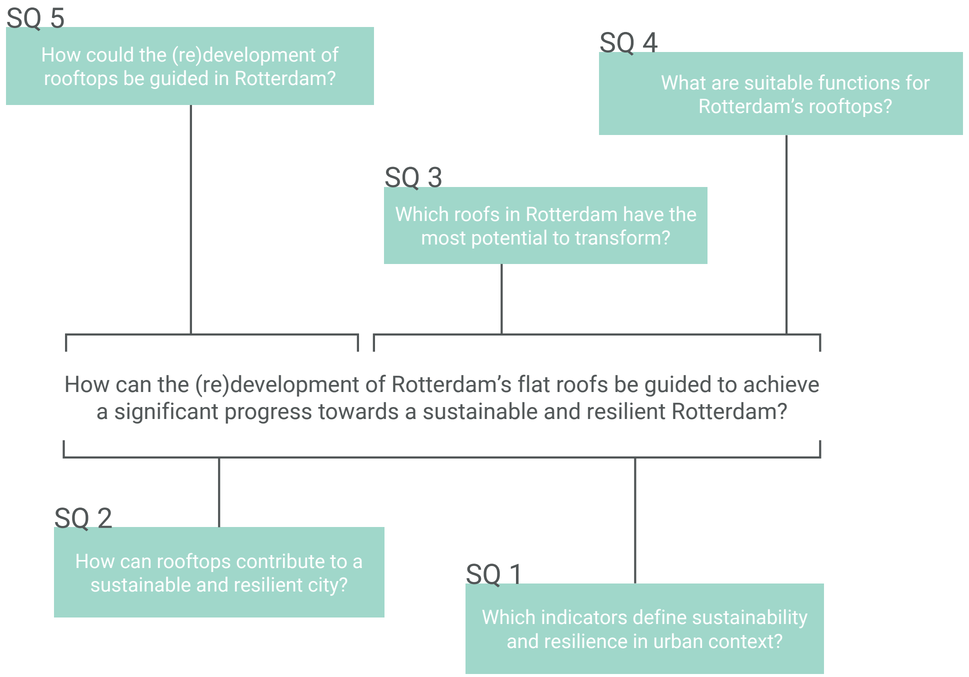


Figure 24. Relation between main and sub questions

3.2 RESEARCH APPROACH AND METHODS

3.2.1 Methods related to subquestions

This overview shows the main (dark grey) and sub (light grey) methods of this research. The main method of this research is research by design, therefore most methods are practice and design-oriented. To structure this way of researching the Delft Design Approach (ADP) is applied. ADP is a design approach that suggests 6 different methods that help designers to tackle complex design assignments (TU Delft, 2014). It is about analysing, developing, selecting, reflecting, and presenting in a continuous and alternating process.

Each sub-question needs other methods to answer the question. Where the first two sub-questions are mainly theoretical, the last three are mainly design-oriented. Per each sub-question, an indication of outcomes is given.

		METHOD	SQ 1	SQ 2	SQ 3	SQ 4	SQ 5
Non-spatial analysis	ADP ADP ADP ADP ADP ADP ADP ADP ADP ADP	literature review	●	●			
		statistical analysis			●		
		policy analysis		●			●
		(expert) interviews				●	●
Spatial analysis		mapping statistics			●		
		mapping observations			○	○	○
Research by design		sketching	○	○	○	○	○
		field work			●		
		case studies				●	
		scenario planning					●
		developing options				●	●
		EXPECTED OUTCOMES	- overview of indicators of a sustainable and resilient city	- overview potentials of roofs in cities	- overview of possible transformation areas	- overview and design of (suitable) rooftop functions in Rotterdam	- toolkit and strategy design for Rotterdam

LEGEND

● main method

○ supporting method

Figure 25. Relation between methods, subquestions and expected outcomes

3.3 EXPECTED OUTCOMES

3.3.1 A toolkit and a strategy for the redevelopment of roofs

This thesis works towards two different outcomes: a strategy and a toolkit. While the strategy is on a city level, the toolkit focuses on the block or neighbourhood scale. The idea is that the strategy elaborates and assesses specific areas that are suitable for specific functions. This to in the end show how a city's roofscape can completely transform into a new urban landscape that contributes to environmental problems and accommodates public life on a larger scale. By creating this strategy, the research gives an idea of how all flat roofs can contribute to a new urban layer. Next to that, the strategy envisions how society and residents will have to work together to accomplish life on roofs (this will be discussed in the implementation chapter).

The second outcome of this project is a rooftop toolkit on a block/neighbourhood scale. The rooftop toolkit concerns not like most rooftop projects in Rotterdam one building plot but already tries to see the synergies between different rooftop functions on a smaller scale, as a first step to the larger network. This is by arguing that the function of a rooftop depends on the urgencies in the specific area.

Examples of rooftop projects in Rotterdam that occupy already several building blocks, a whole building block, or a street, are for instance De Peperklip (LIFE Rotterdam, 2020) and Robert Fruinstraat (LIFE Rotterdam, 2022). The toolbox aims to develop a set of possibilities to redevelop rooftops on a block, and neighbourhood scale, that is not only applicable to neighbourhoods in the city of Rotterdam, but to cities all over the world. However, all decisions will be based on statics, environmental aspects, and spatial features of roofs in Rotterdam.

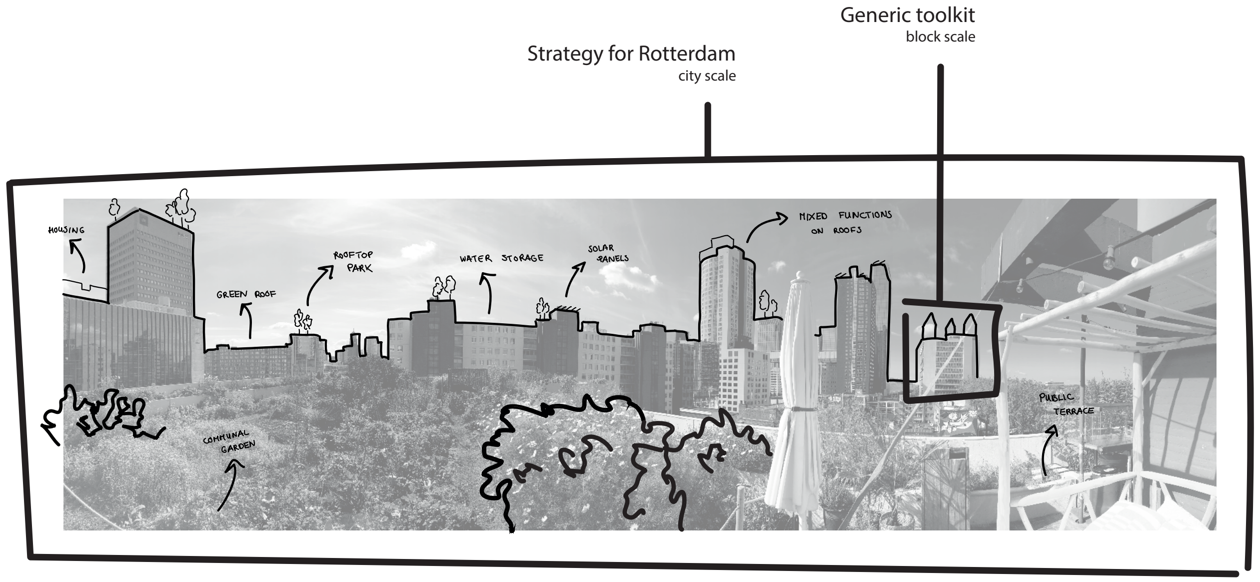


Figure 26. Outcomes of the project

3.4 TIME WORKING SCHEDULE

3.4.1 From P1 to P5

From P2 to P3 the focus is on the design by research by design. After P3 the focus is on detailing, assessing, and fine-tuning the design. This is to have a complete strategy and toolkit for P4. So after P2, the focus shifts to the design and implementation of the defined topic. The weeks between P4 and P5 are about the finalisation of the project.

As can be seen in figure 27, the diagram always links the research phase (in black letters), the main focus during the phase-in question (dark grey bar), and the most commonly used methods (light grey bars).

In the scheme below, an overview of the graduation year is depicted. P1 to P5 stand for all hand-in and presentation moments. P5 is the final presentation.

In the subchapter 'project lay out' the different phases of the project were already introduced. P1 is focused on the orientation and exploration of the topic of this thesis, by doing case studies, fieldwork, and spatial analysis. From P1 to P2 the focus is on the problem definition and research by design. Methods that are used in this phase, the research phase, are spatial analysis, and literature review.

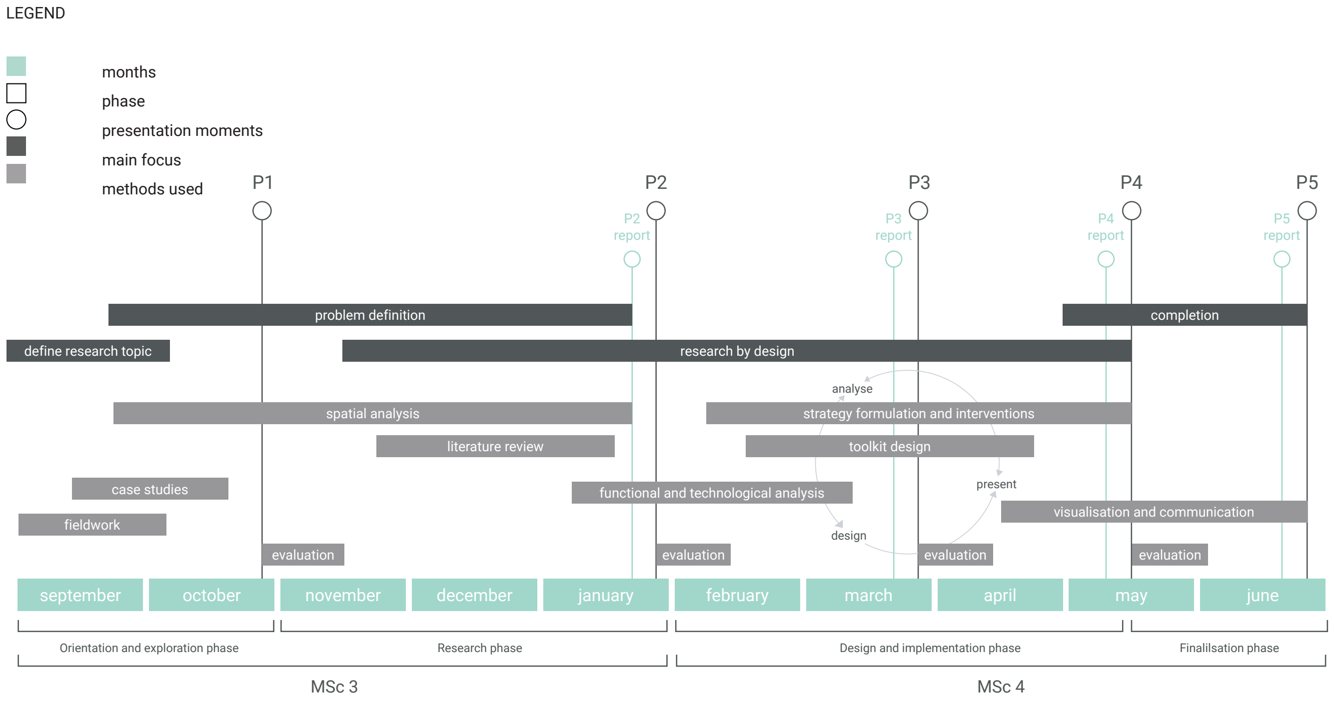


Figure 27. Time working schedule

THEORETICAL FRAMEWORK

- Sustainable cities
- Towards a sustainable city form
- Rooftops as an extension of the city
- The impact of green (roofs)
- Glossary of terms
- Conceptual framework

This chapter is about the concept of urban transformation, urban sustainability, and urban resilience, and discusses what sustainable urban forms are. It gives an overview of the main concepts of this research and their interrelations.

4

4.1 SUSTAINABLE CITIES

4.1.1 An introduction

By 2030, the United Nations Sustainable Development Goals (SDG's) are expected to surpass 60% of the total global population to save our planet (United Nations, 2015). Cities have an enormous responsibility in terms of achieving those goals by reducing greenhouse gas emissions since cities cause 70% of the total emission (Elmqvist, et al., 2019). Next to that, cities are responsible for the highest global energy demand. But these are not the only challenges cities are facing in the upcoming years. Take for example rapid urbanization, due to the growth of our population in combination with an increase in the number of people who move from rural areas to cities (United Nations, 2015). Like gas emissions, and high energy use, (rapid) urbanization directly affects social- and environmental problems, such as ecosystems, water quality, habitat fragmentation, air quality, noise, soil pollution, and the global climate (Jabareen, 2006). Therefore, it is urgent that urban designers should on the one hand focus on the attractiveness of cities, and on the other hand on the adaptiveness to unforeseen circumstances and changing demands (Wall, 2012). Cities should transform into sustainable urban forms that increase and ensure urban resilience (in the future). Therefore, the first part of this chapter will elaborate on the concept of urban transformation, urban sustainability, and urban resilience, and what urban forms can be considered sustainable. After that, rooftops as contributors to sustainable, resilient, and liveable cities will be discussed, following with the impact of green (roofs). Finally, an overview of the main concepts of this thesis and their interrelations will be shown in the conceptual framework.

Figure 28. Dakakker - Rotterdam Rooftop Days 2022

Figure 29. Dakakker - Rotterdam Rooftop Days 2022

4.2 TOWARDS A SUSTAINABLE CITY FORM

4.2.1 Components of sustainable urban form

To achieve a sustainable urban form, cities need to be transformed. Urban transformations are about large-scale changes in urban structures, for instance, infrastructure, agency configurations, and ecosystems. It indicates the process and the outcome of changing the systemic configuration of urban areas, in terms of technological, economic, societal, and environmental systems (Elmqvist et al., 2019). Urban transformations mostly aim for a more sustainable city performance (Wolfram et al., 2016).

The concepts of urban sustainability and sustainable urban development have been applied to urban planning, design, and sciences, since the early 1990s (Wheeler and Timothy, 2010). Urban sustainability is about achieving a balance between justice, economic development, environmental protection, and social equity. In other words, sustainable cities are liveable, prosperous, and healthy human environments, that have a minimal demand for (renewable) energy, decrease sound and air pollution and reduce the need for material resources. This is to reduce the negative impact on our direct environment, including people, planet, and profit, and so strengthen the quality of life in the city (Bibri & Krogstie, 2017).

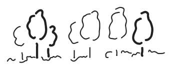
Where urban sustainability focuses on lowering the impact of the city on our environment and how we can meet our (current and future) needs, urban resilience is about the way cities could anticipate (prepare and absorb) future unexpected natural disasters and the ability to recover and adapt fastly (Elmqvist et al., 2019).

But how can a city become a sustainable and resilient city? What urban forms need to be present or have to be transformed? And what are exactly urban forms? All spatial patterns and physical objects in cities can together be seen as the urban form (Lynch, 1981). Building blocks, public spaces, land-use patterns, street patterns, and transportation systems are examples of physical objects in a city.

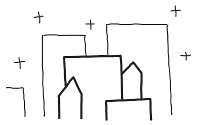
According to Jabareen (2006) there are seven design concepts that indicate to what extent a city has a sustainable form. He proposes a sustainable urban form matrix that aims to help designers, policymakers, authorities, and others in analyzing and assessing the sustainability of different urban forms related to the design concepts.

The seven design concepts are visible on the next page. The design concepts are the criteria of the matrix. With the use of a scale of three points per concept, sustainability is measured. 1 represents a low level of presence, so a low level of sustainability, 2 a moderate level, and 3 stands for a high level of sustainability. This means that when a specific neighbourhood features high compactness, diversity, and a high level of mixed land uses, it receives three times three points. The more the form contributes to sustainability, the more points it receives. There are different combinations of design concepts possible to achieve sustainable development goals (Jabareen, 2006).

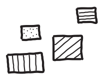
By the use of these seven elements of sustainable urban form, the design of this research is assessed in the implementation/finalisation phase to conclude whether the design proposed in this report comes up with a future sustainable form for Rotterdam or not. All sustainable urban form elements are explained on the next page.



It contributes to the maintenance of (native) species and biodiversity, the purification of air, urban cooling, and drainage systems. Besides, it has an educational function and health benefits. It also has a positive impact on the urban image, quality of life and the economic attractiveness of a city. It creates more appealing and pleasant urban places.

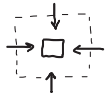


The ratio of people or dwelling units to land area. The higher the number of people within a given area, to more interactions and social functions there are sufficient/viable.

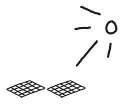


Compared with mixed-land use, diversity is about variety in a broader sense. It is for instance about a range of housing types, building densities, household sizes, ages, incomes and cultures.

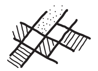
Towards a car free, and pedestrian and bicycle friendly city.



The urban contiguity and connectivity, which suggests that new urban structures should be adjacent to existing ones. Besides, it refers to intensification (additions, extensions, or redevelopments) and the adjacency of living, working, amenities, and leisure in a city, which results in the minimalization of (public) transport of goods, materials and people. Lastly, a compact urban environment preserves rural areas.



To reduce the demand for energy and the environmental impact city's have. It is also about the urban microclimate, and how to minimize the need for cooling, heating, and energy generation. This can be done by the use of flat, open terrains, such as roofs, but also by orientation of buildings (thermal and visual comfort, and reduction of car traffic and so of air and noise pollution), street withs, to influence airflow, view of sun, and building design (thermal capacity of external surfaces).



Diversity and proximity of functional land uses related to transportation, such as industrial, institutional, residential, and commercial. It also enhances security in public places.

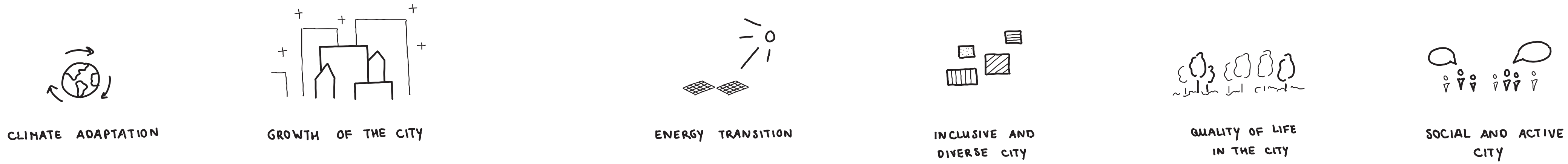
Figure 30. Indicators of sustainable urban form (Jabareen, 2006)

4.3 ROOFTOPS AS AN EXTENSION OF THE CITY

4.3.1 The possible impact of transformed roofs on our city

In Rotterdam, there are in total 18km2 of flat roofs. In The Netherlands there are in total 600km2 of flat roofs, this is as big as Rotterdam, Amsterdam and Utrecht combined. So, you could say that we could build three completely new cities on top of our roofs (MVRDV & Municipality of Rotterdam, 2021). However, how could rooftops withstand urban challenges? How could they contribute to a more sustainable, resilient, and liveable urban environment? And what specific functions will be needed on the roofs, to combat different urban challenges? This part of the chapter discusses the potential of rooftops to combat urban challenges and the relation of those challenges to various possible rooftop functions defined by MVRDV and the Municipality of Rotterdam (2021).

Rooftops can be used as an amplifier for future city goals. They have the potential to withstand urban challenges, such as climate change, energy transition, densification of cities, and the growth of our population, while preserving the quality of life, and enforcing inclusivity, diversity, and (social) activities. In the drawings on the right, the way how roofs could combat urban challenges is explained.



Combat heat stress and water storage. The Rotterdam WeatherWord tries to prepare the city for the future and makes the climate change manageable while maintaining the city liveable and creating added value to public spaces. Roofs with vegetation and water storage retain water during heavy rainfall, reduce the city's heat stress, and ensure irrigation of greenery during long periods of drought.

Rooftops can be an option to densify the city. Up to 2022, 18.000 new homes will be built of the in total 50.000 that will be needed in the upcoming years. These dwellings will require extra space. Additionally, new residents demand outdoor space, sports facilities, amenities, green, and tranquillity. Especially for these 'extra' social functions, rooftops can be a solution.

Space for renewable energy sources, additional insulation of buildings. In 2050 Rotterdam should be energy neutral, therefore roofs are considered for a large part of the realisation of solar panels, and so sustainably generated energy. Industrial estates and the port area are at this moment a logical choice to implement as much as solar panels as possible, because of the large roof surfaces and the absence of public life.

Rooftops can contribute to mixed-use neighbourhoods, places that are accessible for everyone, and buildings/ building blocks that have mixed purposes.

By adding more green, a city becomes healthier and increases biodiversity. 26% of Rotterdam's surface is covered by green. However, most of the green spaces are located out of the city center. Therefore the municipality wants to realise an additional 0,2 square kilometers of green in the city. 30-40%, so 60.000-80.00m2, will be realised on roofs. The municipality offers subsidies available for both roofs as facade gardens to greenify the stony city center. In 2019, there already were 400.000m2 of green roofs in the city (Gemeente Rotterdam, n.d.).

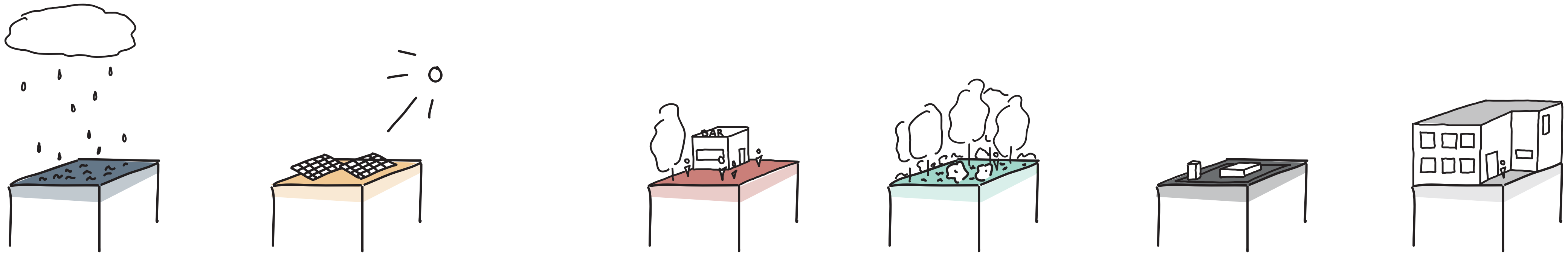
Rooftops can be a place for sports facilities, meeting points, and/or community facilities. They can enhance social interactions in a city.

Figure 31. Roofs in relation to future city goals (MVRDV& Municipality of Rotterdam, 2021)

4.3.2 Specific features of different rooftypes

To address all the different urgencies introduced in the previous chapter, various roof types are needed. You could say that every roof type has its specific character and its possibilities and limitations to cope with different urban challenges. Therefore, when transforming rooftops, the optimal case for an even more resilient city would be the combination of different roof types on top of our roofs.

On these pages, five different roof types are introduced and explained. The Municipality of Rotterdam together with MVRDV formulated these five types as main roof types, to give a certain roof function a specific color (Municipality of Rotterdam and MVRDV, 2021). For every roof type, there is explained how that certain roof type could combat urban challenge(s).



Blue roof

Blue roofs are used to catch rainwater on wet days, retain it and make use of it during hotter summer days. By this, blue roofs ensure delayed drainage and contribute to the city's water management. Besides, these roofs ensure a constant water supply for plants, especially during periods of drought.

Yellow roof

Yellow roofs are roofs with solar panels and contribute to a sustainable city and its climate objectives. The solar panels can be placed directly on the roof, but also on an additional floor or in another creative way. For citizens involved, it ensures lower energy costs due to the local production.

Red roof

Red roofs can accommodate various social functions, such as restaurants, sports accommodations, cultural institutions, or playgrounds. The main function of these kinds of roofs is that they create a meeting place in a specific street, building block, or district and strengthen social cohesion. Especially in a city such as Rotterdam where there is a lack of space in urban areas.

Green roof

Green roofs can be used for the implementation of green structures, and increase the biodiversity in the city. The advantage of a green roof is that it can store water in a natural way (green-blue roof), cool air, but also cool the building. Next to that, green spaces create attractive places to spend time in, in contrast with the current stony city of Rotterdam (red-green roof).

Grey roof

Grey roofs are unsuitable for the redevelopment of roofs, because of the presence of transmission masts, chimneys, air treatment units (ventilation systems), or window cleaning systems. In general, these roofs are necessary but do not prefer to stand out in the city view.

Light grey roof

Light grey roofs are residential roofs. Due to the growing population, and the space scarcity there is a demand for more homes, especially in the city center. Roofs can be equipped with tiny houses, or houses could be extended onto the roof for instance.

Figure 32. Specific features of different rooftypes (MVRDV& Municipality of Rotterdam, 2021)

4.4 THE IMPACT OF GREEN (ROOFS)

4.4.1 The benefits of green (roofs) on the environment and our well-being

For over 100 years green roofs have been established all over the world. They are a solution to multiple, environmental and ecological challenges cities are facing nowadays. Many researchers focus on its ability to combat air pollution, cool air (to combat the UHI-effect, see image above), collect and retain excess (rain)water, and enrich biodiversity (Li & Yeung, 2014). In other words, green roofs can be a very good way to combat climate change. However, there is a relatively narrow scope of the existing research on green roofs concerning psychological benefits, compared with research on psychological benefits of green urban areas.

The importance of urban nature for human well-being has already extensively been discussed in the research. It is proven that green urban spaces reduce stress and negative mood, renew a sense of vitality, and improve attention (Hartig et al., 2014). In figure 34, environmental and psychological benefits of green spaces are elaborated.

Although various researchers have suggested that green roofs provide similar benefits as green urban spaces, the way people perceive and experience green roofs differ from ground-level green spaces. For instance, the surface of green roofs is smaller, they are not always well visible from the street, poorly accessible, and they often cannot possess large masses of vegetation, for instance, trees (Williams et al., 2019). As a result, the amount of greenery that can be realized is less. All possible limitations are shown in the table below.

Urban green in relation to	Objectives
Environmental aspects (Lundholm and Williams, 2015; Williams et al., 2014)	- Rainfall retention - Reduce building energy use - Enhance biodiversity - Reduce noise pollution (Shafique et al., 2018) - Reduce urban heat (Shafique et al., 2018)
Psychological aspects (Hartig et al., 2014)	- Reduce stress and negative mood - Improve productivity and creativity (Wiliams et al., 2018) - Renew sense of vitality - Improve mental and physical health - Reduce aggression and crime (Kuo, 2003)

Figure 34. The impact of urban green on environmental and psychological aspects (Shafique et al., 2018) (Williams et al., 2018) (Kuo, 2003)

Design aspects of green roofs	Limitations
Accessibility	- Physical access: only accessible for residents, workers in the building. No public entrance or facilities such as an elevator for disabled people (Yuan and Hien, 2005)
Visibility	- green roofs are not visible from ground level, so only people who work/live in the building will use it, others will overlook it (Sutton, 2014)
Size	- less opportunity for larger masses of vegetation(trees)) - can be a limitation of the range of physical activities
Physical aspects of the roofs	- Weight-bearing capacity of roof preclude high dense vegetation (Weiler and Scholz-Barth, 2009)

Figure 33. Design aspects of green roofs (Yuan and Hien, 2005) (Sutton, 2014) (Weiler and Scholz-Barth, 2009)

Due to these limitations, the benefit of urban green spaces could not simply be generalised to green roofs. Despite this, Williams et al. (2019) have investigated how green roofs can support the social, and psychological functioning of people in cities, and they at least hypothesise the same benefits of green roofs as green urban spaces. They analysed a diverse range of green roofs, from lightweight green roofs and low vegetation, to intensive green roofs, such as roof gardens, and their benefits. Besides, they argue that green roofs can have a positive influence when they are literally on the green roof, but also when they view it. The hardest thing why green roofs can not be perceived as 'normal' green environments, is because everyone experiences a green roof differently, caused by the limitations (size, accessibility, and access). Grassy and flowering vegetated roofs support positive aesthetics but are unlikely to have an impact on heat and wind-related to human comfort. They showed how attributes of social climate, activity, individual resources, and the physical environment, shape our experience of green roofs and eventually have a potential positive phycological benefit. In the diagram below the interrelations are shown.

Figure 35. Boomveren - Rooftop Walk 2022

4.5 CONCEPTUAL FRAMEWORK

4.5.1 The three layers of the conceptual framework

As a basis, a social-ecological framework is used for the conceptual framework. This is to incorporate the natural, built, and socio-cultural dimensions and their interrelations in one framework. It gives insight into the way human-green and the built environment interact with each other (Williams et al, 2019). The framework defines three different factors: the natural, the physical, and the socio-cultural. The natural factors are all abiotic (climate) and biotic aspects (vegetation) that are present in our environment. The physical factors are about the urban form and its capacities (buildings, public places, and infrastructure). And the socio-cultural factors are about us as humans (use, social activities, organisational objectives, and ownership for example). In the conceptual framework, these three dimensions are visualised by the different circles and their interrelations (the arrows).

As visible in the images below, the conceptual framework is composed of three different layers: the roofscape, urban challenges, and sustainable urban form. The concepts used in the conceptual framework are all based on concepts from previous sub-chapters. The roofscape defines 'rooftops as an extension of the city' and the way they can contribute to a sustainable urban form (red texts and arrows). The grey arrows represent the growth of the roofscape, and the increasing impact it has on our city.

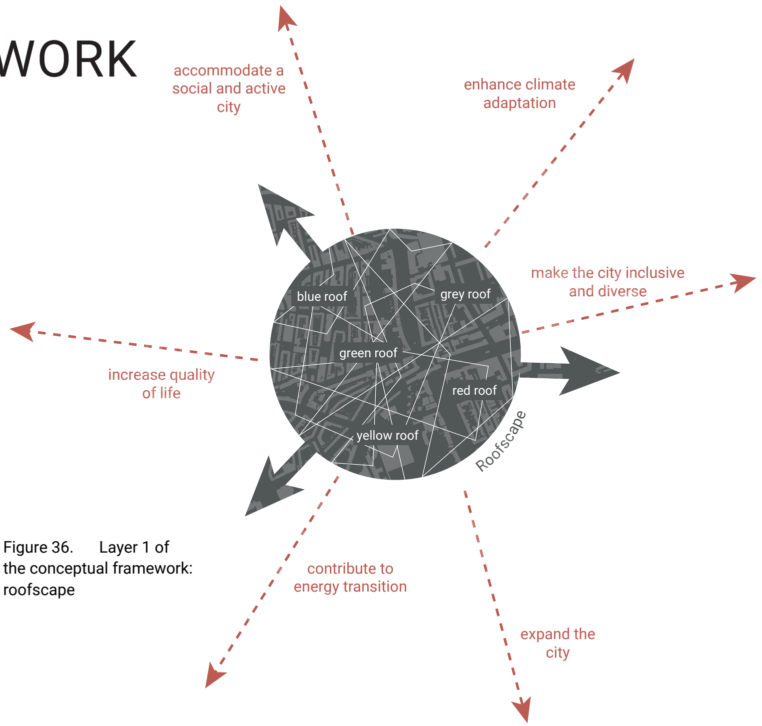


Figure 36. Layer 1 of the conceptual framework: roofscape

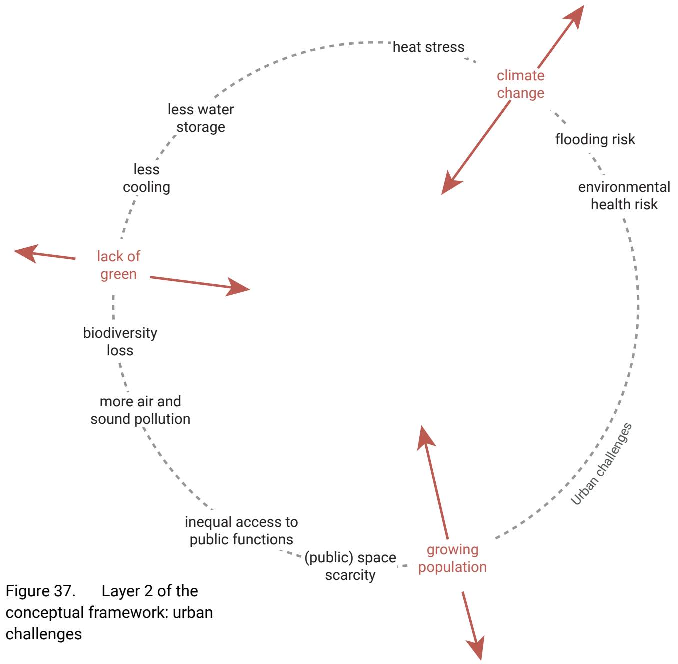


Figure 37. Layer 2 of the conceptual framework: urban challenges

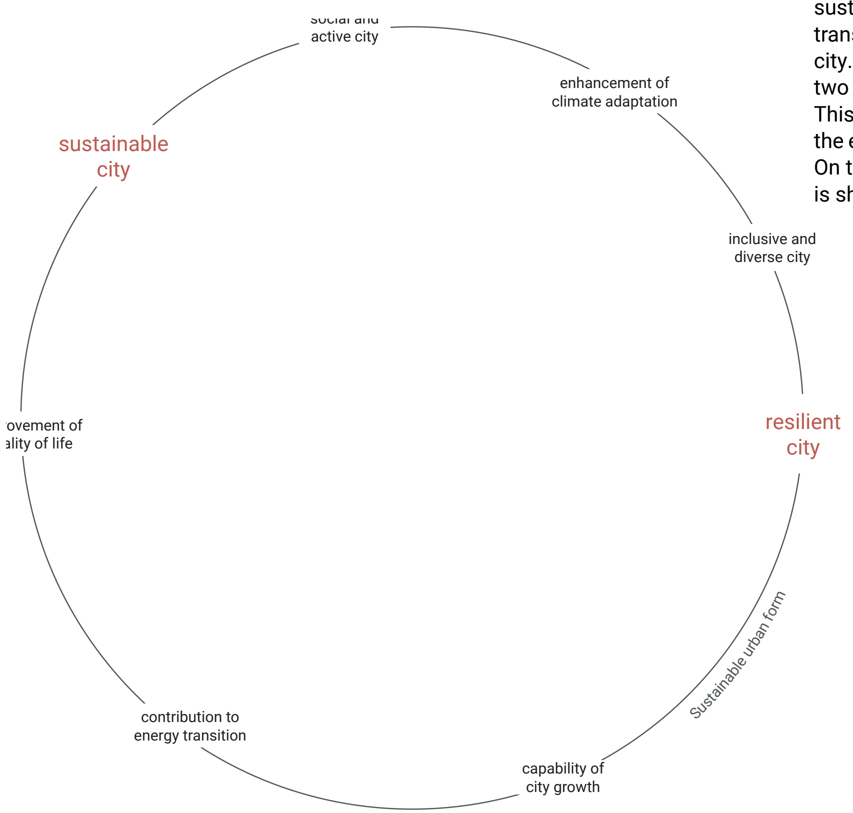


Figure 38. Layer 3 of the conceptual framework: sustainable urban form

The second circle visualises the defined urban challenges of this project: climate change, lack of green, and the growing population. All these challenges can be divided into more specific (environmental) problems. These are placed around the main concepts. The negative impact of the urban challenges, the drivers of change, on the other circles, the roofscape and sustainable urban form, are displayed by the red arrows.

The last circle consists of the indicators of a sustainable urban form. The elements we need to transform Rotterdam into a sustainable and resilient city. All these elements are put in the circle around the two main concepts: sustainable city and resilient city. This circle is the outer circle of the framework, as it is the end goal, the kind of city the project works towards. On the next page, the complete conceptual framework is shown.

4.5.2 Main concepts and their interrelations

Today’s cities are surrounded by three main urban challenges: increasing climate change, growing population, and the lack of green. The red arrows show how these three big urban problems attack the ideas of a sustainable and resilient city and the roofscape. However, transforming this impressive abundance of space on roofs can be a solution to tackle those urban challenges and achieve a sustainable and resilient city (this is visualised by the red dashed arrows). With a growing roofscape (dark grey arrows) the impact of green, blue, yellow, and red roofs becomes bigger and bigger.

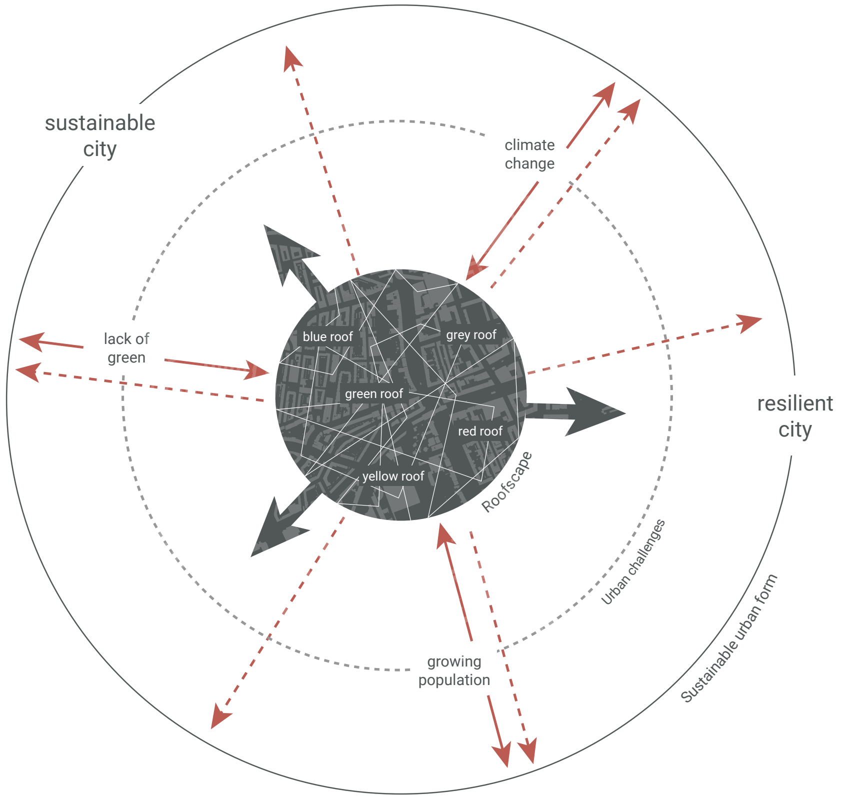


Figure 39. Conceptual framework

Figure 40. Hofpoort - Rotterdam Rooftop Days 2022

SPATIAL ANALYSES

- Fieldwork
- Roof shapes
- Existing rooftop projects
- Flat roof scales

This chapter focuses on the type of space of this project, roofs. It looks at existing rooftop projects, different shapes of roofs, different flat roof scales, and it elaborates more specifically on the type of space that will be redesigned later in the project.

5

5.1 FIELDWORK

5.1.1 Get to know the type of place

To get a good feeling of the type of place this thesis is about, fieldwork is inevitable. For this analysis, three different rooftop projects were visited. The first two were combined, as they are connected: the Luchtsingel and Luchtpark De Hofbogen in Rotterdam. The Luchtsingel is a 400-meter-long pedestrian bridge that connects three districts in the center of Rotterdam, which is separated by a railway and busy roads. Luchtpark De Hofbogen reconnects the former Hofplein train station by a green promenade to the rest of the city. It gives green back to the increasingly densified city center and is connected with the surrounding landscape in the northern part of the city. Both projects are designed by ZUS. During the fieldwork, the main focus points were the social use of these projects and in what way historical elements are included in a new design. The third project is PAKT, a unique ecosystem where work, leisure, sport, and urban farming are combined in the city center of Antwerp. During the field trip, the focus was especially on the urban agriculture project on top of the warehouses. This rooftop farm has a surface of 1800m2 and gives 100 people from the neighbourhood the opportunity to grow their herbs and vegetables on the roofs.

In other words, three enormous inspiring rooftop projects, show in different ways how we could use green rooftops in combination with a public, communal, or private social function.

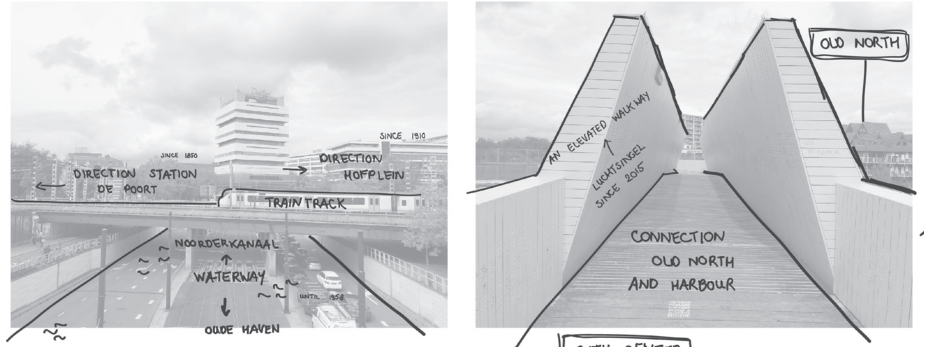


Figure 41. Fieldwork Luchtsingel and Luchtpark De Hofbogen: historical use

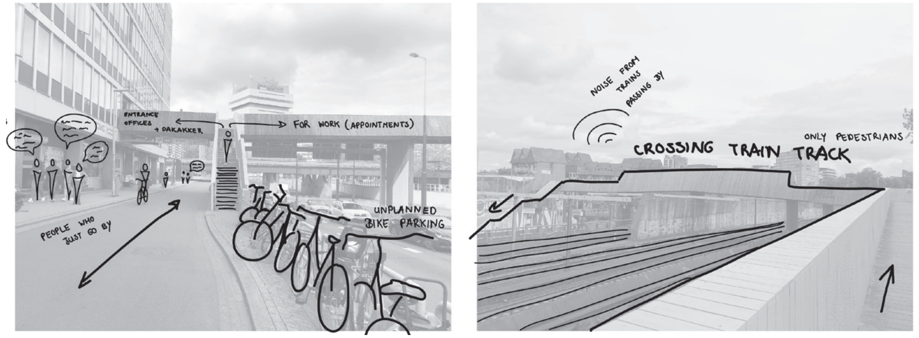
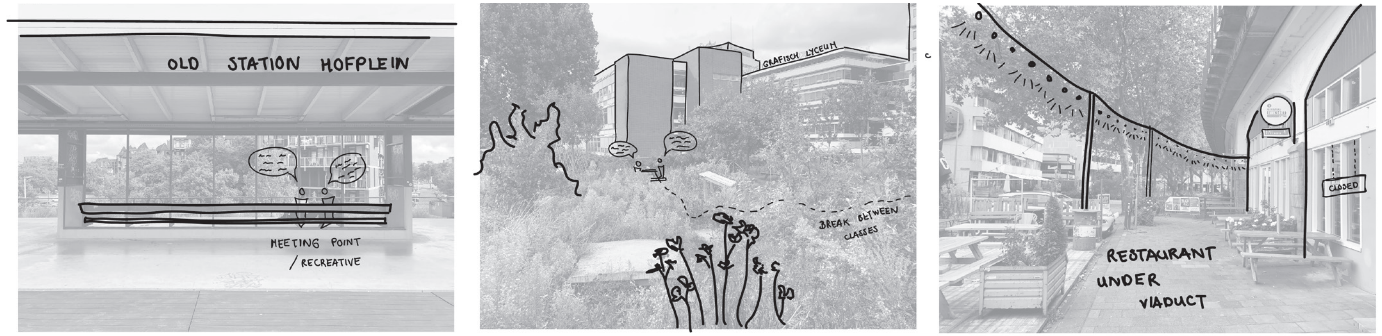


Figure 42. Fieldwork Luchtsingel and Luchtpark De Hofbogen: ethnographic mapping



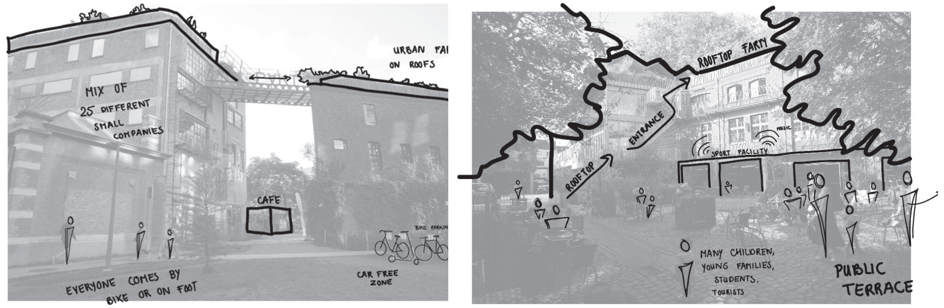
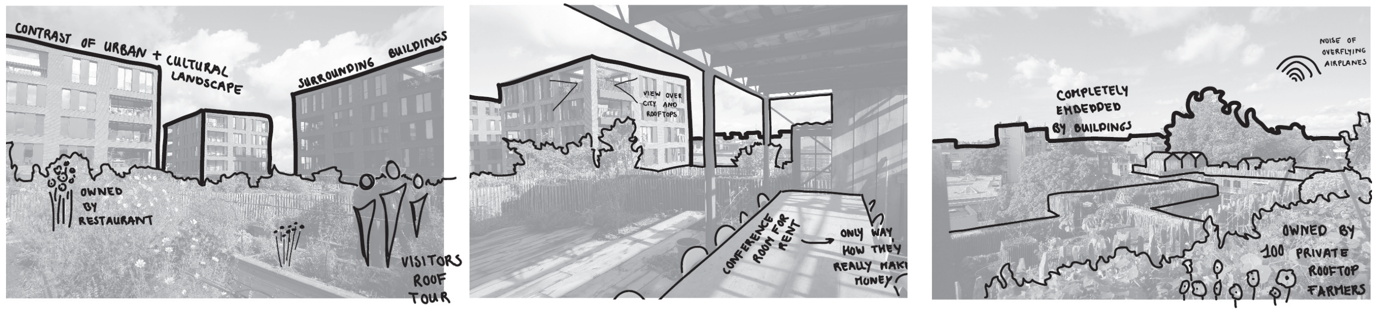


Figure 43. Fieldwork PAKT Antwerp: ethnographic mapping



5.2 ROOF SHAPES

5.2.1 Roofshape categories

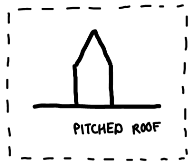
The fieldwork gives a first idea of how roofs are used, perceived, and experienced in busy city centers. For the project, it is important to define the features of the type of place more specifically, in terms of shape and scale (surface). Redesigning all roofs in Rotterdam would be an enormous design task, so therefore a focus on a specific kind of roofs need to be argued.

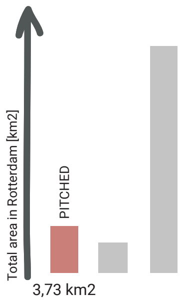
The spatial analyses started by indicating the different shapes of roofs. It is possible to easily distinguish three different forms of roofs: sloping roofs, semi-flat roofs, and flat roofs. These different categories are defined with the database of flat roofs in The Netherlands (Atlasleefomgeving, 2018). Pitched roofs have a fully sloping roof, flat roofs are more than 80% flat, and semi-flat roofs are partly flat (less than 80%), and partly pitched. In Figures 44, 45, and 46 the maps visualise where these three different roof shapes are located in Rotterdam's city center.

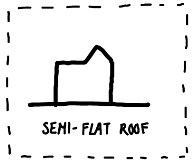
The graphs on this page indicate the total surface of each roof shape type occupies in Rotterdam. This number is based on all roofs in the municipality. There are in total 3,73km2 of buildings with a sloping roof in Rotterdam. This is 15% of all buildings in the city ((3,73km2/24,31km2)*100=15%).

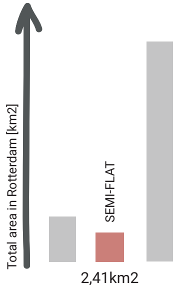
The second category is the semi-flat roofs. These type of roofs occupy 10% of all roofs in Rotterdam ((2,41km2/24,31km2)*100%=10%). Compared with the sloping and flat roofs, they are completely spread around the city center and do not have one specific area where they are clustered (see figure 45).

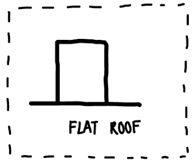
In the last category, the flat roofs are the most present in the city. There is in total a surface of 18,17km2 in Rotterdam that is covered with flat roofs. This is 75% of all roofs ((18,17km2/24,31km2)*100=75%). In Amsterdam, there are 12km2 of flat roofs (without the roofs of small sheds) (Rooftop Revolution, 2016).

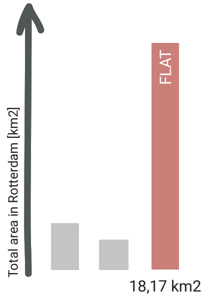












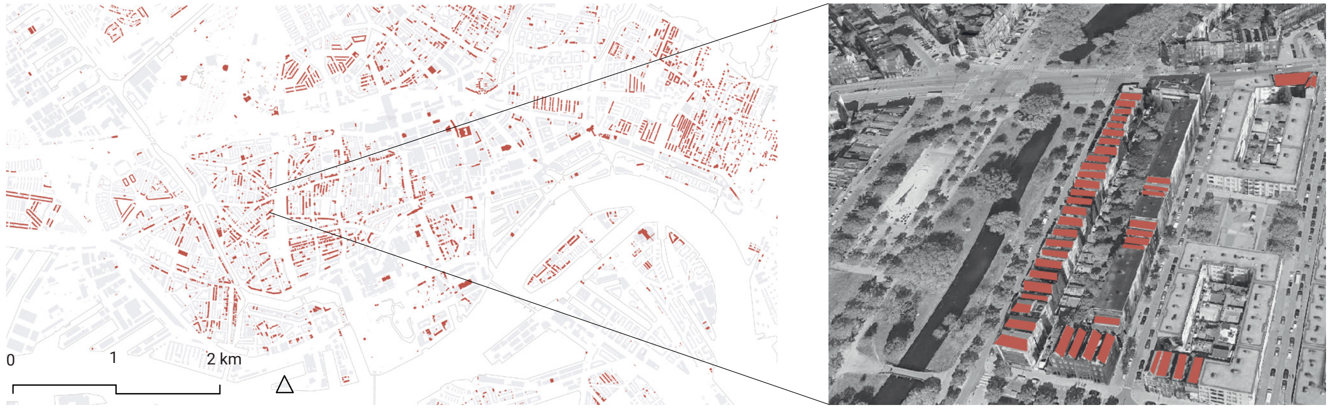


Figure 44. Sloping roofs Rotterdam (Atlas Leefomgeving, 2021)

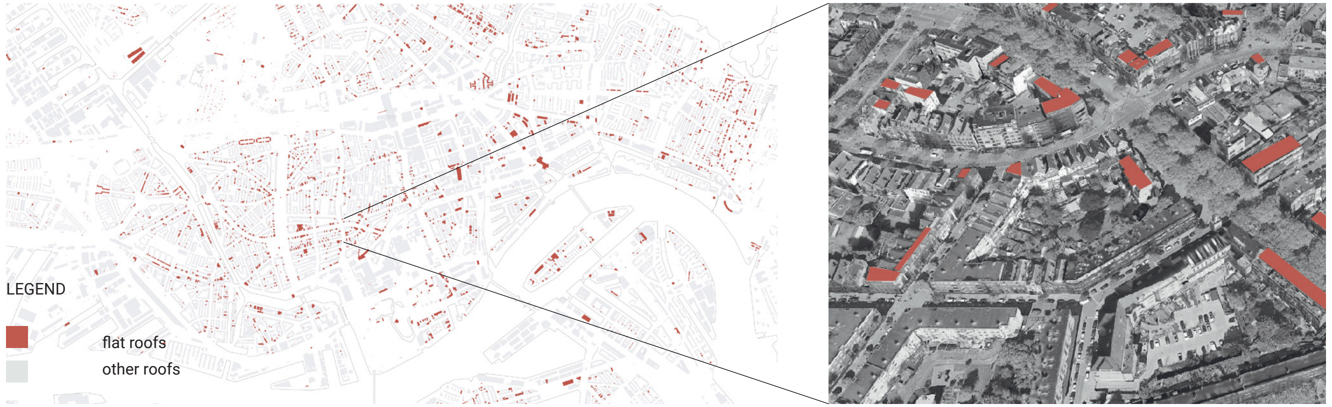


Figure 45. Semi-flat roofs Rotterdam (Atlas Leefomgeving, 2021)

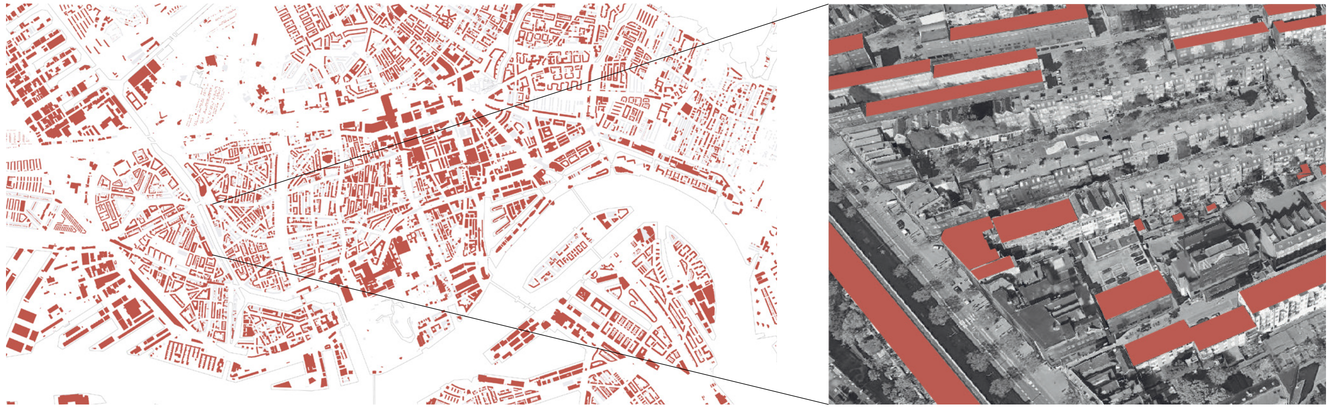


Figure 46. Flat roofs Rotterdam (Atlas Leefomgeving, 2021)

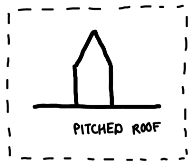
5.2.2 Location of different roofshapes

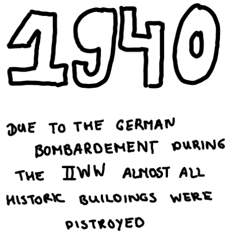
The maps on the next page visualise in a more abstract way where which type of roof is located. The diagrams on these two pages show specific features of the specific roof shape are depicted.

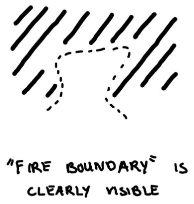
As visible, the pitched roofs are very much clusters in a specific area in the inner city (see figure 47 and diagrams pitched roofs). The largest areas are in Kralingen/Crooswijk, Oude Westen, and nearby Delftshaven. These are the historical (sub) centers of the city. Due to the German bombardment in 1940, a large area of the original old center has been swept away. In the history map of Rotterdam in the introduction chapter, the fire boundary is visible.

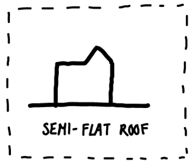
The semi-flat roofs occur in almost the same areas as the sloping roofs but are even more scattered. As visible on the previous page, most of the semi-flat roofs are located at the corner of a building block. Next to that, they often function as 'connecting elements' or 'transition blocks' between the buildings with a sloping roof and a flat roof.

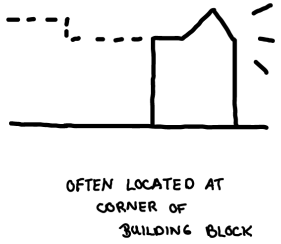
Lastly, the flat roofs are located throughout the city and are mostly very present in the former old center, since there are hardly pitched or semi-flat roofs. In general, 70-100% of all roofs in a neighbourhood in Rotterdam are flat. Compared with the semi-flat roofs, buildings with flat roofs do not stand in themselves but appear in a larger block or sequence of flat roofs.

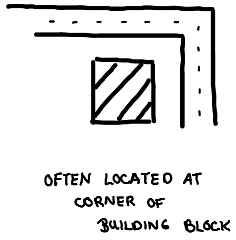


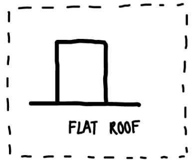


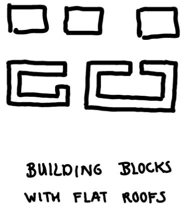












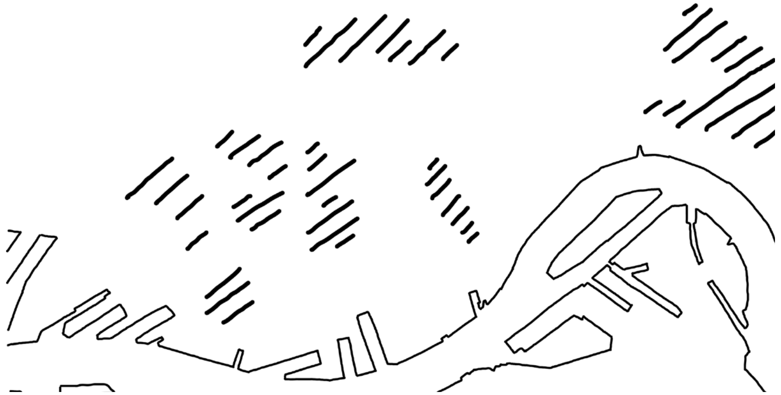


Figure 47. Synthesis sloping roofs Rotterdam

Figure 48. Synthesis semi-flat roofs Rotterdam

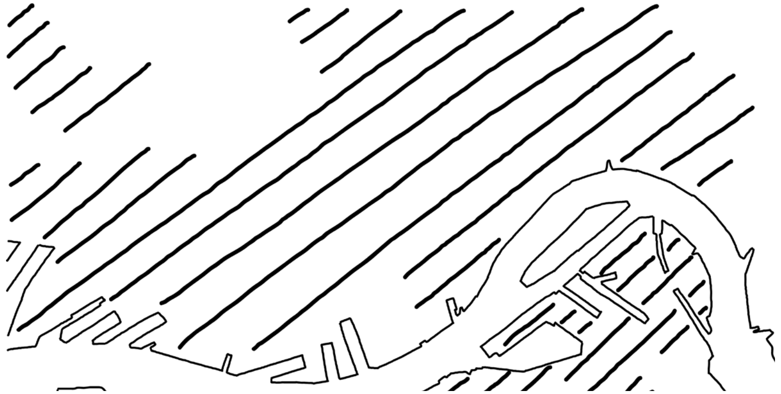


Figure 49. Synthesis flat roofs Rotterdam

Figure 50. Dakpark Rotterdam (Buro Sant en Co, 2016)

Figure 51. De Groene Kaap (Bureau Massa, 2014)

Figure 52. Didden Village (MVRDV, 2006)

Figure 53. Dak Erasmus MC (Frank Hanswijk, 2018)

Figure 54. Depot Boijmans (BAM, 2020)

Figure 55. Luchtpark Hofbogen (ZUS, 2018)

Figure 56. Dakakker (Op het Dak, 2019)

Figure 57. Hoogkwartier Rotterdam (Rooftop Revolution, 2020)

Figure 58. De Peperklip (LIFE Rotterdam, 2020)

Figure 59. De Doelen (Kraaijvanger Architecten, 2020)

Figure 60. Luchtsingel (Ossip van Duivebode, 2013)

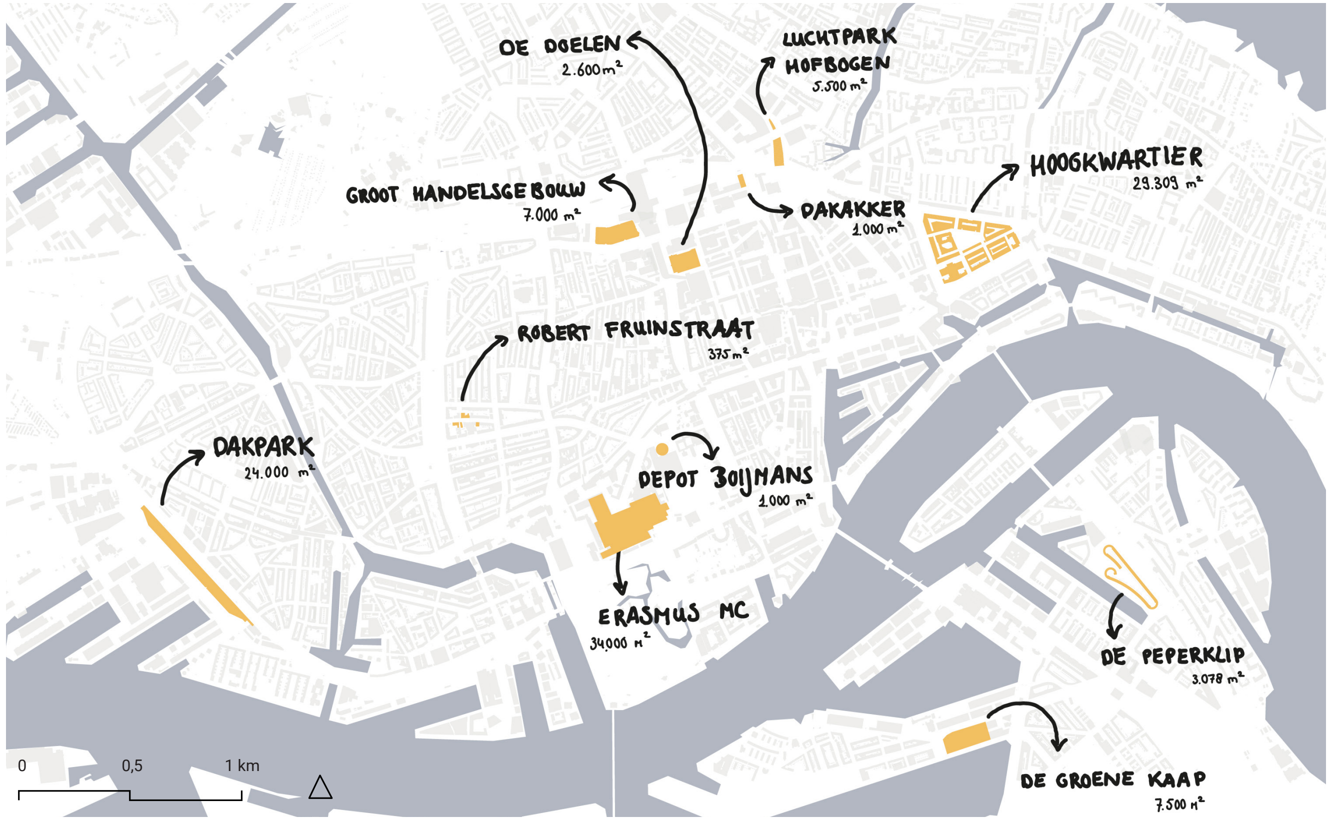
• • •

5.3 EXISTING ROOFTOP PROJECTS

5.3.1 Permanent rooftop projects in Rotterdam

To get a grip on the amount of space concerning a certain rooftop function, all permanent rooftop projects in Rotterdam that occupy more than 1-2 housing blocks are illustrated in figure 61. Per rooftop project, also the amount of space it occupies is noted.

In this thesis, the focus will be on flat roofs, so 75% (18,17km2) of all roofs of Rotterdam. However, within this roof type, there still is a lot of difference findable, in terms of surface, height, property, and usage.



LEGEND

rooftop project
buildings
water

Figure 61. Existing rooftop projects (including surfaces) in Rotterdam

Next to permanent rooftop projects, there are some temporary rooftop projects in Rotterdam as well. Some are yearly recurring, for instance, Rotterdams Rooftop Days and Dâk, while others are a one-off manifestation, to draw attention to the possibility of using roofs as an extension of the city, such as Stairs to Kriterion (2016), and the Rooftop Walk (2022). Interesting is the enormous amount of public and viewers these events attract. 368.000 people have visited the Stairs to Kriterion (figure 62). In the weekend, The Rotterdam Rooftop Walk (figure 63) attracts 200 visitors per fifteen minutes, so more than 7.000 people a day. So this event will have almost the same or even more visitors as the Stairs to Kriterion in a month time. Compared with the permanent rooftop projects, some temporary projects already make connections between several flat roofs, instead of focussing on 1 single roof, or 1 single building block. All temporary rooftop projects in Rotterdam are shown on the map and in the pictures below.

Figure 65. Existing temporary rooftop projects (including surfaces) in Rotterdam

Figure 62. Stairs to Kriterion (Laurian Ghinitoiu, 2016)

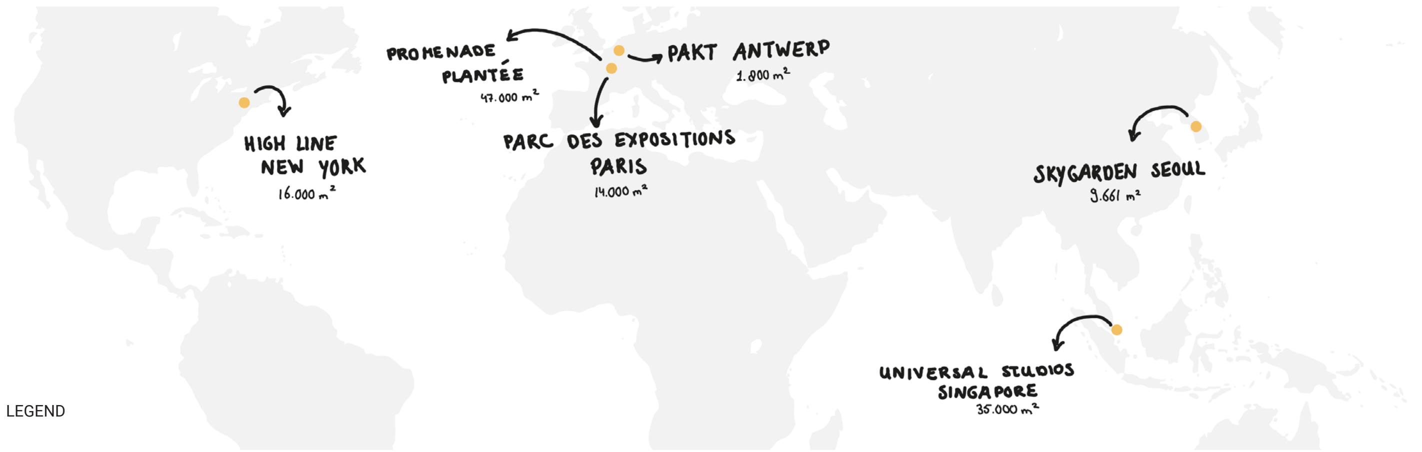
Figure 63. Rotterdam Rooftop Walk (MVRDV, 2021)

Figure 66. Green bus stop (Kuhlman, 2008)

Figure 64. Rotterdamse Dakendagen Dakakker (Petra Starink, 2017)

Other international projects, that are not as far developed in The Netherlands are large urban farming projects on roofs. Take for example Parc des Expositions (14.000m2) in Paris (figure 68) and PAKT in Antwerp (1.800m2) (Figure 67). Compared with urban farming projects on top of buildings in Rotterdam, such as the Dakakker (1.000m2), there is still a lot to be achieved. Comparing rooftop projects worldwide show not only the possibilities but also the urge and wish of people to build new structures on top of their existing urban fabric.

It is obvious that the Netherlands is not the only country in the World that does experiments on roofs. A well-known rooftop project is the Highline in New York. A public park on top of an old Highline that reimagine the role of public spaces in creating healthy neighbourhoods and cities. Similar projects can be found in both France and the Netherlands: Promenade Plantée (Coulée Verte) in Paris (figure 70) and Luchtpark De Hofbogen in Rotterdam. While the Highline of New York reaches a length of 2,33km, the green elevated promenade in Paris is twice as long, 4,7km.



LEGEND

rooftop project

Figure 71. Existing rooftop projects all over the world (including surfaces)

Figure 68. Parc des Expositions (Valode Pistre Architectes, 2020)

Figure 69. Skygarden Seoul (MVRDV 2017)

Figure 70. Promenade Plantée Paris (Alamy, 2017)

Figure 67. PAKT Antwerp (Visitflanders, 2017)

5.4 FLAT ROOF SCALES

5.4.1 Different scales of flat roofs

After looking into different roof shapes and several permanent and temporal rooftop projects in and outside The Netherlands on flat roofs, different scales of flat roofs could be distinguished. Five different roof scales are defined, see the drawings below (figure 72). Important to point out is that all flat roofs that are directly connected with another flat roof are clustered in this analysis. Therefore, five buildings with a flat roof of 100m2 that are directly next to each other, are seen as 1 area of 500m2 for instance. In this way, streets and building blocks that consist of several buildings with flat roofs can also be seen as a potential larger flat roofs to transform later in the project. There may be small differences in heights between the buildings and so the flat roof areas. This will not be taken into account at this moment. Design solutions later on in the project will cope with these height differences between smaller flat roofs.

On the map at the right, the different flat roof scales (tiny, extra small, small, medium, and large) are visualised in the inner city of Rotterdam (figure 73).

The smallest scale is the tiny scale flat roof. These roofs are less than 50m2 and are generally roofs on (private) sheds or electric cabinets. In Rotterdam they occupy 0,98km2 of the total flat roof area in the city, so 5% ((0,98km2/18,17km2)*100=5,4).

The second scale is the extra small scale. These are single building blocks with a flat roof that do not form a connection with other flat roofs. they form 14% of all flat roofs in the city ((2,41km2/18,17km2)*100=14).

The last three scales are flat roofs all bigger than 500m2. These could be streets with 5 or more buildings with flat roofs (that are directly next to each other), building blocks, or large public buildings. These three scales together form 81% ((14,78km2/18,17km2)*100=81) of all flat roofs in Rotterdam (figure 74).

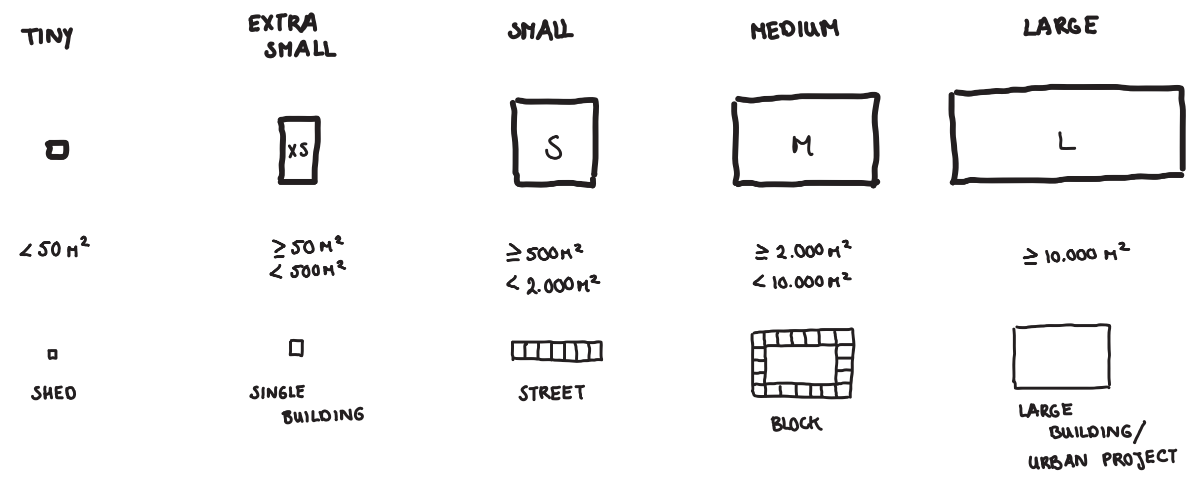


Figure 72. Explanation different flat roofscales

Figure 73. Different flat roofscales in map

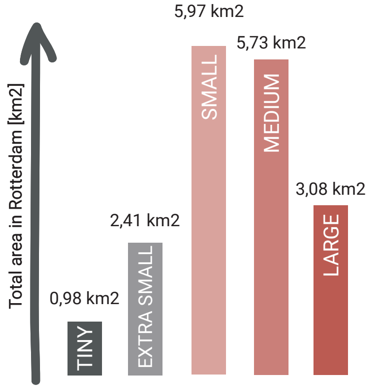
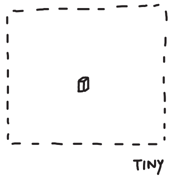
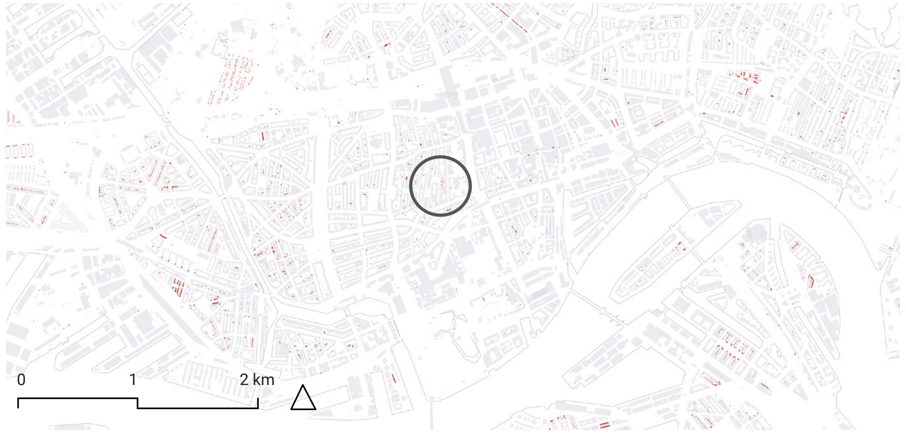


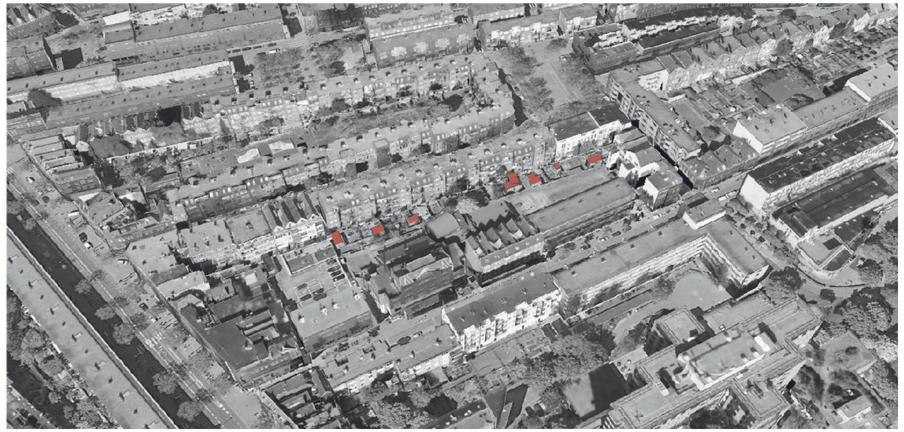
Figure 74. Statics flat roofscales

5.4.2 Tiny and extra small scale flat roofs

Tiny and extra small flat roofs are flat roofs smaller than 500m2. As said before, the tiny scale flat roofs are on sheds, bus stops, or electric cabinets. They are generally separated from each other, and often located within a larger building block, in the courtyard.







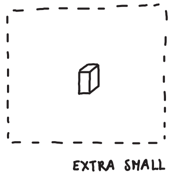
LEGEND

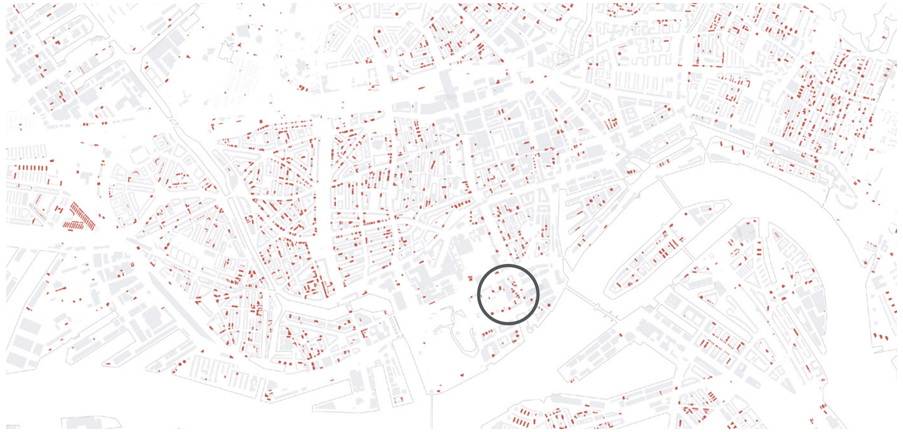
flat roofs <50m2

other roofs

Figure 75. Tiny scale flat roofs Oude Westen Rotterdam (Google Earth, 2021)

Extra small-scale roofs are single buildings with a flat roof between 50-500m2. As visible in the image below, they pop up everywhere in the city, and like the tiny scale roofs, they are completely separated from each other. They do not form a cluster with other tiny or extra small-scale roofs.





LEGEND

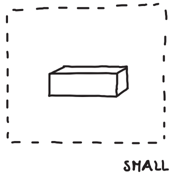
flat roofs 50-500m2

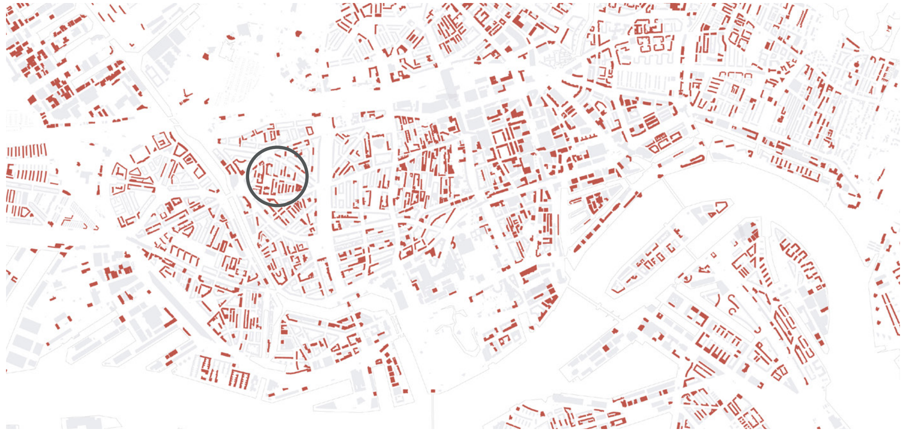
other roofs

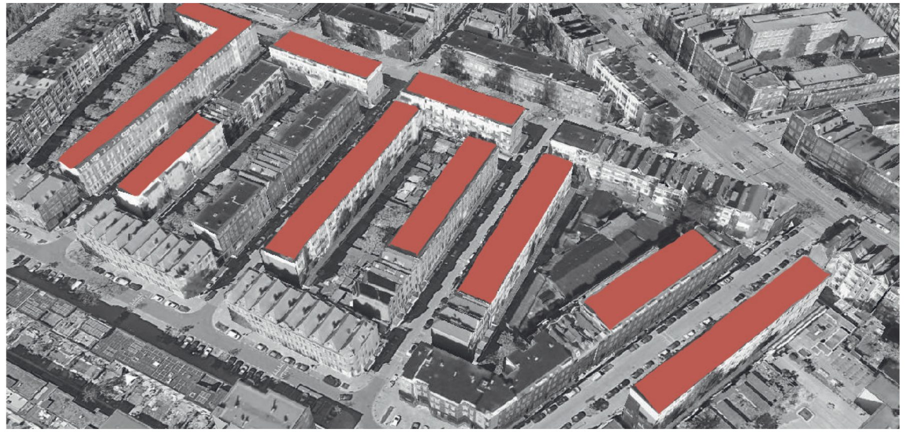
Figure 76. Extra small scale flat roofs Nieuwe Werk Rotterdam (Google Earth, 2021)

5.4.3 Small, medium, and large scale flat roofs

The third flat roof type is the small scale, between 500 and 2.000m2. This roof scale usually consists of five or more single buildings with flat roofs that are directly located next to each other. The small-scale rooftops are a part of a street block.







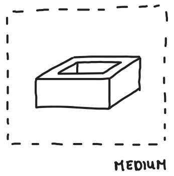
LEGEND

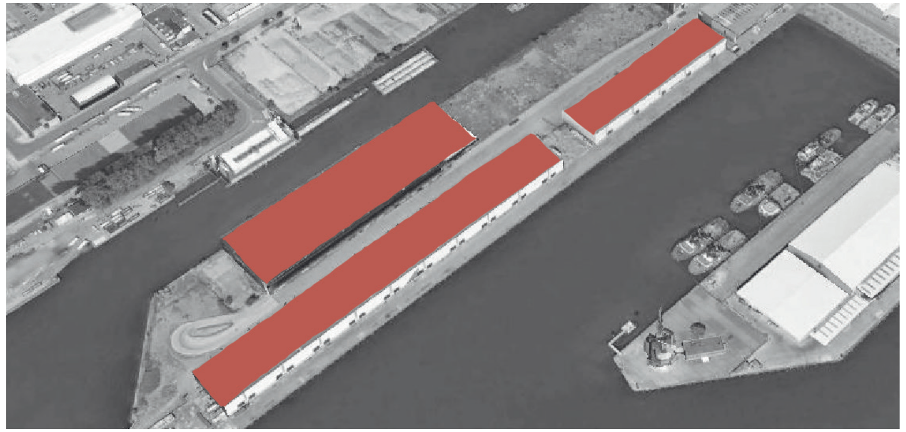
flat roofs 500-2.000m2

other roofs

Figure 77. Small scale flat roofs Nieuwe Westen Rotterdam (Google Earth, 2021)

The fourth roof scale type is all flat roofs, between 2.000m2 and 10.000m2. These roofs are mostly on top of large building blocks and often located in industrial and commercial areas (see figure 78). Besides, these areas of flat roofs can also be reached in building blocks of 20 or more buildings.





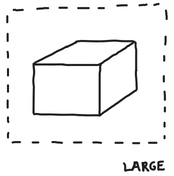
LEGEND

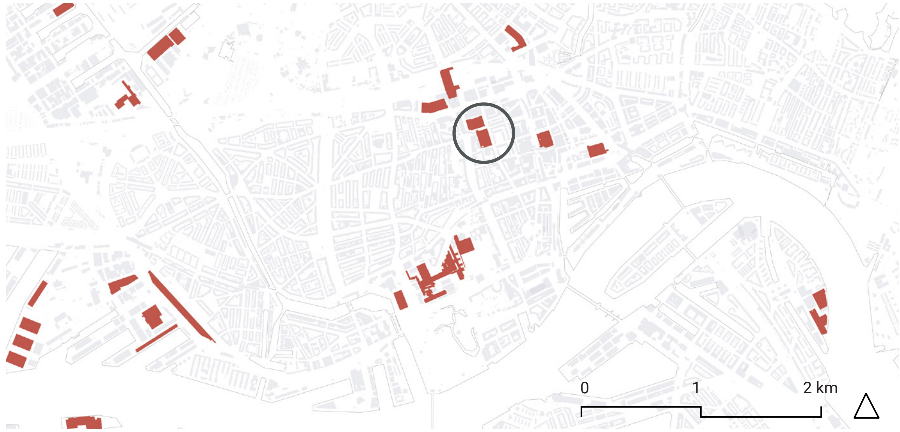
2.000-10.000m2

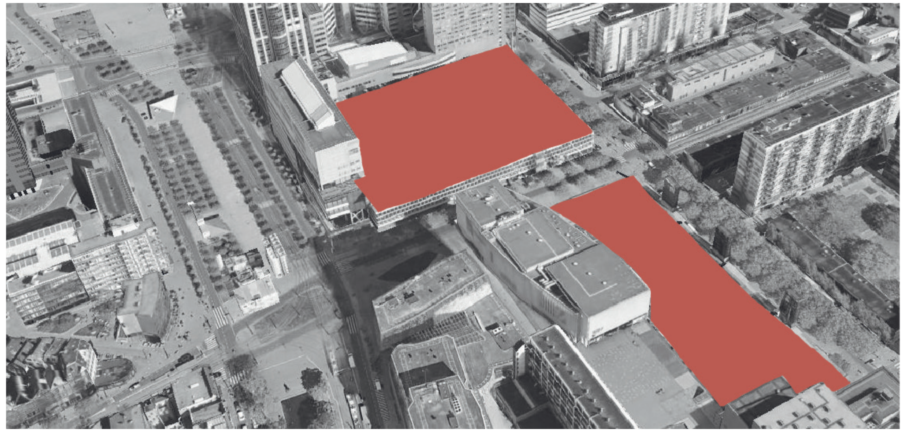
other roofs

Figure 78. Medium scale flat roofs Nieuwe Mathenesse Rotterdam (Google Earth, 2021)

The last flat roof scale is the large scale, flat roofs larger than 10,000m2. These roofs can be found at the Erasmus MC, Dakpark, and De Doelen for example. This roof scale has a great potential for transformation and has usually already (partially) transformed into a green or yellow roof.







LEGEND

>10.000m2

other roofs

Figure 79. Large scale flat roofs Cool Rotterdam (Google Earth, 2021)

5.4.4 Choice of flat roof scales

After having divided flat roofs into five different scales, the most logical follow-up question is what scale is suitable for what function? What scales are used to be taken further into the study (regarding the surfaces? And why?

To begin with the tiny and extra small-scale flat roofs. Both roof scales consist of roofs smaller than 500m2. This means that those roofs are on sheds, bus stops, small buildings, or single housing blocks. When looking at all existing rooftop projects, the smallest communal or public access, permanent rooftop projects in Rotterdam are Dakakker and the roof of Depot Booijmans. Both roofs are 1.000m2. This already gives an idea of the 'minimum' area of a green and social rooftop, so a flat roof where 2 functions are combined.

This thesis aims to contribute significantly to large urban challenges. Therefore the main focus will be on roofs larger than 500m2 to be able to make an impact and really make Rotterdam more sustainable and resilient in the future. Next to that, when taking all flat roofs in the inner city into consideration in this study, 4km2 of flat roofs should be redesigned, which means that 2415 buildings will be transformed. Since this is way too much for this research, only small, medium, and large-scale flat roofs will be redesigned, so all roofs >500m2.

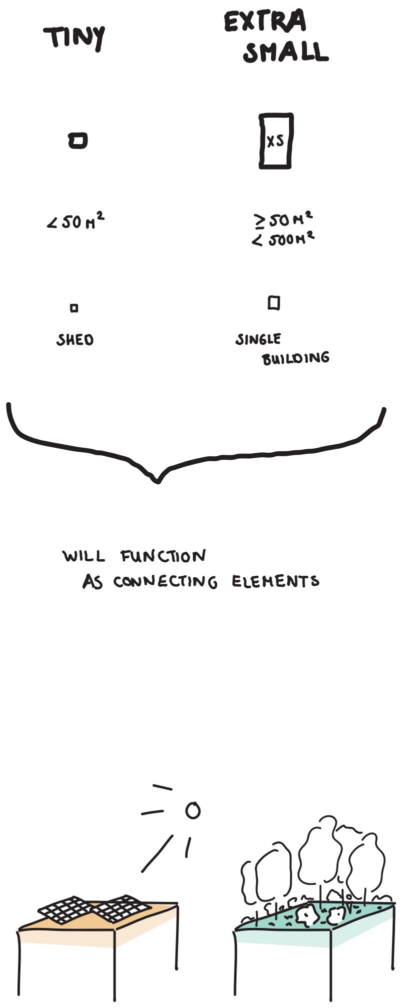


Figure 80. Tiny and extra small scale roofs

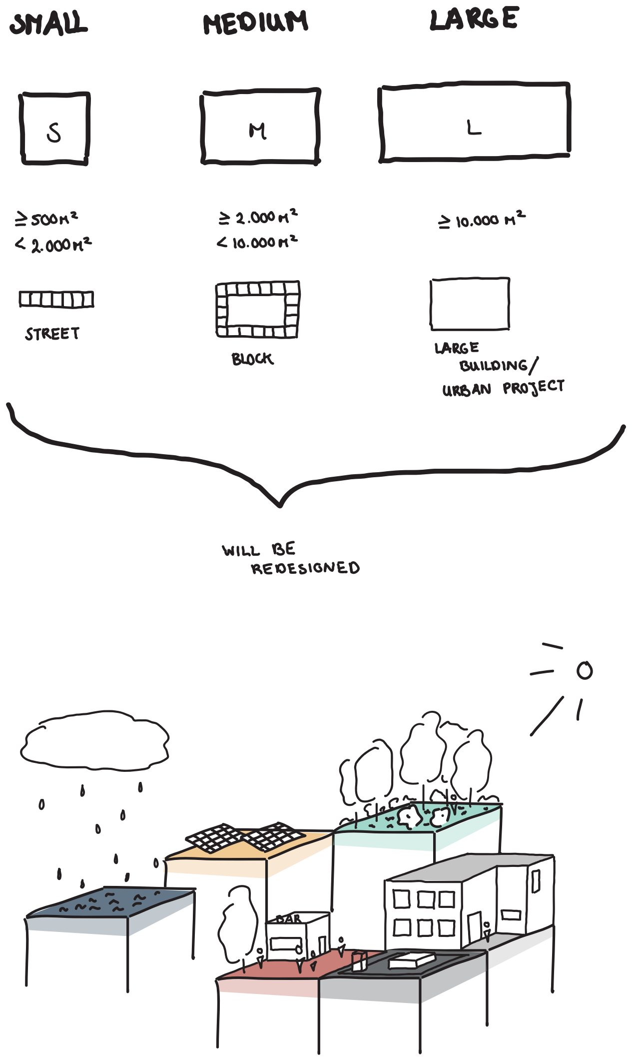


Figure 81. Multi scale rooftop network

However, there is still potential in all flat roofs smaller than 500m2. They can contribute to the energy transition for instance (see figure 80). These small sites could also serve as a support for new ecological connections in the city. Both yellow and green roofs would be possible functions for these smaller scales. However, these scales will not be specifically thought out.

As depicted on the right side of this page, small, medium, and large-scale flat roofs will be taken further in the design process. They have the potential to accommodate all kinds of rooftop functions: yellow (solar panels), green, blue (water storage), red (social functions), and light grey (housing). Especially the combination of several functions close to each other, or even connected with each other, and its effect on the existing urban fabric is something that will be investigated further (figure 81).

DESIGN OF THE BASE LAYER

- Flat roofs >500m2
- Urgencies projected on roofs
- Focus areas
- Calculations solar energy
- Urgencies per area
- Design rules for the base layer
- Current rooftop uses
- Climate analyses

This chapter is about the design of the base layer for all flat roofs>500m2. This new layer on top of our roofs copes with different urgencies defined in the problem statement. This chapter shows where, and what urgencies are present on Rotterdam's roofs, and it defines per urgency the design rules needed to transform the roofs concerning (multiple) urgencies.

6

6.1 FLAT ROOFS >500M2

6.1.1 The basis to define the base layer

As described in the previous chapter, all roofs larger than 500m2 are the roofs that have the most potential to achieve the project ambitions. These roofs can withstand major problems such as the growing population, climate change, and the lack of green in cities. All the more, when they are connected and create a network of roofs. The focus area is the city center of Rotterdam.

Until this moment, there are a lot of ideas for rooftop functions, however, most strategies or visions focus on single building blocks and do not look at the roofscape on a larger scale. As mentioned before, in the city center there are 4km2 of flat roofs. To use this enormous amount of space to tackle the urban problems addressed in the problem definition chapter, a strategy needs to be formulated that relates the urban problems (heat stress, flooding, energy transition, lack of green, and the growing population) to the type of space (flat roofs >500m2).

In this chapter, the first new layer on top of those flat roofs will be introduced. Based on the problem statements (energy transition, lack of green, climate change, growing population) and the type of place (flat roofs >500m2) the function and layers of the roofs will be investigated and determined.

LEGEND

pitched roofs, semi-flat roofs, flat roofs <500m2
small scale flat roofs
medium scale flat roofs
large scale flat roofs
green
water

0 400 800m

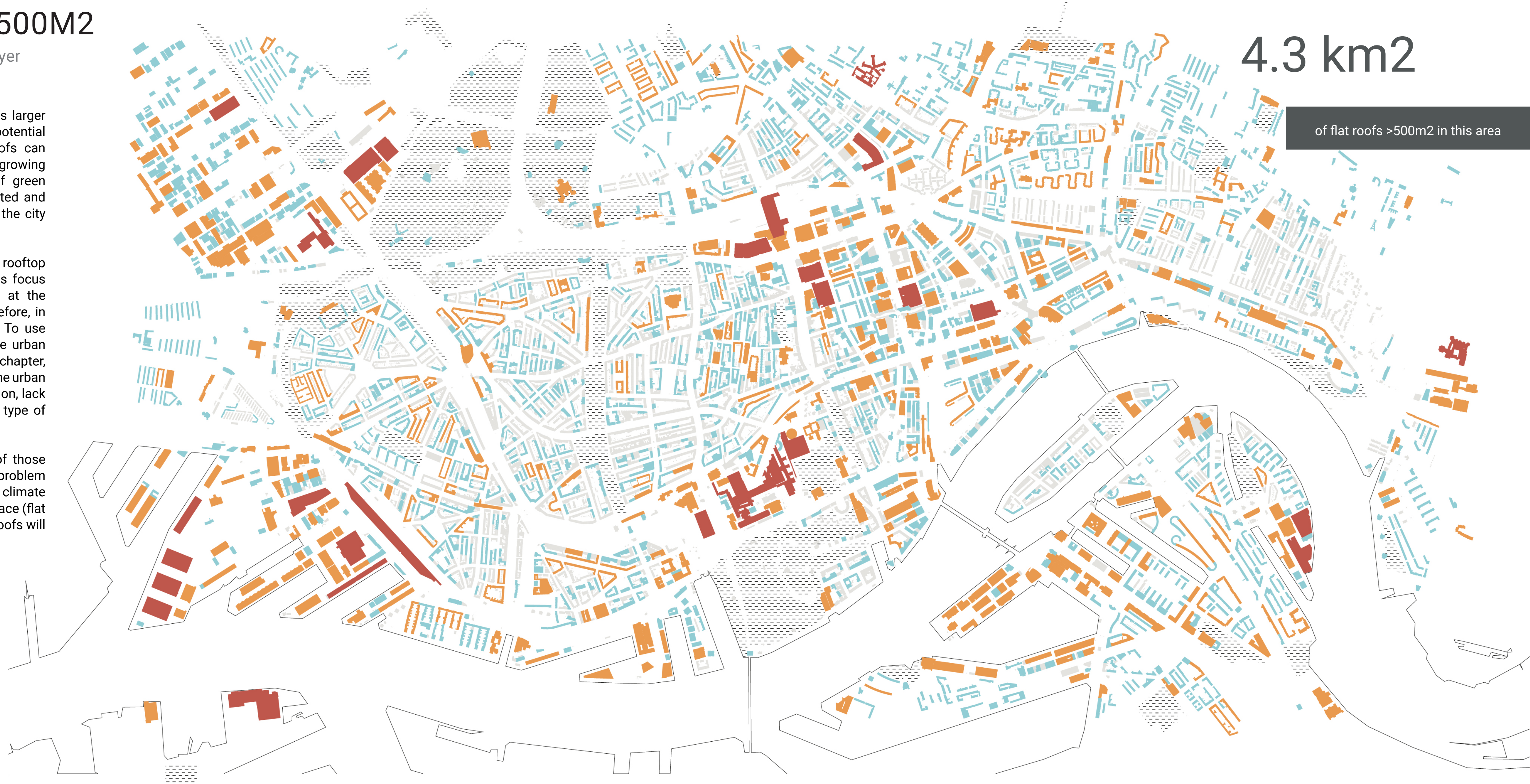


Figure 82. Different roofscales Rotterdam

6.2 URGENCIES PROJECTED ON ROOFS

6.2.1 The relation between the problem definition and the type of space

Figure 83. Urgency map

LEGEND

- flat roofs >500m2
- roofs x heat stress
- roofs x biodiversity
- roofs x flooding
- roofs x energy transition
- water
- green

0 400 800m

In the problem statement, five major problems cities are facing nowadays were addressed: lack of green, flooding, energy transition, heat stress, and the growing population. The urgency map above shows all flat roofs >500m2 concerning a specific urgency. The urgency the roof holds is based on the urgency which is most present in that specific location. In other words, the color of the roofs shows which places suffer the most from a certain urban problem. On the right page, all urban problems on roofs are shown seperately.

Desired green connections in Rotterdam, that connect the natural areas outside the city with the green structures in the center.

Areas that suffer from flooding after precipitation of 70mm in 2 hours. This causes especially streets to flood.

Areas that suffer the most from the Urban Heat Island Effect nowadays. Especially on summer days when temperatures are above 30 degrees.

The surface on flat roofs needed to provide all households in Rotterdam with solar energy (34% of all flat roofs >500m2 in the city center) (details are visible on page 92 and 93).

6.3 FOCUS AREAS

6.3.1 Zooming in on two areas considering present urgencies

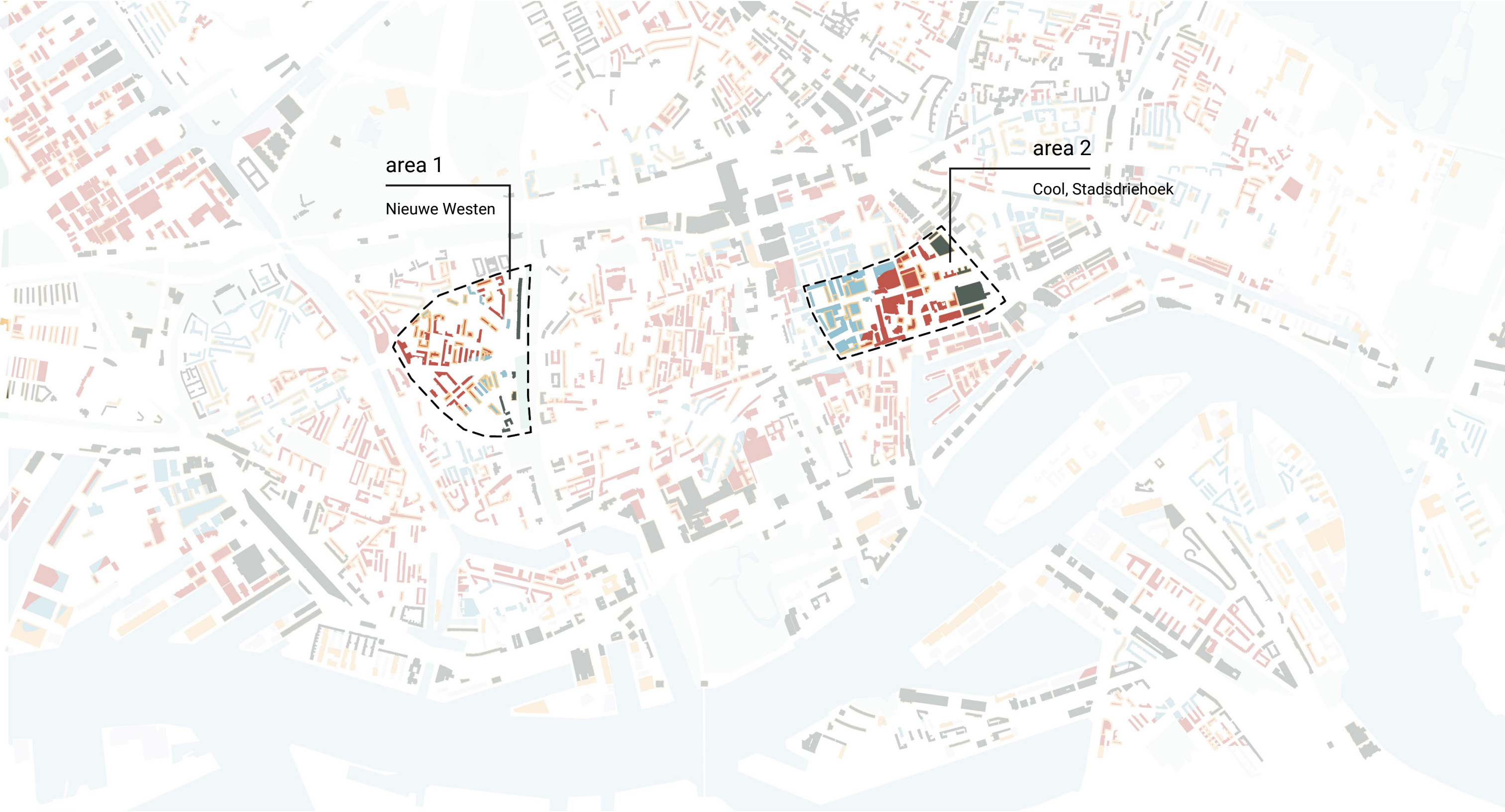


Figure 84. Focus areas in relation to the urgencies

LEGEND

- flat roofs >500m2
- roofs x heat stress
- roofs x biodiversity
- roofs x flooding
- roofs x energy transition
- water
- green

0 400 800m

To further elaborate on where urgency needs to be tackled, two areas are chosen to look more in-depth at which places suffer the most from which problem and how this can be solved by using flat roofs. Important to point out is that both areas suffer from all the four major problems (lack of green, flooding, heat stress, and the energy transition). The areas differ from each other in function. Where area 1 has a more residential function, is area 2 located in the middle of the city center of Rotterdam, with especially a commercial function.

For both areas, an urgency map is made (see next pages). In the diagrams on this page, an explanation is given about when a roof encompasses a certain problem and when not. The idea is that those analyses indicate which areas (and so the roofs) suffer from which problem. The underlying problems/urgencies namely determine the function of a certain rooftop >500m2 later in the process. So, when a roof >500m2 is located in an area that suffers highly from heat stress and flooding, there should come a rooftop function that on the one hand can cool the environment, and on the other hand can store temporarily water to release the sewer system.

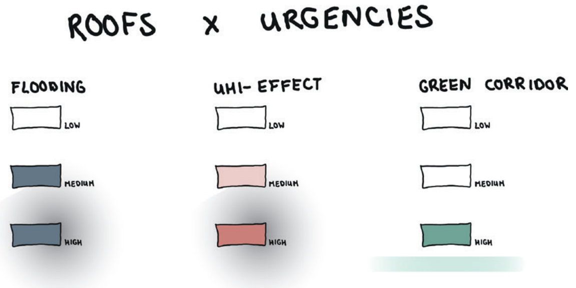


Figure 85. Explanation roofs x urgencies

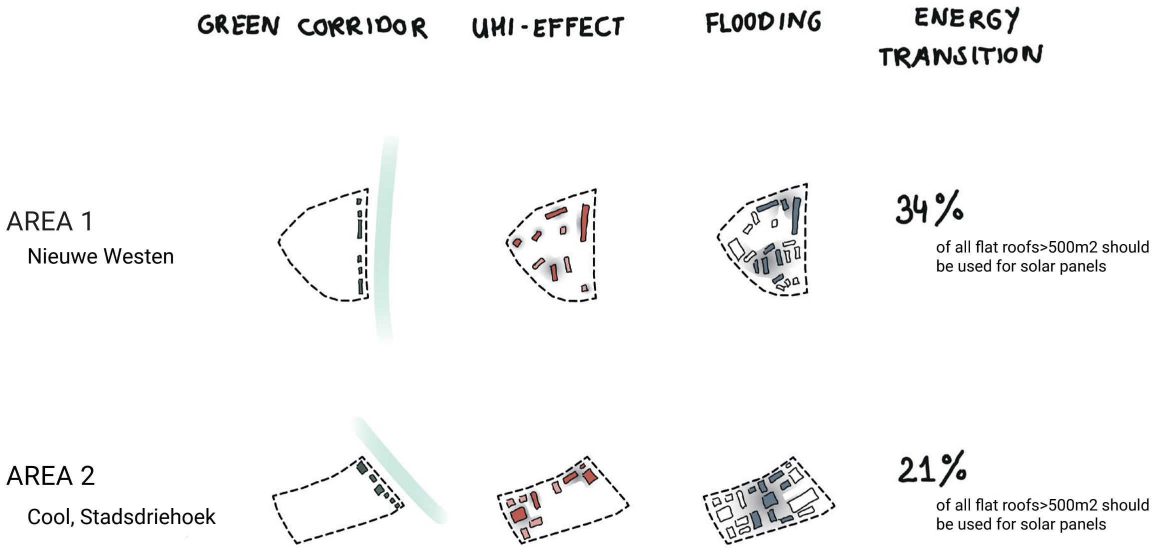


Figure 86. Explanation roofs x urgencies per area

6.3.2 Phase 1 of the design process: type of place

In the previous chapter, the focus areas of this research are defined regarding the urgencies those areas are facing. In the image below the type of space in area 1 (flat roofs>500m2) that will be observed, analysed, and redesigned is visualised. On the image on the right page, a picture of this neighbourhood is visible.

Figure 87. Flat roofs >500m2 area 1

Figure 88. Area 1 (Google Earth, 2022)

In the image below, all flat roofs >500m2 in area 2 are visualised. Comparing the scale of the flat roofs >500m2 in area 2 and area 1, the flat roofs in area 2 are mainly medium and large-scale flat roofs. However, the height differences between the buildings are larger, so medium or large-scale roofs in this area are less continuous spaces.

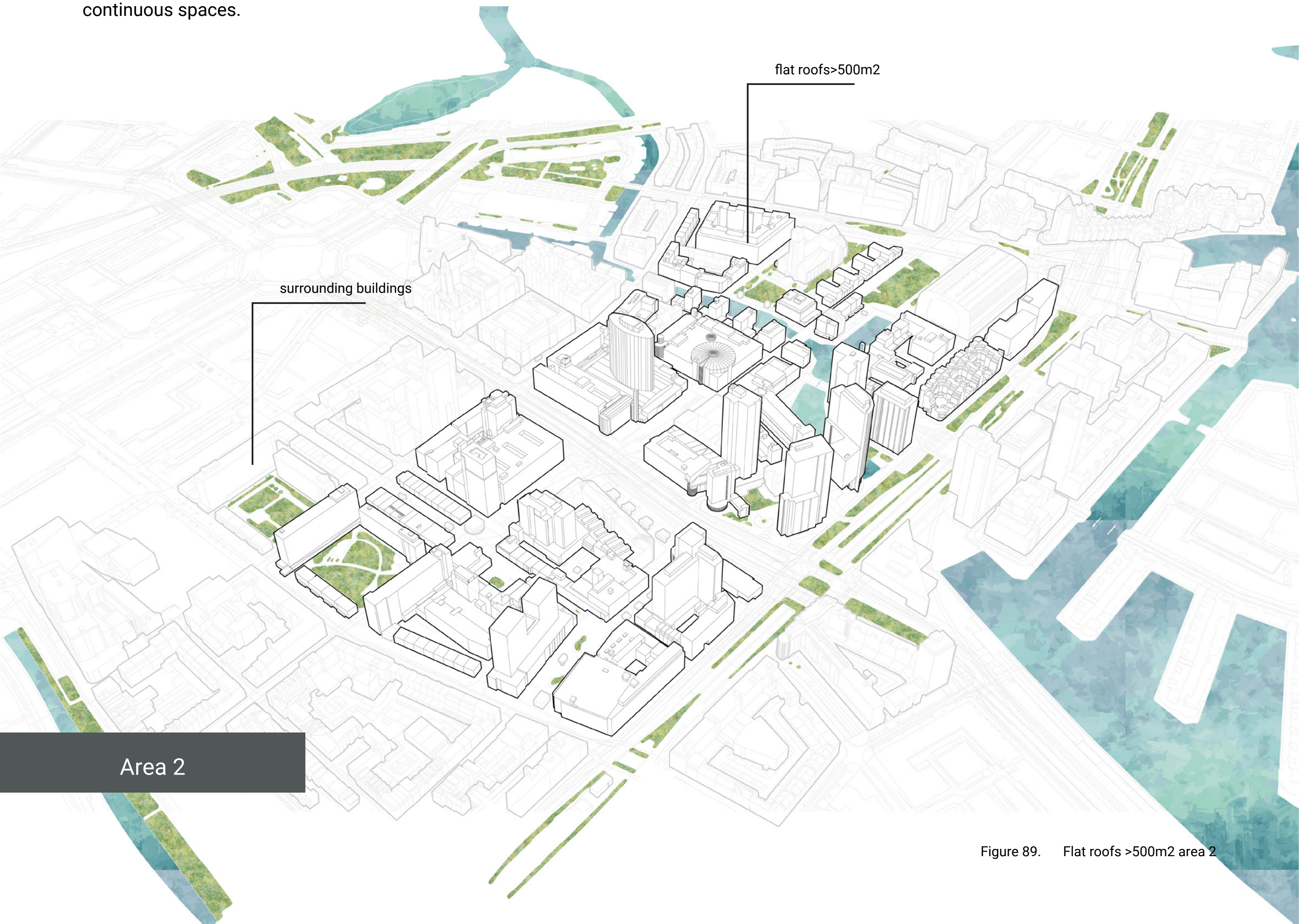


Figure 89. Flat roofs >500m2 area 2

Figure 90. Area 2 (Google Earth, 2022)

6.4 CALCULATIONS SOLAR ENERGY

6.4.1 Ambition

The municipality of Rotterdam has the ambition to become energy neutral in 2050. This means that all energy used in the municipality must come from renewable energy sources, such as solar panels. Roofs are very sufficient to be used for solar panels. However, this thesis states that solar panels are not the only function that roofs should accommodate. Therefore a calculation of the number of solar panels on roofs is needed in the future to foresee all households in the municipality from solar energy.

It has been decided to only look at the energy demand of households in this calculation. This is because there are multiple other ways to generate renewable energy, for instance, hydropower, wind energy, tidal energy, geothermal energy, and biomass energy. These ways can be used for the rest of the energy demand of the city. Next to that, in this calculation, there will be only looked at solar panels on top of buildings. There are many other places where solar panels can be implemented or placed, for instance on meadows (solar fields), on water (floating solar fields), on parking lots, and next to infrastructure (windshields next to highways). As visible in the image below, The Rotterdamse Zonneladder shows that roofs and facades of buildings are most sufficient to cover with solar panels compared with infrastructure, water, and land (Gemeente Rotterdam, 2021).

317.945

households in Rotterdam need to be foresee from solar energy in 2050

6.4.2 Energy demand households Rotterdam in 2022

- Energy use per house/household in Rotterdam is 2.600kWh per year (Centraal Bureau voor de Statistiek, 2019).

- 1 solar panel produces 350Wp. To foresee in the energy demand on a yearly basis we need: 2.600kWh*1.1 = 2860kWh / 350Wp = 8 solar panels per household on average ((van der Wilt, 2022).

- At this moment there are 317.945 households in Rotterdam (AlleCijfers, 2022). Rotterdam strives to become energy neutral in 2050. If we want to foresee all households in the municipality of renewable energy by solar panels, 8*317.945=2.543.560 solar panels need to be installed in total.

- In 2021, Rotterdam counted already 270.000 solar panels on its roofs. This means that (270.000/2.543.560)*100=10,6% is already realised. And we still need to realise 89,4% in the upcoming 28years (not taken into consideration new households in the next years). 89,4% are (2.543.560*0.894=) 2.273.942 solar panels that we will going to install on Rotterdam's roofs to accomplish this ambition.

2.273.942

solar panels needed to achieve the ambition

6.4.3 Potential area for solar panels in harbour area

- The Port of Rotterdam counts 1.345 flat roofs >500m2, with an average surface of 3.457m2 (Atlas Leefomgeving, 2018).

- The surface of 1 solar panel on a flat roof is 3,23m2. This surface includes a marge (in between the solar panels, and the unusable edges of a roof).

- So it is possible to realise (3.457m2*1.345 flat roofs)/3.23m2 = 1.440.002 solar panels on the roofs of the port of Rotterdam. (In this calculation, I didn't look into the roofs that are already occupied or are not suitable for this rooftop use. Besides, industries that are located there can't use their roof anymore to foresee themselves from solar energy.)

- This means that (1.440.002 /2.273.942)*100= 63% of all solar panels needed to provide all households in Rotterdam from solar energy in 2050 can be realised in the harbour area. Only 37% of the solar panels need to be realised on the roofs in the city center.

63%

in harbour area

6.4.4 Amount of solar panels in area 1 (Nieuwe Westen)

- Area 1 is located in the neighbourhood 'Nieuwe Westen'. This neighbourhood counts 9.815 households (AlleCijfers.nl, 2022). As stated before, 37% of all solar panels for households in Rotterdam need to be installed in the city center. This means that there is a need of solar energy for 9.815*0.37=3.631 households. To foresee this amount of households from solar energy we need 8*3.631= 29.052 solar panels in this neighbourhood.

- On google maps is visible (see images below) that on average 12 solar panels can be installed 1 side of pitched roofs (on the southern side). This neighbourhood counts 964 buildings with pitched roofs (Atlas Leefomgeving, 2018). Imagen you can place on all those roofs already 12 solar panels, 12*964=11.568 panels can be placed on pitched roofs, so only 29.052-11.568=17.484 solar panels will be on flat roofs. (Google Maps, 2022)

- 'Het Nieuwe Westen' has in total 145 buildings with flat roofs >500m2 (Atlas Leefomgeving, 2018). The average surface of the flat roofs>500m2 in this area is 1142m2. From the previous reasoning, it appeared that 17.484 solar panels need to be installed on those 145 flat roofs to become an energy-neutral neighbourhood and so city.

- 17.484*3,23m2= 56.473m2 is needed for those solar panels. And the neighbourhood consists of 145*1142m2=165.590m2 of flat roofs>500m2. When 56.473m2 of this 165.590m2 of roof surface will be covered with solar panels, (56.473/165.590)*100= 34% of the roofs will be used for the generation of solar energy.

34%

of flat roofs>500m2 in area 1 will be yellow roofs

6.4.5 Amount of solar panels in area 2 (Cool and Stadsdriehoek)

- Area 2 is located partly in the neighbourhood Cool and the other part is located in the neighbourhood Stadsdriehoek. Those two neighbourhoods together count 14.070 households (3.590 in Cool (AlleCijfers.nl, 2022), and 10.480 in Stadsdriehoek (AlleCijfers.nl, 2022)). 37% of the households in this area need to foresee of solar energy in the neighbourhood itself. This means that there needs to be realised (14.070households*0.37)*8solar panels=41.647 solar panels on the roofs.

- As mentioned before, on small pitched roofs a maximum of 12 solar panels can be placed (see example in Nieuwe Westen). The neighbourhoods Cool and Stadsdriehoek have 379 buildings with pitched roofs (Atlas Leefomgeving, 2018). So it is possible to install 379*12=4.548 solar panels on pitched roofs. This means that 41.647-4.548=37.099 solar panels will remain for the flat roofs>500m2 in these neighbourhoods.

- Cool and Stadsdriehoek count 326 flat roofs>500m2 with an average surface of 1.779m2 (Atlas Leefomgeving, 2018). To foresee all households from solar energy 37.099solar panels*3.23m2=119.829m2 of the flat roofs>500m2 will be covered by solar panels. In total there is a surface of 326*1.779m2=579.954m2 available on flat roofs>500m2. So, (119.829m2/579.954m2)*100= 21% of all flat roofs>500m2 need to be covered with solar panels at least.

21%

of flat roofs>500m2 in area 2 will be yellow roofs

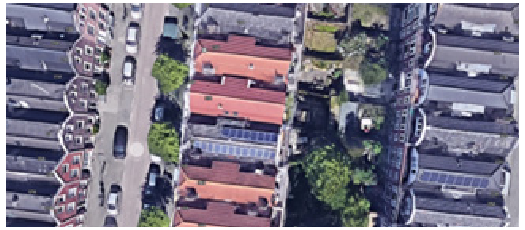


Figure 91. Solar panels pitched roofs Nieuwe Westen (Google Maps, 2022)

6.5 URGENCIES PER AREA

6.5.1 Urgencies projected on roofs in area 1

To get more grip on the urgencies of the urban heat island effect, flooding, lack of green, and the energy transition in the designated areas, an urgency map for both areas is made. On this page, the effect of the different urgencies on the environment in area 1 is shown. All roofs >500m2 area highlighted. When a flat roof >500m2 is located in or nearby an area that suffers highly from a certain problem, this roof gets the color related to that problem. In other words, all roofs located next to the desired green corridor become dark green. This means that those roofs must accommodate a certain rooftop function that contributes to the creation of a green corridor in this area.

When looking at heat stress, all roofs in red are located in areas where heat stress is most strongly present. The light red roofs are located one block further away from high urgent areas, but are still located in an area where heat stress is strongly present.

Figure 92. urban heat island effect area 1

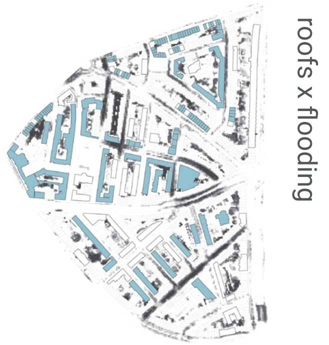


Figure 93. flooding area 1

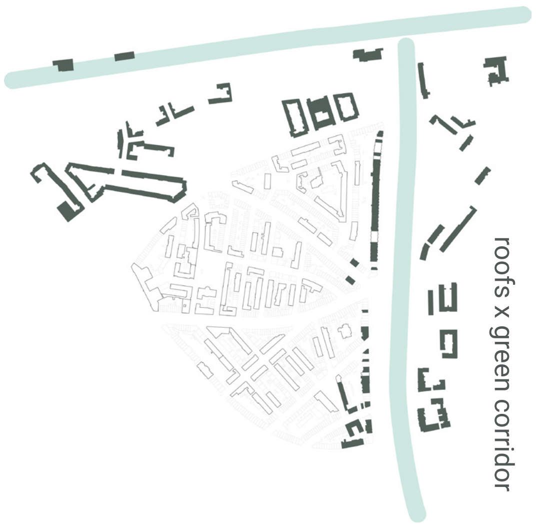


Figure 95. green corridor area 1

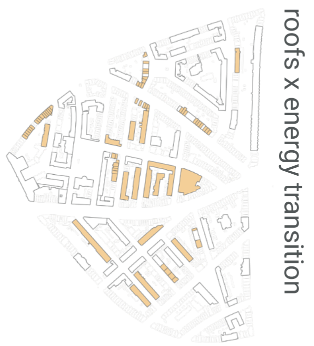


Figure 94. energy transition area 1

Figure 96. Urgency map area 1

6.5.2 Urgencies projected on roofs in area 2

On this page, the effect of the different urgencies on the environment in area 2 is shown. Compared with area 1, suffers area 2 much less from flooding. However, as visible in figure 97, the urban heat island effect in this area is strongly present. The urban heat stress map that lies underneath is a map that visualises the current situation. This means that in the upcoming years the problem will become even more present and the (perceived) temperatures in this area will become higher and higher.

For the energy transition, 21% of the flat roofs >500m2 will be used for the integration of solar panels (see calculations in chapter 6.4). This contributes to the ambition to foresee all households in the municipality of Rotterdam from solar energy in 2050. In area 1 34% of the roofs will be covered with solar panels. Since these calculations are done with the number of households in 2022 instead of 2050, also 34% of the flat roofs in area 2 will be covered with solar panels. This to grow with the increasing number of households in Rotterdam in the upcoming years.

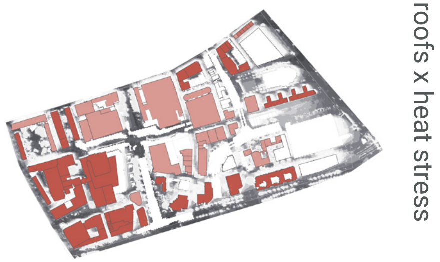


Figure 97. urban heat island effect area 2

Figure 98. flooding area 2

Figure 99. energy transition area 2

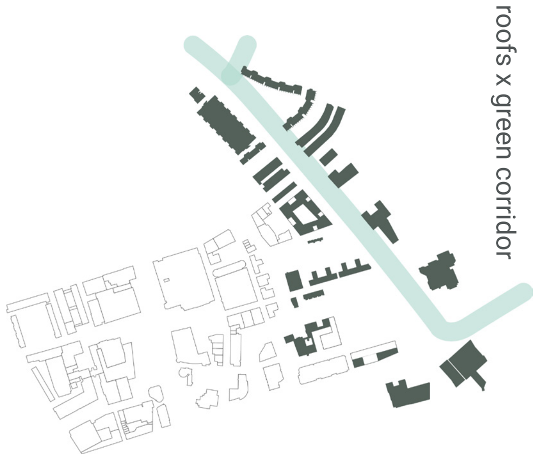


Figure 100. green corridor area 2

Figure 101. Urgency map area 2

6.6 DESIGN RULES FOR THE BASE LAYER

6.6.1 The introduction of design rules to deal with different urgencies on flat roofs

In the previous subchapter, there is investigated which roofs suffer from which problem. The urgency maps give an indication of what problem where needs to be addressed. The next question is how can those problems be solved by roofs. Therefore per the problem statement design rules are set that argue what the conditions of the roofs should be to address a specific problem. This means for example that the red roofs in the urgency maps need to address the heat stress in that specific area. The design rules will explain more elaborately what the features of these roofs need to become to prevent heat stress, for example.

On this page is shown what the base function of the roofs should be regarding a specific urban problem. To realise the green corridor, an intensive green roof is needed. To cope with heat stress an intensive or extensive green roof is needed. To prevent flooding, water storage is needed on the roofs where this problem is strongly present. The only problem which is not place-specific is the energy transition. To foresee households from solar energy, solar panels on roofs are the solution to deal with this specific problem.

As in figure 104, some roofs have to deal with more than 1 problem/urgency. Take for example the green corridor and flooding, or heat stress and flooding. The diagrams in figure 103, visualise which combinations of problems can be tackled on one and the same roof.

These diagrams also show which urgency and rooftop function can be combined with solar panels. Since this urgency is not place-specific, it is important to have an idea about which combinations work and do not work. Next to that, there are not enough sloping roofs in Rotterdam to foresee every household in Rotterdam from solar energy. Therefore those solar panels need also be added to flat roofs >500m2 (in combination with water storage and/or an extensive green roof).

In this subchapter, there will be elaborated on the specific features of flat roofs in the future to deal with 1 or more different urban challenges.

Figure 102. Relation urgencies and rooftop functions

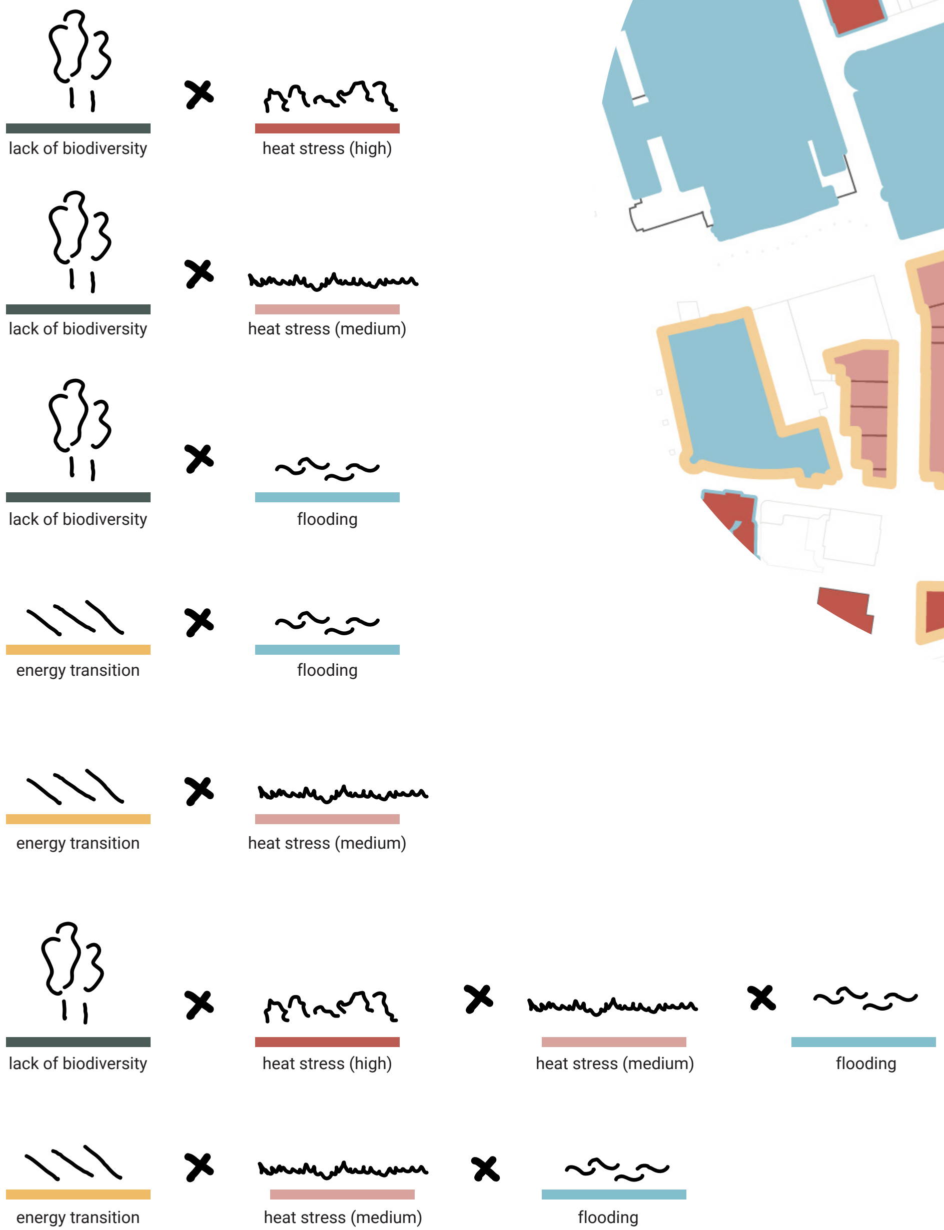


Figure 103. Combinations of urgencies on roofs

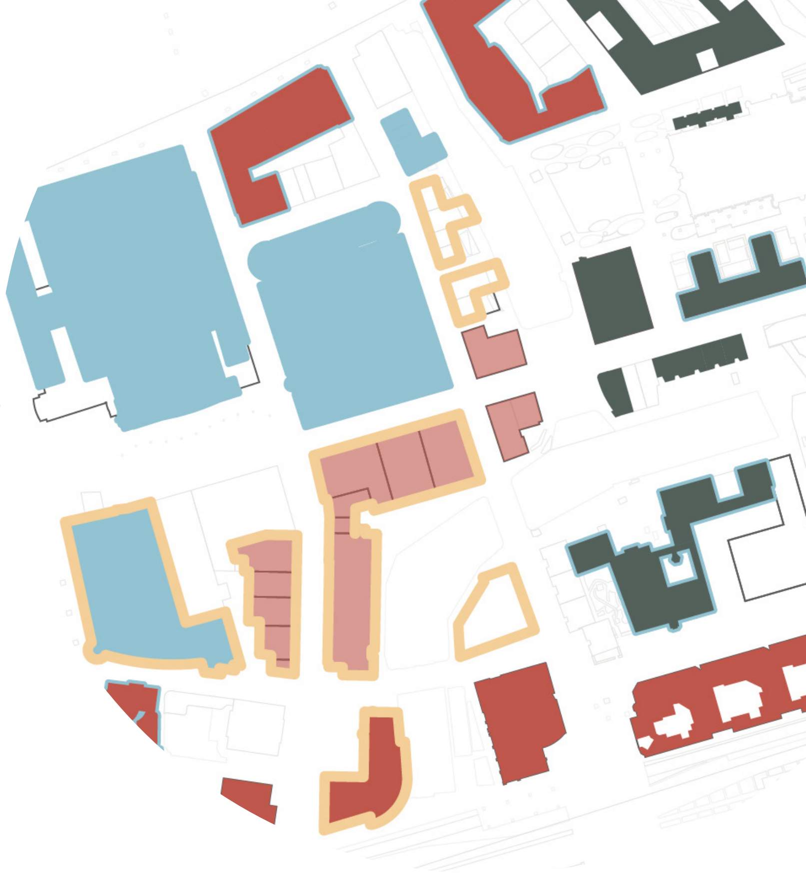
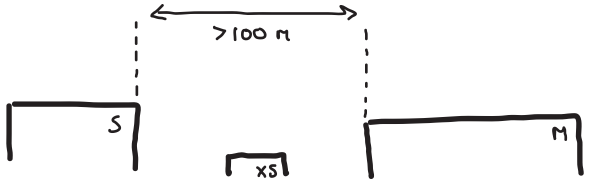


Figure 104. Zoom-in urgency map area 2

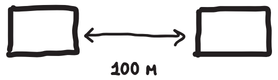
6.6.2 Design rules flat roofs x green corridor

To realise a green corridor on top of roofs or to enrich an existing part of the green corridor with greenery on roofs, different design requirements need to be set. Take for example the distance between the roofs (horizontally and vertically), the thickness of the substrate layer, and the kind of vegetation. The requirements of green roofs located in the green corridor are visible in the diagrams below.

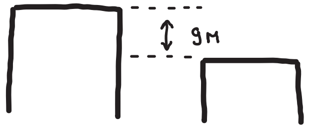
CONFIGURATION OF ROOFS



tiny and extra small flat scale roofs will be used as stepping stones when distance between flat roofs>500m2 is more than 100m (Gout, 2014)



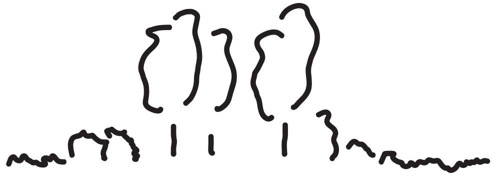
100m maximum distance between roofs (maximum fly distance bees) (Lee & Lin, 2015)



9m is maximum height difference between roofs (maximum distance bees can bridge) (Lee & Lin, 2015)

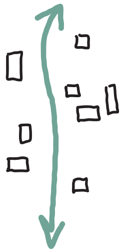
REQUIRED ROOF STRUCTURE

minimum thickness of substrate (Wageningen University&Research, 2017)



rich and diverse vegetation (MacIvor & Lundholm, 2010)

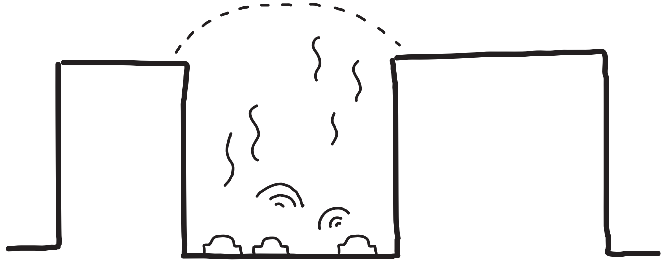
LOCATION



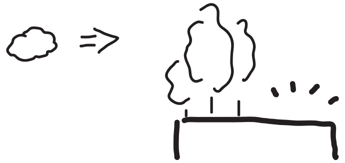
located directly next to desired green corridor in the city

place specific

ORIENTATION



green bridges when corridor is disturbed by traffic zones (sound and air pollution) (Gout, 2014)



habitats in a wind free zone (Dunnett and Kingsbury 2010).

nesting places in the sun (Dunnett and Kingsbury 2010).

Figure 105. Design rules green corridor

6.6.3 Design rules flat roofs x flooding

Many places in cities suffer from flooding nowadays. Water storage on roofs can reduce the amount of water on the street and relieve the sewer. However, for example, the average bearing capacity of roofs needs to be taken into account when designing for water storage on roofs. The requirements for water storage on roofs are visible in the diagrams below.

AMOUNT OF PRECIPITATION

2 L/M² IN 1 DAY

is the average amount of rainfall per day in The Netherlands (Rijksoverheid, n.d.)

50 L/M² IN 1 DAY

is a "wet" day in The Netherlands (Rijksoverheid, n.d.)

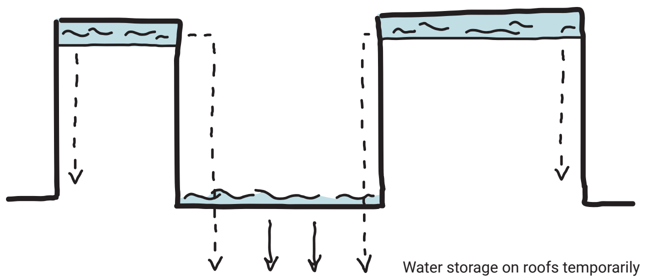
70 L/M² ON A ROOF

is the ambition of Rotterdam for the capacity of water storage on blue roofs (Duurzaam 010, 2021)

100 L/M² MAXIMUM

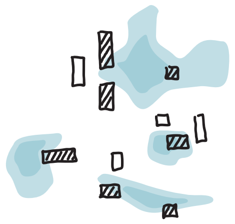
standard load bearing capacity of a roof construction in The Netherlands (de Vree, n.d.)

WATER STORAGE/RETENTION



Water storage on roofs temporarily release sewage system. Rain water can also be used for toilet flushing in buildings (Rainproof Amsterdam, 2022).

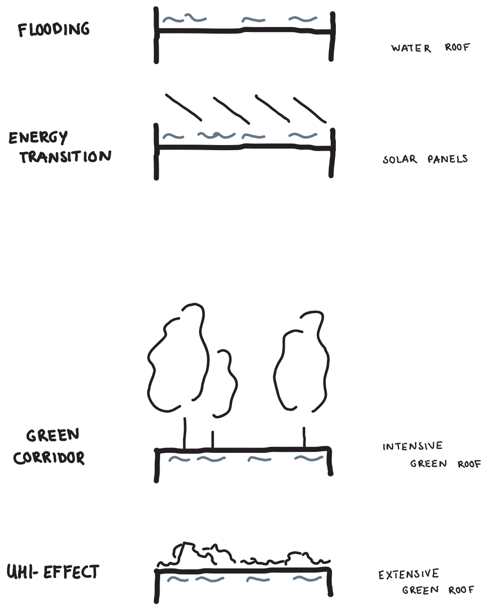
LOCATION



roofs located in or next to areas that flood after heavy precipitation (70mm/2h)

place specific

COMBINATION WITH OTHER ROOFTOP FUNCTIONS



open water storage roofs can be combined with solar panels (Rainproof Amsterdam, 2022)

closed water storage systems can be combined with intensive and extensive green roofs (Rainproof Amsterdam, 2022)

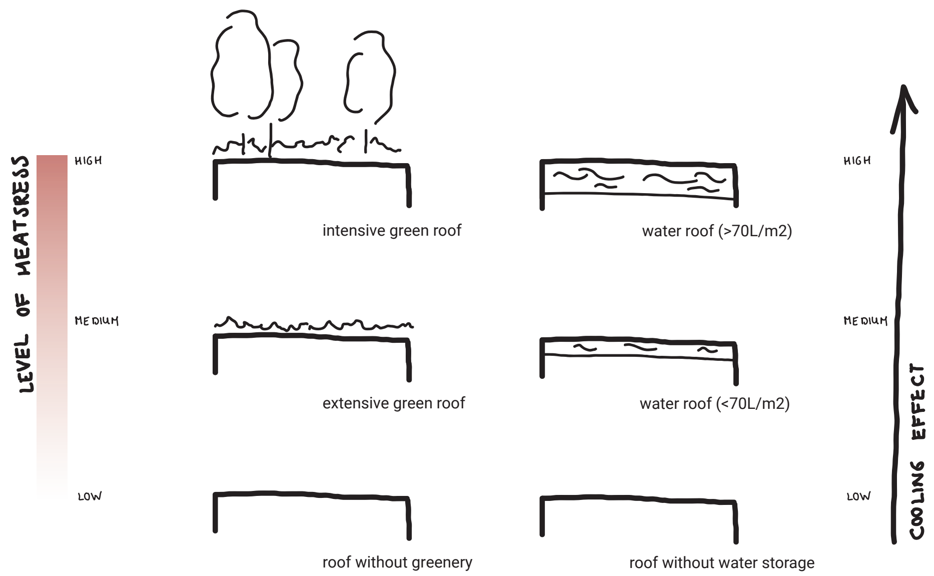
Figure 106. Design rules water storage

6.6.4 Design rules flat roofs x heat stress

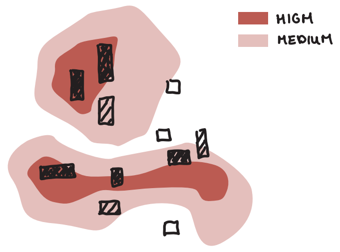
Green roofs can respond to different urban problems: green corridor, flooding, and heat stress. Depending on the problem and the urgency of a certain problem the thickness/vegetation of the green roof layer is determined. The higher the heat stress in a specific location is, the more vegetation or water storage is desired. This to cool the environment and the building underneath. The requirements for green roofs in relation to heat stress are visible in the diagrams below.

EFFECT OF GREEN & BLUE ROOFS ON HEAT STRESS

(Langelaar, 2019) (Solcerova et al., 2017)



LOCATION



flat roofs>500m2 located in high heat stress zones (high) and next to high heat stress zones (medium)

place specific

COMBINATION WITH OTHER ROOFTOP FUNCTIONS

the appropriate urgency determines the thickness of the green layer on the roof

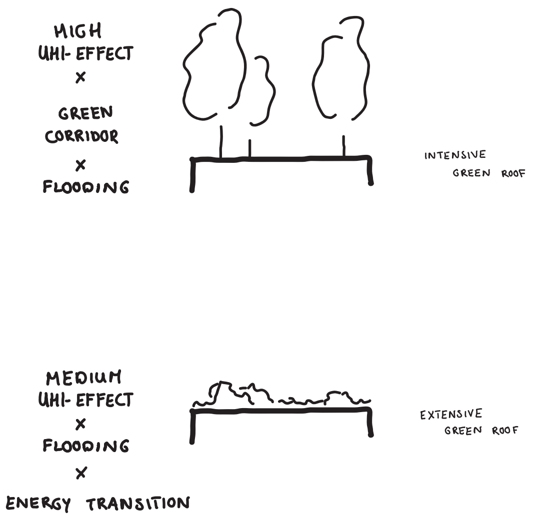


Figure 107. Design rules heat stress

6.6.5 Design rules flat roofs x energy transition

This research aims to foresee all households in Rotterdam from solar energy in 2050 (see chapter 6.4). The conclusion of those calculations and the design requirements for solar panels on roofs are visible in the diagrams below. Solar panels are the only rooftop function that is not tied to a specific place. However, the highest located flat roofs in the city are most appropriate to use for the generation of solar energy (from both a climate and an aesthetic point of view).

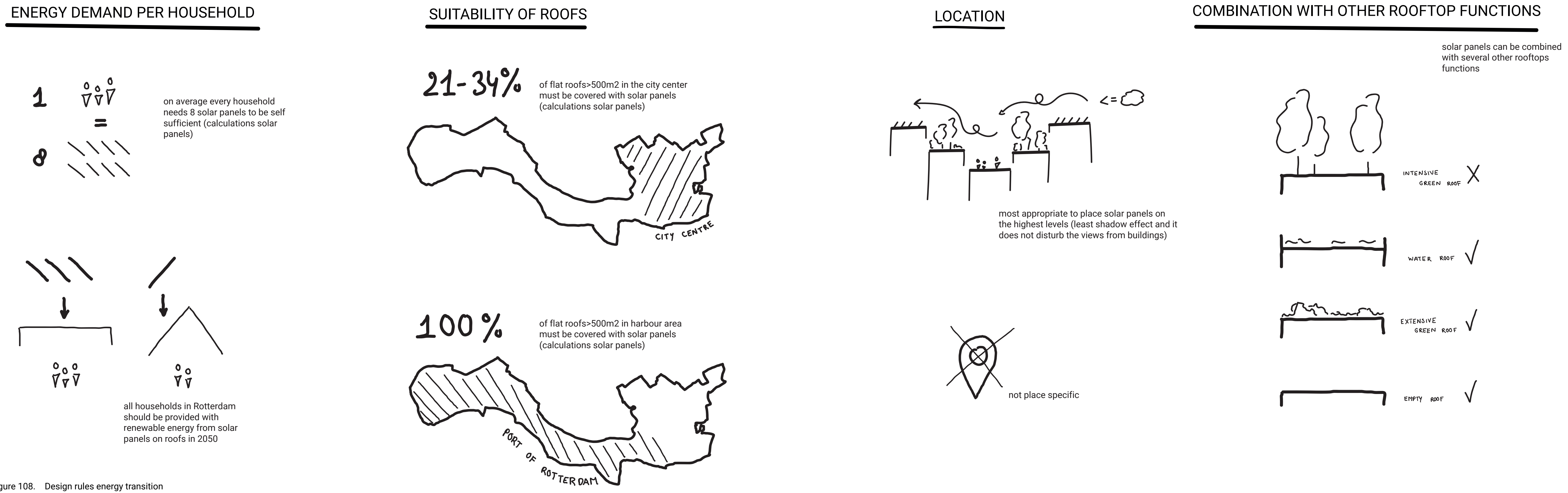


Figure 108. Design rules energy transition

6.6.6 Conclusion

As said before, this research tries to solve large urban problems by using roofs. Any problem that has been formulated in the problem statement will have to be solved differently. By using flat roofs >500m2 an enormous amount of space comes free to deal with those problems. In t his subchapter there is looked more elaborately at how large flat roofs in a city can deal with a certain urgency. These investigations have led to specific design requirements for roofs at a specific location. The vision maps show where what problem is most present (so the location of specific roof types). This in combination with the design rules, gives a first indication of how those roofs need to be 'filled in' to reach the ambition of the project.

Chapter 6.1.1. pointed out that some roofs suffer from more than 1 problem. For the design of those roofs in the future, it is mandatory to create an arrangement/ sequence in which functions on roofs have to be realized first. The second step is to look at extra functions that can be added to those roofs. Take for instance the roofs in/nearby the green corridor. Looking at the design rules a maximum possible distance between the roofs is set. This means that if a flat roof in between gets a different function, for example, that it is covered with solar panels, the green corridor will no longer work properly. Therefore a sequence in rooftop functions about specific urgencies is set, to make sure these connections will not be disturbed by other rooftop uses.

Besides, when a rooftop needs to deal with the lack of green in a city and has to become part of the green corridor, an intensive green roof will be added to that roof. In general, intensive green roofs store more than 70 mm/m2 of rainwater. This mean that automatically the problem of flooding on the roofs is tackled, and it is not needed to add water storage later to these roofs.

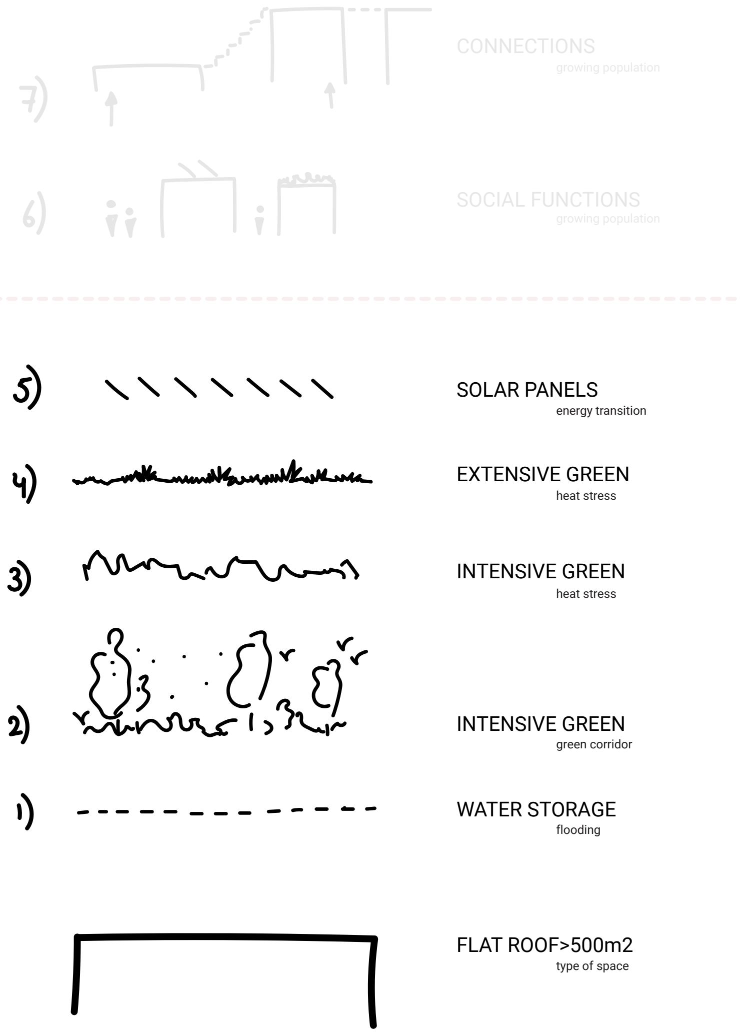


Figure 109. Sequence of rooftop functions

Figure 110. View Rotterdam Building 2022

6.6.7 Phase 2 of the design process: design of the base layer

Concluding from the design rules per urgency, every urgency requires several properties of the new rooftop function to deal with a certain problem. Take for example flooding the minimum water storage capacity of 70L/m2. The roofs directly next to the flooding area need to have this water storage capacity.

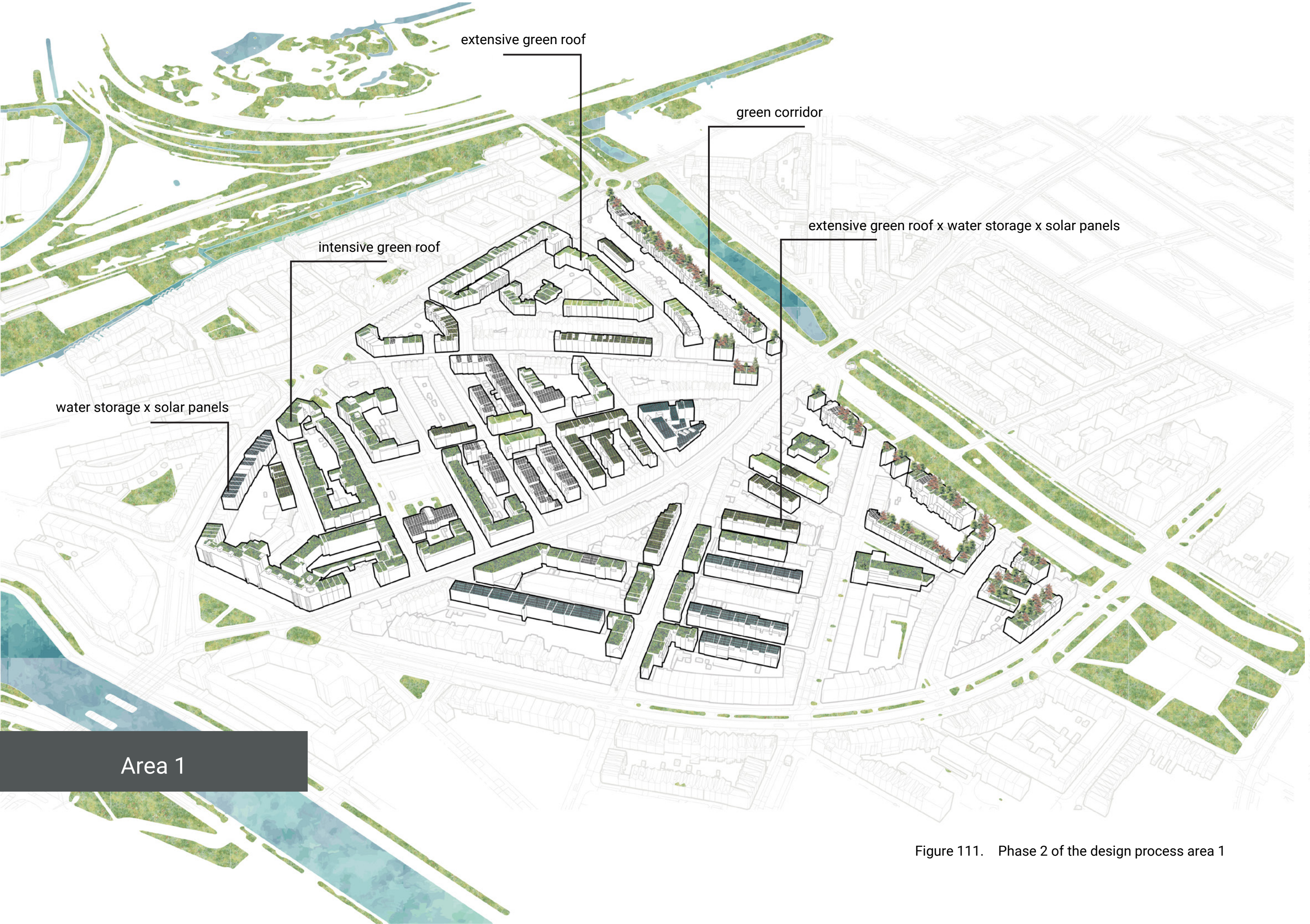


Figure 111. Phase 2 of the design process area 1

The images on those pages show where what kind of rooftop function is most convenient. The images show what Rotterdam’s rooftops will look like when adding water storage, solar panels, extensive green, and intensive green to flat roofs >500m2. In fact, these images are an outcome of the urgency maps and the design rules.

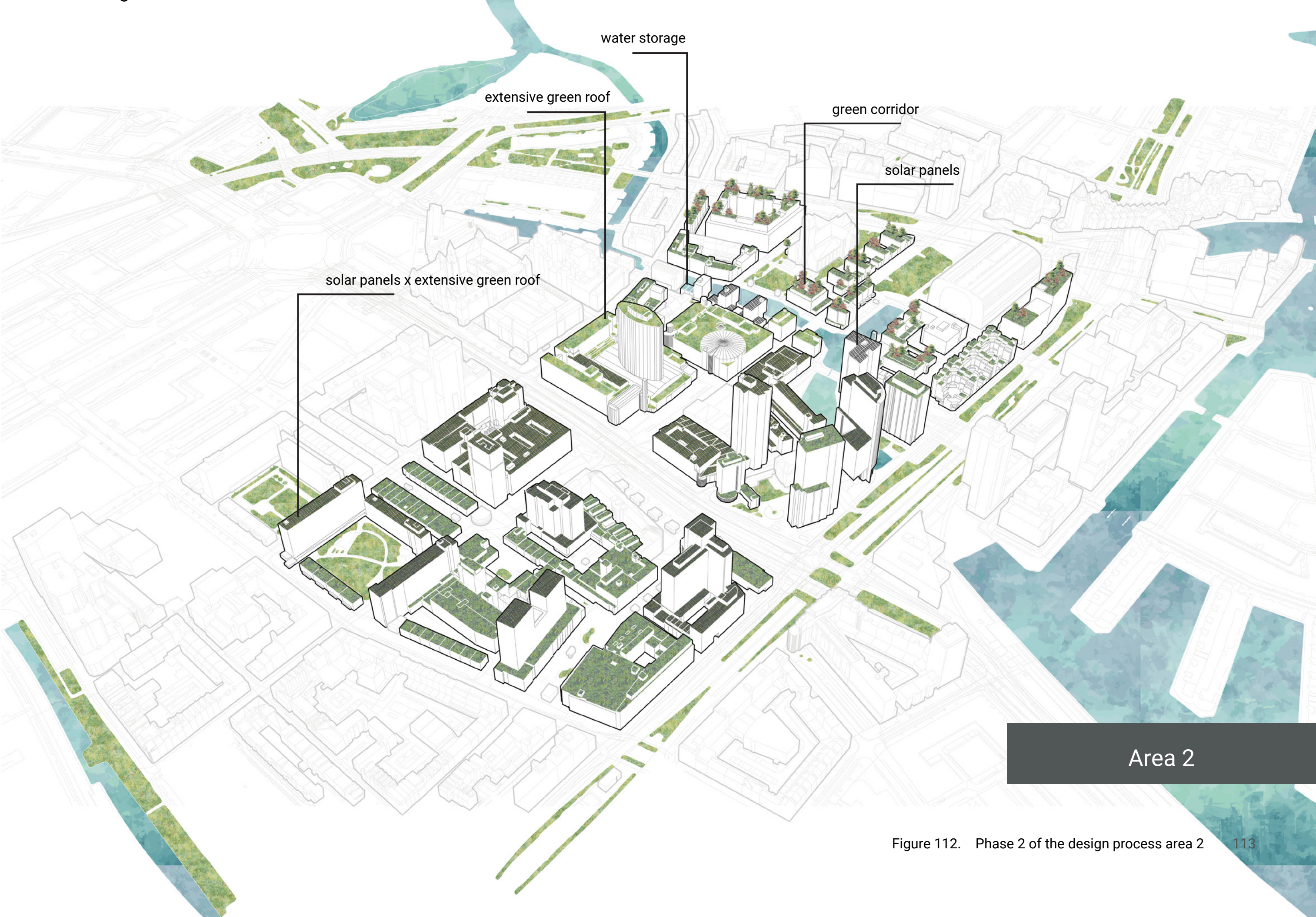


Figure 112. Phase 2 of the design process area 2

6.7 CURRENT ROOFTOP USES

6.7.1 Current rooftop uses - area 1

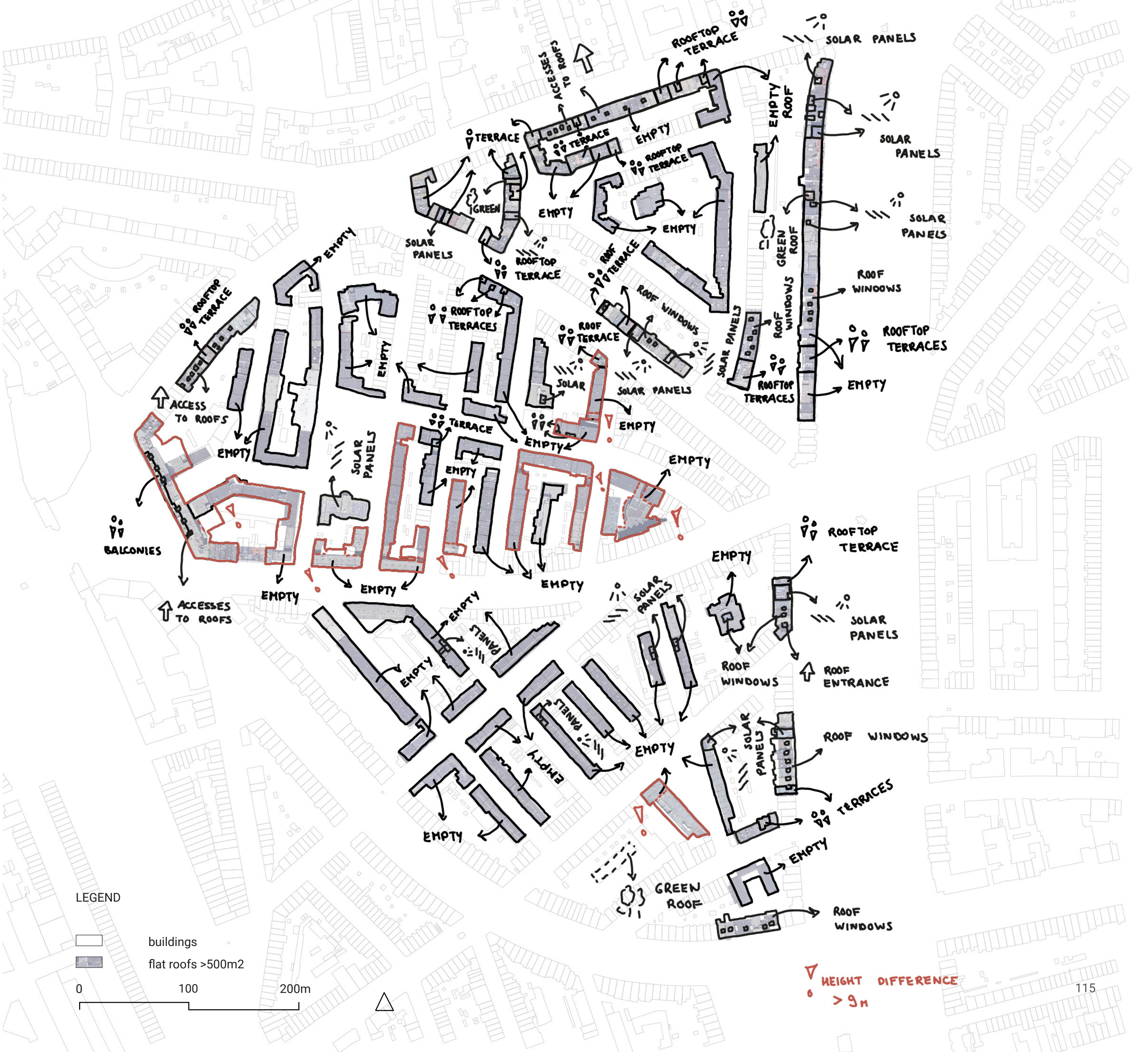
To get an idea of what the roofs look like right now, what functions they already accommodate, and where height differences between the buildings are large, every flat roof>500m2 in the two areas is observed, analysed, and mapped with its current functions and structures.

As visible in the circles on the right, for area 1 there is mainly looked at which roofs are empty, where there are already (private) roof terraces, and where there are large height differences between 2 buildings with a flat roof (more than 9 meters), if there are already rooftop entrances, and/or installations on roofs. Lastly, there is investigated on which roofs there are already solar panels visible.

All these analyses together, give an overview of the current situation on roofs as visible on the next page.

Figure 113. Flat roofs >500m2 area 1

Figure 114. Current functions and uses of roofs area 1



6.7.2 Current rooftop uses - area 2

The same analysis is done for area 2 this to get an idea of what the roofs look like right now, what functions they already accommodate, and where, and where the height differences between the buildings are large, every flat roof>500m2 is observed, analysed, and mapped with its current functions and structures.

As visible in the circles on this page, for area 2 there is mainly looked at which roofs are empty, where there are already communal or public rooftop terraces, and what the height differences are between buildings that together form a large flat roofscape. Compared with area 1, there are already quite a lot of rooftop entrances visible on the roofs in area 2. Besides, large percentages of the flat roofs in area 2 are already occupied with installations or air handling units. This has to do with the fact that the buildings in area 2 are much higher and have more complex climate regulation installations in the buildings, which also result in installations on the roofs.

All these analyses together, give an overview of the current situation on roofs in area 2 as visible in figure 116.

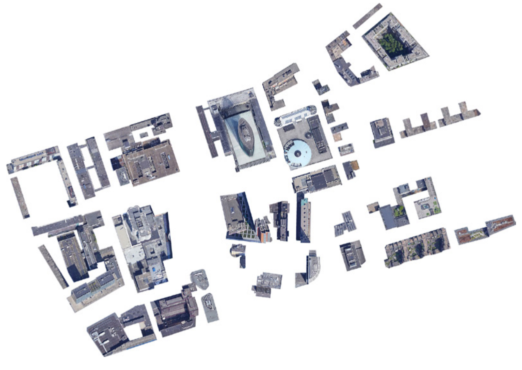
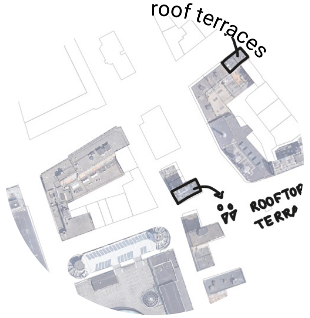
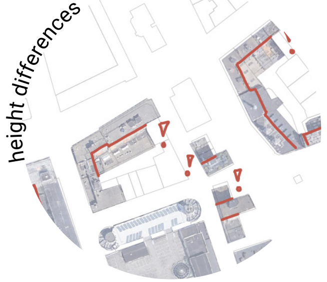
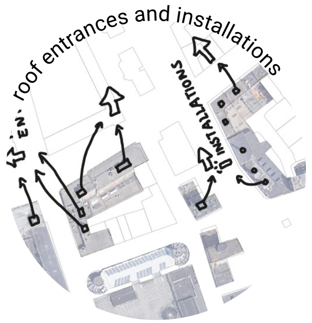


Figure 115. Flat roofs >500m2 area 2







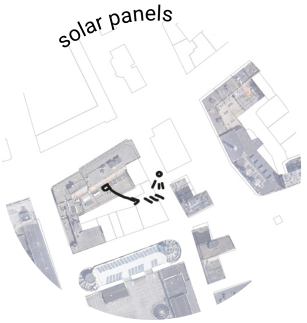


Figure 116. Current functions and uses of roofs area 2

6.7.3 Differences between the areas

As mentioned before, areas 1 and 2 differ from each other in function. Where area 1 is more a residential area, area 2 is more commercial. When zooming in on the flat roofs>500m2 in those areas there are also quite a lot of differences visible in shape, heights, surfaces, and uses. In the drawings on this page, these differences are visualised.

When looking at the type of space, the roofs in area 2 are larger (often >2.000m2) compared with the roofs in area 1. Besides, the buildings are much higher in area 2 than in area 1. Especially for green and social functions on roofs, the heights should be taken into consideration.

Next to that, the current functions and structures on the roofs in area 2 are different from the ones in area 1. It is clearly visible that the social functions are often communal or public, whereas the social functions in area 1 on top of the roofs are mainly private. Lastly, installations such as air handling units, and window clean systems are only visible in area 2. Because of these installations on the roofs, there are often also rooftop entrances. While most of the roofs in area 1 are only accessible via a roof window.

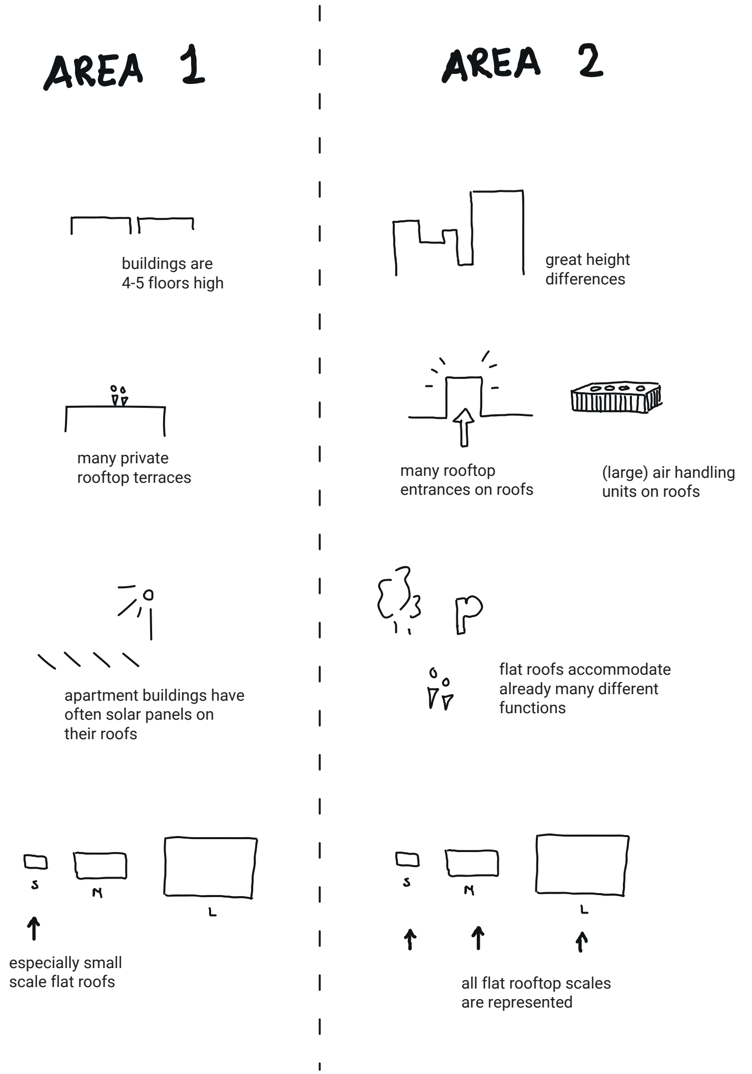


Figure 117. Sequence of rooftop functions

Figure 118. Lijnbaanflat 2022

6.7.4 Limitations existing rooftop functions

In chapter 6.6 an overview is given of new rooftop functions that can be combined on the same roof to cope with 1 or more urgencies. Take, for example, the combination of water storage and an extensive green top layer on a roof. By adding multiple rooftop layers an even more sustainable and resilient Rotterdam will be achieved.

However, there are as well rooftop functions that can not be combined that easily. By doing fieldwork (chapter 6.7.1-6.7.3), roofs that do not allow new or extra rooftop functions came to light, for example, roofs with installations, social roofs, or roofs with solar panels. All these types of roofs can not be combined with an intensive green layer. However, these social functions and solar panels on roofs can still be combined with extensive green roofs.

Figure 119 shows with rooftop functions can not be combined. Whether these are existing features on roofs or new features.

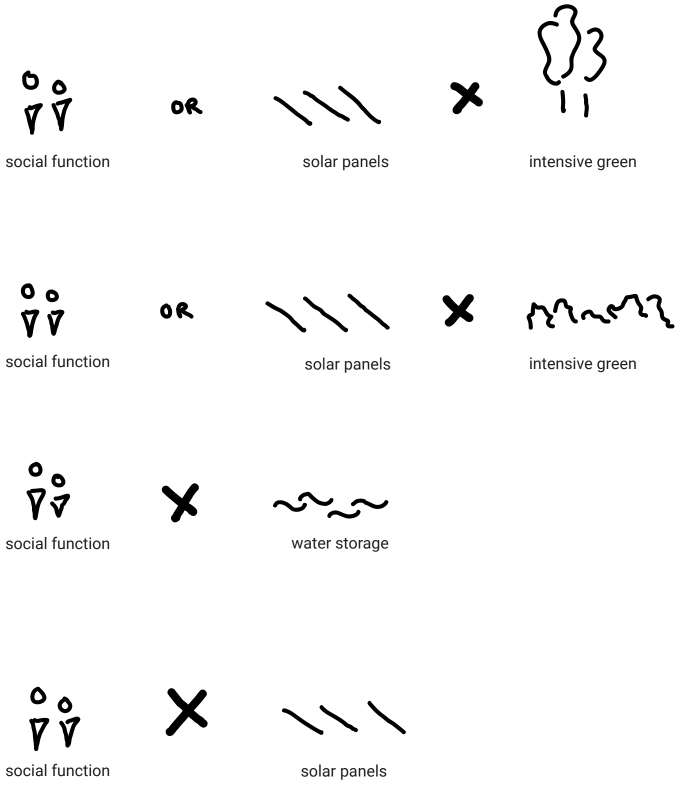


Figure 119. Limitations existing rooftop functions

Figure 120. De Groene Kaap 2022

6.7.5 Phase 3 of the design process: current rooftop uses

This chapter started with explaining the presence of different urgencies in areas 1 and 2, where all flat roofs >500m2 are located, and how these roofs can be transformed to deal with (multiple) large-scale urban problems. Besides, this chapter discussed the current rooftop functions on top of those flat roofs >500m2 and in what way these roof structures can (not) be combined with a new rooftop layer. All these analyses together form the base layer of the new roofscape design. In the 3D images on these pages, the current rooftop uses as well as the new rooftop uses are visualised.

It is visible that in area 1 there are quite a lot of private rooftop terraces spread around the whole neighbourhood. Whereas in area 2 there are more communal rooftop terraces or green roofs visible. Besides, the size of the social rooftop functions in area 2 is larger than in area 1. Take for instance the playground on top of a school building in area 2.

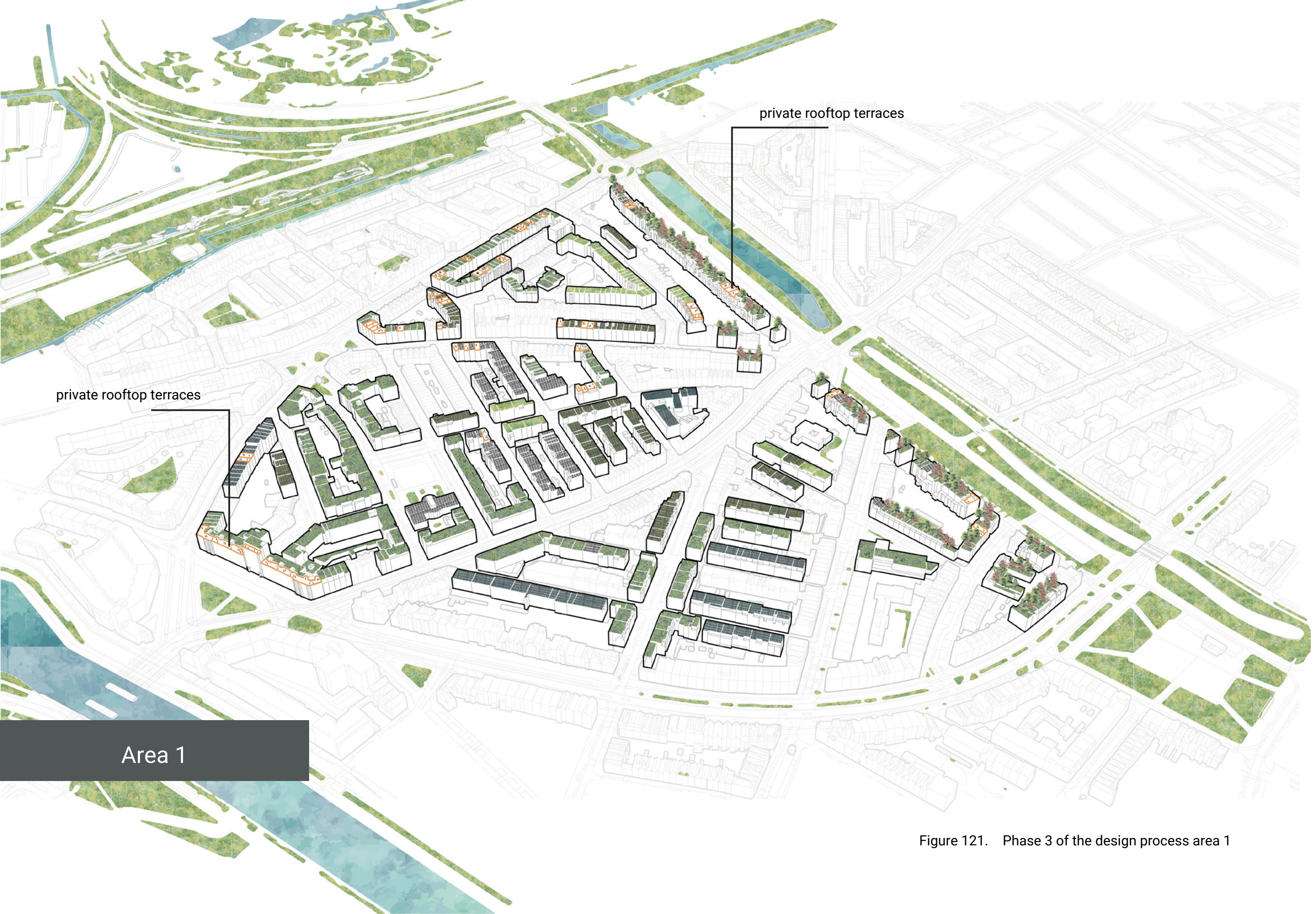


Figure 121. Phase 3 of the design process area 1

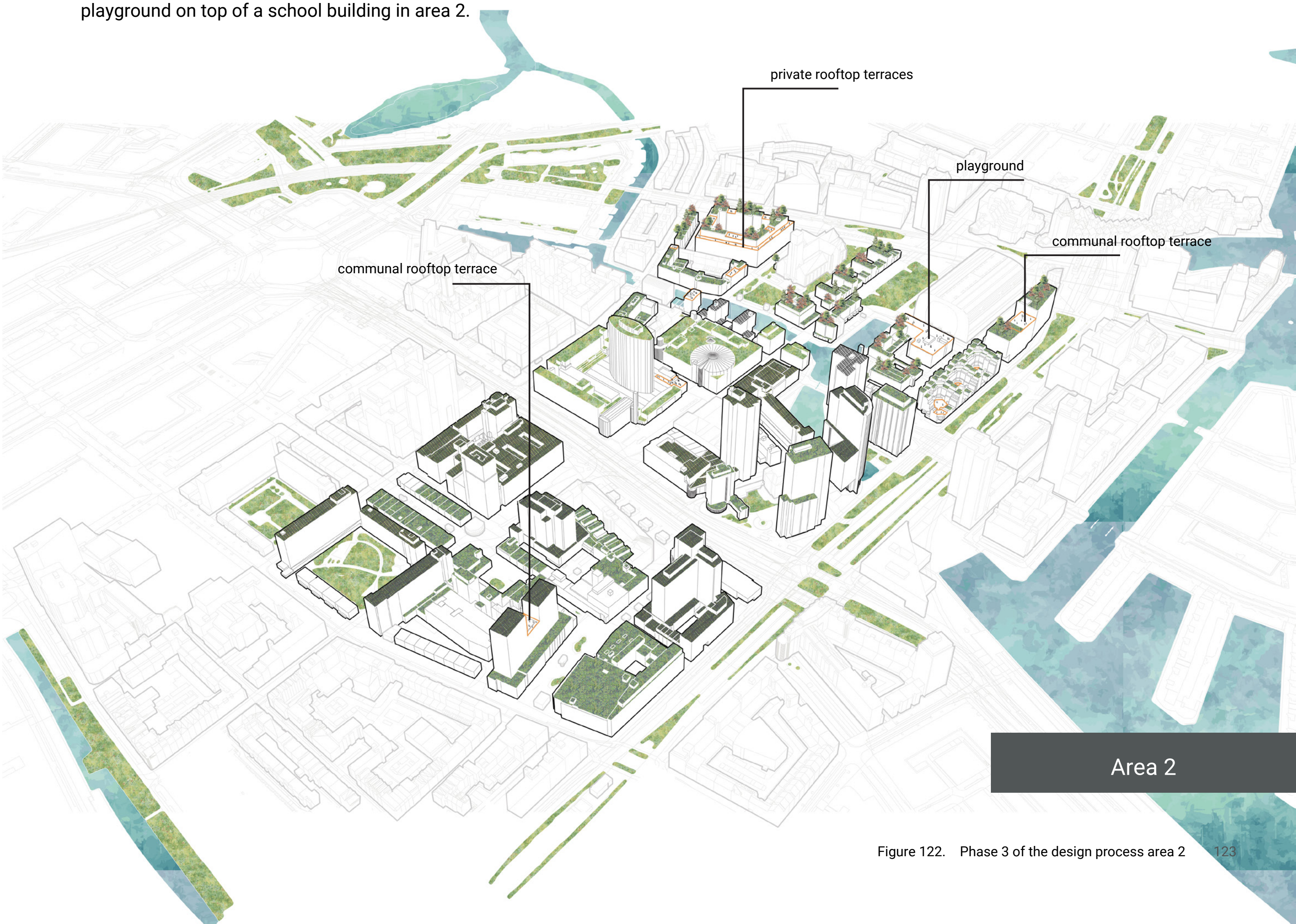


Figure 122. Phase 3 of the design process area 2

6.8 CLIMATE ANALYSES

6.8.1 Introduction

To implement new functions on flat roofs it is important to take into consideration that climate can also affect the possibility or impossibility of new rooftop functions at specific locations. These pages give an idea of the climate in Rotterdam. The information shown in the wind rose and in the weather graph is based on average temperatures, precipitation, and wind speed in this region in the last 30 years (Meteoblue, 2022). The climate in the city is sub-oceanic (rainy and humid) and influenced by the Atlantic Ocean and the North Sea. The wind blows frequently from a south-westerly direction and is influenced by the North Sea and the Atlantic ocean, from which it has cold winters and quite cool summers.

When zooming in on areas 1 and 2 and looking at the prevailing wind and the path of the sun, it is clearly visible that in area 1 only the roofs of the sheds in the backyards are shaded during the day. Next to that, figure 125 depicts that the wind is not blocked by buildings in area 1. This is because almost all buildings have the same building height. This means that all flat roofs are located in a very open and windy environment.

However, almost the opposite is visible in area 2. Due to the height differences between buildings, many roofs on lower buildings are shaded during the day and are in a wind-quiet place. As visible in figure 126, the direction of the southwestern wind in area 2 is strongly influenced by the differences in building heights, and so less predictable than in area 1.

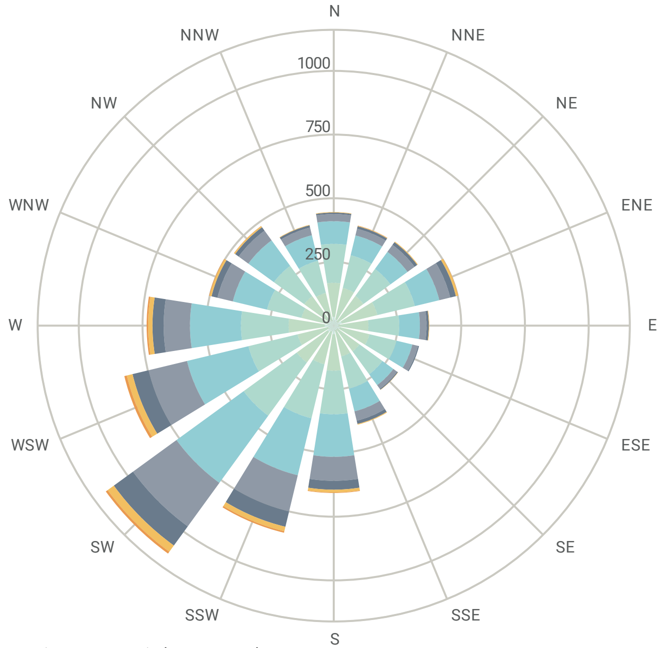


Figure 123. Wind rose Rotterdam

0 > 1 > 5 > 12 > 19
> 28 > 38 > 50 > 61 km / h

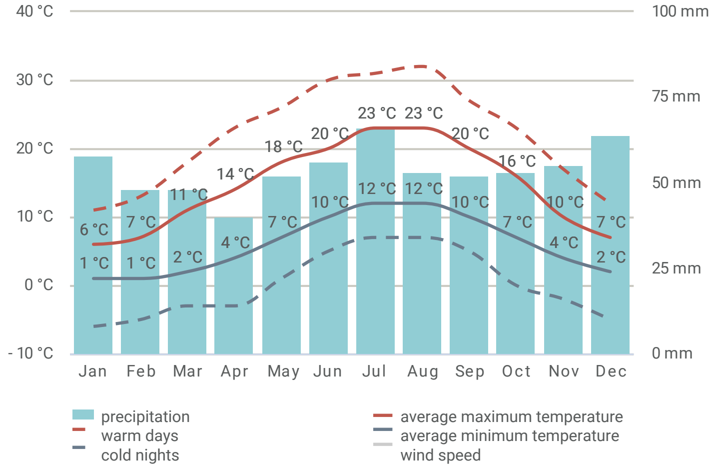


Figure 124. Weather chart Rotterdam

area 1

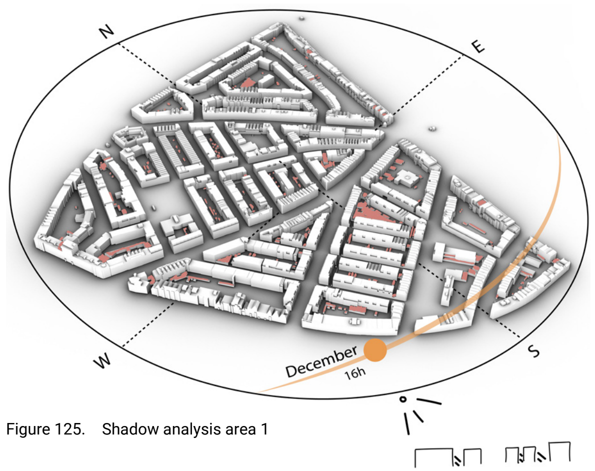


Figure 125. Shadow analysis area 1

shaded roofs

area 2

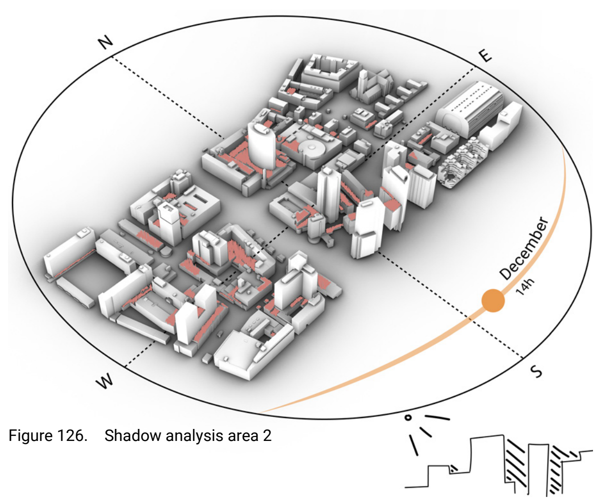


Figure 126. Shadow analysis area 2

shadow analysis

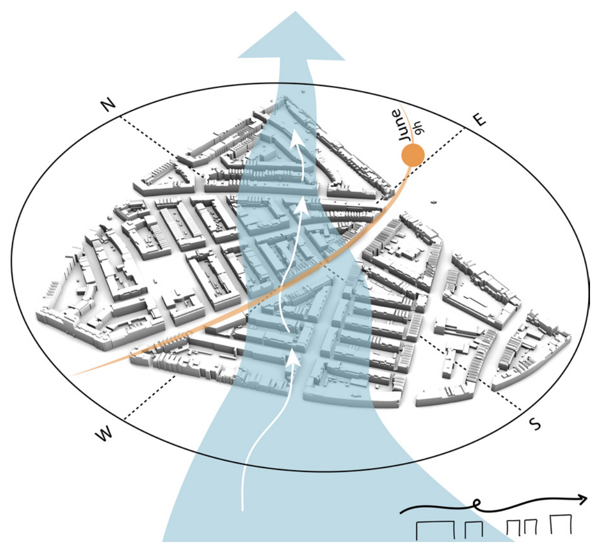


Figure 127. Prevailing wind area 1

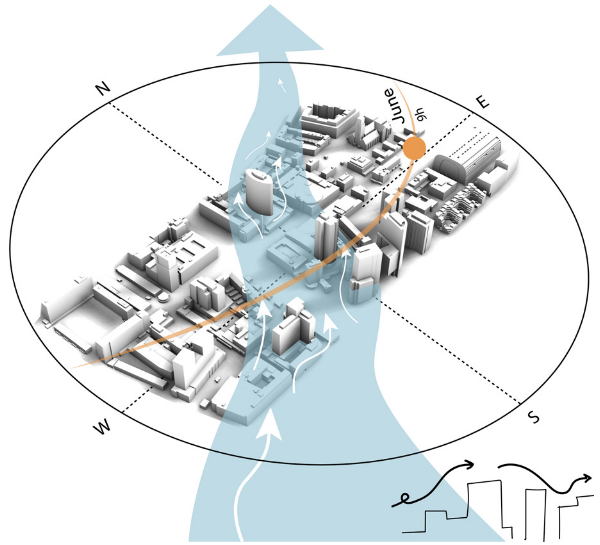


Figure 128. Prevailing wind area 2

wind analysis

6.8.2 Extreme weather conditions area 1

As visible in the wind rose on the previous page, the wind in The Netherlands from a Southwestern direction. So this is also the case for the city of Rotterdam, and as well for areas 1 and 2. However, this is a general situation. Since our climate is changing rapidly, more often we have to deal with extreme and different weather circumstances. Especially for the implementation and the maintenance of green roofs, it is important to have an idea of the extreme weather conditions and to see which flat roofs are not very well suited for a green roof for instance.

The first extreme situation takes place in summer when there is strong south or southeastern wind, and a high-angle sun. The roofs (especially with a green top layer in the future) that are not in the wind and do not have any shade during the day, have a high risk. This situation is visualised in figures 129 and 131.

The second extreme weather situation is in winter. When there can be a strong cold wind from a northeast or east direction. The roofs that are shaded and located in an open area (and so suffer from cold, strong wind) are not suitable for a green rooftop function (see figures 130 and 132).

The roofs that suffer from one of the two extreme weather conditions have a black color. These roofs will not be redesigned in this project.

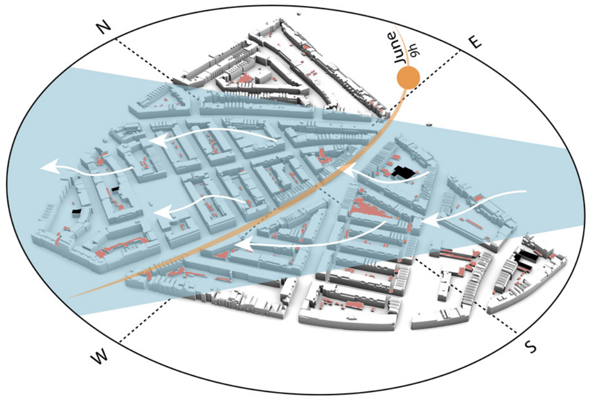


Figure 129. Extreme weather situation in summer area 1

Roofs which are located in a warm wind stream and have no advantage of shade

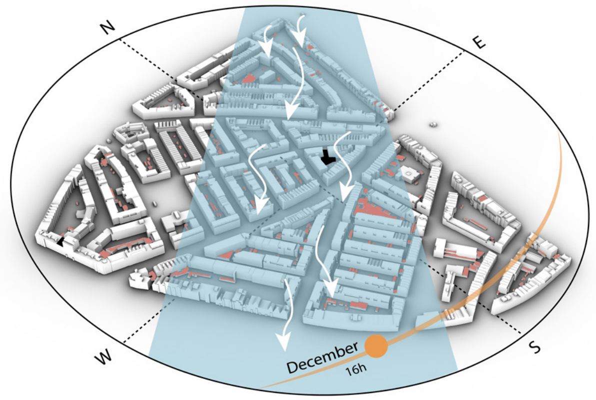


Figure 130. Extreme weather situation in winter area 1

Roofs which are located in a cold wind stream and are largely shaded during the day

6.8.3 Extreme weather conditions area 2

As visible on the left page, not many roofs in area 1 suffer from extreme weather conditions compared with area 2. Because of the great height differences between buildings, many lower roofs are shaded during the day and experience strong or even no wind at all. The combination of shade and strong cold wind or no shade and no wind can cause green roofs to fail. Therefore the roofs that suffer the most from these extreme weather situations are black colored. These roofs are not suitable for a green rooftop function and will not be redesigned.

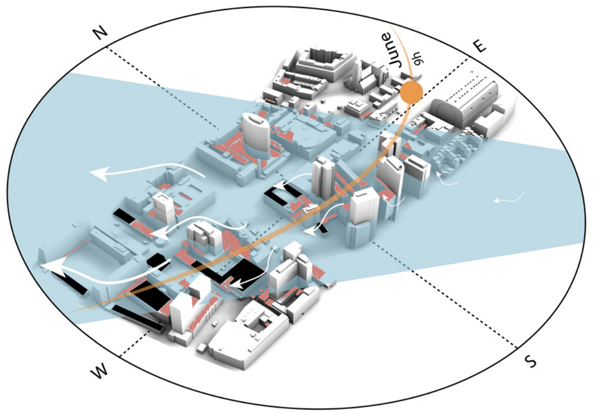


Figure 131. Extreme weather situation in summer area 2

Roofs which are located in a warm wind stream and have no advantage of shade

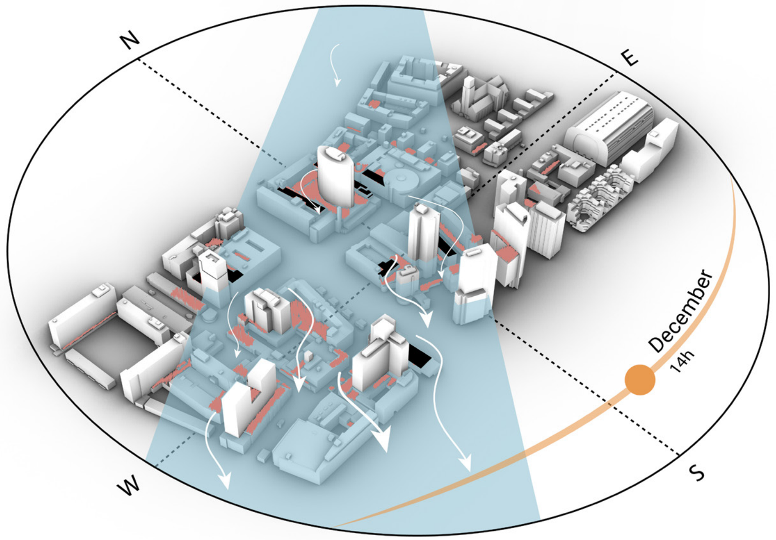


Figure 132. Extreme weather situation in winter area 2

Roofs which are located in a cold wind stream and are largely shaded during the day

Design of the social layer

- The social layer
- Spatial analyses
- Social functions on roofs
- Design rules for the social layer

This chapter focuses on the social elements that can be added to the roofs as an additional layer to the defined base layer in chapter 6. The chapter zooms in on multiple flat roofs in Rotterdam to see to what extent those roofs can accommodate private, communal, or public use.

7

7.1 THE SOCIAL LAYER

7.1.1 Adding a new layer to the base layer

For over 100 years, green roofs have been established all over the world. They are a solution to multiple, environmental and ecological challenges cities are facing nowadays. Many researchers focus on its ability to combat air pollution, cool air (to combat the UHI-effect, see image above), collect and retain excess (rain)water, and enrich biodiversity (Li & Yeung, 2014).

In The Netherlands, Rotterdam was the first municipality that launched a program to develop and subsidy green roofs in 2008. Nowadays, there are more than 360.000m2 of green roofs spread across the city. In total, all these green roofs can accommodate 9 million liters of water. As a comparison, that are 4 Olympic swimming pools.

You could say that green roofs are a mandatory base function for all roofs that will be transformed, as they have the capacity to respond to so many different urban challenges, and will have an enormous impact on achieving a sustainable, resilient, and liveable city when all available space would be used to add green. However, as mentioned in the problem statement, we also face the problem of the growing population, especially in big cities. We have to search for new areas to densify, but also make sure that we don't lose all our recreational and public space to solve the housing problem. Therefore, this part of the research looks at the base layer we have identified so far and how we can one extra layer to this, namely the social layer.

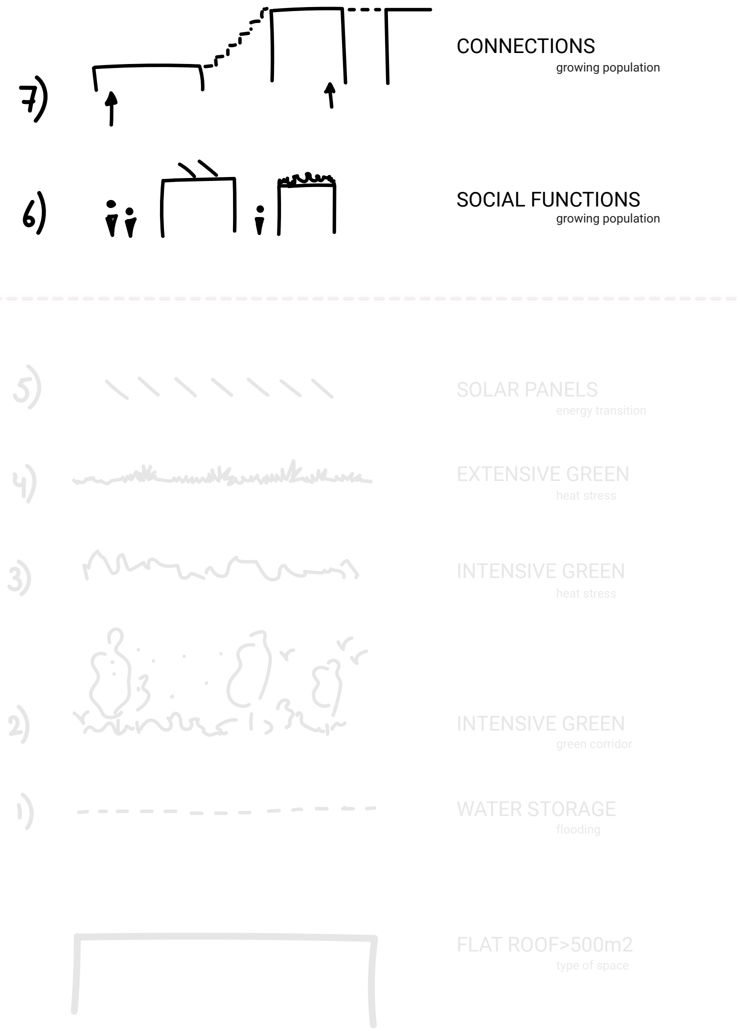


Figure 133. Sequence of rooftop functions (2)

Figure 134. Pink stage - Rotterdam Rooftop Days 2022

7.2 SPATIAL ANALYSES

7.2.1 Building heights

The heights of roofs do not only have an influence on the suitability of green and solar panels on the roofs, but also on the connection with the ground level. Marit Haaksma (2017) researched in her master thesis the compact city and how roofs could contribute to a more vital environment, using this space as a new public layer. To realise this fifth layer, especially for pedestrians, she also looked into the maximum height of the buildings that can be connected to the ground level. Therefore she defined low roofs as buildings with a maximum height of 15 meters. This assumption is based on the hypothesis, that a maximum of 15 meters enables an 'easy transition' to the roof (Haaksma, 2017).

The maps on the right side show which roofs in area 1 and 2 are in between 0-9m, 9-15m, 15-40m, and 40-80m and gives an indication of which roofs are relatively low and could be easily accessible with a ramp or staircase from the street. Whereas in area 1 there almost are no roofs higher than 15m, the height differences in area 2 are very high. Therefore, adding the public social layer to roofs, there is only focused on the roofs that are lower than 15m.

Figure 136. Building heights area 1

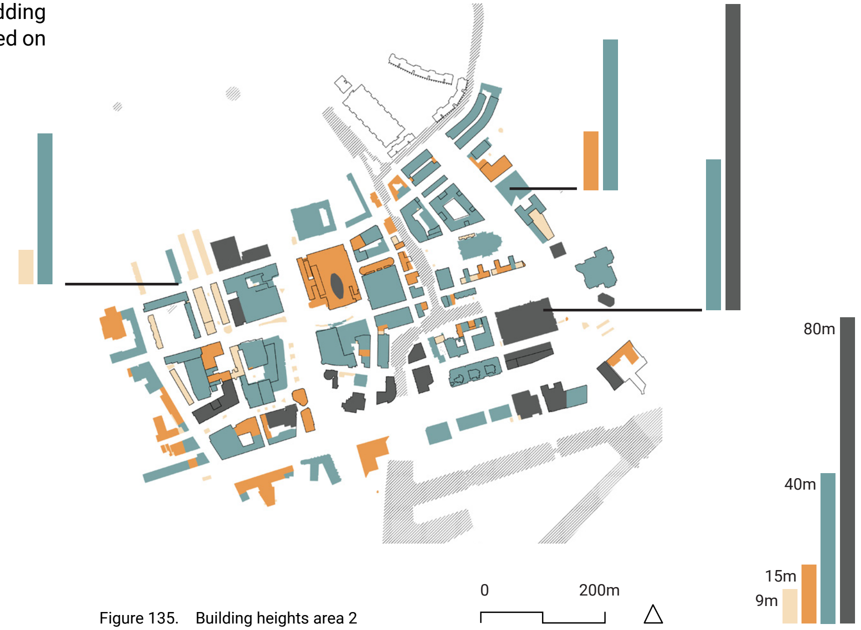


Figure 135. Building heights area 2

7.2.2 Ownership

When looking into social functions on roofs, ownership of the buildings should be taken into consideration. When a building is for example owned by the municipality, it is more appropriate to add a public or communal function to this roof than when this is done by a privately owned roof.

In figure 137 and 138, only flat roofs in the two areas are visible. This because only the flat roofs have the potential to add a social function to it (based on the limitations of existing rooftop functions (chapter 6.7.4)) All 'white' roofs have either already a social function or are covered with solar panels. So those roofs are not suitable for a new social function.

Figure 137. Ownership area 1

Figure 138. Ownership area 2

LEGEND

owned by municipality

(partly) owned by housing corporation

private ownership

roofs with solar panels, green roofs, or rooftop terraces

7.2.3 Green structures

On the previous two pages, there has been focused on characteristics of the building itself to add a social function, and ownership. As mentioned in the introduction, social functions on roofs are especially valuable to consider in the future, because cities become more and more compact, the population in cities is growing and the amount of public and recreational (in other words, open space) comes under pressure. Therefore, we still should create this 'open' space in cities, where we as residents have space to breathe.

Figure 139. Green structures Rotterdam

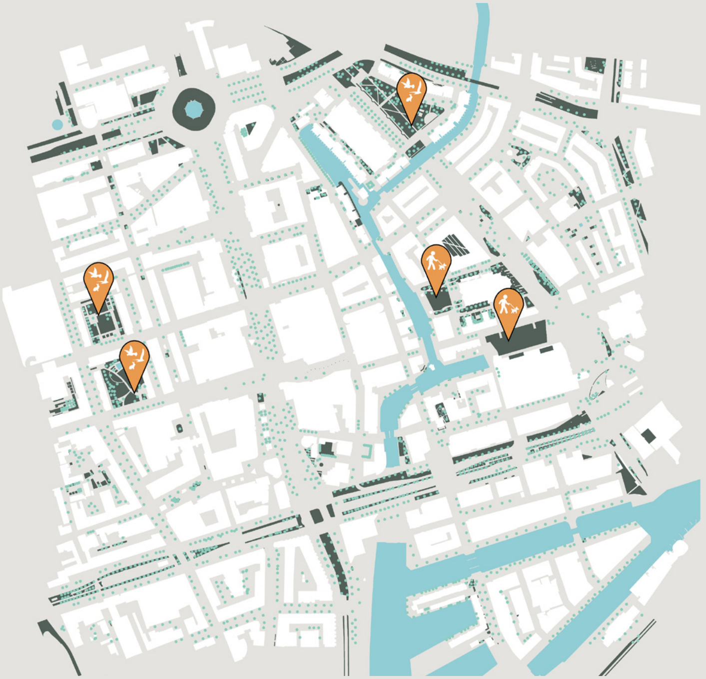


Figure 140. Green structures area 2

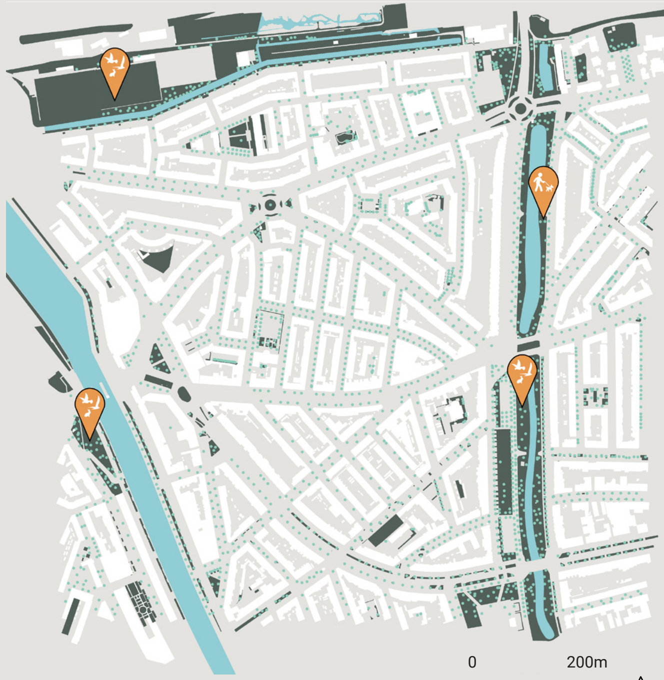


Figure 141. Green structures area 1

LEGEND

- building
- water
- green
- tree
- nature area/park
- grass field

The Rooftop Catalogue by MVRDV (2021) suggests 130 innovative ideas to transform rooftops. Many of those ideas introduce new space for people on roofs. In other words, literally every function you could imagine you can add to a rooftop according to the Rooftop Catalogue. However, it is more interesting to look at what there is really missing in a certain neighbourhood or in a part of a city and what of those missing elements can be added to which roofs.

The analyses on these pages look into the green structures in Rotterdam and in areas 1 and 2. Especially on the northern side of the municipality, there are quite large nature areas. When zooming in on the city center, those areas seem to disappear. Especially in the neighborhoods Cool and Stadsdriehoek there is little existing green space.

7.2.4 Public and communal functions

It is clearly visible that in area 1 there are a lot of 'red' social functions. These functions are playgrounds and/or sports fields, so small public squares with a social or sports element. These squares are often meeting places for the neighbourhood. Area 2 is full of bars, restaurants, and cafes. Almost all buildings have a social plinth, where residents, neighbours, and tourists can meet. It is clear that this part of the city has few communal spaces.

As said before, social functions on roofs could be a valuable addition to the current functions of roofs, or to the base layer (that is defined in this report in chapter 6). The previous pages looked into green structures whereas this subchapter focuses on public (commercial) functions and public squares in Rotterdam and in the two defined focus areas. In figure 144, all vegetable gardens in Rotterdam are highlighted. Figures 142 and 143 show all bars, cafes, playgrounds, sports fields, and public parks in the two areas.

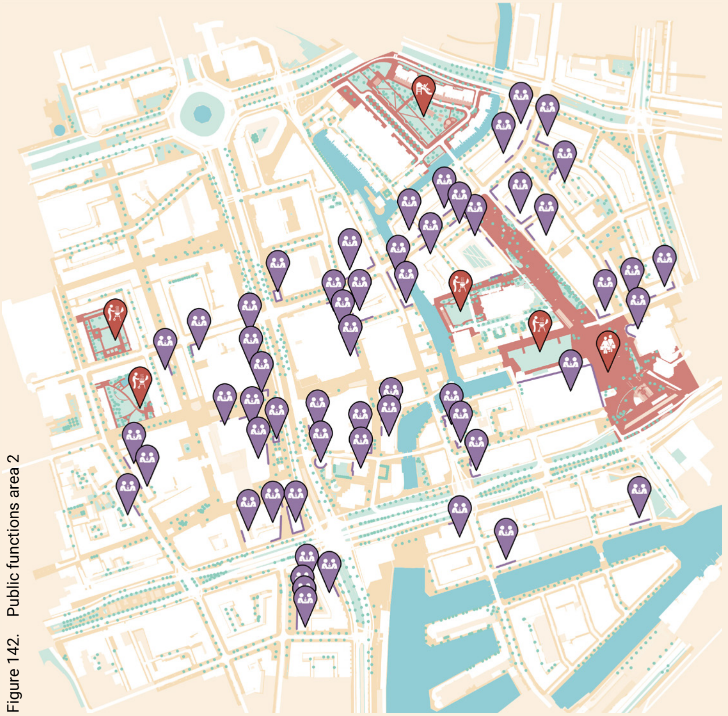


Figure 142. Public functions area 2

Figure 143. Public functions area 1

Figure 144. Vegetable garden in Rotterdam

7.3 SOCIAL FUNCTIONS ON ROOFS

7.3.1 Possibilities social layer area 1

When combining all the information of the last few analyses and combining this with the formulated base layer on the flat roofs >500m2 from the previous chapter, the map on this page comes into being. The next step to see which roofs are most suitable to accommodate a social function next to an intensive or extensive green roof is looking at the accessibility of the roofs in question. Per type of ownership (municipality, housing corporation, and private ownership), three different flat roofs are chosen, analysed, and compared with each other in terms of accessibility. Figure 146 focuses on roofs from the municipality, figure 147 on roofs of housing corporations, and figure 148 on roofs that are privately owned. Besides, the roof that seems to be most accessible in a certain category (in terms of ownership) is chosen. For these roofs, a first idea of a social function on top of it is formulated.

LEGEND

- buildings
- streets
- water
- green
- tree
- playground
- park
- cafe/bar
- sportfield
- nature area/park
- grass field
- owned by municipality
- (partly) owned by housing corporation
- private ownership
- extensive green roofs
- intensive green roofs
- roofs<15m
- roofs with a possibility for a social layer

0 100m 200m

Figure 145. Concluding map social function area 1

PUBLIC ROOF // green community centre

- building owned by the municipality
- publicaly accessible
- combination of green, recreational and commercial (meeting place)
- a bar: maintenance & surveillance, only open during opening hours

1 Emmaus School

2 De Vierambacht school

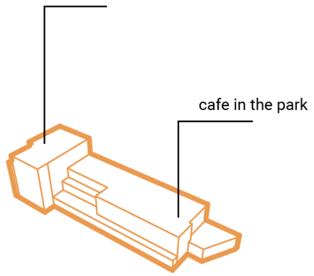
3 housing block

1 Emmaus School
- no access via facade/indoor
- owned by municipality
- strengthen existing public structures (playground, sportfield)

2 De Vierambacht school
- access via gate/staircase
- different layers
- owned by municipality
- strengthen existing public structures (playground)

3 housing block
- no access via facade/indoor
- owned by municipality
- strengthen existing public structures (playground, sportfield)

Figure 146. Roofs owned by the municipality area 1



COMMUNAL ROOF // common vegetable garden

- building owned by housing corporation
- only accessible for residents
- shared green backyard, vegetable garden
- maintained and surveilled by inhabitants (social control)

4 Adrien Mildersstraat

- no existing entrance via porch/facade
- owned by housing corporation

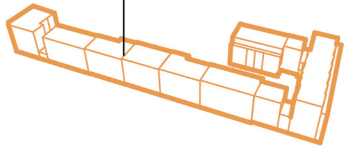
5 Van Oosterzeestraat

- access via two porches
- continuous (communal) space
- owned by housing corporation

6 Gerrit Jan Mulderstraat

- no existing entrance via porch/facade
- owned by housing corporation
- connect buildings via elevated walkways

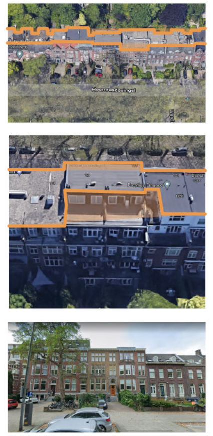
Figure 147. Roofs owned by housing corporation area 1



PRIVATE ROOF // private roof terrace

- privately owned
- green roof as a base, terrace or plants can be added
- depends on underlayer to what extent the green layer of the roof is determined
- only accessible for residents

7 Heemraadsingel



- private ownership
- located in the middle of the green corridor
- no passage from inside

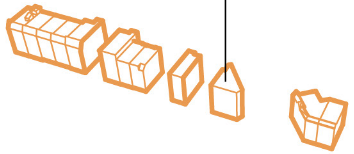
8 Heemraadsingel

- private ownership
- social function with stepping stones of the green corridor
- no passage from inside

9 Van Weelstraat

- private ownership
- social function combined with sedum roof
- no passage from inside

Figure 148. Privately owned roofs area 1



7.3.2 Possibilities social layer area 2

The same kind of analysis regarding the accessibility of different roofs is done for the flat roofs in area 2. However, since there are not that many buildings completely owned by the municipality in this area, for the public roofs there are also buildings chosen that are from a housing corporation. Next to that, the building heights for the public rooftops are also carefully looked at. The maximum height for a public rooftop is set at 15meters. So only the buildings in grey have the potential to get a social function.

LEGEND

- buildings
- streets
- water
- green
- tree
- playground
- park
- cafe/bar
- sportfield
- nature area/park
- grass field
- owned by municipality
- (partly) owned by housing corporation
- private ownership
- extensive green roofs
- intensive green roofs
- roofs<15m
- roofs with a possibility for a social layer

0 100m 200m

Figure 149. Concluding map social function area 2

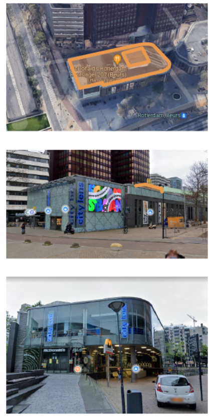
PUBLIC ROOF // public park, event area

- building owned by housing corporation
- publicaly accessible
- (partly) <15m height (connected with public plinth)
- lack of green in the city heart, add a public green park

1 WTC & Bijenkorf

- indoor access, not public yet
- owned by housing corporation
- roof partly occupied by solar panels
- part of the roof is not flat

2 Coolsingel 215

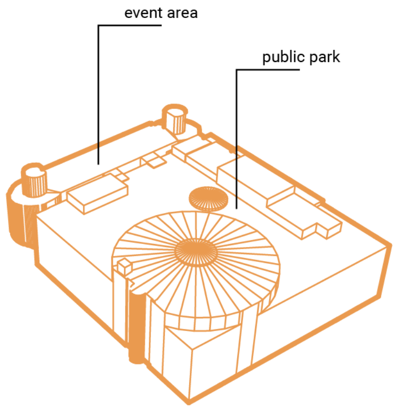


- no access to roof
- owned by housing corporation
- relatively small roof

3 Hoogstraat 1005 (Vestia)

- indoor access, not public yet
- owned by private party
- large scale flat roof

Figure 150. Roofs owned by municipality area 2



COMMUNAL ROOF // green workspace, flex spots, mini bar

- building owned by housing corporation
- only accessible for employes
- connected to offices
- meeting/green workspace
- roof accessible via porch/staircase/elevator
- !!! HEATSTRESS high in this area, so social function should be combined with medium-high dense green vegetation

4 Lijnbaan 150

- outdoor escalator
- owned by different parties (private and corporation)
- large scale flat roof

5 Hoogstraat 194

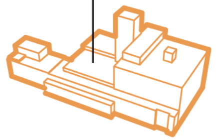
- indoor access to roof
- small/medium scale roof
- private space
- owned by private party
- partly <15m heigh

6 Lijnbaan 86

- no access to roof
- small scale roof
- owned by housing corporation
- partly <15m heigh

Figure 151. Roofs owned by housing corporation area 2

work spaces



SEMI-PRIVATE ROOF // shared garden (child friendly/playground)

- privately owned, but more than 1 families live under on and the same roof, so a shared garden is more suitable in this area
- only accessible for residents
- shared green backyard, vegetable garden (residents have no courtyard/backyard, so add valuable green space nearby house)
- roof accessible via porch/staircase/elevator
- !!! HEATSTRESS high in this area, so social function should be combined with medium-high dense green vegetation

7 Minervahuis

- indoor access
- residential function
- no outdoor space
- privately owned

8 Lijnbaan 76

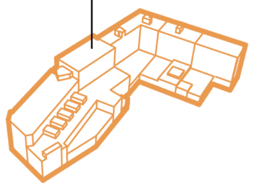
- no access
- no residential function
- no outdoor space
- privately owned

9 Karel Doormanstraat 334

- access possible via porch
- located next to small public park
- no private outdoor space
- privately owned

Figure 152. Privately owned roofs area 2

shared rooftop garden

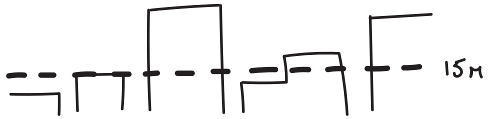


7.4 DESIGN RULES FOR THE SOCIAL LAYER

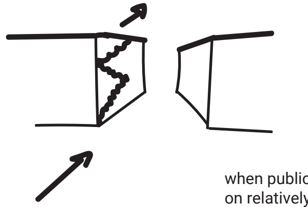
7.4.1 Design rules for social functions on flat roofs

To conclude, design rules have been set to guide the development of social function on flat roofs>500m2 in Rotterdam as an addition to the base layer (defined in chapter 6). The requirements for social function on roofs are building heights, ownership of the building, the enrichment of the environment, and accessibility. In the conclusion of the previous chapter, there are already limitations set about the combination of a social roof with an extensive green roof, intensive green roofs, water storage, or solar panels.

BUILDING HEIGHTS



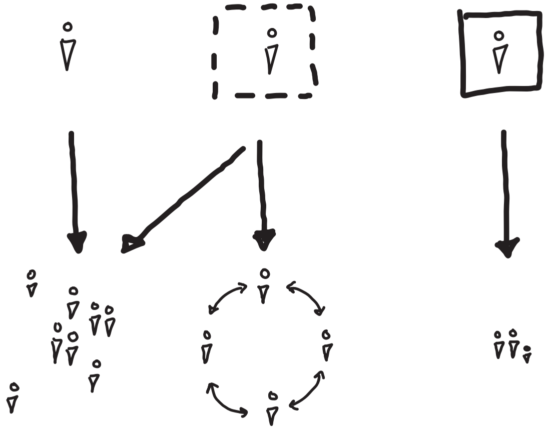
maximum rooftop height for roofs with a public (social) function is 15m



when public social roofs are located on relatively low roofs, there is a smooth connection between the public roofs and the public plinth

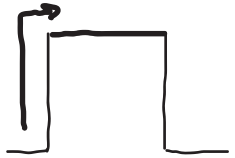
OWNERSHIP x USERS

OWNERSHIP	municipality	housing corporation	private ownership

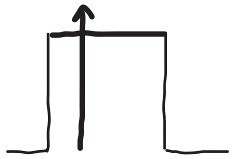


USERS	public	community	private

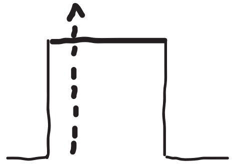
ACCESSIBILITY



(public/communal) outdoor access via staircase or elevator



(public/communal) indoor access via staircase or elevator



(private) indoor access via staircase or elevator

VALUABLE ADDITION TO PUBLIC SPACE

what functions are already there in the neighbourhood and what is valuable to add

7.4.2 Phase 4 of the design proces: the social layer

Concluding from the analyses in this chapter, a new layer is added to the defined base layer in chapter 6. The new rooftop layer consists of several private, communal, and public social functions on top of flat roofs in area 1 and 2.

Depending on the location (ownership of the building, and adjacent public/communal functions) a suitable social functions is chose to implement on the roofs.

In area 1 and in area 2, 1 private, 1 communal, and 1 public rooftop function is added to the rooftop design for those areas. They can be recognised by the orange elements on those roofs.

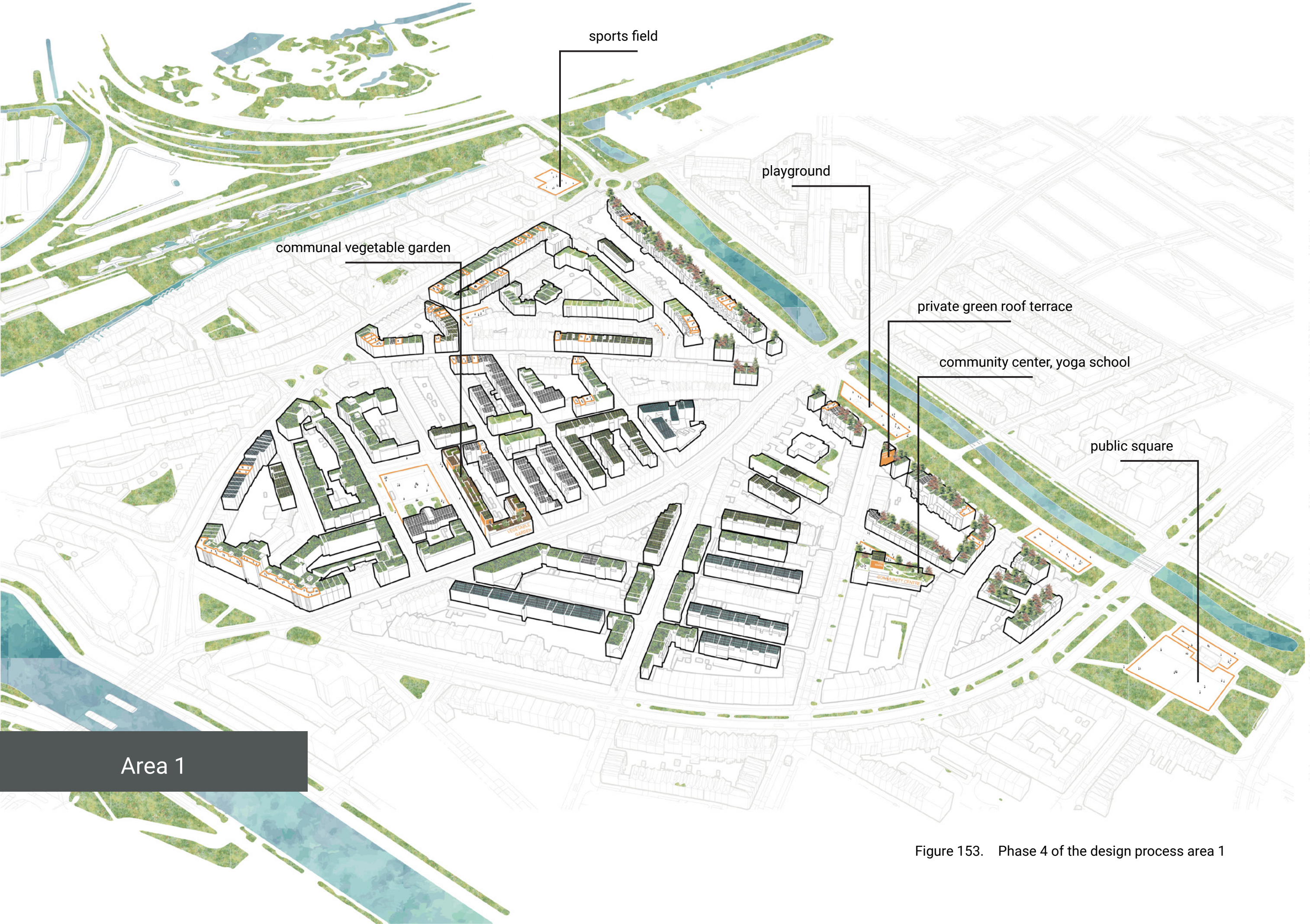


Figure 153. Phase 4 of the design process area 1

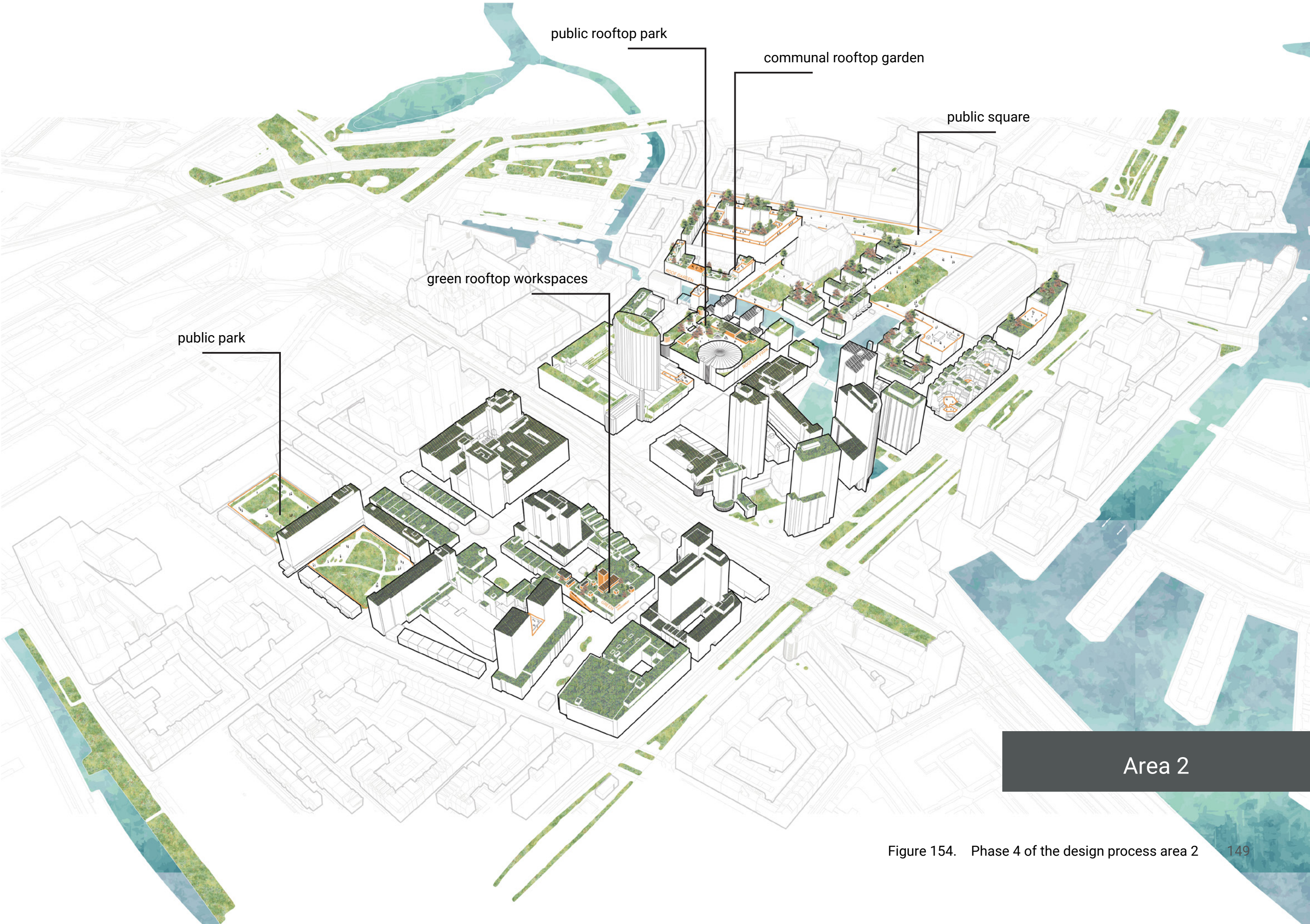


Figure 154. Phase 4 of the design process area 2

Toolkit design

- The design of the toolkit
- Decision tree
- Toolkit in practice

This chapter summarises all rooftop functions that are formulated in the previous two chapters. It shows what rooftop functions are suitable to cope with one or more urban challenges, and what suitable social functions could be. Next to that, a decision tree will be introduced, to help residents, the municipality or housing corporations to choose which function they should add to their roof.

8

8.1 THE DESIGN OF THE TOOLKIT

8.1.1 Elements of the base layer

Concluding from the analyses in chapter 6, 16 rooftop designs are generated (see figure 155). Every urgency can be addressed by 1 or more rooftop types. Depending on the urgency or urgencies at a certain location, the following rooftop types should be applied to cope with the problem in question. All different rooftop types have specific properties, such as the amount of water storage, vegetation, and the weight of the whole rooftop package.

PROPERTIES	ENERGY TRANSITION	FLOODING	UHI-EFFECT (medium)			UHI-EFFECT (high)	LACK OF BIODIVERSITY			FLOODING X ENERGY TRANSITION	UHI-EFFECT (medium) x ENERGY TRANSITION	UHI-EFFECT (medium) X FLOODING	UHI-EFFECT (high) X FLOODING			UHI-EFFECT (medium) X FLOODING X ENERGY TRANSITION
water storage	0mm	70-300mm	18mm	25mm	19mm	30-80mm	30-80mm	150-370mm	110-160mm	95-150mm	95-150mm	70-80mm	70-80mm	70-126mm	180-230mm	95-150mm
substrate layer	0mm	0mm	30mm	60mm	60mm	60-150mm	150-210mm	230-400mm	230-400mm	0mm	80mm	60-80mm	80-210mm	80-400mm	250-400mm	80mm
weight	>6kg/m2	70-300kg/m2	55kg/m2	90kg/m2	90kg/m2	<95kg/m2	95kg/m2	310kg/m2	320kg/m2	<120kg/m2	120kg/m2	<95kg/m2	95kg/m2	150kg/m2	600kg/m2	120kg/m2
vegetation	no	no	sedum	sedum (herbs, grasses)	sedum, herbs grasses	herbs, bushes	herbs, bushes	perennials, trees, grass, pavement	perennials, trees, grass, pavement	no	sedum	herbs, bushes	herbs, bushes	vegetables, fruits	perennials, trees, grass, pavement	sedum
reference	Solarge DUO	Waterdak (Amsterdam Rainproof)	Dakbegroeiing lichtgewicht (Optigrün)	Dakbegroeiing economisch dak (Optigrün)	Meander FKM 30 (Optigrün)	Natuurdak (Optigrün)	Natuurdak (Optigrün)	Drossel Intensief (Optigrün)	Daktuin (Optigrün)	Solargroendak WRB (Optigrün)	Solargroendak WRB (Optigrün)	Natuurdak (Optigrün)	Natuurdak (Optigrün)	Dakbegroeiing (dakmoestuin) (Optigrün)	Dakpark (verblijfsdak) (Optigrün)	Solargroendak WRB (Optigrün)
cost	€257/m2 (Vattenfall)	€100-150/m2 (Duurzaam 010)	€45-100/m2 (Sedumdak-bedekking)	€45-100/m2 (Sedumdak-bedekking)	€45-100/m2 (Sedumdak-bedekking)	€100-120/m2 (Sedumdak-bedekking)	€120-150/m2 (Interpolis)	€120-150/m2 (Interpolis)	€120-150/m2 (Interpolis)	-	-	-	-	-	-	-

Figure 155. Toolkit base layer

8.1.2 Elements of the social layer

Based on the analyses of possible roof usages in areas 1 and 2 (see chapters 7.3.1 and 7.3.2) the toolkit for the social layer has been made. The social roof functions differ from each other in terms of usage, users, and the combination of rooftop functions from the base layer.

GROWING POPULATION

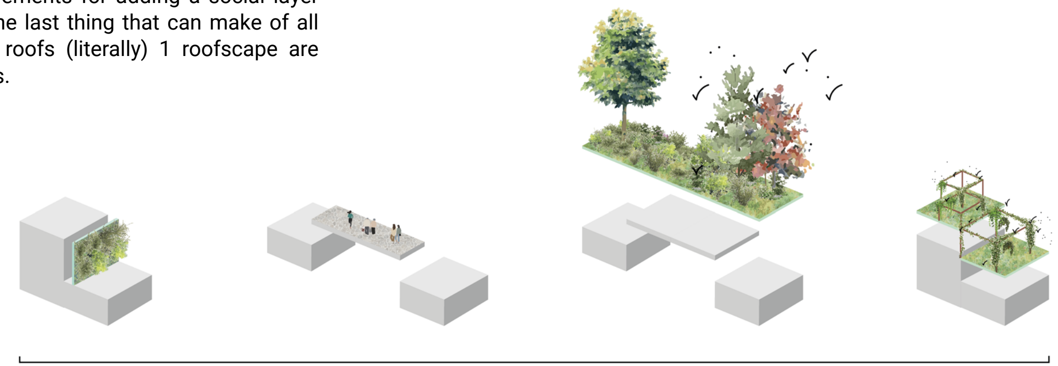
PROPERTIES						
function	public park, event area	green community centre, cafe, yoga school	green, outdoor workspace	vegetable garden	shared rooftop garden, playground	rooftop garden, terrace
accessibility	public	public	communal	communal	private	private
maintenance	municipality	municipality	municipality, private ownership	housing corporation	housing corporation, private ownership	private ownership
building height	<15m	<15m	0-40m	0-40m	0-40m	0-40m
reinforce supporting structure	yes	yes	yes	yes	yes	no
ownership	housing corporation, municipality	municipality	property manager	community (residents)	community (residents)	owner

Figure 156. Toolkit social layer

8.1.3 Connecting elements

So, we have the place: roofs, we have the shape: flat roofs, we have the minimal rooftop surface: 500m2, we have the urban challenges: flooding, lack of green, energy transition, heat stress, and the growing population, we have the elements of the base layer of the roofs and the elements for adding a social layer to the base layer. The last thing that can make of all tools and available roofs (literally) 1 roofscape are connecting elements.

Think of an elevated walkway, or green connections such as a green facade, a green bridge, or pergolas that can connect the intensive green roofs (especially when the roof construction is not strong enough to carry heavy green roof constructions).



CONNECTION

PROPERTIES				
function	green facade	elevated walkway	green bridge	green pergolas: enrich, strenghten connetions for flora and fauna
accessibility	public, community, private	public, community	nobody	nobody
maintenance	municipality, community, house owner	municipality	municipality	municipality, community, house owner
reinforce supporting structure	no	yes	yes	no
ownership	housing corporation, municipality,private ownership	housing corporation, municipality	housing corporation, municipality	housing corporation, municipality,private ownership

Figure 157. Toolkit connecting elements

8.2 DECISION TREE

8.2.1 Elements of the base layer

In the next 5 years, the municipality of Rotterdam aims to transform all potential flat roofs in the city center to transform into either green surfaces or surfaces that provide our city with renewable energy, by implementing solar panels. To achieve this ambition we need all residents, and housing corporations to participate. In particular private homeowners are important to engage. This is because 71% of all buildings in Rotterdam are privately owned, and so most of all flat roofs are>500m2 (figure 159).

To achieve this, a decision tree is designed, to help people decide which function is most suitable on top of their roof, considering the roof shape, surface, present urgencies, ownership of the building, communities, and access to the roof (see figure 158).

The decision tree (figure 160) tells what the potential is of a roof. A large format of the decision tree is added to the appendix. On the next pages, two examples are given of flat roofs in the city center of Rotterdam that will be transformed by using the decision tree.

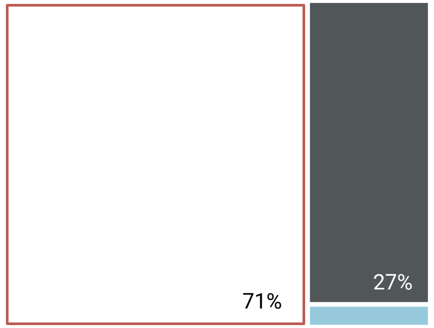


Figure 158. Distribution house ownership Rotterdam

LEGEND

privately owned
owned by housing corporation
owned by municipality

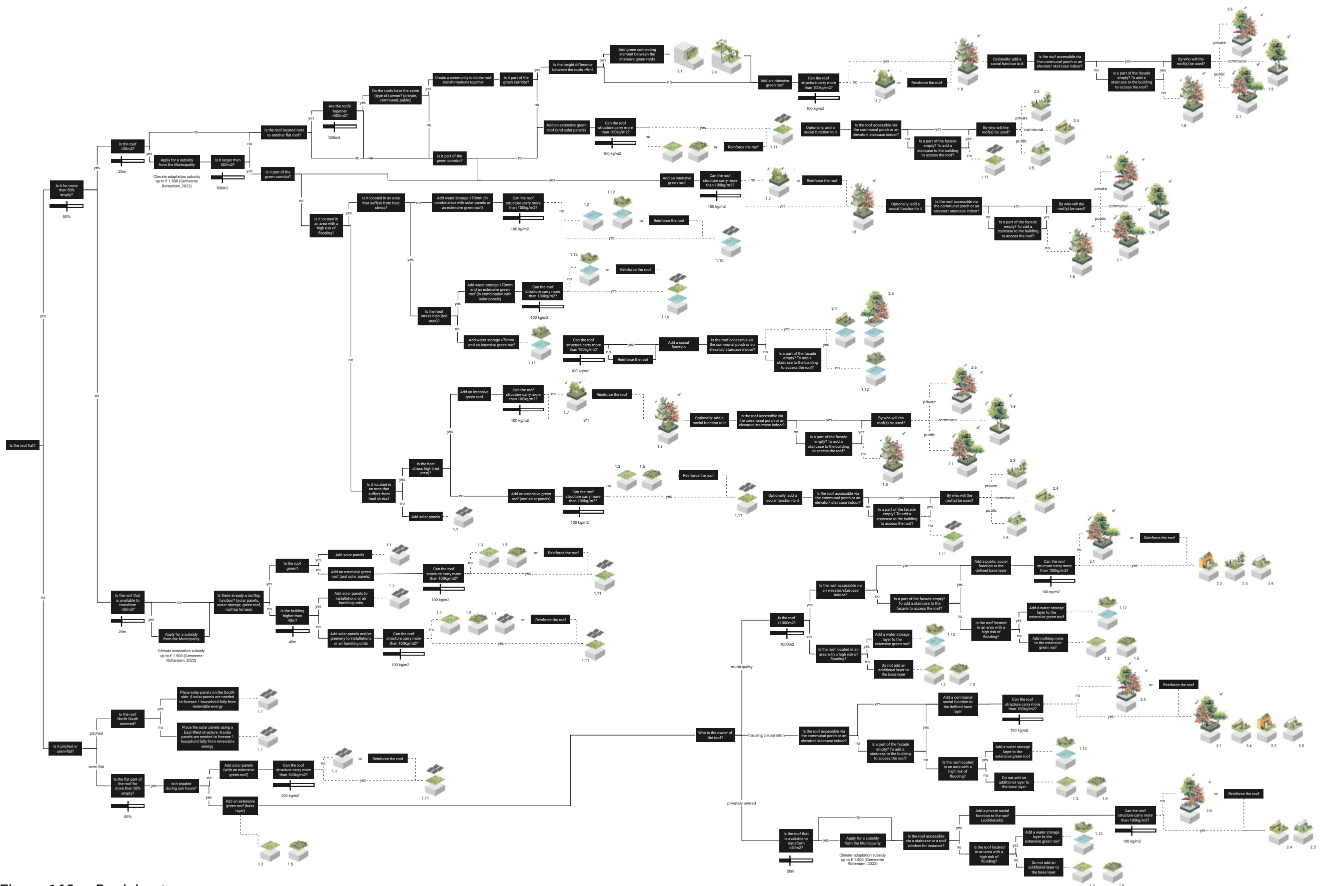


Figure 160. Decision tree

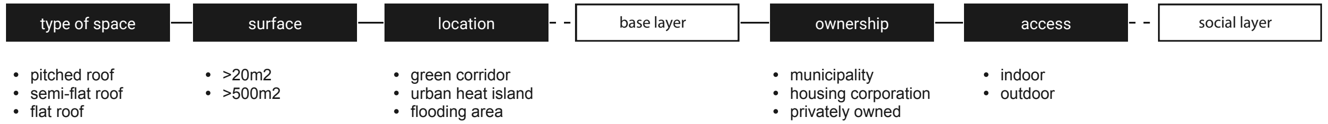


Figure 159. Outline decision tree

8.3 TOOLKIT IN PRACTICE

8.3.1 Route 1

To see how the toolkit in combination with the decision tree can be used, two examples are given. The first one (route 1) is taken by a homeowner in the neighbourhood Het Nieuwe Westen. As visible in figure 162, the rooftop on top of this building is located in the green corridor and suffers from a medium level of heat stress, and highly from flooding.

The roof of the building itself is 157m2 (figure 161), while in combination with the flat roofs of its neighbours, the roofs are 784m2. This means that when they form a community, they can together create a roofscape, with an intensive green layer as base layer and additionally (some) private roof terrace(s) (figure 163). When the roofs are not strong enough, green pergola's could be a solution to contribute to the green corridor.

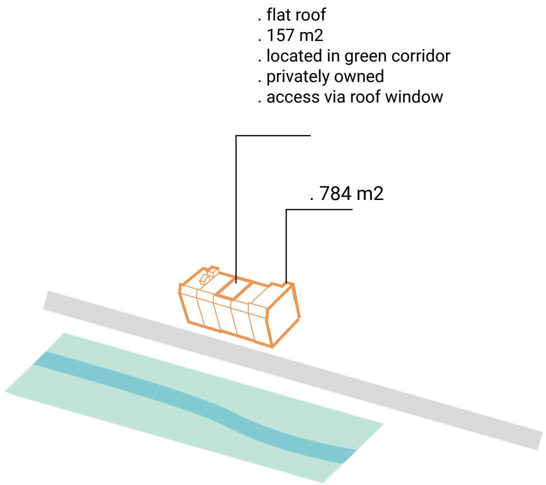


Figure 161. Characteristics building 1

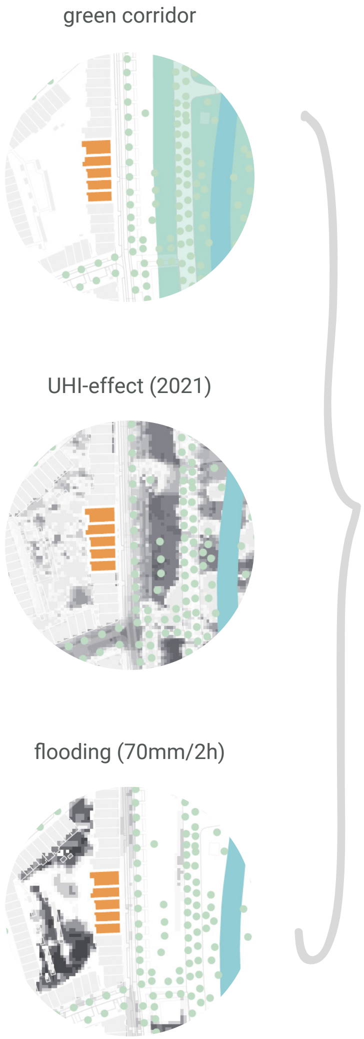


Figure 162. Urban challenges around building 1

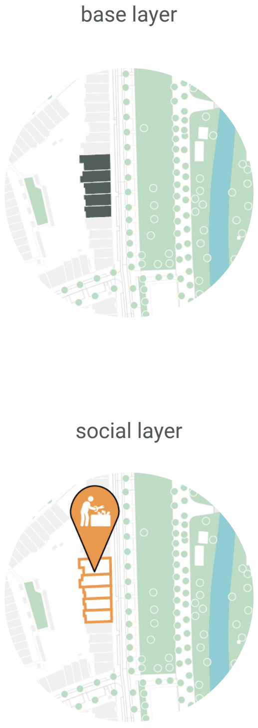
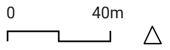


Figure 163. New rooftop layers building 1



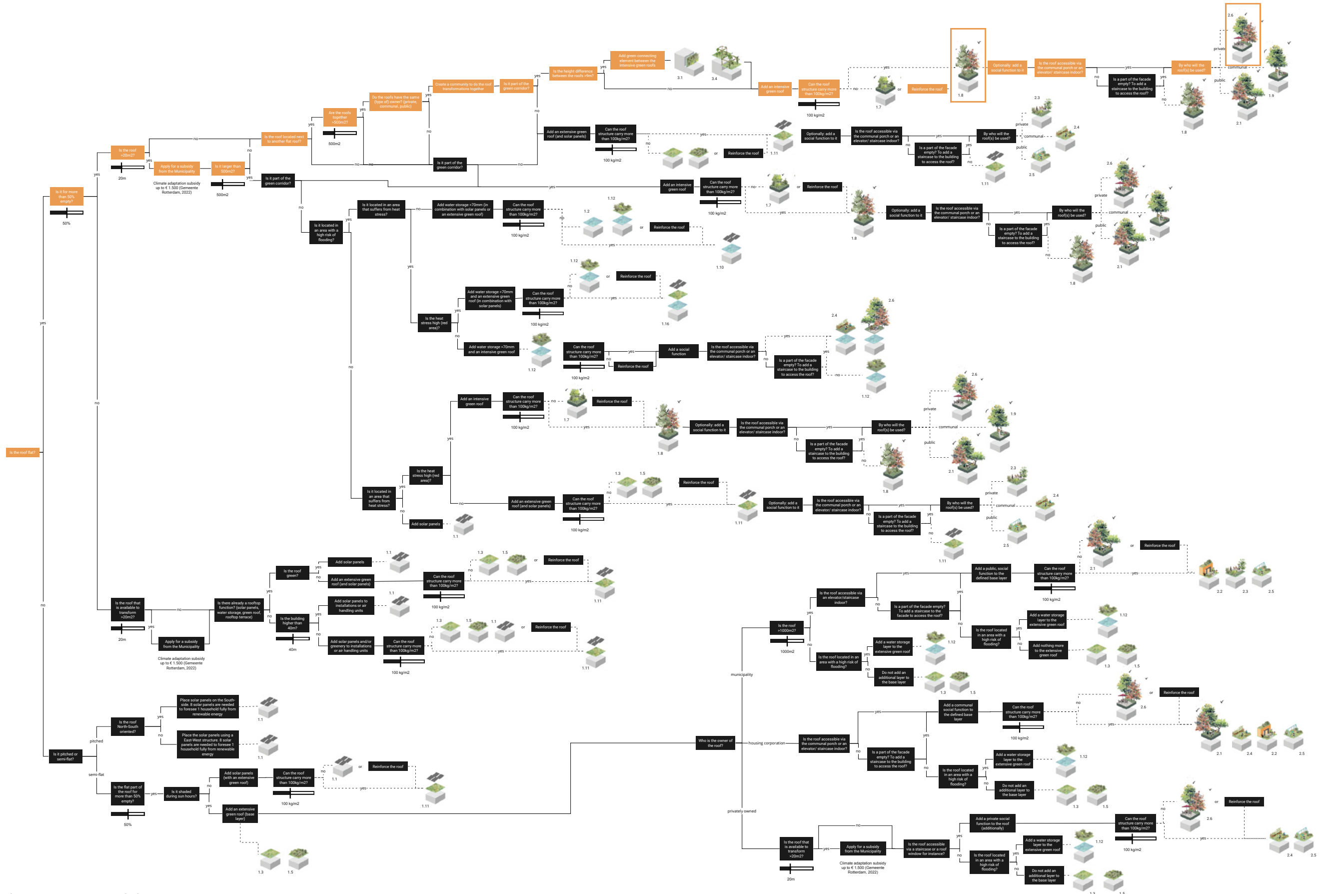


Figure 165. Decision tree route 1

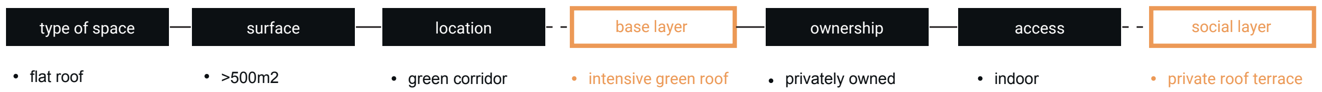


Figure 164. Outline decision tree route 1

8.3.2 Route 2

The second route is taken by a person that rents with his family an apartment in the neighbourhood Het Nieuwe Westen. Since he/she is not the owner of his/her roof, and the residents share their roof, in this situation the resident could ask the housing corporation to transform their flat roof and create an outdoor space for the community.

As visible in figure 167, the rooftop on top of his/her building is located in an area that suffers medium-high from heat stress and highly from flooding, especially in the backyard.

The roof above his/her apartment is 204 m2 (figure 166), while in combination with the flat roofs of his/her neighbours, the roofscape is 2062m2. However, the housing corporation should invest in a rooftop development, and make from the grey, bitumen roof an extensive roof, with water storage and a communal urban farm on top for instance. That can later be maintained by the residents of this complex.

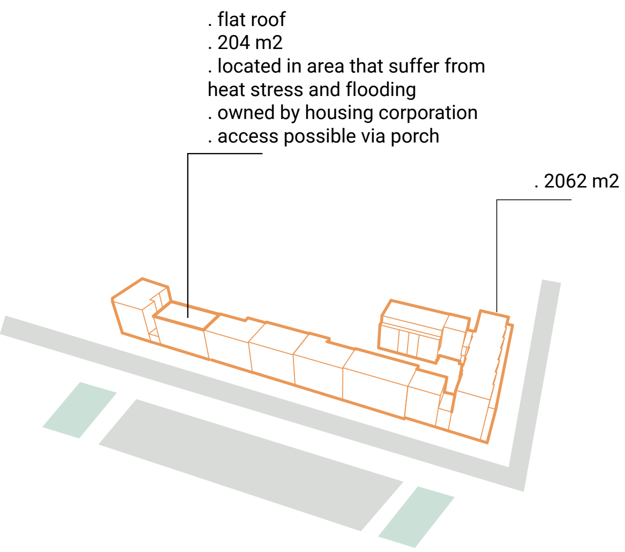


Figure 166. Characteristics building 2

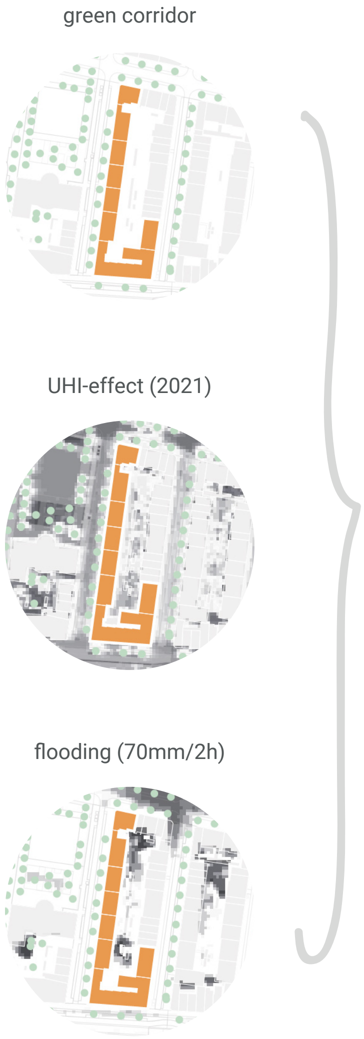


Figure 167. Urban challenges around building 2

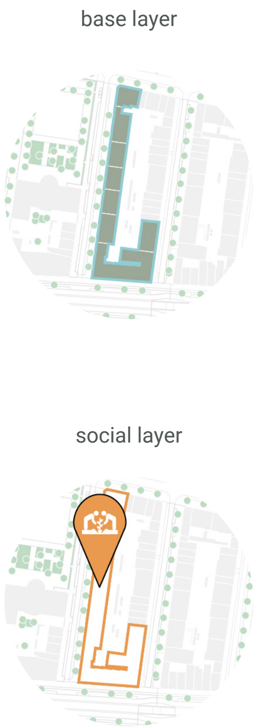


Figure 168. New rooftop layers building 2

0 40m

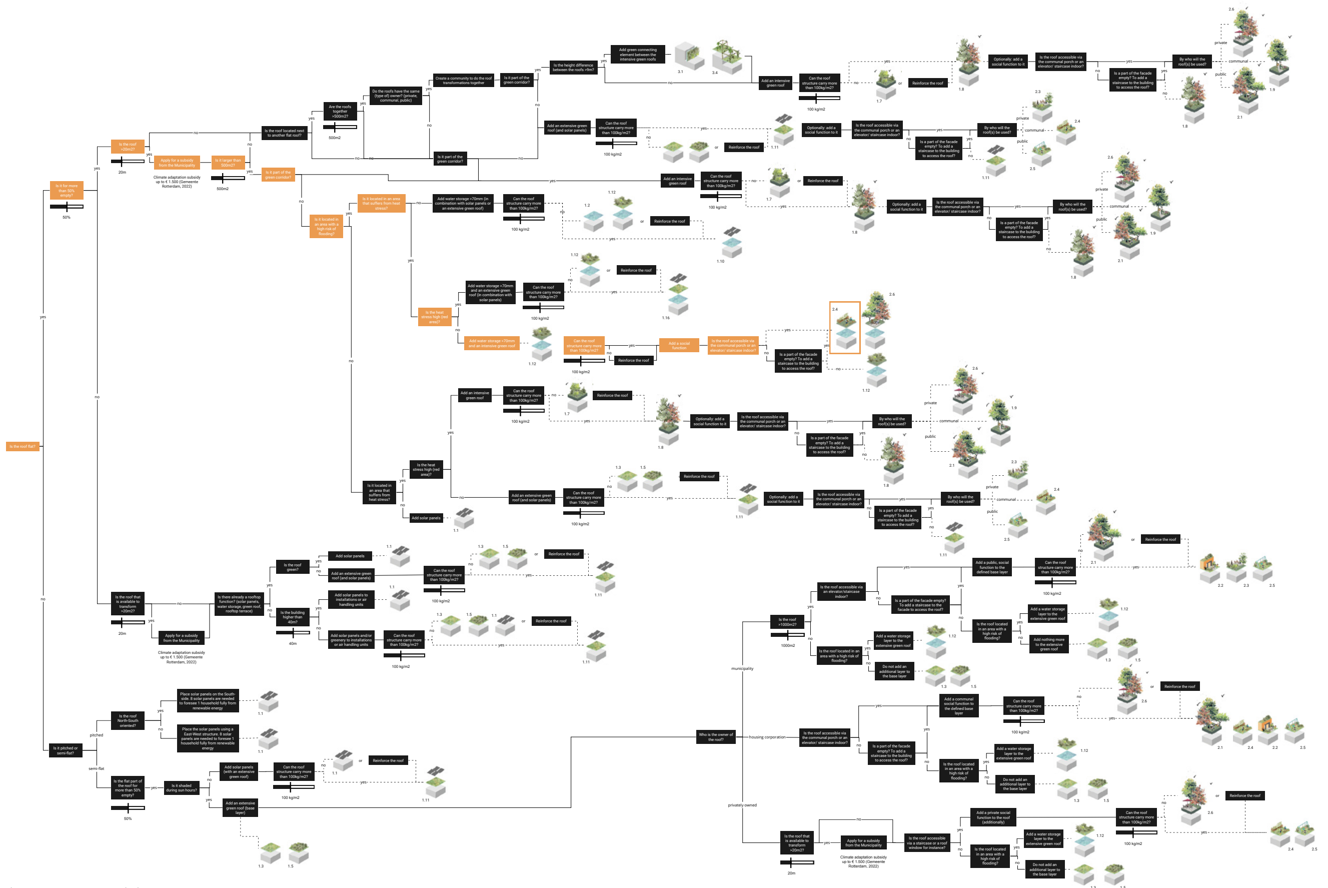


Figure 170. Decision tree route 2

type of space	surface	location	base layer	ownership	access	social layer
• flat roof	• >500m2	• urban heat island • flooding area	• extensive green roof • water storage	• housing corporation	• indoor	• communal urban farm

Figure 169. Outline decision tree route 2

IMPLEMENTATION

- A vision for Rotterdam's roofs
- The task for the muncipality

This chapter shows how Rotterdam's roofscape will emerge in the upcoming years when implementing the strategy in combination with the toolkit as formulated in the previous chapters. Next to that, it discusses what the task of the municipality will be to reach the ambition of this project.

9

9.1 A VISION FOR ROTTERDAM'S ROOFS

9.1.1 Vision map Rotterdam

The inner city of Rotterdam counts 4,3km2 of flat roofs >500m2. To deal with large urban scale problems such as heat stress, flooding, the lack of biodiversity in the city, the energy transition and the growing population in cities, flat roofs can be used to add new functions.

Many of these problems can (partly) be solved by green roof elements. It depends on the urgency and the type of urgency what kind of green is most efficient to add.

By adding this new layer to the city, the roofscape, the city of Rotterdams turns into a green environment, when looking from a top view (see image on this page). Intensive green roofs alternate with extensive green roofs and open water storages.

Figure 171. Vision map Rotterdam

LEGEND

- buildings
- water
- green

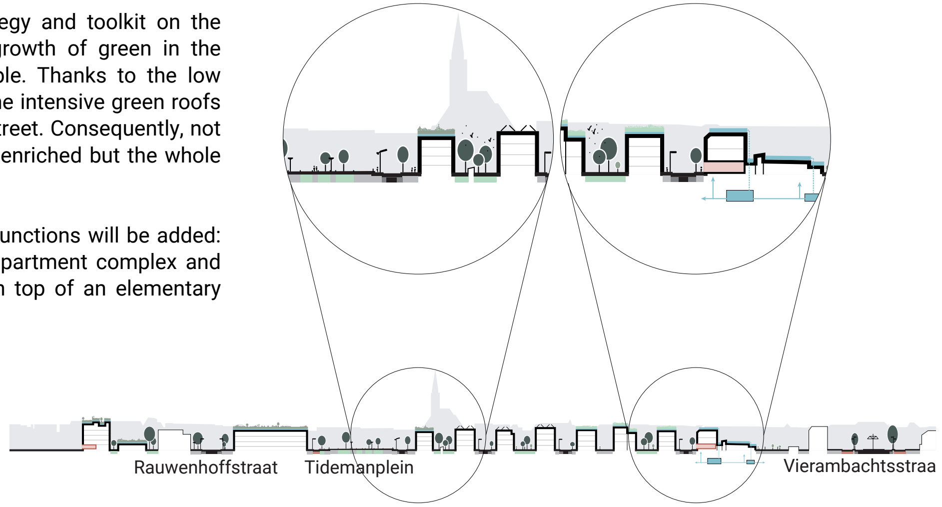
- roofs x flooding
- roofs x heat stress
- roofs x green corridor
- roofs x energy transition

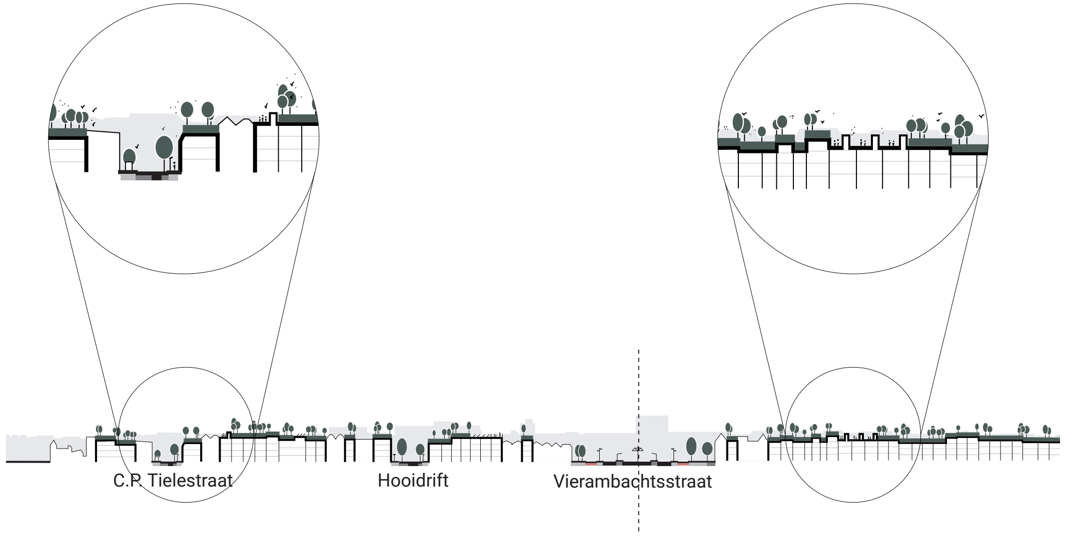
0 400 800m

9.1.2 Vision map and sections area 1

When implementing the strategy and toolkit on the roofs of area 1, significant growth of green in the neighbourhood becomes visible. Thanks to the low building heights in this area, the intensive green roofs will become visible from the street. Consequently, not only the fifth city layer will be enriched but the whole neighbourhood.

Besides, two new communal functions will be added: an urban farm on top of an apartment complex and a yoga school, with a cafe on top of an elementary school.





0 100m

LEGEND

flat roofs
buildings in focus area
buildings background

sidewalk
bikepath
parking
road

solar panels
water storage
extensive green
intensive green
green corridor

cafe/restaurant
shopping area
daily amenities
roof entrance
air handling unit

Figure 172. Sections area 1

LEGEND

water
green
buildings
flat roofs >500m2

existing roofs with a roof terrace
existing roofs with solar panels

roofs x intensive green
roofs x extensive green
roofs x water storage
roofs x green corridor
roofs x solar panels

roofs x extensive green x solar panels
roofs x intensive green x water storage
roofs x extensive green x water storage
roofs x water storage x solar panels

roofs x extensive green x water storage x solar panels

roofs that are unusable for green or blue rooftop functions due to their orientation and location in times of extreme weather circumstances

private rooftop garden

communal vegetable garden

community center

0 200m

Figure 173. Vision map area 1

9.1.3 Before and after area 1

The images on these pages show the transformed roofs >500m2 in area 1. Next to that, an impression is given of the old situation in area 1, before the transformations and after. Figure 176, shows all layers from all different analyses in this research: flat roofs >500m2, the base layer, the social layer, the social functions in the neighbourhood, and the existing green and blue structures.

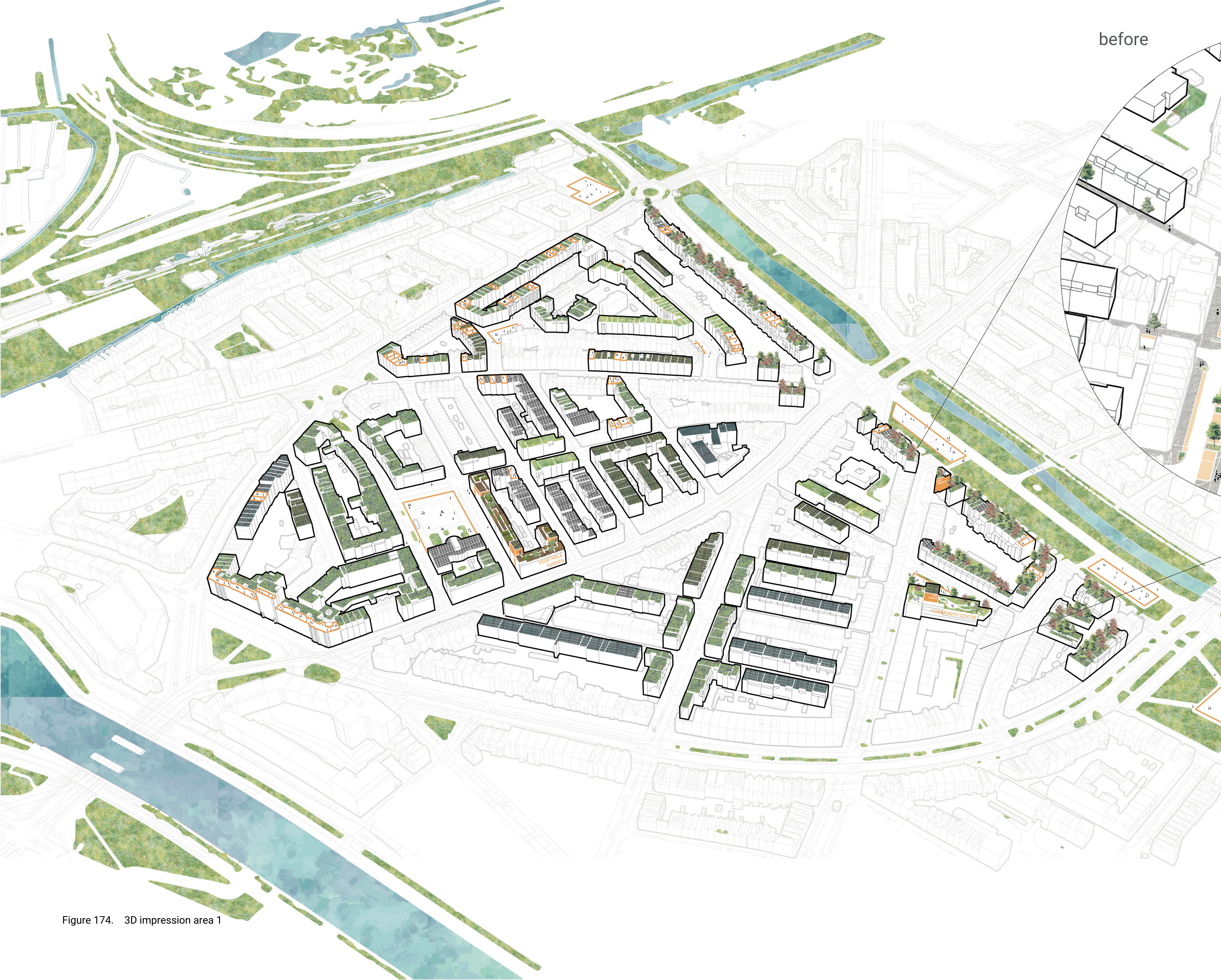


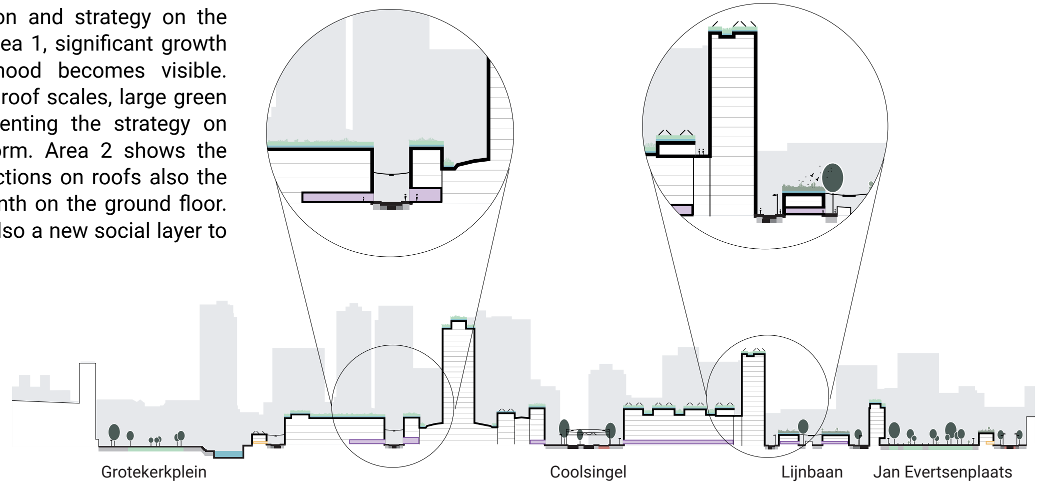
Figure 174. 3D impression area 1

Figure 175. Old situation area 1

Figure 176. New situation area 1

9.1.4 Vision map and sections area 2

When implementing the vision and strategy on the roofs of area 2, just like in area 1, significant growth of green in the neighbourhood becomes visible. Thanks to relatively large flat roof scales, large green areas emerge when implementing the strategy on all potential roofs to transform. Area 2 shows the implementation of social functions on roofs also the interaction with the public plinth on the ground floor. In this way, the roofs create also a new social layer to the public plinth.



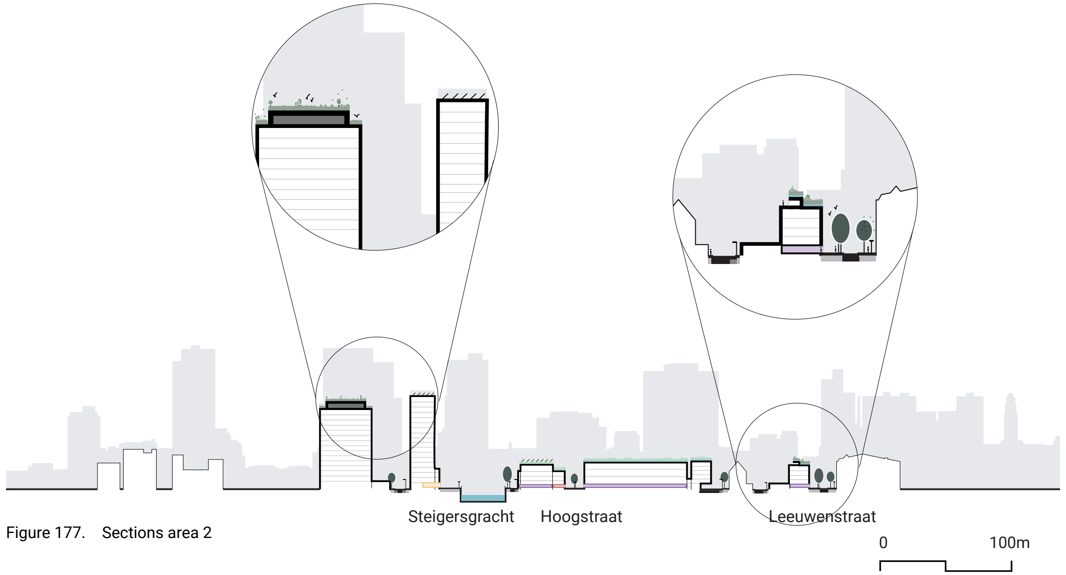


Figure 177. Sections area 2

LEGEND

- flat roofs
- buildings in focus area
- buildings background
- sidewalk
- bikepath
- parking
- road
- solar panels
- water storage
- extensive green
- intensive green
- green corridor
- cafe/restaurant
- shopping area
- daily amenities
- roof entrance
- air handling unit

LEGEND

- water
- green
- buildings
- flat roofs >500m2
- existing roofs with a roof terrace
- existing roofs with solar panels
- roofs x intensive green
- roofs x extensive green
- roofs x water storage
- roofs x green corridor
- roofs x solar panels
- roofs x extensive green x solar panels
- roofs x intensive green x water storage
- roofs x extensive green x water storage
- roofs x water storage x solar panels
- roofs x extensive green x water storage x solar panels
- roofs that are unusable for green or blue rooftop functions due to their orientation and location in times of extreme weather circumstances
- private rooftop garden
- communal vegetable garden
- community center

Figure 178. Vision map area 2

9.1.5 Before and after area 2

Area 2, compared with area 1, a grey and almost completely paved area located in the heart of the city center of Rotterdam. Flat roofs in this area give not only the opportunity to lower temperatures during warm summer days, but also give space to residents and visitors of the city center to enjoy green urban spaces since those public spaces are under pressure in this dense area of the city. On these pages the old situation and the new situation is visualised.

Figure 180. Old situation area 2

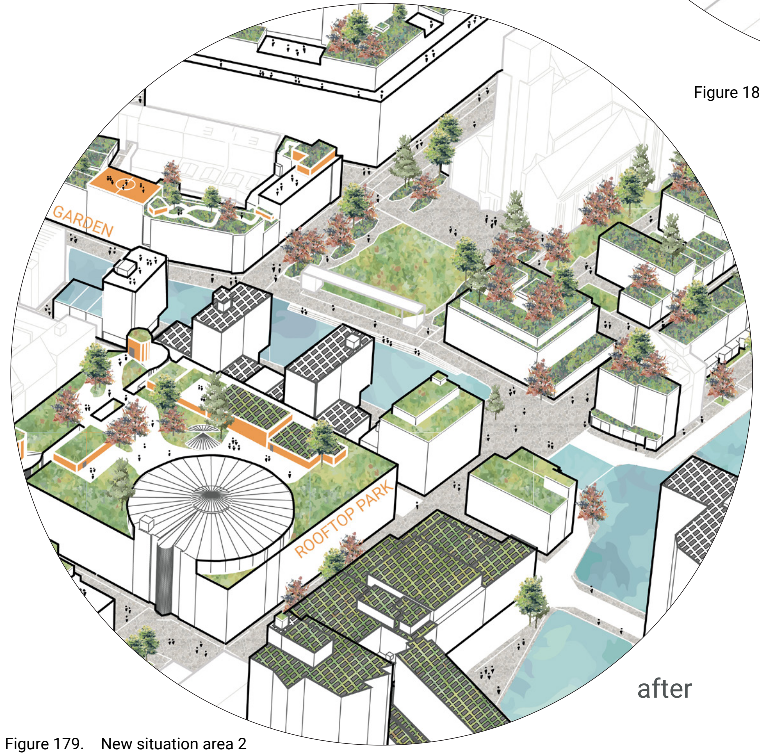


Figure 179. New situation area 2

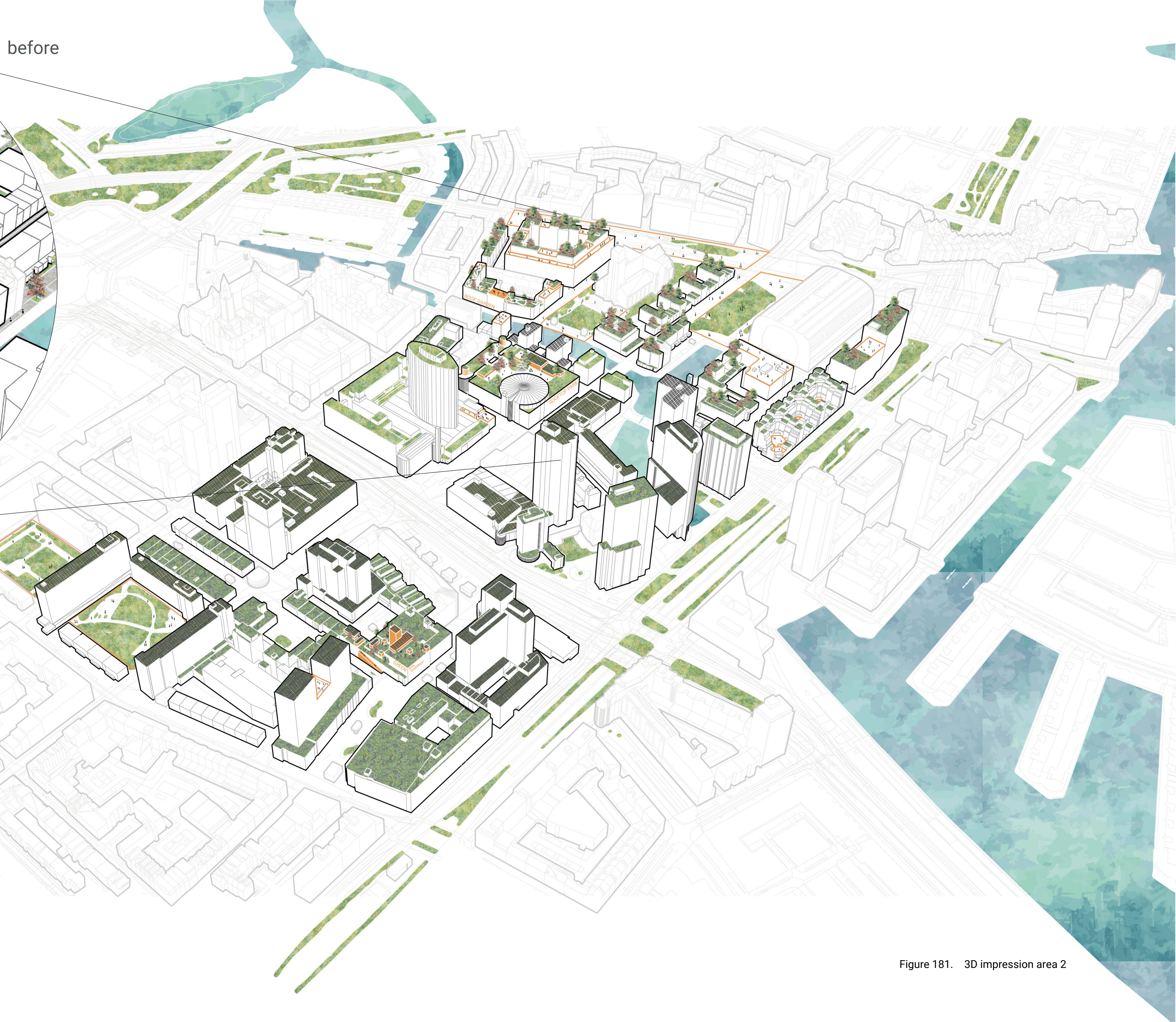
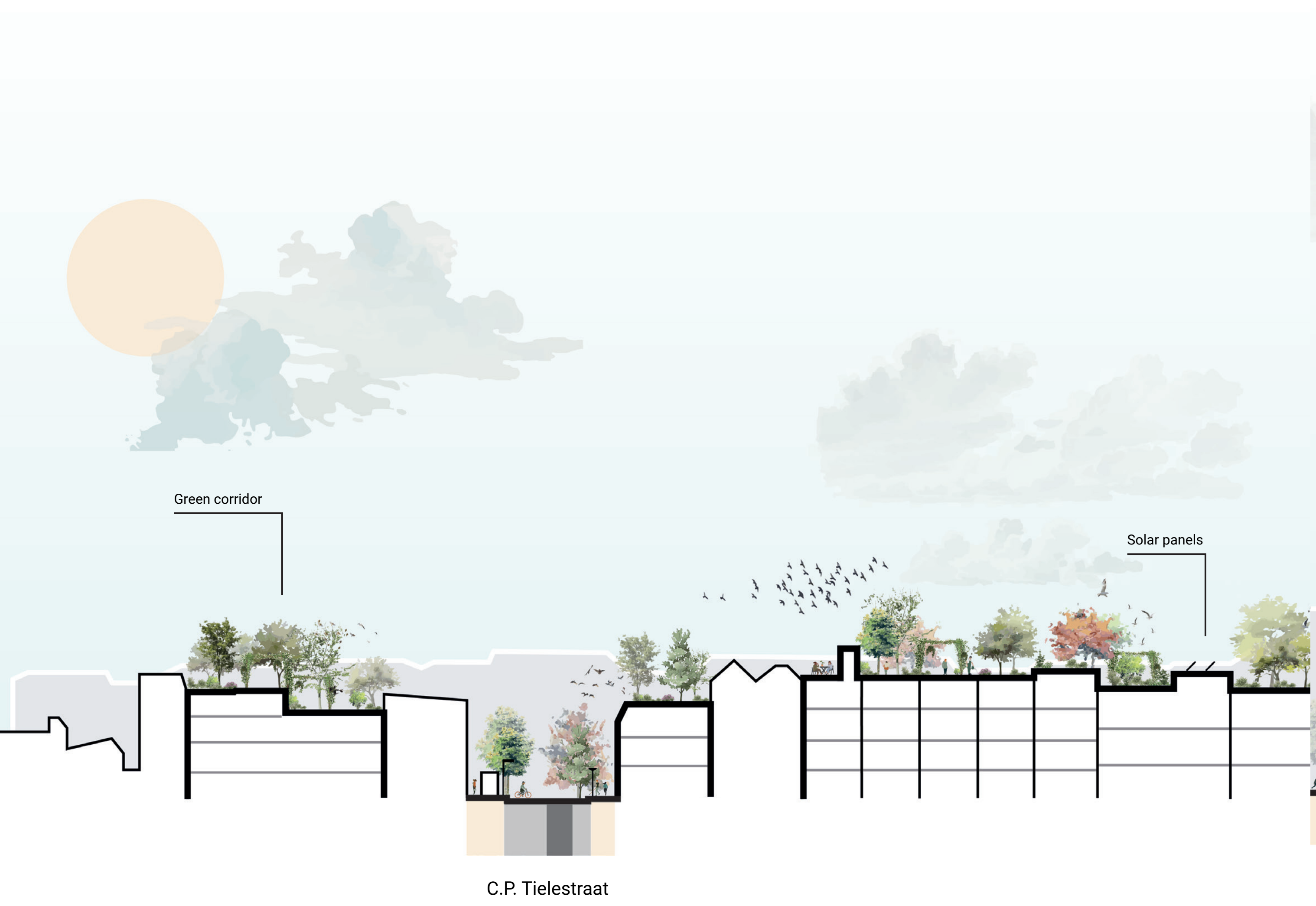


Figure 181. 3D impression area 2

9.1.6 Detailed sections area 1 and 2



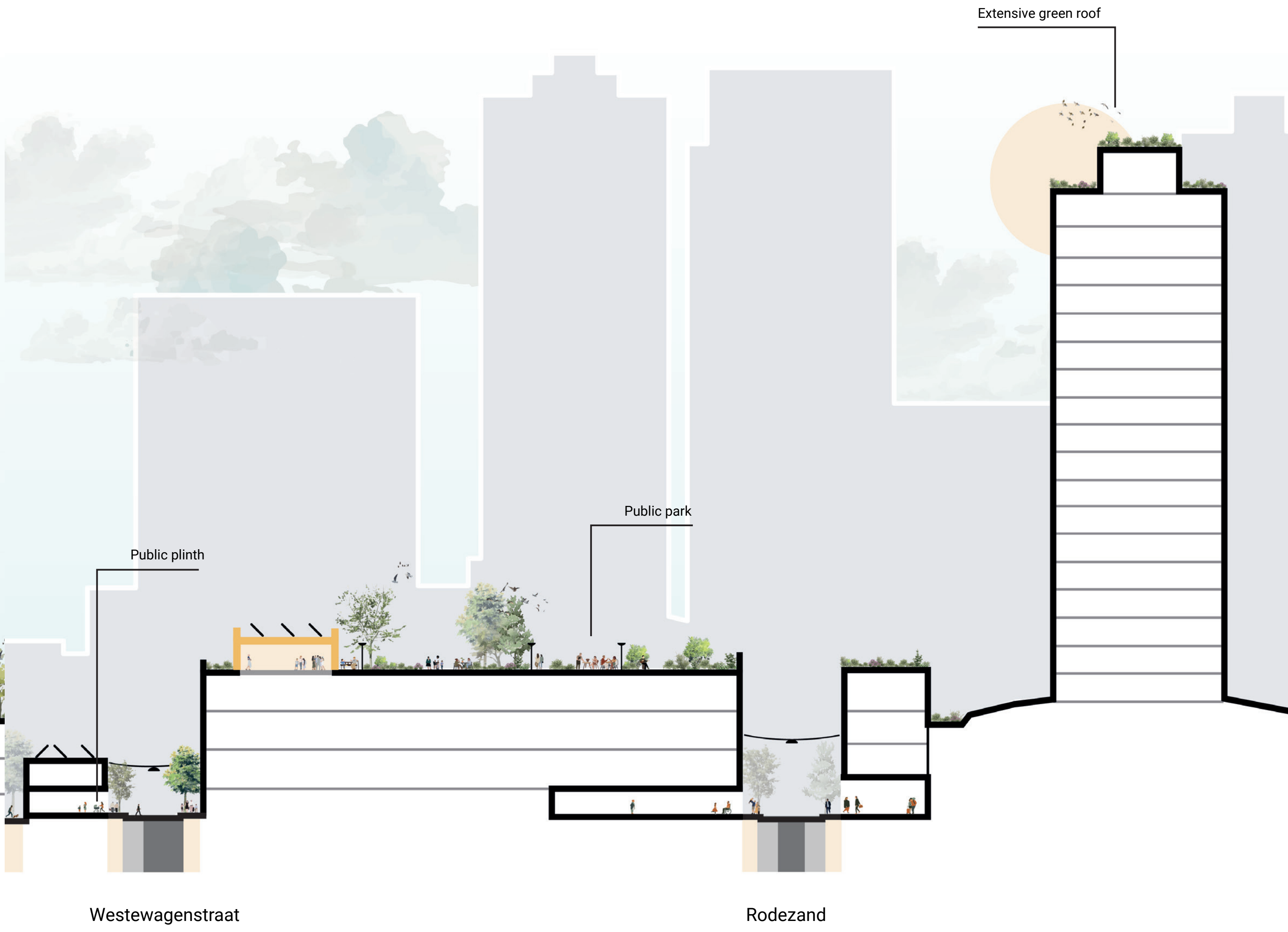


Figure 182. Section area 1

Figure 183. Section area 2

9.2 THE TASK FOR THE MUNICIPALITY

9.2.1 Next step in the implementation phase

Now that the vision is complete, the toolkit is made and most of the limitations of the project are set, it is interesting to look at how long it will take before the roofs of Rotterdam are (completely) transformed. This depends on the type of roofs, the duration for requestioning environmental permits, obtaining subsidies, the duration for placing, and the extra time indication such as the time period before the green roofs will be full-grown for instance. The images, table, and diagram on these pages show the process through the years and how long it will take per roof type before it will have the expected appearance or use.

It will take at least 5-10 years before the whole roofscape will be visible and the green corridor will function as a network than green, single, spots.

In figures 185 and 186 is visible what the distribution of new rooftop functions is in the two focus areas.

However, to be able to start with those transformations, something even more important is needed: financial support and the support and guidance of the municipality. The decision tree is a first step in making the residents of Rotterdam aware and enthusiastic about these new ideas for their roofs.

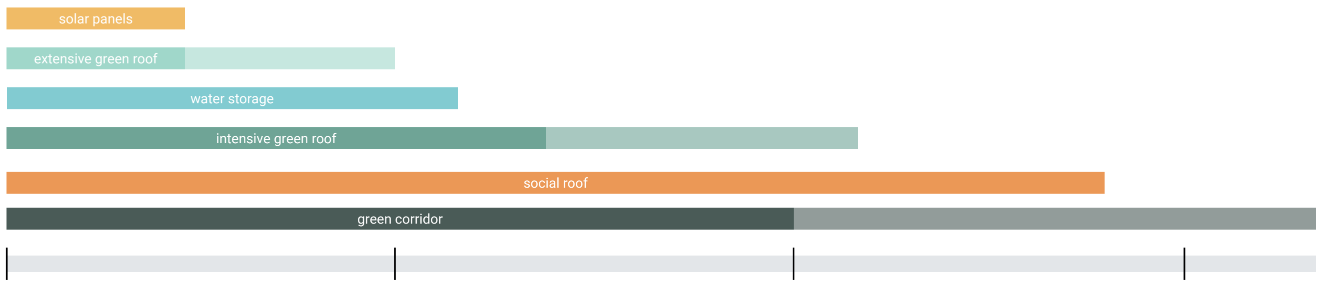


Figure 184. Phasing of the project

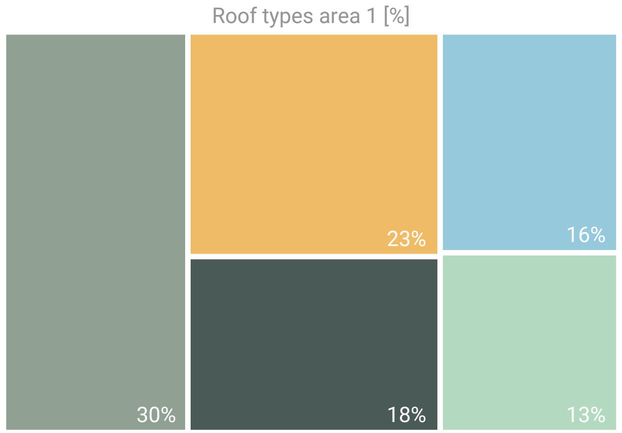


Figure 185. Percentage of new roof types area 1

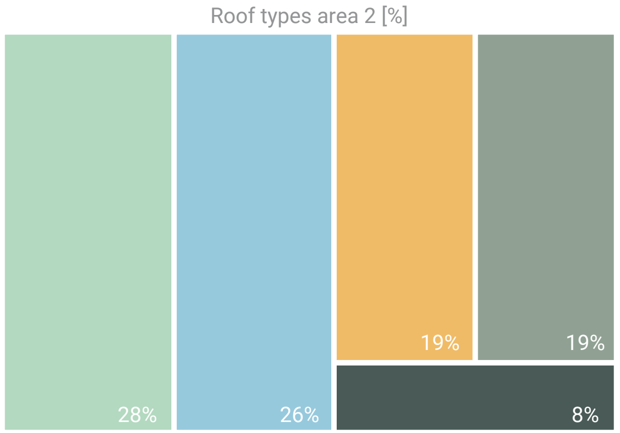


Figure 186. Percentage of new roof types area 2

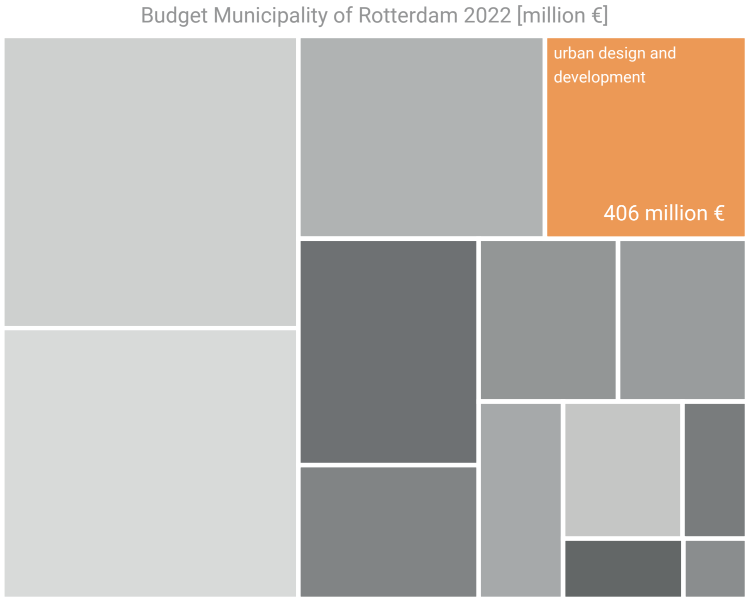


Figure 187. Budget municipality of Rotterdam

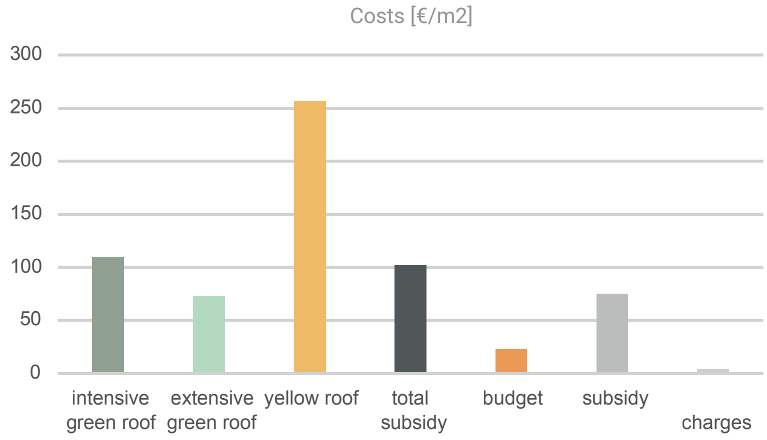


Figure 188. Comparison of costs

Next to engaging citizens, the municipality of Rotterdam needs to make funds available to support these transitions. As visible in figure 188, the costs of roof layers such as an intensive green roof (110€/m2), an extensive green roof (72€/m2), and solar panels (257€/m2) are relatively high compared with the available subsidy. In Rotterdam, a maximum of 100€/m2 is available for residents to transform their roofs. The higher the multifunctionality of the new roof will be, the more subsidy the person will receive.

In other words, only the extensive green roofs can be covered with the given subsidy. This year, the municipality has a budget of 406 million € for urban design and development. There are 18km2 of flat roofs in Rotterdam, when we want to transform them all, you have: €406million / 18km2 = 23 €/m2.

However, when redesigning roofs, you need fewer costs for the maintenance or transformation of the sewer system. The municipality receives from all inhabitants sewage charges (€236 per year) (Gemeente Rotterdam, 2022). This is in total €86 million. Suppose you spend the next 5 years on roofs to avoid sewer dilation. We would have: (€86million + €406million / 18km2 = 27 €/m2.

So, 150 €/m2 (subsidy, budget, sewage charge) can be spent on the transformation of roofs. With this subsidy all extensive roofs, the begin of intensive roofs, and the investment for solar panels can be paid. However, than we need to spend all our sewage charges + the budget for urban design and development on roofs in one year. We would then only have the roof structure/elements, not including maintenance and construction costs. That could again be an investment for the next year. In the end, we would profit of it.

Another important aspect is stakeholders. When the municipality gives residents not only more subsidies to transform their roofs but also arranges contacts with businesses such as green roofing companies, the step to transform their roofs will be reduced. Especially in a city such as Rotterdam where there are lots of initiatives focussing on roof transformations, the only thing that rests is bringing parties in contact with each other.

9.2.2 Business cases

To realise the ambition and the proposed possible transformations of flat roofs >500m2, we need the muncipality, investors, housing corporations and residents to be involved. When the ambition is to deal with large urban problems, there should be looked on a bigger scale, communities and partnerships should emerge, to achieve the proposed ambitions of this project for future cities. It is not about 1 or 2 roofs, it is about this roof landscape that can make the difference.

Roofs should become part of our city, just like streets, parks, canals, squares, and all other elements in our public space nowadays.

To achieve this, several business cases should be considered. The municipality should take the lead and start with informing and engaging citizens. It depends on the willingness of residents to what extent they are all going to take responsibility for the transformation of their roof. With subsidies, they can be supported, but also by offering different business cases. Ways to rent, buy, or sell your roof to other parties that will perform the foreseen (re)development (see figure 189).

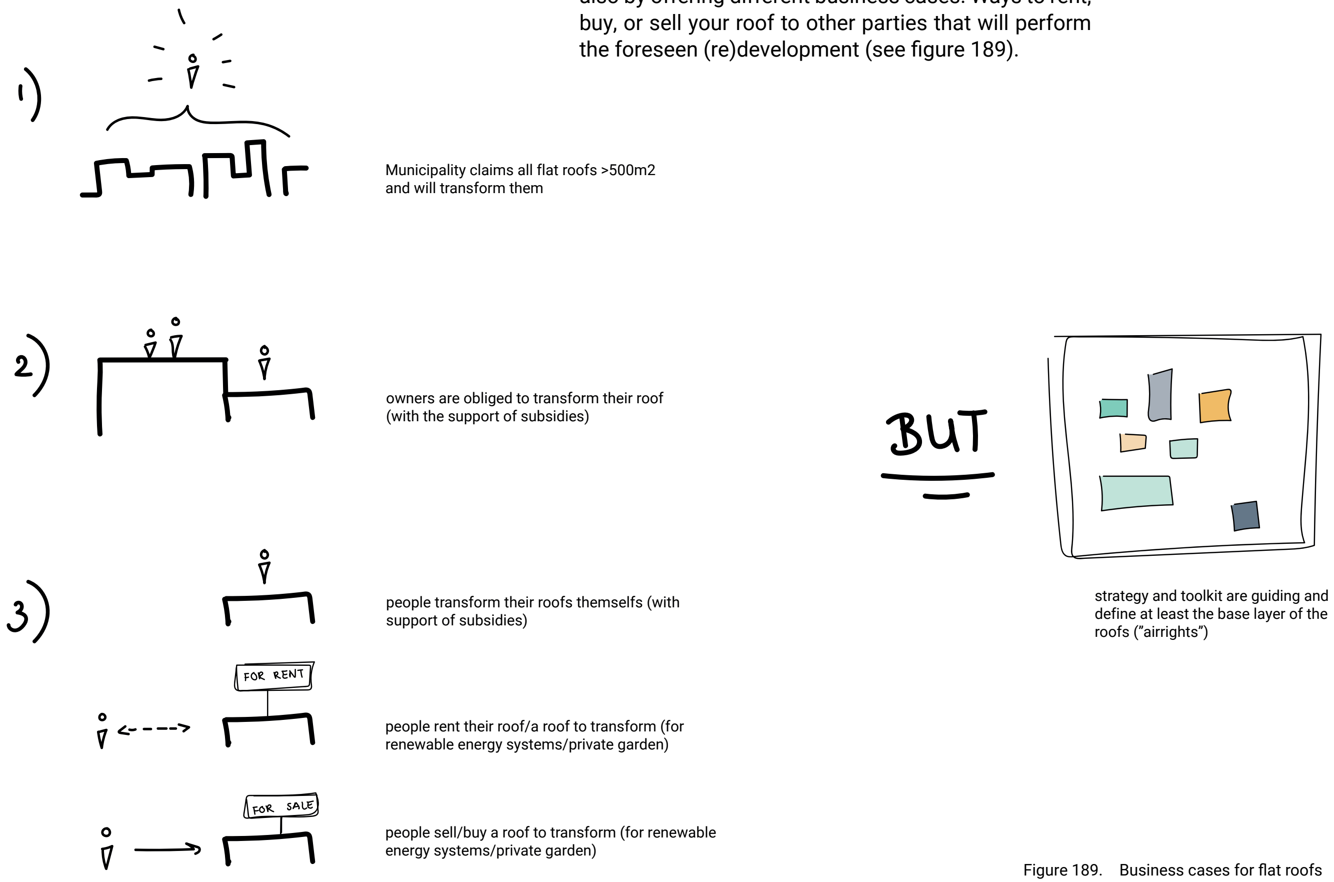


Figure 189. Business cases for flat roofs

Figure 190. Roof Maassilo (2022)

CONCLUDING REMARKS

- Conclusion
- Assessment
- Limitations
- Recommendations
- Reflection
- Aknowledgements

10

10.1 CONCLUSION

10.1.1 Summary of the project

Rotterdam's relatively untapped roofscape offers an exceptional opportunity to solve large urban and environmental problems cities are facing nowadays, such as heat stress, flooding, loss of biodiversity, and space scarcity. A way to deal with those problems is by rethinking flat roofs and so exposing their potential. Rooftops could contribute significantly to achieving a sustainable and resilient Rotterdam in the future, by accommodating green structures, water storage, solar panels, and various social functions for instance. The thesis 'Rethinking Rooftops' explores possible transformations and uses roofs, and explores to what extent at which location new functions can be and have to be implemented, combined, connected, and how the future goal of a roofscape as part of our city can be guided and realised in the upcoming years.

To answer the research question: How can the (re) development of Rotterdam's flat roofs be guided to achieve significant progress towards a sustainable and resilient Rotterdam? Several steps have to be taken. The order of the steps in the process of rethinking flat roofs corresponds to the order of the analyses in this booklet. The first part of this book focuses on the urgencies addressed in this research (heat stress, flooding, loss of biodiversity, energy transition, and the growing population) and the areas that suffer the most from 1 or more urgencies. Besides a more precise description of the type of place that will be redesigned in this research is given. The focus is on roofs >500m2. These can be roofs on top of large buildings or multiple smaller flat roofs that are directly located next to each other and form together with a flat surface of 500m2 (not looking at the height differences between those roofs).

The second step of the research was the investigation and formulation of design rules to cope with one or more problems on a roof. Per problem statement, a list of requirements for the roofs in those areas is set in order to deal with a certain problem in a specific place. These requirements define the thickness of the substrate layer of green roofs, the amount of water storage, the vegetation, and the total weight of the rooftop structure.

These requirements, in combination with the urban problems projected on the roofs >500m2 form the base layer of the new rooftop functions. From these analyses, 16 different roof types are emerged.

The third step was analysing what kind of social functions are valuable in the considered neighbourhoods and where and how these functions could be implemented on the available roofs. To define the roofs that are suitable for a second layer on top of the base layer, there has been looked at which of the 16 roof types has the possibility to add a social function to it. This by considering ownership of the buildings, possible access to the roofs, and building heights. As a result, 6 social roof types are formulated. 2 public functions, 2 communal functions, and 2 private functions.

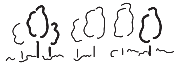
The last part of the research was about the implementation of those 22 different roof types on flat roofs>500m2 in 2 different focus areas in Rotterdam. Before implementing those different roof types on the roofs, present roof structures or uses have been mapped to see which roofs are truly available for new rooftop functions. Besides, a climate analysis is done to see which flat roofs suffer from shade and/or warm/cold wind streams during the year and are less suitable to accommodate roof functions such as greenery and solar panels.

All these steps together define a way, a strategy to rethink (Rotterdam's) flat roofs. To become resilient and sustainable in the upcoming years, rooftops should be taken into account in the (re)design of public/urban spaces. Especially in cities that densify fast and where limited space is available to transform. We have to rethink what space is and how we can use them, especially on top of roofs. The future is this layered city, where roofs are part of the city and considered useful, valuable space to transform to make the city more liveable, resilient, and sustainable. It should be seen as a landscape, rather than 'just' the top of our city. Not only by the municipality, but also by investors, housing corporations, and residents. Only then we can really rethink our roufs!

10.2 ASSESSMENT

10.2.1 A sustainble urban form for Rotterdam

The research started with a definition of sustainable urban form. To answer the research question, it is important to assess to what extent the strategy and toolkit this research have resulted in, contribute to a more sustainable, resilient, and liveable (Rotterdam) future. Per indicator of sustainable urban form on this page, there is indicated to what extent the strategy and toolkit have met the concerned goal. 5 out of 7 conditions for a sustainable urban form have been achieved.



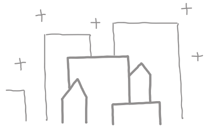
GREENING

It contributes to the maintenance of (native) species and biodiversity, the purification of air, urban cooling, and drainage systems. It also has a positive impact on the urban image, quality of life, and the economic attractiveness of a city.

+

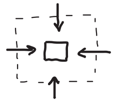
DIVERSITY

The research does not bring variety in a broader sense. Diversity is about a range of housing types, building densities, household sizes, ages, incomes, and cultures. This is not what the thesis focuses on.



DENSITY

The thesis does not enlarge the ratio of people or dwelling units to land area. The higher the number of people within a given area, to more interactions and social functions there are sufficient/ viable.



COMPACTNESS

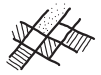
The urban contiguity and connectivity is strengthen by this research. It is about new urban structures that should be adjacent to existing ones. Besides, it refers to intensification (additions, extensions, or redevelopments) and the adjacency of living, working, amenities, and leisure in a city.

+

SUSTAINABLE TRANSPORT

The thesis contributes to the idea of a car free, and pedestrian and bicycle friendly city

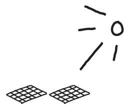
+



MIXED LAND USE

It enriches diversity and proximity of functional land use related to transportation, such as industrial, institutional, residential, and commercial. It also enhances security in public places.

+



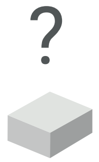
PASSIVE ENERGY DEMAND

This research helps to reduce the demand for energy and the environmental impact city's have. By creating new urban microclimates on top of roofs, heat stress, flooding, and air pollution will be reduced.

+

Figure 191. Indicators of sustainable urban form (Jabareen, 2006)

10.3 LIMITATIONS



General limitations

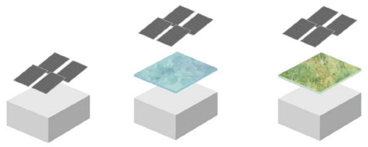
-Urban challenges are place-specific. The possible transformations in this research are based on the urban challenges in the specific areas. Therefore, there is limited freedom in the choice of the base layer of the roofs. While the social layer, it is more about the wishes of the house-owner and the defined base layer.

-Financial support. Who is going to pay for all those transformations? Are it the homeowners themselves, or the municipality?

-The capacity of the roof structures. It is hard to get insight in the bearing capacities of roofs. Therefore, very specific investigations need to be done.

-You can't predict or foresee the future. Urban environmental problems we face at this moment can evolve or change in the upcoming years. Therefore it is important to not transform all roofs in the next 5 years and to stay 'open' to new insights, and adjustments. For instance, 15% of all roofs should be kept free for unforeseen circumstances to really make the city resilient and sustainable.

-Climate (sun and wind) influences strongly the growth potential of green. Therefore, roofs that are completely in shade or experience strong cold/warm wind streams, are less easily to transform.



Limitations yellow roofs

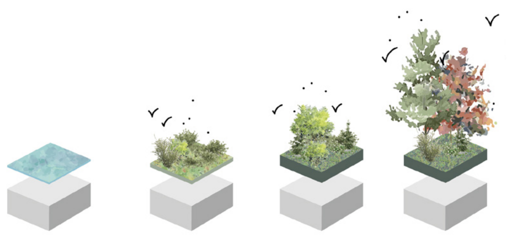
-The amount of solar panels needed to foresee all households in Rotterdam with solar energy is based on the number of households in the municipality right now, it does not foresee new households in the future. However, new-build buildings need to be energy sufficient and often already have solar panels on top of their roofs.

-Only solar panels are considered as renewable energy resources to foresee all households with renewable energy. Other sources such as wind turbines, hydropower, biomass, or geothermal are not taken into account.

-Only looked at flat roofs >500m2. Flat roofs <500m2, and semi-flat roofs are excluded, while these also have a potential to get solar panels.

-The thesis assumes that all flat roofs >500m2 in the harbor area can be used for solar panels. This means that industries there can't use their roof for private uses anymore. Besides, in terms of ownership this is a difficult assumption and not so realistic.

-The carrying capacity of the existing roofs has not been investigated extensively. It has been assumed that each roof can carry a variable load of 100kg/m2 (de Vree, n.d.).



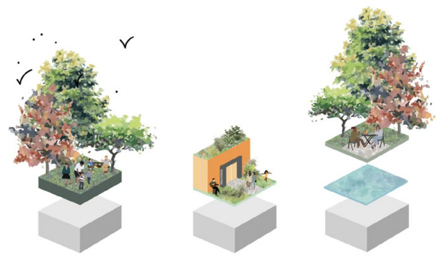
Limitations green and blue roofs

-There is a great difference between the load of different green and blue rooftop functions. The higher the density of vegetation is or the amount of water storage on a roof, the heavier the new roof layer will be. You can not say that every green or blue roof can be implemented anywhere. It depends on the specific roof type and characteristics of that type.

-A major hazard in the case of a water roof is a water leak, which can result in flooding and water damage inside the building. The preparatory phase is therefore very important.

-Open water roofs will suffer from algae in summer. Therefore these roofs must be maintained/cleaned occasionally. Closed water roofs (water storage underneath a green substrate) do not have this problem.

-To achieve rich and diverse vegetation and a range of animal species, a variety of plants on top of the roofs in the green corridor is required. This means that the roofs should be maintained regularly. This should be done by an organisation, neighbourhood initiative, or community for instance.



Limitations multifunctional roofs

-In general, roof constructions are not strong enough to carry multiple roof functions. So therefore the roofs should be reinforced before there can be taken care of.

-Water roofs, social roofs, and dense green roofs should be maintained by the people who own or live in the building underneath.

-Social roofs need to be surveilled during the day (and night). Adding functions such as a cafe, and sports facility can be a natural way to tackle this problem.

-For social functions, ownership of the roofs should be taken into account very carefully. When a roof is not the property of the municipality or a housing corporation, it's not an option to add a communal or public function to it. The target group of the social roof should be adjusted to the ownership of the building.

Figure 192. Roof Rotterdam Central Station (2022)

10.4 RECOMMENDATIONS

10.4.1 Suggestions for further research

A lot of research is already done on what possible functions on roofs could be in the future to deal with big urban problems. However, to realise the bigger network suggested in this research, more information about the construction, the capacities of buildings, and an idea about the role of residents, housing corporations, and the municipality is valuable as a next step to investigate. Several follow-up steps, and further studies are listed below.

An elaboration of the implementation phase. This by, for instance, zooming in on a new building block or street and seeing how the strategy and the toolkit in combination with the decision tree work out and what is missing.
1

Zooming in on the toolkit and adding details in roof constructions. What is more specifically needed from the roof construction of existing roofs? What are the requirements of new built roofs to accommodate rooftop functions
2

Translating the strategy and toolkit of this research to new-build buildings, so that from now on all new realised roofs will get a suitable, appropriate rooftop function and directly create a network with each other.
3

Investigation on the bearing capacity of buildings nowadays and how current structures need to be reinforced to accommodate multiple rooftop functions and what the costs will be.
4

Interviewing residents, housing corporations, and the municipality to hear their opinion about redesigning rooftops, and creating communities to realise the ambitions suggested in this thesis.
5

Creating an overview of all rooftop plans, suggestions, and ideas about the roofs in Rotterdam, bringing the creators of those plans together with the municipality, and sharing knowledge to bring the plan of the possible rooftop uses the further to a higher level.
6

Investigating how the formulated strategy and toolkit could be an addition to the existing Multifunctional Rooftop Program of the municipality of Rotterdam.
7

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...

10.5 REFLECTION

Me as researcher

The first phase of my graduation year, from P1 to P2, has been a period where I spend full-time on my graduation project, a period in which working from home became the norm again. In other words, a period in which in my opinion I was completely dependent on myself for the first time. A project that does not have hard edge conditions determined by the course coordinators.

Providing yourself with a (work) structure, a direction, and doing what you get most excited about, to make your mentors and the people around you enthusiastic about your project, which will again help you further, were the key points of what I have learned in the first months. The formulation of the problem statement, the first research (by design), and the way of analyzing, illustrating, and telling a story, were for me not the bottlenecks. For me, it was much more about gaining confidence in my work, and daring to show and share my project with the people around me.

In my opinion, my confidence in the project grew after the P2. I focused more on what I had done. Besides I focussed a lot on whether the products and analysis I had done were coherent or not. And if I had the idea I had taken everything out of it until then or not. Especially the latter helped me a lot. Not focusing on what you could do, but on what you have done.

The approach

My main method during this project was research by design. I think this worked out very well. During the first quarters of the master's, we learned very well how you can carry out research by design as an urban designer. It is especially about looking at our environment, and reference projects. This to learn how projects or research, have been set up, implemented, and currently used. Since there is not much literature about the way we should rethink our roofs in a multifunctional way, looking at Rotterdam and existing ideas and projects, helped me a lot to get insight into the current situation, the ambitions, and the enablers and limitations. By observing, analysing, and designing, most insights were gained. However, I still wanted to base my thoughts on statistics. Information derived from open source geographic information systems helped me to underpin most of my observations.

The process

When reflecting on my final designs and the research process, there are several aspects that went quite easily, while other components of the research have cost more thought and effort.

TOPS

- Constantly thinking about the previous and the next step, to keep the story coherent.
- Constantly trying to address new challenges or formulating new (sub)questions that are a valuable addition to the project
- Drawing and sketching all thoughts and ideas. They give on the one hand a very personal touch to the project. On the other hand, they translate and communicate thoughts to the audience.
- Creating filters to keep a focus (filter type of roofs for instance)

TIPS

- Have confidence in your work!
- Not all products have to be perfect from the beginning. It is a process, you need draft versions to improve them later in the process.
- Work more on different scales: block scale, neighbourhood scale, and city scale. When working on a different scale you're also working on the pixel of your drawings, not all information has to be visible on every scale

In general, I'm quite content with the products, process, and planning of my project. I have been working very steadily throughout the year. I constantly asked myself what I wanted to achieve in the upcoming weeks, and why I should do it regarding previous investigations. By doing so, in my opinion, you don't really need planning from the beginning till the end. I knew in general terms what I wanted to achieve and so the path toward it gradually came about.

Figure 193. Rooftop Walk (2022)

10.6 AKNOWLEDGEMENTS

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Next to that, it has been an enormously valuable addition to work for one day a week at Rotterdam Rooftop Days. By organizing events on roofs, I have seen so many opportunities and possibilities for roofs in the future, besides the way how visitors react to and experience this new city layer. Which was extremely special. So, therefore, also many thanks to Nikki and Léon who gave me this opportunity.

And last but not least I want to thank my family and friends for the support, for thinking along with me, and for offering a listening ear when needed. And above all the enthusiasm I get from everyone gave me even extra energy to develop this research even further.

Figure 194. Rooftop Walk (2022)

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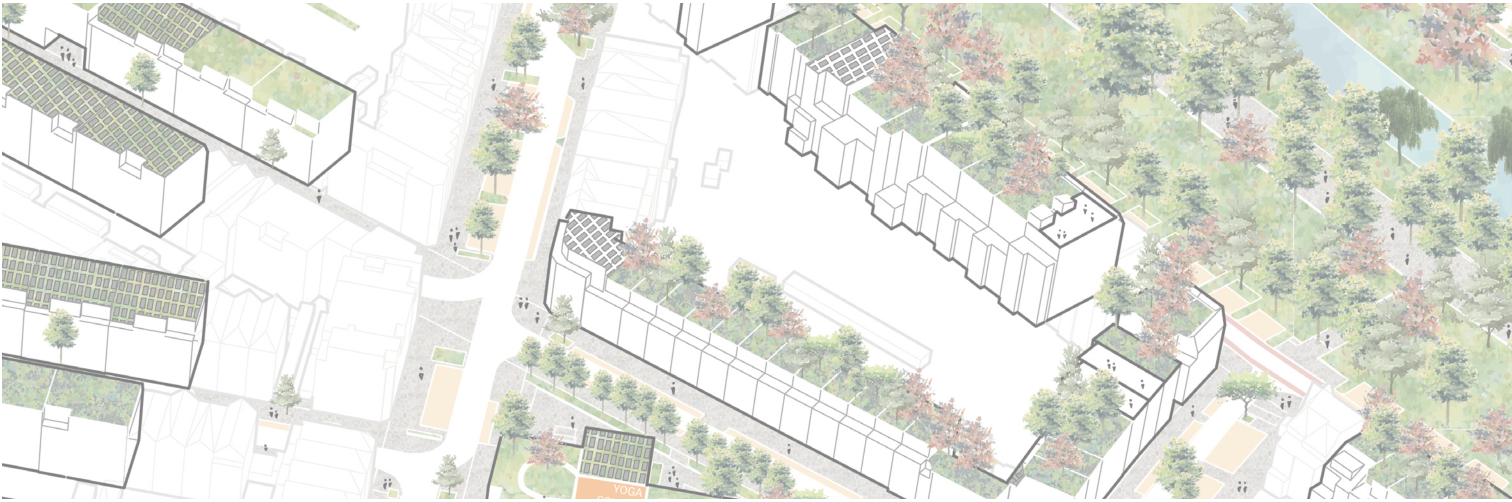
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