Climate-responsive urban edges

Designing thermally comfortable locations for urban growth at the peri-urban zone from the city of Utrecht, the Netherlands.

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Master Thesis
Landscape Architecture
Wageningen University

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Preface

This thesis report is the result of my research to the design of climate-responsive urban growth in the city edge from Utrecht. I conducted this research as part of my Master study landscape architecture at the Wageningen University. This report is the result of work executed between July 2014 and July 2015.

My thesis started from a fascination about the varied Dutch landscape in which the area where the city meet the landscape became my favorite. Cities makes it possible to live in this landscape, but also causes negative effects on its liveability. Problems in the city's urban climate, caused by climate change and centuries of urban growth, inspired me to use my landscape architecture expertise for the investigation of future urban growth in a continuing warming urban climate.

The progress of this thesis was not possible without the help of many. Foremost I would like to thank my supervisor, Wiebke Klemm, for here feedback and conversations about the topic and the content of this thesis. Furthermore, the critical eye from Sanda Lenzholzer did help and stimulate the research process in my thesis project. The talks and discussions with my former fellow student Christy Tang supported me to focus on my own goals and interests within the project. Also the expertise from Bert Heusinkveld and Bert van Hove was pleasant in gaining information and the discussion of result. The critical eye and ears of my fellow students helped to get back on trace in difficult times and the pleasant atmosphere created by them in the thesis room has definitely helped to stay motivated. Finally, a thanks to family and friends who support the process of this thesis.

Rick Lensink
July, 2015

Abstract

Keywords:
The city of Utrecht
Urban growth
Urban climate
Thermal comfort
City edge
Climate-responsive design

In this thesis, locations for urban growth are proposed for the city of Utrecht. These locations are designed from the perspective of urban climate and future inhabitants' thermal comfort. Existing urban climate knowledge is the starting point for the design and is used to develop different analyses and methods.

Current population and household predictions (relative population growth of 21% and relative household growth of 18%) designate the city of Utrecht as the fastest growing municipality in the Netherlands, between the years 2012-2025. This growth is mainly focused in the city edge and results in a densification and expansion of the city's built-up surface. At the same time, urban growth result in negative effects on the urban climate because of the change in land use and increase in built-up surface, especially during warm periods. This causes negative effects for humans with emphasis on vulnerable groups; young children, elderly people, and people with cardiovascular diseases. Due to the climate change predictions, these problematic warm periods will only increase.

The challenge in this thesis project is to design locations for climate-responsive urban growth at the city edge, since it appears that urban growth is mainly focused here. Locations for urban growth that are positioned to minimizes the negative effects on the city's climate, and are configured to ensure inhabitants' thermal comfort in the new expansions and their surrounding neighbourhoods. The main research question is to find out "what are key aspects in the design of locations for climate-responsive growth at the city edge of urbanizing cities?". To answer this question, the thesis started with evaluating methods to determine the city edge and a literature study on existing urban climate knowledge. According to different literature, greenery, wind, water and urban geometry are the key aspects that have different influences on the urban climate. On the basis of these key aspects, a step-by-step analysis has been developed and applied to the city edge of Utrecht to position and configure locations for climate-responsive urban growth. In addition, the step-by-step analysis applied to a specific growth location, has determined different design challenges: Implementation, preservation, and strengthening of climate influencing spatial characteristics and elements have a positive effect on the urban climate and the future inhabitants' thermal comfort.

By using the city of Utrecht as case study area, the validity of the developed methods could be evaluated. The positioning of locations resulted in eight locations for climate responsive expansion and the configuration of one of those locations has been tested in a Master plan and in detailed designs. In addition, the research approach and the developed methods could be used as a tool for other cities dealing with the same problems. The site specific outcomes can be an inspiration to other cities as well.

Contents

1.0
Voorddorpsepolder

1. Introduction

I started this thesis being fascinated by the varied Dutch landscape (see fig. 1.1). A patchwork in which 'grey' urban areas lie within their 'green and blue' surrounding landscapes. Cities make it possible to live in this landscape, but can cause negative effects on the liveability as well. The city structure with its complexity of buildings, paving, greenery, waterbodies and relief, together with human activities – such as traffic and industry – have a major impact on the local thermal climate. It clearly differs from the climate in the rural surroundings and has significant impact on human temperature perception (Lenzholzer, 2013).

Due to predictions for urban growth and global climate change, I found it interesting and profitable to research the effect of urban growth on the urban climate. What these predictions are, and why this could be interesting will be presented in this chapter. A chapter with an introduction on the topic of the research carried out and related issues.

1.1 Urban growth: facts and figures

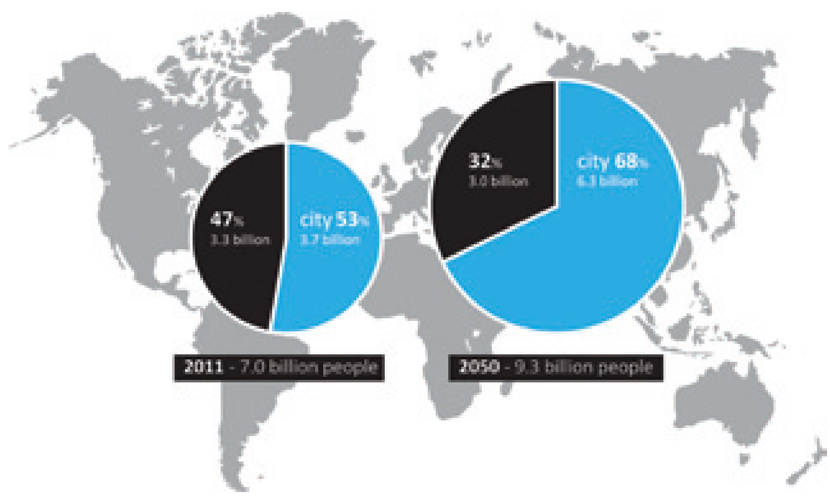
By the year 2050 the world population is expected to grow with 2.3 billion people to 9.3 billion. At the same time the urban population is growing even faster. Between 2011 and 2050, the urban population will grow with 2.6 billion people to 6.3 billion people (United Nations, 2012). So, it is expected that almost 70 percent of the world population will live in cities by the year of 2050 (see fig. 1.2).

1.1
The Netherlands in bird's-eye view
Source: https://www.google.nl/maps

As a result, cities are expected to expand – what will have an influence on the surrounding landscapes – to meet the urban population growth. This means not only a high concentration of people and economic activity in select places, it also implies a fundamental restructuring of the relations between cities and their hinterlands (Ruth and Baklanov, 2012).

In one decade – from 1990 to 2000 – at least 2.8% of the land in Europe changed its use, from which a significant increase caused by growth of urban areas (EEA, 2006). Increase in urban areas, urban growth, is a complex process in which rural lifestyle change in urban ones. It causes conflicts between spaces by changing population density, economic activity and mobility (Antrop, 2004).

In the Netherlands, the issue of urban growth is also recognizable. New empirical data show that the Dutch population increased with 344 thousand inhabitants between 2009 and 2014. Nearly three-quarters of them are centred in the large municipalities. This means that the process of urbanization continues (CBS, 2014). Especially in the Randstad area, a strong population growth is predicted between the years 2012 and 2025 (see fig. 1.3). This strong growth is also recognizable in the predicted household growth for the Netherlands by the year 2025 (see fig. 1.4).



1.2
Expected growth for the world population
In 2050, 70% of the world population will live in cities.
Based on: United Nations (2012)

1.3
Relative population growth by COROP-region, 2012-2025
Source: Huisman et al. (2013)

- strong growth 5%+
- growth 2.5- 5%
- stable -2.5- 2.5%
- shrinkage 2.5 - 5%
- strong shrinkage 5%+

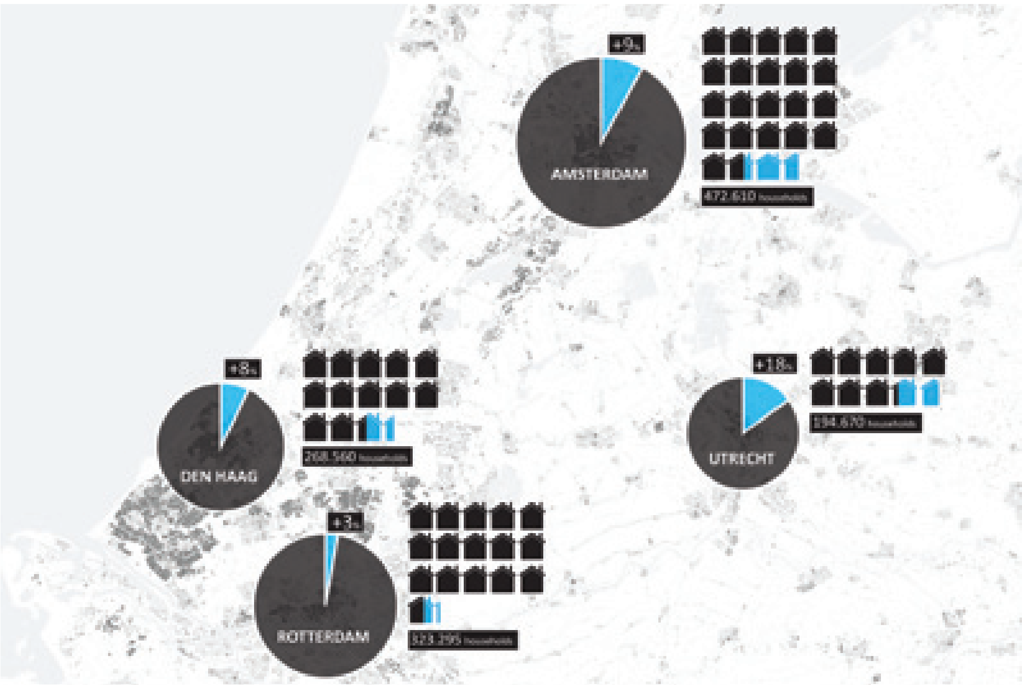
1.4
Relative household growth by COROP-region, 2012-2025
Source: Huisman et al. (2013)

- extreem growth 10%+
- strong growth 5- 10%
- growth 2.5- 5%
- stable -2.5 - 2.5%
- shrinkage 2.5%+

The four major municipalities from the Netherlands (Amsterdam, Rotterdam, Den Haag, and Utrecht) will face the largest growth in the near future, of which Utrecht will be the strongest growing one. A relative growth of 65 thousand people (21%) and 30 thousand households (18%) is predicted for Utrecht in the period 2012-2025 (Huisman et al., 2013) (see fig. 1.5 – 1.6). A continues growth, that is also expected in the population development scenario's till 2040 (Huisman et al., 2013).

1.5
Population development for the four major municipalities in the Netherlands, 2012-2025.
Based on: Huisman et al. (2013) and http://www.stadindex.nl/

x 20 000

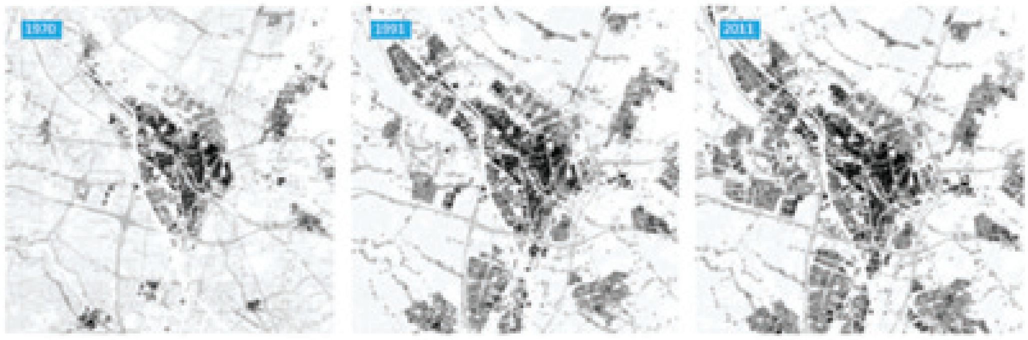


1.6
Household development for the four major municipalities in the Netherlands, 2012-2025.
Based on: Huisman et al. (2013) and http://www.stadindex.nl/

x 20 000

1.2 The city edge

Population growth is an ongoing process in the history of many cities. Years of growth resulted in an increase of build-up surface that put pressure on public space in cities (densification) and on surrounding landscapes (expansion)(Antrop, 2004). On the maps in figure 1.7, it is obvious that the urban growth from the city of Utrecht did result in large urban expansions and growing suburbs in the past decades. This fits the description for urban growth; low-density expansion or leapfrog development of large urban areas into surrounding rural land (Nilsson et al., 2013). A process that moves and changes the area under pressure of predicted growth; the city edge (Hamers et al., 2009)(LOLA, 2013).



1.7
Urban growth from the city of Utrecht and surroundings
Growing city Utrecht, 1970-1991-2011. A population growth of more than 32.000 inhabitants, between 1970 and 2011.
Source: PBL (2012)

1.3 Problems in urban climate

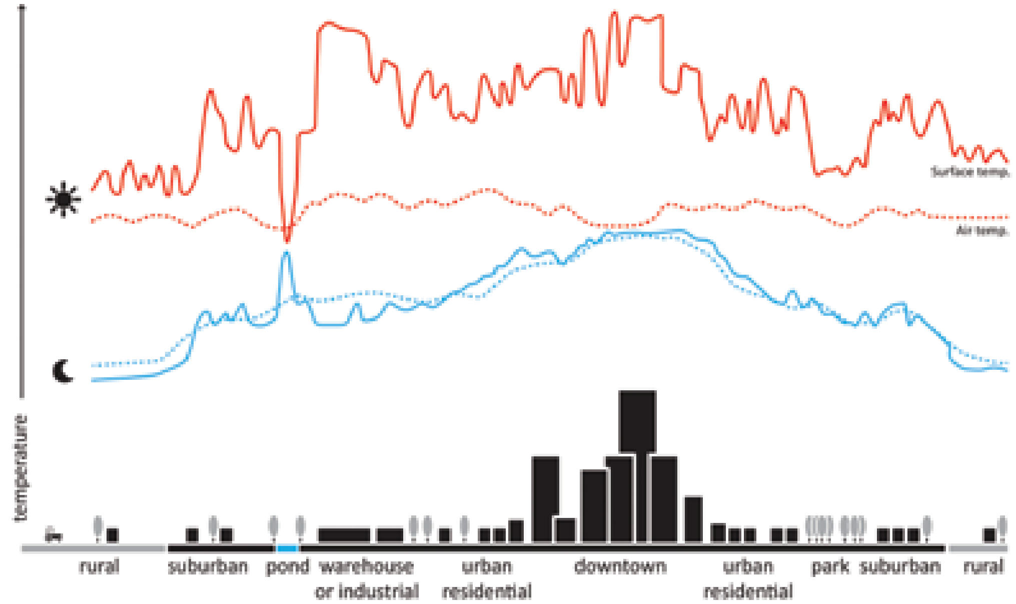
Next to the pressure on public space and surrounding landscapes, urban growth also has a negative influence on the liveability in the city. Changes in land use and land cover, expansion of infrastructure, choice of building materials and many more decisions related to urban growth, in combination with direct anthropogenic emissions from human activities (heat, carbon dioxide and pollutants), result into distinct climates in the urban environment (Ruth and Baklanov, 2012)(Grimmond, 2007).

1.3.1 Problems in urban climate

When the air and surface temperature of a place in the urban area is warmer compared to the temperature of the surrounding rural land, the place deals with an urban heat island (UHI) phenomenon (Oke, 1987)(see fig. 1.8). Each settlement exhibits an UHI regardless of its size. The temperature difference depends on the urban structure, building density, canyon geometry, surface materials, human activities, vegetation coverage and water surfaces (Steeneveld et al., 2011). For example, the air temperature in an urban park is in general 1°C cooler than a non-vegetated site (Van Hove et al., 2011), 10% tree cover in a park can lower mean radiant temperatures about 3.2°C (Klemm et al., 2015).

Types of UHI can be divided into surface UHI's and atmospheric UHI's. Surface UHI's are a difference in surface temperature between city and rural surroundings, while the atmospheric UHI is a difference in air temperature (Van Hove, et al., 2011). Differences in air temperature between urban and rural are the largest during the evening and night (see fig. 1.8). During the night, when the rural area has cooled down, the city still retains the heat from the surface that is accumulated during daytime (Hawkins et al., 2004).

Values of UHI's up to 7°C are measured in Dutch cities (Steenveld et al., 2011). This makes urban areas vulnerable to heat waves and their negative effects for humans during warm summer periods. Especially for vulnerable groups, like young children, elderly people, and people with cardiovascular diseases (Wang et al., 2009)(Reid et al., 2009). Thermal uncomfortable conditions can also result in a decrease of labour productivity and causes plants to flower earlier, which may trigger hay fever earlier in urban areas than at the countryside (Kovats and Hajat, 2008)(Mimet et al., 2009).



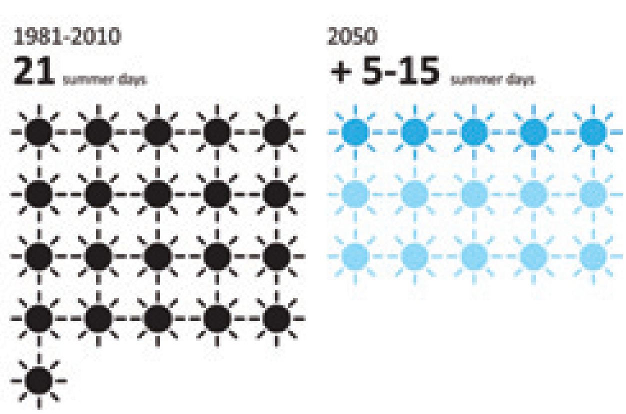
1.8
Urban heat island effect (UHI)
Captured solar radiation by the urban structure during the day, is heating they urban environment by night. This results in a temperature difference between the city and its surrounding landscapes; UHI.
Based on: http://www.epa.gov/heatisland/images/

1.3.2 Climate change predictions

The future climate change predictions do make the UHI issue even more important. "Baseline scenarios result in global mean surface temperature increases in 2100 from 3.7 to 4.8°C compared to pre-industrial levels[1] (median values; the range is 2.5°C to 7.8°C when including climate uncertainty)" (IPCC, 2014, p.8). Only strong new measures will reduce the emission of greenhouse gases enough to limit the global warming with 2°C, which is the goal of the IPCC (KNMI, 2014[1]).

[1]*pre-industrial levels*
Refers to the period before 1750

Predictions for the Netherlands show that the temperature in the Netherlands will continue to rise in which mild winters and hot summers become more common (van den Hurk et al., 2006) (Klein Tank et al., 2009). An average summer in 2050 will be 1.0 till 2.3°C warmer than in the reference period 1981-2010, and will have 5 till 15 more summer day's (a maximum temperature of at least 25˚C) (KNMI, 2014[2])(CPC, 2014) (see fig. 1.9). So, problems in the urban climate are likely to increase in coming decades.



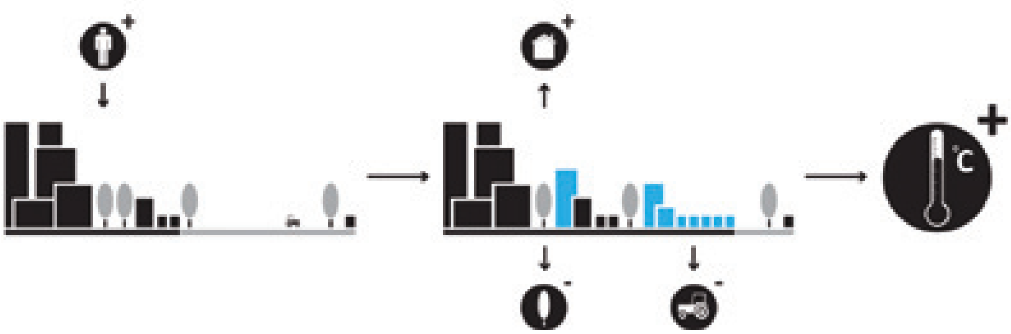
1.9
Increase in summer days
Average summers are expected to contain 5 till 15 more summer day's (at least 25˚C) by the year 2050.
Based on: CPC (2014)

1.4 Problem identification

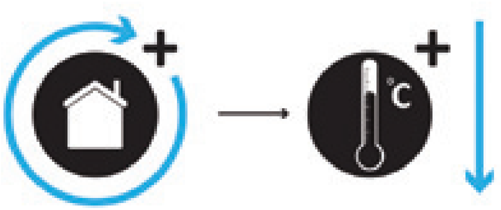
On the basis of the information above, the topic of this thesis focusses on the effect of urban growth on urban climate (see fig. 1.10). Ongoing urban growth leads to a need for more build-up surface which puts pressure on green open areas in cities and on the surrounding rural land. As a result, existing surfaces change into urban ones with distinct urban climates and a negative effect on the inhabitants thermal comfort. Especially when we look at climate change projections, this problem will likely only increase.

The challenge in this thesis project is to design locations for climate-responsive urban growth (see fig. 1.11). Locations for urban densification or expansion that are *positioned* in a way which minimizes the negative effects on the cities climate, and are *configured* to ensure inhabitants' thermal comfort in the new expansions and their surrounding neighbourhoods. The city edge is used to investigate this challenge since it appears that urban growth is mainly focused here (Hamers et al., 2009)(LOLA, 2013)(see fig. 1.7).

To study the challenge in this thesis, a case study has been used. Since the identified problem starts from the perspective of urban growth, the main growing city of the Netherlands has been used; Utrecht (Huisman et al., 2013). This city will be further introduced in chapter 3.



1.10
Problem identification
Urbanization lead to more build-up surface at the expends of green and rural land, which has a negative effect on the urban climate and inhabitants' thermal comfort.



1.11
Challenge
The challenge in this thesis project is to design locations for climate-responsive urban growth.

1.5 Landscape architectural lens

My perspective in this thesis is from a pragmatic worldview, described by Creswell (2009). Research considered as always problem centred, and about consequences of actions. The world and the landscape are no unity, researchers should use many approaches and techniques that fits their needs, and purposes, instead of subscribing the only one way. In this research this worldview is used to gain knowledge for the positioning and configuration of locations for climate-responsive urban growth in the city of Utrecht.

For solving the problem in this project, the main idea of *design as synthesis* has been used (Crewe and Forsyth, 2003). Landscape architecture is used for problem solving, to analyse the problem and to synthesize an approach for solving the problem. Depending on type and scale of the design, other approaches from Crewe and Forsyth (2003) have been used. On large scale, a *landscape analysis* lens is used, in which all the elements of the landscape are important and in their combinations in between. For the detailed designs the lens shifted towards the cultivated expression, where the artistic expression is used for the design of an unique environment.

The way in which I see and use landscape architecture is highly influenced by my former education. My design education started at Van Hall Larenstein, where I obtained my professional bachelor in Garden architecture. This education was mainly focused on solving problems in real world situations by combining knowledge from other disciplines. The master Landscape architecture, at the Wageningen University, added more theory and changed my lens into the implementation of knowledge to solve real world problems.

For this thesis, the city is seen as part of the landscape; the main idea from Landscape Urbanism. An idea in which landscape replaces architecture as the basic building block of contemporary urbanism (Waldheim, 2006). The landscape is recognized as “a medium uniquely capable of responding to temporal change, transformation, adaptation and succession. These qualities recommend landscape as an analogue to contemporary processes of urbanization and as a medium uniquely suited to the open-endedness, indeterminacy, and change demanded by contemporary urban conditions” (Corner in Waldheim, 2006, p.39).

In this thesis, cities are seen as a typology within the landscape since I describe the whole as an patchwork. Cities have their own administrative borders, like municipality borders for the purpose of planning and controlling the city. Influences from urban growth and climate do not stop at administrative borders, so these borders will not be leading in this thesis.

2.0
Ruigenhoek

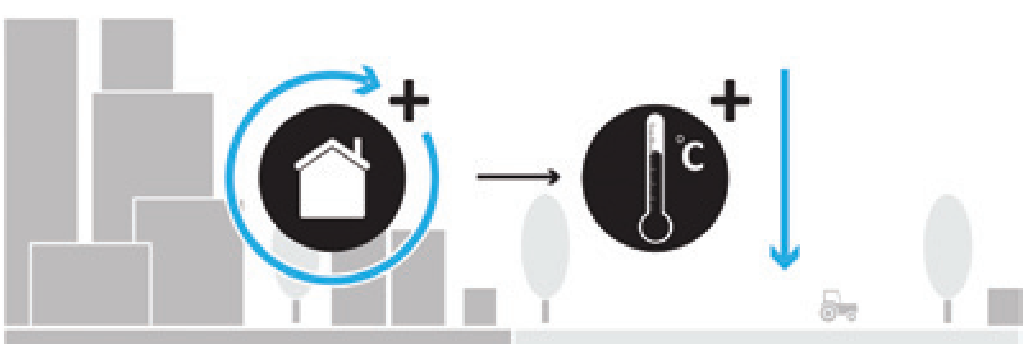
2. Research outline

The previous chapter introduced the challenge in this thesis: designing locations for climate-responsive urban growth. This chapter describes the missing knowledge to fulfil in the challenge, followed by the way to research. Research questions will be presented together with applied strategies and methods.

2.1 Knowledge gap

To fulfil the challenge in this project, designing locations for climate-responsive urban growth, more knowledge is needed about the key aspects in the design of those locations. Locations for urban growth that are *positioned* in a way which minimizes the negative effects on the cities climate, and are *configured* to ensure inhabitants' thermal comfort in the new expansions and their surrounding neighbourhoods (see fig. 2.1).

Many research has already been done on urban climate, such as; Arnfield (2003), Oke (1987), Souch and Grimmond (2006), Steeneveld et al. (2011), and Wilby (2003). Together with possible interventions for urban climate – e.g. Grimmond et al (2010), Klemm et al. (2015), Steeneveld et al. (2012), and Steeneveld et al. (2014) – much is known about how spatial characteristics and elements can influence urban climate and thermal comfort of the city's inhabitants. For example, the effect of tree cover in a park on the mean radiant temperature (Klemm et al., 2015).
So, spatial characteristics and elements that influence urban climate are well known, but these are hardly ever used in the planning and design of urban growth. New insights can be gained by researching how this existing knowledge can be used in the process of positioning and configuring locations for climate-responsive urban growth in the area of predicted urban growth, the city edge. Knowledge that is needed to ensure climate-responsive expansion of urbanizing cities and contributes to the existing body of knowledge on urban climate studies.



2.1
Knowledge gap
Researching the positioning and configuration of locations for climate-responsive urban growth at the city edge, to minimize the negative effects on urban climate and inhabitants thermal comfort.

2.2 Research objective

In order to formulate the main research question and supportive sub-research questions, the research objectives and goals are stated. *The purpose of this study is to investigate the key aspects in the positioning and configuration of locations for climate-responsive urban growth, and apply them in the case city of Utrecht.*

As became clear previously, the city of Utrecht will be the main growing city in the Netherlands for the upcoming years. Historical growth and different sources, such as Nilsson et al. (2013), Hamers et al. (2009) and LOLA (2013), describe that this growth results into expansion and densification at the edge of the city. So, it is possible to frame the area of research by *determining the city edge.*

Secondly, *it is important to investigate how existing urban climate knowledge can be used for the positioning of climate-responsive urban growth locations.* As described before, paragraph 2.1, many knowledge exist about spatial characteristics and elements that influence urban climate and inhabitants thermal comfort. Large scale characteristics and elements could steer in the positioning of growth locations. Smaller scale characteristics can be used *in the configuration of a climate-responsive urban growth location.*

Finally, the whole research is applied at the city of Utrecht to *evaluate the validity of the research concepts.* The design objective does not only provide a location for climate-responsive urban growth at the city of Utrecht, the approach of research can also be used as a tool for other cities, dealing with the same problems. In addition, site specific outcomes can be used as an inspiration for other cities. So, the design should not only be functional, but also enrich the environment for man and nature in both process and form.

2.3 Research questions

The main research question in this study is:

[RQ] What are key aspects in the design of locations for climate-responsive growth at the city edge of urbanizing cities?

To answer the main research question, three sub-questions are brought forward:

[SRQ1] What determines the city edge?
[SRQ2] How can existing urban climate knowledge be used in the positioning of climate-responsive urban growth locations?
[SRQ3] How can existing urban climate knowledge be used for a climate-responsive configuration of an urban growth location?

2.4 Strategy & methods

For researching the objective in this study, a *research-for-design* (RFD) approach is used as the main strategy. Research on positioning and configuration of locations for climate-responsive urban growth informs the design process of a growth location at the city of Utrecht. The research improves the quality of the designed artefact and makes it more reliable (Lenzholzer et al., 2013).

Within this strategy, research involves the acquisition and assessment of knowledge to produce general rules, as described in the analysis-synthesis model (Milburn and Brown, 2003). The design process divides the design problem into separate elements for the purpose of analysis and evaluation by using research information (Idem).

[RQ] *"What are key aspects in the design of locations for climate-responsive growth at the city edge of urbanizing cities?"*

The main research question is about finding the key elements in the process of positioning locations for climate-responsive urban growth, and the configuration of these locations to promote thermal comfort for its future inhabitants. A descriptive case study is done at the city of Utrecht, to explore the method in a real-world situation (Deming and Swaffield, 2011). Sub-research questions are brought forward to find the final answer on the main question.

The first sub-research question is clarifying the boundaries of the case study, by building a method that points out the area under pressure of future urban growth; the city edge. The defined edge will be the area to investigate locations for urban growth. The question to be answered is: [SRQ1] *"What determines the city edge?"*

This question is evaluating existing definitions and methods, found by a conducted literature study. Two methods have been investigated by map analysis and field observations (see bike trip route in appendix I) at the city of Utrecht. Evaluation of these methods resulted in advantages and disadvantages forming the basis for the developed working method in this thesis project. The working method is used to define the boundaries of the city edge from Utrecht.

The second sub-research question is: [SRQ2] *"How can existing urban climate knowledge be used in the positioning of climate-responsive urban growth locations?"* For this question, a literature study has been conducted on existing urban climate knowledge. On the basis of relevance, 8 sources are selected and investigated on its content. Climate influencing characteristics and elements are extracted and categorized. In addition, secondary research has been used to investigate climate characteristics and elements in the case study area. On the basis of this climate information and the found characteristics and elements, map studies have been developed (Martin and Hanington, 2012). Map studies that are combined in a step-by-step analysis and verified during an expert consultation with dr. ir. LWA van Hove (personal communication, November 20, 2014)(assistant professor at Wageningen university; Earth system sciences, meteorology and air quality). The test of the step-by-step analysis on the city edge from Utrecht resulted in the answer on [SRQ2], the use of existing urban climate knowledge for the positioning of climate-responsive urban growth locations.

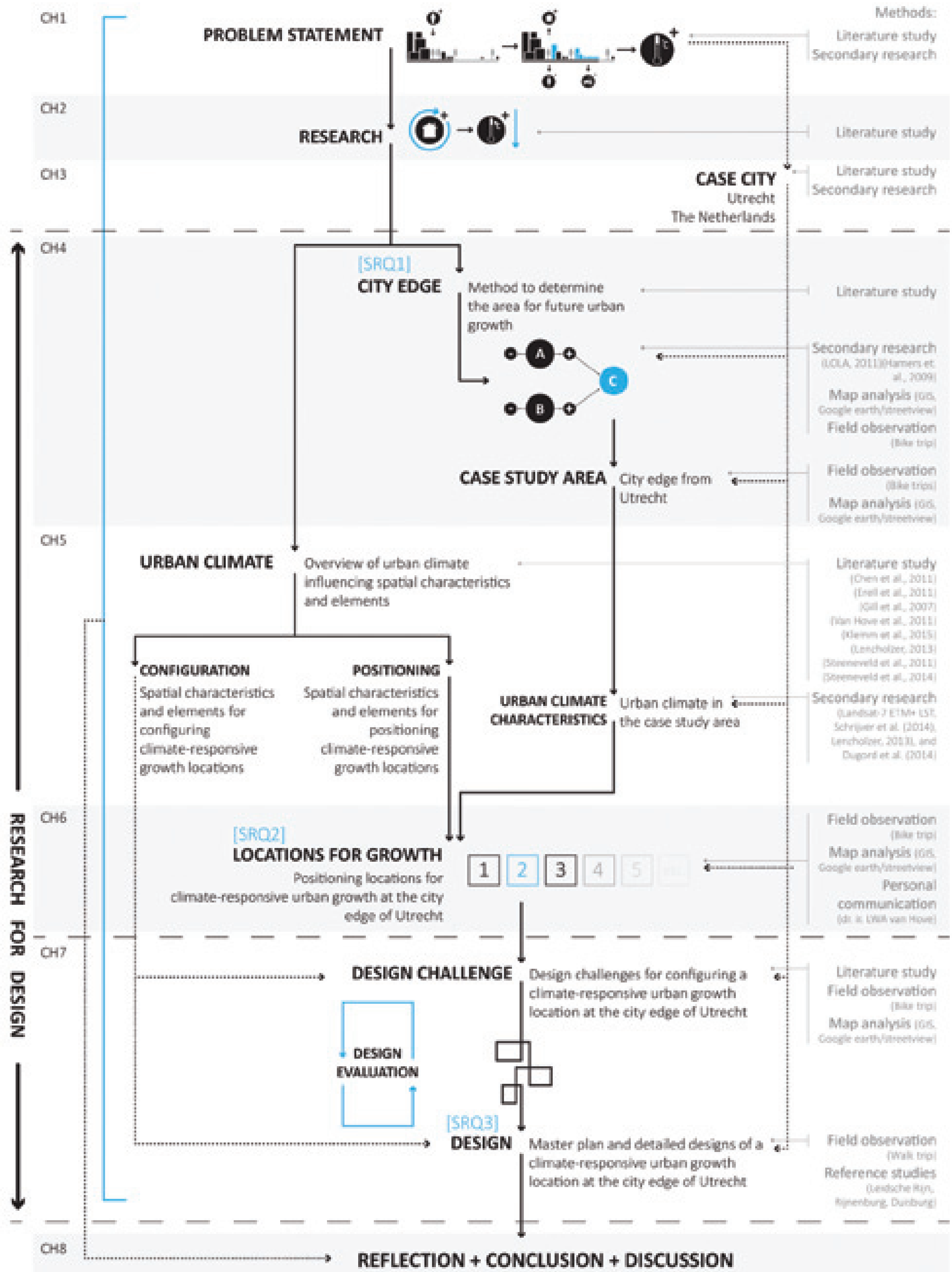
After generating the necessary knowledge and investigating locations for future urban growth. A third question did help to configure a location for climate-responsive urban growth.

The third question is: [SRQ3] *"How can existing urban climate knowledge be used for a climate-responsive configuration of an urban growth location?"* To answer this question, one of the growth locations for the city of Utrecht is worked out in a Master plan and related detailed designs. Step-by-step analysis on before extracted urban climate knowledge, did determine areas for future build-up surfaces and design challenges to promote and straighten thermal comfort for its future inhabitants.

The design shows the configuration of a growth location for the benefit of thermal comfort in the city of Utrecht. Evaluation of the design, based on urban climate knowledge, explains the validity of the configuration and the detailed designs visualize the implementation capability of the design.

The whole research outline, and related methods, is visualized in figure 2.2.

2.2
Research flowchart



2.5 Guide for the reader

The structure in this thesis report is as followed: Chapter 3 introduces case city Utrecht in which later chapters the different research concepts are tested on their validity. Chapter 4 presents the outcome of [SRQ1] in which the boundaries of the case study area are defined. Chapter 5 provides the results from the conducted literature study on urban climate knowledge and examines the urban climate in the case study area. In chapter 6, the outcomes from [SRQ1] and the result from literature study are combined in a step-by-step analysis for the positioning of locations for climate-responsive urban growth; the answer on [SRQ2]. Chapter 7 shows the configuration from one of these urban growth locations, [SRQ4]. Followed by the conclusions, recommendations, and reflection of this thesis in chapter 8.

3.0
Voordorpsedijk

3. Case study area Utrecht

Because of its predicted urban growth (Huisman et al., 2013), the city of Utrecht is introduced as the case study area in the first chapter. Next to a predicted growth, there are several more reasons for selecting this city for the investigation of locations for climate-responsive urban growth. The surrounding landscapes put a high pressure on the city edge and measurements show that the city deals with a relative high UHI effect (TNO, 2012). Together with an introduction of the city, these reasons will be explained in this chapter.

3.1 The city of Utrecht

Utrecht is the capital city from the same named province, situated in the middle of the Netherlands, and part of metropolitan area 'The Randstad'. The city of Utrecht forms in combination with the major cities Amsterdam, Rotterdam, and Den Haag, the largest metropolis of the Netherlands (see fig. 3.1). With a wide range of economic activities and more than 6.7 million inhabitants (41% of the Dutch population) on only 16% of the country, the Randstad area has the highest population density in the Netherlands (PURPLE, 2013).

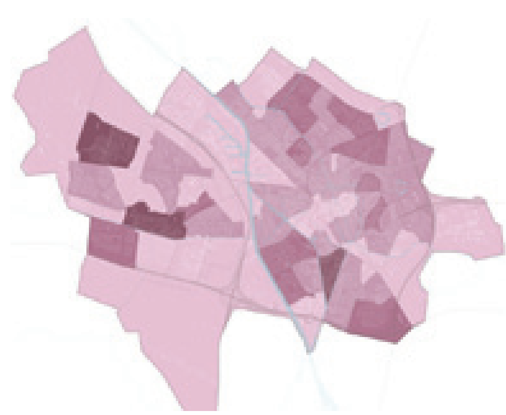
3.1
The location of Utrecht
The city is located in the middle of the Netherlands and part of the Randstad area.

3.2
Population density
Source: Schrijver et al. (2014)

- 0- 1000 inh./neighbourhood
- 1000- 5000
- 5000- 10 000
- 10 000+

3.3
Vulnerable group 0-11 years
Source: Schrijver et al. (2014)

- 0- 0.5 %
- 0.5- 1.5
- 1.5- 3
- 3- 5

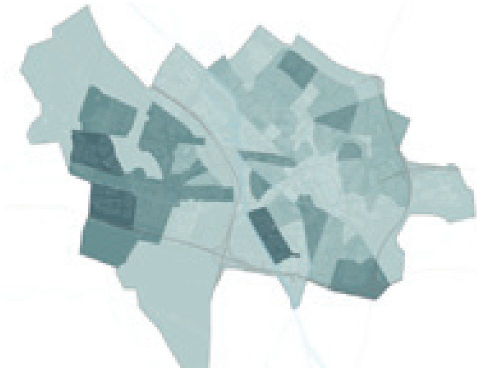


3.4
Vulnerable group 55+ years
Source: Schrijver et al. (2014)

- 0- 0.5 %
- 0.5 - 1.5
- 1.5 - 3
- 3- 5

3.5
Build surfaces
Source: Schrijver et al. (2014)

- 0- 10 %
- 10 - 20
- 20 - 40
- 40 - 90

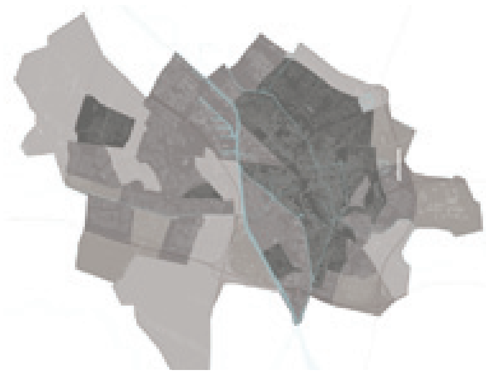


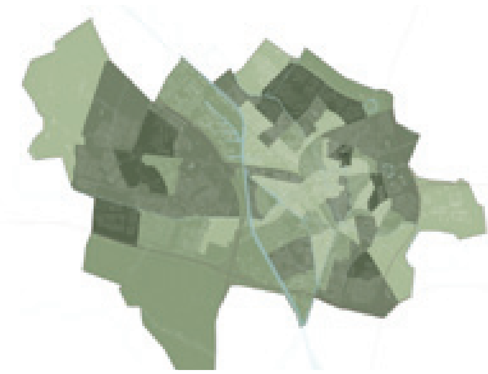
3.6
Paved surfaces
Source: Schrijver et al. (2014)

- 0- 10 %
- 10 - 20
- 20 - 40
- 40 - 90

3.7
Green surfaces
Source: Schrijver et al. (2014)

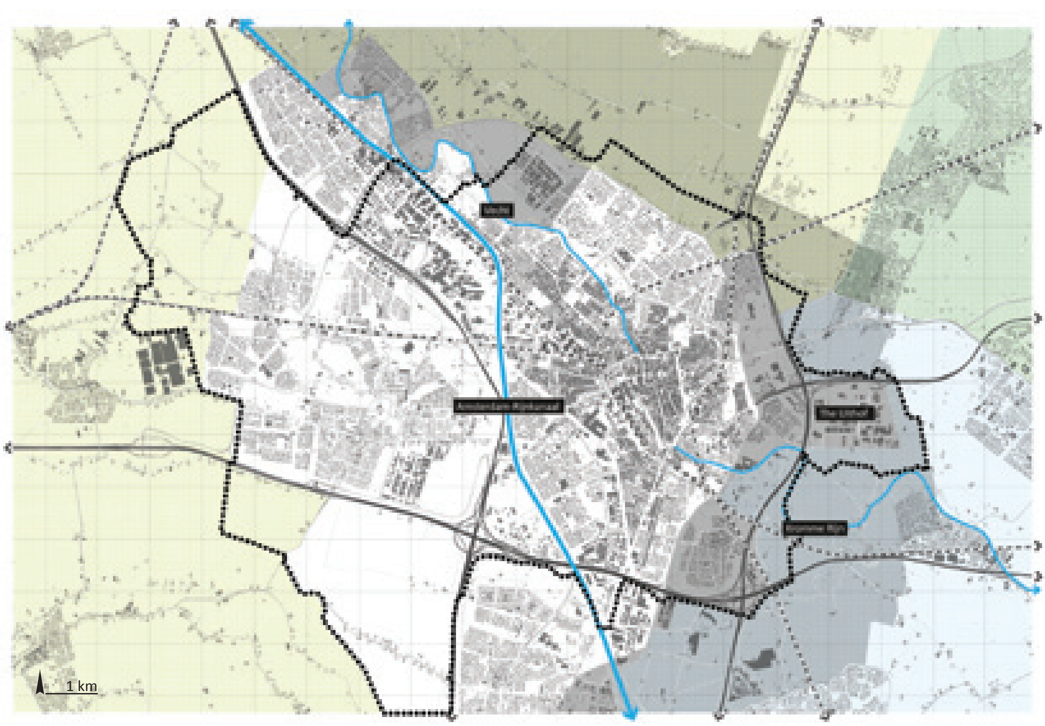
- 0- 5 %
- 5 - 10
- 10 - 20
- 20 - 60





3.8
Utrecht and its surroundings
Utrecht is surrounded by 4 valuable landscapes, including National landscapes; the Green Hart, the River landscape, and Dutch Water lines.

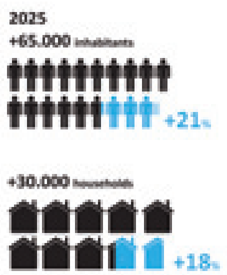
- Green Hart
- River landscape
- Utrecht Hills
- New Dutch Waterline
- Municipality border



The population density in the city of Utrecht is spread out (see fig. 3.2), with the highest building density in the city centre (see fig. 3.5). Population groups, vulnerable for high UHI values, mainly life in the outskirts of the city (see fig. 3.3 and 3.4). There, the highest value of green surfaces can be found and a low amount of paved surface (see fig. 3.6 – 3.7).

The surroundings of the city are part of different characteristic landscapes; the Green Hart, the River landscape, the Utrecht Hills, and the New Dutch Waterline (see fig. 3.8). Apart from the Utrecht Hills, these are all National Landscapes. Valuable landscapes, but separated from the city since infrastructures became dominant at the city edge. Only at some places, connections are formed by rivers (Kromme Rijn and Vecht), cannels (Amsterdam-Rijnkanaal), and urban expansions (The Uithof and Leidsche Rijn). The province sees opportunities to enhance the quality of the city edge by making it valuable and accessible to the residents of the city (Provincie Utrecht, 2013).

3.2 Urban growth through time

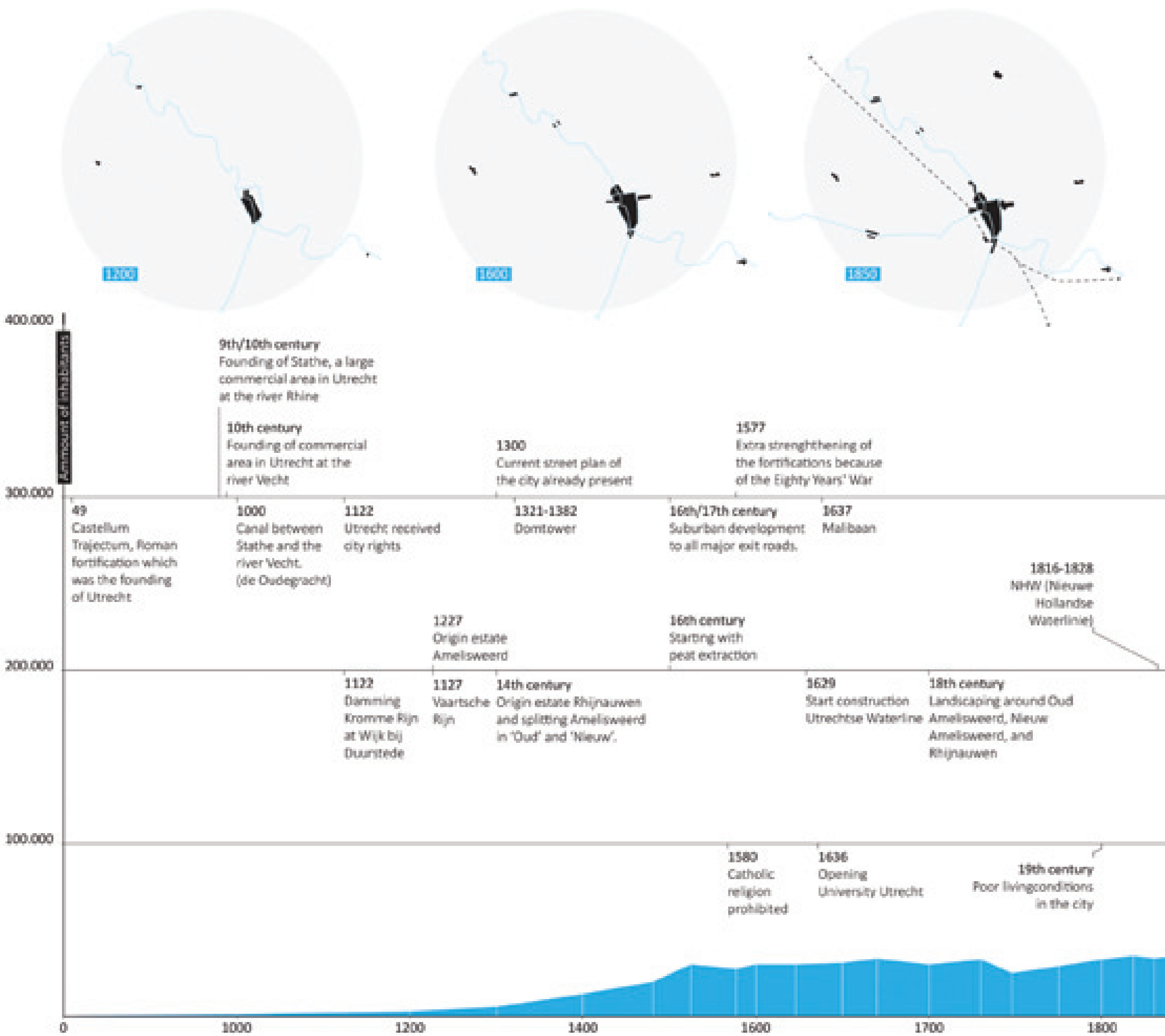


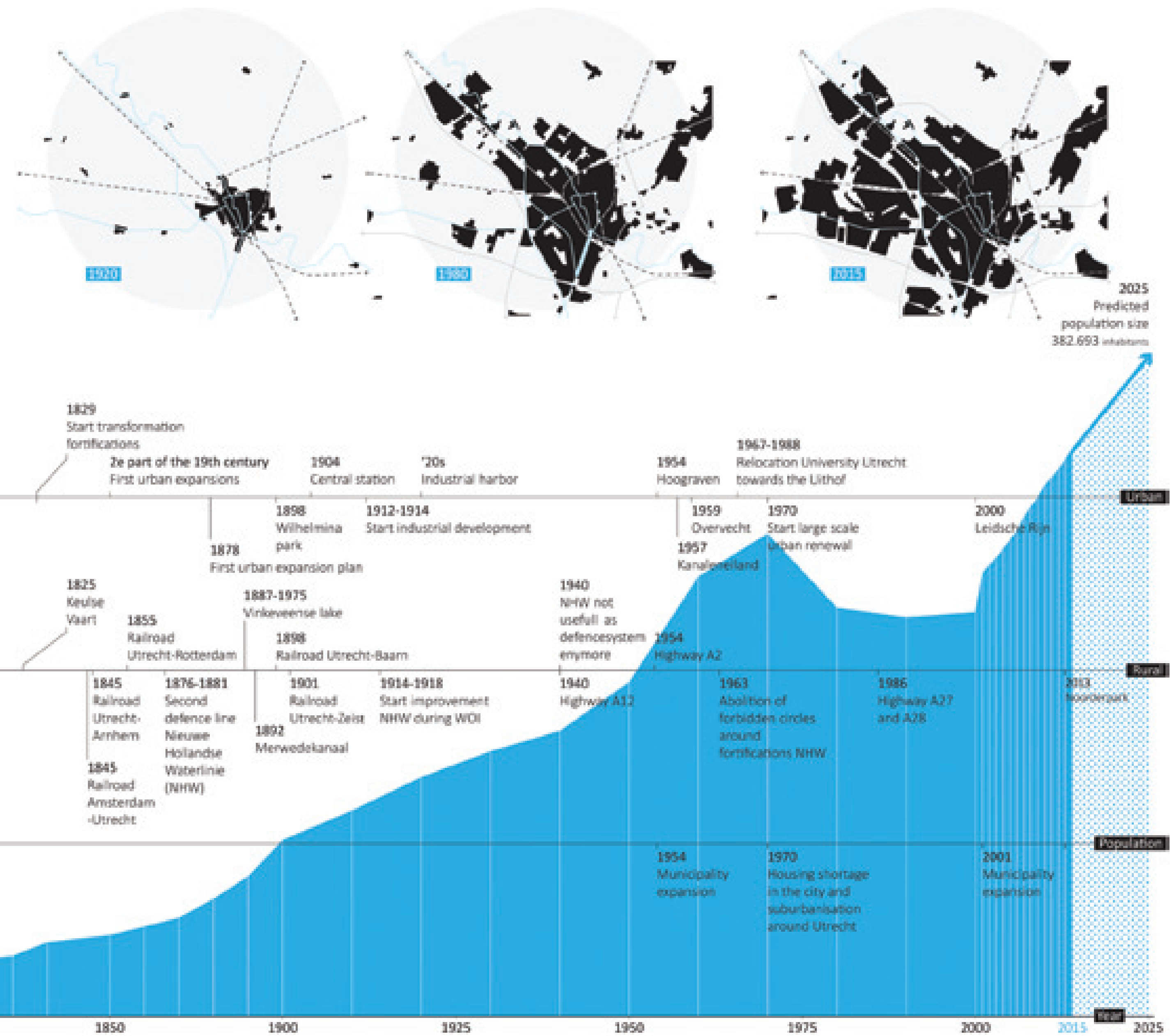
The founding of Utrecht goes back to the year 49 CE on the basis of a Roman fortification at the river Rhine (see fig. 3.9). In 1122 Utrecht received its city charter, which resulted in an acceleration of population growth and developments in and around the city (see fig. 3.9, page 28-29). Today, almost 20 centuries after its founding, the city is home to more than 330 thousand people and the fourth largest city of the Netherlands. Growth predictions (21% inhabitants and 18% households) describe it as the main growing municipality of the Netherlands for the upcoming years (Huisman et al., 2013).

The newest urban expansion of the city is the district Leidsche Rijn (Utrecht, 2014[1]). Construction of this expansion started in the year 2000 and will be, because of its size (100 thousand inhabitants), the main district to fulfil in the predicted growth (see fig 3.10). Next to Leidsche Rijn, the municipality did reserve more space for expansion with district Rijnenburg (7000 households). Due to stagnations in the housing market, the planning is interrupted since 2012 (Utrecht, 2014[2]).

3.10
Expanding Utrecht
Municipality border (blue dotted line) and urban expansions Leidsche Rijn and Rijnenburg.

3.9
The history of the city
The growth of the city true history and predictions for the future.



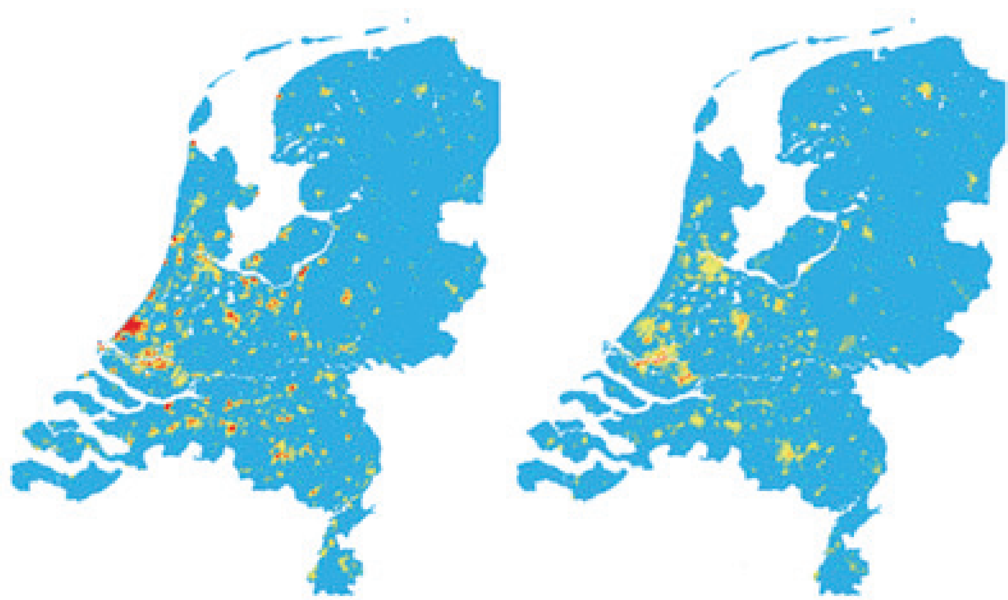

1920
1980
2015
2025
Predicted
population size
382.693
1829
Start transformation
fortifications
2e part of the 19th century
First urban expansions
1904
Central station
'20s
Industrial harbor
1954
Hoograven
1967-1988
Relocation University Utrecht
towards the Lithof
Urban
1898
Wilhelmina
park
1912-1914
Start industrial development
1959
Overvecht
1970
Start large scale
urban renewal
2000
Leidsche Rijn
1878
First urban expansion plan
1957
Kanaleneiland
1825
Keulse
Vaart
1855
Railroad
Utrecht-Rotterdam
1887-1975
Vinkeveense lake
1898
Railroad Utrecht-Baarn
1940
NHW not
usefull as
defencesystem
anymore
1954
Highway A2
Rural
1845
Railroad
Utrecht-
Arnhem
1876-1881
Second
defence line
Nieuwe
Hollandse
Waterlinie
(NHW)
1901
Railroad
Utrecht-Zeist
1914-1918
Start improvement
NHW during WOI
1940
Highway A12
1963
Abolition of
forbidden circles
around
fortifications NHW
1986
Highway A27
and A28
2013
Noorderpark
1892
Merwedekanaal
1845
Railroad
Amsterdam
-Utrecht
Population
1954
Municipality
expansion
1970
Housing shortage
in the city and
suburbanisation
around Utrecht
2001
Municipality
expansion
Year
1850
1900
1925
1950
1975
2000
2015
2025

3.3 The UHI effect in the city

TNO (2012) have researched the surface UHI effect for all Dutch cities. Surface temperatures in Dutch cities are during the day generally 2.9°C higher than outside the city, and 2.4°C during night time. High surface temperatures are mainly concentrated in the Randstad area, which can be explained by the higher density of build-up surface (see fig. 3.11).

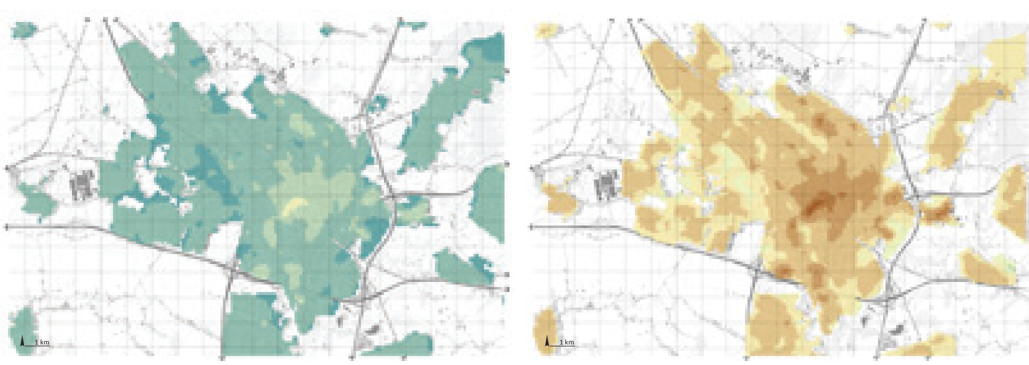
For the city of Utrecht is the surface UHI problem even higher. Utrecht is during day time, with a surface temperature difference of 4.8°C, the 7th warmest city in the Netherlands. During night time is Utrecht rated as 3rd with a surface temperature difference of 4.9°C (TNO, 2012). This means that Utrecht is, based on surface temperatures, one of the warmest cities in the Netherlands.

Also mobile measurements, carried out at a summer day (minimal 25°C), show an atmospheric UHI effect of 5.3°C during night-time in the city of Utrecht (Heusinkveld, 2013). This UHI effect can result in high night temperatures (minimal 20°C) that currently occur for one day to 1,5 week a year. Climate predictions for 2050 (according to the W+ scenario from KNMI'2014) show that this amount of high night temperatures will increase to 1,5 week to more than one month a year (KRA, 2015)(see fig. 3.12).



3.11
Surface UHI
Maps with surface temperature difference during day time (left) and night time (right). Utrecht is in bought situation high rated.
Source: TNO (2012)

- 0- 2 °C
- 2- 4
- 4- 6
- 6- 8
- > 8



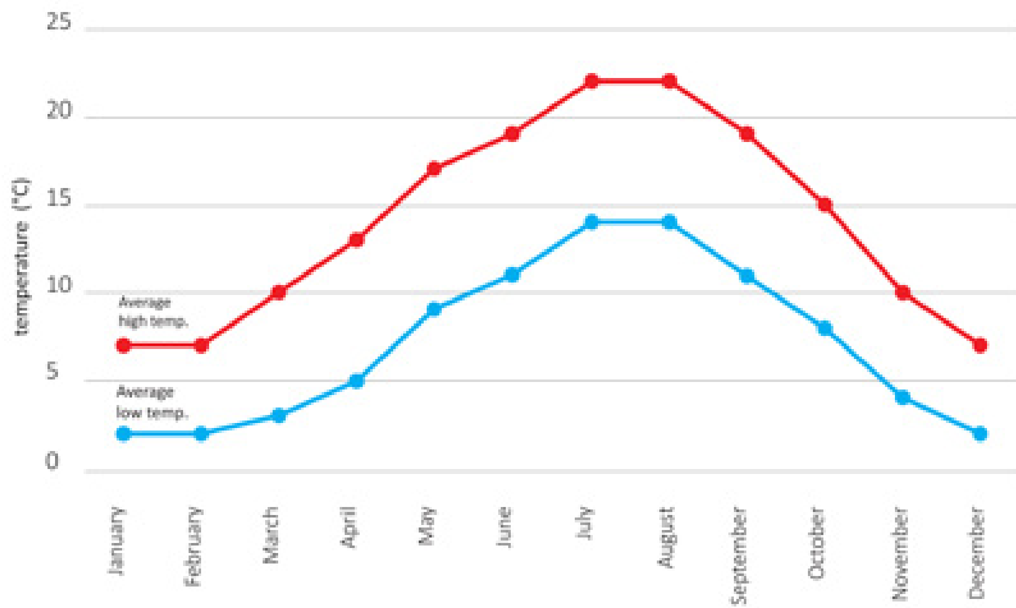
3.12
Increase amount of warm nights
Maps showing the predicted increase, according the W+ scenario from KNMI'14, of nights with a temperature above 20°C between now(2015) and the year 2050.
Source: based on Klimaat Effect Atlas (2015)

- 1 day
- 1 week
- 2 weeks
- 3 weeks
- > 1 month

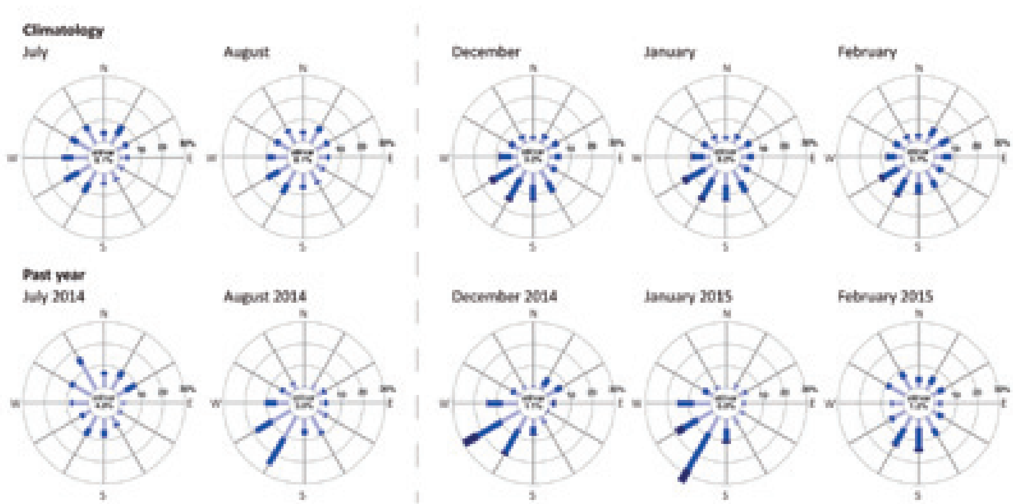
3.4 The general climate in the city

The Netherlands a temperate maritime climate influenced by the North Sea and Atlantic Ocean, with cool summers and moderate winters (WeatherOnline, 2015). For the city of Utrecht this climate results in an average temperature variation between 2°C and 22°C. July and August are the warmest months of the year, and December to February is the coldest period of the year (see fig. 3.13). So, thermally uncomfortable conditions can be expected to take mainly place in the months July and August.

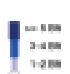
The general pre-dominant wind direction during the cold and warm months is South West. A direction which is better observable during the cold winter months, because the general wind speed is quite low during the warm months of the year. By comparing the climatological data with the wind data from the past year, it is evident that wind speed and direction can also vary (see fig. 3.14).



3.13
Average temperature graph for Utrecht
July and August are the warmest months of the year. The data for charts above are taken from year 2000 to 2012.
Redrawn from: http://www.worldweatheronline.com/Utrecht-weather-averages/Utrecht/NL.aspx



3.14
Wind roses
South-west is according to weather station De Bilt in general the main wind direction during the warm and cold seasons.
Source: http://www.knmi.nl/klimatologie/windrozen/index.cgi



4.0
Groeneweg

4. The edge of the city

Hamers et al. (2009) and LOLA (2013) did already mention the city edge as the area under pressure of predicted urban growth in the Netherlands. Next to that, urban growth from the city of Utrecht resulted in large urban expansions at the edge of the city. So, it would be helpful to define this edge for the investigation of locations for climate-responsive urban growth. But where does the city end? And where does the landscape start (see fig. 4.1)? This chapter introduces a method, based on existing methods, to determine the area in which future urban growth can be predicted. The method is developed for and applied to the city of Utrecht.

4.1
Part of Utrecht in bird's-eye view
Source: https://www.google.nl/maps

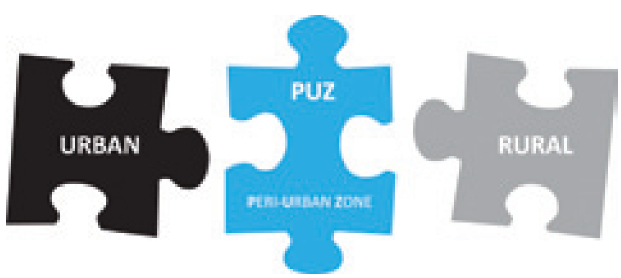
4.1 Definition of city edge

As long as there have been cities, there have been city edges. With every expansion in the history of a city, these edges are moved and formed by the prevailing movement in urban planning (LOLA, 2011)(see fig. 4.2-4.7). All these expansions together have formed a zone which describes a transition between the city and its surrounding rural land, which is in specialist terms called the peri-urban zone (PUZ).

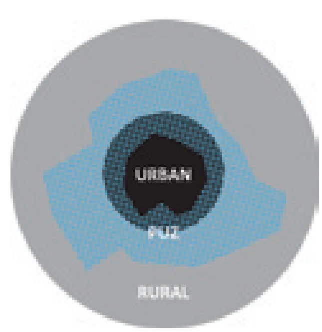
Many definitions for this PUZ occur, but all with a comparable explanation;

A transition zone, where urban and rural activities are juxtaposed, and landscape features are subject to rapid modifications, induced by human activities (Douglas, 2006). They are defined spatially and functionally by their intimate relationship with nearby urban metropolitan areas and the rural hinterland (Buxton et al., 2006), often a mixture of urban functions and rural morphology (Caruso, 2001). The PUZ is situated between 'real' urban and 'real' rural from which new urban and rural figurations change its boundaries. So, the PUZ is not a fixed zone (Hamers, et al., 2009)(see fig. 4.8 and 4.9).

Much is written about the presence of the PUZ around cities, its appearance, and its influence on both the city and the surrounding rural landscape. However, it is necessary to know its exact boundaries for determining the PUZ on the map and in the landscape.



4.8
Peri-urban zone (PUZ)
The PUZ is situated on the edge of the city, between 'real' urban and 'real' rural.



4.9
Peri-urban zone (PUZ)
A transition zone from urban to rural.

[background information]

The history of the city edge

Stages from the city edge of Utrecht through time, based on information from LOLA (2011).

4.2
Clear boundary between urban and rural
Utrecht 1570
Source: http://watwas-waar.nl/

Defensive 1500-1800
Cities arise because of the safe form of cohabitation. The edge, along with public buildings, squares and access roads, is the essence of the historical city. It is a defensive structure that forms the boundary between the outside world and the safe world inside. Outside the gates of the city were already typical suburban functions present.

4.3
First expansions
Utrecht 1874
Source: http://watwas-waar.nl/

Dismantling 1800-1900
Technical advances in warfare force to construct large-scale defenses, like the Dutch Waterline. Fortifications became superfluous and were dismantled to accommodate urban growth; city parks and residential areas. This period can be regarded as the beginning of the shifting city edge.

4.4
Workers district Tuindorp
Utrecht 1948
Source: http://watwas-waar.nl/

Early Modern 1900-1945
Industrial development resulted in a large influx of port and factory workers to the city. For housing, garden suburbs-and neighborhoods were developed at the outskirts of the city. Reflection on the development of the city and suburbs as an urban, demographic and economic whole did start as well in this period.

4.5
Gallery apartments
Overvecht, Utrecht 1970
Source: http://watwas-waar.nl/

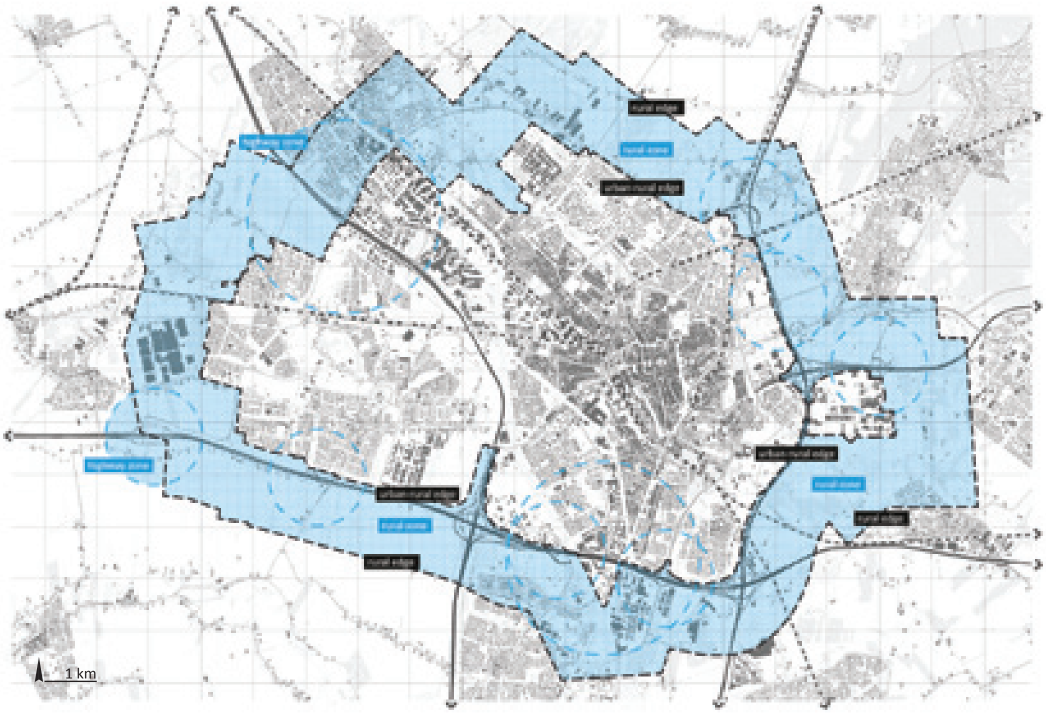
Reconstruction 1950-1970
Development of the city edge zone accelerated after World War II. New residential areas were developed as urban experiments with the idea of the open city. Spacious gallery apartments with views over the countryside, wide roads and lots of green.

4.6
Sharp edged district
De Meern, Utrecht 1988
Source: http://watwas-waar.nl/

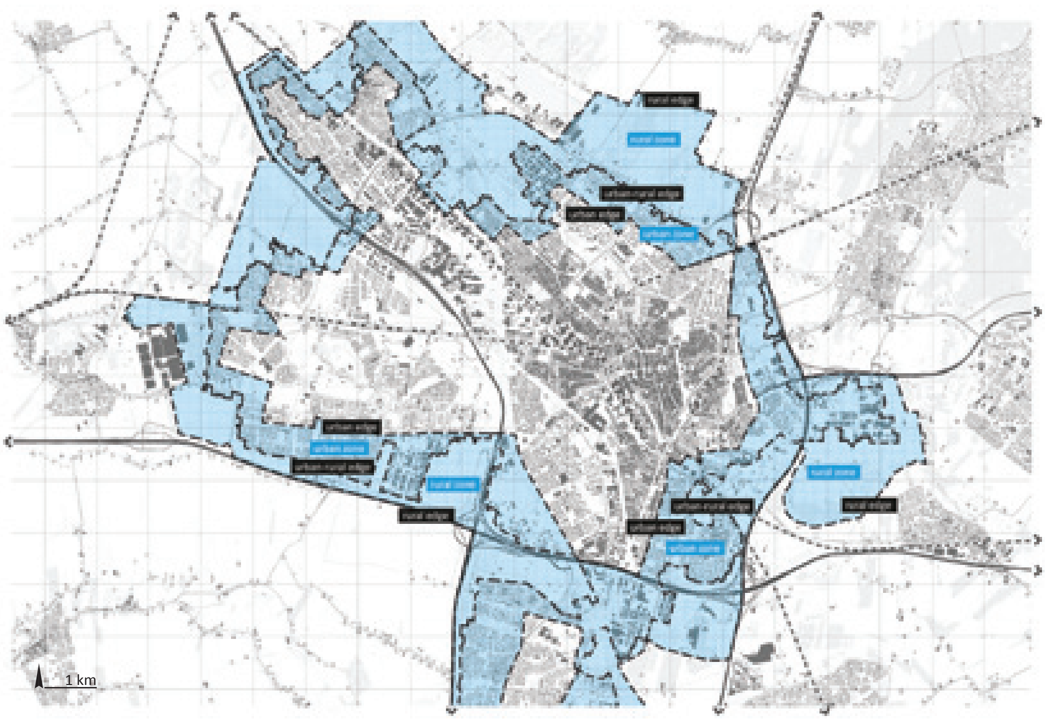
Sharp edges 1970-1990
Sharp edges were the result of physical doctrines and rules. The new middle class rises and displaces the gallery flats with terraced houses-with-garden, that tripled the need for space. This building density resulted in sharp boundaries between city and countryside.

4.7
Vinex district
Leidsche Rijn, Utrecht 2014
Source: https://www.google.nl/maps

VINEX 1990-2010
With the advent of the VINEX policy in the nineties, many residential districts have been designated at the outskirts of cities and villages. In addition, many business areas are realized in very accessible and on cheap land near highway exits at the city (Hamers et. Al., 2009).



4.10
PBL method
The result from the PBL method on the city of Utrecht.



4.11
LOLA method
The result from the LOLA method on the city of Utrecht.

4.2 Existing methods for determining city edges

In the conducted literature study are two methods found for the determination of the PUZ's boundaries. A method from Netherlands Environmental Assessment Agency (in Dutch: Plan Bureau voor de Leefomgeving, PBL) with a planning background and one with a landscape architectural background from LOLA Landscape Architects (both methods are described in Appendix II).

While carrying out both methods on the city of Utrecht (see fig. 4.9 and 4.10), the background differences became immediately clear. The planning method from the PBL can be carried out behind your desk and is not interacting with the underlying landscape. The landscape architectural method from LOLA is the opposite. Boundaries are defined by physical and spatial elements which you can see on the map, but have to experience in the landscape. The evaluation of both methods, in comparison to the working definition, did result in a list of advantages and disadvantages (see table 4.1). These advantages and disadvantages are used in the development of the working method.

Table 4.1
Advantages and disadvantages
The advantages and disadvantages from both methods.

	PBL method	LOLA method
Advantages	• A quick way to calculate the influence from the city on its rural surroundings. • A clear division between urban and rural, defined by the boundary build-up surface.	• Physical and spatial barriers makes it possible to determine the PUZ on a map and in the landscape. • The method describes a PUZ in which both – urban and rural – have an influence, which fit the working definition.
Disadvantages	• A general method that, apart from the highway junctions, does not include site specific influences. • The PUZ derived from this method can only be visualized on a map, the boundaries are not visible in the landscape. • The method only investigate the rural site of the PUZ, while the working definition also include a urban site.	• The edge between urban and rural (urban-rural edge) is hard to determine since it is unclear what the last buildings from the city is. • The urban part of the PUZ shows a shredded whole. Neighbourhoods are divided into pieces whether or not part of the PUZ. • The rural part contains a buffer zone between neighbourhood and highway at many sides. Utrecht shows with neighbourhood Leidsche Rijn and The Uithof, that highways do not form boundaries for urban expansion, so the influence of the city on the landscape can reach beyond the highway.

4.4 Determination of the city edge

A working method has been developed to determine a PUZ, that can be used in further research, without the before presented disadvantages. The working method is a step by step process, comparable to the method from LOLA (2011). The landscape architectural background of this method fits nicely with the study in this thesis, since this is a landscape architectural thesis. The practical way of determining certain edges in the PBL method is used to solve some of the disadvantages from the LOLA method.

The PUZ can be determined based on four steps. The first step marks the border between urban and rural. Step 2 and 3 determines the urban and rural part of the PUZ, which together form the PUZ in step 4. The method is carried out for the city of Utrecht and explains the method step by step.

Step 1: Marking the urban-rural edge

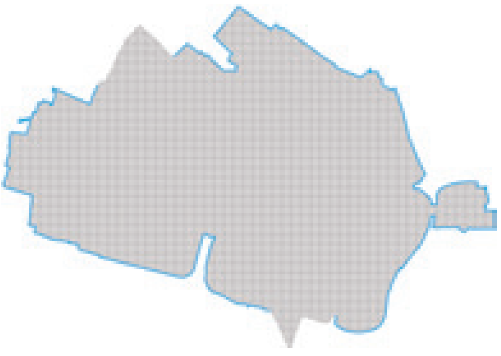
The urban-rural edge describes the border between the build-up city and the rural land. Because it is hard to define whether a building at the edge is part of the urban or the rural part (LOLA method), the urban-rural edge will be defined by the administrative border from the build-up area (PBL method). In some cases, the urban area is merged with another urban or suburban area. In that case, there is not an edge between urban and rural, so not an urban-rural edge (see fig. 4.12).

Step 2: Determining the urban part

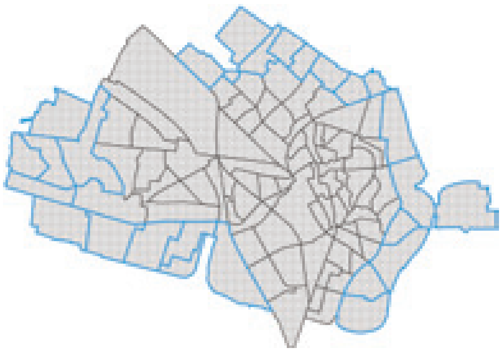
The urban edge forms de inner boundary and, together with the urban-rural edge, the urban part of the PUZ. To avoid a shredded urban part, as in the LOLA method, this method sees the urban part as the youngest ring of build-up surface. This ring is mostly formed by the newest neighbourhoods that represent the different stages in city edge development. On the basis of findings in the city of Utrecht, neighbourhoods do in most cases form an urban area with the same age, structure, and consist of clear boundaries; like district roads and canals (see fig. 4.13).

Step 3: Determining the rural part

The rural edge is marked by an edge, closest to the urban-rural edge, in the rural surroundings. Instead of locating the rural edge from the urban-rural edge (LOLA method), this method locates an edge within the rural surrounding. So, the PUZ will not stop directly at the highway and it also describes expansion opportunities outside the highway, like The Uithof.
The rural edge is determined as much as possible by physical and spatial barriers found in the rural surroundings of the city. Field observations around Utrecht did result in 10 typologies of barriers, which form together the rural edge from the PUZ (see fig. 4.14- 4.18). On places where no barrier was present, the shortest line between two barriers has been used. The area between the rural edge and urban-rural edge is the rural part from the PUZ.



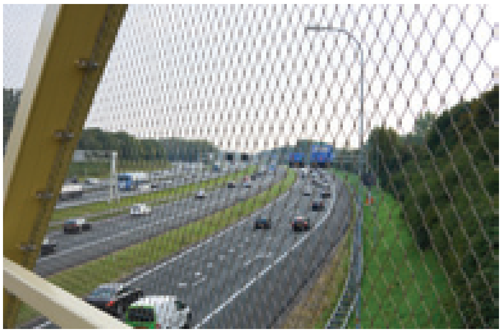
4.12
The urban-rural edge
The urban-rural edge (blue line) from the city of Utrecht



4.13
The urban edge
The urban part from the city of Utrecht, formed by the edge neighbourhoods (blue).

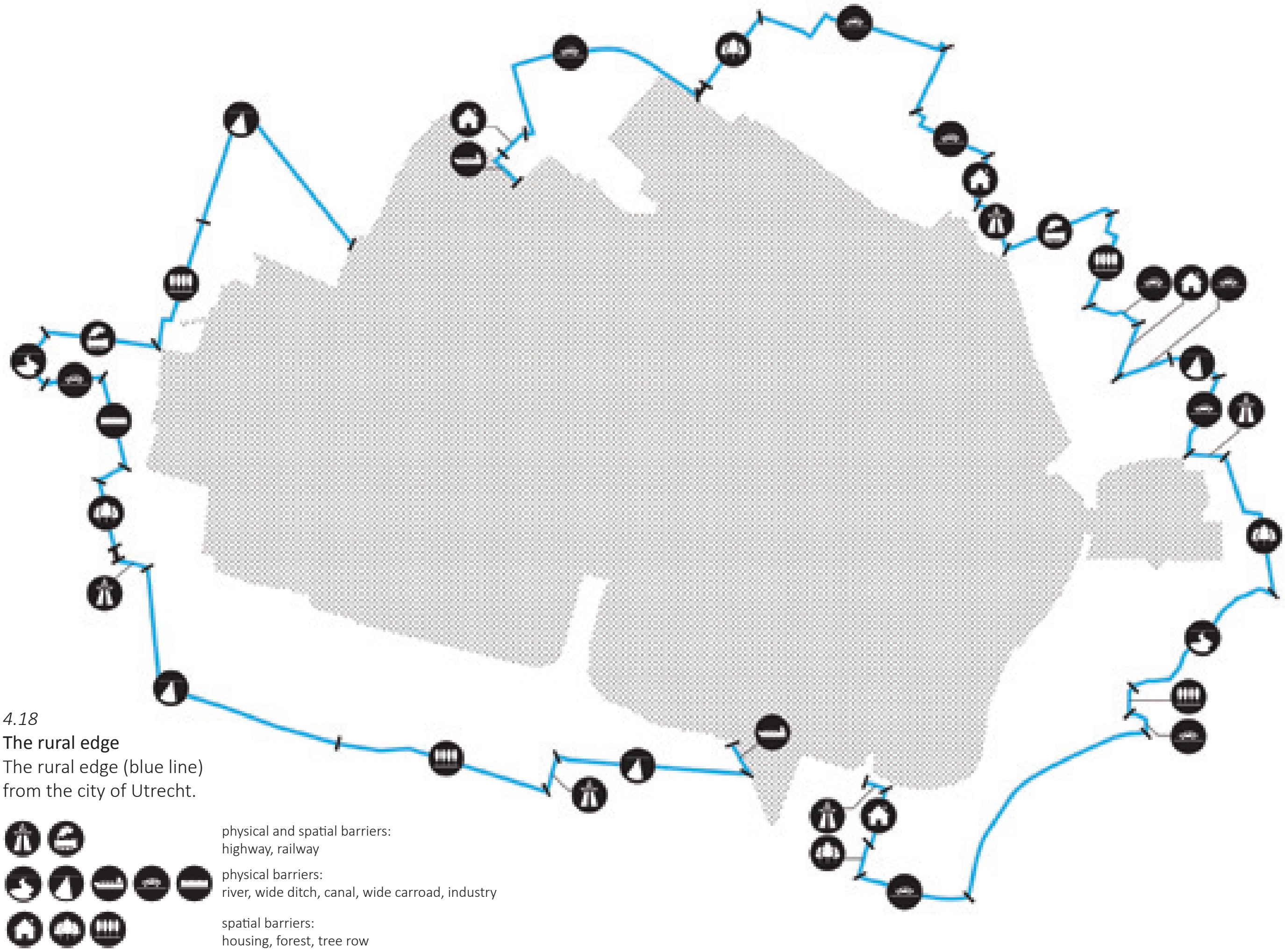
4.14
Physical and spatial barrier
Highway

4.15
Physical and spatial barrier
Railway



4.16
Physical barrier
River

4.17
Spatial barrier
Row of trees



4.18
The rural edge
The rural edge (blue line) from the city of Utrecht.

physical and spatial barriers: highway, railway

physical barriers: river, wide ditch, canal, wide carroad, industry

spatial barriers: housing, forest, tree row

Step 4: The PUZ from the city of Utrecht

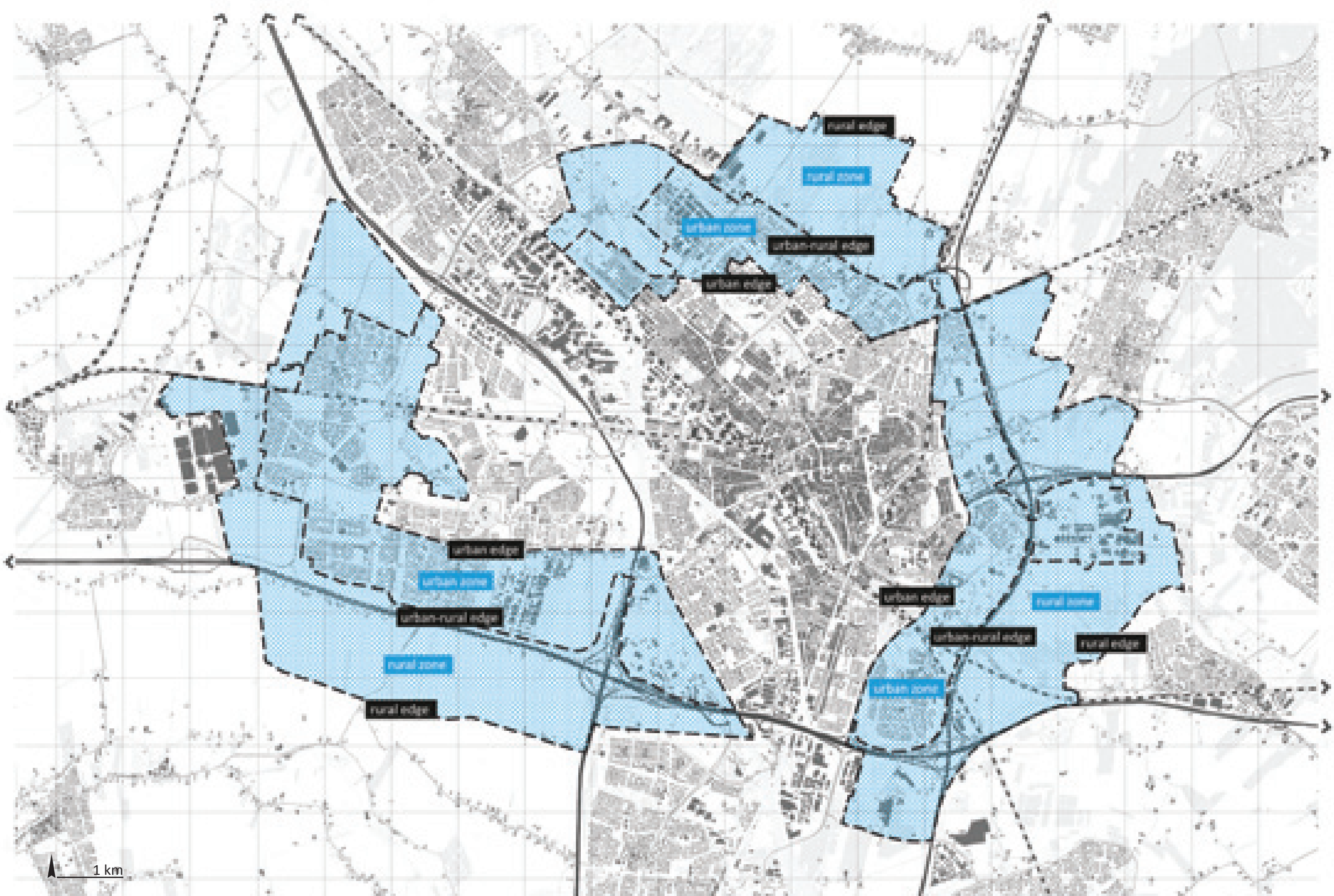
When all the edges are known, the PUZ can be marked by combining the urban and rural part. For the city of Utrecht, the result is a PUZ with a diameter between 0.5 and 4 kilometres. The city of Nieuwegein and the village Maarssen are dividing the PUZ into two zones; north-west and south-east (see fig. 4.19).

4.5 Synopsis

In this chapter, a working definition for the city edge – peri-urban zone (PUZ) – has been presented. Methods for the determination of a cities PUZ where found in literature. By the evaluation and observation of those methods in the case study area, advantages and disadvantages emerged. The (dis)advantages are used to develop an method which defines the boundaries of the PUZ.

The developed method improves the disadvantages from the LOLA method by using the practical way of thinking from the PBL method. The application of the method in the city of Utrecht did result in a PUZ with a diameter between 0.5 and 4 kilometre. This zone is used for the rest of the study as the case area in which climate-responsive urban growth will be investigated.

4.19
PUZ from Utrecht
Result from the working method on the city of Utrecht. The blue dotted area will be the case area in further research.



5.0
Strijkviertel

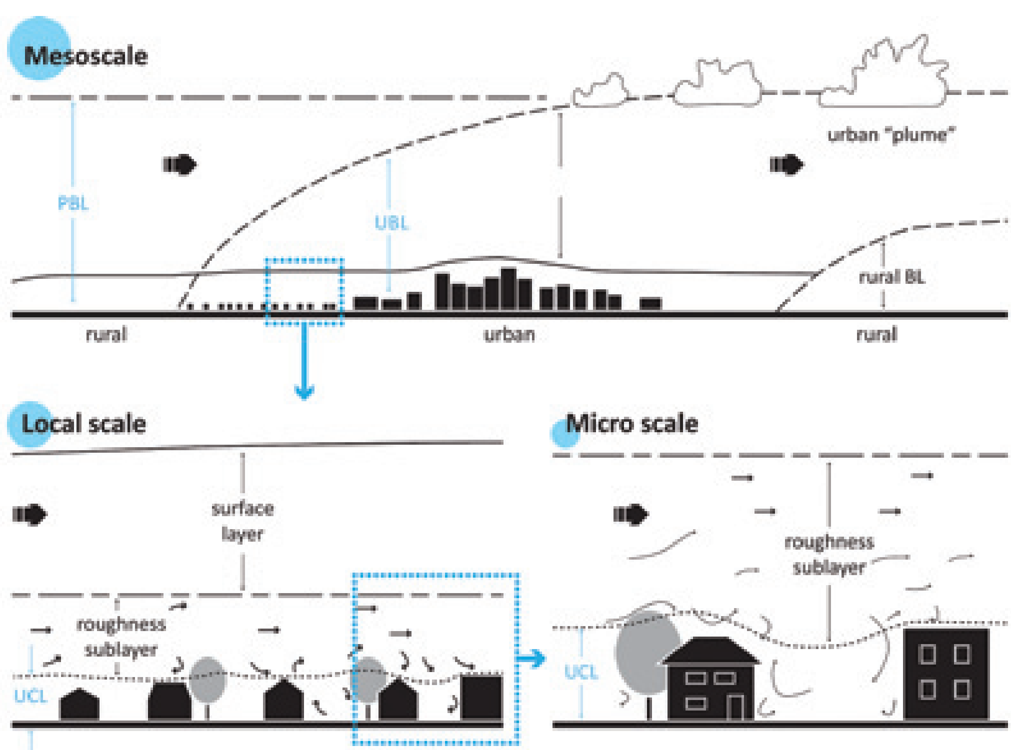
5. Urban climate and thermal comfort

The city edge form Utrecht is determined in the previous chapter, but more knowledge is needed when we want to investigate locations for climate-responsive urban growth within this case study area. That is why this chapter presents prior urban climate knowledge, climate expectations for Utrecht, and the results from a conducted literature study on urban climate influencing spatial characteristics and elements.

5.1 Scales in urban climate

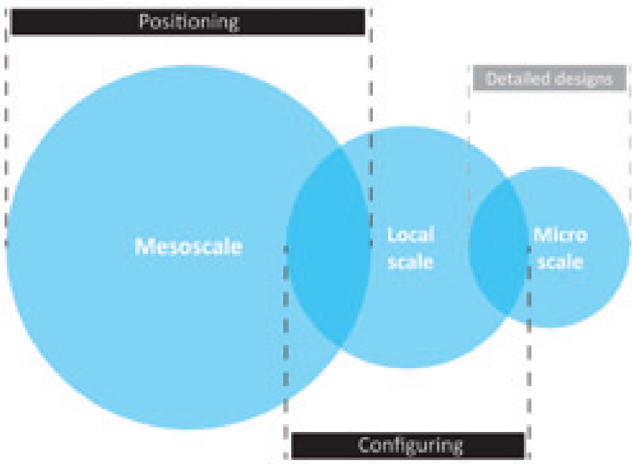
Urban climate phenomena play on various spatial scales, from human to city scale. These scales are used to distinguish atmospheric processes in urban areas and the related layers. Briefly, three horizontal scales can be distinguished in urban climate; *micro scale, local scales, and mesoscale* (Oke, 1988)(Van Hove et al., 2011)(see fig. 5.1).

The construction of new urban expansions does change non-built environments into built-up ones, which negatively affect the absorption and reflection of solar radiation (Bowler et al, 2010). This change will have a major influence on the urban climate. Design parameters – such as proportions of space, choice of materials, and the use of vegetation – can be used to positively influence the urban climate at the micro scale (Erell et al., 2011). So, these micro scale parameters are useful in the design of for example a climate-responsive street.



5.1
Scales in urban climate
Three scales used to distinguish atmospheric processes in urban areas and the related layers; PBL the planetary boundary layer, UBL the urban boundary layer, and UCL urban canopy layer. Bold arrows indicates the mean wind direction, and the smaller arrows shown indicate the mean and turbulent flow.
Redrawn from: Van Hove et al. (2011) and Erell et al. (2011)

Before implementing design parameters on street level, locations for urban growth have to be positioned and configured first. According to the challenge in this thesis, the positioning of new expansions should minimize the negative effects of urban growth on urban climate in the whole city. The urban climate in this case relates to the *Mesoscale level*, since this scale level describes the city's overall climate. Configuration of new locations for urban growth, to promote climate and inhabitant thermal comfort, relates to the *Local scale* that describes the climate at the neighbourhood scale. Boundaries in urban climate are not strict, so the scales for positioning and configuring climate-responsive urban growth will also overlap (see fig. 5.2).



5.2
Positioning and configuring
Overlap in scales for positioning and configuring locations for climate-responsive urban growth

[background information]

Scales in urban climate

On the basis of the classification from Oke (1988), three horizontal scales in urban climate and related vertical layers are described by Van hove et al. (2011)(see fig. 5.1):

Micro scale, street canyon or human scale
Scale of urban microclimate related to the dimensions of individual buildings, trees, roads, streets, courtyards, gardens etc. The urban canopy layer (UCL) is the related atmospheric layer from below the ground to the top of the trees and roofs. It is the layer of air in which the people live.

Local scale or neighbourhood scale
Includes landscape features such as topography, but excludes micro scale effects, and describes mean climate of neighbourhoods with similar types of urban development (surface cover, size and spacing buildings, activity). The related atmospheric layers are the UCL and urban boundary layer (UBL), starting from the surface with a maximum height of 1,5 km. The UBL is dividable into sub-layers; roughness sub-layer, surface layer, and mixed layer.

Mesoscale or city scale
The micro scale is affected by the local scale. In their turn, the local scale is affected by the mesoscale and the other way around. The atmospheric layer of this scale is the UBL that interacts with the planetary boundary layer (PBL), which is the lowest part of the atmosphere.

[background information]

Thermal comfort

UHI effects can result in thermal unpleasant conditions for humans. Conditions which can have a large influence on the liveability in urban environments, as described in the introduction (1.3.1). Thermal comfort plays mainly a role in the layer of air in which people live, the UCL.

A person might feel thermally uncomfortable when the energy received from the environment does not equals the energy loses from the body (Brown and Gillespie, 1995). Through extreme conditions, the thermal management of a human being can become unbalanced. This unbalance relates mainly to heat impact. You can dress or stay inside for cold, but heat is very difficult to avoid (Lenzholzer, 2013).

The main sources for heating a person are metabolic energy (body generated) and radiation (from the sun and surrounded objects). The main ways in which energy can be lost from a person's body are through evaporation (transpiration), convection (due to the wind) and radiation of the body itself. The energy streams together result in an energy budget of the body, or physiological equivalent temperature (PET, measured in °C) (Brown and Gillespie, 1995).

Neutral temperatures towards human perception differs from region and season, and different human activities require different thermal conditions (Nikolopoulou and Lykoudis, 2005)(Katschner, 2004). So, the urban environment with its many ongoing activities has to be organized for different needs.

5.2 The climate in the city edge from Utrecht

Research from TNO (2012) indicates, compared to other Dutch cities, relatively high surface urban heat island (SUHI) values for the city of Utrecht. SUHI's are measured on the basis of land surface temperatures (LST's). However, it is the air temperature which is the main factor of temperature perception (Lenzholzer, 2013).

Since air temperature data from the urban environment is hardly ever available, SUHI data is proved to be convenient for studying UHI on the large scale (Dugord et al., 2014). Figure 5.3 gives an indication of warm and cool areas in the city of Utrecht by showing the differences in LST. SUHI data give quickly an indication, but can be misleading and inaccurate at curtain points (see fig. 5.4).

The climatope map from the city of Utrecht (see fig. 5.5) is already providing more information. This map provides an indication of the climatic characteristics in and around the city (Lenzholzer, 2013). A useful differentiation, but still quite rough when zooming in on the PUZ. Data from Dugord et al. (2014) is therefore used to add more detailed information to this roughness by adding expected LST information per land-use type in the morning and evening. However, it should be taken into account that Dugord et al. (2014) does make use of LST's (see fig. 5.6-5.8).

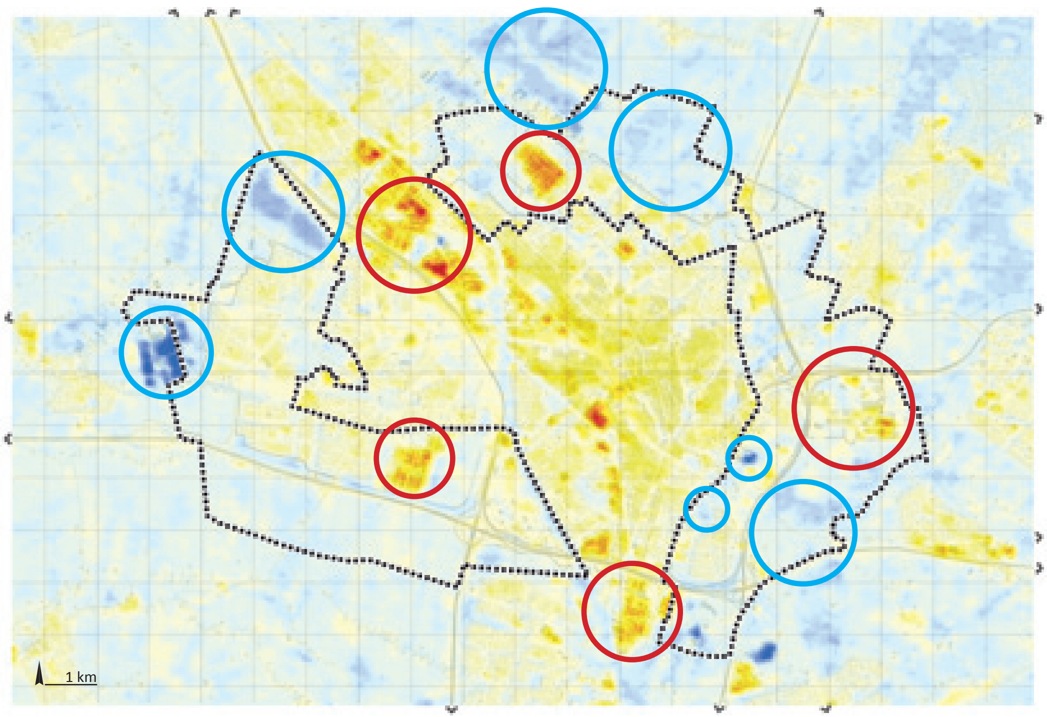
Roughly it can be concluded that the PUZ from Utrecht consist of *City edge and Garden city climatopes* at the urban site. Districts with a tempered temperature change and alternation of clear and limited cooling at night. Ventilation takes place in the *Garden city climatopes*, but is towards the *City edge climatope* curbed by buildings and vegetation. *Open landscape and Park climatopes* at the rural site exist of larger temperature changes per day. These climatopes produce cool breezes and there is space for free wind at the open landscape. The warmer *Business climatopes* in the PUZ warm according to the surface temperature methods as well. Water and forested surfaces are cooling during day-time, which is the result of grassland surfaces at night.

[Intermezzo]

Landsat data from Utrecht

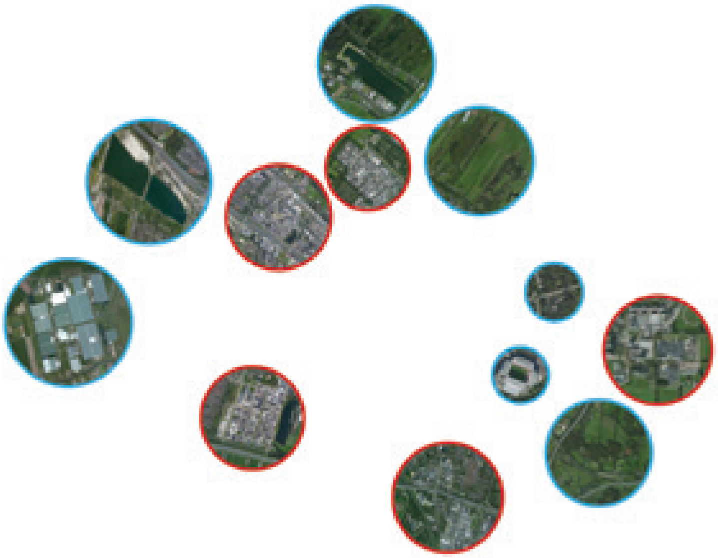
SUHI's in the city of Utrecht are indicated by using Landsat-7 ETM+ LST data (see fig. 5.3). On the map, the differences in LST are easily recognizable. In general , the LST within the city are higher than from the rural surroundings. High temperatures can be found at the industrial areas which are the opposite from the cool forest and water areas (see fig. 5.4).

At some points, the LST is misleading. For example, the glasshouses in the west turn blue on the map, but glasshouses in general produce much heat. It is because of the material (glass) that the LST is low, but this does not mean that the air temperature is cool above the surface. Also, the moment in time when the map is produced has influence on the outcome. The water surface turns out to be cooler than its surroundings at this map (10:24am), but during night times – especially during warm periods – water can heat its surroundings (Steeneveld et al., 2014). So, the interpretation of Landsat data can be misleading.



5.3
LST on the basis of Landsat data
Map with the different LST in Utrecht on 6 September 2010, at 10:24:06AM. Global temperature difference of 16°C – 50 °C. Red: area with high LST. Blue: area with low LST.
Source: Landsat-7 ETM+ LST data derived from http://glcfapp.glcf.umd.edu:8080/esdi/index.jsp

PUZ border

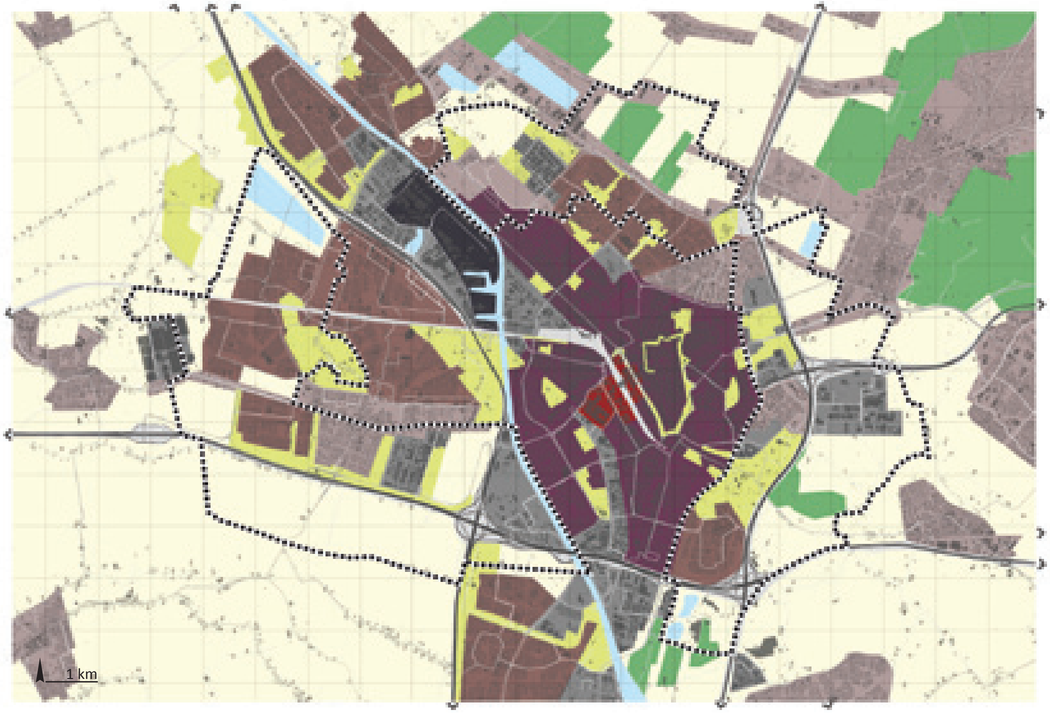


5.4
Cool and warm spots
Actual situation from cool and warm spots.
Satellite image derived *from http://www.bing.com/maps/*

[background information]

Climatope map from Utrecht

A climatope map provides an indication about the climatic characteristics of the urban environment. The concept of climatopes means that different types of areas and neighbourhoods have specific microclimatic characteristics. Microclimate characteristics are determined by for example; building structures, vegetation, paved areas, and water bodies (Lenzholzer, 2013). For Utrecht the climatope analysis did result in 11 different climatope typologies (see fig. 5.5). An explanation of the different climatopes can be found in Annex II.



5.5
Climatope map
Map with the different climatopes in the city of Utrecht.

- City centre climatope
- City climatope
- Garden city climatope
- City edge climatope
- Forest climatope
- Park climatope
- Open landscape climatope
- Business climatope
- Industry climatope
- Infrastructure climatope
- Open water climatope
- PUZ border

[background information]

LST per land-use type

An investigation method from Dugord et al. (2014) is used to investigate the LST at the PUZ more detailed. Dugord et al. (Idem) investigated the LST distribution, with regard to underlying land-use typologies, to help identifying areas at potential risk towards heat in the city of Berlin. They compared the mean LST per land-use type with the total mean LST in the city. The outcome resulted in an overview of positive and negative effects, in temperature, from different land-use types on the mean LST in the city of Berlin at 10am and 10pm. These outcomes are more accurate than those from Landsat data, since they describe the influence per land-use type at two moments of time during the day.

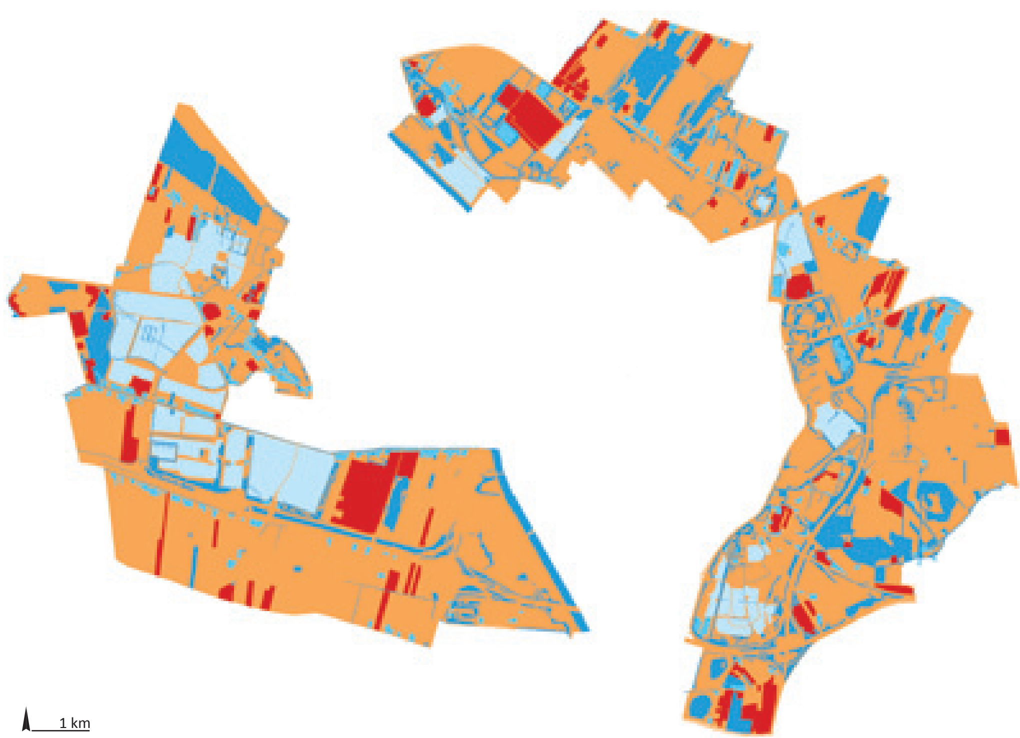
The data from Dugord et al. (2014) has been used to investigate the LST in the PUZ from the city of Utrecht. First of all, the land-uses at the PUZ are divided according to the typologies their (see fig. 5.6). The residential areas are divided on the basis of floor area ratios (FAR), that represents the total area of built floors divided by the area of the considered parcel (Dugord et al., 2014).

Then, the outcomes from Dugord et al. (2014) have been used to show the impact of the different land-use types on the mean LST. This has been done for the situation at 10am (see fig. 5.7), and 10pm (see fig. 5.8).

At 10am, we see high influence on the mean LST in the city from the industry and agriculture surfaces. Surfaces lowering the mean LST are water, forested green spaces and in lesser extent, residential areas with a relative low FAR. In the evening (10pm) is a high influence recognizable from water, transport infrastructures, and residential areas. The high LST from grasslands in the morning are changed in cool LST. Grasslands are warming during the day, but quickly lose their heat during the evening and night (Lenzholzer, 2013).

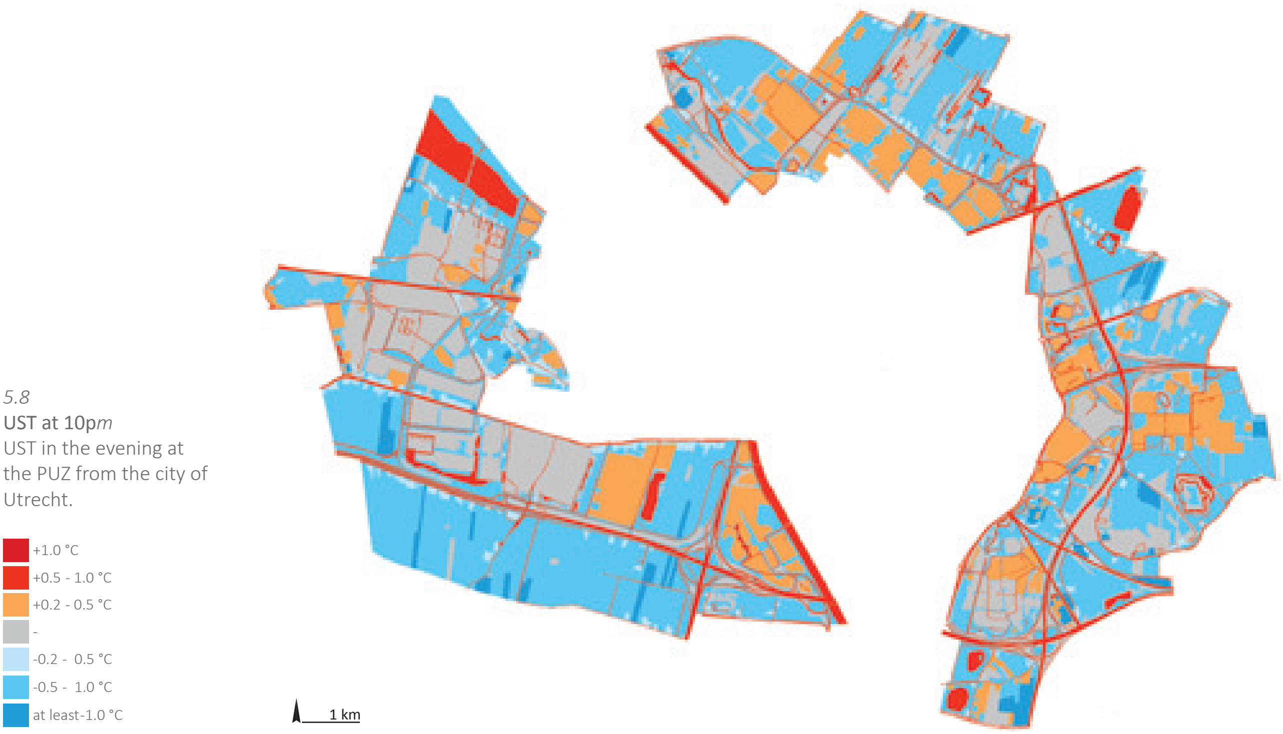
5.6
Land-use typologies
The different land-use typologies at the PUZ from the city of Utrecht.

- Residential W2
- Residential W3
- Residential W4
- Forested green space
- Non forested green space
- Agriculture
- Industry
- Allotment garden
- Public-private facility
- Water
- Urban brownfield
- Transport infrastructure



5.7
UST at 10am
UST in the morning at the PUZ from the city of Utrecht.

- +1.0 °C
- +0.5 - 1.0 °C
- +0.2 - 0.5 °C
- -
- -0.2 - 0.5 °C
- -0.5 - 1.0 °C
- at least-1.0 °C



5.8
UST at 10p*m*
UST in the evening at the PUZ from the city of Utrecht.

5.3 Influences on urban climate

A description of climate difference within the PUZ is not enough for the design of climate-responsive urban growth locations. More knowledge is needed, existing knowledge about the influence of spatial characteristics and elements on the urban climate. Spatial characteristics and elements, because the positioning and configuration of locations for urban growth is a spatial integration and are the tools from a landscape architect in this kind of challenges. Spatial characteristics describes spaces with the same typology or characteristics of typologies, for example a park or the wind in an open landscape. Spatial elements are single elements with a spatial influence, such as trees or a dike.

For the use in this thesis, 8 sources have been investigated to extract those influencing characteristics and elements; Chen et al. (2011), Erell et al. (2011), Gill et al. (2007), Van Hove et al. (2011), Klemm et al. (2015), Lenzholzer (2013), Steeneveld et al. (2011), and Steeneveld et al. (2014). These sources are well known within the Wageningen university and have been selected on relevance and year of publication, which provides up to date data.

After the literature study, the findings could be categorized in; greenery, wind, water, and urban geometry. Greenery describes all the spatial characteristics and elements related to vegetation. Wind itself is a spatial characteristic, but can be influenced by different elements. Water is an element that can have different characteristics, and the urban geometry consist of both; spatial characteristics and elements that influence the urban climate. In the following paragraphs are the findings from the different categories summarized.

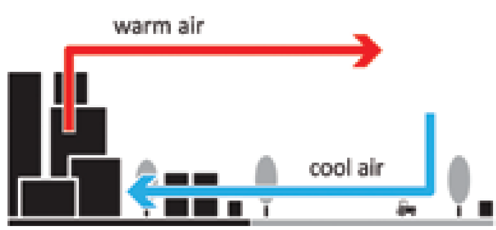
5.3.1 Greenery

Urban green space improve thermal comfort in physical as well as in psychological terms (Klemm et al., 2015). All the green space in the city describe the green infrastructure of a city. This green infrastructure is one of the most promising opportunities for climate adaptation, from the small courtyard to the urban scale (Gill et al., 2007).

Vegetation is cooling the air temperature through evaporation of water (Van Hove et al., 2011). It is because of this evaporation that urban greenery has a large impact on the urban climate and makes vegetation coverage an effective measure to mitigate strong urban heat islands (Steeneveld et al., 2011). Parks maintain and increase the vegetation coverage in the city and are often described as cool islands within the urban structure (Steeneveld et al., 2011). Different types of vegetation have different effect on the climate. For example, grass is cooling at night-time while trees are cooling the air during the day. Besides, trees can also provide a welcome shade (Lenzholzer, 2013) (Van Hove et al., 2011).

5.3.2 Wind

The 'cliff' to the urban climate is especially marked on the windward urban-rural boundary (Oke, 1982). This is due to the cooler air derived from the rural surroundings, entering of regional wind can therefore be used to cool the air in the city. The same counts for wind from the direction of a park that is cooling the air temperature in its surroundings (Van Hove et al., 2011). Wind does not only have positive effects, positions and dimensions of buildings and streets can influence the airflow which result in uncomfortable wind patterns and velocities (Lenzholzer, 2013).
Besides wind, thermal breeze can reduce the air temperature in the urban environment as well (Erell et al., 2011). Thermal breeze can be described as a slow airflow that arise between cooler and warmer areas (Lenzholzer, 2013), when the mean wind speed is low (Hidalgo et al., 2008) (see fig. 5.9). Especially during night-time, when air and surface temperature differences are the largest, breezes are plausible (Erell et al., 2011).



5.9
Thermal breezes
Slow airflow between cooler and warmer areas, when the mean wind speed is low.

5.3.3 Water

Water can absorb heat and therefore is not always an cooling element. It absorbs heat during the day and releases it during the night, what can have a warming effect on its surroundings (Van Hove et al., 2011) (Steeneveld et al., 2014). Flowing water has therefore a larger cooling effect than still water, but the main positive point from waterbodies is its free wind path (Van Hove et al., 2011), or as 'heat escape area' when the water body has a recreational function (Lenzholzer, 2013). The best cooling effect from water is on the smaller scale, due to evaporation or in other dispersed forms (Van Hove et al., 2011).

5.3.4 Urban geometry

Higher population densities related to higher UHI effects, because more population generally result in higher values of build-up surface (Steeneveld et al., 2011). Also typologies or field functions related to warmer or cooler climates (Lenzholzer, 2013). This is already described and discussed in the before presented climatope map (see fig. 5.5). The climatope differences affect the urban-rural temperature difference, which promote thermal breeze if the edge is free from wind barriers (Lenzholzer, 2013). Height to width ratio, position on wind direction, and the length of a street influence the climate on smaller scale, for example in streets (Lenzholzer, 2013).

5.3.5 Categories vs. urban climate scales

Within the before described four categories is tried to make a division on the basis of the different scale levels in urban climate; micro-, local-, and mesoscale (see fig. 5.10). For example, regional wind has the main effect on the mesoscale while thermal breeze influence the local- and micro scale.

The presented knowledge can be seen as the starting point for reaching the key aspects in the design of locations for climate-responsive urban growth. Spatial characteristics and elements which fits the mesoscale, and in lesser extent local scale, are used to investigate locations for urban growth (chapter 6). Local- and micro scale characteristics and elements are used for the configuration of urban growth locations (chapter 7).

	Mesoscale	Local scale	Micro scale
Greenery			
Vegetation coverage	✓	✓	✓
Park cool islands	✓	✓	☐
Green infrastructure	✓	✓	✓
Psychological cooling effect	✓	✓	✓
Vegetation typology	☐	✓	✓
Wind			
Cool winds	✓	✓	☐
Ventilation excess	✓	✓	☐
Thermal breeze	☐	✓	✓
Water			
Flowing water	✓	✓	☐
Recreational water	✓	✓	✓
Evaporation	☐	☐	✓
Urban geometry			
Population density	✓	✓	☐
Surface typology	✓	✓	✓
Edges	✓	☐	☐
Height to width ratio	☐	☐	✓

5.10
Overview results literature study
Founded spatial characteristics and elements are categorized in greenery, wind, water, and urban geometry, with a division in their influence on micro-, local-, and mesoscale.

5.4 Synopsis

This chapter has described the scales and layers in the urban climate, which introduced the next steps in further investigation. Extensive literature research resulted in the knowledge, about climate influencing spatial characteristics and elements, for the positioning (chapter 6) and configuration (7) of locations for urban growth in the city edge of Utrecht. This knowledge can be seen as the starting point for the key aspects in the design of climate-responsive urban growth.

6.0
Veldhuizen

6. Positioning growth in the city of Utrecht

After understanding levels and layers in urban climate, in combination with the determined city edge, possible locations for climate-responsive urban growth are designated within Utrecht's PUZ. This chapter describes on the basis of found spatial characteristics in chapter 5, a step by step analysis to investigate locations for climate-responsive urban densification and expansion.

6.1 Positioning locations for climate-responsive urban growth

The investigation of locations for climate-responsive urban growth contains five steps of analysis. The subject of analysis in each step is based on results from the literature study in chapter 5 (see fig. 5.8), supplemented with more specific information from other literature. The key aspect from literature are;

- *Support, preserve, and strenghten the green infrastructure of a city.*

- *Safe wind corridors and support thermal breeze.*

- *Indicate large waterbodies and flowing water.*

- *Indicate and analyse areas for densification, wind barriers, and urban-rural edges.*

Case specific urban climate information and results from spatial analysis function as background information in certain steps, such as wind directions, climatope information and build-up surfaces percentages.
Step 1 till 4 contain individual influences on the urban climate. In step 5, the previous steps are combined to determine locations for densification and expansion. These locations are planned for the purpose of housing. To verify, the investigation has been discussed during a expert advice with dr. ir. LWA van Hove (personal communication, November 20, 2014)(assistant professor at Wageningen university; Earth system sciences, meteorology and air quality).

[background information]

Characteristics and elements for positioning
Overview of climate influencing spatial characteristics and elements that can steer the positioning of locations for climate-responsive urban growth.

Greenery
Support, preserve, and strenghten the green infrastructure of a city. The green infrastructure is described as one of the most promising opportunities for climate adaptation (Gill et al., 2007). Especially because of the cooling effect from vegetation, from microscale to mesoscale, by the evaporation of water (Chen et al., 2014)(Van Hove et al., 2011). Next to that, green spaces can improve thermal comfort in psychological term as well (Klemm et al., 2015).

Wind
Safe wind corridors and support thermal breeze. The 'cliff' to the urban climate is especially marked on the windward urban-rural boundary (Oke, 1982). So, regional winds can therefore be used to cool the air in the city. The same counts for wind from the direction of a park that is cooling the air temperature in its surroundings (Van Hove et al., 2011). Thermal breezes reduce the urban-rural temperature difference with its slow airflow between cooler and warmer areas (Erell et al., 2011)(Lenzholzer, 2013).

Water
Indicate large waterbodies and flowing water. Water can absorb heat and therefore is not always an cooling element. During the night, this absorbed heat can have a warming effect on its surroundings (Van Hove et al., 2011)(Steeneveld et al., 2014). Flowing water has therefore a larger cooling effect than still water, but the main positive point from waterbodies is its free wind path (Van Hove et al., 2011). Recreational waterbodies can function as a 'heat escape areas'(Lenzholzer, 2013).

Urban geometry
Indicate and analyse areas for densification, wind barriers, and urban-rural edges. Higher population densities related to higher UHI effects, because more population generally result in higher values of build-up surface (Steeneveld et al., 2011). Also typologies or field functions related to warmer or cooler climates (Lenzholzer, 2013). This all affect the urban-rural temperature difference, which promote thermal breeze if the edge is free from wind barriers (Lenzholzer, 2013).

6.1.1 Step 1: Defining open areas

The first step locates open space, because you simply need available space for the construction of new urban expansion. By studying the map, the non-build areas within the city edge can be determined. For example, open areas are brownfields, grass- and agricultural land. The size of these areas should be large enough for building a neighbourhood, because this investigation is on the city scale. This means that small open spaces, like neighbourhood parks, are not included. Single houses and farms at the rural site are categorized as open space as well.

Besides open spaces, this step localizes low density neighbourhoods. Rebuild of these neighbourhoods in a higher density can decrease the amount of necessary new build-up surface. However, peri-urban neighbourhoods are mostly relatively young so they do not quickly qualify for redevelopment. Furthermore, redevelopment of old industrial areas for instance can also be an opportunity to locate predicted urban growth.

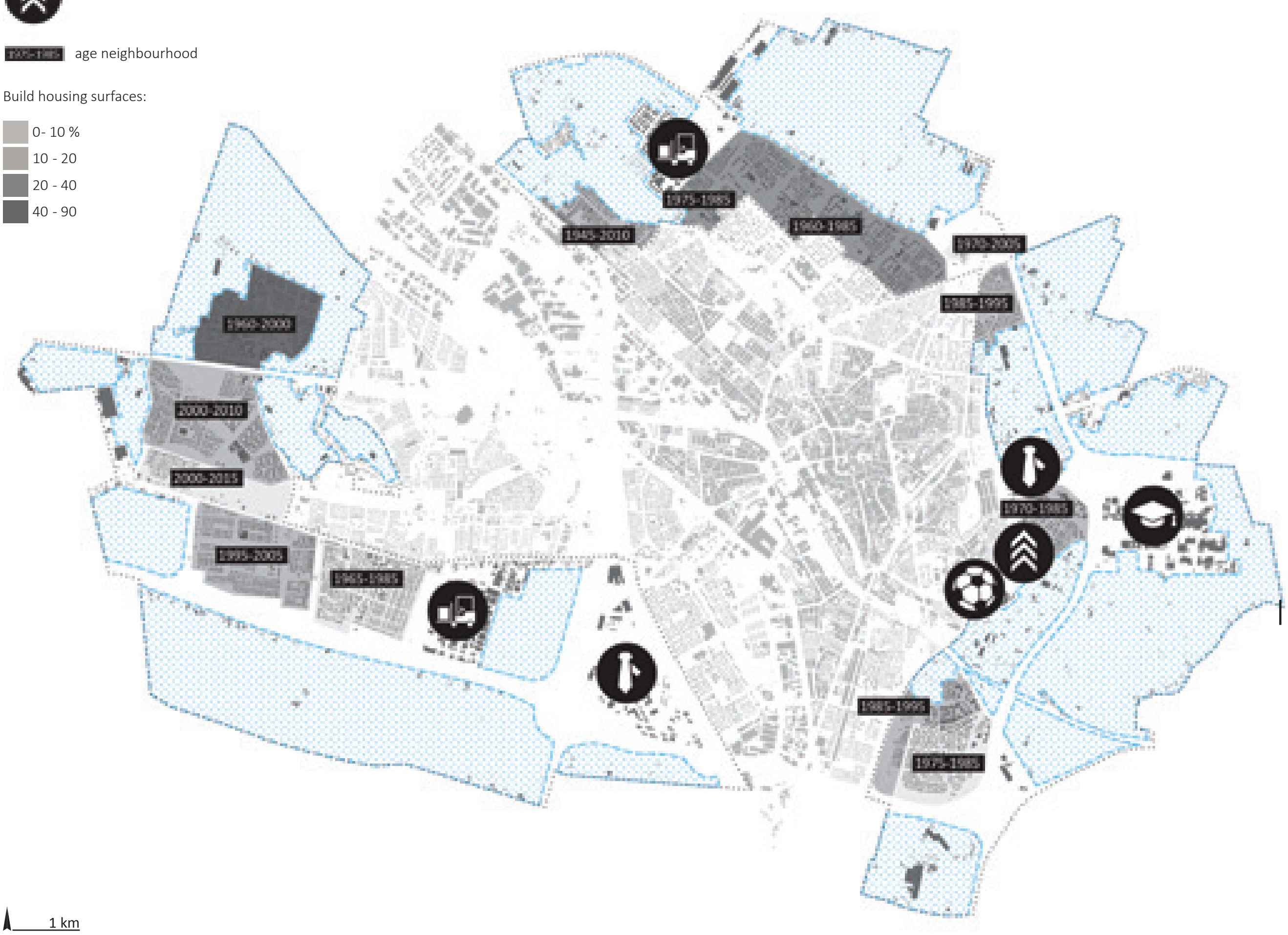
The analysis from the first step is carried out at the city edge from Utrecht (see fig. 6.1). The results are larger and smaller open areas within the city edge. Neighbourhoods with a low building density (building surface of 20% or lower) exist mainly in the southern part (extracted from fig. 3.5), but these are mainly relatively young and not directly qualified for redevelopment.

6.1.2 Step 2: Indicate wind corridors

Regional wind is considered a cooling system in this step, since the temperature in the rural surroundings is cooler than in the city (Oke, 1982). Regional winds derive from the rural surroundings where the air is cooled through the evaporation of water by forests, grass-, and croplands (Van Hove et al. 2011). Wind corridors, through which cool wind can enter the city, can improve the thermal climate at the local scale. So, new urban expansions should not block these winds. The effectiveness of regional wind during hot summer periods should be taken into account, since the wind speeds are mostly quite low during these periods. Although, wind corridors can support thermal breeze on city scale and bring the breeze further into the city.

To indicated where wind corridors are situated, barriers for wind should be indicated. At places where barrier do not exist, wind can enter the city. These areas are qualified as wind corridors and are mainly valuable at the direction of the main wind during summer, since the most problems with UHI effect arise during this time of the year. However, the wind direction can always vary which means that every corridor should be saved from urban growth. Wind barriers can be indicated on a height map and by locating high areas, such as forests.

6.1
Open areas
The open areas within the city edge from Utrecht.



The analysis from step 2 is carried out at the city edge from Utrecht (fig. 6.2). Wind barriers are mainly formed by the elevated highways around the city. Next to that, some forested areas are blocking regional winds from entering the city, especially those in the northern part of the city edge. In between the wind barriers around the city are wind corridors located that should be saved from urban growth. At the main wind direction, south-west (see fig. 3.15 in chapter 3.4), wind corridors does not exist. Development of wind corridors in this direction could have large opportunities for ventilation of the city.

6.1.3 Step 3: Indicate edges for thermal breeze

According to Erell et al. (2011), thermal breeze can reduce the temperature difference between city and its rural surroundings. Thermal breeze can be described as a slow airflow that arise between cooler and warmer areas (Lenzholzer, 2013), when the mean wind speed is low (Hidalgo et al., 2008). Especially during night-time, when air and surface temperature differences are the largest, breezes are plausible.

By indicating areas where thermal breeze is desirable, it is possible to locate areas that should be saved from urban growth. At places where a clear temperature differences exist, without

6.2
Wind barriers and corridors
Map with wind barriers and corridors in the city edge from Utrecht.

barrier for wind (line)
barrier for wind (area)
areas to safe from growth

main wind direction

Summer
Winter

1 km

barriers for breeze in between, edges for thermal breeze can be indicated. Those night breezes are mainly desirable at places where people are during the night, residential areas. Densification of existing neighbourhoods could also increase the temperature difference, that promotes thermal breeze, something that can be executed when a neighbourhood will be redeveloped.

The analysis from step 3 is carried out at the city edge from Utrecht (fig. 6.3). On the basis of the climatope map and the urban surface temperature map (see fig. 5.5 and 5.8 in chapter 5) are edges from neighbourhoods indicated with a clear temperature difference at night. These edges should be saved from urban growth developments. Neighbourhoods with a low building density (building surface of 20% or lower) exist mainly in the southern part (extracted from fig. 3.5 in chapter 3), but these are mainly relatively young and not directly qualified for redevelopment.

6.3

Indication of thermal breezes

Map with edges for thermal breeze in the city edge from Utrecht.

edge for thermal breeze

areas to safe from growth

age neighbourhood

Build housing surfaces:

0- 10 %
10 - 20
20 - 40
40 - 90

6.1.4 Step 4: Indicate greenery

In literature, the most influences were founded in the category 'Greenery'. According to Steeneveld et al. (2011), vegetation coverage is an effective measure to mitigate strong UHI's. All vegetation reduces air temperature by evaporation, as long there is enough supply of water (Van Hove et al., 2011). Grass- and croplands are the most effective in cooling the air temperature, but forests and trees can evaporate longer during long heatwaves (Idem.). Next to physical effects, greenery can have a psychological effect on residents thermal comfort as well (Klemm et al., 2015).
All this makes greenery an important measure for influencing the urban climate. So, new locations for urban growth must strengthen or expand existing green infrastructures, green areas and connections in between. Incorporating, instead of removing, existing greenery can have important values on urban climate. New planting must grow for decades before it will have the same influence on urban climate as existing ones. That is why existing greenery should be identified in step 4.

The analysis from step 4 is carried out at the city edge from Utrecht (fig. 6.4). Important green areas and connections are derived from the Greenvision map 2030 from the city of Utrecht (gemeente Utrecht, 2007). As visible on the map, the city edges from Utrecht are valuable green areas of the city.

6.4
Green infrastructure
Important green areas (dotted areas) and connections in the city edge from Utrecht.

green areas
green connections

Surfaces:
Forested green space
Non-forested green space
Agriculture
Water

6.1.5 Step 5: Combining steps and position locations for urban growth

In this step, a combination should be made from all the before mentioned steps. By combining the results from the previous analysis, locations for climate-responsive urban growth can be positioned. A step-by-step analysis is necessary to develop, because the map in figure 6.5 is too complicated to develop and thorough understanding in one step.

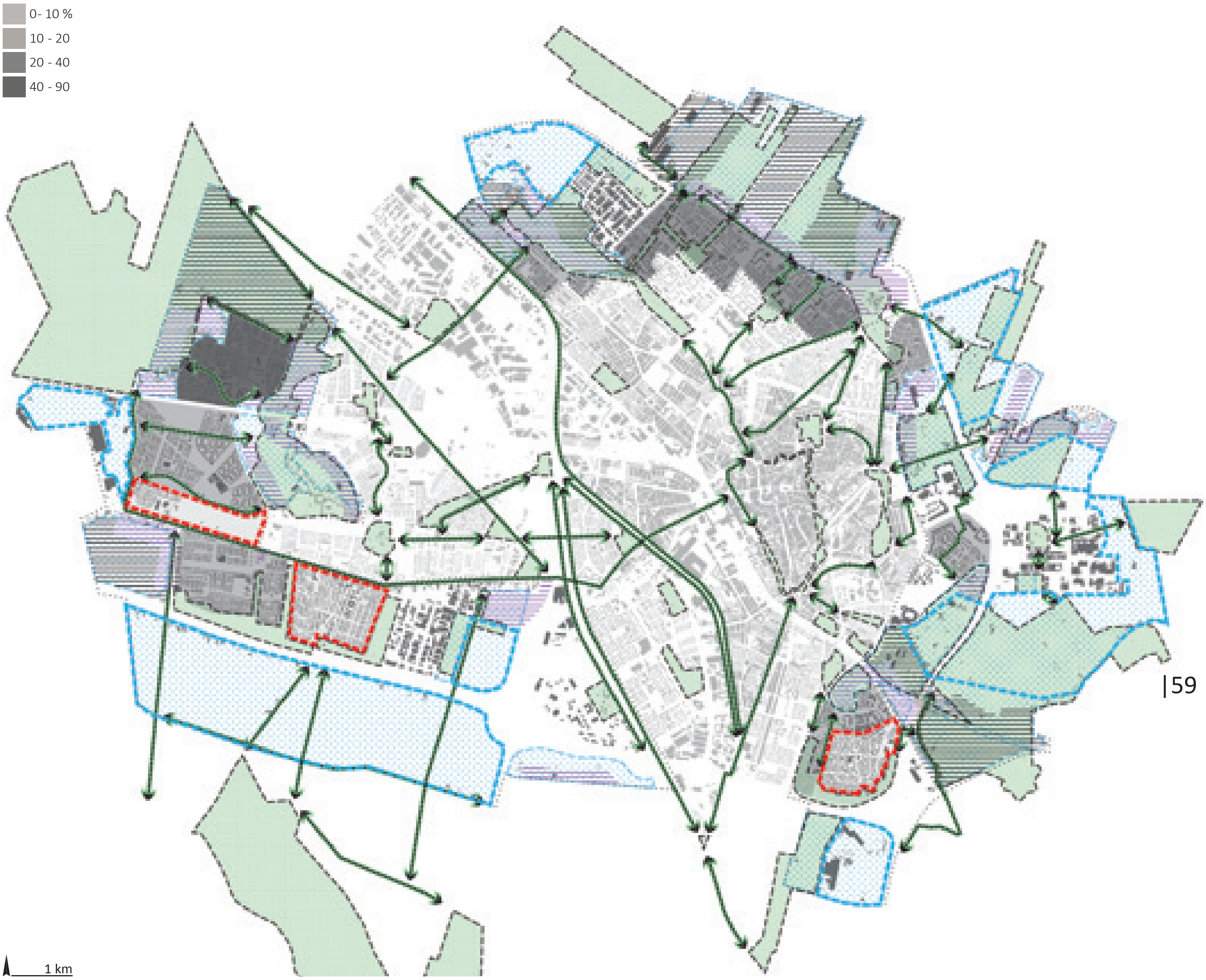
The step by step analysis at Utrecht's PUZ resulted in eight possible locations for climate-responsive urban expansion; Strijkviertel, Rijnenburg, Breudijk, Old Zuilen, Voordorp (North and South), Maarschalkerweerd, and Wayen (see fig. 6.6). Besides, three locations are qualified for densification by redevelopment. Redevelopment is not expected in short term since these neighbourhoods are quit young.

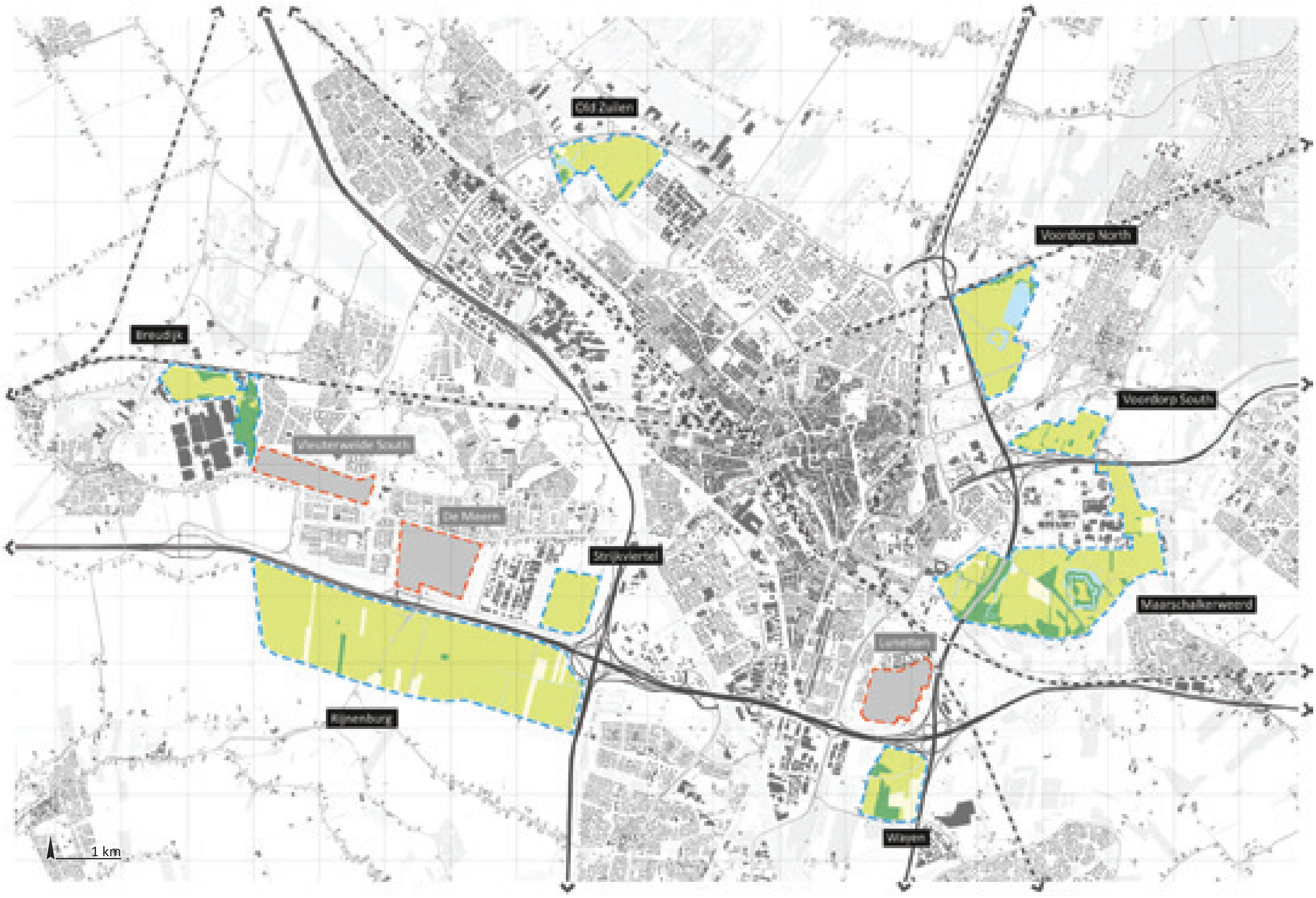
6.5
Combined steps 1-5
Open areas, regional wind, day vs. nigh cooling, thermal breeze, and greenery combined.

- open area
- are to safe from growth wind corridor
- are to safe from growth thermal breeze
- green area
- green connection
- expansion location
- densification location

Build housing surfaces:

- 0- 10 %
- 10 - 20
- 20 - 40
- 40 - 90





6.6
Locations for urban growth

location for expansion

location for densification

Surfaces:

Forested green space
Non-forested green space
Agriculture
Water

6.2 Locations for urban growth

The proposed locations for urban growth that could be developed in short term are further explained in this paragraph. The location Maarschalkerweerd is used in further configuration, to visualize how existing landscape characteristics and elements can contribute to design a thermally comfortable urban expansion location. This location has been selected because of its complexity and historical background, which will be explained further in the next chapter.

6.7
Impression of Strijkviertel

Strijkviertel
The 52 ha large expansion location Strijkviertel is situated on the urban part of the PUZ and is the smallest one from the eight. The location is bordered by the highways A2/A12 and is situated next to an industrial area. The surface is mainly used as grassland (see fig. 6.7).

6.8
Impression of Rijnenburg

Rijnenburg
This location of 563 ha is the largest expansion location from the eight. It is directly situated behind the highway A12, at the rural part of the PUZ. The land is mainly used as grassland by the farmers at the location (see fig. 6.8).

6.9
Impression of Breudijk

Strijkviertel
The 52 ha large expansion location Strijkviertel is situated on the urban part of the PUZ and is the smallest one from the eight. The location is bordered by the highways A2/A12 and is situated next to an industrial area. The surface is mainly used as grassland (see fig. 6.7).

6.10
Impression of Old Zuilen

Breudijk
Breudijk, 63 ha is situated at the rural part of the PUZ in the direction of the railway. The expansion is bounded by the small river Bijleveld and is mainly used as grassland and orchards (see fig. 6.9).

Voordorp
Voordorp North and South are together 195 ha large. They are situated behind the highway A27 at the rural part of the PUZ. Striking at the northern location is the old fortification Voordorp, which was part of the Dutch waterline. The land is mainly used as grassland and has a small lake, the result of sand excavation for the construction of highway A27 (see fig. 6.11 – 6.12).

6.11
Impression of Voordorp North

6.12
Impression of Voordorp South

Maarschalkerweerd
This is the second largest expansion location with a size of 360 ha. Maarschalkerweerd is situated in the east and located on the urban and rural part of the PUZ. The urban part is dominated by sport fields, infrastructure and fortifications from the old Dutch waterline. The rural part has a fortification as well, and three real estates surrounded by forest in the southern part. Other land is used as grass- and cropland. The division between both parts is made by the highway A27, but the river Kromme Rijn functions as a connection in between (see fig. 6.13).

Wayen
Location Wayen is 55 ha large and situated in the highway armpit A12 an A27. The location is situated on the rural part of the PUZ and consist of forest, grassland, and agricultural land (see fig. 6.14).

6.13
Impression of Maarschalkerweerd

6.14
Impression of Wayen

6.3 Synopsis

This chapter has described, on the basis of urban climate knowledge, a step-by-step method to determine locations for positioning climate-responsive urban growth. By testing the method at the city edge of Utrecht, eight locations for expansion have been determined; Strijkviertel, Rijnenburg, Breudijk, Old Zuilen, Voordorp (North and South), Maarschalkerweerd, and Wayen.

Besides locations for expansion, three neighbourhoods are qualified for densification; Vleuterweide South, De Meern, and Lunetten. Redevelopment of these neighbourhoods can be in a higher density, but is not expected in short term since they are quit young.

7.0
Haarrijnseplas

7. Configuration [design] of Maarschalkerweerd

After showing the different locations for positioning climate-responsive urban growth, this chapter has the objective to answer [SRQ3]; *How can existing urban climate knowledge be used for a climate-responsive configuration of an urban growth location?* Expansion location Maarschalkerweerd is used as the case area for this design question.
The answering of this question is done by investigating the landscape challenge for the location, followed by the Master plan of the design. Several parts of the plan are further detailed and the complete design is evaluated at the end of this chapter.

7.1 Introducing Maarschalkerweerd

Based on previous investigation, it is clear that many climate influencing characteristics appear in expansion location Maarschalkerweerd (see fig. 7.1 and 7.2). To start with, the presence of several historic estates and remains of the New Dutch Waterline have resulted in a rich variety of greenery. Greenery in the form of forests, avenues, tree rows, orchards, and grasslands. Secondly, a potential wind corridor exists at the southern part of the area. The area where the highway is lowered and open areas are situated. Cool open areas can provoke thermal breezes at night because of the higher temperature in surrounding neighbourhoods.

7.1
Maarschalkerweerd
Overview of the location and its climate influencing characteristics and elements.

Finally, the river Kromme Rijn flows through the entire expansion location. It is the connecting element in the area and can be followed from the city centre to the rural surroundings. The flowing water in the river can be cooling, but more important is its support in the green infrastructure.

The variety of influencing characteristics is one of the reasons why this locations is used as a case area for the design question, but there are also other grounds. For example, Maarschalkerweerd is – with a walking distance of 2.5 km. – the closest expansion locations to the city centre (Domtower). Legislation of the New Dutch Waterline and the cultural and natural values of its surroundings protected this area of the city from large urban expansions (Renes, 2005). The legislation has been abolished (1963), but the cultural and natural values are still there and became a challenge in the design process.

Figure 7.3 till 7.9 give an impression of Maarschalkerweerd.

7.2
Boundaries
The boundaries are defined by the highway A28, railroad Utrecht-Arnhem, and the boundaries of the PUZ

7.3
Kromme Rijn

7.4
New Dutch Waterline remains

7.5
Sport fields

7.6
Highway barrier

7.7
The Uithof

7.8
Estate New Amelisweerd

[background information]

Characteristics and elements for configuration

Overview of climate influencing spatial characteristics and elements that can steer the positioning of locations for climate-responsive urban growth.

Greenery

Support, preserve, and strenghten the green infrastructure of a city. The green infrastructure is described as one of the most promising opportunities for climate adaptation (Gill et al., 2007). Especially because of the cooling effect from vegetation, from microscale to mesoscale, by the evaporation of water (Chen et al., 2014)(Van Hove et al., 2011). Next to that, green spaces can improve thermal comfort in psychological term as well (Klemm et al., 2015).

Wind

Safe wind corridors and support thermal breeze. The 'cliff' to the urban climate is especially marked on the windward urban-rural boundary (Oke, 1982). So, regional winds can therefore be used to cool the air in the city. The same counts for wind from the direction of a park that is cooling the air temperature in its surroundings (Van Hove et al., 2011). Thermal breezes reduce the urban-rural temperature difference with its slow airflow between cooler and warmer areas (Erell et al., 2011)(Lenzholzer, 2013).

Water

Indicate large waterbodies and flowing water. Water can absorb heat and therefore is not always an cooling element. During the night, this absorbed heat can have a warming effect on its surroundings (Van Hove et al., 2011)(Steeneveld et al., 2014). Flowing water has therefore a larger cooling effect than still water, but the main positive point from waterbodies is its free wind path (Van Hove et al., 2011). Recreational waterbodies can function as a 'heat escape areas'(Lenzholzer, 2013).

Urban geometry

Indicate and analyse areas for densification, wind barriers, and urban-rural edges. Higher population densities related to higher UHI effects, because more population generally result in higher values of build-up surface (Steeneveld et al., 2011). Also typologies or field functions related to warmer or cooler climates (Lenzholzer, 2013). This all affect the urban-rural temperature difference, which promote thermal breeze if the edge is free from wind barriers (Lenzholzer, 2013).

7.2 Landscape (design) challenges

The use of a step-by-step analysis – with the existing urban climate knowledge; greenery, wind, water, and urban geometry on the location Maarschalkerweerd (see fig. 7.19-7.13) – resulted in an overview of areas that could climate-responsively be built in the future (see fig. 7.14). These areas are used in the design as the locations for future new neighbourhoods and are the occasion to configure Maarschalkerweerd for the purpose of future inhabitants' thermal comfort. For this configuration, the analysis resulted in an overview of interventions that support urban climate and thermal comfort as well. Thermal comfort for the inhabitants of the future new neighbourhoods and from its surroundings.

The design and the inventory of the challenges goes beyond the boundaries of Maarschalkerweerd, because the new neighbourhoods has to connect to the structure of the city and lays in the transition between the city and its rural surroundings. The transition, earlier described as the PUZ (chapter 4), is good recognizable in this lower scale inventory. The different stages – urban, urban zone, rural zone, and rural- have their own consequences for the design (see fig. 7.15). In the urban stage there is minimal space for intervention, totally the opposite from the rural stage. For the urban and rural zone, the largest differences in the underlying layout are present; urban and rural structures. For the design this means that especially in the rural zone landscape qualities and cultural values, such as the estates, influences the design and can be reinforced.

7.9
Open areas
The blue dotted areas show the open areas in the expansion location. The neighbourhood in the north has a low density. Redevelopment could be done in a higher density, but this is for the future since it is a relative new neighbourhood.

open area
university
stadium
army barracks

Build housing surfaces:

20 - 40 %

7.10

Wind corridor

The growth location is not situated in the main wind direction, but winds can still derive from other directions (see chapter 3.4). East-South winds will be blocked by the highway A27 and the forested areas. Only a lowered part of the highway can function as a wind corridor and should therefore be saved from urban expansions. Besides, the wind corridor can function as a corridor for thermal breeze as well.

barrier for wind (line)

barrier for wind (area)

areas to safe from build-up surface

7.11

Thermal breeze

The adjacent neighbourhoods are dominated by day cooling activities, areas where people stay during day-time . Thermal breezes are the strongest during the night (Hidalgo et al., 2008), which means that day cooling areas are not interesting for thermal breeze. Only in the north is a small housing neighbourhood where thermal breeze can be effective. Therefore the open area in front should be saved from urban expansions, and the edge be designed for breeze.

edge for thermal breeze

day cooling

areas to safe from build-up surface

age neighbourhood

Build housing surfaces:

20 - 40 %

7.12
Greenery
Many valuable green areas and connections exist in Maarschalkerweerd and its surroundings. These areas and connections can contribute to inhabitants thermal comfort in the expansion, so this greenery should be saved from urban expansions and expanded, strengthened and connected where possible.

green area
green connection
Surfaces:
Forested green space
Non-forested green space
Agriculture
Water

7.13
Combination
By combining the steps before, areas for climate-responsive future expansion can be appointed.

open area
areas to safe from build-up surface (wind)
areas to safe from build-up surface (TB)
green area
green connection
area for build-up surface
Surfaces:
Forested green space
Non-forested green space
Agriculture
Water

7.14
Areas to build
Areas for future build-up surfaces. For the purpose of design, the areas to be build are divided into 4 neighbourhoods and one location for future expansion of the Uithof.

location for build-up surfaces

Surfaces:

Forested green space
Non-forested green space
Agriculture

7.15
Stages
Stages in the location; urban, urban zone, rural zone, and rural.

The inventory of the existing landscape resulted in five design challenges, visualized in figure 7.16. These design challenges can be seen as the key aspects for the design.

1. Integrating existing greenery
Vegetation coverage is a strong measure to mitigate strong UHI's, but has also positive influences on inhabitants thermal comfort (Steeneveld et al., 2011)(Klemm, 2014). Maarschalkerweerd consist of many greenery that for this reason has to be integrated in the design. Besides, new planting must grow for decades before it will have the same influence on urban climate as exciting ones.

2. Improve and expand the green network
Green infrastructures has the ability to effectively reduce heat and improve outdoor thermal comfort, physical and psychological (Klemm et. al. 2014). Strengthening the connections between the city centre and Maarschalkerweerd, the different green areas, and along the river Kromme Rijn can improve the green infrastructure and urban-rural transitions.
3. Safeguard the wind corridor

To enhance entrance of cool winds from rural surrounding into the city, the wind corridor in the south has to be kept open. Besides regional wind, it can also function as a corridor for city scale thermal breeze. The design has to avoid future development of wind barriers by allowing only open functions to the wind corridor.

4. Support thermal breeze
The neighbourhood in the north has the ability to be cooled by a welcome thermal breeze. Therefore barriers at the south-east edge should be avoided and the area facing this edge should be kept open and have a low air temperature during night-time.

7.16
Design challenges

5. Making use of the flowing water

Large open water bodies does not exist in expansion location Maarschalkerweerd, but it does have flowing water from the river Kromme Rijn. New developments should make use of this little cooling effect. Besides, the river has a good opportunity to support the green network in Maarschalkerweerd.

7.3 Master plan

The Master plan map, see figure 7.17, shows the proposed design of the expansion location Maarschalkerweerd. The configuration strives to enhance thermal comfort for the future inhabitants, and will be explained by the five design challenges.

1. Integrating existing greenery

Existing greenery in the areas for future neighbourhoods, will be saved by reuse in the planning and design of future new neighbourhoods. The larger green areas are integrated in the design by adaptation to future developments and by opening for recreation. The estate structures – avenues, tree rows, and orchards – are integrated in the structure of the expansion location. They function as guidance of slow traffic and where possible for the wider fast traffic (car roads). The grasslands behind estate New Amelisweerd is turned into a new sport accommodation. The removed sport fields, for development of expansion 1 Maarschalkerweerd, are here relocated to keep the openness and to promote thermal breeze for it future surrounding neighbourhoods.

2. Improve and expand the green network

In the urban stage, all possibilities for improvement should be used since there is little space for changes. With redesign of the closed railway 'Oosterspoorbaan', it is possible to strengthen the slow traffic network (biking and walking) between the city centre and Maarschalkerweerd. Extending this connection, with a bridge over the railroad, makes it even possible to connect the Beatrixpark and the adjacent residential district Lunetten. Extra routing along the Kromme Rijn, between the Lunetten, and between the surrounding neighbourhoods improves the accessibility of greenery and supports the green infrastructure.

3. Safeguard the wind corridor

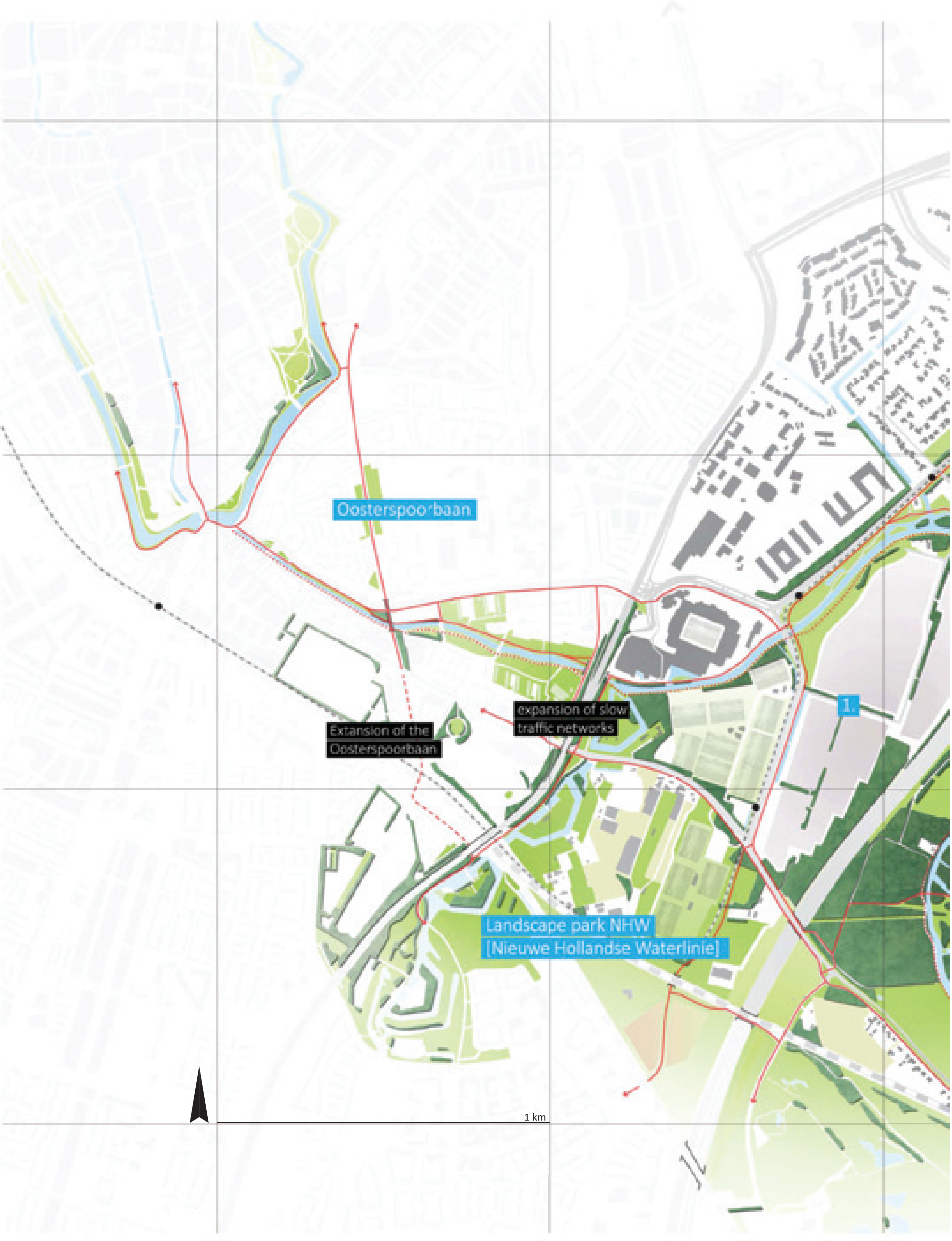
Golf course Amelisweerd keeps the wind corridor open at the rural site and removal of forested edges, along the highway A27, makes it possible to let cool winds enter the urban site. The planning of a landscape park for the inhabitants of the city makes it possible to avoid the development of wind barriers. The concept of the park is derived from the existing remains of the New Dutch Waterline (the Lunetten). The reintroduction of the Waterline legislation prohibits new build-up surfaces within certain distances of the fortifications (Provincie Utrecht, 2011). The recreational park will contain sport fields and other open functions, such as allotment gardens.

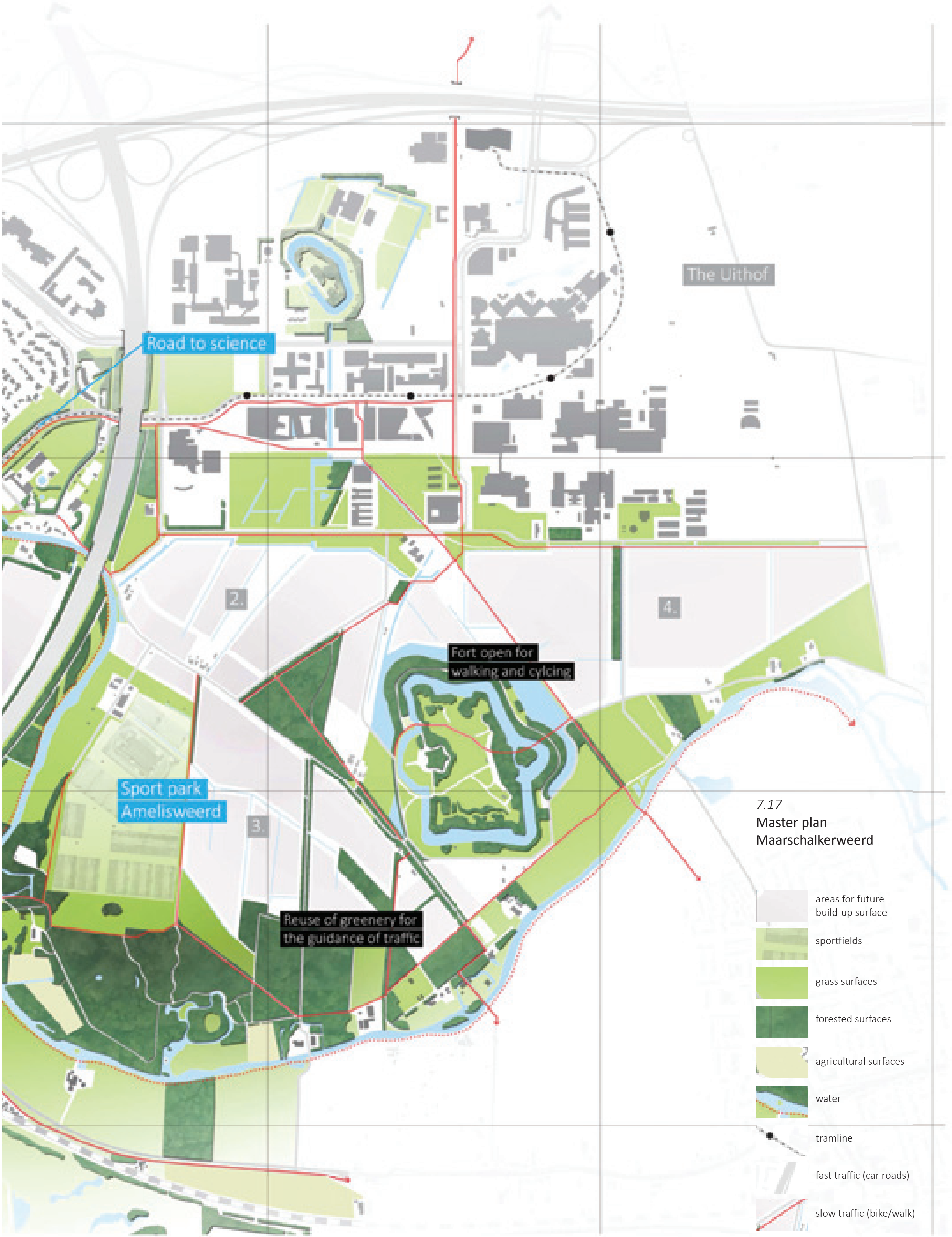
4. Support thermal breeze

The first row of houses from the northern neighbourhood is removed to support the thermal breeze. A rigorous intervention, but one with large opportunities for the neighbourhood. Thermal breeze can now exist between the neighbourhood and the adjacent open area. Next to that, a nice buffer can be developed between the neighbourhood and the road 'Weg tot de Wetenschap'.

5. Making use of the flowing water

The first expansion, neighbourhood Maarschalkerweerd, has little benefit from the river Kromme Rijn. The river stream true a park setting on the edge neighbourhood 1. An edge that has to be designed for the entering of thermal breeze. Although, the largest positive effect from the river derives from its support in the green network of expansion location Maarschalkerweerd.


Oosterspoorbaan
expansion of slow
traffic networks
Extansion of the
Oosterspoorbaan
1.
Landscape park NHW
[Nieuwe Hollandse Waterlinie]
1 km



7.17
Master plan
Maarschalkerweerd

7.4 Detailed designs

The explanation of the main points in the Master plan are supported by detailed designs; Oosterspoorbaan, landscape park NHW, sport park Amelisweerd, 'Road to science', and neighbourhood Maarschalkerweerd. Visuals show how the Master plan of Maarschalkerweerd can be implemented and how small scale interventions can support thermal comfort. Some sketches from the design of these details can be found in appendix IV.

Oosterspoorbaan

Since the closing of the railroad between station Utrecht Maliebaan and the Lunetten in 2012, it fell into disrepair. Redesign results into a fast connection for slow traffic (walking and cycling) between the city centre and Maarschalkerweerd. The structure of the railroad is still recognizable in the surface and greenery is "spontaneously" scattered along the route, as if nature did take over the railway. Trees provide shade for the users and will break a possible channelling-effect of the wind (see fig. 7.18- 7.20).

7.18
Existing situation and visual Oosterspoorbaan

7.19
Existing situation

7.20
Inspiration
Emscher Park, Essen
Germany

Landscape park NHW

Park NHW makes the New Dutch Waterline re-liveable and is a proposed extension of the Beatrixpark. Several functions are spread through the park, but all without blocking the entering of regional wind into the city. The remains of the New Dutch Waterline form the main concept of the park, and rules for development – at the time of the waterline – are reintroduced to prevent future development of wind barriers. According to the rules it is only possible to build small wooden construction within 300 meter from the fortifications. Between 300 and 600 meter, only small stone foundations are allowed (provincie Utrecht, 2011). Routing through the park allows recreational activities and connection to neighboring districts. Function like sport fields, grassland, and allotment gardens keep the wind corridor open (see fig. 7.21 and 7.22).

7.21
Existing situation and visual landscape park NHW

7.22
Existing situation NHW
Relicts New Dutch Waterline, sportfields and railway

Sport park Amelisweerd

The valuable open grassland behind estate New Amelisweerd will lose its function when farmers are moving because of the development of new neighbourhoods. The openness from the grassland is replaced by the openness of the removed sport accommodations from neighbourhood Maarschalkerweerd. The different sport fields are relocated between the remaining bunkers of the NHW, and the empty farm is in use of the main building from sport park Amelisweerd. Artificial grass is as less as possible used for sport fields, because natural grass can cool the air temperature by night. Edges between the sport park and the surrounding neighbourhoods promote thermal breeze (see fig. 7.23-7.24).

7.23
Existing situation and visual sport park Amelisweerd

7.24
Existing situation

Road to science
Road to science (named after the name of the road; Weg tot de Wetenschap) forms the line between the existing housing district and the open grass fields from swimming pool 'De Krommerijn'. Demolishment of the first row of houses gives opportunities for thermal breeze and creates a buffer park between the road and the neighbourhood. To support the cool airstream, the tramline is designed with a grass surface and an extra row of trees is planted. The trees give shade to the asphalt, that will heat up less rapidly (see fig. 7.25-7.27)

7.25
Existing situation and visual Road to science

7.26
Existing situation

Neighbourhood Maarschalkerweerd

For neighbourhood one, Maarschalkerweerd, a configuration of building blocks is designed which safes the existing greenery and is open for thermal breeze. This configuration can be used as an example for all the future new neighbourhoods in expansion location Maarschalkerweerd.

The edges of the neighbourhood are open for thermal breeze, and there is plenty of space for ventilation of the neighbourhood. Existing greenery is reused in the design and is manly used for guiding slow traffic in the neighbourhood. The neighbourhood is well connected to its surroundings, which makes it possible for the inhabitants to enjoy (see fig. 7.27-7.28).

7.27
Existing situation and visual neighbourhood Maarschalkerweerd

7.28
Existing situation

7.5 Evaluation of the design

In this paragraph, the design is evaluated according to the research of this thesis. The design of Maarschalkerweerd is related to the four climate influencing typologies, greenery, wind, water and urban geometry (see fig. 7.29). Urban climate and thermal comfort influences cannot be measured, but assumptions are made on the basis of existing knowledge.

Greenery

Although many grassland is converted into built-up area, valuable greenery is saved and reused for the thermal comfort of future inhabitants. Existing forests, avenues, tree rows, and orchards have partly determined the locations for expansion and have functioned as the basis for the configuration of Maarschalkerweerd. The design improves the connections between the different green areas and expand the city's green infrastructure. Redesign of the Oosterspoorbaan resulted in a stronger connection between the city centre and Maarschalkerweerd.

Wind

With the landscape park NHW, the wind corridor is saved for future wind blocking developments and Maarschalkerweerd has an extra contribution to the city's green infrastructure. The opening of the northern neighbourhood supports thermal breeze between the housing district and the grass fields during night-time. Thermal breeze can also take place between the new neighbourhoods and many green open areas.

7.29
Evaluation
Evaluation of the design

Water
The river Kromme Rijn flows through the whole neighbourhood and crosses the different barriers. This opportunity is used in the design by combining the river and the slow traffic network for improvement of the green infrastructure. Next to that, the flowing water can have a cooling effect for its surroundings.

Urban geometry
In the design of the 360ha. large expansion location, 40% of the surface is reserved for new build-up areas. Enough for four new neighbourhoods and space for future expansion of the Uithof. Choices in the design of these neighbourhoods can strengthen the thermal comfort for the future inhabitants. Next to build-up areas, 10% of the surfaces is reserved for sport facilities.
Reuse of existing greenery resulted in a variety of build and un-built areas that support thermal breeze. Existing facilities are replaced (sport park Amelisweerd) and new function are added (Landscape park NHW and allotment gardens).

7.6 Synopsis

This chapter has shown the configuration for the climate-responsive expansion location Maarschalkerweerd. Climate influencing characteristics and elements determined the locations for future build-up surfaces and delivered the design challenges. Detailed designs visualize the design and explain small scale choices for the support of thermal comfort. The whole design is evaluated on its assumed influence on the urban climate aspects; greenery, wind, water, and urban geometry.

8.0
Strijkviertel

8. Conclusions, discussion and reflection

This final chapter summarizes the research and shows the conclusions, discussion, and recommendations for further research. The chapter will end with a short reflection on the whole project.

8.1 Conclusions

This thesis proposes, on the basis of existing urban climate knowledge, step-by-step analyses to position and configure locations for climate-responsive urban growth. Methods that has been developed and tested at the city of Utrecht and helped for answering the main research question; [RQ] "What are key aspects in the design of locations for climate-responsive growth at the city edge of urbanizing cities?" (see fig. 8.1).

To answer the main research question, a conclusion is drawn up on the three sub-research question in this thesis;

[SRQ1] What determines the city edge?
[SRQ2] How can existing urban climate knowledge be used in the positioning of climate-responsive urban growth locations?
[SRQ3] How can existing urban climate knowledge be used for a climate-responsive configuration of an urban growth location?

[SRQ1] First, an indication of the area under pressure of predicted urban growth (the city edge) can delineate the area of research. Existing methods are applied at the city of Utrecht and evaluated for the development of a working method to determine the city edge, which is in specialist terms called the peri-urban zone (PUZ). This edge can be determined by indicating its boundaries; the urban-rural edge, urban edge and rural edge. The urban-rural and urban edge are easily drawn from administrative borders, but rural edges has to be determined on the basis of physical and spatial barriers. The method did result in a PUZ with a diameter between 0.5 and 4 kilometre around the city of Utrecht.

[SRQ2] Second, a step-by-step analysis on the determined PUZ can determine locations for climate-responsive urban growth. An analysis based on mesoscale, and to al lesser extent local scale, urban climate knowledge. Knowledge on climate influencing spatial characteristics and elements in the categories; greenery, wind, water, and urban geometry. The following key aspects did derive from existing knowledge and are translated into steps of analysis;

- Greenery: Support, preserve, and strenghten the green infrastructure of a city.
- Wind: Safe wind corridors and support thermal breeze.
- Water: Indicate large water bodies and flowing water.
- Urban geometry: Indicate and analyse areas for densification, wind barriers, and urban-rural edges.

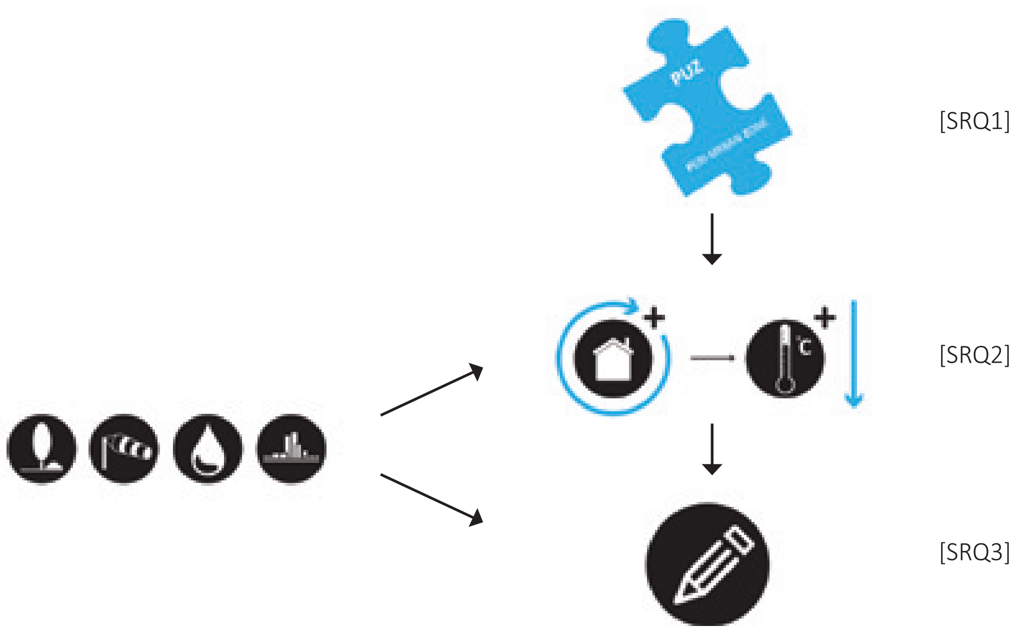
The analysis indicates open areas, wind corridors, thermal breeze supporting edges, and valuable green areas/infrastructures. The combination of these layers of analysis resulted in eight expansion and three densification locations for the city of Utrecht.
Third, one of these locations is worked out in a Master plan and related detailed designs for showing how a climate-responsive growth locations has to be configured, [SRQ3]. Maps studies, on the basis of local scale – and to a lesser extent meso- and micro scale – knowledge on urban climate influencing spatial characteristics and elements, result in the determination of areas for future build-up surfaces. The key aspects in existing urban climate knowledge are;

- Greenery: Support, preserve, and strenghten the greenery in a growth location, from the cities green infrastructure till the smaller green areas and connections in between.
- Wind: Safe wind corridors and support thermal breeze.
- Water: Indicate large water bodies and flowing water.
- Urban geometry: Indicate and analyse areas for densification, wind barriers, and urban-rural edges

Besides areas for future build-up surfaces, conclusions from the analysis can formulate design challenges as well. Challenges that implement, preserve and strengthen climate positively influencing characteristics and elements. In a design process, these challenges can be solved for the support of future inhabitants thermal comfort in an urban growth location. Design challenges for expansion location Maarschalkerweerd did consist of;

- Integrating existing greenery
- Improve and expand the green network
- Safeguard the wind corridor
- Support thermal breeze
- Making use of the flowing water

To conclude, this thesis project gives an overview of the key aspects for the design of locations for climate-responsive urban growth. Developed methods, determination of the PUZ and the step-by-step analysis for the positioning and configuration of growth locations, can be used for other cities that are dealing with the same or related problems. The design from Maarschalkerweerd is site specific, but can function as an inspiration for comparable projects.



8.1
Conclusion
Overview of the conclusions

8.2 Discussion and recommendations

There are several factors that are essential in the discussion and interpretation of the results. Therefore (potential) weaknesses in the research and related recommendations are drawn up.

The research started from the perspective of predicted urban growth that results in a need for expansion or densification of the city. For the city of Utrecht, where in a short time frame (2012-2025) a household growth of 30 thousand households (18%) is predicted (Huisman et al., 2013), expansion is the most obvious solution. Especially when you take a look at the close history in which Leidsche Rijn is constructed and plans are made for Rijnenburg. Next to that, large open spaces to household predicted growth and locations for redevelopment are lacking within the city. Nevertheless, densification may be an effective measure to household a part of the growth, or the whole predicted growth from other cities. Therefore, testing the spatial characteristic (greenery, wind, water, and urban geometry) for climate-responsive urban densification is recommended.

Secondly, the presented method for indicating the PUZ can be a point of discussion. Existing methods from LOLA (2011) and Hamers et al. (2009) does locate a PUZ, but tests on the city of Utrecht resulted in advantages and disadvantages. These (dis)advantages does not say that the methods are right or wrong, they are the result of an evaluation on the before set working definition and the later use of this PUZ; areas for future urban growth. The development, tests, and evaluation of the described working method are all done at the city of Utrecht. Testing the validity of the working method on other cities is therefore recommended.

Thirdly, the selected sources for the conducted literature study are chosen on its close relation to the field of landscape architecture and the prominence of these sources within the Wageningen University. Although, not all valuable sources could be included since the body of urban climate knowledge is quite large. In addition, climate research is emerging and will therefore produce much more knowledge in the coming years. Continuing of the literature study is therefore recommended.

The fourth point of discussion is the developed step by step analyses for positioning climate-responsive urban expansions and the following configuration in the design of Maarschalkerweerd. This thesis project did focus on the urban climate topic, and its related thermal comfort, to straighten the research. However, for positioning and configuring new urban expansions does more aspects have an influence. Further design steps are recommended when the process in this design will be used for an actual project. Besides, other tests are required to demonstrate the operation of the results. The results are based on assumptions derived from existing knowledge since possibilities for measuring the effects were not available.

8.3 Reflection

This thesis started from the interest in researching the effect of urban growth on the urban climate, due to urban growth and global climate change predictions. After carrying out the research, it is time to shortly reflect upon the results and the process of the research.

Value of the research

First, the research shows another way of positioning locations for urban growth. New locations are common at locations where the land prices are the lowest, or where implementation is the most obvious. This thesis project presents a process that locates climatologically the most comfortable locations for growth. So, with an eye on climate predictions a valuable research.

Secondly, the research gives an overview of existing urban climate knowledge, with in specific climate influencing spatial characteristics and elements. This is knowledge derived from different disciplines that for the use in this thesis is combined. The outcomes are based on assumptions but could stimulate the different disciplines for future research.

Third, the research did focus on expansion of the city. The step by step analysis at the PUZ did already add some densification, but did exclude the rest of the city. The research outcome could have be more valuable by adding densification in the city as well.
Finally, as a landscape architect I added my expertise to create possibilities and solutions. The outcome is more than only an answer to the problem, the design enrich the environment for man and nature in both process and form.

Process
The process in this thesis is mainly influenced by the case, the city of Utrecht. Knowledge, strategies, and methods derived from literature have been applied and evaluated on this case. This did help to rethink, include, exclude, and improve certain elements of the research. It did improve the value of the research, but also influenced the before set directions in the project. For example, the developed method for determining the PUZ some time but became in the end only a small part of the total research.

The design process, despite of being a notional plan, did help in the end to visualize the whole research. The process helped to rethink the matter and steered in the final outcomes. In future research it can be valuable to integrated it earlier, because it speeds up the process and give depth to the research.
The results are based on assumptions derived from existing knowledge since possibilities for measuring the effects were not available.

9.0
The Uithof

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Appendices

i.i
Amsterdam Rijn Canal

I Field visits

As explained in chapter 2.4, field visits are undertaken in the city of Utrecht (see fig. i.ii). An intensive zigzagging bike tour at the city edge of Utrecht, for the purpose of testing, evaluating and developing methods for determining the PUZ. A bike trip, for the purpose of detailed analysis on urban climate influencing spatial characteristics and elements, through expansion location Maarschalkerweerd. Followed by an walk, for getting a feeling of the area and inspiration for the design process. During these trips, notes and pictures are made.

i.ii
Bike and walk trips
Performed bike and walk trips in the city of Utrecht.

Legend

II Methods to determine the city edge

In the conducted literature study are two methods found for the determination of the PUZ's boundaries. A method from Netherlands Environmental Assessment Agency (in Dutch: Plan Bureau voor de Leefomgeving, PBL) with a planning background and one with a landscape architectural background from LOLA Landscape Architects. Both methods are described here.

PBL method: Calculation method

The PBL (Netherlands Environmental Assessment Agency) defines the PUZ as a transition zone between city and rural land. It is the area – with a diameter varying between hundreds of meters and circa two kilometers – which is directly adjacent to the existing city, including the direct surroundings of motorway exits (Hamers, et al., 2009).

The PBL wants to provide policymakers and politicians more knowledge about spatial planning in the PUZ, because much is still unclear about ongoing spatial developments at the PUZ from Dutch cities(Idem). A part of this knowledge is a method to calculate the PUZ.

In the method, the inner boundary of the PUZ (urban edge) is defined by the administrative border of the build-up area. The diameter of the zone will be the result from the outcome of the following calculation;

Diameter PUZ (m) = √surface size urban area (m2) / 6

In addition, the PUZ takes another form of urbanization into account as well. The one at (former) peripheral locations near highway junctions. Around highway junctions, within the calculated zone, a circle with a radius of 1.8 km is part of the PUZ. Outside the calculated zone, the circle has a radius of 0.9 km (see fig. ii.i). The distances of the circles are based on a car ride of around 5 minutes (Hamers, et al., 2009).

In a test, the method from PBL has been used to determine the PUZ from the city of Utrecht (see fig. 4.6 – 4.8). The figures 4.5 until 4.7 are showing the steps in between. The calculation resulted in a zone with a diameter of 1350 meters. The PUZ from the city of Utrecht has been visualized, together with the circles around highway junctions (see fig. ii.ii).

ii.i
PBL method

LOLA: Physical and spatial method

The second method is from LOLA Landscape Architects. Commissioned by the province, they have investigated the spatial differentiation in city edges in the province of South Holland (The Netherlands). LOLA defines the edge of the city as the separation of urban and rural. In their idea, not only the physical edge is relevant, but also the zone in which urban and rural influence each other; the PUZ. For the investigation of the PUZ's, LOLA developed a method based on physical and spatial edges to define the PUZ (LOLA, 2011).

The method of LOLA determines the PUZ on the basis of four steps. A fifth step divides the PUZ in sections to determine differences in the zone. This last step is irrelevant for the purpose of this research. In a test, the method from LOLA is used to determine the PUZ from the city of Utrecht (ii.iii).

Step 1 Marking the urban-rural edge.

The build-up surface is marked by the line between the outer buildings and the rural land. The method uses not a specific city, but includes all the urban areas with a population of 10.000 inhabitants. Exceptions are made when smaller urban areas are part of a bigger urban structure.

Step 2 Marking the rural edge.

This is the closest edge from the urban-rural edge at the rural site. The influence of the city on the landscape is determined, as far as possible, by physical and spatial barriers, like; dikes, rows of trees, roads and waterways. For the determination, a clear hierarchy is used.

A.	Physical and spatial barrier	highway, railway
B.	Physical barrier	provincial road, dike, canal, ditch
C.	Spatial barrier	ribbon development, row of trees, hatch
D.	No barrier	shortest line between two barriers

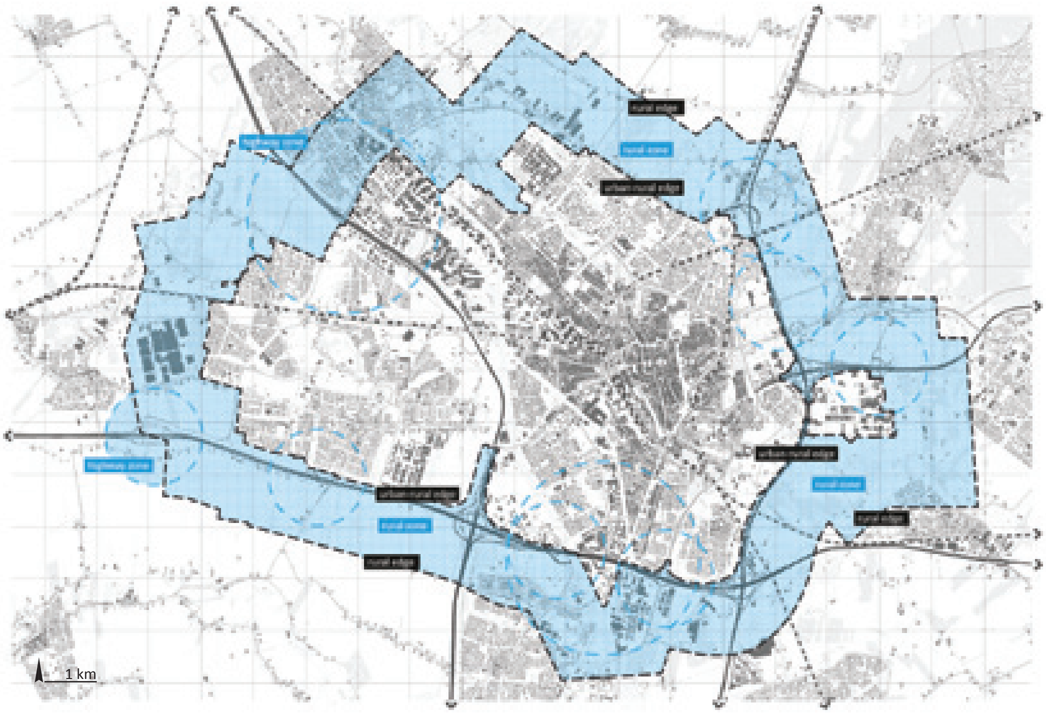
Step 3 Marking the urban edge

This is the edge from the urban-rural edge closest to the urban fabric. The marking of the urban edge is mostly related to physical barriers; infrastructure, lanes, buildings, etc. Also in here a clear hierarchy has been used.

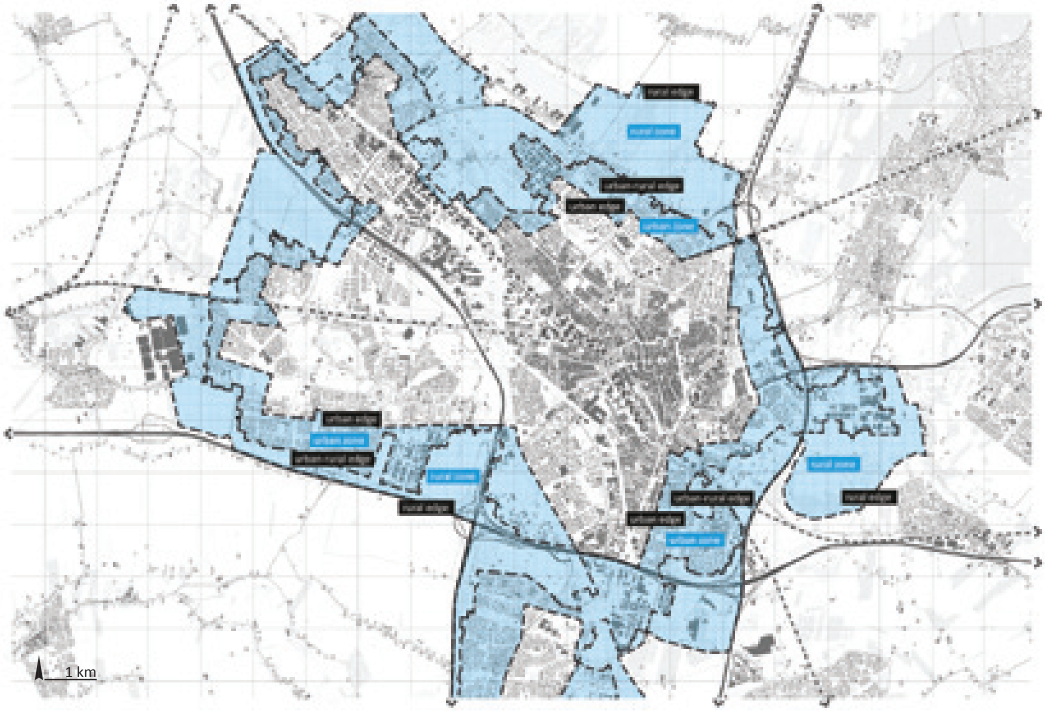
A.	Physical and spatial barrier	highway, railway
B.	Physical barrier	provincial road, district road, dike, canal, street
C.	Spatial barrier	park, row of trees, hatch
D.	No barrier	shortest line between two barriers

Step 4 The PUZ

The PUZ is the sum of the urban edge, rural edge, and urban-rural edge (LOLA, 2011).



ii.ii
PBL method
The result from the PBL method on the city of Utrecht.



ii.iii
LOLA method
The result from the LOLA method on the city of Utrecht.

Advantages and disadvantages
To evaluate the methods from the PBL and LOLA, the outcome is compared to the working definitions of PUZ in this thesis and the experience from field observations. This evaluation has led to an overview of advantages and disadvantages for the this method.

PBL method
Advantages:
- The method is a quick way to calculate the influence from the city on its rural surroundings.
- The boundary build-up surface is a clear definition of the edge between urban and rural.

Disadvantages:
- A general method that, apart from the highway junctions, does not include site specific influences for the PUZ.
- The PUZ derived from this method can only be visualized on a map. The determined edges from the zone are not visible in the landscape.
- The working definitions describes an transition zone between urban and rural. The method from PBL is only investigating the rural part of the PUZ.

LOLA method
Advantages:
- Physical and spatial characteristics makes easier to define the PUZ. On the map and in the landscape as well.
- The method describe the zone in which both urban and rural had an influence, which fit to the working definition in this thesis.

Disadvantages:
- The urban-rural edge is hard to locate since it is hard to define what the last buildings from the city are.
- The urban part of the PUZ shows a shredded whole. Neighborhoods are divided into pieces whether or not part of the PUZ.
- The rural part contains at many sides a buffer zone between neighborhood and highway, in state of the influence of the city on the landscape. Utrecht showed in the case of neighborhood Leidsche Rijn and with The Uithof, that highways do not form boundaries for urban expansion, so the influence of the city on the landscape can reach further than only the highway.

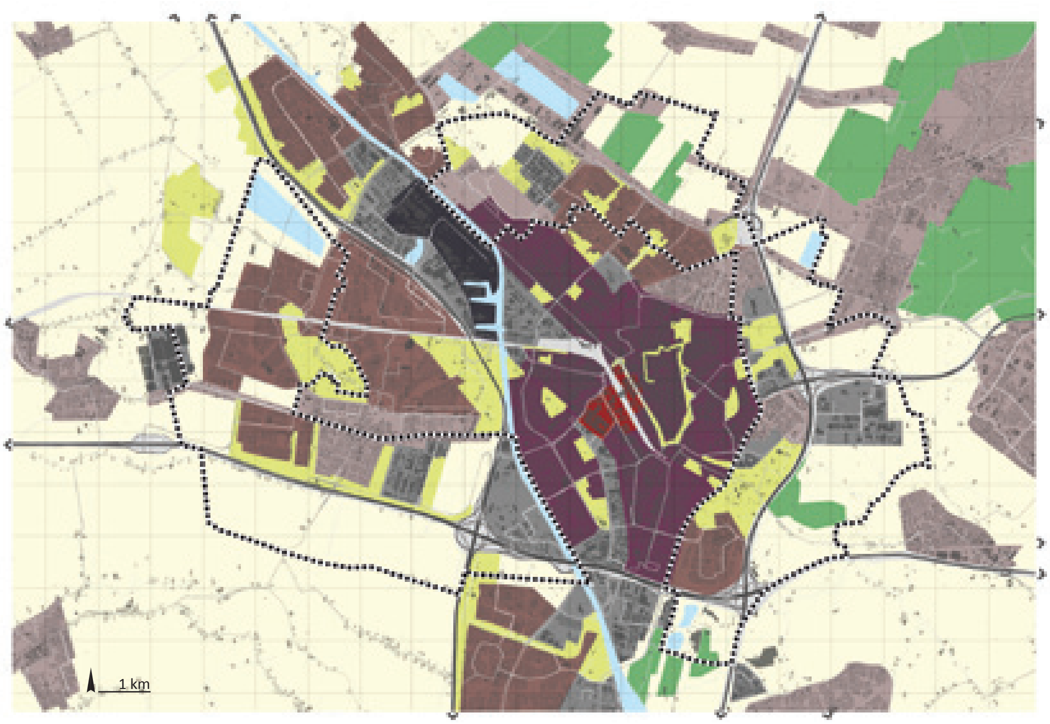
III Climatope map

A climatope map provides an indication about the climatic characteristics of the urban environment. The concept of climatopes means that different types of areas and neighbourhoods have specific microclimatic characteristics. Microclimate characteristics are determined by for example; building structures, vegetation, paved areas, and water bodies (Lenzholzer, 2013). For Utrecht the climatope analysis did result in 11 different climatope typologies (see fig. iii.i).

City centre climatope
The city centre climatope is characterised by a high building density with massive and partly high-rise building volumes. In these areas, there is little presence of green elements and the cooling effect of evaporation is strongly diminished. During daytime, the city centre climatope heats up rapidly. At night-time, the climatope cannot cool down due to the massive heat storage in the buildings and paved surfaces.

City climatope
The city climatope is characterised by enclosed buildings up to multiple floors. The amount of vegetation is relatively low which causes little cooling effect. Green consists mostly of small gardens and tree lanes. During daytime the area heats up due to the high number of paved and built surfaces and hardly cools down at night. This can create an UHI, prominently present during night-time.

Garden city climatope
The garden city climatope is characterised by semi-detached buildings with a maximum of three building layers. They contain spacious gardens and a high coverage of public green areas. Low density neighbourhoods with villa's and building typologies from the 1950's and 1960's are typical for this category. There are only minor fluctuations in temperatures during daytime, but a strong decrease in temperature during night-time. This is due to the large amount of open- and green-blue surfaces which improve ventilation.



iii.i
Climatope map
Climatope map from the city of Utrecht.

Legend

- City centre climatope
- City climatope
- Garden city climatope
- City edge climatope
- Forest climatope
- Park climatope
- Open landscape climatope
- Business climatope
- Industry climatope
- Infrastructure climatope
- Open water climatope
- PUZ border

City edge climatope
In the city edge climatope are lighter constructions available than in the garden cities. This can range from detached houses up to five floors or clustered buildings up to three layers – for example, terraced houses or block perimeter development with a large courtyard. The cooling at night is limited and ventilation is often hampered by buildings and planting.

Forest climatope
Forest and large scale bushes in parks have a lower temperature fluctuation and a relatively constant humidity. This is due to the shading and evaporation of water during day-time. Heat that is stored in the tree trunks is slowly being emitted during night-time because of the dense green roof of the forest.

Park climatope
Urban parks and gardens have a more extreme temperature shift than the built-up areas. Due to their larger sky view factor (openness towards the sky), they can easily emit their stored heat at night that can creates cool air flows. Urban parks with scattered tree plantings have a slightly lower temperature during daytime due to their ability to create shade and evapotranspiration. This makes the urban park an important producer of lower air temperature, with a potential to cool its surroundings. These open green areas can also enhance the ventilation in the city.

Open landscape climatope
During the day, an open landscape climatope is characterised by a strong fluctuation in temperature. The landscape can freely emit heat into the sky at night, because of its openness. This creates a cool air flow rather quickly. Wind speed can easily increase because there are hardly any obstacles present. Therefore this climatope is an important producer of cool air flows.
Infrastructure climatope
The infrastructure climatope is characterised by the presence of large areas covered with asphalt and concrete. These paved areas heat-up quickly during day-time, because of their colour and materialization. During night-time, they release this heat slowly due to the high sky view factor. Moreover, they also produce anthropogenic heat from cars, together with hazardous fumes.

Business park climatope
The business park climatope is characterised by massive buildings with large pavements for parking and such. There is hardly any cooling by evaporation, because there is only little amount of green areas. However, the often metal roofs of these massive buildings decrease in temperature at night due to the conduction of the metal. The paved areas remain warm at night due to heat stored in stones.

Industry climatope
The industry climatope consist primarily out of large buildings and raw materials. The heat storage is more intensive than the business park climatope. During day-time, these areas warm up by the sun but also by anthropogenic heat from production processes. If the production process is continuous, it can also have an impact on the temperature during night-time. Metal roofs can cool down easily but streets, parking lots and logistic areas remains warm.

Open water climatope
Open water climatope has got a tempering effect on the air temperature due to the fact that water slowly warms-up and cools down. This results in relatively little and slow fluctuations in temperature. During day-time, water evaporates and the air temperature is lower than in the surroundings. At night-time, the air temperature is higher than its surroundings due to the slow emission of stored heat. You can consider these large open water climatopes as batteries, that are charged with heat during daytime and emitting this heat during night-time. Wind also can flow easily over these open water bodies.

Information and method from Lenzholzer (2013).

IV Sketchbook

The explanation of the main points in the Master plan are supported by detailed designs; Oosterspoorbaan, landscape park NHW, sport park Amelisweerd, Road to Science, and neighbourhood Maarschalkerweerd. Visuals, in chapter 7.4, show how expansion location Maarschalkerweerd will look and how small scale interventions can support thermal comfort. In this appendix, the sketches behind these visuals will be showed.

iv.i
Overview location detailed designs

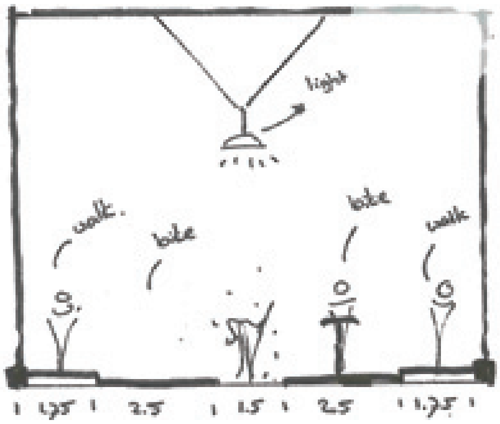

Road to science
Sport park
Amelisweerd

Expand green network
Channeling wind break
Shade

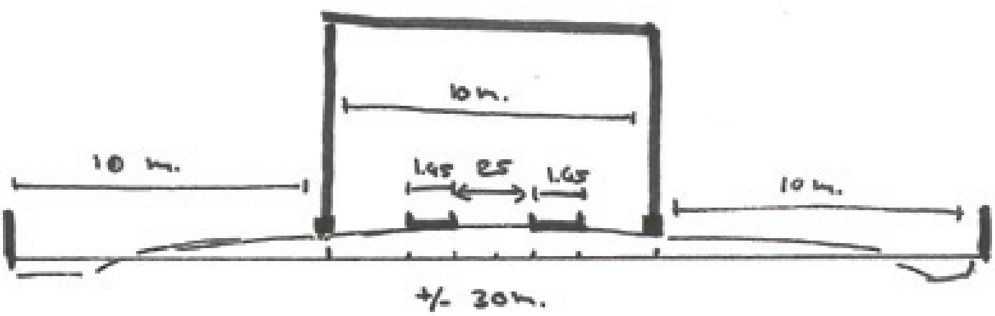
Oosterspoorbaan

The main task for the design of the Oosterspoorbaan was the implementation of bike and walk paths within the boundaries of the old railway. The offset from the rail traces are changed from 1.45 m to 2.5 m for the purpose of bike paths, in both directions. In between the red asphalt bike paths, a 1,5 meter median strip is designed. The concrete sidewalks did get an width of 1.75 meter. The existing Oosterspoorbaan is a width open elongate strip, implementation of trees can break channelling wind and provides shades for the users of the new Oosterspoorbaan.

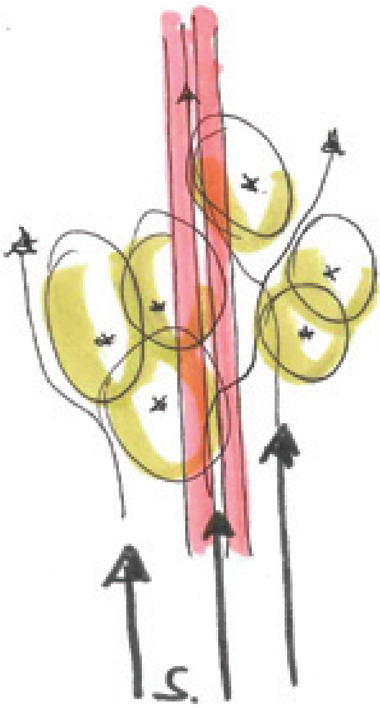
Detailed section



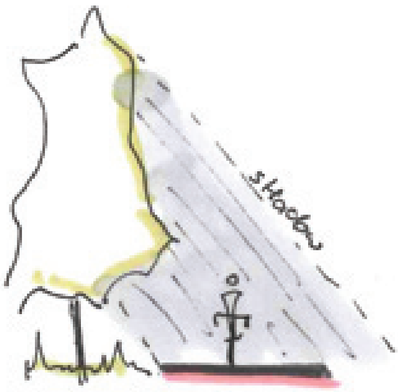
Existing situation section



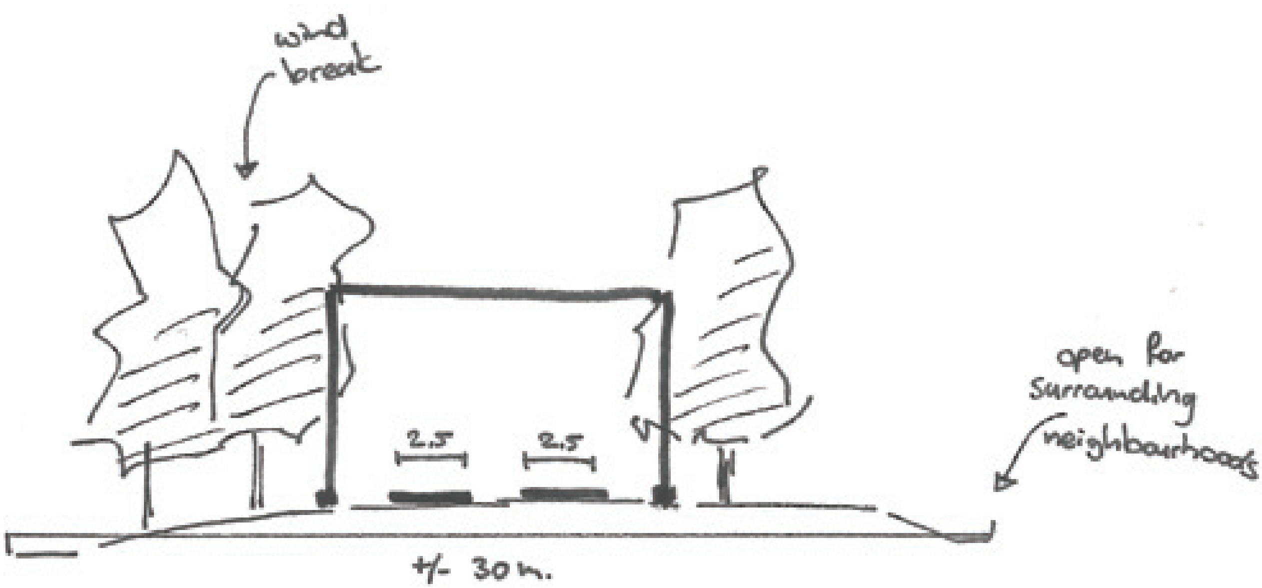
Wind break



Shade from trees



Design section



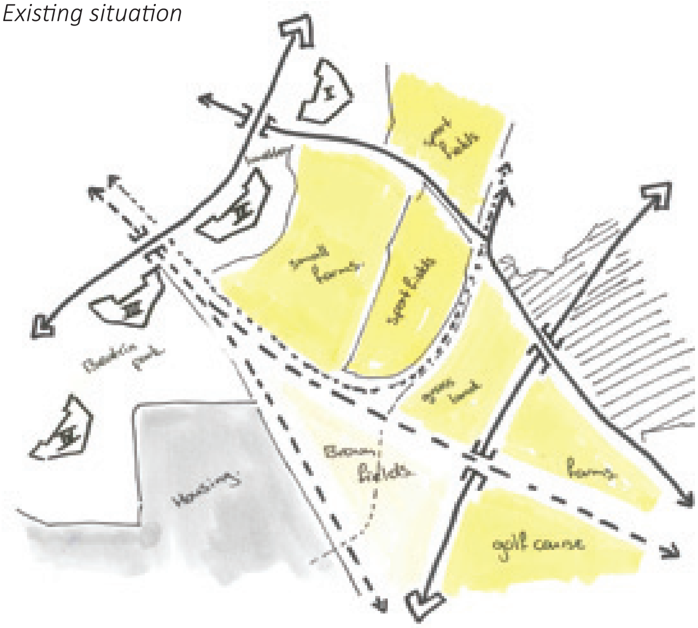
Wind corridor
Intergrating greenery
Expand/improve green network

Landscape park New Dutch Waterline

Park NHW makes the New Dutch Waterline re-liveable and is a proposed extension of the Beatrixpark. According to the rules from the old NHW, it is only possible to build small wooden construction within 300 meter from the fortifications. Between 300 and 600 meter, only small stone foundations are allowed (provincie Utrecht, 2011). Reintroduction of these rules will prevent the landscape park from wind blocking developments and let the park function as a wind corridor for the city.

Concept

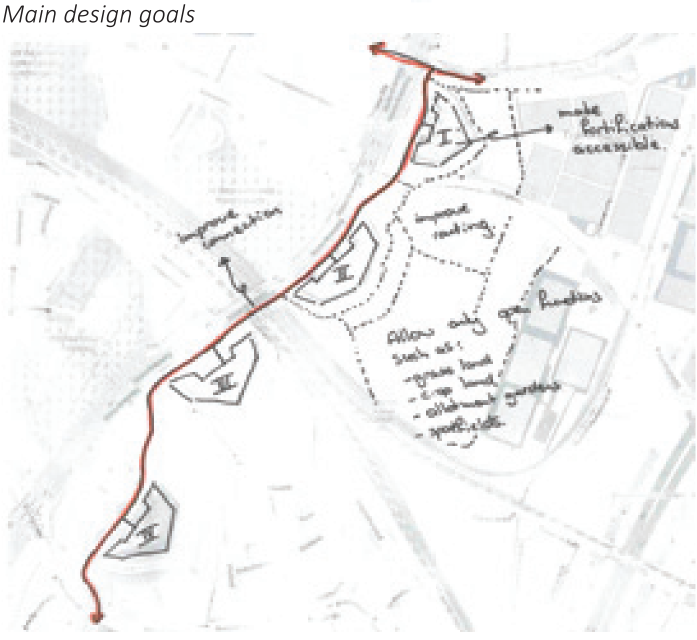
Existing situation



The existing situation of the park is already quit open. At the rural site, golfcourse Amelisweerds keeps the park open. At the urban site are brown fields, sport fields, and grasslands are located. The idea of the park is to keep this open rural setting and make it accessible for recreation.

To accomplish this, routing is implemented and only open land-uses are allowed within the park. A bike/ walk path is connecting the different relicts from the NHW. A stronger connection over the railway makes it possible to connect the Beatrixpark.

Main design goals

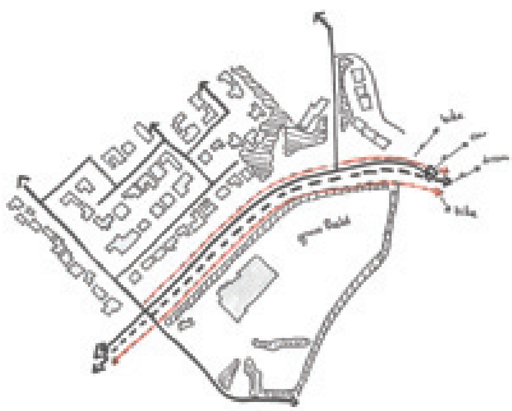


Thermal breeze
Shade
Surface typology

Road to Science

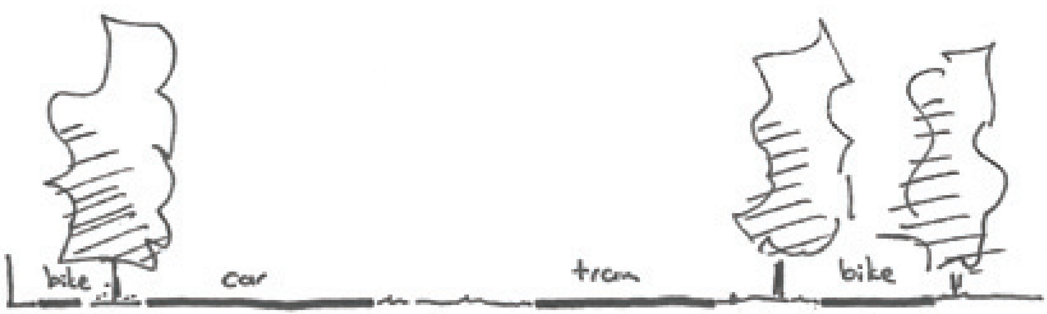
Road to science (named after the name of the road; Weg tot de Wetenschap) forms the line between the existing housing district and the open grass fields from swimming pool 'De Krommerijn'. Demolishment of the first row of houses gives opportunities for thermal breeze and creates a buffer park between the road and the neighbourhood. To support the cool airstream, the tramline is designed with a grass surface and an extra row of trees is planted. The trees give shade to the asphalt, that will heat up less rapidly.

Existing situation

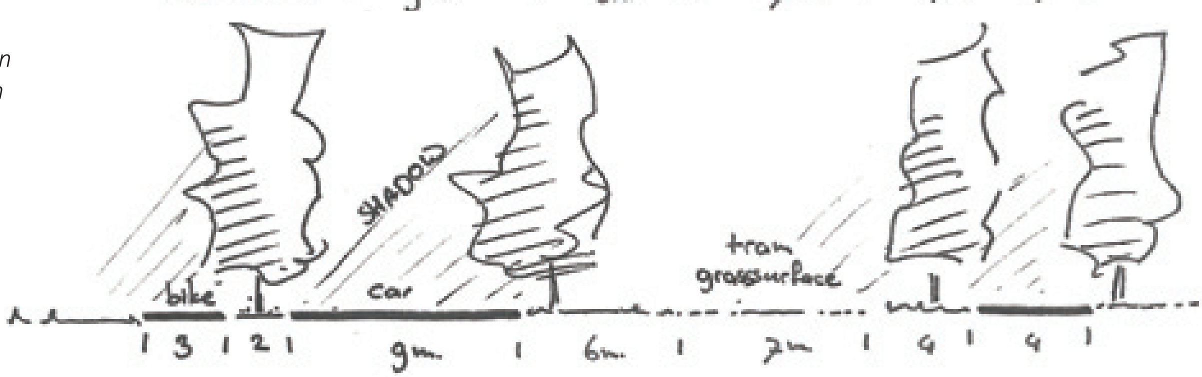


Designed situation

Section existing situation



Section design

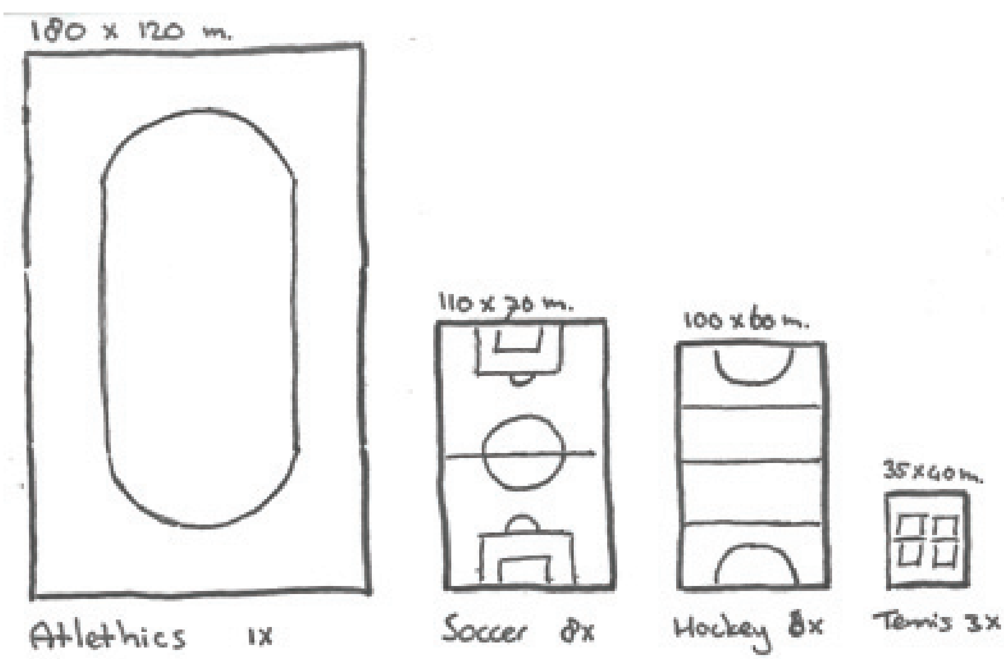


Relocation functions
Intergrating greenery
Thermal breeze

Sport park Amelisweerd

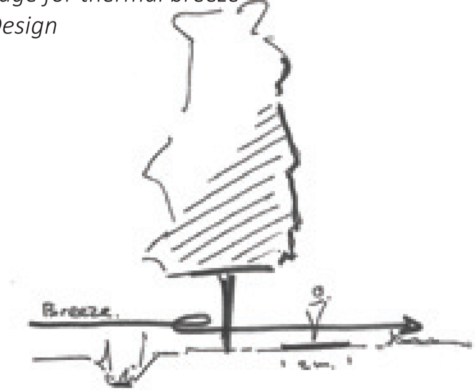
The valuable open grassland behind estate New Amelisweerd will lose its function when farmers are moving because of the development of new neighbourhoods. The openness from the grassland is replaced by the openness of the removed sport accommodations from neighbourhood Maarschalkerweerd. The different sport fields are relocated between the remaining bunkers of the NHW, and the empty farm is in use of the main building from sport park Amelisweerd. Artificial grass is as less as possible used for sport fields, because natural grass can cool the air temperature by night. Edges between the sport park and the surrounding neighbourhoods promote thermal breeze.

Relocation of

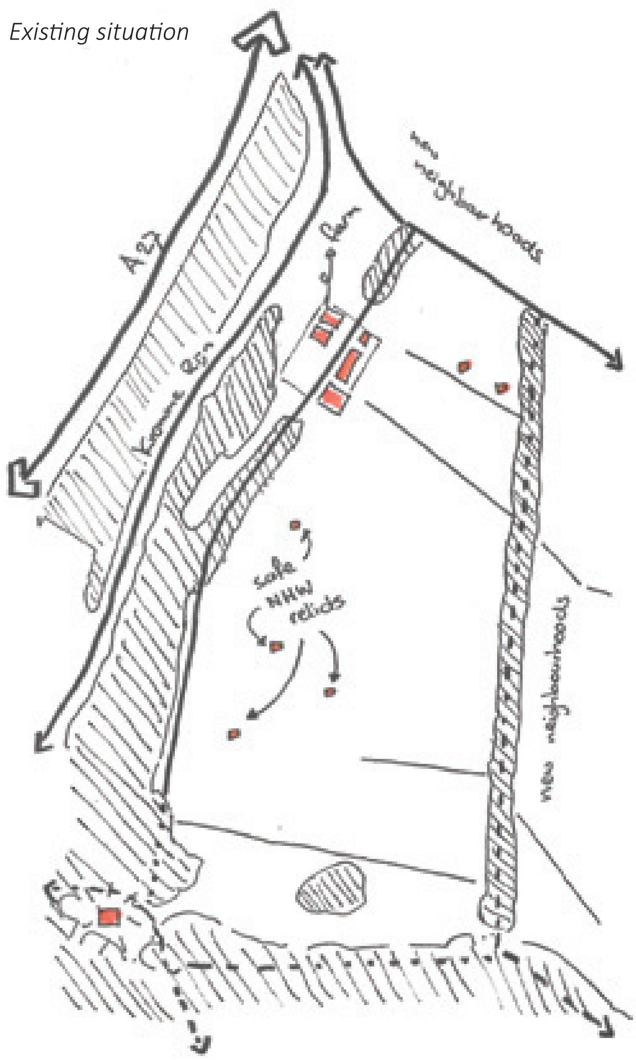


Edge for thermal breeze
Existing

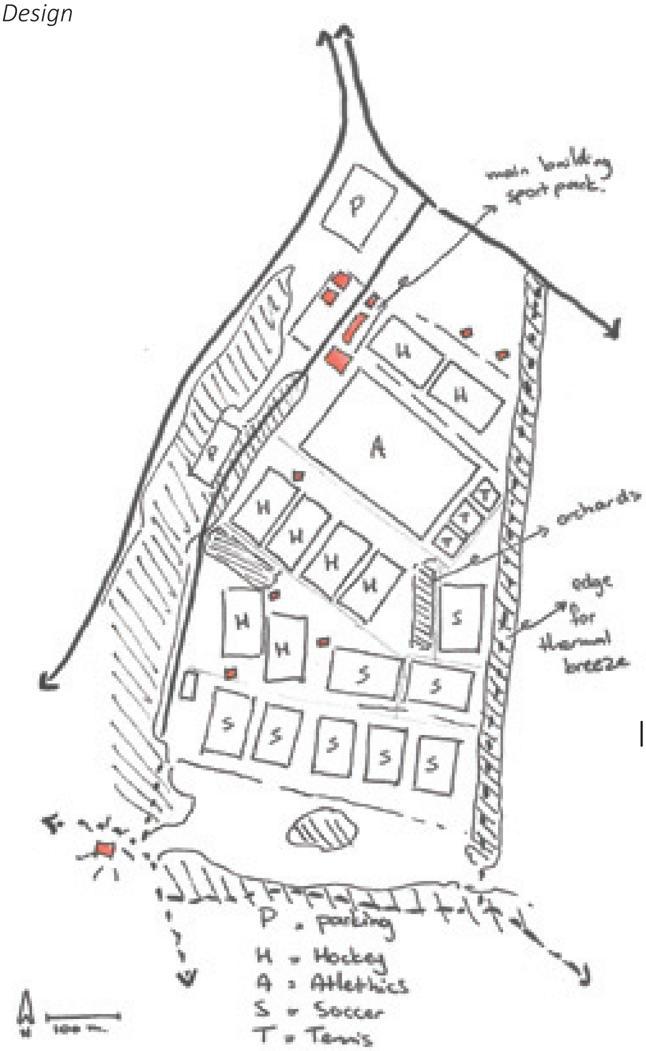
Edge for thermal breeze
Design



Existing situation



Design



Intergrating greenery
Thermal breeze
Making use of flowing water

Neighbourhood Maarschalkerweerd

For neighbourhood one, Maarschalkerweerd, a configuration of building blocks is designed which can be an example for the other new neighbourhoods. The edges of the neighbourhood are open for thermal breeze, and there is plenty of space for ventilation of the neighbourhood. Existing greenery is reused in the design and is manly used for guiding slow traffic in the neighbourhood. The neighbourhood is well connected to its surroundings, which makes it possible for the inhabitants to enjoy them.

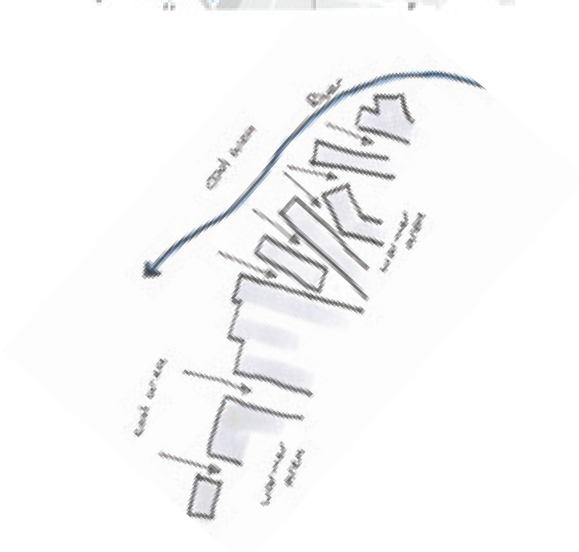
For the design, first are the existing green structures identified. The location exist of many green structures in form of lanes, forested areas, grass fields. Besides, the river Kromme Rijn is flowing along the edge of the neighbourhood and can thereby have some cooling effects. Therefore, the areas around the river is designed as a park strip. The adjacent neighbourhood edge should make use of this cooling effect by being open for thermal breeze.

For the positioning of building blocks are first some simple sketches made. Of course it is desirable to safe as much as possible open space, but it is necessary to build as much as possible houses as well. So, in the first sketches there was more open space than the last ones.

Inventory

Sketches for positioning building blocks

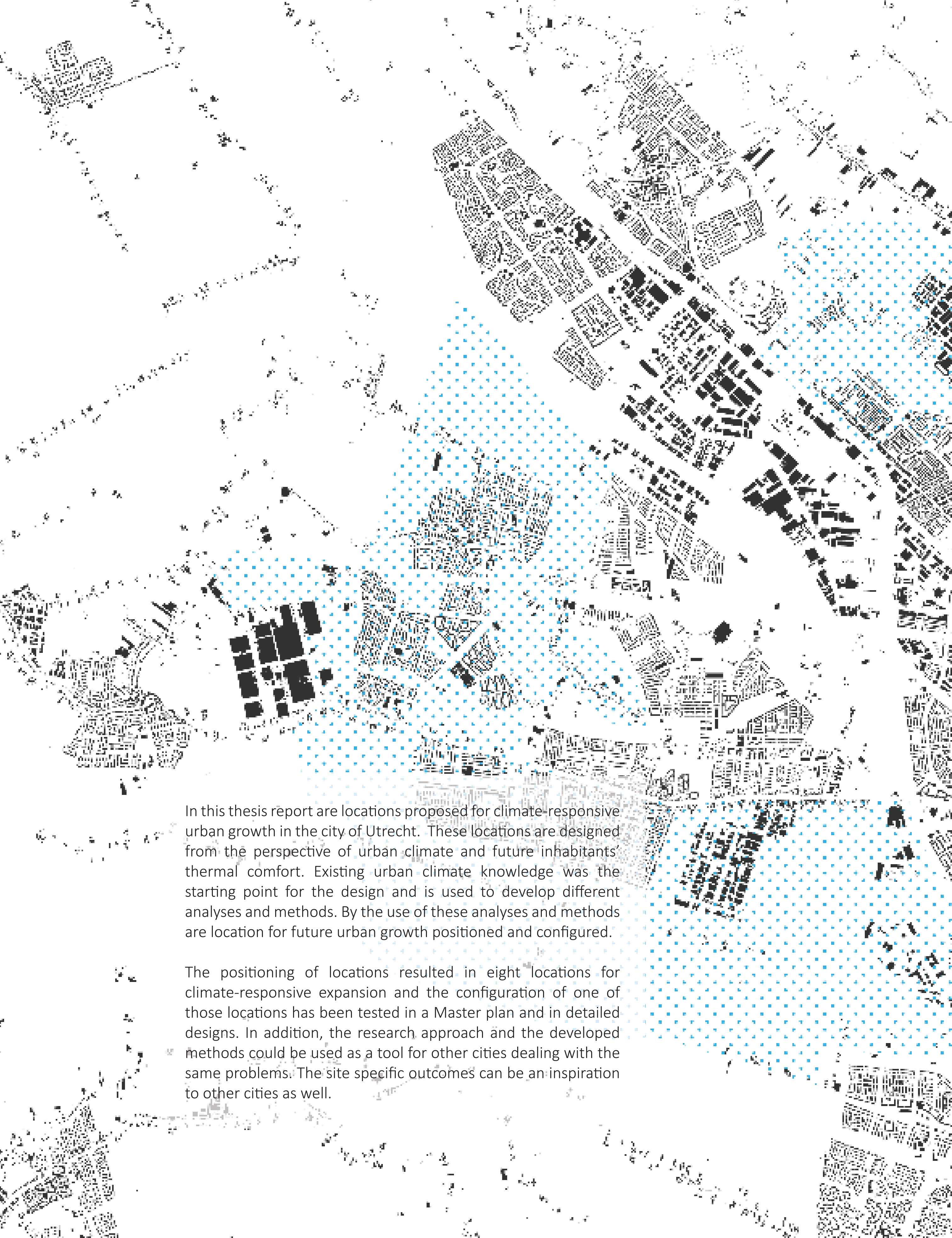
Location
Maarschalkerweerd



iv.i
Design
Maarschalkerweerd

Legend

- housing
- grass surfaces
- forested areas
- water
- tramline
- tram stop
- walk path
- bike path
- car roads



In this thesis report are locations proposed for climate-responsive urban growth in the city of Utrecht. These locations are designed from the perspective of urban climate and future inhabitants' thermal comfort. Existing urban climate knowledge was the starting point for the design and is used to develop different analyses and methods. By the use of these analyses and methods are location for future urban growth positioned and configured.

The positioning of locations resulted in eight locations for climate-responsive expansion and the configuration of one of those locations has been tested in a Master plan and in detailed designs. In addition, the research approach and the developed methods could be used as a tool for other cities dealing with the same problems. The site specific outcomes can be an inspiration to other cities as well.