Heat Stress in a Densified City

A case study to investigate the effects of densification strategies on heat stress in Utrecht

Master thesis Spatial Planning | Daan Simmelink

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Abstract

The number of people living in urban areas is expected to increase all over the world. In Europe and the Netherlands, densification strategies have been widely promoted as a development strategy for cities, following the Compact City concept. However, dense cities could be more vulnerable to the effects of climate change, such as increased temperatures and heatwaves. If high temperatures negatively affect the human body, this can be called heat stress, especially for vulnerable groups of people heat stress could contribute to morbidity and mortality. The elderly and people with a low-income were identified as groups who were more vulnerable to climatic hazard. This research aims to assess how densification strategies in the city of Utrecht will affect heat stress in the future. A model was created to estimate future temperature after densification. Industrial areas and buildings appeared to amplify the Land Surface Temperature (LST), whereas water, green space and the distance to the city centre were indicators which had a cooling effect. This research illustrates that it is important for urban planners who are concerned with densification to understand that tackling heat stress is not only about reducing the temperature. It is also about taking into account areas with high concentrations of vulnerable people, as these areas are more prone to heat stress.

Keywords: Compact City, densification strategies, heat stress, climatic hazard, vulnerable inhabitants

Summary

It is expected that by 2050 85% of all European inhabitants will live in urban areas. This is true for The Netherlands as well, wherein the coming decades most of the new dwellings will be created within urban areas. This makes cities more vulnerable to the consequences of climate change, such as high temperatures and more frequent heatwaves. Because of the Urban Heat Island (UHI) effect, cities will warm up even more, which could lead to negative health effects for humans, also called heat stress.

For decades, densification has been promoted as a development strategy both in Europe and the Netherlands, in accordance with the Compact City concept. This concept is often described as a sustainable concept for the growth of cities because it makes cities more efficient and it preserves natural area at the edge of the city. However, it implies challenges as well, densification leads to space becoming even more scarce, and the city getting less adaptable to future increases in temperature, thus potentially amplifying the UHI.

The goal of this research is to assess how densification strategies in a city will affect the heat stress in the future. Utrecht is chosen as a case area, as it is going to experience a lot of densification in the coming years, therefore, a good estimation can be made of how the city will change because of densification, and what the strategies are. In this research, it is examined how landscape characteristics influence the UHI, which is hereafter used for assessing heat stress in the city. Heat stress is defined as the phenomenon when heat negatively affects the human body, leading to an increase of heat-related morbidity and mortality. This is especially the case for vulnerable groups of inhabitants, which are in this research defined as the elderly (65+) and people with a relatively low income.

From interviews and documents from the municipality of Utrecht, it appeared that for different reasons, which could be related to the Compact City concept, a lot of densification will take place in the coming years. In the strategies, the changing climate is taken into account, especially by implementing green spaces. However, when heat stress was mentioned, it was mainly about reducing the temperature, and to a much lesser extent about taking care of vulnerable inhabitants who are more affected by heat.

For estimating the temperature in Utrecht in 2025, after densification has taken place, a regression model was created to assess the role of certain landscape characteristics (computed through a GIS software) on temperature. From the results, it appeared that increasing buildings and industrial areas amplify the temperature, whereas more green, water and a longer distance to the city centre have a cooling effect. The hottest areas were found in and around industrial areas and in the city centre. When looking at temperature, different potentially favourable densification strategies were identified. These included densification on former industrial areas, densification on locations further from the city centre and by densifying with higher buildings so that on the ground space for cooling elements such as green and water is preserved.

This research highlights that densification strategies should be designed considering not just the potential rise in temperature due to changed landscape characteristics, but also the influence of densification on the concentration of vulnerable inhabitants. This means identifying areas where densities are already relatively high as well as areas where a relatively high share of vulnerable people live, and making sure that densification interventions do not end up combining high concentrations of vulnerable people and climatic hazard, thus amplifying the heat stress risk.

Samenvatting

In 2050 zal de totale Europese bevolking die in steden woont gestegen zijn tot 85%. Ook in Nederland is dit merkbaar, de komende decennia zal het grootste gedeelte van de nieuwe woningen in steden worden gebouwd. Dit maakt steden extra kwetsbaar voor de gevolgen van klimaatverandering, zoals hogere temperaturen en meer frequente hittegolven. Door het Urban Heat Island (UHI) effect, zullen steden extra opwarmen, wat kan leiden tot negatieve gezondheidsgevolgen voor de mens, ook wel hittestress genoemd.

Al decennia lang wordt in Europa en in Nederland gestimuleerd om bevolkingsgroei op te vangen door middel van verdichting, dit is in overeenstemming met het Compact City concept. Dit concept wordt beschreven als duurzaam, onder andere omdat het steden efficiënter maakt en natuurlijke gebieden aan de randen van de stad behouden blijven. Maar verdichting leidt er ook toe dat ruimte binnen de stadsgrenzen schaarser is en er minder ruimte is om klimaatadaptatief in te richten.

Het doel van dit onderzoek is om te beoordelen hoe strategieën van verdichting zullen bijdragen aan het versterken van hittestress in de toekomst. Utrecht is gekozen als onderzoeksgebied. Eén van de belangrijkste redenen is dat Utrecht in de komende jaren veel gaat verdichten. Hierdoor kan er een goede inschatting worden gemaakt van hoe de stad gaat veranderen door verdichting en wat de strategieën daarbij zijn. Voor dit onderzoek is er gekeken naar verschillende landschapskarakteristieken die invloed hebben op het UHI. Vervolgens onderzocht of hittestress toeneemt, hierbij is hittestress gedefinieerd als het fenomeen wanneer hitte een negatief effect heeft op het menselijk lichaam en daarbij leidt tot een toename van hitte gerelateerde morbiditeit en mortaliteit. Dit is vooral het geval bij kwetsbare bevolkingsgroepen, in dit onderzoek wordt om hittestress te bepalen gekeken naar ouderen (65+) en mensen met een relatief laag inkomen.

Uit interviews en documenten van de Gemeente Utrecht bleek dat er om verschillende redenen, die aansluiten bij het idee van de Compact City, veel wordt verdicht in de komende jaren. Hierbij wordt ook rekening gehouden met het veranderende klimaat, vooral door het toevoegen van groen. Wel werd als het over het verminderen van hittestress ging, vooral besproken dat de temperatuur moest worden verlaagd door bijvoorbeeld groen toe te voegen. In mindere maten werd er gesproken over kwetsbare bevolkingsgroepen die er hinder aan kunnen ondervinden, dat terwijl de kwetsbaarheid van bepaalde bevolkingsgroepen een belangrijke indicator van hittestress is.

Voor het schatten van de temperatuur in Utrecht na verdichting is een regressie model gecreëerd. Aan de hand van dit model kan op basis van landschapskarakteristieken de temperatuur worden geschat (met GIS software). Uit de resultaten bleek dat gebouwen en industriegebieden het UHI versterken, en dat meer groen, water en een langere hemelsbrede afstand tot het stadscentrum verkoelend werken. De warmste gebieden werden gevonden in en rondom industriegebieden en het centrum. In relatie tot temperatuur werden verschillende potentieel succesvolle verdichting strategieën geïdentificeerd. Dit zijn verdichten op voormalige industriegebieden, verdichten op plekken verder van het centrum en verdichten door de hoogte in te gaan om zo op de grond meer ruimte te behouden voor verkoelende elementen zoals groen en water.

Dit onderzoek toont aan dat bij verdichting strategieën niet alleen gekeken moet worden naar de potentiele toename van temperatuur door veranderde landschapskarakteristieken, maar ook naar de invloed van verdichting op de ruimtelijke concentratie kwetsbare bevolking. Hiervoor is het belangrijk dat locaties waar populatiedichtheden al relatief hoog zijn en locaties waar de concentratie kwetsbare bevolking al hoog is geïdentificeerd worden, zodat verdichtingsinterventies er niet toe leiden dat er hoge concentraties kwetsbare bevolking ontstaan op locaties waar het erg warm kan worden, en hiermee de kans op hittestress vergroten

Preface

Urbanization and the challenges arising with climate change have always interested me. That is also why, after I finished my Bachelor of Spatial Planning, I started the Master of Urban Environmental Management. In this Master program, the focus was more on climate adaptation and the urban area and less on ambiguous theories without relevant conclusions as was the case in my Bachelor. Still, I have always kept my soft spot for spatial planning. This thesis allowed me to combine my love for spatial planning with the more pragmatic content of urban environmental management. This research included everything I liked from my five years of my Bachelor and Master study; from including planning theories (with relevant conclusions), to implementing GIS and statistical knowledge and drawing conclusions on climate adaptation and urbanization phenomena. In the past, I worked on a project on densification during the Masters' atelier, but in this research, it was very interesting to dive further into the subject and learn more on what the actual influence of densification is on the climate in the city and subsequently heat stress.

Writing a thesis during the COVID-19 pandemic was quite strange. I was not able to play hockey, which is my biggest hobby, the weekends did not really feel like weekends as the bars were closed and nothing special happened, and because I was not allowed to work in the thesis room from March to June I had to do most of the work (including GIS calculations) on my very slow laptop with studentish internet connection. Still, it all went relatively smooth: the thesis work went on, in running I extensively rediscovered my next best hobby, in the weekends I came up with the most creative plans with my friends to still drink a beer, and working on my laptop appeared not to be that bad after all. I'm happy that my thesis gave me some purpose in the months of (partial) lockdown due to this terrible virus.

This final result would have not been possible without the help of different people. I am very grateful to the people which I interviewed, I would like them for their time and useful insights during this intense period for regional and local governments. I also want to thank my supervisor during this Master thesis, Francesco Orsi, who helped me to give form to my vague ideas to create a very interesting research, and also majorly contributed to expanding my knowledge on GIS and statistics. Further, I want to thank my girlfriend for the walks during working at home, the mental support and answering my questions on the English language. Lastly, I want to thank my family for their mental support, my friends for the beers after thesis time and my fellow students for the coffee breaks and for allowing me to crush them during a game of ping-pong in the thesis room.

I hope this research provides interesting insights into the subject of densification and the relation with heat stress, as I believe that both densification and heat stress will be key topics in future urban planning.

Hope you enjoy reading my Master Thesis!

Daan Simmelink

Wageningen, August 2020

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1. Introduction

1.1 Introduction

Everywhere around the world urbanization is taking place. In 2018, 55% of the total world population lived in urban areas, it is expected that by 2050 68% of the world population will live in urban areas, whereas in Europe the percentage of urban population will increase from nearly three quarters in 2018 to 85% in 2050 (United Nations, 2019). With increasing urbanization trends in the coming years, cities will likely become denser due to both natural urbanization mechanisms and active planning policy. However, density is identified as one of the elements influencing the ways in which urban areas will be affected by climate change, potentially leading to less resilient and less sustainable cities (Dodman, 2009). In the next decades, it is expected that climate change will affect the earth in terms of altered precipitation patterns, more frequent extreme weather events and higher temperatures (United Nations, 2017). Increased density in cities, in combination with climate change leading to higher temperatures, could lead to major challenges in the future which need to be assessed by urban planners, to keep urban areas liveable.

1.2 Societal problem

Especially in cities, higher temperatures as a result of climate change become a challenge, because of the Urban Heat Island (UHI). The UHI is the phenomenon by which the atmospheric and surface temperature is higher in the urban area compared to the rural area, due to human modification of the surface and the atmospheric properties associated with urban development (Oke, 1995). High temperatures which occur because of the UHI could lead to heat stress, namely a situation in which hot atmospheric conditions have a negative impact on the health of the human body, potentially increasing heat-related mortality and morbidity (Kovats & Hajat, 2008). The elderly, lower socioeconomic groups and people already experiencing health issues can be particularly vulnerable to heat stress (see, for example, Harlan et al., 2006; Basu, 2009; Oudin Åström, Bertil & Joacim, 2011; CBS, 2019).

Next to the challenge of climate change, and the rise of temperatures in cities because of the UHI, the Netherlands also faces the challenge of building one million new houses by the year 2040 (EIB, 2015). Because the Netherlands is a highly populated country, most of these houses need to be created within the built environment to preserve agricultural lands and natural areas (Broitman & Koomen, 2015; Koopmans et al., 2018). Dutch policies, following the European guidelines, have promoted strategies of densification for decades, making it a more popular building strategy in all regions of the Netherlands (Daneshpour & Shakibamanesh, 2011; Nabielek, 2012). Jabareen (2006) supports the trend of densification by describing different advantages of a Compact City instead of a sprawled city. The Compact City is often seen as a sustainable urban form. Neuman (2005) questions if the concept can be called sustainable, as sustainability is not only achieved by just an urban form, but by the processes that take place within the city.

A negative influence of the Compact City is that it could increase the UHI, as densification could change landscape characteristics and elements of the city which have an impact on the city temperature, thus amplifying the UHI (Oke, 1995; Steeneveld et al., 2011; Yin et al., 2014; Heusinkveld et al., 2014). A few examples of spatial characteristics which influence the UHI by changing the land surface temperature (LST) are building density, vegetation fraction and water fraction (Ivajnšič, Kaligarič & Žiberna, 2014; Yin et al., 2018). Haaland & van den Bosch (2015) found for example that processes of densification can be a threat to green space in the urban area, therefore, compact cities from a major challenge for the provision of urban green space. When densification leads to a higher UHI, the amount of heat stress could also rise because more people are affected by the heat, especially in areas where a lot of vulnerable groups of people live (Dugord, Lauf, Schuster & Kleinschmit, 2014). This is something that urban planners need to take into account while creating densification strategies: they need to know whether and how densification badly affects urban climate and human well-being.

1.3 Scientific relevance

A lot of research has been carried out on UHI and heat stress (see, for example, Oke, 1995; Kovats & Hajat, 2008; Basu, 2009; Ivajnšič, 2014). Also, the UHI in Dutch cities has been widely investigated (Steeneveld et al., 2011; Brandsma & Wolters, 2012; van Hove et al., 2015). Multiple studies have focused on densification as well, which has become a more prominent strategy in urban planning in the last decades (Jabareen, 2006; Nabielek et al., 2012; Broitman & Koomen, 2015). However, less is known about the link between the two.

There are studies which have focused upon the relation between urban expansion strategies, like densification, and the Urban Heat Island (Williams, Joynt & Hopkins, 2010; Lemonsu et al., 2015). Some have tried to link the UHI to the landscape characteristics (as landscape characteristics often change due to densification). These studies used regression modelling, which seemed quite a promising method for dealing with problems related to the urban thermal environment (see, for example, Ivajnšič, 2014; Yin et al., 2014). In the Netherlands, different studies analysed the relation between landscape characteristics and the temperature. Steeneveld et al. (2011) found a correlation between the UHI and population density and the UHI and area covered by green fraction. Heusinkveld et al. (2014) found that the UHI can be linked to different types of land use, particularly built-up area, green space and water. So, different studies identified different indicators which have an impact on the UHI, but these studies did not go beyond assessing the relationship between landscape characteristics and the temperature.

Some studies focused on how densification strategies could influence future LST. Deilami & Kamruzzaman (2017) looked at smart growth policy scenarios in Brisbane. They tried to predict the future UHI in each of these scenarios looking at porosity and density in the different scenarios. A comparable study was executed by Koomen & Diogo (2015) in the city of Amsterdam. Koopmans et al. (2018) looked at two neighbourhoods where densification is taking place in The Hague to quantify the effect of different urban planning strategies on the UHI. They found that high-rise buildings are often the best solutions in limiting the rise in UHI when densifying, as green areas on the ground can be preserved by building into the air. However, they did not look at what groups of people (e.g. elderly people) lived in the analyzed neighbourhoods, and no link to heat stress was made.

Some studies made the link between the UHI and heat stress, looking at the population in an area (Harlan et al., 2006; Scherer et al., 2013). Dugord et al. (2014) linked heat stress to landscape characteristics by assessing the influence of urban structure on LST and subsequently investigating the association between the UHI and demography in Berlin to identify heat stress risk. However, while this study included the heat stress component, it did so only for the current situation, therefore disregarding possible densification trends, and using simply age to identify vulnerable people.

In conclusion, three streams of research on the UHI and densification can be identified. Research has been conducted on the influence of landscape characteristics on the UHI, the influence of densification strategies on the future UHI, and lastly the relation between UHI and heat stress. Yet a link between these three is missing, namely how densification strategies could influence the future UHI and as a result increase heat stress in the city. This knowledge could be important as cities in the Netherlands will need to densify in the future to meet the housing demand, hereby the right strategies are important to do so without exacerbating the effects of climate change.

1.4 Report objective

The objective of this research is to assess how densification strategies in a city will affect the heat stress in the future. This will be researched by looking at densification strategies, investigating their impact on the built environment and looking at where and to what extent heat stress risk is likely to increase due to densification. In order to research this, the city of Utrecht has been chosen as a case study area. A case area was needed to quantify the effects of densification on heat in the city and investigate whether and how densification strategies affected heat stress. As Utrecht is going to experience a lot of densification in the coming years, a lot of data on how densification is planned is available. Besides, Utrecht is a good city for calculating the UHI, as it is a compact settlement surrounded by rural area. In section 4.2 the choice for Utrecht will be elaborated further upon.

1.5 Report structure

This paper will first introduce the theoretical framework (2) on which the research will be based on, followed by theoretically informed research questions (3). Hereafter, the methodology (4) of how the research questions will be investigated is elaborated on. In the results chapter (5) the outcomes of the research will be presented, that will be discussed in the discussion part (6). Finally, conclusions and recommendations are given based on the results and the discussion in the conclusion (7).

2. Theoretical framework

2.1 Compact City concept

In the past decades, population density has increased in a lot of cities in the Netherlands. This is mainly due to natural agglomeration phenomena like urbanization and the aim to preserve valuable natural and agricultural land (Broitman & Koomen, 2015). On the other hand, policies also led to the promotion of densification. A concept that has been widely used to describe the densified city, is the Compact City concept. For decades, the Compact City concept has been promoted as a planning strategy, eventually becoming a dominant strategy in urban planning (Daneshpour & Shakibamanesh, 2011; Nabielek, 2012; Van der Woude, 2016).

2.1.1 Characteristics of the Compact City

According to Jabareen (2006); "the idea of a Compact City includes many strategies that aim to create compactness and density that can avoid all the problems of modernist design and cities" (p. 46). The Compact City can be seen as the opposite of urban sprawl (Neuman, 2005). The rise in popularity of sustainable development has contributed to the promotion of the compactness idea. The concept has several ecological and environmental justifications behind it. Compactness can reduce fuel consumption for travelling, as different facilities are more close to each other. It is favoured as well because the urban land can be used more intensely, while rural land at the edge of the city is preserved. A third advantage is that compactness and mixed-use lead to increased social cohesion, cultural development and diversity. Last, it is argued that the Compact City strategy is economically attractive, as the infrastructure, like street lights and roads, can be provided more effectively (Jabareen, 2006). Burton (2000) identifies advantages as well, namely, improved public transport use, reduced segregation and better access to facilities. However, she states that compactness could be negative for different aspects of social equity, such as less domestic living space and lack of affordable housing. The Compact City is often also related to mobility as it privileges public transport over private vehicles (Westerink et al., 2013), and is specifically associated with the traffic concept of Transit-Oriented Development (TOD), which is about dense development around locations served by public transit. Neuman (2005) has identified several characteristics of a Compact City, they are listed in table 1.

Table 1. Compact City characteristics (Neuman, 2005)

1.	High residential and employment densities
2.	Mixture of land uses
3.	Fine grain of land uses (proximity of varied uses and small relative size of land parcels)
4.	Increased social and economic interaction
5.	Contiguous development (some parcels or structures may be vacant or abandoned or surface parking
6.	Contained urban development, demarcated by legible limits
7.	Urban infrastructure, especially sewerage and water mains
8.	Multimodal transportation
9.	High degrees of accessibility; local/regional
10.	High degrees of street connectivity (internal/external)
11.	High degree of impervious surface coverage
12.	Low open-space ratio
13.	Unitary control of planning of land development, or closely coordinated control
14.	Sufficient government fiscal capacity to finance urban facilities and infrastructure

One of the key characteristics of the Compact City concept is density. Jabareen (2006) sees density as a critical typology for determining sustainable urban form. The definition that is given for density is the ratio of people or dwelling units to land area. The assumption that is made for the fact that density is seen as design concept related to sustainable urban form is based on the concept of viable threshold. Jabareen (2006, pp. 41) states that “at certain densities (thresholds), the number of people within a given area becomes sufficient to generate the interactions needed to make urban functions or activities viable”.

Multiple definitions of density are provided by different scholars (Boyko & Cooper, 2011; Batey & Forsyth, 2018; Dembski, Hartmann, Hengstermann & Dunning, 2020). In spatial planning, density could be simply defined as the number of units in a specific area. However, these units could be different things (e.g. people, jobs), therefore there are many different definitions that depend on the kind of density that is being investigated. Besides, different kinds of density could also have different scales (Boyko & Cooper, 2011). Batey & Forsyth (2018) came up with a basic equation to define density for planning. According to them, a numerator which represents objectively observed planning relevant items is divided by a denominator which represents an area. While all the planning densities can be described by this formula, not all of them have the same character, as the objectively observed planning relevant item as well as the (kind of) area can be different. Within planning densities, Batey & Forsyth (2018) describe two characters:

- Discrete planning densities indicate densities where the numerator is a discrete item, such as population, housing, job and business densities.
- Intensities or proportional planning densities are densities on proportions of the built area to land use, such as the floor area ratio, floor space index or building footprint.

In this research, the main focus will be on discrete planning densities, hereby population is the most suitable numerator to quantify density. This is since this research will focus on the relation between densification and heat stress. When researching heat stress, the population within an area should be taken into account, as heat stress only occurs when the heat negatively affects the human body (Scherer et al., 2013). Thus, when densification is mentioned, it can be defined as the net increase in population within a specific area, that is realized within the urban area.

Density affects sustainability by reduced consumption of energy, materials, transportation, land for housing, and urban infrastructure. Besides the conservation of resources, density provides for compactness that encourages social interaction as well (Churchman, 1999). Broitman & Koomen (2015) state that densification is seen as a strategy for providing extra houses within a city, without expanding the city and thus claiming valuable land. However, densification of a city implies several challenges as well. In fact, different aspects of a city which are important for a healthy and comfortable environment are challenged by densification (Boverket, 2017). Multiple disadvantages of dense urban forms identified by Churchman (1999) are possible higher levels of congestion and pollution, reduced green and public space, higher housing prices, psychological stress and negative health effects.

Lemonsu et al. (2015) have shown that the Compact City strategy compared to other planning strategies in Paris, affects the UHI the most, and therefore amplifies the overall vulnerability of the population. Williams, Joynt & Hopkins (2010) argue that the Compact City agenda is in line with the climate change agenda because of the aim to reduce both CO_2 and the use of resources. However, they also argue that some of the policies for achieving Compact City forms do challenge the capacity for built environments to adapt to future climate change. Because of scarcely available land in densified areas, it is difficult to adapt the built environment to respond to climate change effects like precipitation and temperature changes. Different geographical scales of interests in the Compact City and climate change discourses could lead to the conflict between mitigation measures on the city level (i.e. densification strategies) and adaptation measures undertaken on the local level (e.g. urban green provision) (Williams, Joynt & Hopkins, 2010). It is stated that *“although the Compact City is positioned within the sustainable urban form debate, the sustainable development and climate change discourses have not yet been integrated fully and there may well be conflicts inherent within these discourses.”* (Williams, Joynt & Hopkins, p. 112). For example, a Compact City may greatly contribute to climate change mitigation at the global level by reducing energy demand and transportation-related pollution, while at the same time performing rather poorly in terms of protecting its citizens from heat waves given the lack of adequate green spaces (Haaland & van den Bosch, 2015; Wingren, 2017). This suggests the need for smart densification and intensification strategies striking a balance between large- and local-scale benefits.

2.1.2 Compact City in Europe & the Netherlands

Since the 1990s, the Compact City has been widely promoted across the world to achieve sustainability through urban form. In Europe, the “Green Paper on the Urban Environment” was published by the European Commission (European Commission, 1990). This paper introduced the Compact City, making it a popular strategy for European cities (Daneshpour & Shakibamanesh, 2011). The Compact City became an important guideline throughout the continent. Cities in Europe seem to promote residential attractiveness in their city centres, leading to re-urbanization processes in these inner-city areas (Haase et al., 2010). This re-urbanization contributes to increasingly densified inner-city areas in Europe (Kabisch & Haase, 2011). In documents from the European Commission, the Compact City strategy is still framed as sustainable use of land and is promoted as a strategy for European cities. Cities should be green, compact and energy-efficient to achieve sustainable development. The balance between the Compact City and high standards of quality of life in a healthy urban environment is stated as the major challenge for Europe’s Urban areas (European Commission, 2017). Density is promoted as dense cities are seen as places where walking, cycling and public transport are more attractive, thus reducing emissions by car. Besides that, it is argued that dense cities are more efficient in energy use, land use and infrastructure (European Commission, 2016). However, a link between the Compact City or high-density levels and an increased UHI is not often mentioned in European policy documents. Besides, if for example greening is promoted in relation to the Compact City, it is mainly promoted for its recreational function instead of its cooling function.

The compact urban form has also been promoted in the Netherlands for quite some time. The first policy documents which mentioned strategies of urban densification and compactness were the second and third National Policy Documents (in Dutch: Nota over de Ruimtelijke Ontwikkeling). In 1988 the Compact City concept was first introduced in the fourth National Policy Document. The main topic was to control the suburbanization and the prevention of further urban sprawl (Van der Woude, 2016). More recent policy documents mention strategies which relate to urban densification as well, thus following the European policy documents. However, research has shown that in the Netherlands, between 2002-2008, there has been a significant decline in the densification of dwellings. This was mainly due to the development of suburban areas around existing urban cores and the increase in demolished houses within the city in this period (Nabielek, 2012). Van der Woude (2016) argues that half a century of the promotion of densification policies could not prevent urban sprawl in Dutch cities. However, Nabielek (2012) states that without a national policy on compactness, cities would have been even more dispersed. Furthermore, the attractiveness and liveability in Dutch cities had increased according to the research of Nabielek et al. (2012) on urban densification. With these arguments, it seems unfair to state that Compact City policies did not work at all. However, when reviewing recent Dutch policy documents, it can be noticed that terms like ‘Compact City’ and ‘densification’ are hardly mentioned. This could be because densification policies have been decentralized in the Netherlands: Provinces and Municipalities are now responsible for their densification policies (Nabielek et al. 2012).

Despite the long history of compactness in the Netherlands, there is not really a clear recent description of how this should be executed, let alone how densification strategies should include heat stress. These specific considerations seem to be mostly dependent on the Provinces and Municipalities today. However, since 2012 every building plan with an urban character needs to follow the ‘Ladder voor Duurzame Verstedelijking’ which is included in the vision of the Ministry of Infrastructure and Environment. The ladder prescribes that a new plan should be located within the urban area, and if not, it should be motivated why this is not the case. The goal is to prevent buildings from becoming vacant and stimulate sustainable use of space (CBS et al., 2018; Dijkstra, 2019). So it can be concluded that there is sort of a general guideline for the Provinces and Municipalities which promotes densification. However, no guidelines were found on how local governments should handle potentially increased heat stress risk as a result from densification, and as Klok & Kluck (2018) state, Dutch local governments often have insufficient understanding of heat-related risk to take the right heat adaptive actions.

2.2 Determinants of the UHI

Various characteristics of the built environment that may change due to densification may have an impact on the UHI (see, for example, Ivajnšič, Kaligarič & Žiberna, 2014; Yin et al., 2018). Most scholars use the definition of Oke (1995) for describing the UHI.

“An Urban Heat Island is simply the characteristic warmth of a town or city. It is almost ubiquitous, in the sense that it is found in cities of all climatic regions. It is due to human modifications of the surface and atmospheric properties which accompany urban development and is probably the best example of inadvertent climate change. The phenomenon is given the "island" designation because the isotherm patterns of near-surface air temperature resemble the contours of an island in the "sea" of the surrounding cooler countryside. The heat island is therefore defined on the basis of temperature differences between urban and rural stations.” (Oke, 1995, pp. 81)

In this research, this definition is used, hence, the temperature difference between the urban area and a rural reference area will be computed to measure the UHI. For determining the UHI the Land Surface Temperature (LST) from the urban- and rural area will be calculated. The LST represents the emission of thermal radiance from the land surface and can be used to measure the temperature on the ground. As this research aims to understand how densification affects heat stress, different elements of the natural and built environment that affect the LST are investigated. Some of those factors, which are proved to have a significant impact on the LST are described below. In table 2 the indicators are presented with a short description.

According to Heusinkveld et al. (2014), greenery can strongly reduce the UHI and is one of the factors that have the greatest influence on the reduction of temperature. An indicator for quantifying the amount of green space on a location is the green fraction, which represents the fraction within an area covered by green space. In this research, the vegetation fraction will be used for determining the LST on a location. The green fraction could affect the LST as vegetation and urban materials differ in moisture, aerodynamic and thermal properties (Givoni, 1991). A key factor in the cooling of urban green is evapotranspiration, which is known as the loss of water from a plant as a vapour into the atmosphere (Taha et al., 1988). Urban greening is seen as an approach to mitigate the human health consequences of increased temperature resulting from climate change (Bowler et al., 2010).

The building fraction, or urban fraction, (fraction of an area covered by built-up land) is a factor which influences the UHI as well. Heusinkveld et al. (2014) showed that the building fraction has a positive impact on the LST: more buildings in an area will lead to higher summertime temperatures. Koopmans et al. (2018) have shown as well, that increasing the building fraction leads to a higher LST. This mainly has to do with the fact that increasing the building fraction often is at the expense of the vegetation fraction. An important reason why the building fraction has a positive effect on the LST is that the urban land-cover fraction absorbs more solar radiation than natural surfaces due to a lower albedo (Oke, 1988). Land uses which absorb more solar radiation as well are industrial land use and the area of road infrastructures. A higher fraction of industrial land use in an area means a higher LST, leading to longer and more frequent heat stress events (Pearsall, 2017). In research by Hua et al. (2020), the presence of industrial areas was even identified as the greatest contributor to surface temperature, as these areas gave the most severe temperatures. This is mainly due to the fact that industrial areas are often characterized by limited green space and concrete impervious structures (Rotem-Mindali et al., 2015). The fraction of road infrastructures have an amplifying effect on the LST as well (Dugord et al., 2014; Jeong, Lee & Kim, 2015), their concrete structures and the anthropogenic activities which are taking place on areas meant for traffic, lead to an increase in temperature near transportation infrastructures. However, due to differences in the intensity of traffic between roads, peak hours and days in the week (e.g. weekends) the amplifying effect could be different per locations or time (Hart & Sailor, 2008).

Another fraction which influences the LST is the water fraction, however, the relation is more complicated than for the previously mentioned indicators. Theeuwes, Solcerová & Steeneveld (2013) found that open water bodies may lower the LST because of their evapotranspiration. But on the other hand, when the water is warmer than the air temperature, which could occur during night-time or autumn, the water has a negative effect on thermal comfort. Steeneveld et al. (2014) found a comparable result when researching the effect of open water surfaces: they argue that water bodies do not necessarily act as cooling mechanisms in urban areas, especially during seasonal transitions and night-time, because water temperatures remain relatively high when the air temperature goes down.

Schwarz et al. (2012) found that the distance to the city centre was a significant predictor of LST in the city of Leipzig. Dugord et al. (2014) found the ability of the distance to the city centre to influence the LST as well. This follows the cross-section of the typical UHI in cities defined by Oke (1987), who defines the characteristics of the city temperature when moving from the city boundary towards the city centre into three parts; the cliff, the plateau and the peak. The cliff represents a steep temperature gradient at the edge of the city, the plateau stands for a large part of the city where the temperature gradient is quite weak towards the city centre. Finally, the city centre presents the peak, where the largest temperature differences with the rural area are observed. This temperature cross-section within a city is described by Unger, Sümeghy & Zoboki (2001) as well (figure 1).

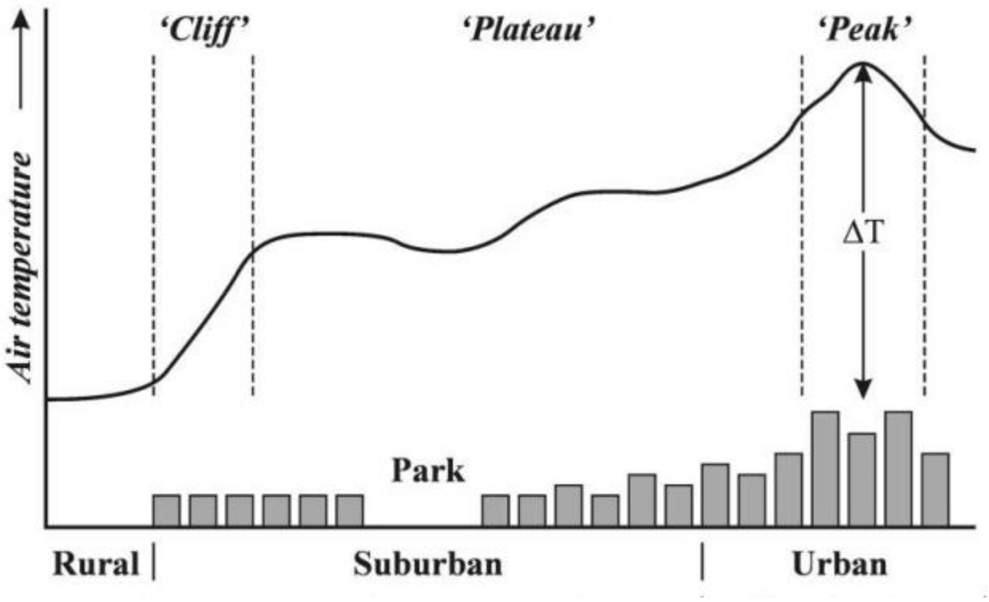


Figure 1 Cross-section of the typical UHI (Unger et al., 2001).

Steeneveld et al. (2011) found a correlation between LST and population density. Their study on the UHI in multiple Dutch cities showed that there was no correlation between total city population and LST, but the population density per neighbourhood was correlated with LST. Hereby their classification of neighbourhoods was based on the classification from the CBS, which is based on the differences in landscapes or socioeconomic structure. Within urban areas, this classification shows uniformity of the building design per neighbourhood. The correlation is a result of the fact that higher population density requires a higher building density, which often results in more trapped radiation between the buildings and a higher building fraction. There are ways to measure building density as well. A common way to measure the building density is the Floor Area Ratio (FAR). The FAR represents the total amount of floors in a building divided by the footprint of the plot (Dugord et al., 2014). Another way to calculate the FAR is by dividing the total floor area of a building by the footprint of the plot (Lan & Zhan, 2017). In general, a higher FAR means higher building heights over the same area (Yin et al., 2018). Dugord et al. (2014) found that the FAR has a strong positive correlation with the LST, indicating that when the FAR is higher the LST is higher as well. They also concluded that there was a strong linear relationship between the FAR and potential heat stress risk, indicating that building density is a good indicator for describing the hazard component of the heat-stress risk. Another very simple indicator related to building density and FAR is the average building height in an area. A correlation is found between this indicator and the LST in multiple studies (Bottyan & Unger, 2003; Van Hove et al., 2015).

Another predictor of LST is the sky view factor (SVF) which indicates the fraction of visible sky on a location. The fraction is between 0 and 1, where a value close to 0 means that on that location the sky is only scarcely visible, often indicating a high building density and high buildings. A value close to 1 means that the sky is very visible, often indicating open parks, squares or low building heights (Dirksen et al., 2019). However, there is still uncertainty about the effect of SVF on LST (Yin et al., 2018). Yin et al. (2018) found in a study in Wuhan, China, that the influence of the SVF on the LST was significant in different models. SVF has a positive influence on the temperature, indicating that with an increased SVF the UHI be more severe. A high SVF in the studied city always occurred in areas which could be described by wide concrete asphalt surfaces which absorbed a lot of solar radiation, where a low SVF indicated areas with tree canopies or building clusters with shadows. However, studies in the Netherlands have concluded that limited sky-view could result in a lower ability to release stored heat in the city during daytime, therefore indicating that limited exposure to the sky leads to a higher LST (van der Hoeven & Wandl, 2014; Dirksen et al., 2019). On the other hand, another Dutch study from van Hove et al. (2015) did not find a correlation at all between the SVF and the temperature in the city of Rotterdam. So some scholars agree that there is a relation between the SVF and the LST, but conclusions about whether this relation is positive or negative are conflicting. Besides that, results are available as well which do not show a correlation at all.

The aspect ratio is related to urban form as well and can be compared to the SVF. The aspect ratio is the height of the buildings divided by the width of the street. In areas with a low SVF indicating a high building density, the aspect ratio is often high. The relation between the aspect ratio and the LST appeared to be quite complex because of two counteractive processes. The process of trapping long-wave radiation has an increasing effect on the UHI, but on the other hand, the process of shadowing has a decreasing effect on the temperature. Research has shown, that if the aspect ratio is below 0.5, it has a positive effect on the temperature, but when there is a large aspect ratio, the shadowing effect becomes more important (Marciotto, Oliveira & Hanna, 2010; Theeuwes et al., 2014). Therefore, the aspect ratio might be a quite complex indicator for estimating the LST in an area.

Table 2 Factors affecting LST in the city.

Indicator	*Description*	*Impact on LST*	*References*
Vegetation fraction	The fraction of green in an area	Negative	Steeneveld et al. (2011) Brandsma & Wolters (2012) Heusinkveld et al. (2014)
Building fraction	The fraction of buildings in an area	Positive	Heusinkveld et al. (2014) Koopmans et al. (2018)
Industrial fraction	The fraction of industrial land use in an area	Positive	Rotem-Mindali et al. (2015) Pearsall (2017) Hua et al. (2020)
Fraction of road infrastructure	The fraction of roads in an area	Positive, higher during peak hours or weekdays	Hart et al. (2008) Dugord et al. (2014)
Water fraction	The fraction of water in an area	Negative, except for when the water temperature is warmer than the air temperature, (e.g. during night-time)	Theeuwes et al. (2013) Steeneveld et al. (2014)
Population density	Amount of inhabitants per square kilometre	Positive	Steeneveld et al. (2011)
Floor area ratio (FAR)	Indicator for building density, the total amount of floors in a building divided by the footprint of the building, or the total floor area of a building divided by the footprint of the building	Positive	Dugord et al. (2014) Lan & Zhan. (2017) Yin et al. (2018)
Mean building height	The height of buildings in an area	Positive	Van Hove et al. (2015)
Distance to city centre	The distance in (km) from a central point within the city centre	Negative	Unger et al.(2001) Schwarz et al. (2012) Dugord et al. (2014)
SVF	The fraction of visible sky	Conflicting results between studies	Van der Hoeven & Wandl (2014) Van Hove et al. (2015) Yin et al. (2018) Dirksen et al. (2019)
Aspect ratio	The aspect ratio is the height of the buildings divided by the width of the street	Below 0.5 the impact is positive; a very large aspect ratio could lead to a negative impact	Marciotto et al. (2010) Theeuwes et al. (2014)

2.3 Heat stress

When the city heats up because of the UHI effect, this could have negative effects on humans. The highest level of spatial hazard in the city is defined by Gabriel & Endlicher (2011) on temperatures exceeding the 95th percentile of the distribution. Excessive heat may lead to greater health risks and higher heat-related morbidity and mortality. Not all populations are at equal health risk from heat, certain groups of vulnerable people may be more affected depending on their ability to thermoregulate (see, for example, Reid, 2013; Dugord et al., 2014). When the heat negatively affects the energy balance of the human body and thereby implying an increase of heat-related morbidity and mortality, this phenomenon is called heat stress (Kovats & Hajat, 2008). In this research, this definition of heat stress will be used, and heat stress will be determined by analysing the UHI (climatic hazard) and comparing it to the vulnerability of the inhabitants, i.e. the concentration of vulnerable people in an area.

Reid et al. (2013) identified four factors which contributed to heat-related health impacts, namely social/environmental vulnerability (i.e. education, poverty, race, green space), social isolation, air conditioning prevalence and the proportion of elderly. Especially the latter is a factor that contributes to heat stress as the elderly (i.e. >65 years) are more sensitive to higher temperatures than other age groups (Ellis, Nelson & Pincus, 1975; Scherer et al., 2013). Not only the elderly but also young children and babies have limited ability to thermoregulate. Therefore, this age group is more at risk as well (Kovats & Hajat, 2008). However, although they are at more risk because of their limited ability to thermoregulate, no significant evidence was found in mortality studies that heat affects the mortality of children (Ishigami et al., 2008). In Dugord et al. (2014), two age-specific groups are seen as 'vulnerable people', namely elderly people (i.e. 65 years or older) and young children (below 6 years old). However, in this research, young children were not taken into account in the classification of vulnerable people looking at age groups. This is because there is no significant evidence that heat affects the mortality of children according to Ishigami et al. (2008).

As Reid et al. (2013) found, not only age affects vulnerability to heat stress, lower socioeconomic and minority groups were as well more affected by warmer temperatures leading to heat stress. This was as well found in other studies (see, for example, Harlan et al., 2006; Basu, 2009; Huang, Zhou & Cadenasso, 2011; Pearsall, 2017). There are multiple reasons for this. First, certain landscape characteristics in neighbourhoods where low-income people live are often less resistant to high temperatures. Most of the previously mentioned studies were in cities outside Europe, but Chakraborty et al. (2019) found that also in European cities, like Copenhagen and Berlin, the UHI distribution falls more heavily on the less affluent. People with a low income are more likely to be living in neighbourhoods with old buildings with poorer temperature regulating conditions (Santamouris et al., 2007; Michelozzi et al., 2005). A second reason is the protection against heat. In the 'poorer' neighbourhoods it was found that the residents lacked adequate social and material resources to cope with high temperatures, decreasing the thermal comfort of the residents (Harlan et al., 2006). For example, people with higher income levels, have a greater ability to protect themselves against heat stress, by e.g. having better access to information on protection to heat or self-protective resources like air conditioning systems or house insulation (Reid et al., 2009; Lundgren & Kjellstrom, 2013; Rohat et al., 2019). Besides, it was found that individuals with a lower income were more vulnerable because they may be more reluctant to respond to warnings, and they have fewer resources to make use of transportation to cooler locations (Gronlund, 2014). Another reason was found by Michelozzi et al. (2005), they found that people with a relatively low income are more likely to suffer from a chronic disease or other medical risk factors, such as mental illness or obesity, and thus these people are more prone to the negative effects of heat.

A study in multiple cities in Canada found that heat in low-income neighbourhoods caused health effects for the elderly as well as people below 65 years old (Belanger et al., 2014). Therefore, it is argued that reducing the temperature in urban low-income neighbourhoods which are vulnerable to high temperatures should get special attention of policymakers (Harlan et al.. 2006). In addition to the elderly, this research will look at people with low-income as vulnerable people, to identify heat stress. This is in line with a study in London and Madrid, which also used the elderly and people with a low income to identify vulnerability to heat (Sanchez-Guevara et al., 2019).

People living in social isolation have a higher heat stress risk as well in comparison to e.g. people with social contacts and access to transportation as Reid et al. (2013) stated. For example, people who are divorced, widowed or have never been married were more likely to die from heat stress than people who were married. However, it should be noted that it does not per se indicate that people who are not married are socially isolated, as they could still have social contacts and access to transportation (Reid et al., 2013). Therefore, it is hard to identify social isolation, as the definition of social isolation is quite complex and data on this risk factor is hard to find. Thus, social isolation will not be used as an indicator of vulnerable people in this research.

2.4 conceptual framework

Based on the theoretical framework as described above, a conceptual framework is created for this research (figure 2). In this research, the Compact City concept will be used as a lens to look at the city of Utrecht. One of the key elements of the Compact City concept is density, to achieve this, strategies of densification can be implemented in a city. However, these densification strategies could increase heat stress. This research will focus on two aspects of heat stress which could become more severe due to densification. First, densification could change landscape characteristics in a way that the UHI could be amplified as described in section 2.2. Second, this research focusses on the vulnerability of the population, the groups that will be looked at are the elderly and people with a low income, as described in section 2.3. The goal of this research is to superimpose areas of supposedly high temperatures with areas where the concentration of vulnerable people is particularly high, to quantify heat stress, and see if there is a relation with the densification strategies implemented in the city of Utrecht.

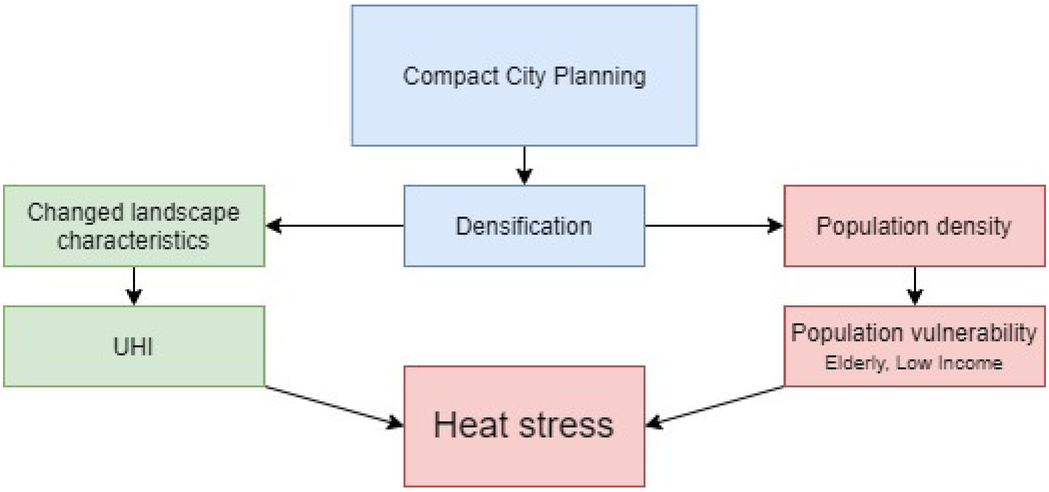


Figure 2. Conceptual framework, each colour represents one sub-question as listed in section 3, created by author

3. Research Questions

As previously mentioned, this research aims to assess how densification strategies in a city will affect the heat stress in the future. This is investigated to conclude what the influence of densification strategies could be on heat stress, and give recommendations on how these densification strategies could be implemented without exacerbating heat stress in the city. To investigate this, the following research question is composed;

RQ: How will urban densification strategies spatially affect heat stress in the future?

To answer the research question, three sub-questions have been formulated, these sub-questions are based on the theory as described in the previous chapter. The sub-questions are:

SQ1: What are the plans/strategies for the future regarding densification in the study area?

SQ2: How are landscape characteristics related to temperature in the city?

SQ3: Where and to what extent will vulnerable groups be exposed to heat stress given the implementation of densification strategies?

SQ1 aims to identify strategies of densification in the city of Utrecht, hereby the Compact City concept will be used as a lens to analyse the city's plans and strategies, besides, the discourse around heat stress will be investigated as well. This sub-question will be answered by conducting desk research and interviews, which will give insights on what is going on regarding densification, and how heat stress is hereby taken into account. Thereafter, SQ2 will provide insight into how changing landscape characteristics due to densification will change the temperature in the city. A quantitative analysis will be executed to estimate the impact of different urban landscape characteristics on temperature with regression analysis. Both the outcomes of SQ1 and SQ2 are used to answer SQ3, where it is analysed in which parts of town heat stress risk is most likely to occur, and what the relation with densification strategies is. Hereby, conclusions can be drawn on what urban planners should take into account while densifying a city in terms of not amplifying the heat stress risk. The methods which are used to achieve the research objective and answer the sub-questions and thus the main research question are described in chapter 4.

4. Methods

4.1 Character of research

From the viewpoint of the objective of the study, the type of research is a correlational study, as the emphasis of the research is to discover the existence of a relationship between two aspects of a phenomenon or a situation (Kumar, 2014). The study will focus on measuring the relationship between the physical characteristics of a densified city and temperature, and subsequently, investigate how densification strategies affect heat stress.

From the perspective of the mode of enquiry, this research can be described as one with a mixed-methods approach. This research uses the strength of both a qualitative and quantitative study design. The first part of the research, which is dedicated to answering the first research question, is a qualitative design in the form of a review of plans and strategies on urban densification by conducting desk research and interviews. Herewith, the aim is to describe the situation within the study area. The second part of the research will be quantitative research and will answer the second and third research questions. First, the research will investigate how the spatial characteristics of Utrecht's built environment affect temperature, and hereafter, this information will be used to estimate the likely effect of densification policies on the future temperature, to identify locations where heat stress risk occurs. This part of the research is a prospective study design, as it is about the likely prevalence of heat stress in the future.

For this study, the municipality of Utrecht was selected as a case. This area was treated as one entity to investigate how densification strategies influenced the heat stress in the future. By conducting a case study, the research can be much more in-depth and detailed than would be possible if a large sample was chosen (Gilbert, 2008). Moreover, investigating multiple areas would become too time-consuming and was therefore deemed unsuitable for this research. The aim of the case study design in this research is to study a phenomenon within one municipality, i.e. heat stress due to densification. For this research, the type of case study that was chosen is an extreme case study, namely an outlier that represents extremely high or extremely low values of the phenomenon. Extreme cases are useful as they reveal more information owing to the fact that under extreme conditions more basic mechanisms are activated, which allows the researcher to dive deeper into the subject and the consequences instead of only describing the situation (Flyvbjerg, 2006). In the next paragraph, the selection of the case area will be elaborated.

4.2 Study area

As said, the municipality of Utrecht was chosen as the study area. Besides the conveniences of a Dutch city, Klok & Kluck (2018) state that it is proven by many different studies and papers that heat stress is a problem in the Netherlands, and the number of events causing heat stress will increase in the future due to climate change. Besides, they conclude from their research that Dutch local governments often have insufficient understanding of heat-related risk to take the right heat adaptive actions. Therefore, a Dutch city like Utrecht seemed interesting to investigate in terms of heat stress.

Utrecht is located in the Province of Utrecht in the centre of the Netherlands (figure 3). In 2019 the city of Utrecht counted 352,941 inhabitants, but the population is expected to grow a lot in the coming years. The strongest growth is expected between 2022 and 2025 when the number of inhabitants is expected to increase by around 40,000 units. All districts within Utrecht are expected to grow due to densification; Zuidwest and Leidsche Rijn will have the strongest growth (afdeling Onderzoek, gemeente Utrecht, 2019). Among the four largest cities in the Netherlands (Amsterdam, Rotterdam, The Hague and Utrecht) Utrecht is expecting the largest growth in percentage (CBS, 2019b). Because of the expected growth in the coming years, Utrecht makes an interesting case area for this research. Besides, the largest amount of dwellings will be created within the built environment, because Utrecht has almost reached its limits of expanding its city boundaries. Utrecht could be seen as an extreme case as a lot of densification is taking place in the coming years, more than in every other Dutch city, because of that more information can be obtained. It is expected that this case is typical of densifying cities, and therefore this single case can provide insights and outcomes which are prevalent in other densifying cities as well.

Utrecht represents a suitable case study also because, owing to an upcoming major population growth (taking place between 2022 and 2025), densification projects will be implemented in the coming years. And as this period of time is not too far away, a lot of project plans are already worked out, which makes it easier to look at how landscape characteristics will change in the coming years. A lot of data is available, such as strategies, estimation on inhabitant increase and building plans. This is different from what happens in other Dutch cities, where either a large growth had mainly happened in the last decades, or it is expected in the next decade(s).

Next to that, the location of Utrecht makes it a city which is simple to investigate as well. Unlike large Dutch cities in the Randstad, Utrecht is an “island” surrounded by rural land and the predominantly land use around the built-up area of Utrecht is pasture (Brandsma & Wolters, 2012). The fact that it is surrounded by rural area makes it a good city to compare the urban climate with the rural climate for the computation of the UHI, which according to Oke (1995) is the difference in temperature between the rural and the urban climate.

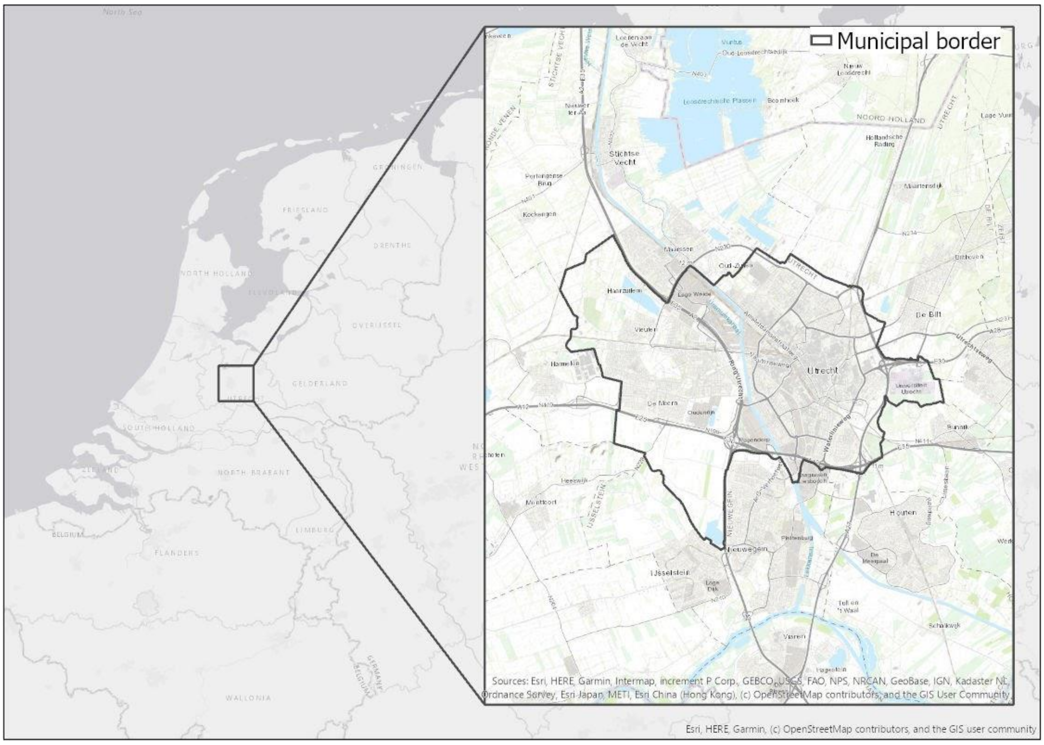


Figure 3 Location of Utrecht, created by author

4.3 Design of data collection and data analysis

4.3.1 Overview of methodology

The methods used to answer each sub-question, are presented in figure 4. The research starts with identifying the strategies and plans for densification. The main activities to answer the first sub-question are conducting interviews and doing desk research in the form of a document review. From the interviews and documents, densification strategies and plans can be identified.

The second sub-question, about the influence of landscape characteristics on the land surface temperature (LST), will be answered by conducting regression analysis. This step is needed to estimate how each characteristic influences the LST. Hereby, the landscape characteristics are the independent variables, and the LST derived from satellite images represent the dependent variable. With regression analysis, the parameters for the influence of the independent variables on the dependent variable are computed, resulting in a multiple linear regression model for estimating the LST. Hereby the Ordinary Least Square (OLS) regression method is used.

For the third sub-questions, where locations of (increased) heat stress-risk after densification are identified, the future LST will be computed. This will be done by editing the data on landscape characteristics and population based on the documents reviewed in part one. When the data is modified, the landscape characteristics will be computed. With the new landscape characteristics representing a situation after densification, the model created with the regression analysis has to be used to estimate the future LST. For identifying heat stress, the categorization method of Dugord et al. (2014) will be used. Hereby, areas with a supposedly high temperature are superimposed with areas where a particularly high share of vulnerable people lived. This is done for as well the current and future situation to identify how densification contributes to heat stress in the city of Utrecht. The steps that have to be taken in this research are presented in a more detailed way in the coming paragraphs.

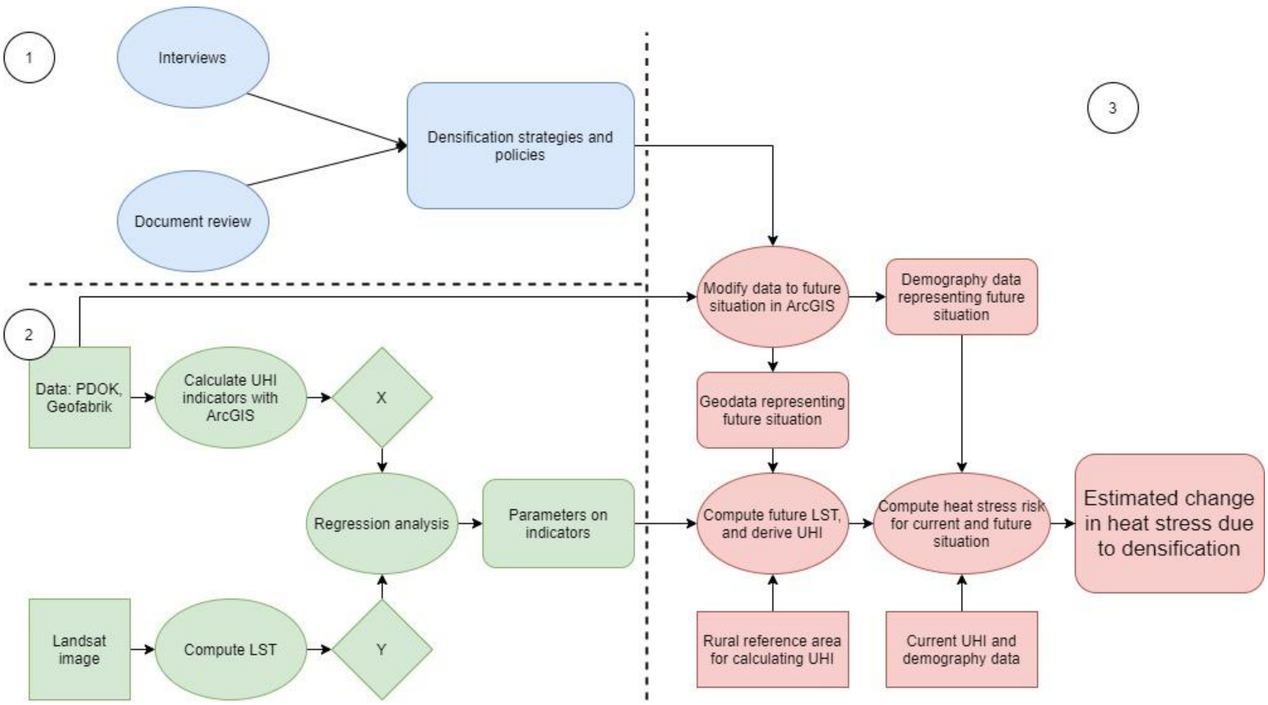


Figure 4 Overview of the methodology used in this research, created by author

4.3.2 Review of densification strategies and plans

The first step in the research was aimed at identifying and spatially locating densification strategies in the city of Utrecht. This was achieved combining the review of policy documents and interviews with municipality officers. The review of policy documents was carried out to identify strategies and policies regarding densification in Utrecht and to create a list of areas where building projects will take place in the coming years to identify densification. The interviews with officers from the municipality and the Province were conducted to check, support and dive further into the researcher's findings from the desk research. The use of multiple data sources allowed for so-called triangulation, whereby different perspectives can be accounted for and explored. Doing this increased the validity of the qualitative research (Creswell, 2014).

A wide range of policy documents from both the Province and the municipality (and available online) were studied (table 3; appendix A). Not only documents for Utrecht in general were investigated, but also documents which were specifically focused on one department, like living, green or mobility. The desk research served different purposes. First of all, it gave a good overview of what was going on in the municipality around densification, and also, if heat stress is an important theme. Second, it was important to identify locations where building projects were planned, a list of (densification) locations was created based on information from the municipality's website. A full list of locations that were analysed is presented in Appendix B: these locations were used later on to edit the data on landscape characteristics, as described in paragraph 4.3.4. Finally, the review of documents enabled the identification of potential interviewees and the type of information to ask them. An overview of the documents is presented below.

Table 3. Overview of policy documents reviewed

CODE	NAME	AUTHOR	YEAR
1	Provinciale Ruimtelijke Structuurvisie	Province	2017
2	Programmaplan Binnenstedelijke Ontwikkeling 2017-2021	Province	2017
3	Ruimtelijk Strategie Utrecht 2030	Municipality	2016
4	Uitgangspunten Ruimtelijke Strategie Utrecht 2040	Municipality	2019
5	Woonvisie Utrecht	Municipality	2019
6	Klimaatstresstest Utrecht	Municipality	2018
7	Volksgezondheidsbeleid Utrecht 2019-2022	Municipality	2019
8	Coalitieakkoord	Municipality	2018
9	Toekomstvisie Utrecht Centrum	Municipality	2015
10	Omgevingsvisie Beurskwartier – Lombokplein	Municipality	2017
11	Nota slimme routes slim regelen slim bestemmen	Municipality	2016
12	Actualisatie groenstructuurplan 2017-2030	Municipality	2018
13	Meerjaren Groenprogramma: Ruimte voor Groen	Municipality	2019

The interviews were conducted to gather more background information on the densification strategies and policies from the municipality of Utrecht. The selection of interviewees was based on the document review. People from different departments were interviewed to get different views on the topic. The people interviewed, the questions and the answers can be found in Appendix C.

There are multiple ways of conducting an interview. There are the unstructured interviews, which are flexible and open, and the structured interviews which consists of pre-determined questions, are rigid and closed when looking at the structure, contents and questions (Kumar, 2011). In this research, an interviewing method which is somewhere in between was chosen, thus a semi-structured interview. A predetermined set of general questions was asked, but when more information was needed or could be useful, more specific questions were asked. The general questions were useful to get a clear picture of densification and heat stress in general, a broad range of information could be obtained by the structured questions. The more in-depth questions were useful to provide more information on certain subjects related to the expertise of the interviewees, which provided a large variety of more specific answers. Besides, the questions could differ slightly depending on the interviewee. For example, specific questions asked to someone from the department of health were slightly different from those asked to a spatial strategist. All the interviews were conducted in a non-physical setting due to the international COVID-19 situation. An overview of the interviews is presented in table 4.

Table 4. Overview of people interviewed.

CODE	FUNCTION		TYPE
A	Coordinator of the area city centre/central station	Municipality	Phone
B	Strategic advisor at the department of spatial planning	Municipality	Phone
C	Advisor healthy environment, department of health	Municipality	Phone
D	Advisor climate adaptation	Province	Email

Finally, from the desk research and the interviews, an overview was created on the densification strategies, policies and plans. For identifying the most important aspects, patterns were identified, and interesting statements were quoted. A link with the Compact City concept is made to see how the densification strategies are related to theory, and if the advantages and challenges of the Compact City as described in paragraph 2.1.1 are present in Utrecht. It is as well analysed if a relation between densification and the UHI is made, and how the municipality is willing to reduce climatic hazard in the future. Besides, it is analysed what the discourse is around heat stress within the municipality, and how they deal with this phenomenon. Hereby, it is investigated as well to what extent the definition of heat stress as presented in 2.3 is in accordance with the definition that the municipality of Utrecht uses to assess heat stress. To get an overview of the outcomes, several questions to be answered in this research are created, these are presented in the result section in 5.1.

4.3.3 Study of the impact of landscape characteristics on temperature.

For the second research question, the impact of Utrecht's landscape characteristics and built environment on the Land Surface Temperature (LST) was calculated. This step was needed to estimate parameters describing the influence of several aspects of the city on the LST, which can be used to estimate the future LST. For this step, a multiple linear regression model was used (equation 1) to study the combined effects of different indicators. The same method was used by Heusinkveld et al. (2014) for measuring the impact of landscape characteristics on the LST.

$$y = \beta_1 x_1 + \beta_2 x_2 + \beta_3 x_3 + \cdots + \beta_n x_n + \beta 0 + \varepsilon$$

Equation 1

Hereby, the dependent variable (y) is the LST, $ß_1,...,ß_n$ represent the parameters quantifying the influence of different landscape characteristics on temperature, the independent variables ($x_1,...,x_n$) reflect these landscape characteristics, e.g. vegetation fraction and building fraction, $\beta 0$ is the intercept or constant, and ε represents the random disturbance with zero mean.

To measure the dependent variable, the current LST was calculated. This was done by using Landsat 8 images, derived from the USGS website (USGS, n.d.). The Landsat images provide different bands which can be used for calculating the LST on a specific day. Several criteria were given for the selection of this day. First, it needed to be a warm summer day, as then the UHI will be stronger. Second, the day should be in a period of drought, as a wet surface could affect the measured LST. Third, it should be a sunny day, as clouds will make the Landsat images less reliable. Finally, there should be Landsat images available for that day, as that is not the case for every day. In the end, an image from the 26th of July, 2018 was chosen to compute the LST. On this day, the maximum temperature at the weather station De Bilt (near Utrecht) was 35.7 °C, making the UHI particularly strong, there had been no rain for 15 days and around 12 hours of sunshine were measured (KNMI, 2018). In the future, it is expected that more hot days like this, combined with periods of drought will occur. As the image was taken around noon, the dependent variable thus only represents a day-time situation, whereas the influence of the characteristics on the LST could differ during day and night. Only one image for one day was chosen, as the image of this day alone was suitable for the computation of the LST according to the above-mentioned criteria. That is justified by the assumption that although temperatures change every day, temperature patterns within the city remain the same (Dugord et al., 2014).

For calculating the LST from the Landsat 8 image, the Radiative Transfer Equation-based method (RTE method) was used to compute the LST in ArcGIS Pro. Yu, Guo & Wu (2014) identified this method as the method for estimating the LST using Landsat images with the highest accuracy compared to other methods, therefore it seems a good method to use for estimating the LST in Utrecht. A flow diagram (figure 5) of the steps to take for this method was created by Oguz (2016).

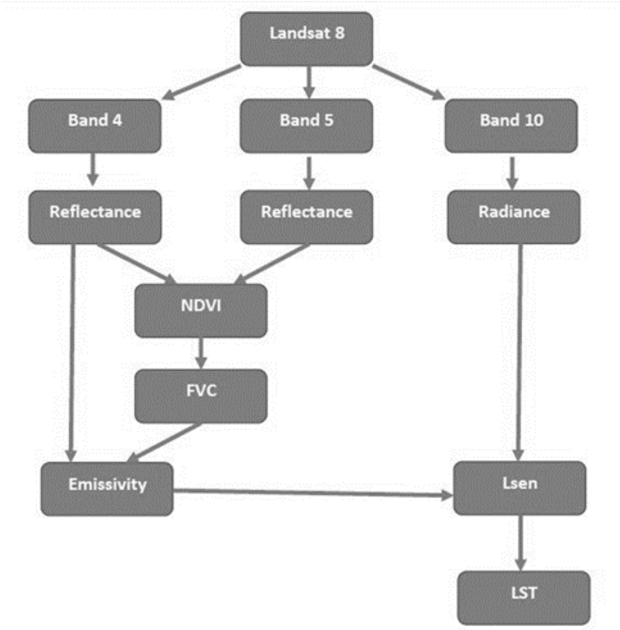


Figure 5. Flow diagram of the RTE method (Oguz, 2016).

Landsat 8 images from the USGS consist of 11 bands. Each band is measured with different ranges of frequencies along the electromagnetic spectrum (a colour). These colours are not all visible to the human eye. As can be seen above, only band 4, 5 and 10 are needed to compute the LST in the RTE method. Band 4 is the visible red band, band 5 represents the near-infrared band, which is important for identifying ecology as healthy plants reflect it due to the water in their leaves. Band 10 is the long-wavelength infrared band, this band identifies heat, however where weather stations identify heat in the air, this band identifies heat on the surface, which is often much hotter (Loyd, 2013).

In the RTE method, band 4 and 5 of the Landsat images are used to compute the normalized differential vegetation index (NDVI). To compute this, the following equation (2) was used (Heusinkveld et al., 2014).

$$NDVI = \frac{R_{nir} - R_{red}}{R_{nir} + R_{red}}$$ *Equation 2*

Where R_{nir} stands for band 5 and R_{red} is band 4. From the NDVI, the fractional vegetation cover (FVC) was computed. From the FVC and band 4, the emissivity on every pixel in the map was calculated. Band 10, the long-wavelength infrared band, was used to first calculate the radiance of every pixel. With the radiance, the thermal radiance at sensor level (L_{sen}) was computed. The L_{sen} together with the emissivity which was previously calculated allowed the computation of the LST. In the end, a dataset was created which represents the temperature in Utrecht per cell with a cell size of 30 meters. An overview of all the formulas needed for these calculations can be found in appendix C.

From the literature review, several indicators were identified as possible indicators which could serve as parameters for the LST. From table 2 of the literature review, only the aspect ratio was excluded, as its effect on the LST is not fully understood and quite complex. The indicators of the variables which constituted the independent variables in the regression analysis are shown in table 5. They were calculated through raster calculations in ArcGIS on data from PDOK, BAG and the Geofabrik.

As the LST at one point is generally determined not just by the landscape characteristics at that point, but the characteristics of a neighbourhood around the point, neighbouring cells also need to be taken into account when calculating the landscape characteristic. Therefore, the landscape characteristics were calculated using GIS-based neighbourhood operations aimed at computing, for each cell, statistics of the cell values within a given radius (neighbourhood) around the cell. The values as presented in table 5 give an indication of what other scholars found as computation radii ensuring strong correlations between the computed variables and temperature. In this research the computation radii for calculating the independent variables are computed by the researcher, thus those from table 5 are not used. This is done by executing a correlation analysis between each landscape characteristic and the temperature with different radii and identifying the radius which ensures the highest correlation with the LST. The final computation radius might differ across landscape characteristics. The radii used in this research are shown in table 6.

The different landscape characteristics were computed in different ways, but all with a cell size of 5 meters. This is different from the temperature resolution, which could only be derived with a minimum cell size of 30 meters. However, because different landscape characteristics, such as buildings, are provided in a more detailed way, a higher resolution was preferred to make it more specific.

The landscape characteristics included five ‘fractions’, which are the building-, green-, industrial-, road- and water fraction. The computation method of these fractions was the same, however, the input data was of course different. All the input data for the fractions were from the Geofabrik. From this open data source, polygon datasets were available for buildings, roads and water which were sufficient as input data for the corresponding fractions. For the green fraction, the land-use dataset was used, from this dataset, multiple land-uses were selected as green, these included allotments, cemetery, farm, forest, grass, heath, meadow, nature reserve, orchard, park and recreation ground. Also for the industrial fraction, the land-use dataset was used, the land-use ‘industrial’ was selected to identify industrial areas. The created features were transformed into a raster dataset. After that, the number of raster cells belonging to that characteristic within a radius was calculated and divided by the total amount of raster cells within the radius. So that the fraction was a value ranging from 0 to 1, explaining the fraction of the indicator within the radius.

For the computation of the distance to the city centre, the straight line distance from different landmarks around the city centre of Utrecht was computed for every cell within the municipality. The landmarks in the city centre that were used to calculate the straight line distance from were Jaarbeurs, Central Station, Domtoren and Neude. Hereafter it was tested which output appeared to be the best predictor of the LST, looking at the correlation between the distance from the landmark and the LST, the output with the highest correlation with the LST was chosen. This was done because the location from which the distance to the city centre was computed was not clearly defined by both Schwarz et al. (2012) and Dugord et al. (2014): in fact, they both used a different landmark within the city centre of the researched cities, as of course, the city centre is in every city different. Therefore in this study, it was first examined which of the landmarks in Utrecht was best to calculate the straight line distance from, in order to predict the LST in Utrecht.

The population density was calculated per neighbourhood with data from the PDOK database. The feature data needed to be transformed to a raster dataset. Whereas Steeneveld et al. (2011) only looked at population density at the neighbourhood level, in this research, it was examined as well if the correlation with the LST would be higher if an average was calculated within a radius from each cell.

For the FAR, which was calculated on the neighbourhood level as well, the height dataset from BAG 3D was used to calculate the number of floors per building. Hereby the assumption is made that one floor is three meters high. No national guidelines were available for this, but in at least seven of the analysed building projects in Utrecht, the height per floor was three meters. By looking at the number of floors per building and the footprint per building, the total floor area could be computed. Finally, the floor area per neighbourhood was calculated and divided by the total area of a neighbourhood, which gave the floor area ratio per neighbourhood. Again the mean within a radius per cell was computed.

For the building height (BH), the BAG 3D dataset was used, from which the height of buildings can be computed by subtracting the ground height from the roof height per building, which were both provided in meters above sea level. To areas where no buildings were located the value 0 was given. Per cell, the average height within a radius was computed.

The last indicator, the SVF, was computed by using a Digital Terrain Model of Utrecht from AHN3 data. With this data, the SVF could easily be calculated in the program QGIS. After that, for every cell, the average of the SVF within a radius was calculated.

Table 5 List of indicators for computing parameters

INDICATOR	SOURCE DATA DERIVED FROM:	COMPUTATION RADII USED BY OTHER SCHOLARS	REFERENCES
GREEN FRACTION	Geofabrik	250 - 700 meters	Heusinkveld et al. (2014) Van Hove et al. (2015) Wüstemann et al. (2016)
BUILDING FRACTION	Geofabrik	250 - 1600 meters	Heusinkveld et al. (2014) Van Hove et al. (2015)
INDUSTRIAL FRACTION	Geofabrik	500 meters	Jeong et al. (2015)
FRACTION OF ROAD INFRASTRUCTURE	Geofabrik	500 meters	Jeong et al. (2015)
WATER FRACTION	Geofabrik	600 - 1000 meters	Steeneveld et al. (2011) Steeneveld et al. (2014)
DISTANCE TO CITY CENTRE	Computed by author	-	Dugord et al. (2014)
POPULATION DENSITY IN NEIGHBOURHOOD	PDOK - Wijken en Buurten	Neighbourhood level	Steeneveld et al., (2011)
FLOOR AREA RATIO (FAR)	BAG 3D PDOK - Wijken en Buurten	150 - 200 meters	Lan & Zhang (2017)
MEAN BUILDING HEIGHT (BH)	BAG 3D	200 - 250 meters	Van Hove et al. (2015) Lan & Zhang (2017)
SKY VIEW FACTOR (SVF)	PDOK - AHN 3	100 - 250 meters	Van Hove et al. (2015) Dirksen et al. (2019)

With the outputs, an Ordinary Least Square (OLS) regression analysis was executed in which the influence of the landscape characteristics (independent variables) on the LST (dependent variables) was calculated. The regression analysis was computed based on 1500 observations within the municipality of Utrecht. These points were randomly created, the space between these points was set at a distance of at least 30 meters to ensure that no points would have the same values. If the 1500 points were evenly distributed in the municipality of Utrecht, this would mean that there would be one point every 6.6 hectares, therefore the variations in the urban fabric were accurately represented. At these points, the LST and the urban characteristics were extracted from the previously defined raster datasets. Descriptive statistics of the outputs are shown in table 6. The radii which were used to calculate the landscape characteristics around each point are given as well. These were defined by looking at which radius gave the best correlation for each characteristic with the LST, as previously described.

Table 6. Descriptive statistics of samples from landscape characteristics in the municipality of Utrecht

INDICATOR	MEAN	STD. DEV.	MIN	MAX	COMPUTATION RADIUS (COMPUTED BY AUTHOR)
GREEN FRACTION	.425	.336	.000	1.000	200 meters
BUILDING FRACTION	.130	.137	.000	.706	150 meters
INDUSTRIAL FRACTION	.060	.216	.000	1.000	100 meters
FRACTION OF ROAD INFRASTRUCTURE	.416	.235	.000	.973	400 meters
WATER FRACTION	.069	.144	.000	1.000	100 meters
DISTANCE TO CITY CENTRE	4.294	2.256	.067	10.237	NA, distance measured from Central Station
FLOOR AREA RATIO	.548	.631	.011	3.990	50 meters
MEAN BUILDING HEIGHT	1.943	2.631	.000	22.293	200 meters
SKY VIEW FACTOR	.931	.073	.672	1.000	150 meters

Both backward and forward regression methods were used to get to a first robust model. In the backward regression method, all the indicators are entered in the analyses and then sequentially removed, the criterion for removal is based on the smallest partial correlation with the dependent variable, this is done until no variables are left that satisfy the removal criteria. In the forward regression method, the variables are sequentially entered into the model, hereby, the variable with the highest correlation with the dependent variable is entered first, and so on until all the variables are entered (IBM, n.d.). With the backward regression, the non-significant outputs ($p>0.05$) were eliminated. The forward regression method was used to look at which model stabilizes the R^2, i.e. the model after which the R^2 did not increase much when adding another variable.

After that, the remaining indicators were analysed based on whether they showed multicollinearity. This was done by looking at the correlation between indicators in SPSS outputs, and by calculating the Variance Inflation Factor (VIF) of every indicator. The VIF quantifies the presence of multicollinearity in an OLS regression analysis per indicator and is calculated using the following formula (equation 3):

$$VIF = \frac{1}{1-R_i^2}$$ *Equation 3*

where R_i^2 is the R-squared value of predictor "i" regressed against every other predictor in the model. Rogerson (2001) identified a value of 5 as a threshold which the VIF should not exceed to prevent potential multicollinearity problems. If an indicator showed high collinearity with other predictors, the indicator was eliminated. These steps needed to be repeated several times until a model was created without multicollinearity and an R^2 which was high enough to explain the variability of the LST ($R^2>0.7$), the steps to take are shown in figure 6.

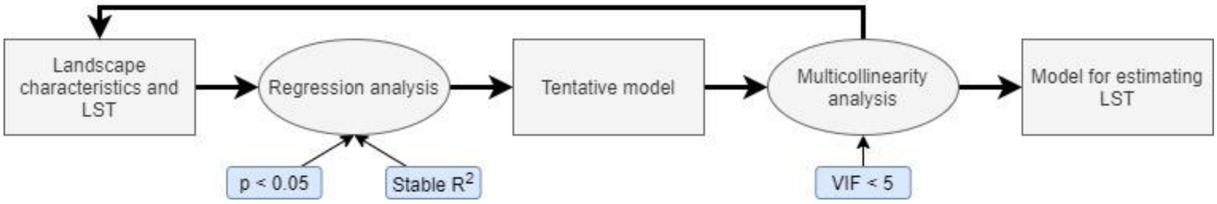


Figure 6. Regression analysis flowchart, created by author

To test the OLS assumptions, a scatter plot of the residuals versus the fitted values, and a histogram showing the distribution of residuals were created. The assumptions of the OLS method are that the scatter plot should not show any pattern in it, whereas the histogram should follow a normal distribution. The results were tested as well for spatial autocorrelation of the residuals as the results of spatial OLS model are more reliable if residuals are not spatially clustered. To test for spatial clustering, the Global Moran's I (Equation 4) was calculated on the residuals to see whether they are spatially autocorrelated.

$$I = \frac{n}{S_0} \frac{\sum_{i=1}^{n} \sum_{j=1}^{n} w_{i,j} z_i z_j}{\sum_{i=1}^{n} z_i^2} \qquad \text{Equation 4}$$

where n is the total number of features, S_0 is the aggregate of all the spatial weights, Z_i represents the deviation of an attribute for feature I from its mean (x_i - ẋ), $w_{i,j,}$is the spatial weight between feature I and j The value that results from this formula and its significance ($p < 0.05$) state whether a pattern is clustered (+1), dispersed (-1) or random (0) (the value has to be interpreted in the light of the null hypothesis – i.e. that the elements are just randomly distributed) (Esri, n.d.). If the residuals appeared to be clustered, other regression models should be tested. For a matter of completeness, the spatial error model and the spatial lag model were also run using the software GeoDa (Anselin et al., 1996) and their results were compared to those of the OLS.

4.3.4 Analysis of the exposure to heat stress given densification

From the model, of which the parameters were computed as described in the previous section, the LST at any location within the city of Utrecht can be estimated using landscape characteristics. In order to use the model to estimate the future temperature patterns after densification, first, the GIS data as shown in table 5 had to be modified towards the future situation. For this step, changes in the landscape because of building projects had to be modified in GIS by editing the data (example: Figure 7). The building projects as identified during the desk research were used for this step (Appendix B). The only criterion was that the building plans included a somewhat detailed visualisation, sketch or drawing of where the buildings are going to be located. These plans were often found on the projects' website or policy documents. If no visualisations were found, the plans were not included in editing the landscape characteristics because that would give too much uncertainty. This was often the case for plans which were planned in the long term. When adding new buildings in GIS, the height of the buildings also needed to be included in the data. The building height was often found in the plan documents. If not, an estimation was made based on the number of floors. This information could be retrieved from each building project, as it was stated somewhere and/or it could be derived from the visualisation of the building. Hereby, again the assumption was made that one floor is three meters in height.

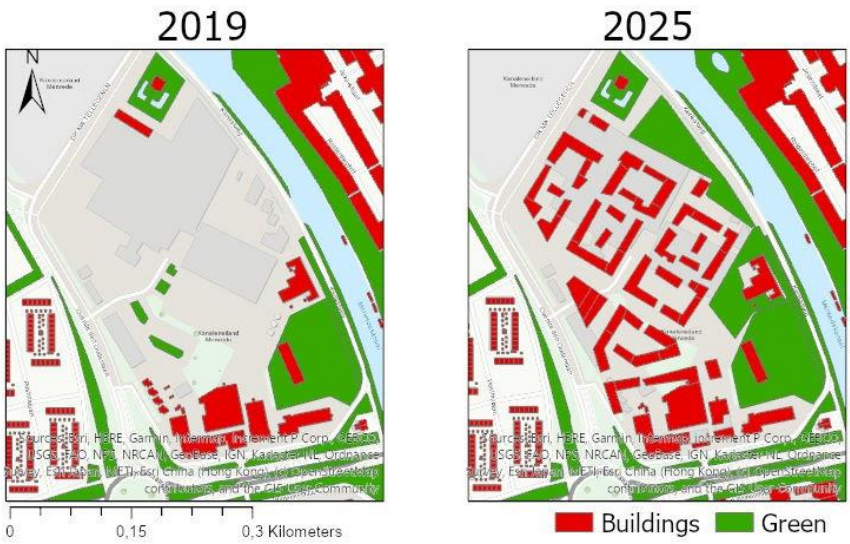


Figure 7. Example of editing the Building and Green data so it represents a situation after densification, location: project Merwedekanaalzone 4. Created by author.

The features of the data from the Geofabrik could easily be deleted, edited or added to configure towards the future situation. For the data for which height was important, such as the SVF, the FAR and BH, it was a matter of adding height to the building features. The distance to the city centre was of course not edited as it is a fixed distance and does not change due to densification.

The data on population density could be edited in the PDOK - Wijken en Buurten dataset, based on the estimated future density per neighbourhood. For the estimation of the future density per neighbourhood, the future population per neighbourhood needed to be estimated. This was done by using the Prognosis 2019 of the municipality of Utrecht in which the population estimations for the year 2025 were given (afdeling onderzoek, Gemeente Utrecht, 2019). However, the estimations were only given per sub-district (In Utrecht, 34 sub-districts are divided into 111 neighbourhoods). To translate the estimation per sub-district to neighbourhood estimations, the number of dwellings to be created per neighbourhood was assessed based on the projects which could be found on the website of Utrecht (Gemeente Utrecht, 2020). The expected increase of inhabitants from 2019 to 2025 per sub-district was divided over the neighbourhoods within this sub-district based on the number of new dwellings per neighbourhood.

Following equation 1, the parameter estimates (ß) and future landscape configurations (Xs) were used to predict the LST induced by future landscape configurations (Y). Because of the standard error in the model, the predicted temperatures may not in every case be very reliable. Because of this, a 95% confidence interval (i.e. the interval within which 95% of the predictions fall) was computed, resulting in a lower bound and upper bound estimation as well. This was done in ArcGIS, the 95% confidence interval for the forecasted values Ŷ of X was calculated using equation 5.

$$Confidence\ interval = \hat{Y} \mp t_{crit} * \varepsilon \qquad \text{Equation 5}$$

Hereby, Ŷ is the forecasted value, t_{crit} is the inverse of the two-tailed T distribution, and ε is the standard error of the model. For the upper-bound of the confidence interval, the product of the t_{crit} and the ε was added to the Ŷ, and for the lower bound it was subtracted.

The output of the created model will only give the estimated values in a situation where the overall temperature in Utrecht was somewhat the same as the 26th of July 2018. Therefore to give an output that could represent a random summer day the UHI needed to be calculated. This is based on the assumption that heatwaves affect absolute temperatures, but temperature patterns remain constant in general (Dugord et al., 2014). Following the definition described in the literature review, to calculate the UHI, the rural LST was subtracted from the urban LST. For the rural LST, an area was used to calculate the mean rural temperature. The area that was used was based on areas within the municipality of Utrecht that were outside the ‘rode contour’, which means red contour. The red contour is used by the Province of Utrecht as a policy instrument to preserve rural area and can be defined as the border of the urban area (Provincie Utrecht, n.d.). The area outside the red contour mainly consists of meadows, grass and farmland. For this area (Figure 8), the mean temperature was calculated using ArcGIS, and this number was subtracted from the temperature in the urban area to compute the UHI. For the computation of the UHI, water bodies were excluded, with the assumption that no people live on the water, hence the UHI on water is unnecessary for the classification of heat stress.

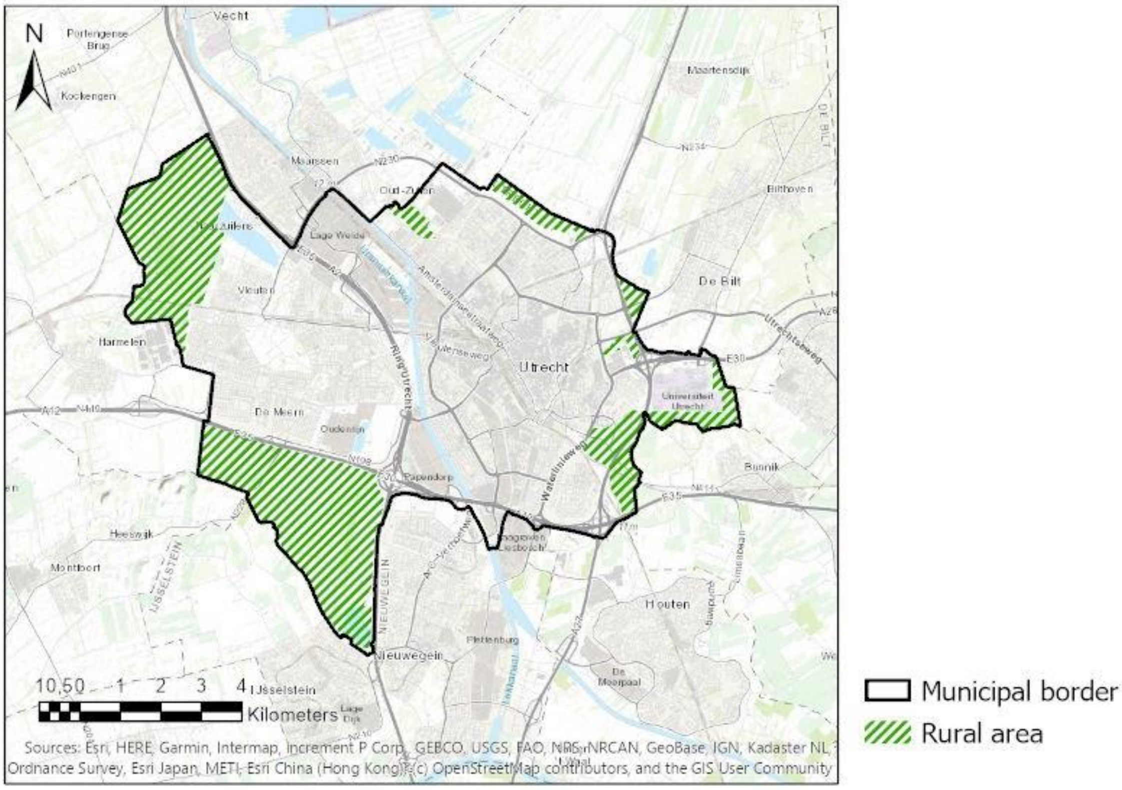


Figure 8. Rural area used for calculating the UHI, created by author

The heat stress risk is calculated for the current situation, as well as for the future situation to identify whether there are changes in heat stress risk due to densification. For the current situation data from the year 2019 was used as the base, and for the future, a prognosis of the year 2025 was made. Population estimations were available on the longer term, but the year 2025 was most consistent with the densification plans which were considered. The population estimations were done as described before. For analysing the heat-stress risk, a categorization method was needed. For this step in the research, the categorization method of Dugord et al. (2014) was used. They came up with the following equation (Eq. 6) to identify heat stress in the residential area. A full overview of the method is shown in table 7.

$$r = h * v \qquad \textit{Equation 6}$$

Hereby, r is the potential risk on the neighbourhood level, v is the vulnerable city dwellers and h is the potential climatic hazard. They used statistical thresholds for the level of vulnerability (i.e. the share vulnerable people and the population density) and the level of climatic hazard (i.e. the UHI) to create four categories, ranging from 0, which indicates no vulnerability or hazard, to 3 indicating maximum vulnerability or hazard, for determining areas at potential risk (table 7).

The highest level of climatic hazard (h) is defined on a temperature exceeding the 95th percentile of the distribution (Gabriel & Endlicher, 2011). Level 1 and 2 are respectively defined at the 85th and 90th percentile (Dugord et al., 2014). The level of vulnerability is more complex. For assessing the vulnerability (v), Dugord et al (2014) combined the share of vulnerable inhabitants with the population density. In this way, a value is given to the density of vulnerable people within an area. For the population density the same classification method is used as with the potential climatic hazard, so ranging from 0 to 3, depending on the 85th, 90th and 95th percentile of the density distribution.

$$Weighted\ concentation\ v = share\ vulnerable\ inhabitants * density\ category \qquad \textit{Equation 7.}$$

As it was not convenient to give a value ranging from 0 to 3 to the share of vulnerable inhabitants (value ranging from 0 to 1) to assess vulnerability, the share of vulnerable people was multiplied by the density category on that location, leading to a weighted concentration, which is shown in equation 7 (e.g. on a location where the share of vulnerable people was 0.2, and the density category 3, the weighted concentration was 0.6). To give a value for vulnerability (v) to the weighted concentration, three thresholds were created by Dugord et al., (2014). To locations where the weighted concentration was below 0.3, a value of 0 was given, from 0.3 and up to 0.6 the value was 1, from 0.6 to 0.9 the value was 2, and when the value was 0.9 or higher the highest vulnerability value (3) was given, representing a highly problematic concentration of vulnerable people.

The percentiles used in this method for determining the thresholds of the categories for climatic hazard and the density levels were calculated for the values of the current situation, i.e. the obtained values before densification has taken place. The percentiles calculated for the current situations were hereafter used for categorizing the values of the current situation as well as the future situation. This is done because if for the categorization of the future situation also the percentiles for the future situation were used, it would be a matter of relative conditions and therefore a comparison between the current and future situation would not provide useful information. As, for example, if the 85th percentile for the density rises because of higher density values, locations within an area of significantly higher density values may be awarded the same density category, as the percentile has risen as well. Because of this, only the percentiles for the current situation were used for assessing the threshold for the categories in both the current and future situation.

From the literature review it appeared that next to the elderly as assumed by Dugord et al. (2014), people with a low income could also be more affected by heat. Therefore, the categorization of heat stress is done looking at the elderly as well as people with a low income, which resulted in two separate outcomes of heat stress-risk per neighbourhood. An overview of the categorization per indicator is presented in table 7.

Table 7. Classification and calculation method for the indicators used for the estimation of potential heat stress related risk, based on Dugord et al. (2014)

Indicator/ potential risk factor		*Value*	*Signification*	*calculation method*
Potential demographical vulnerability (v)	Population density	0	Relatively negligible density	Population density < 85th percentile (current)
		1	Relatively low density	Population density > 85th percentile (current)
		2	Relatively medium density	Population density > 90th percentile (current)
		3	Relatively high density	Population density > 95th percentile (current)
	Share of vulnerable inhabitants	0-1	Percentage of elderly (> 65 years old), or people with a low income (as defined by PDOK) divided by 100	The concentration of vulnerable inhabitants is multiplied by the population density value to give more importance to the absolute amount of vulnerable inhabitants
	Concentration of vulnerable inhabitants in a block	0	Not problematic concentration	Weighted concentration < 0.3
		1	Quite problematic concentration	Weighted concentration > 0.3
		2	Problematic concentration	Weighted concentration > 0.6
		3	Highly problematic concentration	Weighted concentration > 0.9
Potential climatic hazard (h)	Distribution of air temperatures	0	Negligible potential hazard	UHI <85th percentile (current)
		1	Low potential hazard	UHI >85th percentile (current)
		2	Medium potential hazard	UHI >90th percentile (current)
		3	High potential hazard	UHI >95th percentile (current)

For calculating the population density, the PDOK data was available on the neighbourhood level, however, the temperature was defined at a finer resolution, as this was derived from LANDSAT 8 images (i.e. one temperature value per 30 x 30 m cell). For accuracy, these temperature variations across space were considered in this research for estimating heat stress. To give more sense to the heat stress calculation, the population density variations across space were considered as well. Hereby, the assumption was made that within a neighbourhood, more people are living where more floor space of buildings is. In order to compute the total amount of floor space within a neighbourhood, first, the previously calculated (FAR computation) amount of floors per building was multiplied by the building footprint to get the floor space per building. Then the total amount of floor space in the neighbourhood was obtained by adding up the floor space of each building in the corresponding neighbourhood. The total population (census data) of the neighbourhood was hereafter divided by the floor space per neighbourhood to get the average amount of people per square meter floor area in a neighbourhood. When this number was multiplied by the floor area per building, the number of people per building could be estimated.

Population density on a square meter basis was obtained by dividing the number of people per building by the total footprint of the building. Clearly, cells with no building on them were assigned a value of zero. The number of people per square metre was then multiplied by 1,000,000 to calculate density on a square kilometre basis. By computing the mean within a square kilometre around each cell, an estimation was given for the number of inhabitants in the neighbouring cells within a square kilometre. The final map of population density represented the population density variations across space looking at the number of people per square kilometre on that location. This was calculated for both the situation in 2019, as the situation in 2025.

For assessing the share of vulnerable people, the database of the municipality of Utrecht (Gemeente Utrecht, n.d.) was used, as it contains data on age distribution and income. For the share of vulnerable people according to age, only people above 65 years old were looked at. As shown in the theoretical framework, there is no consensus as to whether young children are significantly more vulnerable to heat than other categories (Ishigami et al., 2008). An overview of the data used is shown in table 8. For the future share of elderly people, only a prognosis on the district level was available for the year 2025. The assumption was made that every neighbourhood has the same rise or decline in the share of elderly as the districts it is located in. For the future share of people with a low income, no prognosis was available at all. Therefore it was decided that for the future situation, the same share of low-income people will be used as it is today.

Table 8. Source data for population characteristics. (note: both the PDOK data and the municipality database are based on numbers from the CBS)

Source	*Type*	*Year*	*Level*
PDOK *Database Municipality of Utrecht*	Population	2019 2025	Neighbourhood
PDOK	Population Density	2019	Neighbourhood
Database Municipality of Utrecht	Age distribution (65+)	2019	Neighbourhood
Database Municipality of Utrecht	Percentage of low income (up to 125% of social minimum)	2017	Neighbourhood

5. Results

5.1 Densification strategies & link with heat stress

This section presents the outcomes of the document review and the interviews. Seven questions were formulated to get more insight into the planning strategies from the municipality of Utrecht and how this is linked to heat stress. The codes in the text refer to the corresponding document or interview from which the information was derived, the codes were presented in table 3 and 4.

5.1.1 What are the reasons for densification?

It is clear from the reviewed documents and interviews, that densification is a hot topic in the municipality of Utrecht these days. Not only in the city of Utrecht but in the whole Province of Utrecht it is the aim to create houses within the built environment to meet the housing demand. Because the Province of Utrecht is an attractive region, the housing demand is high, therefore the province wants to build a lot of houses within the built environment[D]. The reasons for densification that are mentioned are to keep the cities attractive to live and work in, and to preserve rural area[2]. A large share of the dwellings that need to be created in the Province will be built in the municipality of Utrecht, a number of 60,000 dwellings was mentioned in an interview[B]. A reason that is mentioned for creating this large amount of dwellings, is that otherwise the pressure on the housing market will become too high, and housing prices will rise within the city. The ambition of the municipality is to create a city for everyone, when housing prices are high, this ambition will be hard to accomplish[B]. However, the size of the municipality is not very large, therefore, solutions need to be found within the built environment[B].

> *"Colleagues from social support have to ensure that there are sufficient facilities, ... other colleagues from the green program say there must be also enough green for sport and recreation. So you will always see a sort of conflict over scarce space." (Interviewee C)*

Different reasons for densification were given in policy documents and interviews. A reason that is mentioned multiple times, is to use densification as a tool to stimulate sustainable modes of transport. The assumption here is that if densification takes place around station areas, the use of the public transport rises, besides, Utrecht is the most centrally located train station in the Netherlands so densification around the station results in a higher accessibility[3,7,10,11,A]. Densification around areas of public transport is in line with what national policy documents stimulate with the Structuurvisie Infrastructuur en Ruimte and the 'Ladder voor Duurzame Verstedelijking'[10]. Also, efficiency is mentioned as a reason for densification in Utrecht. For example, waste, water and energy streams could become more efficient when population density is high[10]. It is mentioned that both the aim to promote sustainable transport and the aim for efficiency due to densification, could lead to a reduction of CO_2 emission within the city of Utrecht[3]. Another reason for densification is based on the assumption that if densification takes place on one location, green and recreational areas will be preserved in another area. This could contribute to a healthy living environment and stimulate social interaction[3,B].

5.1.2 How is densification proposed?

In the spatial strategies of Utrecht[3,4], it is described what the key points of densification are. An order of priority for the development of the city is formulated; first, densification within the city around nodes, second, densification within the city, third, densification at the edge of the city around nodes, and lastly, development outside the city boundaries. The implementation of this strategy can be seen when looking at the expected growth of inhabitants per neighbourhood until 2025, as shown in figure 9, which also highlights that densification is taking place around train stations. The priority for locations around nodes in the city is also based on the focus on slow transport and public transport. The aim is to stimulate sustainable modes of transport like walking, cycling and public transport[4,11]. Diversity in the city is an important aspect as well. Utrecht tries in its strategy to keep and even strengthen the diversity in the city. It is looked at what kind of people live in which neighbourhoods, and how stimulation of a certain dwelling type will contribute to diversity in the neighbourhood[5,A,B].

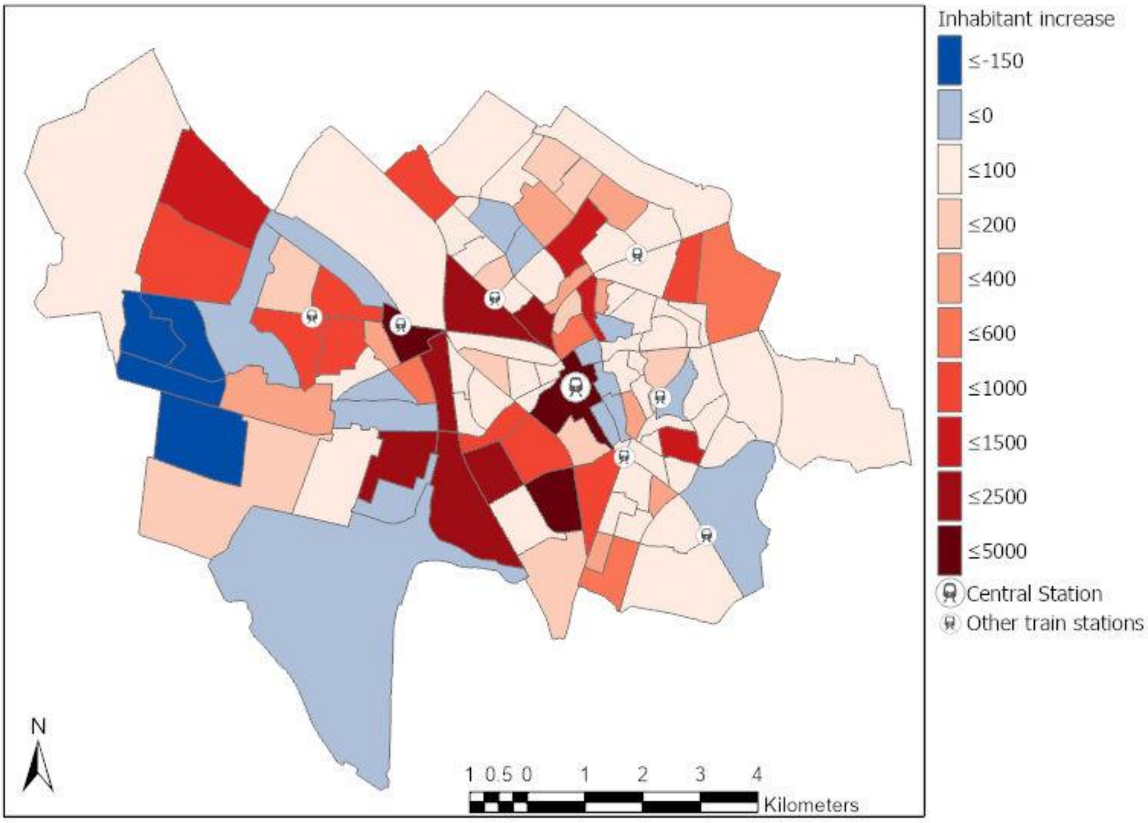


Figure 9. The expected increase in inhabitants per neighbourhood between 2019 and 2025. Created by author, data based on Municipal database and author's estimations.

Another important element in the densification strategies of Utrecht is health[3,4,7]. In every spatial project, a health advisor is involved. These advisors look at the plans that are created and advise on how the plans could be changed to contribute to 'Healthy Urban Living[3]. For example, a health advisor could discourage building dwellings next to a highway, as this is seen as an 'unhealthy' location. The advice is based on three aspects; first, the pressure on health should be minimized, so as mentioned in the example, no dwellings on unhealthy locations. Second, healthy behaviour should be stimulated, by for example supporting healthy mobility. And third, people need to live in a pleasant environment, so there should be sufficient green and facilities in the surroundings[c].

While reviewing policies, a list was created of densification plans that are taking place in Utrecht or that will take place in the coming years. The full list of the reviewed plans is shown in appendix B. In figure 10, a map is shown of reviewed building plans in Utrecht, the map also consists of plans which are more expansion rather than densification.

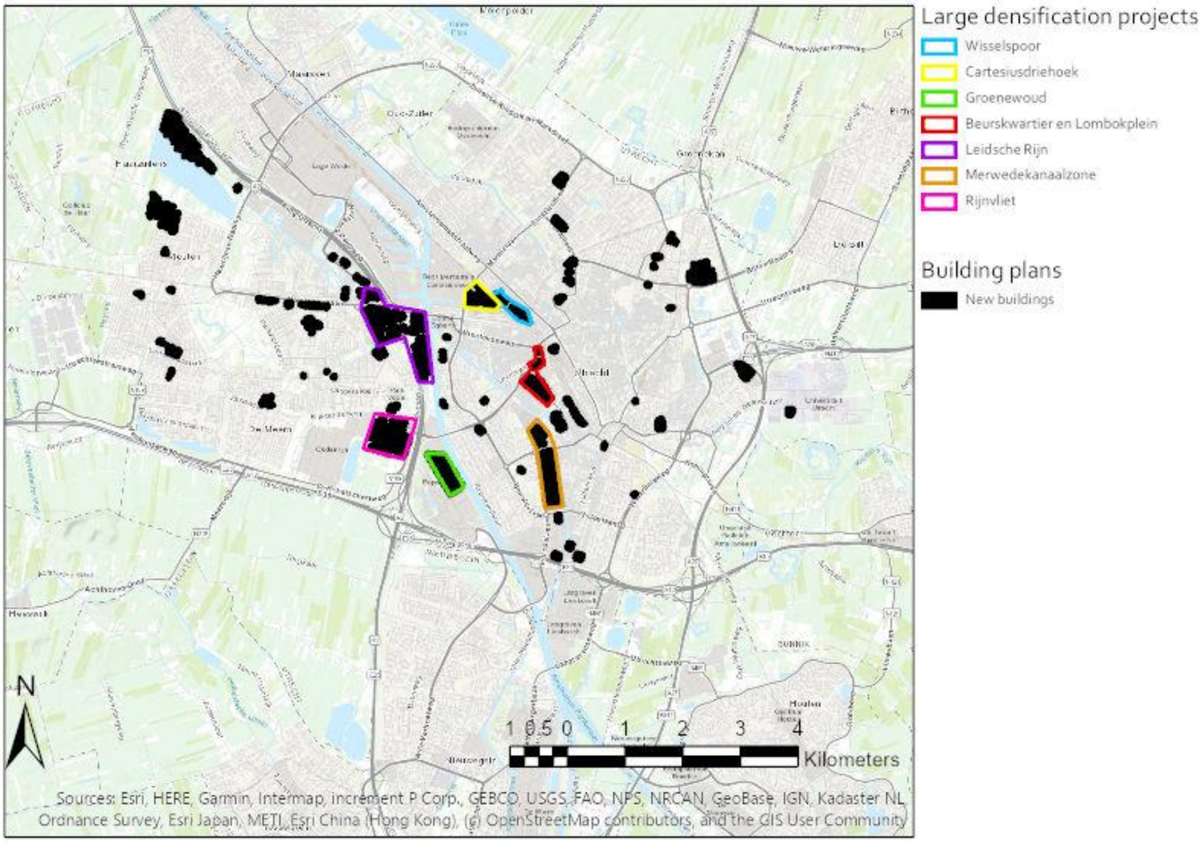


Figure 10. Map of large densification projects and reviewed building sites in the municipality of Utrecht, created by author.

5.1.3 How do the strategies take climate change into account?

Climate change is mentioned in documents from the Province, possible effects of climate change that are mentioned are floods, water shortage and heat stress. Water and green infrastructures are mentioned as ways to adapt to climate change[1,2]. However, from an interview, it appeared that in practice, only a small part of the created dwellings in the province do take climate change into account. In 2018 there were 87,000 houses built in the Netherlands, in 90% of the cases, no attention was paid to the changing climate. In the province of Utrecht, this was probably also the case, however in the plans, there is an increasing amount of attention paid to climate change, but costs are often the reason that some of these plans fail[D].

In the city of Utrecht as well, attention is paid to climate change in documents. The municipality focusses in its strategies on both mitigation and adaptation. On the one hand, the municipality wants to contribute to the reduction of CO_2 emissions, by reducing energy use, becoming more efficient in the use of fossil fuels, stimulating sustainable energy and emphasizing the role of the bicycles in the city. On the other hand, it tries to adapt the city to the inevitable rise in temperature, by means of climate adaptive measures. Hereby heat stress, drought and floods are mentioned as potential risks of climate change, especially in the older parts of the city. Again green and blue infrastructures are mentioned as tools to adapt to the increasing risks[3,4,7,12]. In the municipality, there are sustainability and climate adaptive rules, which are not only for buildings but also for public space[A]. This is a challenge however in densification projects, due to densification there is a continuous 'battle' over scarce space. As densification claims a lot of space within the city[C], smart and technical solutions are required. The goal is to as much as possible prevent the public space from losing green, unless there is no other option: this is based on the policy of 'groen, tenzij…' (English: green, unless…)[12,B].

5.1.4 Is a relation between densification and the UHI made?

The link between densification and the UHI is not often mentioned in policy documents, or at least not in a direct way. What is sometimes mentioned is that densified areas with a lot of concrete structures do contribute to an increased risk of high temperatures[12]. It is mentioned, by both documents and the interviews, that densification is a major challenge when you look at increased temperatures, as the pressure on green becomes high. In an increasing amount of areas in the city, concrete structures dominate the landscape, also given the fact that multiple neighbourhoods in Utrecht do already lack green[12,B,C]. The landscape characteristics that are often mentioned as the one amplifying the UHI are those that are of concrete and stone. For example, industrial areas are identified as the hottest areas in Utrecht, as there is a lot of concrete and not much shadow is found, but also Jaarbeurs, in the city centre near the Central Station, is known as a place where severe temperatures occur[6]. The landscape characteristics that are seen as cooling mechanisms and that are mentioned multiple times are green and water[3,10,12]. Especially an emphasis on green is made in different policy documents and interviews. Greening is even mentioned as the key element of densification. Tackling increased heat due to densification needs to be done on the street and neighbourhood level, therefore, implementing green in the streets is very important[B]. However, especially in policy documents, greening was not only promoted as a cooling mechanism but often for its recreational function and its positive impact on (mental) health of the inhabitants.

"Greening is the key element in densification, otherwise densification is not possible" (Interviewee B)

5.1.5 Are preconditions given for the built environment in densifying areas?

As mentioned, there is in densifying areas often the focus on water and green infrastructures to prevent the UHI to become severe. This implies an impact on the built environment and the landscape characteristics in an area, as in dense areas, the space is scarce[C]. An important policy for implementing green, is the green, unless… policy that was mentioned before[B]. This policy states that green should be implemented in projects and city developments unless this is not possible due to the required functionality on a specific location [13]. More small scale-, horizontal- and vertical green must be created and in the public space more places with the ability to cool, like trees, need to be provided[6]. An interviewee mentioned that an increasing focus will also be on green roofs, in the future the municipality could stimulate this even more[A]. There are already rules for project plans to provide more green and water infrastructures, especially in public space[A].

The main challenge in densified areas is that the space is scarce[C] and to save space the building height will be increased[3,B]. Also with the focus on reducing cars in the city and focussing more on walking, cycling and public transport, areas that were meant for cars could in the future be used to provide green[B]. However, the main goal is not to increase the amount of green in Utrecht, as this would be hard to accomplish together with densification. The focus is more on maintaining and increasing the quality of the public space[3]. Another important aspect is that the connection with the rural and green areas around the city are sufficient, it is important that the cool areas around Utrecht are easily accessible for the inhabitants[3,B].

5.1.6 Is a link found between densification strategies and heat stress?

The municipality of Utrecht has its own 'climate stress test'[6], according to which areas in the cities are identified where heat could become a problem due to a severely high UHI, especially considering climate change in the future. In the stress test, heat stress is mentioned as well, which is defined as the inconveniences we experience when extreme heat occurs. Different effects of heat on health, public space, liveability, water and infrastructures are given. While this stress test focuses on the adverse effects of heat on humans, the policy documents that were studied did not really focus on heat stress, and in even less extent the relation between densification and heat stress. Of course, it was mentioned that densification could lead to changed landscape characteristics which could amplify the UHI, but not really a link was made on what medium-high density meant for the thermal comfort of humans, so in most documents, it was more of an indirect link.

One interviewee mentioned that in the Province of Utrecht, heat stress is something that is talked about, but that there are only limited measures against it[D]. As appeared from the policy documents and some interviews, in the city of Utrecht there is a focus on green and blue infrastructures to reduce heat stress, and that greening is a key element in densification. This is mainly the physical side of heat stress. In Utrecht, there is also a focus on the social side, as the department of health is working on a 'heat plan'. This is mainly about communicating and informing inhabitants about possible threats of heat, but also by looking at people who are more socially isolated, and checking if they are well protected against heat[C]. So in this case, a clear link can be seen between heat and what it does to the inhabitants, but more in an adaptive way. So on the physical side, it is mainly about changing landscape characteristics to reduce the UHI, but the policy documents do not really dive into the relationship between the UHI and the thermal comfort of inhabitants.

5.1.7 What is the relation between heat and vulnerable people?

In almost all documents reviewed, no link was found between heat, heat stress and vulnerable people who might be more prone to heat. Only in the climate stress test of Utrecht, it was mentioned that "especially vulnerable people, like the elderly, could get health issues when there is heat"[6]. In other documents, it seems that heat stress is mainly linked to the temperature, and in less extent to the people who might be negatively affected by the thermal conditions.

From the interviews, the relation between heat stress and vulnerable people was as well not mentioned a lot. The interviewee from the Province told that they were talking about the subject of taking vulnerable people into account, but that it was not really an issue yet.

"... Something I stressed was to take into account vulnerable people (concerning heat, author). I mentioned pregnant women, the elderly, children and people with some disabilities. But until now it is more 'crying in the desert'" (Interviewee D)

Another interviewee mentioned that in projects it is not really experienced that heat stress is linked to certain groups of people[A]. The interviewee of the department of health did mention that vulnerable people were taken into account in relation to heat in their department, that they knew what the composition of inhabitants in neighbourhoods is, and they try to take that into account. The groups that were mentioned as groups which needed extra care were elderly, but also homeless people, the chronically ill and children. About the children, it was mentioned that every child care needs to have a protocol for when a heatwave occurs[C]. So it appears that they do take into account vulnerable people, but more in an adaptive way. No evidence was found that in making densification strategies, it was looked at where people live which might be vulnerable to heat and that the densification strategies were influenced by this information.

5.2 Influence of landscape characteristics on the Land Surface Temperature

The LST across Utrecht was derived for the 26th of July 2018 and is presented in figure 11. The maximum temperature was 44.8829 degrees Celsius. The highest temperatures were mainly found around open places with less shadow and concrete structures, such as industrial areas, and squares in the city centre, like Jaarbeurs. The minimum was 22.8287 degrees Celsius, temperatures like these were found around water bodies.

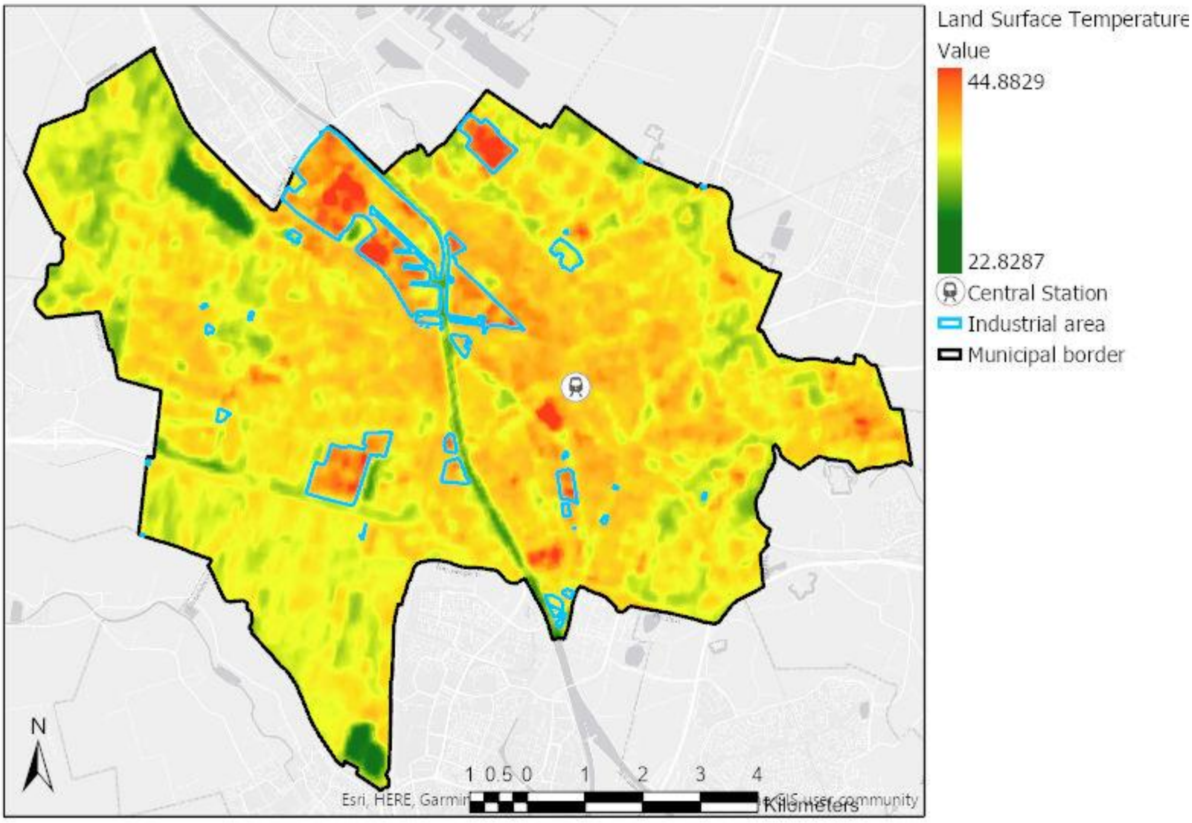


Figure 11. LST on 26th of July 2018, in degrees Celsius

An overview of the correlations of the independent variables with the LST is given in table 9. It is as well specified which radius was used for computing each variable according to the best correlation with the LST. The descriptive statistics of these indicators were already given in table 6. From highest to lowest, the building fraction, building height, road fraction, FAR, industrial fraction and population density appeared to have a positive correlation with the LST, indicating that when these values rise, all else being equal, the LST rises as well. The independent variables which show a negative correlation are the water fraction, green fraction, SVF and distance to the city centre. From all the predictors, building fraction seems to be the best predictor (0,677), followed by the water fraction (-0.559) and the green fraction (-0.487). Quite a low correlation was found between the LST and the population density (0.335).

Table 9. Overview of radii used and Pearson correlation with LST for each landscape characteristic

LANDSCAPE CHARACTERISTIC	PEARSON CORRELATION WITH LST
BUILDING FRACTION	0.677
WATER FRACTION	-0.559
GREEN FRACTION	-0.487
BUILDING HEIGHT	0.474
SVF	-0.466
DISTANCE TO CITY CENTRE	-0.432
ROAD FRACTION	0.430
FAR	0.430
INDUSTRIAL FRACTION	0.397
POPULATION DENSITY	0.335

It appeared that the population density, the FAR, the road fraction and the building height were not significant in the model ($p>0.05$), and they were thus eliminated. After that, the multicollinearity was analysed. It appeared that the SVF had a high correlation with the green fraction (0.731), and with the building fraction (-0.849). Besides, the SVF showed a relatively high VIF (5.411), indicating the presence of multicollinearity in the OLS regression for this indicator. Therefore the SVF was eliminated as well, resulting in a model with the following predictors; building fraction, water fraction, green fraction, distance to the city centre and industrial fraction. The R square of the model is 0.730 with a standard error of 1.1559. In the model, all the Variance Inflation Factors were below 5. The model outputs are shown in table 10.

Table 10. Model summary

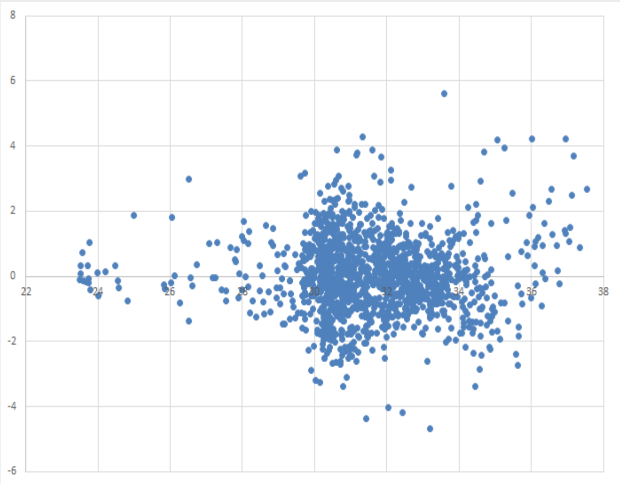
		UNSTANDARDIZED ß	COEFFICIENTS STD. ERROR	SIG.
ß0		31.964	.125	.000
GREEN FRACTION (GF)		-1.108	.161	.000
INDUSTRIAL FRACTION (IF)		2.389	.148	.000
DISTANCE TO CITY CENTRE (DCC)		-0.069	.017	.000
BUILDING FRACTION (BF)		5.809	.367	.000
WATER FRACTION (WF)		-7.763	.231	.000
R	**R SQUARE**	**ADJUSTED R SQUARE**	**STD. ERROR OF THE ESTIMATE**	
0.854	.730	.729	1.1559	

In table 10 the parameters are shown describing what the influence of the five predictors is on the LST. The number below the unstandardized ß represents the value of the rise or decrease in LST if that predictor rises by one unit. So, all else being equal, when the water fraction rises by one unit, the LST is expected to decline by 7.8°C. The building fraction (+5.8°C) and the industrial fraction (+2.4°C) both have an amplifying effect on the LST if they increase by one unit. The cooling capacity of green appeared to be 1.1°C when the related fraction rises by one unit. An increase of distance to the city centre by 1 kilometre, makes the LST decline by 0.07°C. This leads to the following equation (8) for predicting the LST.

$$LST = 31.964 + GF * -1.108 + IF * 2.389 + DCC * -0.069 + BF * 5.809 + WF * -7.763$$

Equation 8

A scatter plot of residuals versus predicted values (figure 12) and a histogram (figure 13) showing the distribution of the residuals are presented. The scatterplot appeared to have a moderate pattern, and the histogram showed a normal distribution with zero mean, approving the assumptions of the OLS model



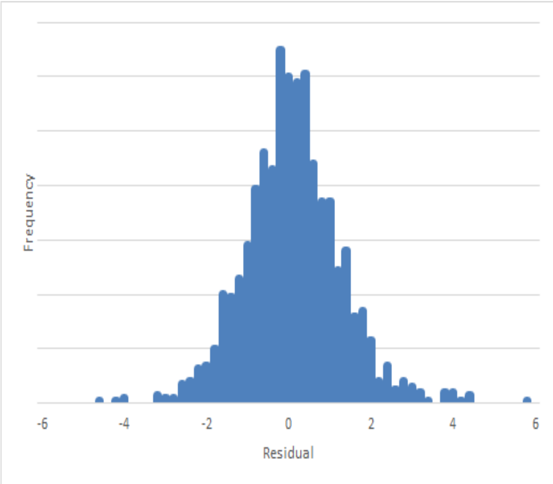


Figure 12 (left). Scatterplot of residuals vs. predicted values, Figure 13 (right). Distribution of residuals

Given a Moran's I of 0.4176, the z-score positive (25.0308) and a p-value of 0.000, the residuals appear to be clustered (Table 11). The spatial distribution of the high and low residuals is more spatially clustered than could be expected, keeping in mind that the underlying spatial processes were random. Due to the spatial autocorrelation of residuals, the Spatial Lag model and the Spatial Error model were tested. A comparison is given in table 12. The spatial lag and spatial error model seem to fit the data better than the OLS model, with the highest R square value for the spatial error model (0.807). However, given the assumptions of the spatial lag model and spatial error model, still, the OLS model was used for estimating the LST. The spatial lag and spatial error model namely include additional terms in their formula, the spatial lag model considers the role of nearby observations, and the spatial error model considers the role of the error in nearby observations. These particular considerations make it not straightforward to use the spatial lag or spatial error for predicting the LST at another location.

Table 11 Summary of Global Moran's I

MORAN'S INDEX	.4176
EXPECTED INDEX	-.0007
VARIANCE	.0003
Z-SCORE	25.0308
P-VALUE	.0000

Table 12. Comparison of different regression models

MODEL	R SQUARE	STD. ERROR OF THE REGRESSION
OLS	.730	1.1559
SPATIAL LAG	.767	1.0699
SPATIAL ERROR	.807	.9736

5.3 Estimating future heat stress

5.3.1 Future UHI

By editing, the landscape characteristics in Utrecht were modified to reflect the situation after densification has taken place. The descriptive statistics of the future landscape characteristics using the same 1500 points as used in table 5 are calculated, they are shown in table 13. These are only the characteristics which were included in the model (equation 8). The descriptive statistics of the distance to city centre is the same as in table 5, as this does not change due to densification. What can be observed is that, from the four fractions, the mean green fraction declines the most, indicating a decrease of green space around the 1500 points. The mean industrial fraction is also expected to decline due to densification, but to a lesser extent, whereas the mean building and water fraction are expected to increase slightly.

Table 13. Descriptive statistics of landscape characteristics after densification

INDICATOR	MEAN	STD. DEVIATION	MIN	MAX	MEAN DIFFERENCE TABLE 5
GREEN FRACTION	.415	.236	0	1	-.009
BUILDING FRACTION	.133	.137	0	0.669	+.002
INDUSTRIAL FRACTION	.056	.209	0	1	-.003
WATER FRACTION	.070	.144	0	1	+.001
DISTANCE TO CITY CENTRE	4.294	2.256	.067	10.237	-

With the new landscape characteristics representing the situation after densification, the future UHI was calculated. The rural area as shown in figure 8 appeared to have an average temperature of 30.3298 degrees Celsius. Therefore, this number was subtracted from the estimated temperature to obtain the future UHI (figure 14). In this figure, the mean, lower-bound and upper-bound are shown. The mean represents an average situation, the lower- and upper-bound were calculated due to the consideration of a 95% confidence interval. Where the lower-bound represents a situation in which the climate is quite mild, the upper-bound represents a situation where the climate is more severe. These outcomes are based on a day where the temperature was the same as the 26th of July 2018, however with the assumption that temperature patterns in the city stay the same.

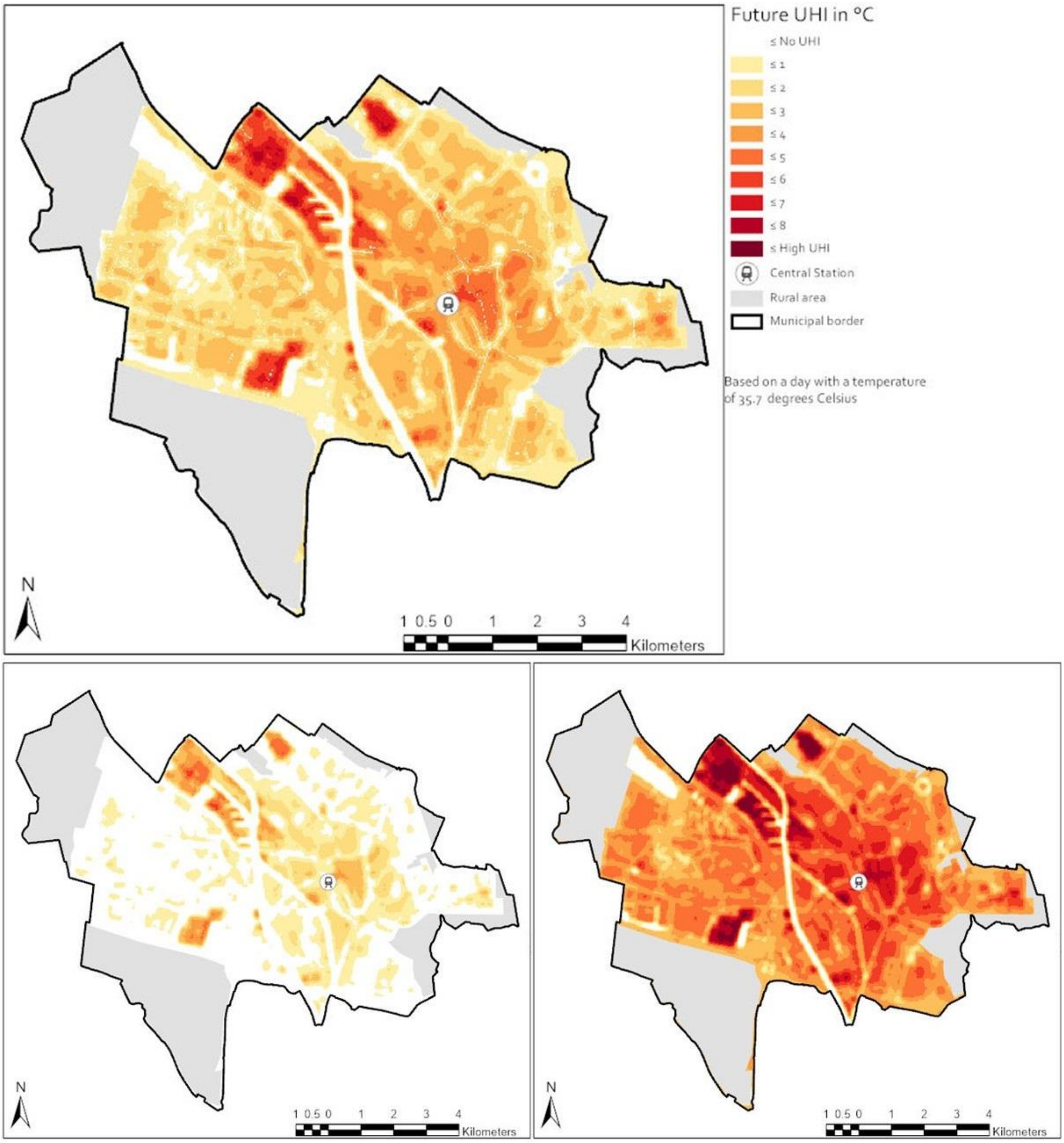


Figure 14. Future UHI in the city of Utrecht, Top: mean, bottom-left: lower bound, bottom-right: upper bound

5.3.2 climatic hazard

The thresholds for quantifying potential climatic hazard are 3.43°C (i.e. the urban temperature is 3.43C higher than the average rural temperature) for the 85th percentile (low potential hazard), 3.91°C for the 90th (medium potential hazard) and 4.95°C for the 95th percentile (high potential hazard). For the potential climatic hazard for the current situation, this resulted in the map below (figure 15). Areas with the most potential climatic hazard are mainly found in industrial areas. Other areas of potential climatic hazard are scattered around the city centre.

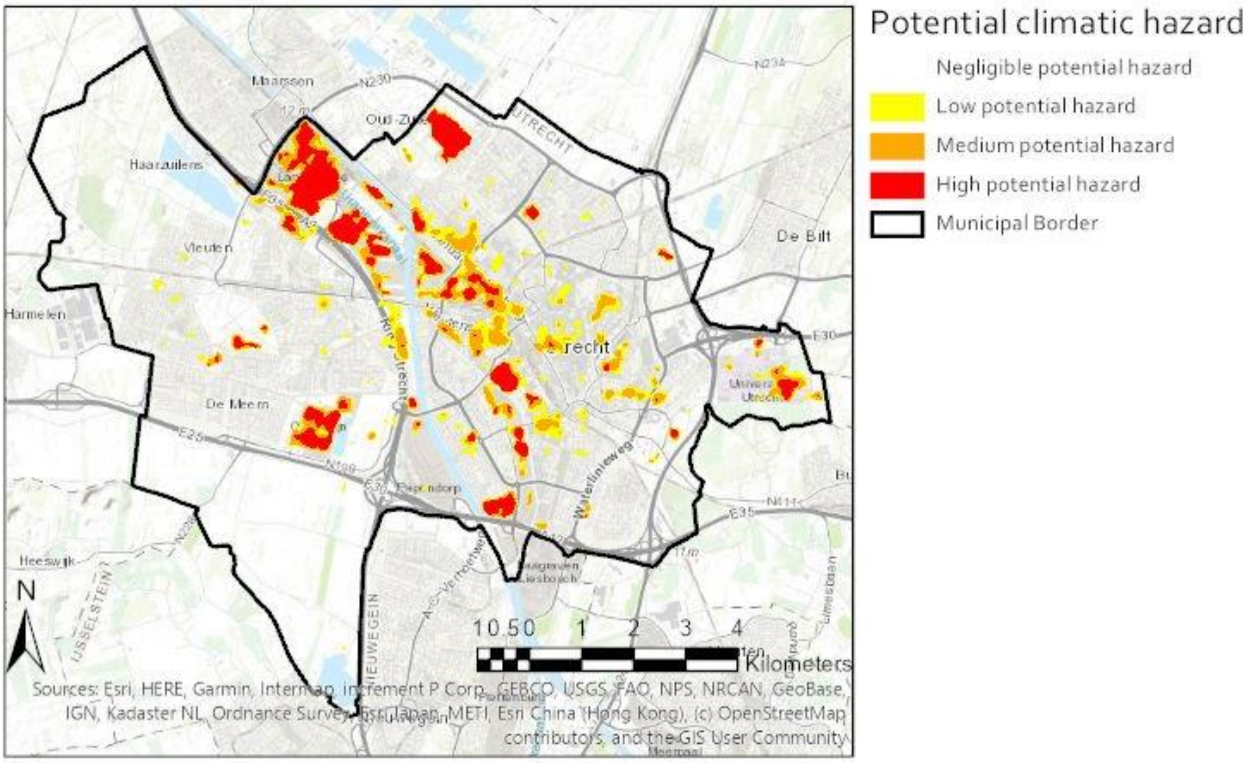


Figure 15. Potential climatic hazard, current situation

For the future potential climatic hazard, the same thresholds were used. Next to the predicted value, also a lower and upper bound were presented for a 95% confidence interval, to take into account the standard error of the model. The lower-bound shows a situation in which the highest UHI will be mild, and the upper-bound shows a situation in which the temperature differences are more severe, which could be a result of, for example, climate change. The outputs are shown in figure 15. As expected, the lower-bound shows a very mild situation, and the upper-bound shows a situation where there is a lot of climatic hazard in the whole city of Utrecht. Again, a lot of red areas are situated on locations where industrial areas are, as could be expected looking at the positive correlation with the LST of the building fraction and the industrial fraction. Other areas of climatic hazard are found in the city centre, especially the upper-bound map shows that in severe conditions, a large area of the city centre has to deal with potentially high climatic hazard. Less affected areas are areas left of the river, in the western part of Utrecht. In this area, large building projects are planned, especially in the area Leidsche Rijn, but as can be seen from the outputs, this will not lead to high potential hazard in the mean situation.

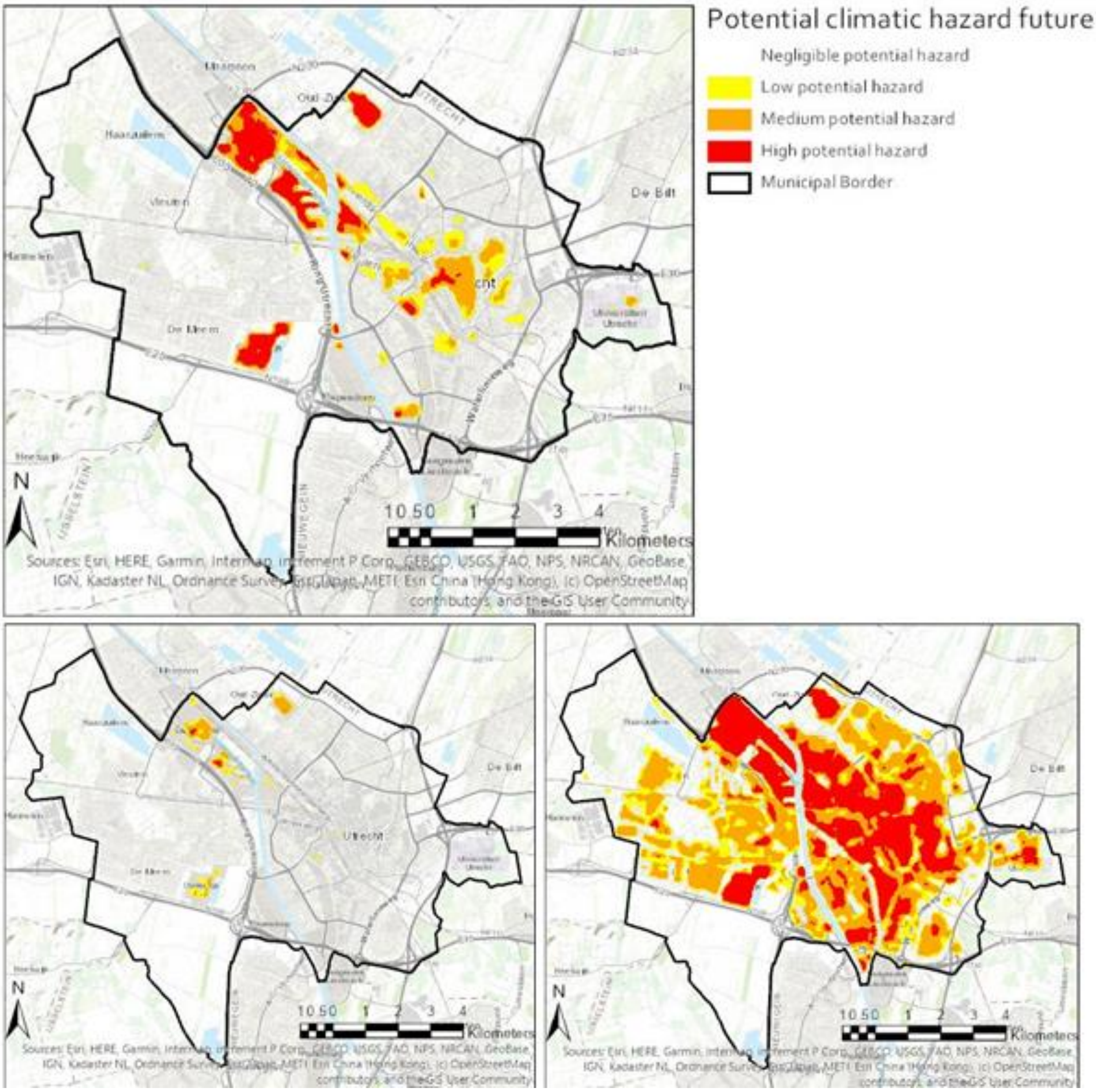


Figure 16. Potential climatic hazard after densification. Top: mean, bottom-left: lower-bound, bottom-right: upper-bound (95% confidence interval).

5.3.3 Vulnerability

The thresholds for assessing the level of density were based on the estimated amount of inhabitants per square kilometre for the current situation. For the 85th percentile, the value was 8753 people km^{-2}, for the 90th it was 9666 people km^{-2} and for the 95th percentile, the density value was 10836 people km^{-2}. In figure 17, the density categorization is shown for the current and future situation. Especially in the city centre, a clear increase in density can be seen. In multiple areas, the areas representing high densities grow in size. When zooming in in areas outside the city centre, it can be seen that in the future situation a yellow area has emerged in the western part of Utrecht: this is the Leidsche Rijn, where a lot of densification is taking place, showing a rise in population density.

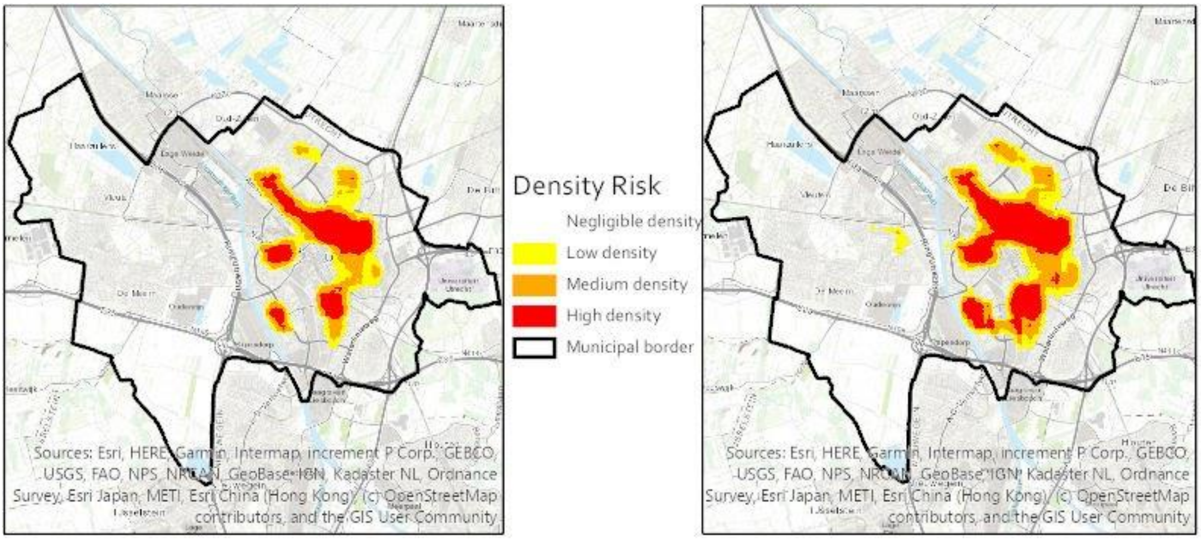


Figure 17. Population density heat stress risk, left: current situation, right: future situation

With the density categorization and the census data on the share of elderly and people with a low income, values could be given to the concentration of elderly people and the concentration of people with a low income. The results are shown in figures 18 (elderly) and 20 (low-income). A small expansion of quite problematic and problematic areas can be seen when comparing the current and future situation. For the elderly, very limited problematic locations are found, for category 3; whereas not a single highly problematic location was found. Locations with higher concentrations of elderly were mainly found around the city centre. On this location, it was more often the case that it was seen as problematic because the density was quite high, instead of the share of the elderly being high. Neighbourhoods with a relatively high share of elderly were mainly found at the edge of the city, where the density is not that high. Besides, in general, the overall share of people who are 65 years or older in Utrecht is only 10%, compared to 18% in the rest of the Netherlands (RIVM, 2020), making Utrecht a relatively young city. The fact that 'older' neighbourhoods are often neighbourhoods where the density is low can be seen when superimposing the density map with a map where only neighbourhoods are presented with at least 20% elderly people (figure 19)

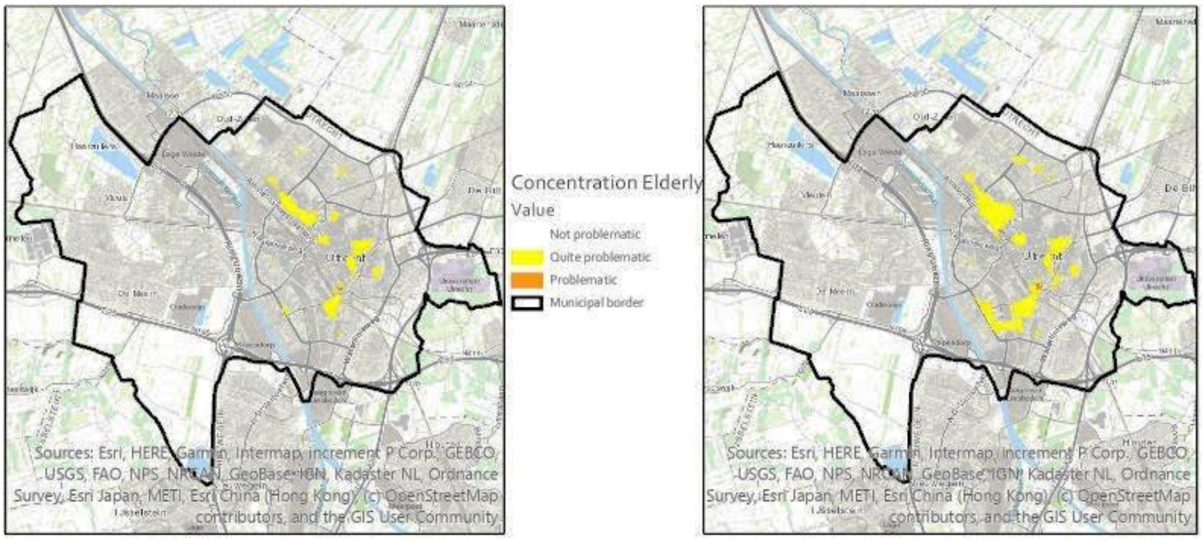


Figure 18. The concentration of elderly, left: current situation, right: future situation

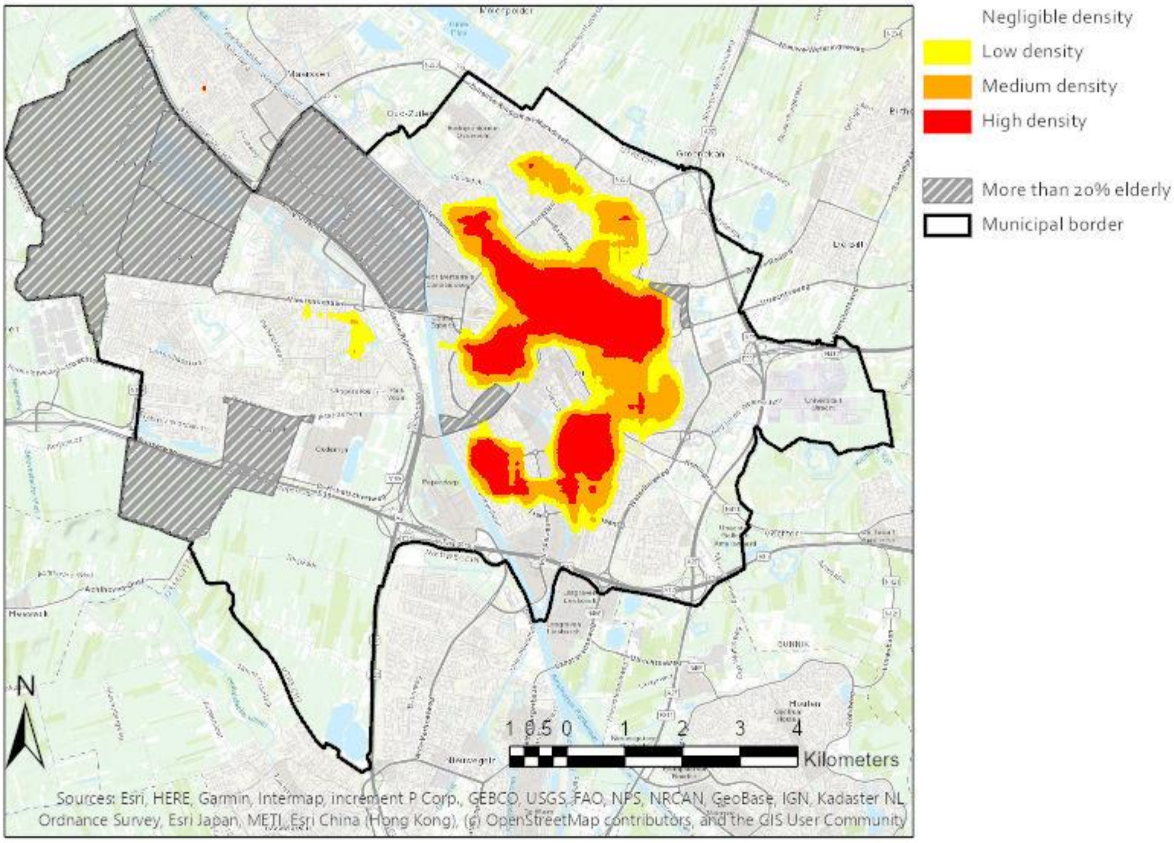


Figure 19. Density level compared to neighbourhoods with a relatively high percentage of the elderly.

The concentration of people with low-income is more often problematic. Besides, an expansion of the problematic areas can be seen regarding the current and future situation. Again, areas around the city centre are identified as problematic, especially in the north and south-east but still not often the highest level of problematic concentration. Again, the density contributes more to the high values than the share of vulnerable people. It can be seen that at one location (Kanaleneiland-Noord), the concentration of people with a low-income is quite problematic. In this neighbourhood, the share of people with an income of up to 125% of the social minimum is 37%. Given a relatively high-density level (medium/high), this area is defined as highly problematic. It can also be seen that the red area will be larger in the future. This is since densification will take place here, it is estimated that the number of inhabitants in Kanaleneiland-Noord will grow by 1520 units between 2019 and 2025.

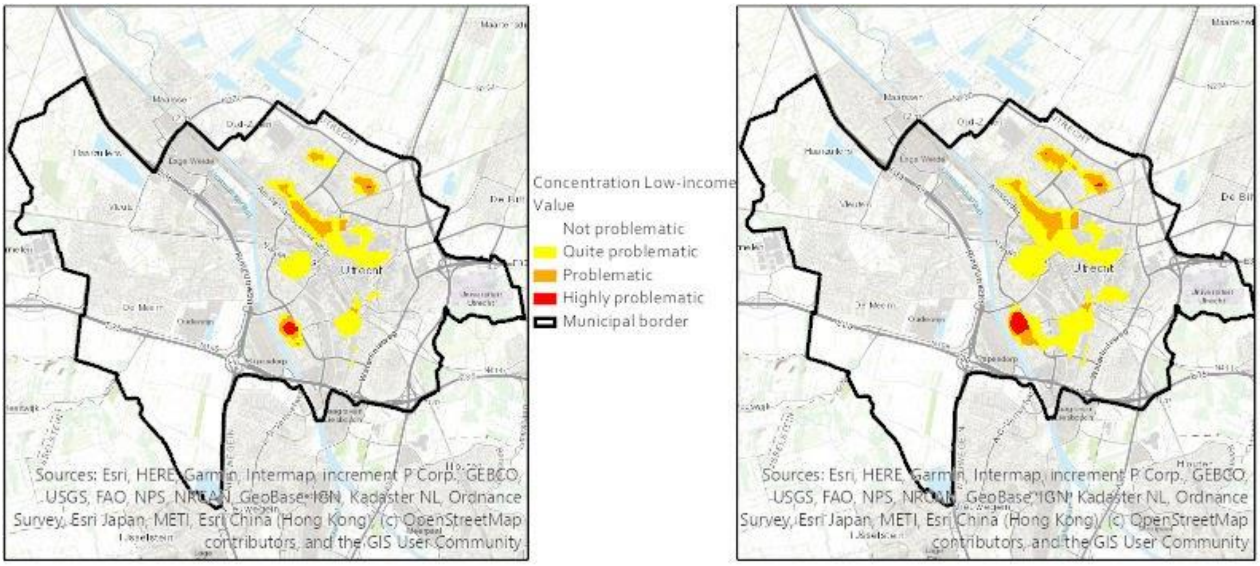


Figure 20. The concentration of people with a low income, left: current situation, right: future situation

5.3.4 Heat stress

By superimposing the areas with potential climatic hazard with the areas with high concentrations of vulnerable people, a categorization can be given to where heat stress could occur. This can result in a value ranging from 0 to 9, based on equation 6 using the numbers of table 7. The categorization is shown for both the elderly as the people with a low-income. For the future situation, again a lower and upper bound is given as well. First, the heat stress risk for the current situation for both the elderly and the people with a low-income is given in figure 21. In the current situation, not much heat stress risk is expected for both the elderly and the people with a low income. For the elderly, only extremely low heat stress risk is expected right now. The main reason for this is that there are very limited areas where the concentration elderly is high. For the people with a low-income, the heat stress risk is higher and on multiple locations in the city, but still, the risk is mainly of very low risk. Figure 21 shows a zoom in on the city centre of the low-income heat stress. Different areas of (small) heat stress risk can be identified. Only at Kanaleneiland-Noord, extremely high risk could occur. Medium heat stress risk is found north of the city centre, in the neighbourhood called Lombok.

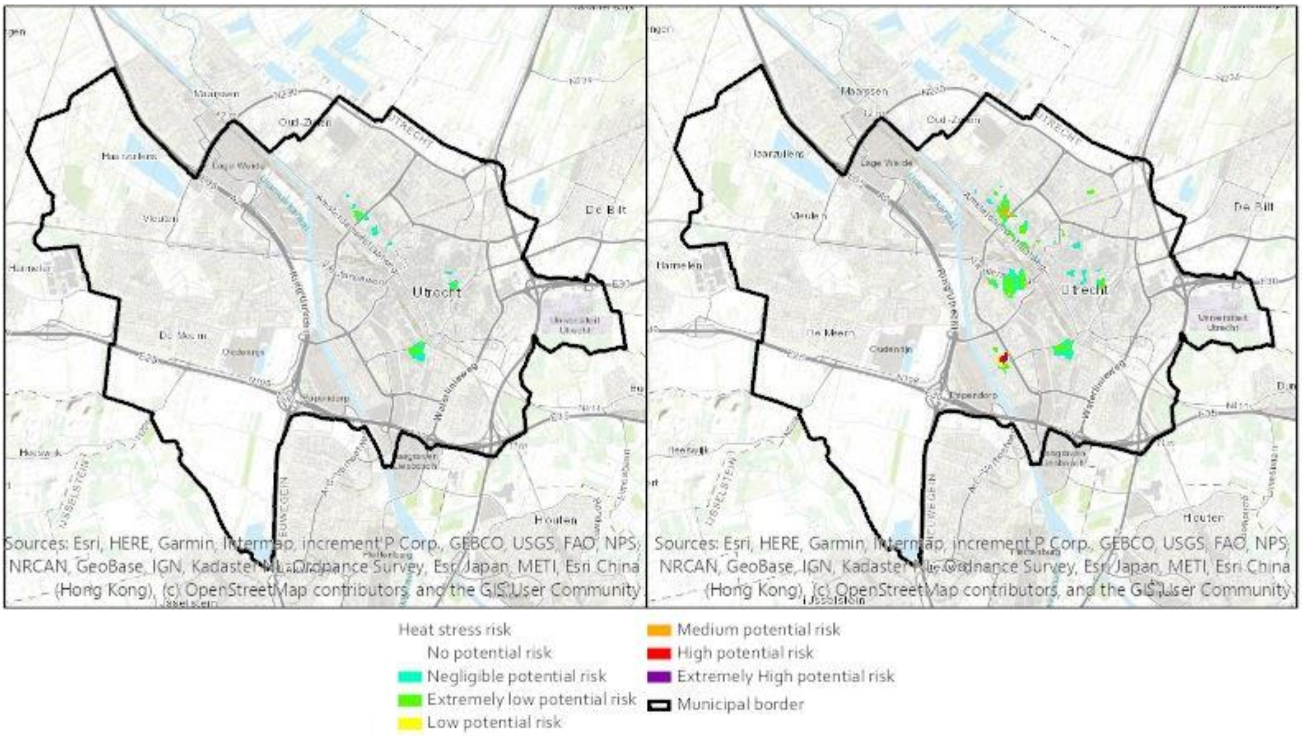


Figure 21. Heat stress current situation, left: elderly, right: low-income

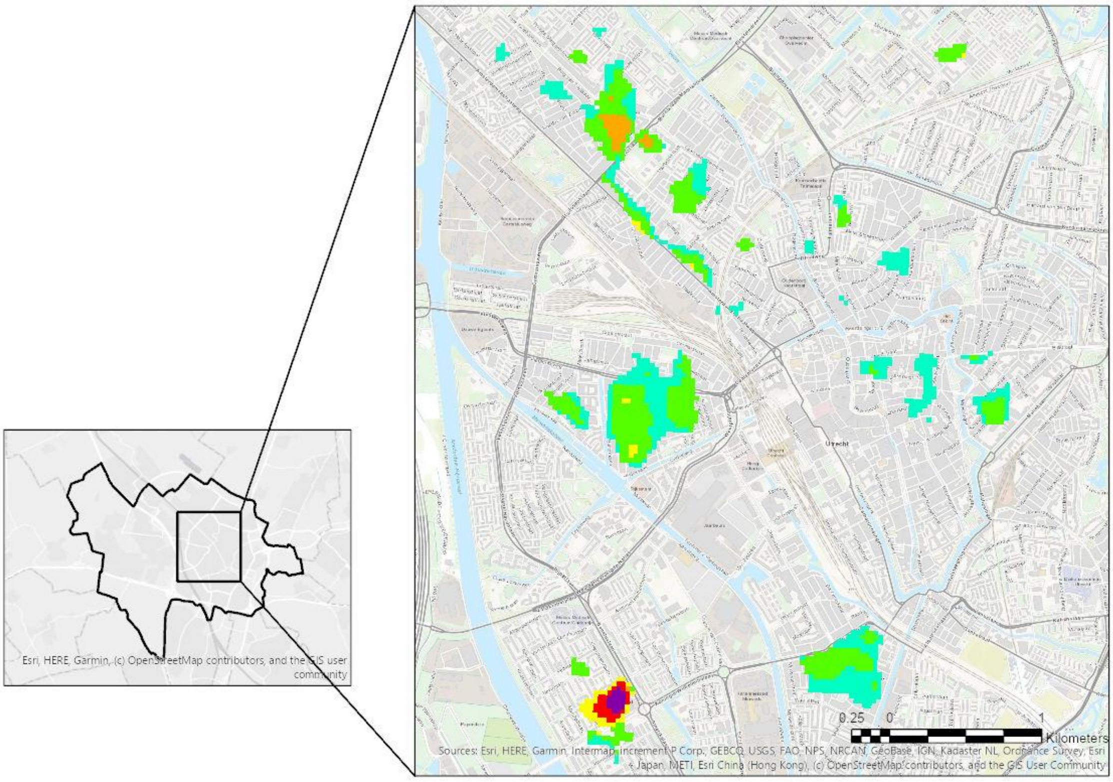


Figure 22. Current heat stress risk low-income, zoom in on city centre

Figure 23 shows the heat stress risk for the future situation, a mean, lower and upper bound are presented. In the lower bound output, the mild situation, no heat stress risk is identified. In the output representing the mean of the estimate, some blue and green areas can be noticed, but still little heat stress risk is shown, as can be expected looking at figure 18. More heat stress risk is shown in the upper bound output, this output represents a more severe situation. A zoom-in is made on the upper bound situation (figure 24). In this figure, locations where there are plans of creating buildings due to densification are presented as well. It is shown that there are not many locations where potential heat stress risk regarding the elderly will directly affect densification sites in the future. However, the densification sites do increase the population density in a neighbourhood, leading to higher potential heat stress risk in the surroundings of densification sites as the concentration of vulnerable inhabitants will rise due to densification in the area.

Figure 23. Heat stress risk future; elderly. Top: median, bottom-left: lower-bound, bottom-right: upper-bound

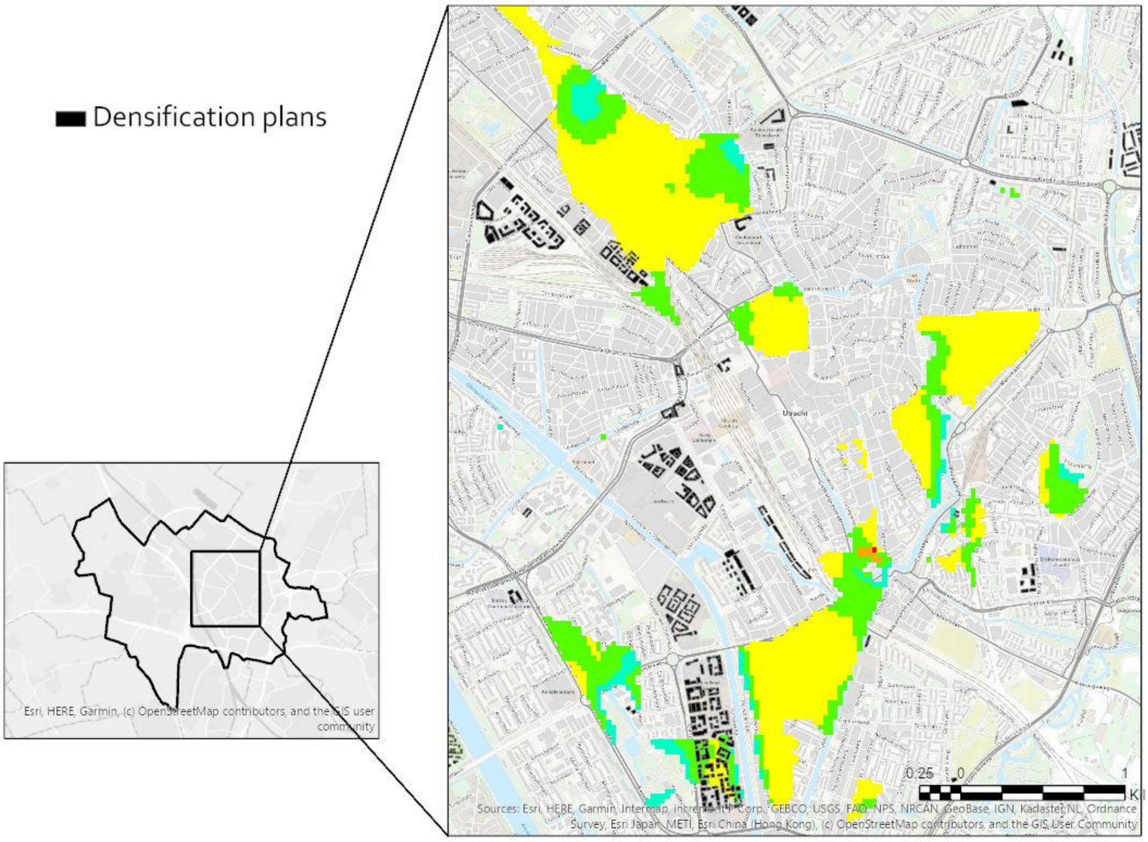


Figure 24. Heat stress risk elderly upper-bound, zoom in on city centre with densification plans shown.

In table 14 it is shown how many people live in areas at risk according to the categorization of Dugord et al. (2014). What can be seen is that in the situation representing the lower-bound of the 95% confidence interval no people live in areas at risk. What stands out while comparing the current situation with the mean future situation, is that while the size of the areas which were at (low) risk did not increase much, the amount of people in category 1 and 2 has more than doubled, this could be a result of densification in these areas. Only in the upper-bound situation, there are expected to be people living in an area categorized as medium to extremely high risk, but this number is still relatively small.

Table 14 Estimated amount of elderly people living in areas of heat-stress risk. Based on population density on each location.

ELDERLY RISK	NEGLIGIBLE (1)	EXTREMELY LOW (2)	LOW (3)	MEDIUM (4)	HIGH (6)	EXTREMELY HIGH (9)
CURRENT	687	378	0	0	0	0
FUTURE – LB	0	0	0	0	0	0
FUTURE - MEAN	1,515	934	5	0	0	0
FUTURE - UB	829	3,593	6,607	49	5	0

Heat stress risk is more present when looking at the categorization with people with low-income as vulnerable people (figure 25). Again, the situation representing a mild future temperature shows no heat stress. The output with the mean of the estimate shows more areas at risk than in the situation with the elderly, however, still the larger part of the 'risky' areas are green and blue, indicating very low potential heat stress risk. If the temperature appears to be warmer than the mean situation however, multiple areas within the city of Utrecht will be at larger risk as is shown on the bottom-right of figure 25. To better compare different neighbourhoods and look at densification sites, again a zoom-in is made in the city centre with the upper-bound situation (figure 26). It can be seen that previously mentioned area Kanaleneiland will have a very high heat stress risk when looking at the economically weaker population. Also north of the city centre, there are locations with high heat stress risk. Again, there are only a few densification sites which are directly in coloured zones. So following the categorization of Dugord et al. (2014) it seems like the newly built buildings do not necessarily contribute directly to heat stress in the city.

Figure 25. Heat stress risk future; low-income. Top: median, bottom-left: lower-bound, bottom-right: upper-bound

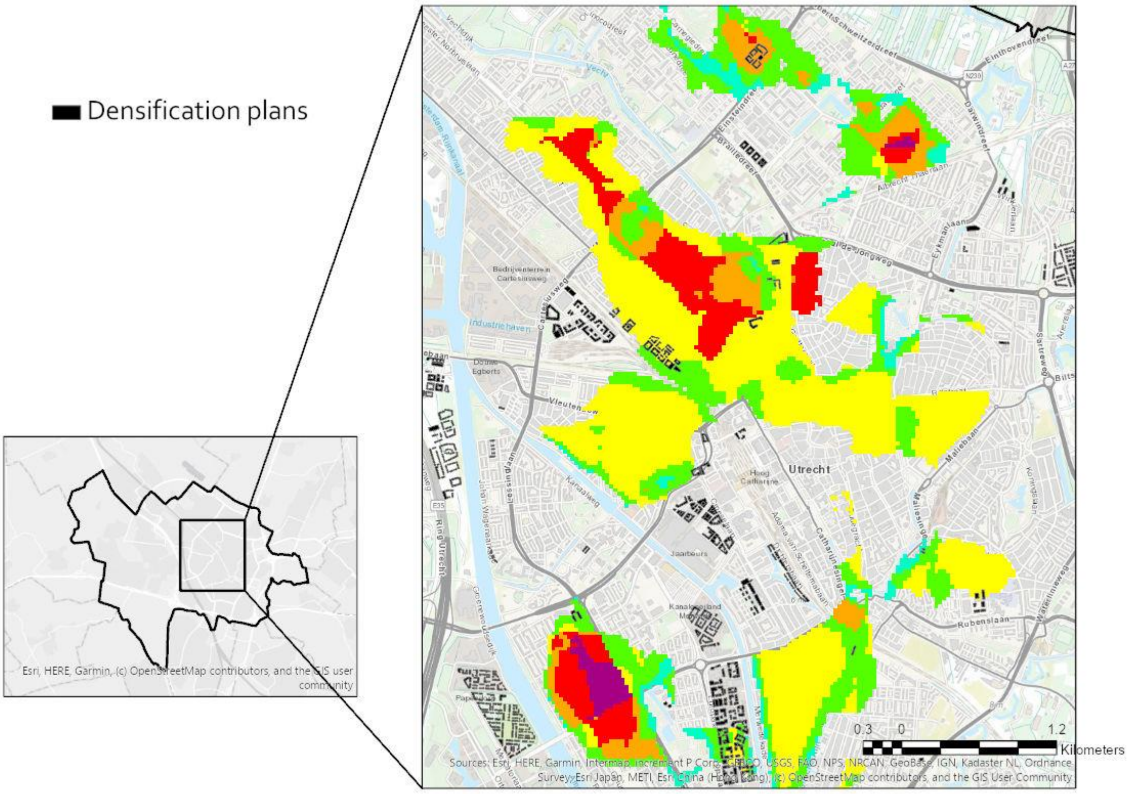


Figure 26. Heat stress risk elderly, zoom in on city centre with densification plans shown.

In table 15 the estimated amount of vulnerable people living in areas at heat stress risk related to low-income are presented. Again, it is expected that in the lower-bound future situation, no inhabitants of Utrecht will be at heat stress risk. When comparing the current situation with the future mean situation, it stands out that in the current situation it is estimated that in every heat-stress category people are found, however for the higher categories this amount is relatively low. For the future mean situation, fewer inhabitants are expected to live in areas of (extremely) high heat stress risk, however, the total amount of people living in areas of the lower categories is higher. The upper-bound future situation shows quite a severe situation, with a lot of low-income people living in areas of heat-stress risk in every category.

Table 15 Estimated amount of people with a low income living in areas of heat-stress risk. Based on population density and share of vulnerable people on each location.

LOW-INCOME RISK	NEGLIGIBLE (1)	EXTREMELY LOW (2)	LOW (3)	MEDIUM (4)	HIGH (6)	EXTREMELY HIGH (9)
CURRENT	2,467	2,998	369	290	277	172
FUTURE - LB	0	0	0	0	0	0
FUTURE – MEAN	4,449	2,722	435	0	56	0
FUTURE - UB	2,563	12,281	17,210	5,604	7,264	1,648

In Utrecht, the increase of heat stress is only clearly visible in a situation where severe temperatures occur (upper-bound of the 95% confidence interval). In general, also looking at the current situation, not much heat stress is observed. This is because particularly hot areas within the city are not that much overlapping with areas where the density is high, this is shown in figure 27 where an overlay is created between the future density risk and the estimated future mean climatic hazard. In the city centre there are some areas which are overlapping, but the larger part of areas with high potential climatic hazard, are located outside locations where density is highest, which is mainly in the city centre. The areas of high climatic hazard are often at industrial sites, where the density is low. Also, densification does not change this a lot.

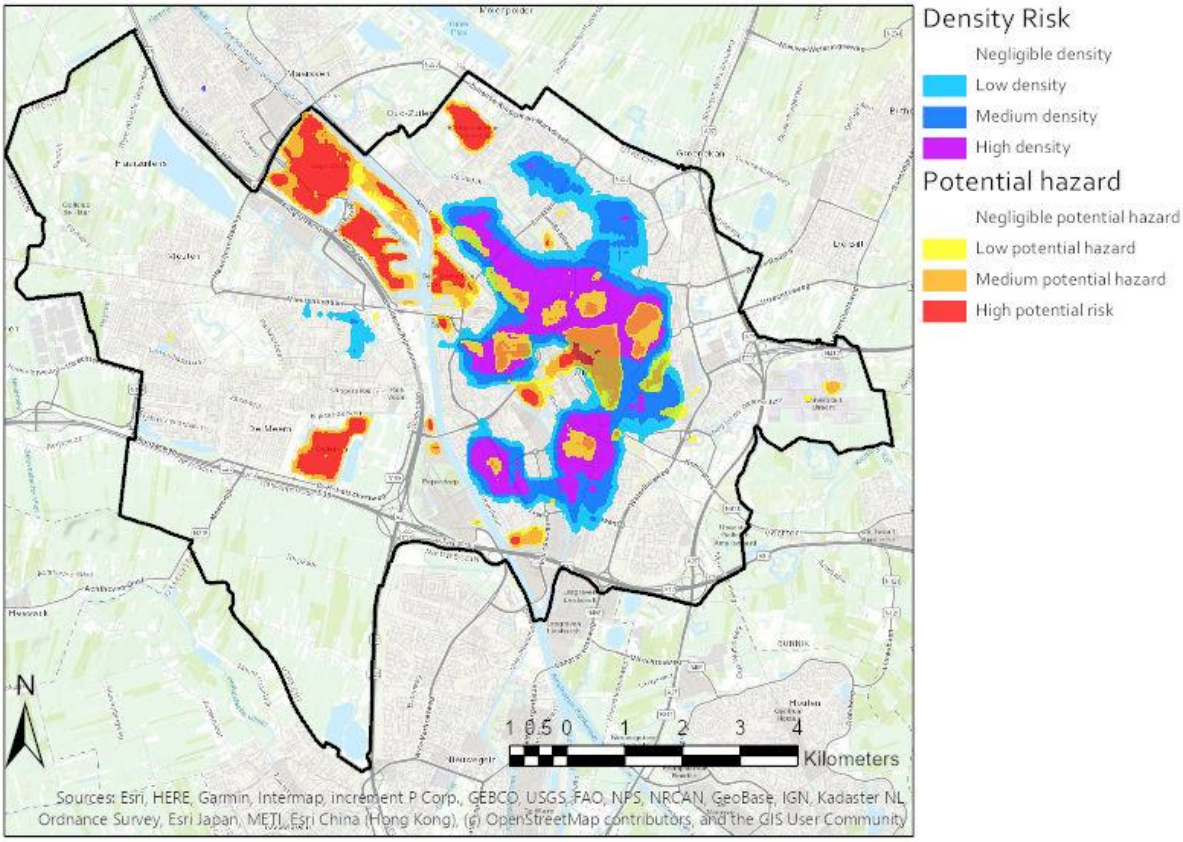


Figure 27. Overlay of future potential climatic hazard (mean) and future density risk.

6. Discussion

6.1 Planning Strategies

From the desk research, it appeared that densification is a hot topic in Utrecht as in the coming years a lot of new dwellings will be created within the built environment. While in national policies not much was found about the Compact City concept and densification, more was found when reviewing the documents of the Province of Utrecht and the municipality of Utrecht. This could be a result of the decentralization of policies in the Netherlands (Nabielek et al., 2012). It is clear that the province as well as the municipality focus on creating houses within the built environment instead of expanding the built environment. So the promotion of the Compact City concept and densification in Europe and the Netherlands, seem to have worked in Utrecht.

The reasons for densification in Utrecht that were mentioned in documents and interviews seem to relate to the concept of the Compact City. Reasons for densification in Utrecht are to keep the city attractive and diverse, to fit within the limited area of the municipality, to stimulate sustainable transport, efficiency and to preserve green and recreational areas. These are reasons which are also widely described in the literature as reasons for the Compact City concept (see, for example, Churchman, 1999; Neuman, 2005; Jabareen, 2006; Broitman & Koomen, 2015). Different characteristics of the Compact City as presented in table 1 can be related to what the aim of Utrecht is. Some of these are high residential and employment densities, increased social and economic interaction and multimodal transportation. Especially the latter characteristic was mentioned multiple times as a reason to densify. The stimulation of densification around mobility hubs is visible when looking at the expected growth of inhabitants per neighbourhood, it can be seen that a lot of densification is taking place around the Central Station, but also around other train stations (figure 9). Aspects of the Transit-Oriented Development (TOD) concept clearly come forward in Utrecht, proving as well that the Compact City concept is closely related to mobility (Westerink et al., 2013). In Utrecht there is as well an emphasis on public transport, the aim to promote sustainable modes of transport and stimulate a modal shift was mentioned multiple times. It was mentioned as well that promotion of sustainable transport, together with the aim for efficiency due to densification, could lead to a reduction of CO_2 emission. Climate mitigation in the form of CO_2 reduction is one of the main goals of the Compact City concept and also appeared to be a goal in the municipality of Utrecht.

However, Utrecht also faces challenges while densifying. Joynt, Williams & Hopkins (2010) identified the challenge of cities willing to densify to mitigate climate change through CO_2 emission reduction, but at the same time trying to adapt to the consequences of climate change (e.g. increased temperatures). Climate adaptation requires space: something that with densification becomes ever more scarce. For example, as Haaland & van den Bosch (2012) found, green provision is a major challenge in densifying areas. The conflict between climate change mitigation by densification, and climate change adaptation, by for example creation of green space, is therefore visible in Utrecht and requires smart planning solutions to create a balance between the large scale benefits (i.e. CO_2 reduction) and the local scale benefits (i.e. adaptation to heat). Despite the challenge of scarce space, the main focus for adapting to climate change and heat stress appears to be on implementing green. Implementing green is seen as a key element of successful densification in Utrecht, and is seen in almost every densification project. Besides horizontal green on the neighbourhood and street scale, where this research mainly focusses on, also vertical green and green roofs were mentioned as cooling mechanisms. However, the impact of climate adaptive measures on the building level are not examined in this research, still, the implementation of these could contribute to the thermal comfort of inhabitants, which could be examined in further research.

The definition of heat stress adopted in this research assumes that stress occurs when the heat negatively affects the energy balance of the human body and thereby implying an increase of heat-related morbidity and mortality (Kovats & Hajat, 2008). Two key aspects for quantifying this are climatic hazard and vulnerability (Dugord et al., 2004). In most of the policy documents reviewed, if heat stress was mentioned, it was mostly linked to the climatic hazard component of heat stress, and barely to the vulnerability component. Therefore it seems that from the document review, the main strategies around heat stress are to change landscape characteristics (i.e. add green and water) to reduce the temperature, instead of looking at where high concentrations of vulnerable people are. When only reviewing the policy documents, it could be stated that the conclusion that Dutch local governments often have insufficient understanding of urban heat risks to take heat adaptation action (Klok & Kluck, 2018) could be right. However, in one interview it was mentioned that vulnerable people were taken into account when looking at heat stress. The groups that were mentioned were elderly, children, homeless people and chronically ill. While the elderly were also taken into account in this research (and in many others), the other three were not, as in this research people with a low-income were seen as vulnerable people.

6.2 Impact of landscape characteristics on LST

In this research, first, the correlation of different landscape characteristics with the LST is computed. For measuring the LST, the RTE-method was used to calculate the LST from Landsat images. By deriving the temperature from satellite images, the temperature on the ground can be obtained quite accurately, which could be used for quantifying heat stress and is preferred over for example air temperature as this is less accurate. The high accuracy leads to large differences across space, this can be observed for example by looking at the minimum and maximum which differs greatly in the municipality of Utrecht (minimum of 22.8°C and maximum of 44.9°C). Besides its accuracy, the method for estimating the LST is also quite accessible, as the satellite images are freely available, and for the computation of the LST only band 4, 5 and 10 have to be used to estimate the temperature from the images.

For each landscape characteristic, a computation radius was used which is shown in table 6. What stands out is that for a lot of landscape characteristics, the computation radius is smaller than the computation radii as found by other authors (Table 5). This could be the result of different temperature deriving methods (satellite images vs. measurements) or different methods to calculate the landscape characteristics. Besides, the characteristics of Utrecht and its surrounding environment could also lead to different radius sizes. The strongest correlation with the LST was found with the building fraction (r=.67). This is also higher than what for example Heusinkveld et al. (2014) found in their study (.50). What also stands out, is that the SVF has a negative correlation (r=-.474), as different studies had conflicting results on whether the SVF had a positive or negative impact as appeared from the theoretical framework. It appears that in the case area in this study, a higher SVF leads to a lower temperature. This could indicate that with a lower SVF, more heat is stored, which is especially the case in dense urban areas, this was also found in other studies in Dutch cities (van der Hoeven & Wandl, 2014; Dirksen et al., 2019). However, what was also observed, is that areas with a low SVF often were areas with a high building fraction, the multicollinearity between these two was quite high, which should be taken into account as a higher building fraction amplifies the UHI as well.

From the landscape characteristics, a model was created with an R^2 of .730 and a standard error of 1.1559. It appeared that the building fraction had a strong amplifying effect on the LST (5.809°C for a one-point increase of BF), industrial areas appeared to amplify the UHI as well (2.389°C for a one-point increase of IF). This can be seen in figure 11: the locations which are red and dark orange are mainly in the city centre, where high building fractions are present, or on industrial areas within the cities. The industrial area was also included in the model despite its relatively low correlation with the LST (r=.40). The main reason for this was that it appeared to be significant in the model ($p<0.05$) and that very limited multicollinearity with other predictors was observed (VIF: 1.15). The industrial fraction appeared to be a good indicator of where severe temperatures within the city occur, as was found as well by Hua et al. (2020).

While in multiple studies the green fraction was identified as the greatest cooling mechanism (see, for example, Heusinkveld et al., 2014; Koopmans et al., 2018), in this study the impact of water fraction appeared to be stronger than that of the green fraction (-7.763°C for a one-point increase of WF against -1.108°C for a one-point increase of GF). This is contradictory to the aforementioned studies, an explanation of this could be that the temperature was taken from a hot day after two weeks of drought, this may have affected the cooling capacity of green in the case area, as drought affects the state of the vegetation and can thus reduce the evapotranspiration of the plant (De Bono et al., 2004), which is seen as a key factor in the cooling capacity of vegetation. Water appeared to be a stronger cooling mechanism compared to green in this study, however, a comment should be made on the time of the day it is about. As appeared from the literature review, the impact from water on the LST is negative, but it could differ during night-time or in autumn, as water temperature cools down and warms up more slowly than the air temperature (Theeuwes, Solcerová & Steeneveld, 2013).

Another parameter which was identified as a cooling mechanism was the distance to the city centre, it was calculated that for each kilometre further away from the city centre, the temperature decreases slightly (-0.069°C for a kilometre increase of DCC). This is in line with the assumptions of Oke (1987) and Unger (2001) about the temperature patterns across the city. Schwarz et al. (2012) and Dugord et al. (2014) also found in their studies in other cities, that in general the further you move away from the city centre, the cooler the expected temperature. Even though the cooling capacity in this study was quite low, this could be taken into account by urban planners while densifying, as densification on locations further from the city centre might be more favourable in terms of temperature. However, the definition of the city centre is not clearly defined. In this study, the Central Station in Utrecht is used because this appeared to be the best predictor of the LST based on its Pearson correlation, but in other studies, different landmarks within the city centre were used to measure the indicator. This should be taken into account when using the distance to the city centre for estimating the LST.

After an autocorrelation test with the OLS model, it appeared that the model had a high score on spatial autocorrelation indicating a high amount of clustered residuals. This is not desirable in an OLS model, and should, therefore, be taken into account. For a matter of completeness, two other models were tested as well. It should be taken in to account that both the spatial lag as the spatial error model gave a slightly higher R^2 then the OLS model, with the spatial error model having the highest output (R^2=.807). So these two models seem to fit the data better. However, the spatial lag model assumes that spatial autocorrelation takes the form of interaction between nearby observation, whereas the spatial error model assumes that spatial autocorrelation takes the form of interaction between error terms of nearby observations. Given these assumptions, the OLS was used for prediction because both the spatial error model and the spatial lag model include additional terms (neighbourhood matrix) that are difficult to compute in a raster environment (Anselin, 1996).

6.3 Potential heat stress and densification

6.3.1 Climatic hazard

As mentioned before, the areas with the highest potential climatic hazard can be found in and around industrial areas. These areas often consist of very limited green space and multiple buildings with a large footprint as was observed by the researcher. Other areas of potential climatic hazard can be found in the city centre, where the building fraction and building density are high, an example of this is Jaarbeurs. Areas like Jaarbeurs may need special attention because of densification in the future, as it is already a relatively hot area. The right densification strategies and spatial design should be implemented to not amplify the climatic hazard on locations where building fractions are already quite high, adding green and water could help as well to cool the areas. Other large densification projects which are close to locations of potential climatic hazard are Cartesiusdriehoek and Wisselspoor. However, when comparing the current and future situation, the temperature is not necessarily expected to rise in these densifying areas. In some areas undergoing densification, the temperature is even expected to go down. This is because, in Utrecht, multiple densification sites are located on former industrial sites. When an industrial area is being transformed into a neighbourhood, it can be expected that the green fraction on this location increases, which was often the case looking at plans from the municipality of Utrecht. Besides, the building fraction did not often rise that much while an industrial area was transformed into a residential area. Of course, residential buildings were built, indicating a rise in the building fraction, however, since the former industrial sites often included buildings with a large footprint which were demolished, the newly created buildings were compensated and the building fraction often remained somewhat the same.

There were also densification sites where it may be expected that the temperature is going to rise due to densification. This was often the case in areas where buildings were created on vacant or green areas, or when the building fraction was expected to go from relatively low to medium or high. Examples of these areas are Leidsche Rijn or Rijnvliet, but while it might be expected that the temperature rises in these areas, this will probably not lead to a potential climatic hazard. This is because the temperature in these areas was already quite low before, and an increase in temperature because of a higher building fraction will thus not necessarily lead to severe temperatures. Also, it is expected that areas further away from the city centre are in general cooler (see Unger et al., 2001), this may lead to the fact that the temperature in several areas further away from the city centre, is less likely to become severe after densification. Therefore, when choosing locations for potential densification, it may be wise to prioritize areas which are not directly in the city centre, as was the case for Leidsche Rijn and Rijnvliet.

In its densification strategies, Utrecht often chooses medium- or high-rise buildings instead of buildings with a low height, which may also lead to the fact that the temperature will not rise that much. When higher buildings are built but with a smaller footprint, more green space can be preserved or even created, and the building fraction does not necessarily have to become very high. The same total floor area can be created compared to low buildings with a large footprint. Densifying by creating higher buildings could, therefore, lead to less severe temperatures compared to densifying by creating lower buildings. This is in accordance to conclusions from Koopmans et al. (2018) who found that while densifying it might be better in terms of climatic hazard to use high buildings with a smaller footprint, instead of low buildings with a large footprint. Vuckovic et al. (2019) state that densifying by high buildings could even lead to improved thermal conditions within more shaded urban canyons and courtyards, as a result of solar shielding. However, a difference was observed between day- and night-time, as at night the higher thermal storage between higher buildings could contribute to a warming effect.

Looking at the influence of densification on the temperature in Utrecht and the potential climatic hazard, it does not seem that the situation becomes much more severe around densifying areas. Of course, there are areas where temperature rises due to densification and an increased building fraction, for example in Leidsche Rijn, but often these temperatures are not identified as supposedly high. The densification strategies within the municipality of Utrecht concerning potential climatic hazard, therefore, seem to be quite good, no major increases in potential climatic hazard are identified. Of course, there are areas, mainly in the city centre, to which urban planners need to pay attention in terms of densification and heat, as the temperature patterns in these areas already show quite high temperatures. But with the right policies, this should be manageable, urban planners should in densification strategies focus on landscape characteristics which have a reducing effect on the temperature, like green and water structures. From the interviews, it appeared that in Utrecht there is already a focus on especially implementing green while densifying. In this research, different strategies for densification are identified as favourable strategies next to implementing green and blue infrastructures. Densification on former industrial sites may eventually lead to even lower temperatures, therefore, it can be concluded that densification on industrial sites may be a favourable strategy for cities aiming to grow. Other favourable strategies are building further away from the city centre, as it may be expected that temperatures are cooler here (Oke, 1987; Unger et al., 2001). Also densifying by creating relatively high buildings might decrease the climatic hazard (Koopmans et al., 2018).

However, it should be taken into account that the created model in this research has an error, 95% of the values for a certain set of landscape characteristics can range between the lower- and upper-bound. Therefore, the situation after densification could also be more severe than as shown in the mean situation, this should certainly be taken into account, as the estimations of the upper-bound as showed in the results could also represent the actual future situation. In this situation, more areas will be at climatic hazard, and further densification might amplify the UHI.

6.3.2 Vulnerability

Where the climatic hazard in a normal situation did not necessarily arise due to densification, this was different for the population vulnerability. It could especially be seen that areas of high population density throughout the city rises significantly. Especially areas in and around the city centre are expected to have high densities by the year 2025. This leads as well to a rise in the concentration of vulnerable inhabitants, which is important for quantifying heat stress. For both the elderly and people with a low income, it can be seen that the area of problematic concentrations rises. Still, for the elderly, this does not lead to highly problematic concentrations, as neighbourhoods with high concentrations of elderly do not superimpose areas of high-density values. No proof was found that city planners did this on purpose, but still, it could be a good strategy to try to locate vulnerable people on locations which are not that dense in cities to prevent areas from becoming vulnerable. Further research could focus on how other densifying cities take the elderly into account. As Utrecht is quite a young city in general, other research could focus on cities which have different age distributions. In the research of Dugord et al. (2014), for example, more areas at higher levels of risk related to the age were found in Berlin compared to Utrecht.

For the people with a low-income, the results showed multiple areas with concentrations of (highly) vulnerable people. Besides, areas where densification plans are found are categorised as problematic as well. Examples of densification projects which are close to areas of vulnerability are Wisselspoor and Beurskwartier. The red area in Kanaleneiland-Noord, as previously mentioned, stands out. In this neighbourhood, only one densification project was found; a hospital is being transformed into a residential building. But this leads to the fact that the density in the neighbourhood, which was already quite high, increases, and thus the concentration of vulnerable inhabitants. Besides, there are different densification sites close to this red area (for example Merwedekanaalzone). From the different outcomes regarding the vulnerability, it can be concluded that increased population density contributes to higher concentrations of vulnerable inhabitants, which is mainly visible on the neighbourhood level around densification sites. These neighbourhoods are mainly found around the city centre, densification areas further away, for example, Leidsche Rijn increase in density, but not to a level as observed in the city centre, therefore, problematic concentrations are barely found here. Therefore, densifying in neighbourhoods of relatively low density might be a good strategy to prevent the share of vulnerable people from becoming problematic.

6.3.3 Heat stress risk

When superimposing areas of high temperatures with areas of problematic concentrations, heat stress for both groups of vulnerable people can be observed. For the elderly, the heat stress in the current and future situation is very limited because of the aforementioned reasons, medium or high heat stress risk is even in the most severe scenario barely found. Lower categorizations of heat stress are mainly found around the city centre, but when looking at figure 24 no relation between densification and the heat stress can be observed. Very limited densification sites around the city centre seem to be prone because of (low) heat stress risk. Still, it can be seen from table 14 that the number of elderly people living in areas of low risk has increased due to densification.

When looking at the heat stress risk for people with a low income, heat stress risk is more visible, but still, for the mean situation, it does not seem to increase much due to densification. When looking at the severe scenario, there are several areas with high potential heat stress, also the number of people with a low income living in these areas has become quite high looking at table 15, but again these areas are not necessarily densification sites. So when looking at both the elderly as well as the people with a low income, it does not seem that densification sites on their own contribute a lot to heat stress in the city of Utrecht. The general reason that not that much heat stress is identified in the mean scenario, is that vulnerable areas and areas of potential climatic hazard do simply not overlap that much, as shown in figure 27. This is important to keep in mind: while making densification strategies concerning heat stress, high temperatures in a city are not necessarily a problem if the concentration of vulnerable people in the area is relatively low.

From the results, it appeared that densification did not increase the size of areas at high climatic hazard, however, it did increase the area size of vulnerability, as the higher densities led to higher concentrations of vulnerable people. Therefore, it seems that the greatest contributor to heat stress in Utrecht as a result of densification is not the modified landscape characteristics which could amplify the UHI in the city, as the locations with the most severe temperatures did not change that much due to densification. The largest impact of densification on heat stress was more the rise of densities within the city, increasing the concentration of vulnerable people in several areas. Besides the fact that the right densification strategies do not increase the temperature in an area too much, planners should take the rise in density and thus vulnerability into account as well. High concentrations of vulnerable people could make certain neighbourhoods within a city more sensible to increased heat, and could also increase the number of people living in these areas at risk. It is important that in neighbourhoods like these either the concentration of vulnerable people does not further increase, or the temperature be not further amplified due to changed landscape characteristics because of densification. This is also important for Utrecht, as this analysis only quantified a situation until 2025, but the city is expected to grow until at least 2040. Hence, as more densification is expected after 2025, several areas where heat stress risk is already present should get special attention by urban planners.

6.4 Limitations of the research

In quantifying heat stress, this research focusses on two groups of vulnerable people, namely the elderly and people with a low income. These were the same groups of vulnerable people as investigated by Sanchez-Guevara et al. (2018) and one more than Dugord et al. (2014), who only looked at age. However, as more groups of people could experience the negative effects of high temperatures, further research could focus on other groups of vulnerable people and assess heat stress risk for these groups. For example, an interviewee mentioned the elderly, children, homeless people and chronically ill as vulnerable people. Children were not taken into account as Ishigami et al. (2008) found no significant evidence that these are more affected by heat in terms of morbidity and mortality, however, it is proven that children may have a lesser ability to thermoregulate, and therefore they could be more vulnerable to heat (Kovats & Hajat, 2008). In further research, this group could also be taken into account. Homeless and chronically ill were mentioned as well, however, as homeless people do not live on one place, it would be hard to take them into account in research with a comparable method as was used in this research. The chronically ill could be investigated further as a vulnerability group. However, as Michelozzi et al. (2005) found, people with a low income are more likely to have medical risk factors. Therefore, it should be taken into account that the vulnerability categories 'low-income' and 'chronically ill' could partly overlap, i.e. a significant part of the chronically ill are also people with a low-income. Because of this, they should not necessarily be seen as separate vulnerable group when quantifying heat stress, and the condition of being chronically ill could also be seen as a reason why people with a low income are more vulnerable. Further research could focus on vulnerability to heat stress in a city like Utrecht for the aforementioned or other vulnerable groups. However, what is important to understand, is that no matter what vulnerable group is investigated, it is important to take into account that densification could increase the concentration of vulnerable people, and thereby amplifying heat stress.

To calculate the landscape characteristics, open GIS data were used from different data sources. This causes some uncertainties as this research is for a large part dependent on this data. Some inconsistencies could be in the open data on which the researcher has no influence, such as that the different data sources could use different snapshots in time. To estimate the future LST, the landscape characteristics had to be modified towards a situation that represents a situation after densification. These modifications were based on project plans which were available on the internet. However due to several aspects, like money constraints or complaints from citizens, these plans can change in the future. Therefore, the data on which the estimations are based might not fully represent the situation after densification, but at least an estimation is made based on what it could look like following the project plans that are now available. Also in estimating the average building heights, there are some uncertainties, as in some projects no building height was given. If this was the case, the height of the buildings was estimated based on the number of floors. No national guidelines on floor heights were found, so the assumption was made that one floor is three meters in height. This was based on the fact that at least eight different projects which were reviewed in Utrecht used a length of three meters as length per floor. Of course, in reality, some buildings could deviate from this number so the average building height for some buildings might not be fully accurate, influencing the computed landscape characteristics for which height was important like the average building height, the SVF and the FAR.

What should be taken into account for this research is the time of the day the parameters on the LST were calculated for. Satellite images, which were used to compute the LST (dependent variable of the regression), were taken at daytime on a hot day in July. However, as appeared from other research, the cooling capacity of water could differ per season and between daytime and night-time as well. However, it was specifically chosen to look at the influence of landscape characteristics in the summer, as in autumn, heat stress in the Netherlands is not very realistic. Regarding the time of day, this research focusses on the daytime heat stress, however, it is still important for urban planners that water is not necessarily a cooling mechanism at night. A higher temperature at night around water bodies compared to the other areas could lead to heat stress because of a decrease in sleep quality for people living nearby water (Klok & Kluck, 2018). Differences between day- and night-time could also occur when looking at densification by high buildings (Vuckovic et al., 2019): during the day higher buildings could contribute to a solar shielding effect, but during the night they could favour higher thermal storage. Given these assumptions, the influence of the mean building height and the SVF on the LST could differ when the temperature at night is taken into account as well. Further research may focus on what the influence of densification strategies on thermal comfort in the city is, also taking into account the influence of landscape characteristics on the night-time temperature.

For quantifying vulnerability, estimations were made on the future share of vulnerable people. However, in census data, the share of vulnerable people on the neighbourhood level for 2025 was not available, therefore simple assumptions were made. These assumptions are as follows: the percentage growth of elderly per neighbourhood is equal to the percentage growth of elderly in the corresponding sub-district until 2025 (data on the sub-district level was available), the percentage of people with a low-income stays the same in each neighbourhood as no data on this was available for the future. These assumptions may not be completely accurate, but due to time constraints and lack of data, it was the best option. Further research could investigate what the influence of densification on a neighbourhood's demography could be, for example, accounting for the flee of some socioeconomic groups from densified neighbourhoods to lower-density neighbourhoods. For estimating the future amount of inhabitants per neighbourhood, estimations were made by the researcher as well, as estimations from the municipality were only available on the sub-district level. The assumptions were based on the estimations of the sub-district and the plans for new dwellings per neighbourhood. However, these might also not be fully accurate, for example, because the household size could differ per neighbourhood. Still, it gave a general view of the growth per neighbourhood, only time will tell how accurate these assumptions were.

7. Conclusion

7.1 The effect of urban densification strategies on heat stress in the future

The objective of this research was to assess how densification strategies in a city will affect heat stress in the city. To investigate this, first, a qualitative analysis was conducted on densification strategies in the city of Utrecht, and how heat stress was hereby taken into account. The second part of this research had a quantitative character and was about estimating where heat stress might occur in the future, and how this was related to the densification strategies. These steps were conducted to answer the main research question; how will urban densification strategies spatially affect heat stress in the future? In this section, the most relevant outcomes and consequences of this research are formulated to answer the main research question.

This research has shown that multiple aspects of the Compact City concept are visible in the municipality of Utrecht. From the interviews and the document review, it appeared that the reasons for densification are related to theory on the Compact City. Some key characteristics of the Compact City which were found as aims of densification in Utrecht were high residential and employment densities, increased social and economic interaction and multimodal transportation. However, several challenges related to densification are found as well. In densifying areas there is a constant battle over scarce space, this makes it harder to adapt to a changing climate by, for example, adding extra green. One of the key elements of densification as mentioned in documents and interviews is greening, which is seen as a cooling mechanism needed to prevent densification areas from becoming areas of only concrete and stone, and hereby areas amplifying the UHI. The conflict between the aim to reduce CO_2 emissions due to the efficiency of densification and to adapt to the consequences of climate change by climate adaptive measures as identified by Williams, Joynt & Hopkins (2010) is visible in Utrecht.

When heat stress was mentioned in policy documents and interviews, it was mainly related to the temperature component and the climatic hazard, and less to the vulnerability component. The definition used in this research for heat stress suggests stress occurs when temperature negatively affects the human body. This is mainly the case for vulnerable groups of people, and therefore these need to be assessed when researching heat stress. In Utrecht, if it was mentioned how heat stress could be reduced, the main focus was on how the temperature could be decreased, and to a lesser extent on what kind of people would be affected. A lack of focus on the vulnerability component could result in ineffective strategies for reducing heat stress.

This research presented a model (R^2=0.73) for estimating the temperature in the municipality. This model could be used as well in other research, and also for other cities which have the same characteristics as Utrecht. The model included predictors of the LST which appeared to be significant in the model and did not show much multicollinearity. These predictors included the building fraction, green fraction, water fraction, industrial fraction and distance to the city centre. The building fraction and industrial fraction had an amplifying effect on the LST, whereas the green fraction, water fraction and distance to the city centre had a cooling effect. The building fraction had the strongest correlation with the LST, indicating that this is the best indicator for estimating the temperature. These results indicate that, when creating new dwellings within a city, it is important in terms of temperature that the building fraction does not become too high, and that there is space for creating or preserving green and water.

After changing the landscape characteristics into a situation after densification, the model could be used for estimating the future temperature. It appeared that the most severe temperatures were found in industrial areas and around the city centre. These areas often consisted of concrete structures or a high building fraction. Cooler temperatures were found around water bodies or green areas like parks, as in these areas the green and water contributed to cooling, and a low building fraction was observed. Because of their cooling capacity, water and green could be implemented in densification sites to not amplify the UHI on these locations, this was already done quite well in Utrecht. When comparing the areas of high climatic hazard to locations where densification takes place, it can be observed that densification in Utrecht does necessarily lead to highly severe temperatures, the densification strategies related to climatic hazard, therefore, seem to be quite good. Several reasons for this were identified in this research. First, multiple large densification sites are created on former industrial areas, the landscape characteristics of residential area appeared to be less severe than the concrete characteristics of industrial area. Second, other densification sites were located further away from the city centre in areas which used to be relatively cool. Densification on these locations did increase the temperature because of the higher building fraction, but not to a level that appeared to be severe. Third, Utrecht chooses in multiple densification sites to build relatively high buildings. The shadowing effect of these high buildings during day-time could contribute to lower temperatures compared to lower buildings with limited shadowing. Hence, densifying through high buildings does not necessarily lead to severe temperatures. Besides, by building high buildings instead of low buildings with a large footprint, more space for green is preserved (Koopmans et al., 2018). These particular reasons can be seen as densification strategies which are favourable in terms of preventing climatic hazard, and therefore could also be used in other cities willing to densify.

When looking at the vulnerability component of heat stress, more changes between the situation before and after densification were observed in this research. A significant increase in density was seen in the city: this does not necessarily lead to more heat stress, however, this could increase the concentration of vulnerable people on a location, making an area more prone to heat stress. This is important for urban planners to take into account while densifying. The concentration of elderly within the city did increase slightly due to densification, however, not to a highly problematic extent. It appeared that in Utrecht, neighbourhoods with a high share of elderly are often not very densely populated. A larger increase was observed when looking at vulnerability related to people with a low-income. Due to densification, more areas were observed where the vulnerability did become problematic because of a rise in the concentration of people with a low-income. It is important for urban planners to understand that densification may not only contribute to higher temperatures but higher levels of vulnerability due to increased concentration of vulnerable people as well. Densifying on locations of low shares of vulnerable people or on locations where the density is relatively low may be a better strategy, in Utrecht, this was already done quite well.

From this research, it did not appear that densification areas are major contributors to heat stress when you look at the areas of heat stress risk. Areas of heat stress risk were not necessarily observed around densifying areas. This was mainly because of the fact that areas of climatic hazard did not that much overlap with areas of vulnerability in Utrecht. While this may be the result of coincidence in Utrecht, it may be an interesting strategy to try as much as possible to keep areas of climatic hazard and areas of vulnerability separated, as severe temperatures do not necessarily imply heat stress when only a few people are experiencing it. When looking at the number of vulnerable people living in areas of heat stress risk in table 14 and 15, it can be concluded that this is expected to increase as a result of densification in an average situation. This is mainly because the concentration of vulnerable people would rise due to densification. In fact, what this research highlights is that in Utrecht the effect of the increase in vulnerable people’s density often outweighs the actual increase in temperature due to densification. This is something that needs to be taken into account by urban planners: although in Utrecht the main focus of reducing heat stress is on cooling the area by certain landscape characteristics, it is also of high importance to look at the vulnerability of an area to assess heat stress.

7.2 Recommendations for further research

This research has clarified the influence of densification strategies in Utrecht on heat stress within the city. This section describes how future research could contribute to a further understanding of the consequences of densification on heat stress.

In policy documents and interviews for this research, greening was often mentioned as a cooling mechanism to reduce the effect of densification on heat. Hereby, vertical green and green roofs were mentioned as well. However, this research mainly focused on horizontal street green, as also in the GIS data green roofs and vertical green were not taken into account in the calculations regarding the influence of green on the LST. Further research could focus on the influence of densification on the implementation of green roofs and vertical green, and what the influence of these green structures is on the UHI. Hereby, the policies and strategies around green roofs and vertical roofs could be studied as well.

As mentioned a few times before, the influence of certain landscape characteristics could differ between different times of the day and different times of the year. The influence of different landscape characteristics on the UHI in the Netherlands in another season than summer would not be very interesting, as heat stress is not likely to occur in this period in the Netherlands. However, further studies could focus on the influence of densification on the night-time temperature, as the influence of, for example, water and the SVF could be different than observed in this research during night-time. Moreover, exacerbated temperatures during the night could lead to heat stress for different groups of people, for example, due to the decrease in sleep quality.

As the researcher observed in this research, it was hard to make estimations on the future demography in a neighbourhood due to densification, like the change in the population of elderly people or people with a low income. Because of time limitations, simple assumptions were made to estimate this. These assumptions might not be fully accurate, therefore further research could focus on the influence of densification on the change in neighbourhood demography, to assess how densification changes the composition of inhabitants. This information could be important for further heat-stress related research, as, in different cities, densification is likely to occur in the future, and it could be important for urban planners to identify areas where high shares of vulnerable people will live in the future.

Lastly, in this research, it was observed that not much heat stress was likely to occur related to the elderly. This was because high-density areas were often not overlapping with areas where a high share of vulnerable people lived. Besides, numbers of the total amount of elderly in the whole municipality of Utrecht showed that the total share of people who are 65 years or older is only 10%. Even though this number will rise in the coming years, this is relatively low compared to other cities. Therefore, the influence of densification on heat stress, where the elderly are seen as a group experiencing heat stress, could in further research be investigated in a city where more elderly people live, to see clearer results. Further research could focus as well on other groups of vulnerable people next to the elderly and people with a relatively low income, as more groups of people are prone to heat stress, as in this research only two groups were investigated.

7.3 Recommendations for urban planners involved in densification

In the future, it is expected that more cities, in the Netherlands and other countries, will grow in population size and hereby densification will often be a favourable strategy, increasing population density within the city. This will make the cities more vulnerable to climate change in terms of higher temperatures and more frequent heatwaves. Therefore, it is important for urban planners in cities willing to densify to pay attention to increased temperatures and potential heat stress. Resulting from this research, different recommendations are composed by the researcher, these are not only for the municipality of Utrecht but for all cities willing to densify.

First, it is important that urban planners have a clear understanding of the definition of heat stress. It was observed from policy documents and interviews, that the main focus when talking about heat stress is on keeping the temperature comfortable by, for example, implementing green structures, thus mainly on the climatic hazard component of heat stress. However, as heat stress is mainly experienced by more vulnerable people, for example, the elderly and people with a low-income as was identified in the literature, the vulnerability component should be taken into account as well in determining areas of heat stress. When densifying in areas characterized by high shares of vulnerable people, it should be taken into account that the temperature should not be amplified that much by changing landscape characteristics. Besides that, population density should not be increased too much when the area is already relatively dense, as otherwise, the concentration of vulnerable people could become too high, leading to potential heat stress. Densification does not only influence the city temperature but the concentration of vulnerable people as well, as population density becomes higher.

In this research, different strategies of densification were identified as 'successful' when only looking at the climatic hazard, and are therefore recommended. First, looking at the estimations made by the model, densification on former industrial areas appeared to not increase, and sometimes even decrease, the temperature on that location. That is because the landscape characteristics of industrial areas, namely buildings with a large footprint and very limited green space and water area, were often found to amplify temperature more than those of residential areas, where more green and water were found. Second, densification locations further away from the city centre often did not lead to severe temperatures. In Utrecht, densification locations further away from the city centre were not generally characterized by high building fraction and were more often green or vacant areas, therefore temperature was relatively low on these locations before densification. So temperature did increase due to densification projects, but not to a level to which climatic hazard would occur. Besides, these areas were further away from the city centre, therefore having cooler temperatures as found in the literature and this research. Third, densifying with higher buildings did often lead to less severe temperatures, as building vertically could preserve space for green and water structures, both of which have a cooling effect. In addition, as green and water structures are cooling mechanisms, it is recommended to include these in every densification project to not amplify the UHI too much, especially when a city is willing to densify in the city centre for example, as these are often relatively hot areas.

To reduce heat stress as a result of densification, different recommendations are made related to the vulnerability of areas. To not increase the number of areas with problematic concentrations, it is recommended to densify in areas where density is currently not that high. By doing this, densities will not become extremely high, and it is less likely that high concentrations of vulnerable people will occur in these areas. Besides, densification could also be stimulated in areas where the share of vulnerable people is relatively low. If the number of people who might be harmed by higher temperatures in an area is very limited, heat stress will be limited as well in this area, therefore, densification in these areas will not majorly contribute to heat stress.

Finally, it is important to understand that areas of high climatic hazard do not necessarily lead to heat stress. As was seen in Utrecht, the hottest areas were often found on and around industrial areas, however as the number of people living here is very low, the heat stress risk is low as well. Urban planners should keep in mind that heat stress is a combination of climatic hazard and vulnerability, so when areas of particularly high climatic hazard and areas of particularly high vulnerability are not overlapping, heat stress risk will less likely occur. In this research, it was seen that in the municipality of Utrecht, intended or not, the separation of these risky areas was done quite well.

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Appendix B: List of reviewed building plans

Not all of these plans were used for modifying the GIS data, only the ones that had designs and visualisations of the plan available.

Nr	Name	Neighbourhood	Nr	Name	Neighbourhood
1	Wisselspoor 1	2e Daalsebuurt	71	Parkeergarage Berlijnplein	Leidsche Rijn Centrum
2	Wisselspoor 2	2e Daalsebuurt	72	Kantoorgebouw Helix	Leidsche Rijn Centrum
3	Wisselspoor 3	2e Daalsebuurt	73	Terraswoningen Bellevue	Leidsche Rijn Centrum
4	Wisselspoor 4	2e Daalsebuurt	74	Change	Leidsche Rijn Centrum
5	Hieronymuserf	Abstede Tolsteegsingel e.o.	75	Stadstuin	Leidsche Rijn Centrum
6	Merwedekanaalzone 6	Bedrijvengebied Kanaleneiland	76	Sociale huurwoningen Mitros Portaal	Leidsche Rijn Centrum
7	Europalaan 101	Bedrijvengebied Kanaleneiland	77	BUUR	Leidsche Rijn Centrum
8	Bedrijventerrein Wetering Zuid	Bedrijventerrein Wetering Zuid	78	Greenville	Leidsche Rijn Centrum
9	Opaalweg	Bokkenbuurt	79	Parkwachter	Leidsche Rijn Centrum
10	Park Zuid Vrije kavels	De Meern-Noord	80	Park Avenue	Leidsche Rijn Centrum
11	Castellumlaan	De Meern-Noord	81	Vestibule	Leidsche Rijn Centrum
12	Keizerhof	De Meern-Noord	82	Leidsche Rijn E5	Leidsche Rijn Centrum
13	De Schatkamer	De Meern-Noord	83	La Boutique	Leidsche Rijn Centrum
14	Zandweg 189	De Meern-Noord	84	Aanleg stuk Vikingrijn	Leidsche Rijn park
15	Pratumplaats	De Meern-Noord	85	Lombokplein	Leidseweg en omgeving
16	T zand (zorg)woningen	De Meern-Noord	86	Lombokplein	Lombok oost
17	Internationale school	De Uithof	87	Einsteindreef	Neckarddreef
18	RIVM	De Uithof	88	Pagelaan	Nieuw-Hooggraven Zuid
19	Heycopstraat	Dichterswijk	89	OudeGeinlaan	Nieuw-Hooggraven Zuid
20	Kruisvaartkade	Dichterswijk	90	Kromme Nieuwegrachtstraat 39	Niewegracht-oost

21	Boerderij den Hoet	Grauwaart	91	Keizerstraat 8	Nobelstraat e.o.
22	Nieuwbouw Dirck Hoetweg	Grauwaart	92	befu terrein	Oud-hooggraven Zuid
23	Groenewoud	Groenewoud	93	Kop Amaliapark	Parkwijk-Noord
24	Nieuwbouw Haarrijn	Haarrijn	94	Nieuwbouw Verlengde Houtrakgracht	Parkwijk-Zuid
25	Nieuwe bedrijven	Haarrijn	95	Kop Amsterdamsestraatweg	Pijlsweerd Zuid
26	Dickensplaats	Halve maan noord	96	Zijdebalen (blok 4)	Pijlsweerd Zuid
27	Johan Wagenaarkade	Halve Maan-Zuid	97	De Muinck locatie	Queeckhovenplein
28	La Sabbia	Het Zand Oost	98	Archimedeslaan 16	Rijnsweerd
29	Sociale huurwoningen willem frederik hermansstraat	Het Zand Oost	99	Rijnvliet - Van Wanrooij	Rijnvliet
30	Zorgwoningen Reinaerde	Het Zand Oost	100	Rijnvliet - Bo Ex	Rijnvliet
31	De Veiling	Het Zand Oost	101	Routes	Rijnvliet
32	5.2 + 5.5	Het Zand Oost	102	Voetselbos	Rijnvliet
33	5.3+5.4	Het Zand Oost	103	Rijnvliet Oost	Rijnvliet
34	De Cascade	Het Zand West	104	Jutfaseweg 178	Rivierenwijk
35	Pablo	Het Zand West	105	Reitdiepstraat	Rivierenwijk
36	Laurierkwartier	Hoge Weide	106	De Kwekerij	Rubenslaan
37	Sociale huur	Hoge Weide	107	Cartesiusdriekhoek	Schepenbuurt Cartesiusweg e.o.
38	Smakkelaarsveld	Hoogh Catharijne NS en jaarbeurs	108	Lauwerecht 2 en 4	Staatsliedenbuurt
39	Beurskwartier (Croeslaan)	Hoogh Catharijne NS en jaarbeurs	109	Van Brammendreef	Taagdreef
40	Galaxy tower (Beurskwartier)	Hoogh Catharijne NS en jaarbeurs	110	Boerderij Hof ter Weide	Terwijde -Oost
41	Wonderwoods	Hoogh Catharijne NS en jaarbeurs	111	Blok A: Stariway	Terwijde -Oost
42	Van Esveldstraat	Huizingalaan	112	Blok B: Sociale huur	Terwijde -Oost

43	Up Living Ziekenhuis	Kanaleneiland-Noord	113	Zorgcentrum Rosendael	Tigrisdreef e.o.
44	Kanaleneiland Centrum	Kanaleneiland-Noord	114	Rotsoord	Tolsteeg en Rotsoord
45	Beneluxlaan 901	Kanaleneiland-Zuid	115	Smaragdplein 170	Tolsteeg en Rotsoord
46	Vleutensevaart 100	Laan van Nieuw-Guinea, Spinozaweg	116	Merwedekanaalzone 4	Transwijk-Noord
47	Vleutenseweg 420-422	Laan van Nieuw-Guinea, Spinozaweg	117	Merwedekanaalzone 5	Transwijk-Zuid
48	ABC straat 5	Lange Nieuwestraat e.o.	118	Lomanlaan 55	Transwijk-Zuid
49	Vrouwjuttenhof	Lange Nieuwestraat e.o.	119	Winkelcentrum de Gaard	Tuindorp Oost
50	Park Voorn	Langerak	120	Kop op Tuindorp Oost	Tuindorp Oost
51	Gerbrandystraat	Lauwerecht	121	Lieflandlaan	Tuindorp van Lieflandlaan west
52	Lauwerecht 7/ Scherhorstlaan	Lauwerecht	122	Cohenlaan	Tuindorp-Oost
53	Willem Dreeslaan/ Lauwerecht 7?	Lauwerecht	123	Antoniuskwartier	Vechtzoom Zuid
54	Sinfonia	Leeuwesteyn	124	Camposdreef	Vechtzoom Zuid
55	Hooge Steenen	Leeuwesteyn	125	Woningbouw Haarzicht	Vleuten
56	Levels	Leeuwesteyn	126	Vernieuwing centrum	Vleuten
57	Academie tien	Leeuwesteyn	127	Achter 't spoor	Vleuterweide Noord Oost Centrum
58	Vogelhof	Leeuwesteyn	128	Vleuterwijde bouw centrum	Vleuterweide Noord Oost Centrum
59	Florijn	Leeuwesteyn	129	De Erven - Pracht	Vleuterweide Noord Oost Centrum
60	Kindcentrum	Leeuwesteyn	130	Laan van Rijn	Vleuterweide-Zuid
61	Sociale huurwoningen Poortrijk	Leeuwesteyn	131	Veemarkt	Voordorp/ Voorveldsepolder
62	Leeuweplaats	Leeuwesteyn	132	Ravellaan Noord	Welgelegen den Hommel
63	Hometown	Leeuwesteyn	133	Bartokstraat	Welgelegen den Hommel

64	Stroom	Leeuwesteyn	134	Rachmaninoffplantsoen 61 67	Welgelegen den Hommel
65	Ronduit	Leeuwesteyn	135	Ivoordreef	Zambesidreef
66	Sociale huurwoningen	Leeuwesteyn	136	DeBuurt	Zamenhofdreef e.o.
67	Hoogbouw MARK	Leidsche Rijn Centrum	137	Studentenwoningen	Zamenhofdreef e.o.
68	Leidsche werf	Leidsche Rijn Centrum	138	Jagerskade	Zamenhofdreef e.o.
69	Hotel Aloft Utrecht	Leidsche Rijn Centrum	139	FC donderstraat 65	Zeeheldenbuurt Engeveldstraat e.o.
70	Sociale huur Mitros	Leidsche Rijn Centrum	140	Zuilense vecht	Zuilen Noord

Appendix C; Formulas for calculating the LST

1) Radiance = Radiance multiplier[1] * "band10" + Radiance add[1]

2) L_{sen} = (K2[1] / Ln((774.89 / "Radiance") + 1)) – 273.15

3) NDVI = (Band 5– Band 4)/(Band 5 + Band 4)

4) FVC = ("NDVI" - NDVImin)/(NDVImax – NDVImin)

5) Emissivity = 0.004 * "FVC" + 0.986

6) LST = "L_{sen}" / (1 + (0.00115 * "L_{sen}" / 1.4388) * Ln("Emissivity"))

[1]The radiance multiplier (0.0003342), radiance add (0.1) and the K2 (1321.08) can be found in the metadata of the image, and are the same for all Landsat 8 images (Esri, 2014).

Appendix D: Interview summary report

Below the different interviews can be found, per interview the role of the interviewee, interviewing method and date are provided. Questions and answers are given in Dutch, as the interviews were conducted in Dutch as well.

Interview 1:

Role: Coordinator of the area city centre/ central station – municipality of Utrecht
Date: April 15, 2020
Type: Phone

Questions and most important answers:

Q: Wat is uw functie?
A: Ik ben gebiedscoördinator centrum/ stationsgebied. Hierbij ben ik alleen verantwoordelijk voor het stationsgebied, beide kanten. Dus ook bijvoorbeeld Jaarbeursplein, Hoogh Catharijne, Noord en Zuid gebouw. Als gebiedscoördinator ben je verantwoordelijk voor alle initiatieven die plaatsvinden op het gebied van herontwikkeling van vastgoed alsook van de openbare ruimte. Als er iemand is die wat wil, dan zorg ik dat daar actie voor wordt ondernomen, projectleiders benaderen. Verantwoordelijk voor totale financiële grondexploitatie van het gebied en ook openbare ruimte.

Q: Wat zijn redenen voor verdichting in Utrecht?
A: Utrecht centraal is het meest centrale station van Nederland, met goede openbare plekken, goed omsloten openbaar vervoer locatie. Openbaar vervoer stimuleren, daarom concentreren. Dat geldt voor kantoren, maar ook woningen.

Q: Zijn er documenten/richtlijnen die gevolgd worden bij verdichting?
A: Weet ik niet. Half jaar werkzaam, veel is al gebeurd en in plannen vastgelegd. Nu nieuw rapport over verdichting van kantoorlocaties, STEC rapport. Onderzoek van hoeveel kantoren Utrecht nodig heeft voor ontwikkeling van komende 20 jaar. En waar zou je dat willen. In dat rapport is ook opgeschreven dat er nog een aanvullende verdichtingsopgave in het stationsgebied ligt. Ik doe stationsgebied, maar je hebt ook beurskwartier, waar veel woningen en kantoren bijkomen, maar daar ga ik niet over.

Q: Wordt er bij verdichting ook gekeken naar welke doelgroepen er al wonen?
A: Ja kijken we naar, beleid ter aanzien van wonen. Afdeling wonen, hoofdafdeling ruimte. Beleid wordt hier gesteld over wat voor soort woningen en waar er moet worden toegevoegd. Hierin staan richtlijnen over percentages sociaal, middel huur en dure woningen die er moeten komen; uitgangspunt. In Utrecht grote vraag naar toevoegen sociale woningen, maar er moeten geen sociale woning enclaves ontstaan. Dus mix is ook belangrijk.

Q: En qua leeftijdsgroepen?
A: Niet zo zeer. Er wordt gekeken naar seniorenwoningen, maar verder geen specificatie op leeftijd. Wel verschillende soorten woningen aangeboden waarmee je vaker verschillende groepen aantrekt. In binnenstad meer appartementen gebouwen en minder grondgebonden woningen. Grondgebonden vindt je meer in Leidsche Rijn. Maar ook in beurskwartier wat grondgebonden.

Q: Hoe wordt rekening gehouden met veranderend klimaat?
A: Er zijn strenge duurzaamheid en klimaatadaptatie regels. Er zijn basiseisen, ook als het niet gemeentebezit is, dit is wel wat moeilijker. Klimaatadaptatie hoor je veel, treft niet alleen

gebouwen maar ook openbare ruimte. Meer aanleggen groen en water elementen. Verder ook opvangen water, bekkens, filters, kasten in de grond. Wordt uitgebreid naar gekeken. Groen kan je misschien beter bespreken met klimaatadaptatie en duurzaamheid. Bij het project Wonderwoods gebeurd veel aan klimaatadaptatie en duurzaamheid, veel bomen struiken en groen in hele gebouwen. Groen adapteert warmte. In openbare ruimte sowieso een ding; meer groen, meer bomen en meer waterpartijen. Ook steeds meer op daken, in Italië verplichten ze elk nieuwe gebouw met groen dak, zo extreem is dat in Utrecht niet. Maar wel in kader van RSU gesprekken gevoerd dat dat iets is waar je uiteindelijk wel naar toe moet. Lagere daken groen, en hogere daken met zonne en wind energie. Verder moeten gebouwen als ze een bouwvergunning willen voldoen aan energie en duurzaamheidseisen, die kunnen ze vaak alleen halen door toevoegen van bijvoorbeeld zonnecellen.

Q: Wordt er bij hitte ook rekening gehouden met kwetsbare bevolkingsgroepen?.
A: Nee, niet naar haar weten. Kan je beter bij klimaat zijn. In projecten wordt dat niet ervaren dat er wordt gekoppeld aan doelgroepen

Interview 2:

Role: Strategic advisor at the department of spatial planning – municipality of Utrecht
Date: May 28, 2020
Type: Phone

Questions and most important answers:

Q: Wat is uw functie?
A: Strategisch adviseur bij afdeling Ruimte. Achtergrond met stedenbouw. Met name rondom complexe ruimtelijke maatschappelijke projecten, vanuit zowel ontwerp als onderzoek. Twee jaar bij gemeente Utrecht, daarvoor Haarlemmermeer. Hou me bezig met RSU 2040, soort omgevingsvisie voor de stad.

Q: Wat is uw link met verdichting in Utrecht?
A: Ik hou mij bezig met de vraag hoe wij willen omgaan met aantal vraagstukken die op stad afkomen, zoals urbanisatie trend die al jarenlang geleden is begonnen en ook invloed op Utrecht heeft, om daar vorm aan te gaan geven. Druk op de stad wordt steeds meer vergroot, zeker als het gaat over woningbouw en werken. Hoe kunnen er 60.000 woningen worden toegevoegd en 70.000 banen. In een periode tot 2040. Bouwtechnisch kan dat amper, want 3000 woningen per jaar. niet alleen nieuwbouw maar ook herstructurering. Utrecht heeft niet extreem veel oppervlak. De keuze is gemaakt om verdichting in te zetten als antwoord op de vragen die nu op Utrecht afkomen. Verdichting is natuurlijk een middel, maar het hangt samen met een heleboel andere opgaven die daarbij zitten. Voorwaarden voor de verdichting is in ieder geval de relatie met het landschap, maar ook het mobiliteitssysteem.

Q: Zijn ruimtegebrek en mobiliteit dan ook de voornaamste redenen?
A: Je kan er ook voor kiezen om niet te verdichten, dat zou betekenen dat de vraag die op de regio afkomt bij hele andere delen in de stad terecht komt, wat zou kunnen betekenen dat het karakter op hele andere plekken wordt aangetast. Of dat het simpelweg qua ruimtegebruik niet kan als je bijvoorbeeld het landschap een prominente plek wilt geven, in de transformatie die het landschap ook heeft, en de kwaliteit van het landschap hier ook bij betrekken. Tweede is, 60.000 woningen toevoegen is geen (... technical issue), maar je kunt wel kijken, wat we binnen de leefbaarheid gedachten die wij hebben - voor iedereen en gezond sterk leven - zouden kunnen doen om voor een gedeelte, of volledig, elkaar tegemoet te komen. Als je het niet doet, en je voegt bijvoorbeeld 10.000 woningen toe, dan zie je gelijk de druk als het gaat om bijvoorbeeld

vastgoed toenemen in de vorm van prijsopdrijving, De vraag is of je dan wel een stad voor iedereen hebt, of alleen voor de rijken. Ik woon zelf in (...), en wat je ziet is dat het hier lastig is om een huis te kopen, meerdere redenen, maar een daarvan is dat er beperkt aanbod is, en bij dat beperkte aanbod proberen ze verdichting toe te passen, maar de grondprijs is zo hoog dat dat niet meer gerealiseerd kan gaan worden. Dus bij het toevoegen van een diverse hoeveelheid en daarmee moet je dus uiteindelijk wel gaan verdichten binnen de grenzen die je hebt, maar ook dat de potentie voor de diversiteit en het diverse karakter voor de stad, dus eigenlijk voor iedereen.

Q: Zijn er documenten/richtlijnen/onderzoeken die gevolgd worden bij verdichting?
A: Ja, verschillende scenario onderzoeken worden bekeken, bijvoorbeeld PBL, maar ook wereldwijd. Hoe gaan andere plekken om met verstedelijking, maar ook de verdichtingsopgaven. Dit zijn plekken met ongeveer de zelfde grootte als waar Utrecht naartoe gaat groeien, en ook de relatie met dat landschap, dat landschap heeft een aantal redenen, het heeft er voornamelijk mee te maken met als je gaat verdichten dat je niet meer alleen grondgebonden woningen kan maken. Dat er wel ruimte wordt geboden om op een goede plek naar buiten te gaan, dat heeft te maken met klimaat en energie, zeker als het gaat om hittestress, wat we ook zien in de stedelijke omgeving om dat tegen te gaan. Er zijn al een paar grote aders zoals Amsterdams Rijnkanaal en (..), maar hoe meer steen je toevoegt, hoe groter die hittestresspotentie er natuurlijk is. Daarnaast ook andere klimatologische vraagstukken die erbij zitten. En ook om ruimte te geven aan de energie vraag. Daar wordt natuurlijk veel over gestudeerd daar zijn veel documenten over. Dat proberen we toch wel zo veel mogelijk tot ons te nemen. Om zo te kijken hoe we daar in de strategie een antwoord op gaan geven.

Q: Kunt u wat voorbeelden noemen van voorbeeldsteden of projecten?
A: Interessante stad voor ons, zeker in relatie met het landschap is Oslo. En ook in relatie met het mobiliteitssysteem wat ze daar maken. Je ziet daar voorbeelden van hoe je die relaties goed kunt leggen. Verder nog Lyon en een aantal andere steden, veel Duitse steden.

Q: Wordt er ook gekeken naar de doelgroepen die er al wonen, of wat je er juist wil krijgen?
A: Jazeker, de diversiteit in de stad wil je behouden, of zelfs versterken. Daar worden heel veel onderzoeken naar gedaan op het gebied van wonen. De vraag naar wonen wordt vaak onderzocht, in het Primosmodel, huishoudensmodel, maar diversiteit wordt vooral uitgedrukt in woonmilieus, voor 2030 is dat voor de stad nu al heel helder. Worden ook afspraken over gemaakt met corporaties. Maar 2040 en 2050 is dat nog ingewikkelder, nu onderzoek hoe ze dat willen doen en waar ze dat willen doen. Voorbeeld; in Overvecht willen we minder sociale woningbouw, want het aandeel is nu boven de 60%, dan kan je zeggen dat ze gaan slopen, of je bouwt meer niet sociale huurwoningen bij waardoor balans beter wordt.

Q: Hoe wordt er rekening gehouden met het veranderend klimaat?
A: We moeten veel ruimte nemen, openbare ruimte, om die verdichtingsslag te maken. Of op een andere manier slim en technisch, Het eerste is natuurlijk en het tweede is technisch, om een aantal dingen te kunnen gaan toevoegen. Wat we daar wel voor proberen te doen is dat we daarvoor condities proberen weer te geven, maar nog niet de oplossing. Stel uit jouw onderzoek komt iets baanbrekends, dan zou het zonde zijn om een technisch iets voor te schrijven waardoor dit uiteindelijk veel minder toepasbaar gaat worden. Dus we proberen ruimte te creëren om een aantal dingen te doen, zonder dat we gaan zeggen dat bijvoorbeeld energieopwekking perse met PV cellen op het dak gerealiseerd moet worden. Als het gaat om klimaat adaptatie, proberen het te doen via groen, tenzij… dus zoveel mogelijk openbare ruimte niet te verstenen, behalve daar waar het moet, dus voor bijvoorbeeld mobiliteit. Omdat wij in de mobiliteitstransitie zitten, dus

autogebruik niet meer laten toenemen en meer inzetten op fiets en OV, zie je dat de openbare ruimte meer de potentie krijgt om te vergroenen. Vergroenen is de insteek bij verdichten, anders kan het niet. Je kan het niet doen op alleen de regio, of buiten de stad. Want zeker hittestress, dat moet je lokaal doen op straat en wijkniveau. Wat we nog niet helemaal scherp hebben, maar dat wordt wel besproken door de mensen die op klimaat zitten, is wat je sowieso moet gaan doen om een groot effect te realiseren. AMS heeft vorig jaar groot onderzoek gedaan, onder andere met ballonen boven de stad, om de hitte boven de stad op verschillende hoogtes te meten en de hittestress daarbij, en de zaken die je vervolgens bij ruimtelijke ordening op orde moet hebben.

Q: Wanneer er gekeken wordt naar hittestress, kijk je dan ook naar kwetsbare bevolkingsgroepen?
A: Er wordt in de ruimtelijke strategie nog niet echt naar gekeken. Ik weet het niet precies, of specifiek wordt genoemd durf ik niet te zeggen.

Q: Zijn er afgelopen jaren ook al verdichtingsprojecten geweest? Reacties hierop?
A: Iets waar we als stedenbouwers niet heel goed in zijn is evalueren. Aantal verdichtingsopgaven zijn al geweest. Zijdebalen is succesvol voorbeeld hoe je onder hoge dichtheid een aangename stad kan maken, met voldoende ruimte, voldoende rust, reuring en ruis. Er wordt nu hard gewerkt aan het masterplan Merwedekanaalzone, Cartesiusdriehoek is een goed voorbeeld, maar dat zijn vooral projecten die nog gerealiseerd gaan worden in hogere dichtheden.

Q: Heeft u nog andere toevoegingen?
A: Wat we vooral proberen te doen met het landschap rondom klimaatadaptatie/hittestress is dat de toegankelijkheid van het landschap rond de stad heen op orde is. Je ziet bij veel steden dat ze rond de jaren 70 afgesloten zijn van het landschap. Utrecht is nog niet heel goed geweest in het opheffen van deze barrière. Alles wat je moet doen om de mensen in Utrecht een plek te geven waar je rust kan vinden zou je vol moeten aangrijpen, maar dat vraagt wel wat. Dat vraag een investering, of afscheid nemen van een weg, daar zit nog wel een mooie opgave, dat is 1. Tweede is; als je verdicht in de stad willen we vooral de nadruk leggen op wandelen fietsen en OV, voorzieningen probeer je dan meer te concentreren op plekken die aantrekkelijk zijn om naar toe te gaan. Hierdoor kan je meer ruimte krijgen, omdat de auto niet meer volle bak aanwezig hoeft te zijn, en zo kan je ook meer vergroening krijgen, en daarmee ook voor het klimaat. Het is nog een lange weg te gaan. Het wordt ook vaak gezien als een kostenpost, maar als je het niet doet, wat voor stad wordt het dan? En als je het later wilt doen kan het veel duurder zijn en kan het maatschappelijke element is veel lager. Nog een tip: probeer het altijd maatschappelijk te maken, als je kijkt naar de maatschappelijke relevantie en de maatschappelijke relatie, kun je soms met hele interessante dingen komen. En dat is meer dan techniek.

Interview 3:

Role: Advisor healthy environment, department of health – municipality of Utrecht
Date: June 5, 2020
Type: Phone

Questions and most important answers:

Q: Wat is uw functie?
A: Adviseur gezonde leefomgeving, bij de afdeling volksgezondheid bij de gemeente Utrecht. Vroeger de GGD Utrecht, is nu overgegaan in GGD van de regio Utrecht die nu in de hele provincie zit, en een deel zit nu bij de gemeente Utrecht gebleven waar ik werk. Ik adviseer over de gezondheidsaspecten bij alle ruimtelijke plannen in de gemeente Utrecht.

Q: Utrecht gaat veel groeien de komende jaren, wat zijn daarbij de uitdagingen/ problemen met betrekking tot gezondheid?
A: Wij adviseren altijd over drie verschillende aspecten, zodat de druk op de gezondheid zo klein mogelijk is. Je kunt je voorstellen dat als er geen ruimte meer is op plekken die redelijk gezond zijn, dus niet te veel geluidsoverlast en niet te veel slechte luchtkwaliteit, als die plekken er niet kun je je voorstellen dat ontwikkelaars naar plekken gaan dicht bij snelwegen of drukke stedelijke plekken waar veel verkeer is. Dus dan zou je kunnen denken dat er dan gebouwd gaat worden op ongezonde plekken. Wij adviseren daar negatief op, dus dat er bijvoorbeeld niet te veel bij snelwegen gebouwd wordt. Dus dat is de druk op de gezondheid. Aan de andere kant proberen we plannen zo te maken dat gezond gedrag gemakkelijk gemaakt wordt. Wij kiezen voor gezonde mobiliteit, dat mensen eerder met de fiets of wandelend gaan, maar ook dat het voor mensen makkelijk is om vanuit hun huis een hardloop rondje te doen of te gaan wandelen. Het derde aspect is dat we willen dat mensen zo prettig mogelijk komen te wonen, dus dat is bijvoorbeeld dat er voldoende groen is, en dat er voorzieningen in de buurt zijn, dat monumenten bewaard blijven, dus dat het een prettige woonomgeving blijft.

Q: Ik las ergens dat er bij elke ruimtelijk project ook een gezondheidsadviseur aan tafel zit, dus dan geven ze dit soort advies?
A: Dan kijk je goed naar het voorliggende plan. Ik ben nu bezig met de herontwikkeling van een watertoren in Utrecht, en dan kijk ik naar die drie aspecten en daar adviseer ik over, en dan zijn er andere collega's van de gemeente die ook beoordelen vanuit hun eigen vakgebied, en dan wordt er een integrale afweging gemaakt hoe het plan uitgevoerd kan gaan worden.

Q: Op welke manier wordt er gekeken naar het veranderend klimaat en dus ook hittestress?
A: Wij adviseren om daar wel rekening mee te houden, wij zijn niet echt binnen de gemeente Utrecht experts op dat gebied, we hebben ook collega's in de afdeling ruimte die met het opstellen van de klimaatadaptatiestrategie bezig zijn. En een aantal mensen komen ook vanuit de duurzaamheidsafdeling onder andere, en wij zijn daar dan ook bij betrokken bij die plannen, maar dat is niet onze primaire expertise. Dat ligt dan meer bij de collega's van het team klimaatadaptatiestrategie. Ik ben wel nu bezig met het opstellen van een lokaal hitteplan. Dat past binnen die klimaatadaptatiestrategie van de gemeente Utrecht. Maar dat is meer een soort van communicatieplan, en hoe je mensen gaat voorlichten hoe ze om moeten gaan met periodes van extreme hitte. Bij die hitte zit een fysieke kant en een meer sociale kant. En vanuit Volksgezondheid zitten wij meer op die sociale kant, meer over hoe je mensen daarbij kunt helpen. Bijvoorbeeld dat mensen meer op elkaar letten, dat mensen die minder sociale contacten hebben in de gaten gehouden worden dat ze voldoende drinken en dat ze proberen hun woning koel te houden. Maar meer de fysieke aspecten van klimaatadaptatie en hitte die worden door de collega's bij ruimte gedaan.

Q: Dan gaat het vooral over adviezen over dat er geïnformeerd moet worden?
A: Ja, er is een nationaal hitteplan, en als dat dan afgekondigd wordt, wanneer er een extreme hitteperiode komt, dan lichten zij het RIVM in dat dat komt, en de RIVM licht dan weer alle GGD'en en gemeenten in. Die moeten dan een protocol volgen waarin mensen geïnformeerd worden over die aankomende hitteperiode en wat ze daar zelf aan kunnen doen. Bijvoorbeeld wat ook meespeelt, bij verdichting als er veel verstening komt, want je ziet vaak dat er allerlei kabels en leiding liggen onder straten en stoepen in Utrecht, dat niet overal groen toegevoegd kan worden, en daar proberen wij dan ook zoveel mogelijk mee te doen.

Q: Stellen jullie dan harde voorwaarden?
A: Nou niet echt strikte regels, maar zijn wel wat algemene dingen die je kan adviseren. Waar we

heel vaak tegenaan lopen bij bijvoorbeeld bij herinrichting van straten als er wordt gezegd dat er geen bomen kunnen komen omdat er anders problemen komen met kabels en leidingen die eronder liggen. Dan adviseren wij om dan geen grote bomen te plaatsen, maar bijvoorbeeld geveltuinen, zodat er wel groen kan komen maar dat dat geen problemen geeft met onderliggende infrastructuur. Wij zijn ook lid van operatie steenbreek, dus we proberen ook mensen te verleiden om hun tuinen te ontstenen. Omdat dat natuurlijk ook bij hitteperiodes extra hittestress oplevert. Mensen kunnen daar via wijkbureaus bij het initiatievenfonds kunnen ze geld vragen om gezamenlijk de buurt wat te vergroenen en geveltuintjes te maken. maar er zijn ook individuele regelingen, die zitten bij een andere afdeling waar mogelijkheden zijn om dingen te vergroenen.

Q: Bij ruimtelijke projecten, in hoeverre kijken jullie dan naar de bewoners die er al wonen?
A: Dat nemen we wel mee, in sommige wijken zijn de samenstellingen wat eenzijdig, dan proberen we die diverser te maken. Er zijn wijken waar relatief weinig sociale woningbouw is, als daar nieuwe plannen komen vinden we wel dat nieuwbouw voor een groot gedeelte sociale woningbouw moet zijn. In andere wijken, bijvoorbeeld Overvecht of Zuidwest, daar zijn relatief veel sociale huurwoningen. En daar proberen we dan ook de wijk wat gemengder te maken.

Q: Met betrekking tot hittestress, kijken jullie dan bij gezondheidsadvies kijken jullie of er veel kwetsbare mensen in die wijk wonen die meer last zouden kunnen hebben van hitte?
A: Ja dat nemen we wel mee, we hebben wel redelijk zicht op hoe de samenstelling van de wijken, subwijken en buurten zijn, en daar proberen we ook rekening mee te houden.

Q: Wat zien jullie als kwetsbare bevolkingsgroepen?
A: Wij gaan er van uit dat ouderen wat meer zorg nodig hebben. Maar ook dak en thuislozen, daar is ook extra aandacht voor, chronisch zieken dus mensen met bepaalde chronische ziekte hebben meer last van de hitte dan andere mensen. En ook jonge kinderen. We hebben bij de gemeente een inspectie van de kinderopvang, en die zien er ook op toe dat die kinderdagverblijven protocollen hebben wanneer er een hitteperiode aankomt.

Q: Maken jullie bij het gezondheidsadvies bij ruimtelijke projecten of een project specifiek verdichting is of niet?
A: Ja, er zijn nieuwe projecten in Utrecht zoals Merwedekanaalzone, maar ook bij de Beurskwartier, waar het echt gaat om verdichting, ik zit zelf niet als adviseur bij die projecten, maar daar houden we wel rekening mee dat het dan om verdichting gaat. Je moet goed kijken als je op die plek nieuwe woningen toevoegt dat je wel goed in de gaten moet houden dat er ook voorzieningen zijn, soms levert dat problemen op. Die plannen van de ontwikkelaars moeten ook financieel haalbaar zijn, en soms zijn we niet gelukkig met wat voor voorzieningen erbij gedaan worden, en dan moeten we dat soms compenseren op andere plekken. Bij de Merwedekanaalzone wordt er vanuit gegaan dat de mensen die daar komen te wonen dat die ook in de omringende buurten moeten kunnen recreëren, kunnen sporten. Dus dat is vaak ook wel een probleem, want er is weinig ruimte in een stad, en iedereen legt claims op die ruimte. Voor wonen maar ook voor allerlei voorzieningen. Collega’s van mij van de maatschappelijke ondersteuning moeten erop toezien dat er allerlei voorzieningen komen, zoals scholen, welzijnsvoorzieningen, sport en recreatie. En andere collega's van het groenprogramma zeggen dat er ook voldoende groen moet zijn waar mensen moeten kunnen ontspannen en sporten. Dus je ziet dat er altijd een soort strijd om de schaarse ruimte is.

Interview 4:

Role: Advisor climate adaptation – Province of Utrecht
Date: June 23, 2020
Type: Email

Questions and most important answers:

Q: Wat is uw rol binnen de Provincie?
A: Nu adviseur klimaatadaptatie/ publiek ondernemer bij programma klimaatadaptatie.

Q: Bent u betrokken bij verdichting in de Provincie Utrecht? Zo ja, op welke manier?
A: De binnenstedelijke druk in de provincie is groot, er liggen grote ruimtevragen. Klimaatadaptatie geeft ook een grote ruimtevraag, zeker ook in steden. De kwaliteit van de woonomgeving is voor bouwers, ontwikkelaars, een lastig onderwerp. De betrokkenheid van mij/ het programma klimaatadaptatie zit hem in het agenderen van het onderwerp en het agenderen van groen in steden, het maken van afspraken over klimaat adaptief bouwen. Agenderen, stimuleren, beleidsbeïnvloeding.

Q: Wat zijn de redenen dat Provincie Utrecht inzet op verdichting?
A: De woningvraag is groot, ook doordat de regio aantrekkelijk is voor bedrijven en bewoners om verschillende redenen. De provincie werkt daarom zo veel mogelijk mee aan het realiseren van voldoende woningen.

Q: Zijn er documenten of richtlijnen die de Provincie volgt bij het maken van verdichtingsstrategieën/richtlijnen/aanbevelingen (landelijke documenten, wetenschappelijke studies, referentieprojecten, …)?
A: Ik weet niet veel over verdichting strategieën. Waar wel aan gewerkt wordt is: Groen Groeit mee: het laten optrekken van groene ontwikkeling samen met de rode ontwikkelingen. En: regionaal programmeren: afspraken met gemeenten over waar welke woningen en hoe de kwaliteit van de leefomgeving (waaronder klimaatadaptatie) te bewerkstelligen. Daarnaast zijn we vanuit het programma een verkenning aan het doen naar het maken van afspraken over klimaat adaptief bouwen met de markt.

Q: Wordt er bij verdichting binnen de provincie actief rekening gehouden met het veranderende klimaat?
A: In 2018 zijn in Nederland zo'n 87.000 woningen gebouwd. In 90% was daarbij geen rekening gehouden met het veranderend klimaat. Er is beperkt reden om aan te nemen dat in het Utrechtse daar veel van af is geweken. Er wordt steeds vaker op papier, in de planfase, wel rekening gehouden met het veranderend klimaat. Een deel van de plannen valt in de uitvoeringsfase nog af ivm kosten.

Q: Worden er bij verdichting ook bepaalde voorwaarden met het oog op klimaatadaptatie gesteld? Wat zijn de voorwaarden waar verdichtingsprojecten aan moeten voldoen? Of voorwaarden waar gemeenten zich aan moeten houden? (bijv. bepaalde regels, drempelwaarden, grenzen, …)
A: Er worden door een aantal gemeenten beginnende voorwaarden gesteld, deze zijn nog zacht. Sommige gemeenten (en bouwers) willen meer regelgeving/ duidelijkheid, anderen juist zoveel mogelijk ruimte aan de markt laten. De komende jaren zullen er steeds vaker voorwaarden gesteld worden, het is een onderwerp dat nog in transitie is, leren van elkaar, nog lang niet uitgekristalliseerd.

Q: Op welke manieren wordt binnen de Provincie geprobeerd hittestress tegen te gaan? Op welke schaal? Kunt u voorbeeld projecten/ documenten noemen?
A: Een voorbeeld is het meten. De snuffelfietsen (500 stuks) zijn uitgerust met een thermometer en brengen in beeld waar hitte speelt. Voor de rest is hittestress vooral iets waar veel over wordt gepraat, maar nog weinig concrete maatregelen. Er zijn een aantal schoolpleinen vergroend, wat heel effectief is. Maar over het algemeen kan je zeggen dat er nog te weinig robuust groen wordt gerealiseerd in de nabijheid van woningen, hittestress op recreatieterreinen, fietspaden, in weilanden, in binnensteden (schaduwdoeken), aanleg extra zwemwater, slimmer Zuid-Europees isoleren ipv tegen kou isoleren, rekening houden met stadsventilatie, etc etc. nog niet plaatsvindt.

In het programma klimaatadaptatie van de provincie, moet nog worden vastgesteld, besteden we extra aandacht aan het onderwerp hittestress.

Q: Wordt er in jullie verdichting strategieën/richtlijnen met betrekking tot hittestress ook rekening gehouden met bevolkingsgroepen die kwetsbaarder zouden kunnen zijn voor hitte (bijvoorbeeld ouderen, zieken, …)? Op welke manier? Zo ja, wat zijn volgens jullie kwetsbare bevolkingsgroepen met betrekking tot hittestress?
A: Dat is een goed onderwerp. Wij zijn als programmateam nog in de fase van het prediken. Zo heb ik eerder deze week een overleg gehad met veel verschillende partijen rond het onderwerp recreatie en toerisme. Een punt dat ik inbracht is het rekening houden met kwetsbare groepen. Ik noemde daarbij zwangere, ouderen, kinderen en mensen met sommige beperkingen. Maar we zijn nog een beetje roepende in de woestijn.

Q: Heeft u zelf nog informatie die nuttig zou kunnen zijn voor mijn onderzoek en dat nog niet besproken is? Of eventuele opmerkingen?
A: Ik geloof heel erg in het aanwijzen van Utrecht (bijvoorbeeld de Utrechtse Heuvelrug) als ‘cool region’ en daarin samen werken met andere regio’s/ landen. Mensen zullen in de toekomst steeds vaker hun recreatiebehoefte/ vakantie afstemmen op verkoelingsmogelijkheden, daar kan je je als regio op profileren. Dit kan in mijn ogen hittestress op een positieve manier op de kaart zetten. Zwemplekken, hoge bomen in steden, parken, forten van de waterlinie, honderden watertappunten, buitenplaatsen, veel kanalen: Utrecht (regio en stad) heeft koele plekken maar kan dit nog meer versterken. Partijen gaan daarmee samen werken om maatregelen te treffen die de regio koeler maken.