Which ecological features can help Utrecht to become better resistant against the consequences of climate change?

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This literature review is the writing assignment of the master program Environmental Biology (Ecology and Natural Resource Management-track) at Utrecht University.

The image on the front-page shows 'Wonderwoods', a vertical forest to be realized in the city center of Utrecht, the Netherlands in 2024. Retrieved from: www.wonderwoods.com

Preface

This writing assignment was the final part of my master program Environmental Biology at Utrecht University. During this program, I followed the Ecology and Natural Resource Managemnet (ENRM) track, which consisted of two large research projects. I examined the potential of Dutch food forest to function as a carbon stock and to mitigate the consequences of global warming in this way. Next to this, I analyzed the needs of Dutch farmers regarding their way to a more sustainable business operation. For me, it was clear that my master program had to be completed with a project on urban ecology, as this was not represented in my program yet.

Although ecology was, is and remains my biggest passion, and I see contribution to mitigate climate change and make our planet more sustainable in a both ecological and social way as my main objective, I decided to start another study last year. While I wrote this review, I was teaching high school students meanwhile, as part of an educational master program, also at Utrecht University. I will use this review during my lessons, in order to learn my students something on urban ecology, climate change, and the importance of vegetation and biodiversity also in their lives. Meanwhile, I believe that it is important to teach all students, even the ones that do not aspire a scientific career, about how science works, and how scientific studies should be interpreted. Using a review written by their teacher himself in a practical project, is an effective way to achieve these objectives simultaneously in my eyes. This is the reason why the layman summary of this review is written at the knowledge level of a 15-year-old (HAVO) student.

I want to thank Marie José Duchateau for supporting and coaching me during this project. It was a challenge to combine both master programs, but with her support I managed to write a review that I am proud of.

Layman summary

In overleg met Marie José Duchateau is besloten dat de samenvatting voor buitenstaanders van dit review is geschreven op het niveau van een havo-4 leerling, vanwege het feit dat de auteur dit review graag wil gebruiken met een educatief doeleinde voor deze doelgroep.

Al sinds de jaren ’60 van de vorige eeuw is het duidelijk: ons klimaat verandert. En het klimaat verandert sneller dan het, voor zover we weten, ooit gedaan heeft. De belangrijkste reden hiervan zijn wij, want het feit dat wij heel veel CO_2 uitstoten, bijvoorbeeld als we vliegen naar onze vakantie of met onze veeteelt, is een van de belangrijkste redenen dat het klimaat zo snel opwarmt.

De gevolgen van deze opwarming van de aarde zijn heel groot. Niet alleen wordt het elk jaar steeds een klein beetje warmer, het klimaat verandert ook behoorlijk. Daardoor krijgen we vaker te maken met extreem weer, zoals hoosbuien, lange perioden van droogte, stormen en, zelfs in Nederland, grotere kans op orkanen. De Verenigde Naties proberen daarom afgesproken de opwarming van de aarde te beperken tot maximaal 1.5 graad. Stel dat de aarde toch opwarmt met 2 graden, dan leidt dat bijvoorbeeld tot drie keer meer verlies aan biodiversiteit en bijna 2 miljard mensen meer die last hebben van extreme hittegolven eens in de vijf jaar.

De gevolgen van het opwarmen van de aarde zijn niet overal hetzelfde. Zo hebben bijvoorbeeld landen die heel laag liggen meer last van zeespiegelstijging en hebben landen dichter bij de Noordpool meer last van toenemende hitte dan landen rond de evenaar. Maar ook bij jou in de buurt zijn de verschillen groot. Woon je in een grote stad, dan zijn de gevolgen namelijk veel groter dan op het platteland. Bossen en weilanden zorgen er namelijk voor dat het land en de lucht minder snel opwarmen en dat ze ’s nachts ook weer sneller afkoelen. In steden is er weinig vegetatie en daar is hitte dus een groter probleem. Hetzelfde geldt voor het opslaan van water. Bossen en graslanden zorgen ervoor dat een overvloed aan water tijdelijk kan worden opgeslagen, zodat het land niet overstroomt. Het kan dus nuttig zijn om gebruik te maken van deze voordelen van beplanting in stedelijke gebieden, maar de grote vraag is hoe dat het beste gedaan kan worden, aangezien er in grote steden een groot gebrek aan ruimte is.

Het allerbeste zou zijn om heel veel bomen te planten. Bomen zorgen namelijk voor nog meer verkoeling dan kruiden en grassen en ze slaan ook nog eens meer water op in hun wortels en stammen. Maar als in een stad bomen gebouwd worden, dan moeten daar huizen, winkels of fabrieken voor wijken. Hetzelfde geldt voor andere voor de hand liggende manieren waarop verkoeling in de stad kan worden gecreëerd, zoals het aanleggen van parken, of het graven van kanalen. Eén van de bekendste creatieve oplossingen om gebouwen en beplanting te combineren is het aanleggen van groene daken. In plaats van dakpannen of harde dakbedekking, zijn de daken dan bedekt met planten: soms alleen met gras, soms alleen met mos, maar soms ook met heel veel soorten door elkaar. Er bestaan zelfs groene daken met struikjes erop. Dit zorgt ervoor dat de temperatuur op het dak, naast het gebouw, maar ook in het gebouw tot wel 10 graden lager komt te liggen. En dat betekent niet alleen een verkoeling van de stad, maar ook minder behoefte aan airco. En dat is dan weer energiezuinig. Kortom: een groen dak kan bijdragen aan het beperken van de gevolgen van klimaatverandering. En het ziet er nog leuk uit ook!

Maar het nadeel van een groen dak is natuurlijk dat je daar geen bomen op kan plaatsen. En dat terwijl het bekend is dat bomen voor meer verkoeling en wateropslag zorgen dan grassen en kruiden. Op sommige plekken in de wereld, zoals in Milaan, hebben ze daarom namelijk een verticaal bos ontwikkeld. Op die flat, waarin mensen wonen en werken, is een groen dak geplaatst, zijn hele muren groen gemaakt, maar is ook een bos ontworpen. Dat bos hangt als het ware tegen de zijkanten van de flat aan, waarbij de bomen in grote bakken zijn geplaatst. Iedereen kan vanuit zijn of haar kamer op het bos kijken en iedereen kan erin zitten. Hoewel het een stuk moeilijker is om zo'n verticaal bos te maken dan een groen dak aan te leggen, lijkt het wel heel nuttig: de temperatuur in de omgeving én in het gebouw dalen namelijk flink. Hier moet wel bijgelegd worden dat er nog niet heel veel verticale bossen bestaan en dat er dus nog niet heel veel onderzoek naar is gedaan. Op dit moment wordt er in het centrum van Utrecht een verticaal bos gebouwd en aangeplant, dus er kan daar veel onderzoek gedaan worden in de komende jaren.

Hoe kijkt een grote stad in de buurt dan tegen deze oplossingen aan? De Gemeente Utrecht en de Provincie Utrecht zijn heel ambitieus om het leefklimaat (dus hoe aangenaam het is om in de stad te leven) de komende jaren flink te verbeteren. Ze hebben doelen gesteld over het vergroenen en verduurzamen van de stad, hoewel ze nog niet precies zeggen hoe veel ze willen bereiken en hoe ze dat gaan doen. Ook hebben ze bepaalde gebieden in de stad aangewezen waar extra aandacht voor nodig is. Deze gebieden (met name het centrum en industriegebieden) hebben weinig vegetatie en vooral veel grote gebouwen en parkeerplaatsen, waardoor deze gebieden extra veel last hebben van hitte en wateroverlast. Verder probeert de gemeente te kijken hoe ze bij het uitbreiden van de stad al meteen rekening kunnen houden met het beperken van hitte- en wateroverlast. Nog niet zo lang geleden hebben ze een stuk polder, waar nu nog vooral grasland is, aangekocht. Het is nog niet duidelijk of dit in de toekomst natuur blijft, of dat ze hier toch woningen of bedrijven willen gaan bouwen. Maar als ze dat gaan doen, is de kans groot dat ze rekening houden met het beperken van de gevolgen van klimaatverandering.

Tot slot is het natuurlijk interessant om te kijken hoe jij zelf je steentje bij kan dragen aan het verkoelen van de stad en aan het verkleinen van de kans op overstromingen in jouw stad. Eén van de meest voor de hand liggende maatregelen is natuurlijk het planten van bomen in je achtertuin. Maar als je nou niet van bomen houdt, dan helpt het ook al om een deel van de bestrating weg te halen. Als je daar planten neerzet, of een stuk grasveld, of een vijver maakt, dan maakt dit jouw tuin koeler en een betere wateropslagplaats. En dan zijn er ook nog andere positieve effecten, zoals het feit dat het insecten en vogels zal aantrekken. Dat is dan weer goed voor de biodiversiteit en daar zijn met name boeren erg blij mee. Die hebben deze insecten namelijk hard nodig om voedsel te kunnen blijven produceren. Als je nu geen tuin hebt, betekent dat niet dat je niets kan doen. Ook een groen balkon kan al helpen, al is het maar voor je eigen gevoelstemperatuur als je op een zomerse dag lekker buiten zit.

Uiteindelijk kunnen we concluderen dat vegetatie ervoor zorgt dat we minder last hebben van de gevolgen van klimaatverandering, namelijk meer kans op extreme hitte en meer kans op overstromingen. Er is in steden vaak gebrek aan ruimte, waardoor het lastig is om grote oppervlaktes aan bomen aan te planten. Maar er zijn andere oplossingen, zoals groene daken en verticale bossen. Deze zorgen voor een significante verkoeling van de lucht in de stad en zijn een goede opslagplaats voor water tijdens een hoosbui. En jij kan als bewoner van de stad ook je steentje bijdragen, door wat meer beplanting in je tuin aan te planten en door een deel van je bestrating weg te doen.

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1 - Introduction: Impacts of climate change in urban areas

The insight that our climate and our environment are changing drastically, is not something humanity acquired in the last decade. Already in 1972, The Club of Rome alarmed politicians from all over the world for the limits of growth (Meadows *et al.,* 1972). This group of highly respected scientists shared their concerns on the negative consequences of ever-growing economies, welfare, and the world population. But back in the 1970s, global climate change was not one of the main interests of the world population, neither of the world leaders, who were for example much more concerned with the Cold War (Meadows *et al.,* 1972). Fifty years later, the alarming state in which our environment is in, is a much wider concerned problem and governments, companies, and citizens around the world – slowly – start to implement climatological interests in their policies and actions.

1.1 – Concerns about the changing climate

Somewhere between 1972 and 2022, the world has become concerned about our rapidly changing environment. Scientists found evidence to prove the insight that unlimited emissions of greenhouse gasses (*see Figure 1*) would lead to an unprecedented temperature rise (Stern & Kaufmann, 2014). There are also many explanations of a natural temperature rise, such as changing aerosols (Kaufmann *et al.,* 2011), so-called global climate feedback cycles (Piao *et al.,* 2008) and black carbon (Bond *et al.,* 2013). However, anthropogenic reasons (*i.e.* large greenhouse gas emissions) are the main reason of the rapidly changing climate (with a chance of over 90%; IPCC, 2019).

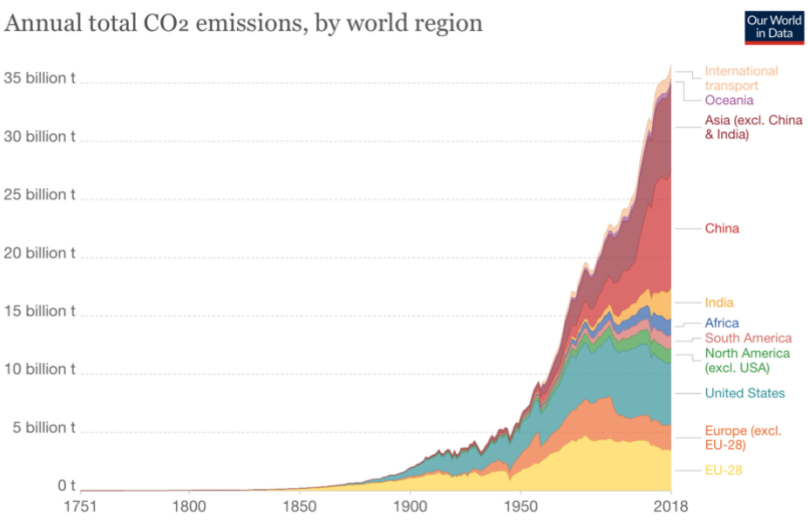

Figure 1: Global annual CO_2-emmission by world region (Our World in Data).

Because of these anthropogenic influences, the current rate of global warming is around 10 times higher than after the last glacial periods (NOAA). And because of this, temperature maximum records are being broken year after year since the start of the annual measurements in 1850 (KNMI, 2021). But a rise in mean annual temperature is not the only consequence of climate change. As a result of global warming, extreme heat events, extreme droughts, and extreme rainfall events will occur more often (IPCC, 2021). Furthermore, sea level rises as a result of melting rise, there is a higher chance of thunderstorms and is the massive biodiversity loss linked to climate change threatening our food production system (IPCC, 2021; WWF, 2014).

In order to report climate change objectively, the United Nations (UN) established the Intergovernmental Panel on Climate Change (IPCC) in 1984. This panel consists of independent scientists all over the world, and all UN member states have pledged to accept the conclusions formulated by the IPCC as truth (IPCC, 2019). This was the first time that all world leaders accepted to examine climate change and its consequences. The start of collecting facts that were accepted by all UN member states might be the beginning of the increasing public concerns.

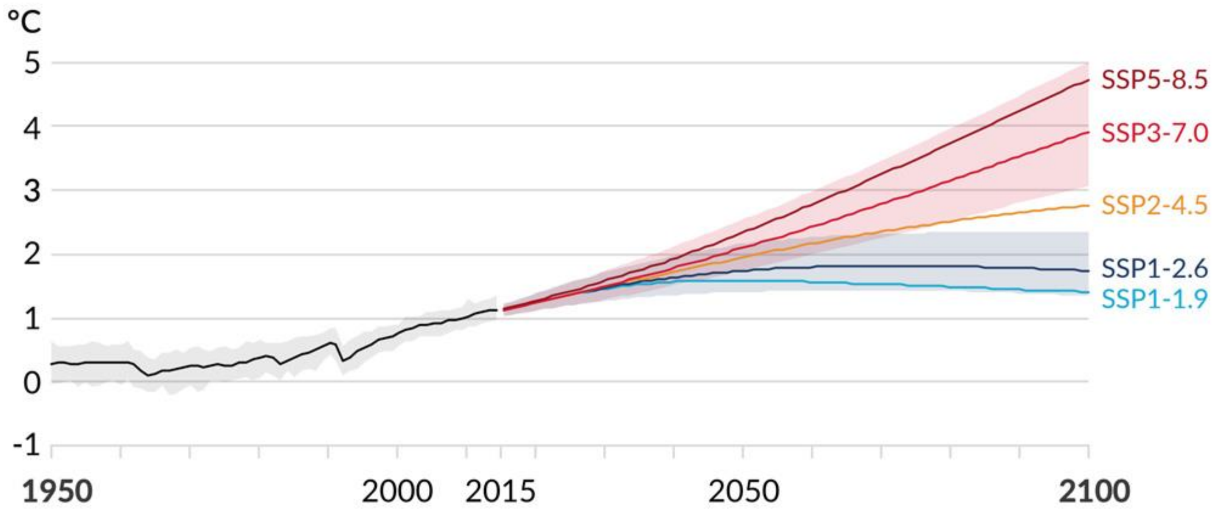

Figure 1: Five scenarios of global temperature rise, compared to the mean temperature in the period 1800 – 1900 as predicted by the IPCC (Mason-Delmotte *et al.,* 2021).

However, it took the world leaders until 2015, after five alarming reports by the IPCC were published, to agree on limiting global warming to 1.5 degrees Celsius and bringing the emission of greenhouse gasses to zero (UNTC, 2015). Although the goals of this Paris' Agreement were not met by many governments (Milman, 2015; Dessler & Parson, 2022) this can be seen as the first step of the widely implementation of climate change mitigating measurements in policies of governments and companies around the world.

The acceptation of the global goal of reducing the consequences of climate change seems to implement the agreement on the fact that climate change is negatively affecting humans. But what are the facts of climate change? In the fall of 2021, the IPCC presented the first part of their three-piece sixth assessment report (Masson-Delmotte *et al.,* 2021). The panel concludes that climate change is even more heavily than described in the fifth assessment in 2014 (IPCC, 2014) and the report is interpreted as final warning (McGrath, 2021). Even though a complete analysis of the IPCC report could only be made after the second and third part will be published (mid 2022), one will not deviate from the tendence of even higher concerns compared to 2014.

In *Figure 2*, the warning of the IPCC in 2021 is shown (Mason-Delmotte *et al.,* 2021). While the IPCC classified the goal to reduce global warming to 1.5 degrees Celsius compared to the period 1850-1900 as feasible (IPCC, 2014), the panel is more sceptic on that in nowadays. Even in the best-case scenario (SSP1-1.9), in which the worldwide net greenhouse gas (GHG)-emissions will be reduced to zero in 2050, the estimated mean global warming will be 1.4 degrees Celsius in the period 2081-2100, with a very likely range of 1.0-1.8. Even though this means the objective agreed on by al UN member states in 2015 will be met, the IPCC classifies this scenario as highly unlikely (IPCC, 2021). In another scenario (SSP2-4.5), which is called the business as usual-scenario, the GHG emissions will just decrease after 2050 and the world will not reach a net emission of zero before 2100. This scenario is classified as most likely, given the current agreements and ambitions of policy makers. In this scenario, the global surface temperature will increase to 2.7 degrees Celsius (with a very likely range of 2.1 to 3.5) in the period 2081-2100 (IPCC, 2021). Global warming and climate change are classified as even a bigger problem than ever thought before and even immediate and massive actions will perpetuate the opportunity to meet the Paris agreements (UNTC, 2015; IPCC, 2021).

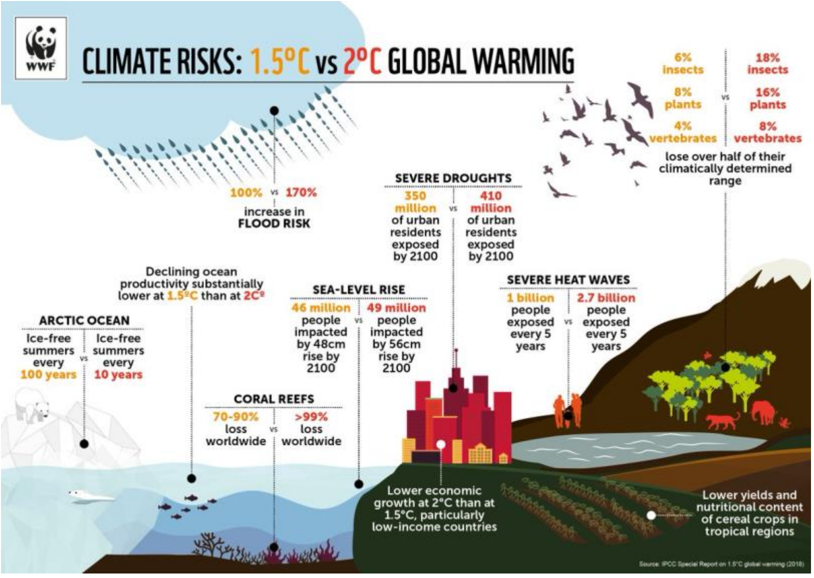

Figure 3: Differences in consequences of global warming between a temperature rise of 1.5 and a rise of 2.0 degrees Celsius (IPCC, 2018).

Even according to the best-case scenario, negative consequences of global warming are inevitable and irreversible. However, climate-sceptics falsely argue that no one could notice an extra temperature rise of 0.5 degrees. The WWF and the IPCC already made analyses of the differences in consequences of global warming between a temperature rise of 1.5 and 2.0 degrees Celsius (and one should consider that even the 2.0-scenario might be optimistic). In *Figure 3,* the some of the differences are visually presented (IPCC, 2018). Among other things, not meeting the objectives of the Paris Agreement will result in a 70% increase flood risk, at least a 100% increase of biodiversity loss, a 10 time more frequent ice-free arctic summer and a 170% higher chance for human beings to severe heat waves (IPCC, 2018). It might be a slight difference, but every tenth of a degree Celsius seems to protect millions of humans and animals for starving, according to the IPCC.

1.2 - Consequences of climate change in urban areas

The consequences of climate change are not equal in all parts of the world. For example, the temperature rise in arctic areas is more than twice the global average (Meredith *et al.,* 2019). But also, at regional and local levels, the differences in consequences of climate change are significant. In its newest report, the IPCC mentioned that cities and urban areas severe more from global warming than country sides (IPCC, 2021). According to the US Environmental Protection Agency (EPA), the differences in temperature between cities and its surroundings can be up to 3-4 degrees Celsius (EPA, 2022). In *Figure 4*, the effect of urbanization on the mean surface and atmospheric temperature is shown (Voogt, 2016). Downtown areas absorb more heath at daytime than suburban and rural areas. This is mainly caused by the large amounts of concrete and the low numbers of vegetated areas in cities (Rizwan, Dennis & Chunho, 2008). The dark-colored concrete absorbs the heat, while the cooling effect of vegetation is absent due to the lack of trees. Even in small, vegetated areas, such as parks, trees lead to a decrease of temperature. Therefore, parks have a lower mean temperature than industrial areas, that are often located outside of the city center (Voogt, 2016). Next

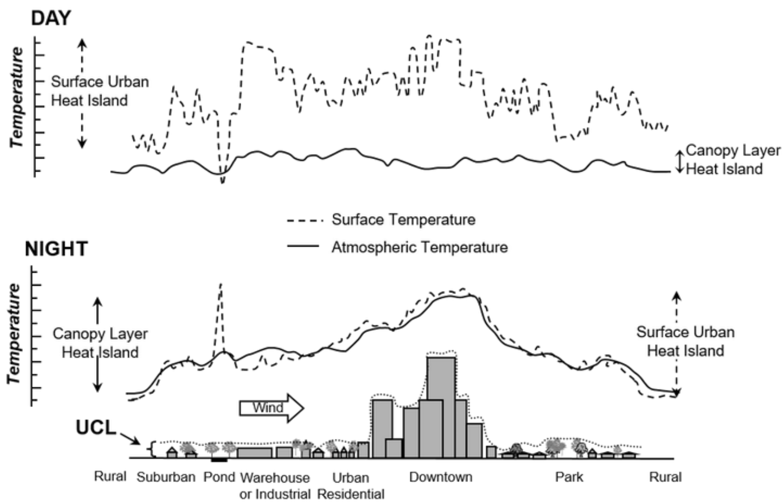

Figure 4: The Urban Heat Island effect (Voogt, 2016). The mean temperature at daytime is higher in city centers than in the surrounding areas (upper diagram). Heat retains longer at nighttime in city centers than in the surrounding areas (lower diagram).

to the effect on day-time temperature, cities retain the heat much more than its surroundings at nights (Rizwan, Dennis & Chunho, 2008; Voogt, 2016). Once visualizing this, one could see an 'island of high temperatures' close to the city center. This effect is called the Urban Heat Island (Voogt, 2016).

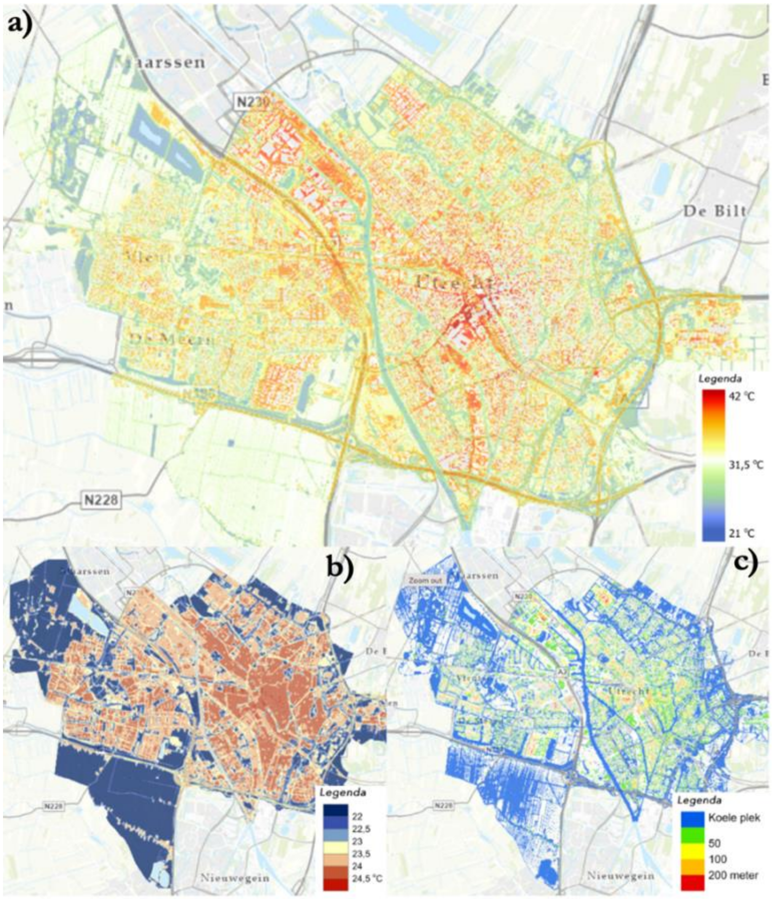

Figure 2: Maps of Utrecht visualizing differences in temperature and lack of cool spots downtown (Utrecht, 2014). a) Perceived temperature when the air temperature was 32 degrees Celsius. **b)** Air temperature at 23pm after six days of heat (at least 28 degrees Celsius). **c)** Distance towards the nearest 'cool spot'.

The municipality of Utrecht examined these temperature differences for their city extensively (see *Figure 5*). At a summer day when the air temperature is 32 degrees Celsius, the average perceived temperature is 7 degrees higher than at the edges of the city, with a maximum of more than 10 degrees (*Figure 5a)*. Next to this, the heat retaining effect of buildings is found in Utrecht. After six days with a maximum air temperature of at least 28 degrees Celsius, the mean air temperature at 23pm was over 2 degrees higher inside the city than in its surroundings (see *Figure 5b*). Both results confirm that Utrecht functions as an Urban Heat Island (Voogt, 2016). Another reason of concern for the municipality of Utrecht is the distance to a 'cool spot', shown in *Figure 5c.* In the center of Utrecht, hardly any cool spots (shown blue in the figure) are found. And the distance to a (often quite small) cool spot, frequently exceeds the desired distance of 100m. All in all, one could conclude that citizens of Utrecht severe much more from heat than citizens of the rural areas.

These differences in temperature are cause for concern. As mentioned before, extreme heat waves cost up to ten of thousands of lives in Europe in recent history (Robine *et al.,* 2008). And as heat waves will occur more often (Michelozzi *et al.,* 2009), more causalities are expected in the coming decades (Anderson & Bell, 2009). However, Harlan & Ruddell (2011) concluded that extreme heath events already cost 'tens, perhaps hundreds, of thousands of excess deaths directly or indirectly'. While there is widespread concern on more frequently occurring natural hazards as result of climate change, like floods, droughts and tropical storms, extreme heat has the highest mortality of all natural hazards in Northern America (Borden & Cutter, 2008). The fact that the city of Utrecht – like all cities around the world, but for Utrecht clear evidence has been provided – is significantly hotter than its surroundings, could lead to excessive mortality, not even to mention the numbers of severely ill patients (Knowlton *et al.,* 2009).

The lack of cool spots, causing extreme perceived temperatures inside cities, is not the only impact of climate change citizens of urban areas must deal with. A second major problem is the water storage capacity of cities. Extreme rainfall events will occur more frequently because of global warming (IPCC, 2014). Given a temperature rise of 1.2 degrees Celsius, the likelihood of extreme rainfall in Western-Europe is up to 9 times higher (Kreienkamp *et al.,* 2021), a factor that will only rise in the knowledge that global warming will not be limited to 1.2 or 1.5 degrees Celsius (see above). Again, cities are expected to suffer more from these extreme rainfall events than rural areas (Ma *et al.,* 2018). On average, cities have limited capacity of store excessive water temporarily (Qiang *et al.,* 2021). Furthermore, due to the relatively high number of buildings, tarmac roads and concrete surfaces like parking lots and squares, water could not be absorbed (Qiang *et al.,* 2021). Instead of being absorbed or stored, an overload of water will flow through cities with all its negative consequences. The effect of urban development (*i.e.* increasing areas of concrete and decreasing areas of natural vegetation) on the frequency of floods is depicted in *Figure 6*. A significant increase in annual discharge of Mercher Creek, which is close to urban areas, was found, while this discharge stayed the same in a closely located river in a rural area (Konrad, 2013). Due to urbanization around the Mercher Creek, rainwater could not be absorbed or stored, through which it flowed directly to the river and causing a higher maximum discharge. Although this diagram does not show floods because of extreme rainfall only – the increase in discharge is also caused by limited river outflow options caused by constructions - it gives an insight in the effect of urbanization on the nuisance caused by abundant water (Konrad, 2013). While the direct danger of extreme heat for civilization could not be clear for everyone, there is no doubt on the potential effect of more frequently occurring - and more heavy - floods on mortality.

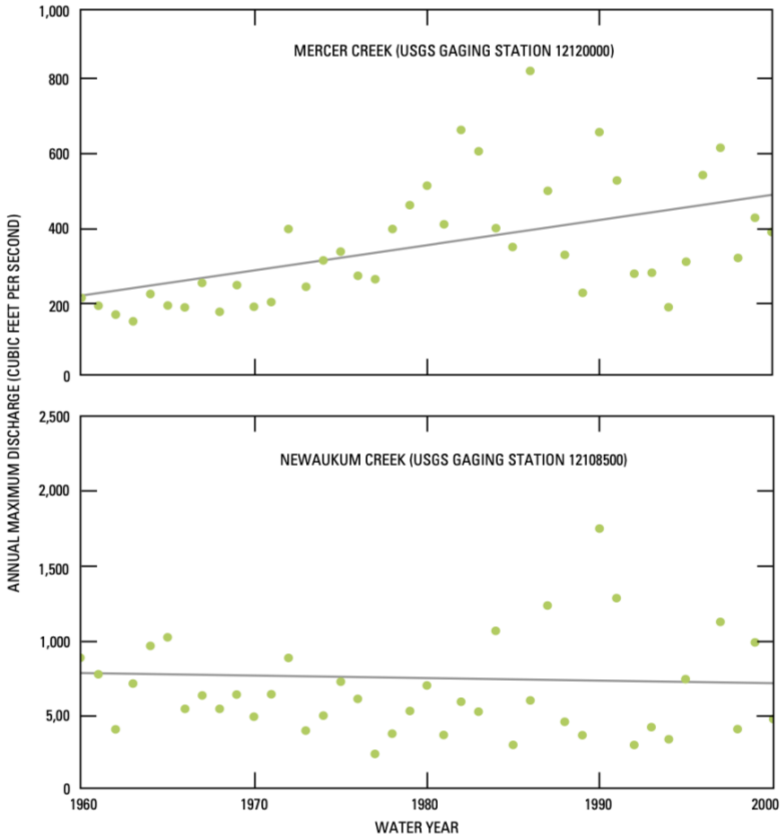

Figure 3: The annual maximum discharge of Mercer Creek and Newaukum Creek between 1960 and 2000, showing the effect of urbanization on river discharge (Konrad, 2013). Significant urbanization took place in the second half of the 20th century near Mercer Creek; meanwhile the annual maximum discharge has increased. Hardly any urbanization took place in the same period near Newaukum Creek; no significant change in mean annual discharge was found in this river.

1.3 - Prevent cities for extreme heat and floods

Although prevention is the best cure, preventing our cities from climate change is not achievable anymore, according to the IPCC (IPCC, 2021). So, while it remains important to limit and mitigate global warming prevent the scenarios for becoming even worse, it seems sensible to focus on adaptation measurements meanwhile. An important question is: how to maintain habitability of our cities? The use of air-conditioning systems has increased exponentially over the last decades

(Lundgren & Kjellstrom, 2013). However, air-conditioning increases the differences between inside and outside temperature and lowers the air quality, causing illnesses and even deaths (Sera *et al.,* 2020). Moreover, these systems are far from sustainable, which rather facilitates than mitigates global warming. In order to limit the likelihood of floods to occur, one could invest in large tanks underneath cities. However, evaluation on the effectiveness of these tanks made clear that this is not an affordable and feasible option to nullify extreme rainfalls as could be expected under the changing climate conditions (Cobacho, Arregui & Cabrera, 2008). Since the presence of vegetation affects both temperature and water outflow beneficially (Borchert & Pockman, 2005; Rahman *et al.,* 2006; Klok *et al.,* 2019) ecological features might be the key to prevent cities for extreme heat events and more frequent floods.

This review focusses on the opportunities of ecological features to improve, or retain, the livability of cities given the changing climate. Although climate change, has numerous of impacts on the life in cites, only the two major direct consequences discussed above - extreme heat and floods – will be considered in this review. This article spotlights the specific possibilities of implementing ecological features for the city of Utrecht, which is the hometown of the author. This is relevant, as Utrecht, and the Netherlands in general, already suffers from the consequences of climate change (KNMI, 2018) and the local authorities of Utrecht explicitly mention the ambition to mitigate these effects by using ecology in their policy (Gemeente Utrecht, 2018).

In the next chapter, the effect of vegetation on temperature and water storage capacity will be described. After this, some opportunities to implement vegetation in densely built and populated cities will be explained. The next chapter will zoom in on the specific situation of Utrecht to determine which of these features could be successfully implemented in this city, supplemented with some suggestions on how individual citizens could contribute to cooling down their city, as well as lower the risk of floods in their surroundings. Finally, all findings and conclusions are being discussed extensively in the last chapter.

2 - The impact of vegetation on temperature and water storage

Differences in temperature between urban and rural areas are significant, as described in the previous chapter. Furthermore, cities suffer more with the increased frequency of extreme rainfalls than its natural surrounding areas. Both factors are (partially) caused by the differences in degree of vegetation, as trees are known to decrease temperature and increase water storing management (*e.g.,* Borchert & Pockman, 2005; Lin & Lin, 2010; Konarska *et al.,* 2016; Kleerekoper & Schrama, 2020). The degree in which vegetation can contribute to both variables (temperature and water storage) is discussed in this chapter. The focus is on trees, to determine the maximum cooling and water storing potential of vegetation, since a tree vegetation has the larger effect on both temperature (Teuling *et al.,* 2010; Dalen, 2017) as water storage (Peng *et al.,* 2019) compared to grasslands, mixed herbal vegetation, and lower shrub vegetation.

Livesley *et al.* (2016) provided an overview of the potential ecosystem services of trees in urban areas, also called urban forests (see *Figure 7*), based on a collection of studies from Central America, Europe, Japan, and Australia. It is important to mention that scientific evidence is not available in large numbers for all these services, however, the presence of these services (to some extent) is generally assumed. Next to the cooling and water storing services, trees inter alia play a role in nutrient uptake, biodiversity, mitigating pollution and saving energy (Livesley *et al.,* 2016; see *Figure 7*). Nevertheless, the focus is only on the two above-mentioned services.

2.1 - The cooling effect of trees

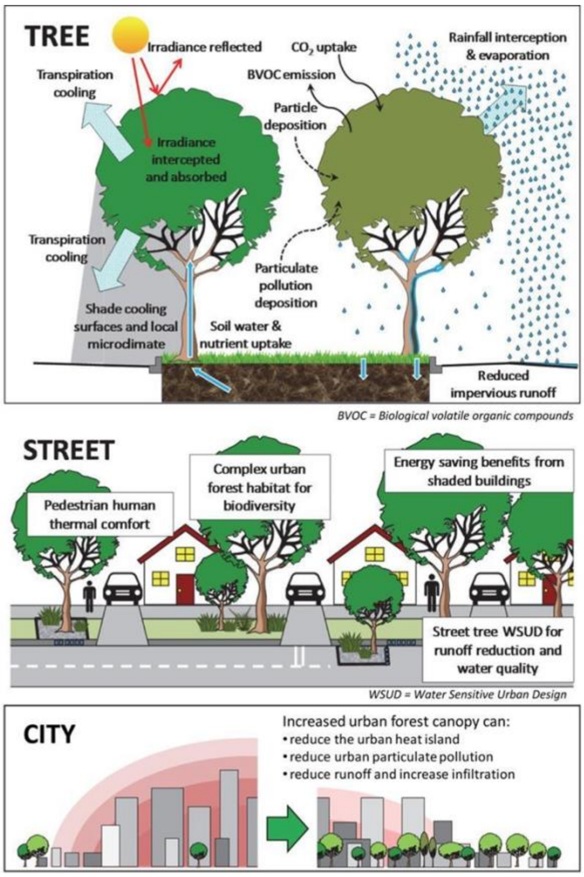

Figure 4: The effect of trees on the microclime of cities at tree level, street level and city level (Livesley *et al.,* 2016).

Bright *et al.* (2017) confirmed the assumption that trees have a larger cooling effect than grasslands and herbal vegetations. Based on both remote sensing and *in situ* examination of land uses across the world, it was concluded that forests have the largest temperature buffering potential. Furthermore, they conclude that reforestation is attractive as local mitigation measure in all non-arctic regions (Bright *et al.,* 2017). In other words, the use of vegetation, and especially the use of large trees, can help to lower temperature. However, it is hard to determine the actual effect of planting a tree on the local temperature.

Many variables must be taken into account to determine this precise effect, making this calculation quite difficult (Saxena, 2002). First, a tree contributes to a lower temperature in two ways, namely transpirative cooling and cooling by providing shade (Manickathan *et al.,* 2018). Trees release water into their environment by transpiration, which cools down the air. Meanwhile, the presence of a tree provides shade and reduces the irradiation of heating sunlight to the surface. These two independent effects are visually shown in *Figure 7* (Livesley *et al.,* 2016). Furthermore, one should consider the size of the vegetation, the climatological circumstances, the species of the planted trees and the design of the surrounding surroundings (Manickathan *et al.,* 2018). The calculation methodology developed by Saxena (2002) contains even more variables than mentioned above (*e.g.* wind speed and atmospheric pressure), however these seem to be the most important and obvious ones, as they are considered in other studies as well. On average, a park with trees could lead to a temperature decline of 0.5 to 3.0 degrees Celsius (Chen & Wong, 2006; Lin & Lin, 2010; Rahman *et al.,* 2017). This range is obviously quite large, making the precise effect of planting trees uncertain. An additional point of discussion is that most studies compared differences in temperature between existing urban parks and its surroundings, instead of inserting a park in an urban area and compare the differences from scratch on (Bowler *et al.,* 2010).

Kleerkoper *et al.,* (2018) found that the air temperature decreased with 0.5 degrees Celsius on average in Amsterdam, after the vegetation area was expanded with 10%. This is in line with the range mentioned above, albeit the lower limit of this range. Another study in Amsterdam has proven that not every tree is equally suitable as temperature reducer. This depends strongly on the degree of transmissivity of the tree (Lindberg *et al.,* 2013), since providing shade is the main contributing factor of a tree (Manickathan *et al.,* 2018). The mean transmissivity of trees is 3%, which means that 3% of all radiant energy reaches the soil. A species with an opportune transmissivity is for example *Tilia cordata,* which is a species that is often used in urban planting (Takács *et al.,* 2016) and *Ulmus parvifolia,* which is closely related to the native Dutch and general *Ulmus minor* (Lin & Lin, 2010). Both studies are performed in Amsterdam, but since Amsterdam is only 50 kilometers away from Utrecht and the climatological conditions are comparable, similar effects could be expected in Utrecht. In conclusion, planting trees will, without any doubt, cause a temperature decline, although the exact effect can hardly be predicted in advance.

Trees are not only affecting the actual temperature, but also influence the perceived temperature of urban areas (Saxena, 2002; Livesley *et al.,* 2016), for example by providing shade and enhancing humidity. This perceived temperature is more representative as variable of livability in the city, since the difference in perceived temperature between urban and rural areas is even bigger than the difference in actual temperature (Bontsema *et al.,* 2021). In other words: although the difference in temperature between cities and their surroundings is only several degrees Celsius, the concrete, buildings and lack of vegetation makes it even hotter than it is. Note that vegetation is not the only factor that explains the difference between actual and perceived temperature, as for example wind speed also has its impact. Klok *et al.* (2019) extensively examined the effect of vegetation on the perceived temperature and concluded that trees could lower this with up to 22 degrees Celsius. Another study confirmed that trees have a two-piece effect, as they provide 'thermal comfort' next to the decrease in air temperature itself (Wang, Wang & Yang, 2018). In this way, one single tree can function as ten air-conditioning systems combined (Döpp, 2011).

Although extensive literature research, there is almost no scientific study that comes up with an exact effect of planting one tree on the air temperature. Therefore, it is nearly impossible to determine which percentage of urban area should be converted into vegetation to equal the air temperature with the air temperature of the surrounding, natural areas. Policy documents that indicate to answer this question therefore only come up with practical objectives concerning the amount of vegetation in their city (Kleerekoper & Schrama, 2020). It might be achievable to design a new city to be built with enough trees to equal the rural air temperature. However, it seems unfeasible to reach these goals within an existing city only by using trees, parks, and forests. Therefore, it seems necessary to use other, innovative, ecological features to lower the urban air temperature.

2.2 - The water storing capacity of trees

Due to comparable reasons as mentioned above, it is impossible to determine the exact water storage potential of trees in general (Baptista *et al.,* 2018). This depends on multiple factors, including the species of the tree, the density of vegetation, the climate, and the amount of precipitation. Nevertheless, there is scientific evidence for the impact of tree vegetation on soil hydration, water storage and transpiration.

First, trees store significantly more water than crops and grasses (Peng *et al.,* 2019). This is mainly caused by the presence and activity of trees in deeper layers of the soil, as the water storage of crops and grasses is higher in the upper soil layer. After extreme rainfall events, trees can store up to 18% more water than low urban park vegetation (Siriri *et al.,* 2013). This is partly due to the storage in plant roots, but trees also capture significantly amounts of rain in their canopy (Livesley *et al.,* 2016) Not all rain will reach the soil in this way, preventing the soil for being saturated in an early stage of the extreme rainfall event. More and more governmental organizations across the world develop a so-called water-sensitive urban design (WSUD) for their city. The addition of tree vegetation to these WSUD systems seems to be beneficial, as trees can provide 46 to 72% of water use in WSUD systems (Scharenbroch *et al.,* 2016). In this way, trees significantly limit the runoff of water from the system.

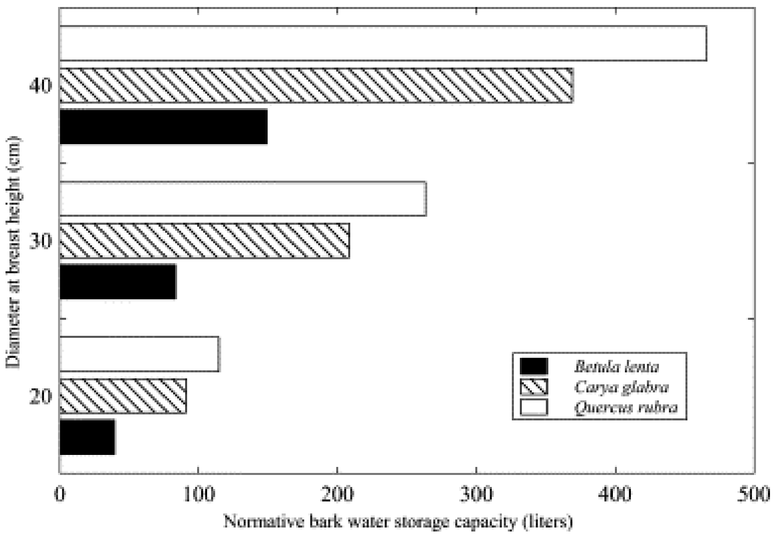

Figure 5: The normative bark water storage capacity of three species at three stem diameters (Levia & Herwitz, 2005). Medium sized trees (30cm diameter) could store up to 250 liters in their bark.

By using 46 to 72% of the water in the water design of a city, trees are not capturing and storing the same percentage of rainfall. Trees can capture 15 to 27% of the annual rainfall, although this is very fluctuating per situation. One of the most important factors is the species of the tree. Drought-avoiding species seem to provide a worse water storing service than species that are adapted to dry conditions (Borchert & Pockman, 2005). These dry-loving species can reduce the water potential in their roots with up to 7 MPa, while drought-avoiding species only show a reduce of 0.7 MPa under dry conditions. The same effect was found under rehydration events. Species with the highest drop of water potential also show the highest uptake of precipitation in a short time (Borchert & Pockman, 2005) and are therefore better suitable in water storage designs. It is important to realize that not all species could immediately be incorporated, as the moisture conditions in cities are strongly fluctuating, something the concerned species should be able to deal with (Scharenbroch *et al.,* 2016).

These percentages give insight in the potential water storing services of trees; however, it does not provide information on the exact amount of water they can store. Levia & Herwitz (2005) determined that this is also strongly species dependent. One medium-sized *Quercus rubra*, which is one of the most common urban trees in The Netherlands can store up to 250 liters of water (see *Figure 8*). On the other hand, a *Betula lenta* of the same size can only store 100 liters. The Dutch meteorological institute classifies a day with 50mm of rainfall as a 'day with heavy rain' (KNMI, 2022). At such a day, the entire city of Utrecht receives 5 billion liters of rain, which means that at least 20 million trees are needed to store all the precipitation. Even though this is only hypothetical - as water is obviously also stored in other vegetation, tanks, ditches, et cetera – planting this number of trees is not feasible, given the current number of 140.000 trees in Utrecht (Gemeente

Utrecht, 2021). It might therefore be useful to determine how much one planted tree can contribute to the water storage of a city. This is again species-specific, but it also depends on the magnitude of precipitation (Levia & Herwitz, 2005). On a day with 'regular rainfall' (KNMI, 2022), trees can store over 50% of the rainfall, but the storing capacity is decreasing with the strength of rainfall. In case of a downpour, which has at least a precipitation of 25mm (KNMI, 2022), the storing capacity of a *Quercus rubra* is only 10% (Levia & Herwitz, 2005). One could also say that still 10% of the rain is stored, instead of 0% when there is an impermeable ground cover.

An additional benefit of trees water management is their transpiration (Livesley *et al.,* 2016). The water stored in trees will gradually flow back into the atmosphere. In this way, trees are providing moisture and cooling in periods without precipitation (Siriri *et al.,* 2013). The cooling and water storing services of trees could therefore not be seen as two separate services. In rocky desertification areas, which are quite comparable to the dry, concrete environment of urban vegetation, a tree can evaporate up to 170 liters of water a day (Waternet, 2019). Trees therefore do not only provide a water service in periods of extreme rainfall, but also in periods of drought.

In general, trees can play an important role in both temperature decreasing and flood preventing policies. Trees can lead to a direct air temperature drop of 0.5 to 3.0 degrees Celsius. But more important, they provide thermal comfort, by reducing the perceived temperature with up to 22 degrees. Meanwhile, these trees can capture 15 to 27% of the annual rainfall in urban areas and store up to 250 liters of water. However, the implementation of enough trees in urban areas to equalize the microclimate of rural areas seem unachievable and it might be useful to focus on other ecological features as well.

3 – Implementation of ecological features in urban areas

Vegetation can contribute to mitigate the consequences of climate change. However, it is hard to insert millions of trees in existing cities, as there is lack of space. Fortunately, there are alternative ways in which ecology and vegetation can be implemented in cities to store water and decrease temperature, of which a few will be discussed in this chapter. First, the beneficial effects of green roofs will be reviewed, followed by the impacts of vertical forests. Lastly, the potential of public park redevelopment will be determined.

3.1 - Green roofs as climatological solution

Since large portions of the surface of cities consist of buildings, it seems logical to first have a look at ecological features that can be implemented on this surface. On average, roofs account for 32% of the surface of a city (Fraser, 2005). Looking at the impermeable surface of a city, which is more relevant as vegetated areas already provide ecological services, this percentage rises to almost 50% (Dunnett & Kingsbury, 2008). These areas large areas are just concrete or asphalt, while these areas might be the key to mitigate climate change. Since these areas could not provide any other function, it might be relatively feasible to achieve this greening (Wong *et al.,* 2003; Heutink & Vlaskamp, 2010) Authorities have already advised governments in densely populated regions to implement green roofing for decades (Wong *et al.,* 2003; Hendriks *et al.,* 2016).

Figure 6: The green roof of Moesgaard Museum in Aarhus, Denmark. Photograph: view Pictures/UIG via Getty; image source: The Guardian.

First, vegetation at roofs affects the temperature of both the air and the building itself. The direct surface underneath the vegetation is 8 to 10 degrees lower when it is located under vegetation compared to a conventional roof with an impermeable, often dark-colored material (Dwivedi & Mohan, 2018). This is mainly caused by the enhanced albedo effect, since green roofs absorb less heat than dark materials. However, the vegetation itself also has a cooling effect on the air and surface of the building. It is again important to mention that the standard deviation of findings is large, meaning that the actual effect of green roofing on the temperature depends on many variables, including surroundings, climate, and design (Dwivedi & Mohan, 2018). Because of this natural cooling, less artificial cooling system is needed in the building, with a significant energy saving as a result (Saiz *et al.,* 2006). This energy saving can reach up to 25% in the upper floors and up to 6% for the entire building on average. This makes a green roof not only beneficial for the outside temperature of the city, but it is also a sustainable investment for the owner of the particular building.

Next to the lowering effect on the temperature, green roofs can also play an important role in the water management of a city (Mentens *et al.,* 2006). Mentens *et al.* (2006) performed extensive research on the runoff of precipitation in the centre of Brussels. Significant differences between the mean annual runoffs were found between different types of roof covering; these differences are shown in *Figure 10*. 81% of all precipitation flowed away on conventional roofs with an impermeable surface and replacing this material with gravel only had a small effect. In contrast, green roofs with vegetation retained significant portions of the rain, reducing the runoff to 50% (a thin layer of 5cm) or even 21% (when the green roof had a thickness of 35cm); see *Figure 10a*. With the implementation of green roofs at 10% of all roofs in Brussels, the runoff of the precipitation could be limited with 3.5% (Mentens *et al.,* 2006). This seems a small percentage, although it can be an important, easily achievable feature that can be beneficial in combination with other water managing designs (White, 2002).

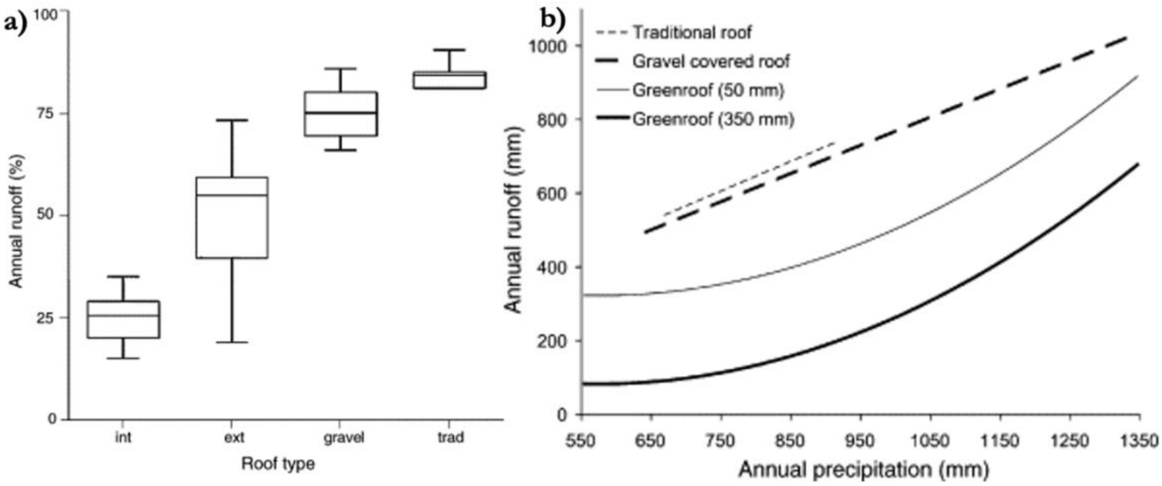

Figure 7: The effect of roof cover on the annual runoff (Mentens et al., 2006). The included roof covers are traditional hard covered (trad), gravel, green roof with a thickness of 50 mm (ext), and a green roof with a thickness of 350mm (int). **a)** Boxplot of the runoff percentages of the four roof cover types, showing that both types of green roofs significantly reduce the annual runoff. **b)** Relation between annual runoff and annual precipitation, showing that runoff of traditional and gravel covered roofs increases linearly, while green roof runoff increases exponentially with precipitation.

As a result of global warming, extreme rainfall events will occur more often in future (IPCC, 2014). Therefore, the beneficial effect of green roofs on water storage with a large magnitude of precipitation has to be determined. Due to a lack of scientific data regarding the functioning of green roofs under these conditions, the comparison in runoff between green and conventional roofs could not be made (Mentens *et al.,* 2006). Nevertheless, it is assumable that the effect of green roofs reduces under extreme rainfall events, as the vegetation and soil at the green roofs will saturate. Furthermore, green roofs function not optimally in relatively dry conditions, as vegetation benefits from moisture (Mentens *et al.,* 2006). While the runoff of conventional roofs is linear related to the annual precipitation, the relation of green roofs is therefore expected to be exponential (see *Figure 10b*).

The functionality of green roofs not only depends on the thickness of the layer, but also on the complexity and the implemented species (Afrin, 2009). The most basic green roofs consist of sedum and although these roofs already influence water storage and temperature (Maclvor *et al.,* 2016), these effects could be higher when the complexity and/or diversity of the vegetation is enhanced (Afrin, 2009). Some roofs also include small bushes in their design, which also increases the beneficial effects (Afrin, 2009). At the same time, this visualizes the limiting effect of green roofs. In principle, green roofs only consist of grasses and herbs, have a thin soil and should be user friendly, as management activities are difficult (Spala *et al*., 2008). Since trees and large bushes have a larger effect on temperature and water storage than grasses and herbs (Teuling *et al.,* 2010; Peng *et al.,* 2019; Siriri *et al.,* 2013), green roofs principally have a limited effect. Therefore, one could have a look at other, more beneficial features, as discussed in the next paragraph.

3.2 - Vertical forests as climatological solution

An ecological feature in which more complex designs could be implemented is a vertical forest. This is a building that is covered with vegetation on all sides, including herbs, grasses, shrubs and even trees. To be classified as a vertical forest, the vegetation should implement built-in trees with a height of at least 3m (Marugg, 2018). The first, and most famous, vertical forest is Bosco Verticale in Milan, Italy. This forest is built on two buildings, with a height of 116m and consists of 5000 shrubs and over 700 trees (Giacomello & Valagussa, 2015). The largest tree in Bosco Verticale has a height of over 9 meters. Soon, the first vertical forests will be realized in The Netherlands as well as projects in Utrecht (Wonderwoods), Eindhoven and Amsterdam (The Valley) will be accomplished in the coming years (Boeri Architetti, 2018; MVRDV, 2018).

Figure 8: Bosco Verticale, a vertical forest in Milan, Italy (Stefano Boeri Architetti, 2018).

The roof of a vertical forest is, obviously, a green roof. The characteristics depend per vertical forest, but the design is generally complex. Next to this, the upright sides of the building consist of vegetation as well. This can be done by attaching green plates with herbs, mosses, and sedum – comparable with the plates of the roofs, to the walls (Kohler, 2008). Alternatively, concrete planters are attached to the walls, in which a large variety of hanging plants and shrubs can be planted (Kohler, 2008). In most vertical forests, both panels and hanging planters are implemented in the design, as both provide different services (Marugg, 2018). Due to this characteristics, green sides can provide a larger plant diversity than green roofs (Fernandez-Cañero *et al.,* 2018). The third aspect and most eye-catching component of a vertical forest is the part in which trees are located. By complex architecture, large trees can be placed in multi-storey balconies. Every floor has a green balcony, with its own plants, shrubs, and trees, but also benefits from trees and shrubs planted at lower balconies.

Hardly any scientific data is available for the exact effect of vertical forests on the air temperature of the environment. Logically, one could conclude that the effect is higher than with green roofs only, as trees have a larger impact than herbs and grasses (Teuling *et al.,* 2010; Peng *et al.,* 2019; Siriri *et al.,* 2013). Furthermore, a well-designed vertical forest can accommodate large amounts of shrubs and trees (Kohler, 2008; Marugg, 2018)). However, it is questionable whether it is achievable to design a vertical forest with the same ecosystem services as a normal forest.

Regardless of the answer on this question, a vertical forest contributes significantly to desired decrease in air temperature.

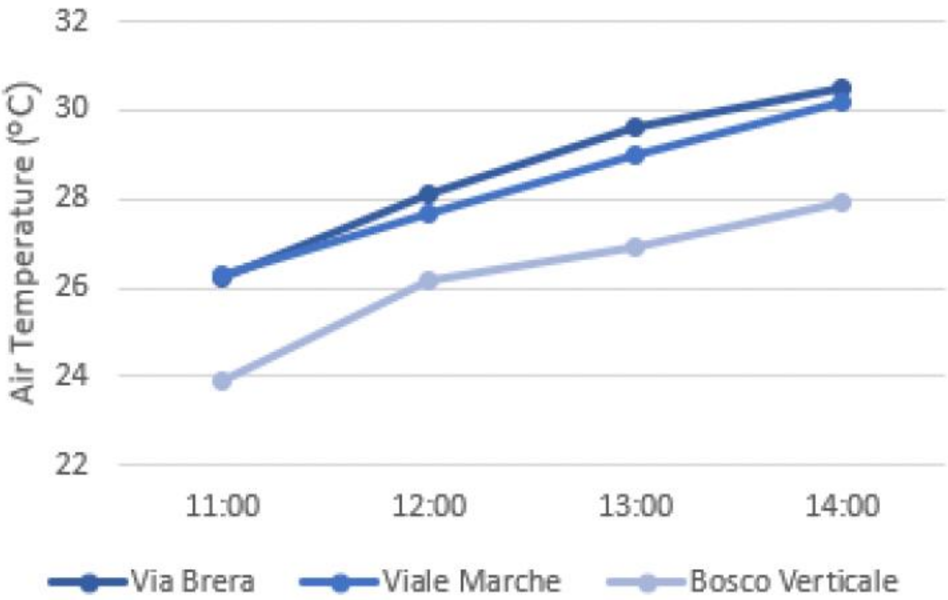

Figure 9: Air temperature near three same-sized buildings in Milan, including two conventional buildings (Via Brera and Viale Marche) and one vertical forest (Bosco Verticale), between 11am and 2pm (Marugg, 2018). During the entire period, the air was cooler next to the vertical forest than next to the other buildings.

Nevertheless, the limited number of studies performed on vertical forests gives us some insights. The presence of green balconies and green sides lead to a direct decrease of 10.8 degrees Celsius of surface temperature of the behind panels (Eumorfopoulou & Kontoleon, 2009). This also influences the temperature inside the apartments, as they lay 1.0 degrees lower in a vertical forest than in a normal building on average (Sun *et al.,* 2015). Both effects lead to a mitigation of the impacts of global warming. There is only one study known regarding the the effects of the air temperature outside the buildings as well (Marugg, 2018). This study compared the air temperature close to a vertical forest (Bosco Verticale) and two normal buildings (Via Brera and Via Marche); the means of these temperatures are shown in *Figure 12*. During the entire day, the air temperature next to the vertical forest was 2.0 to 2.5 degrees lower than next to the other buildings (Marugg, 2018). This implicates that a vertical forest could significantly contribute to mitigating climate change. However, it is important to be reluctant, as no other studies can confirm these dataSimilar findings were found in a recent, extensive case study in China (Ren *et al.,* 2022).

It is hard to determine the effect of vertical forests on the water storage of urban areas, as no scientific studies have been performed on this topic yet. Nonetheless, one could argue that vertical forests are likely to have a positive effect on reducing the chance of floods caused by extreme rainfall events. As discussed extensively in the previous chapter, trees have a large water storage potential, up to 250 liters per tree (Levi & Herwitz, 2005). There are no reasons to assume that trees in vertical forests are not able to store water as well. In fact, the planters in which the trees, shrubs and hanging plants are housed could function as water tanks as well, regardless of the effects of the vegetation (Cobacho, Arregui & Cabrera, 2008). However, it is conceivable that there are architectonical limitations of storing large amounts of water on the sides of a building. Moreover, the planters could not be saturated with water, as this will lead to a higher mortality of the plants (e.g. Basak *et al.,* 2015). More scientific research is necessary to determine the water storage potential of vertical forests, but it seems assumable that this potential is lower than in normal forests, not to say that there is no potential at all.

4 – What are the ecological options to mitigate climate change in Utrecht?

This chapter closes in on the specific situation of Utrecht. First, the impacts of climate change on the temperature and precipitation – and therefore water storage issues – is examined. Some concrete opportunities to implement ecological features to mitigate these consequences are mentioned. It is important to mention that these opportunities are based on plans of the municipality of Utrecht, the province and on my own analysis and suggestions and that no independent, scientific studies have been performed on this topic.

4.1 - The impacts of climate change on Utrecht

While the temperature rise is considered as a serious problem around the world, the temperature rise is even higher in Western-Europe than the global average (KNMI, 2021). Due to the relative vicinity of the rapidly warming poles, the temperature rise in Western-Europe is twice the global average. This implicates that the mean annual temperature has already risen by 1.9 degrees Celsius since 1950 in the Netherlands, based on a 10-year trend to limit the effect of outliers (KNMI, 2022). The mean temperature in Utrecht will equalize the current temperature of Bordeaux, which is located more than 750km south of Utrecht, in 2050 (Gemeente Utrecht, 2018). With the rising temperature, the annual precipitation has risen as well, with 17.0% to 915mm in 2021 (KNMI, 2022). Since 2010, the annual precipitation was stable. However, the seasonal peaks in winter and summer continued to grow, and with it the potential nuisance. Both temperature and extreme rainfall are therefore already affecting Utrecht.

Figure 10: Assessment on the temperature across the transect Nieuwegein-De Bilt, crossing downtown Utrecht (KNMI, 2018). a) The Urban Heat Island-effect was found since air temperature was significantly higher downtown than in the rural areas (at both the start and the finish of the transect (n=106)). Differences in temperature were higher at mornings than at afternoon measures. **b)** Image of the location where the highest temperatures were found: an almost completely paved zone of 200m between Neude en Vredenburg at downtown Utrecht.

Even more important than the mean temperature in Utrecht, is the difference in temperature between the city center of Utrecht and the rural surrounding areas. Since Utrecht is considered as a medium-sized city internationally (Rizwan *et al.,* 2008), one could expect that the Urban Heat Island-effect (UHI) applies to Utrecht. To examine this presumption, the KNMI has performed over 100 measurements on the air temperature on a transect (Gemeente Utrecht 2015; KNMI, 2018). This transect started in a rural area in Nieuwegein (southwest of Utrecht) and finished in a rural area close to the KNMI-measuring station in De Bilt (northeast of Utrecht). A significant difference in temperature between downtown, greener suburbs and rural areas was found (see *Figure 13a*). This difference was bigger in mornings (up to 1.8 degrees Celsius) than in afternoons (up to 1.0 degrees Celsius). It is remarkable that the temperature hardly increased over time downtown, while the air temperature increased with several degrees outside the city (KNMI, 2018). The KNMI also examined the difference in temperature between this spot in downtown Utrecht and the temperature at their measuring station, which is located at a rural area, at nighttime (KNMI, 2018). During these nights, the difference in air temperature can reach up to 7 degrees Celsius.

Both findings confirm that cities retain heat significantly better than rural areas (Voogt, 2016). The highest temperatures were found at kilometer 9 of the transect, which was located between Neude en Vredenburg. Since this area only consists of buildings, tarmac roads, and concrete squares (see *Figure 13b*), this is not surprising.

Next to the rising temperature, the increased chance of extreme rainfall events and floods is a reason for concern. As mentioned above, the mean annual precipitation has increased with 17% in De Bilt (KNMI, 2022). But for the risks of floods, it is more important to analyze the frequency of extreme rainfall events. The number of days with a precipitation of more than 20mm in Utrecht has doubled between 1905 and 2010 (see *Figure 14*; KNMI, 2018). Even though a rainfall event of more than 20mm is already considered as 'extreme rainfall' (IPCC 2014; Kreienkamp *et al.,* 2021), these rainfall events will not automatically lead to floods. To examine the chance of floods, the municipality of Utrecht has examined the effects of more than 80mm precipitation for the city (Gemeente Utrecht, 2014). These events occur once a year for the last 20 years, and this number is expected to rise further in the coming years. As shown in *Figure 15*, the large areas of Utrecht will flood in this scenario, with peaks of 50cm of water at the streets, squares, and sidewalks at some downtown spots. In the knowledge that a flood of only 2cm is enough to cause damage to properties, Utrecht does not seem to be able to handle these rainfall events according to this image. It seems therefore necessary to enhance the water storage capacity of the city.

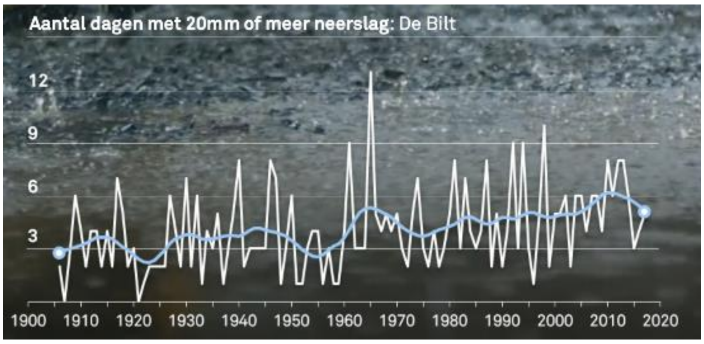

Figure 11: Days in De Bilt (northeast of Utrecht) with more than 20mm of precipitation since 1905 (KNMI, 2018). The blue line visualizes a 10-year trend. Even though the fluctuation is high, the occurrence of these so-called 'extreme wet days' has doubled between 1905 and 2010.

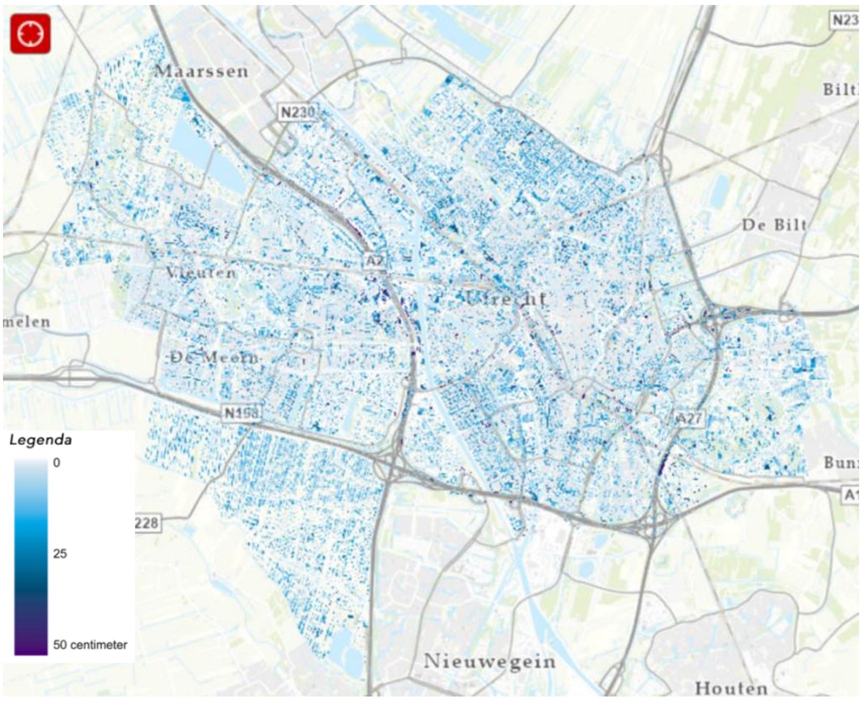

Figure 12: Map of Utrecht showing the height of floods after an extreme rainfall event of 80mm (Gemeente Utrecht, 2015). Large areas of the city will flood, especially downtown. These events currently occur once a year and are expected to occur more frequently because of climate change.

4.2 - Government plans to green Utrecht

In the most recent long-term vision regarding green structure, the municipality of Utrecht compiled five objectives (Gemeente Utrecht, 2018). Three of these goals already existed in previous long-term visions: enhance the ecological and recreative values of existing green, build large green areas around the city, and make green areas more accessible. These three objectives have been expanded with two, to respond to the urgent climate problem. Since 2017, climate adaptation and healthy urbanization are priority of the municipality of Utrecht in their infrastructure policy. It is a challenge to achieve these goals in a city that grows from 350.000 citizens in 2021 to more than 410.000 citizens within nine years.

Both water retention and cooling are explicitly mentioned as yields of green structures in the city (Gemeente Utrecht, 2018). However, no actual and verifiable objectives are mentioned concerning temperature reduce and water storage. The Province of Utrecht is even more careful in their vision. The province has the objective to 'create awareness' and 'embedding climate adaptation in their policy', investments in pilots and innovations has been made, but no concrete objectives regarding climate adaptation are mentioned (Provincie Utrecht, 2022).

So even though there are no clear objectives, and one could discuss the prioritization, both governmental organizations seem to intend to invest in climate adaptation. One of the main concerns of the municipality is the fact that over 50% of the city is covered with stones (Gemeente Utrecht, 2018). Green roofs are high on the list of potential measurements against this concrete desert, and grants have already been provided to implement green roofs (Gemeente Utrecht, 2018). Again, they do not express their vision on how many roofs should be regreened within a certain period of time. The provincial government has the objective to achieve more square meters of public green per household. But again, any facts are lacking in the published policy papers (Provincie Utrecht, 2022). In this publication is mentioned that 'the current amount of public green per household is known internally; nothing is written about an intended goal.

By contrast, the municipality of Utrecht explicitly mentions the priority zones in the city (Gemeente Utrecht, 2018). The main problems concerning heat stress are expected at industrial and business parks, as well as in the station area, in which the Jaarbeurs is also located (see *Figure 16*). Based on this, the local governance decided to designate four priority areas, in which the station area and Utrecht Science Park (two of the problematic areas) are included, as well as two yet to be (partly) built neighborhoods: Leidsche Rijn and Merwedekanaalzone. The local governance also has some explicit goals concerning water retention (Gemeente Utrecht, 2018). All precipitation of a rainfall event up to 20mm should be stored temporarily, meaning that no flood will occur in this situation. To achieve this, 2 hectares of asphalt roads are replaced by permeable cobblestones annually, even though this has some negative consequences regarding noise pollution and usability. Furthermore, 4 hectares of stone-covered areas should be regreened every year.

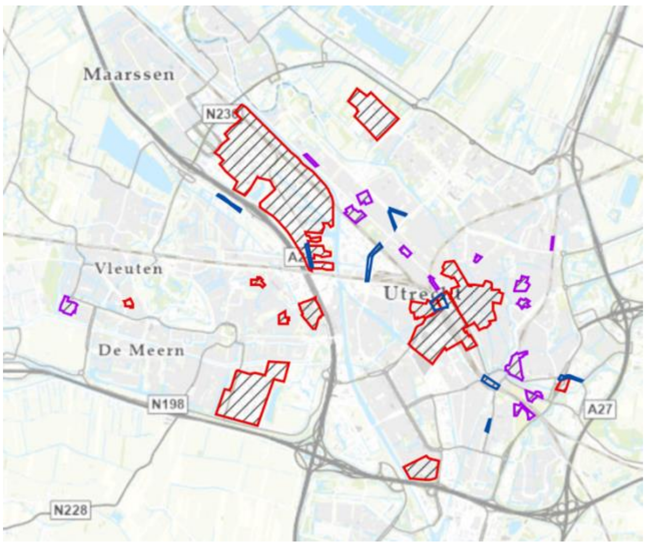

Figure 13: Map of Utrecht showing main areas of concern regarding heat stress (red circled areas; Gemeente Utrecht, 2018). Main problem areas are industrial and business parks and the area around central station and Jaarbeurs (downtown).

Despite these measures, the local governance does not deem itself capable to mitigate the consequences of climate change. In its vision, the municipality explicitly mentions the indispensable role of individual citizens, referring to the fact that 60% of the surface of the city is privately owned (Gemeente Utrecht, 2018). The governance supports citizens to regreen, for example by offering a free collection service of removed garden tiles. An even more effective measure is the obligation to compensate a concretion of more than 500 square meters, a legislation that also counts for companies and the government itself. With these measures, the municipality of Utrecht seems to aim for a situation in which anyone contributes to the improvement of the livability of the city.

4.3 – What are the potential opportunities for the local governance?

Based on the facts regarding the consequences of climate change in Utrecht and the analysis of the plans and policy of the local authorities, the opportunities to mitigate temperature rise and risks of floods in an ecological way could be determined.

The priority areas, as appointed by the local governance, all have one thing in common: these areas mainly consist of buildings, roads, and parking spaces. Due to its function, there was hardly any space for green in its initial design. In order to retain these functions, it is impossible to implement large green areas in these zones. Therefore, it is highly necessary to search for other features that can contribute to mitigate the consequences of climate change.

One of the things that could help is a *vertical forest* (see the previous chapter). In 2023, Wonderwoods, the first vertical forest of Utrecht will be achieved (Drukker, 2018). It is uncertain what the actual effect of this forest on the temperature and water storage of the completely gray area will be, although any significant effect could be expected (Marugg, 2018). To deliver the station area from its image as 'problem area' regarding heat and flood stress, only one vertical forest does not seem enough, based on the effect of one tree (Manickathan *et al.,* 2018) and the calculation that 10% more green can lower the temperature with 0.5 degrees (Kleerekoper *et al.,* 2018).

Green roofs is another possibility, and might be easier to implement in these existing, dense areas. Since roofs count for 32% of a city surface on average (Fraser, 2005), this feature has a high potential. Especially in these areas (Utrect Science Park, industrial areas, and the station area), buildings typically feature a flat roof. The implementation of green roofs on these buildings would not only reduce outside air temperature (*e.g.,* Afrin, 2009; Dwivedi & Mohan, 2018) it will also improve the indoor working climate (Saiz *et al.,* 2006). Of course, it would be better to regreen the areas by implementing parks including trees and ponds, however this is not achievable in these areas. Green roofs might therefore be the most feasible ecological way to reduce heat and flood stress, without compromising on the functioning of these areas.

The opposite applies for two other priority areas, Leidsche Rijn and Merwedekanaalzone. Both neighborhoods are (partly) yet to be built, which implicates more possibilities regarding the implementation of green areas. Utrecht has implemented large green areas in an already finished part of Leidsche Rijn in the last decade, indicating that the local governance is taking green structure seriously. The Merwedekanaalzone is still in the designing phase, meaning that there is room to implement the current visions and objectives. Based on its beneficial effect, it seems logical to implement green roofs at least. The inclusion of vertical forests in the design could be useful, although it might become superfluous when enough public green areas are already included in the design, an option that is less expensive. By using much high-rise buildings, the available space is used effectively, and more priorities could be realized in less space. This could free up space for green areas, without compromising on the intended aim of number of residents.

The local governance of Utrecht is currently brainstorming on the future plans of the Rijnenburgpolder. This area currently mainly has an agricultural function and is bought by the local governance of Utrecht (Havermans, 2021). The destination plan of the Rijnenburgpolder was one of the main issues for political parties during the campaign regarding the municipal elections of March 2022 (DUIC, 2022). Some parties want to build it up with houses totally, while other parties prefer investments in green energy sources like windmills or more valuable nature. Since the city expect to grow further in the coming decade and the already escalated housing crisis in the Netherlands (the national shortage of houses has reached 285.000 in 2021; Ronald & Dol, 2011; ABF, 2021), it seems inevitable that this polder should get a housing-function. Meanwhile, the local governance has the ambition to realise large areas of green with high recreative and ecological values at the edges of the city (Gemeente Utrecht, 2018). Both objectives must be combined in the destination plan of Rijnenburgpolder, therefore it is interesting to see what the final design of this polder will become in the coming years.

The local governance of Utrecht has already implemented large improvements regarding water storage of the city. The best example is the restoration of the Catharijnesingel, a canal located between the city center and the 'concrete desert' around Jaarbeurs and central station in downtown Utrecht (Tieleman, 2015). Back in the 1960s, the authorities decided to realise a highway across Utrecht and therefore drained the canal. In the last decade, the highway was removed, and the canal has been dug again. This decision has made a huge difference in the water storage of the city center (Bradbee, 2017), not even to mention the beneficial effects on livability and psychology. In combination with a reduced runoff caused by more green roofs (Madsen *et al.,* 1998; Mentens *et al.,* 2006) and a refurbishment of city parks to retain more water (Livesley *et al.,* 2016; Peng *et al.,* 2019), the possibility to store more water in surface tanks significantly reduces the chance of floods (Bradbee, 2017). In the neighborhoods yet to be build, it might be useful to learn from this earlier mistake to underestimate the importance of sufficient water storage capacity, and enough space should be considered for canals, ponds, or ditches.

5 – How could an individual citizen of Utrecht contribute to reduce heat and risk of floods?

While the authorities of Utrecht include climate adaptation in their policies, or at least they mention some measures in their vision and objectives, the local governance also mentions that they need support and contribution of the citizens of the city (Gemeente Utrecht, 2018). Without the help of individuals acting on their private areas, Utrecht cannot become protected against heat stress and floods, Gemeente Utrecht writes.

In their communication, the authorities refer to the abundance of pavements in the city. At least 60% of the city its surface consists of concrete, asphalt, and pavement (Gemeente Utrecht, 2022). Although precise data is missing, it is assumable that a significant proportion of these pavements is on private areas, as most of the city its surface is privately owned (Gemeente Utrecht, 2022). But how could an individual citizen contribute to the mitigation of climate change?

The municipality council of Utrecht came up with some ideas for citizens to get them going. Most of these measures are relatively small and easy to realize (Gemeente Utrecht, 2022). For example, a homeowner could disconnect his downspout and store precipitation in a barrel instead of letting it flow into the sewer. The local governance also mentions the implementation of green roofs in this communication, which is not surprising as green roofs are proven beneficial (Saiz *et al.,* 2006; Heutinck & Vlaskamp, 2010; Dwivedi & Mohan, 2018) and at least 32% of the surface of the city consists of roofs (Fraser, 2005). Another option is to replace a fence by a hedge, which has significant cooling and water storing services (Gemeente Utrecht, 2022).

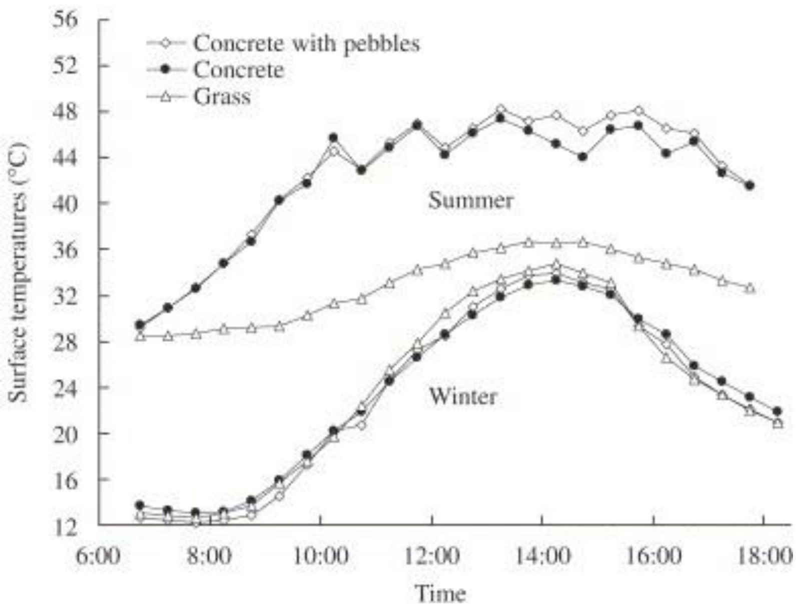

Figure 14: The mean surface temperature of three types of gardens during summer- and winter days in Taiwan (Lin *et al.*, 2007). In summers, grass-covered gardens had a significantly lower surface temperature than concrete-covered gardens; the presence of pebbles had hardly any effect. During winters, no significant difference between these three garden types was found.

One of the opportunities for an individual citizen to mitigate the consequences of climate change in their city is the regreening of their private garden. Many people choose for maintenance-free, totally paved 'gardens', where there is no space for plants and trees and where all precipitation runs off. But when tiles are replaced by grass, plants, shrubs or even trees, a citizen can contribute to both cooling their city, and prevent their city for being flooded (Lin *et al.,* 2007; Irmak *et al.,* 2017). The surface of a single garden can be over 10 degrees Celsius cooler at noon when this is covered with grass instead of concrete during summers (see *Figure 17;* Lin *et al.,* 2007). This effect was found in a subtropical climate and since both temperatures and solar radiation are higher in these areas, this result could not be copied 1 on 1 to Utrecht. However, even if the difference in temperature is smaller, the effect of grass on surface temperature is likely to be comparable. This difference in surface temperature has an impact on both air temperature and thermal comfort in a garden (Lin *et al.,* 2007). The air temperature in grass-covered garden is at least three degrees lower than the air temperature in an entirely tiled garden (again measured in summers at noon; Irmak *et al.,* 2017). The effect on thermal comfort and heat stress could hardly be expressed in figures, especially for the temperate climate of Utrecht, however both are proven affected by the presence of grass instead of tiles (Irmak *et al.,* 2017).

The effect of replacing a hardcover by grass (or other low vegetation) on temperature is comparable to the effect of green roofs (Spala *et al.,* 2008). Although this could be interpreted as a limited effect, vegetation in gardens has some serious advantages in relation to vegetation at rooftops. The most important one is that gardens have the potential to include large trees, while roof tops only contain medium-sized shrubs in the best-case scenario. Since trees have a greater effect on both temperature and water storage than grass (Teuling *et al.,* 2010; Peng *et al.,* 2019), the removal garden tiles potentially have a larger effect on microclimate than the implementation of green roofs. Furthermore, the soil underneath garden pavements store water automatically if the water reaches the soil. Replacing only 35% of an impermeable surface by any semipermeable alternative leads to a 35% increase in water storage (Zabret, 2013). This effect could already be accomplished without any vegetation, so even using gravel instead of concrete or tree bark instead of tiles could contribute to a higher water storage (Zabret, 2013). The local governance of Utrecht explicitly mentions the potential and importance of garden tiles removal in their long-term vision (Gemeente Utrecht, 2018). And since the governance especially needs help regarding flood prevention, they name the insertion of a pond in a garden as preferable tile-replacing surface cover.

One of the ways in which citizens could be encouraged to remove concrete and tiles from their garden is by devising a tax. Some local Dutch authorities have developed plans to replace a fixed water board tax by a system in which households pay in proportion to the degree of petrification of their garden (Boluijt, 2017). Other governances, like the Gemeente Utrecht, prefer a reward system. Citizens already can receive subsidies to achieve green roofs or greener gardens. Moreover, garden tiles are picked up for free in Utrecht and anyone can apply for an initiative grant (Gemeente Utrecht, 2018). With this grant, any sustainable project could be financed, such as the realization of facade gardens or the planting of precious trees. In conclusion, garden owners have various greening options, which seems to have a significant effect on both temperature and water storage.

Although this is an option for many, not every citizen of Utrecht has a garden. This does not mean that these individuals cannot contribute to climate adaptation. In terms of temperature, small-scale greening measures can already yield major benefits (Saiz *et al.,* 2006; Livesley *et al.,* 2016). Facade gardens and green balconies at least enhance thermal comfort (Wang *et al.,* 2018; Klok *et al.,* 2019) and therefore reduce heat stress (Irmak *et al.,* 2017). Furthermore, the beneficial effect on indoor climate is even bigger than the actual effect on the outside temperature (Saiz *et al.,* 2006). Next to these measures, the realization of green roofs is, perhaps in cooperation with co-residents, for most citizens achievable. In terms of water storage potential, the absence of a garden is more disadvantageous, as trees could hardly be used, and large-scale water retention is difficult. Vertical forests might be able to fulfil this need (Eumorfopoulou & Kontoleon, 2009; Sun *et al.,* 2015), but citizens depend on the decisions of housing associations for that. In short, all citizens can contribute to climate adaptation, to varying degrees reliant to the situation.

6 – Discussion on the potential of ecological climate adaptation

This review has provided an analysis of the necessity of climate adaptation in urban areas and the potential of several ecological features to provide this. Although these features seem beneficial on reducing flood risk and providing thermal comfort, these factors do not provide a complete overview on this topic. In this chapter, some side issues will be discussed. For example, the other beneficial effects provided by these ecological features and to what extent these features are affordable.

6.1 - Ecological features can help Utrecht to handle climate change

This review provided insight in the possibilities of ecological measures to mitigate the effects of climate change, especially increased heat stress and flood risk. There are several ways in which vegetation can contribute to climate adaptation. It is hard to determine the actual effect of one three, or one square meter green roof. Nevertheless, vegetation has a significant influence on increasing thermal comfort and water storage in urban areas. The extent to which a feature is beneficial depends on multiple factors, including the type of vegetation, the structure of the city map, and the size of the feature. For Utrecht, green roofs seem to be the most easily implementable feature, especially in Jaarbeurs-central station area and even in combination with other purposes, such as generating green energy. Water storage of the city center has benefited from the restorage of the Catharijnesingel, which indicates that water tanks are an important feature providing flood risk reduction. Food forests could be an interesting way to finance ecological climate adaptation, with multiple beneficial side-effects. In general, vegetation has many beneficial effects next to climate adaptation, including biodiversity restoration, mental health improvement and cost reduction.

6.2 - The price tag of ecological climate change mitigation

Even though the benefits of green roofs, vertical forests and more complex urban parks are significant, critics argue that these measures are not affordable (Stein *et al.,* 2013). To determine whether regreening is financially beneficial, one should consider all positive effects of vegetation mentioned before. However, it is hard to express these benefits in monetary amounts. Foster *et al.* (2011) tried to examine the potential financial effect of vegetation and concluded that green infrastructure has a huge value. For example, one fully vegetated hectare affords 2000 dollars a year because of improved air quality, and even 16,000 dollars by reduced energy consumption annually in New York City (for example by reduced need for air-conditioning (Saiz *et al.,* 2006). In combination with all other values, New York City claims to save 2.4 billion dollars in the coming 20 years by accomplish their regreening plans. Other findings in this study are a value of 30 to 90 dollars a year for each planted tree and an annual yield of green roofs of 300 million dollars for Toronto, Canada. All these amounts are just estimates, although these conclusions indicate a large potential value of regreening measures.

Considering this potential value, one could argue that ecological climate adaptation is not that expensive. However, most features mentioned in these review benefit from high-rise, leaving a lot of space for a green environment. High-rise buildings are way more expensive than low-rise (pphp, 2018), costs that should be taken into account when analyzing the value of vegetation. It is hard to determine which value is more important, the cost of high-rise on the one hand and climatological, psychological, and even financial benefits on the other hand.

Another argument for regreening is the fact that a green surface not always fungates as a vegetation layer only. For example, a green roof can effectively be combined with energy generation (Hui & Chan 2011; Shafique, Luo & Zuo, 2020). In fact, vegetation can strengthen the capacity of solar panels (Hui & Chan, 2011). Solar panels generally benefit from a moderate temperature. And since vegetation reduces air temperature (Rahman *et al.,* 2017; Manickathan *et al.,* 2018), solar panels in a green environment provide up to 8.3% more energy than panels on a hard-covered roof (Hui & Chan, 2011). Again, the effectiveness of this combination depends on the design of the vegetation and the solar panel type, nevertheless it is an option to combine both (Shafique, Luo & Zuo, 2020). Despite of a slightly reduced thermal benefit of green roofs in presence of solar panels, the combination has 'many advantages and a few disadventages', according to Saadatian *et al.* (2013).

6.3 - Regreening enhances physical and mental health

Even though the focus of this review was on reducing global warming and flood risks, regreening measures like the green roofs, vertical forests and pavement replacements also have a beneficial effect on well-being. First of all, a green environment provides fun, although it is difficult to express this in numbers and figures (Livesley *et al.,* 2016). Something which is measurable is the reduction of psychological stress caused by a green environment (Livesley *et al.,* 2016; Marugg, 2018). Less stress could lead to less health issues and therefore positively influences well-being (Thoits, 2010). Next to the direct effects of the presence of vegetation on stress and pleasure, the activity of gardening also has an influence. A relatively short, 10-minute gardening break (and even at a small balcony) already reduces long-term stress levels (Mladenovic *et al.,* 2017).

Companies that have doubts on investing in regreening the environment of their offices should look at the productivity of their employees. A green environment enhances labor productivity with 10 to 15% on average (Mangone, 2015). All effects of vertical forests, whether proven in numbers or not, are shown in *Figure 18*. These effects include for example a reduction of noise and an improvement of air quality (Marugg, 2018). All in all, the presence of green positively influence human well-being in many ways.

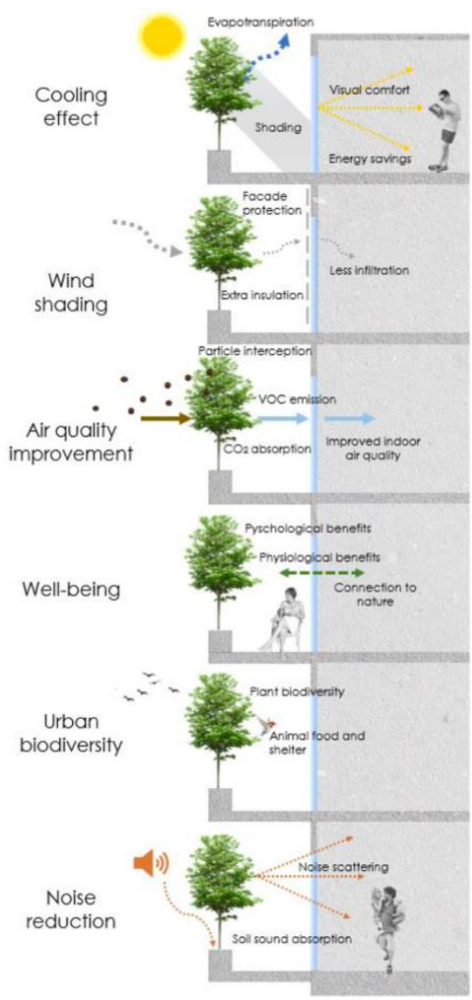

Figure 15: Summary of the potential benefits of vertical forests and green balconies (Marugg, 2018).

6.4 - Urban vegetation is salvation for biodiversity

Since several decades, the world is facing an enormous biodiversity crisis. Since 1970, over 52% of biodiversity has been lost worldwide (Brooks, 2002). The most important reason for this loss of species is the disappearance and destruction of natural habitat, for example because of urbanization (Fahrig, 2003). Insect diversity is an indicator for biodiversity in general, as they strongly depend on plant diversity and most insects are key stone species as they are essential for birds and mammals (Hallmann *et al.,* 2017). At least 75% of all insects have been disappear within several decades (Hallmann *et al.,* 2017). This is not only affecting other organisms, but also human beings. The financial damage in the agricultural sector caused by more difficult fertilization of crops due to a lack of insects is estimated at 57 billion dollars worldwide (Losey & Vaughan). Measures that enhance insect diversity could therefore be beneficial in multiple ways and are needed more than ever.

Vegetation always has a positive effect on insect diversity and abundance (Zhao & Duo, 2021). But since both strongly depend on management and composition of vegetation, this does not automatically mean that ecological measures in urban areas have a significant effect on insects. Therefore, Drukker (2018) examined the insect abundance at green roofs and concluded that all green roofs are positively influencing insects. However, the highest roof included in this study was 70m. It is unknown whether the green roof of for example Wonderwoods, with a height of more than 116m, still has a positive effect on insect abundance. Further research is necessary to determine this, but one can already conclude that low and medium-high green roofs are beneficial. Next to this, green roofs also accommodate a large insect diversity. A study on 25 green roofs in the Netherlands found 579 species, which can be interpreted as a large diversity (Tanis, 2020). However, insect diversity at green roofs strongly depends on the vegetation type (Tanis, 2020). The simplest green roofs with only sedum do not seem to have a large impact.

All in all, protecting and restoring biodiversity is an important side-effect of regreening urban areas. The extent to which a climate adaptation measure benefits biodiversity strongly depends on the design and specific situation of the project.

6.5 - Are food forests the best of all worlds?

Local authorities always must consider many interests in their policies. While they mention that it is important to act on climate adaptation, they experience great pressure on facilitate sufficient housing, a beneficial economic situation, and not insignificant, sufficient food production. A food forest might be the solution to combine all these interests in an urban area.

A food forest is a modern way of producing food, based on the principles of a natural forest (Björklund, 2012; Nytofte & Henriksen, 2019). Since many species are included, more mutualistic symbioses arise. A crop production system that looks and functions like a natural forest provides many benefits. For example, a forest accommodates significant more biodiversity and carbon storage than traditional agricultural land (Buinink, 2020). Furthermore, an environment that looks like a forest has a positive effect on mental well-being, has an educational value, and could be an affordable investment.

One of the priorities of the local authority of Utrecht in their latest long-term vision was to accomplish more precious green at the edges of the city (Gemeente Utrecht, 2018). Instead of designing a conventional urban park, the local governance could consider the promotion of a food forest at these locations. It is unclear whether food forest produce sufficient food to replace conventional agricultural farms. However, this might not be the goal for these food forest. One might consider these food forests as climate adaptation or as urban regreening project, instead of an agricultural feature. From that point of view, a food forest might be a way to finance regreening and climate adaptation. Since a food forest provides both local-produced and health food and psychological advantages (Riolo, 2019), it might be beneficial for local citizens to invest in a food forest. The realization of a food forest might therefore be more affordable than a 'normal' urban park with a comparable ecological value. A food forest perfectly fits within the objectives of the local authorities of Utrecht, making it an attractive ecological feature that mitigates climate change (Gemeente Utrecht, 2018).

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