A Greener Hoefkade

A research on the effects of green spaces on heat stress, flooding, and livability in the Hoefkade, The Hague

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Executive Summary

Many urban areas struggle with the consequences of climate change. The Hoefkade in The Hague suffers from heat stress in summer and from flooding after heavy rainfall. The Municipality of The Hague wants improvement and has commenced planning the redevelopment of the street. ECOnsultancy has been asked to assist this redevelopment by focusing on green measures. In our research we aimed to answer the question:

> How can more greenery and other climate adaptation measures be incorporated into the Hoefkade to mitigate heat stress and flooding while taking into account the opinions of residents and local employees?

To answer this question, we combined two research methods. We conducted qualitative interviews with the main stakeholders - residents and local employees - of the Hoefkade, and we used quantitative modelling in the Tygron Geodesign platform. With this, we created and analysed five scenarios in which green spaces are the basis for redevelopment of the Hoefkade. The five scenarios include a baseline scenario 0 showing the current situation in the Hoefkade, an all green scenario 1, the current redevelopment plan of the municipality (scenario 2), and two greener variations on this plan (scenario 3 and 4). For all of these scenarios, we analysed the effect of the introduction of greenery on heat stress and flooding. These results were then combined with the results of the interviews, in order to give a set of recommendations to the municipality.

From the qualitative research, we found that the residents and employees in the Hoefkade in general would like to see more greenery. They experienced heat stress as a problem, but flooding had not caused any inconvenience thus far. Additionally, the interviewees expressed the wish for more colour in the street and to be more involved in the redevelopment of the Hoefkade. The municipality can meet these needs by introducing for example facade gardens, hanging flower baskets, and by having regular information meetings in the Hoefkade.

After analysing heat stress in Tygron, we found that adding the amount of greenery that the municipality has planned is already highly effective. Temperatures can be reduced up to 5.2 °C. Adding more green measures, like we did in scenario 3 and 4, will only reduce the temperature by an extra 0.1 °C. More green measures like hedges, facade gardens, and green parking spaces do not add much to the already considerable cooling effect of trees. Therefore, the municipality can use trees to alleviate heat stress.

In contrast to heat stress, we found that flooding is relatively more difficult to mitigate with greenery. In most scenarios, there was little improvement and sometimes even a deterioration. However, the rain showers in our calculations presented a rather extreme

situation (100 mm in two hours), but they are relevant, as such showers will occur increasingly often in the future due to climate change. Scenario 4 went further than just green measures, and implemented water storage tanks and permeable bricks in the street, which have a large storage capacity. This proved effective for shorter rain showers. However, during longer, heavier showers, this storage does not suffice. The municipality will need to look further into improving the sewer system to tackle the problem of flooding.

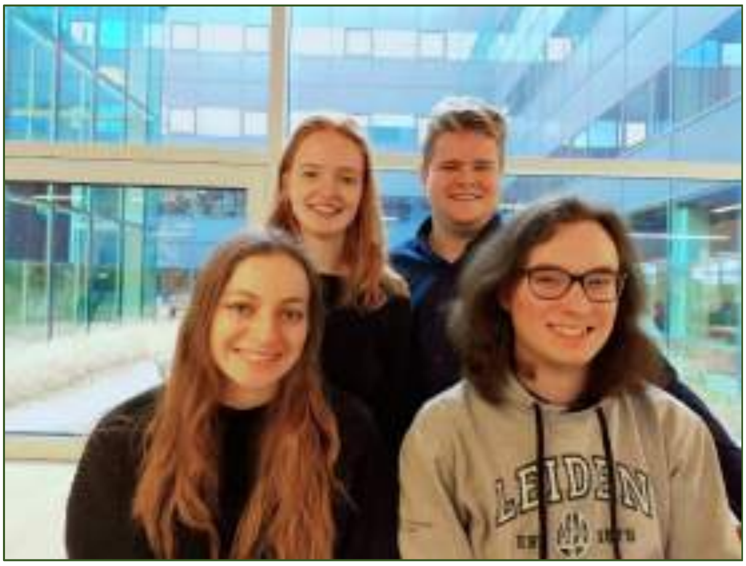
All in all, this research provides the Municipality of the Hague with a spectre of options for making the Hoefkade a greener, cleaner, cooler, and drier place, to be enjoyed by all residents and local employees. Our findings form the building blocks necessary to achieve higher-level goals concerning liveability in the Hoefkade. An attractive and climate-resilient Hoefkade will serve as an example for many other streets in The Hague and the Netherlands.

1. About ECOnsultancy

We are ECOnsultancy, a student Environmental Consultancy Organisation based in The Hague, Delft, and Leiden. We are a small, but varied group of Bachelor of Arts and Science students who all have a common interest in sustainable development. As part of our minor in Sustainable Development at Leiden University, we have decided to combine our different backgrounds and knowledge to create an interdisciplinary consultancy team adopting a systems approach to problem-solving. We advise and support our clients with regards to sustainable city planning, working collaboratively with the different stakeholders to enable optimal results. Our approach is characterised by:

- Research-based analysis: we believe that thorough research is the foundation of successful decision-making.
- An interdisciplinary approach: our variety of backgrounds ensures we always take a holistic approach, examining multiple perspectives, and focusing on comprehensive solutions.
- A real long-term impact: we try to make our research and advice as useful as possible, focusing on long-term plans and real solutions to significant issues.

We aim to contribute to the United Nations' Sustainable Development Goal 11 "Sustainable Cities and Communities" in everything we do. The SDG targets include, but are not limited to, creating greener cities, limiting environmental impacts, and working towards more inclusive communities ("Goal 11: Sustainable cities and communities", n.d.). ECOnsultancy applies these global targets to make a difference at a local level.



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2. Introduction

Climate change is one of the most pressing problems of today. Cities are major contributors to climate change as a result of their high energy consumption and greenhouse gas emissions (Taylor, 2017). In addition, cities are the centres of human population. Although urban areas are a major part of the causes of climate change, they are also especially vulnerable to the effects of climate change. Over the past decades, more and more cities around the world have been facing challenges regarding climate change, which is why urban resilience and sustainability have become increasingly important topics all around the world. In the Netherlands, issues like heat stress and flooding continue to be of importance in city planning (Runhaar et al., 2012). In light of recent years' record-breaking heat waves in the Netherlands, heat stress mitigation has become an increasingly important topic, especially within Dutch cities as a result of the urban heat island effect (Van Hove et al., 2019). Moreover, climate change has resulted in more extreme weather events that have caused flooding to become another prominent topic in the urban planning of Dutch cities ("Klimaatontwikkeling extreme neerslag", 2019).

Because climate change is not likely to slow down any time soon, issues like heat stress and flooding will only worsen over time. Therefore, it is extremely important that solutions to these problems are quickly implemented in urban areas. Not only will the mitigation of heat stress and flooding contribute to the prevention of major problems in cities, it also has the ability to improve the liveability of urban areas, resulting in more pleasant places to live and work. Solving climate-related issues like heat stress and flooding cannot be done without taking into account the complexity of cities. All layers of the urban system are interconnected - from socio-economic dynamics to governance networks (Meerow, Newell, & Stults, 2016) - and therefore a challenge can never be tackled in isolation.

The introduction of greenery can have positive effects on all layers of this urban system. Introducing more greenery - especially trees - in an urban area is an effective measure against heat stress (Santamouris et al., 2018). A typical tree can lower the temperature of its surrounding area by 2-3 °C, and sometimes even more. A tree does this in two ways: through evapotranspiration and by providing shade. Besides heat stress, greenery can mitigate pluvial flooding in a city in different ways. Firstly, greenery is usually in or surrounded by soil, and it is easier for water to infiltrate into soil than into asphalt or other types of hard paving which create quick runoff (Sörensen, 2018). Secondly, the foliage of a plant or tree slows down the rain water, giving it more time to infiltrate into the ground. This slows down and eventually decreases runoff ("How do urban trees reduce flooding", 2019). Therefore, more leafy greenery like trees and larger plants are most effective in combating flooding. Besides making it more liveable by decreasing heat stress and flooding, a greener urban environment also has a positive effect on the mental well-being of residents and visitors (Santamouris et al., 2018). A greener environment has the potential to reduce stress and anxiety, making people calmer and more peaceful, and it can even improve social cohesion. On top of that, more greenery has been shown to reduce aggression and violence (Kuo & Sullivan, 2001). All these positive effects of greenery have the potential to drastically improve the liveability and resilience of urban areas.

A good example of a Dutch urban area where many challenges - climate-related or otherwise - come together is the Hoefkade street in The Hague. This is why the Municipality of The Hague has decided to invest in redeveloping the Hoefkade to improve its urban resilience. ECOnsultancy has been asked to examine how greening the Hoefkade can mitigate heat stress and flooding, consequently making the Hoefkade more sustainable and resilient.

The next sections will explain the Hoefkade Challenge more in depth, as well as introduce the research question and main direction of this report, and elaborate on the structure of this report.

Box 1. Key concepts

Sustainable development
"Development that meets the needs of the present without compromising the ability of future generations to meet their own needs" (United Nations World Commission on Environment and Development, 1987).

Sustainable city
An urban area in which there is a high quality of life, shared prosperity, and social stability, without harming the environment (Cieraad, 2019).

Liveability
The extent to which a direct urban environment meets its people's needs and wishes (Leidelmeijer and Van Kamp, 2003).

Urban resilience
"The ability of an urban system - and all its constituent socio-ecological and socio-technical networks across temporal and spatial scales - to maintain or rapidly return to desired functions in the face of a disturbance, to adapt to change, and to quickly transform systems that limit current or future adaptive capacity" (Meerow, Newell & Stults, 2016).

2.1. The Hoefkade Challenge

In a densely populated and compactly built-up area in the Schilderswijk and Stationsbuurt in The Hague, the Hoefkade is facing several challenges. These include heat stress, flooding, different types of pollution, and cut-through traffic, and they severely impact the quality of life in this street. With the aim of solving these issues, the Municipality of The Hague has produced a draft redevelopment proposal (Plan van Aanpak Hoefkade) in which the current situation of the Hoefkade and the desired improvements are laid out (Gemeente Den Haag, n.d.). The information about the Hoefkade in the following paragraph is derived from this draft proposal.

An important factor in the redevelopment of the Hoefkade is the mobility transition from cars to bicycles as the main means of transport. To facilitate this, the speed limit has already been lowered from 50 km/h to 30 km/h in order to discourage people from driving through this street and to make the neighbourhood safer. Moreover, the Municipality of The Hague is planning to redirect car traffic to other streets altogether, making the Hoefkade a car-free zone with the exception of the emergency services. This will make the street more attractive for cyclists in order to fulfil its function as Sterfietsroute - a bicycle freeway ("Netwerk sterfietsroutes," 2019).

Despite the fact that The Hague has already done a lot of work and research on these mobility measures, there is still room for improvement when it comes to climate adaptation in the Hoefkade area. Although a good first priority is making the Hoefkade more liveable by means of improving the traffic flow, the Municipality of The Hague has expressed the wish of combining this with the introduction of more greenery. Therefore, the focus of this research is greenery. More green spaces, in combination with other climate-adaptation measures, could simultaneously tackle a variety of issues, eventually creating a living environment that is not only much more attractive to residents and visitors, but one that is also more sustainable and resilient. To this extent, the main research question which ECOnsultancy aims to answer is:

> How can more greenery and other climate adaptation measures be incorporated into the Hoefkade to mitigate heat stress and flooding while taking into account the opinions of residents and local employees?

To answer this question, different green scenarios are created and discussed, taking into account the interests of the three main stakeholders: the Municipality of The Hague, our client, and the residents and local employees of the Hoefkade. In the following section we will discuss the topics of heat stress, flooding, and liveability more in depth.

2.1.1. Heat Stress

With an increase in temperatures, cities like The Hague - and especially their densely built-up streets like the Hoefkade - are dealing with higher peak temperatures in the summer (Hansen et al., 2010). In this research, urban heat stress is defined as the increase in temperature of an urban area relative to the rural area (Solecki et al., 2005). Heat stress is a problem because it is uncomfortable to work, walk, or leisure in a hot environment. Severe heat stress can even affect the health of human beings, leading to death in certain cases (Harlan et al, 2006). According to research by Haaglanden, the conurbation surrounding The Hague, the number of deaths could potentially increase by 12% during a heat wave ("Regionale Klimaat AdaptatieStrategie Haaglanden," 2014).

Urban heat stress is caused by both the low albedo - the proportion of radiation reflected by a surface - of dark structures within cities, as well as by the high energy consumption in the city (Li & Zhao, 2012). Whereas reducing the energy consumption in urban areas is often difficult and costly, heat stress can more easily be reduced by introducing more vegetation and by increasing the albedo of the urban area. Increasing the albedo of buildings and surfaces lowers the heat by radiating sunlight back into the atmosphere (Liang & Wang, 2012). In addition, greenery has the ability to reduce heat by evapotranspiration and by providing shade (Ban-Weiss et al., 2011; Santamouris et al., 2018). Additional green spaces therefore decrease the temperature of both the atmosphere and the surface.

In summer, the Hoefkade is considerably warmer than the rest of The Hague (figure 1). To make the Hoefkade a more liveable place especially at times when temperatures are high, measures must be taken to decrease the heat stress. Therefore, in this research we will create different scenarios that display the effects of different types of green measures on heat stress in the Hoefkade.

Figure 1. Heat stress in the Hoefkade area (adapted from Gemeente Den Haag, n.d).

2.1.2. Flooding

In addition to heat stress, flooding is a considerable problem in the Hoefkade area (figure 2). The present urban structure of the Hoefkade does not make the street resistant to flooding in the event of heavy rainfall ("Gemeentelijk Rioleringsplan Den Haag 2016-2020," 2015) (figure 2). This problem of flooding will most likely be exacerbated in the future because of climate change and more extreme weather events ("Pinning extreme weather", 2018). Therefore, it is vital for the Municipality of The Hague to take action. A flood-proof Hoefkade will improve liveability and resilience now and in the future.

In this research, flooding is understood as water in the street that is unable to quickly infiltrate into the ground, be drained by the sewage system, or stored otherwise. At the moment, the existing sewers that serve the Hoefkade are simply not wide enough to deal with the large amounts of water after heavy rain (H. Pilot, personal communication, December 9, 2019) and the composition of the road and pavement does not allow for sufficient infiltration. As a consequence, in the case of heavy rainfall, water levels in the Hoefkade can reach over 20 cm within two hours (figure 2). The ideal situation we aim for is when water levels in the street stay close to zero at all times, including at times of heavy rain showers.

Measures need to be taken to improve infiltration and drainage. Green spaces have the ability to improve infiltration greatly by delaying runoff and decreasing sealed surface area (Sörensen, 2018). ECOnsultancy investigated which measures related to greenery have the potential to mitigate flooding in the Hoefkade.

Figure 2. Flooding in the Hoefkade area (adapted from Gemeente Den Haag, n.d).

2.1.3. Liveability

The third and last topic that needs attention is liveability. The Municipality of The Hague has mentioned that since the Hoefkade will be redeveloped, this is a good opportunity to make the neighbourhood more appealing to its residents and employees (Gemeente Den Haag, n.d.). The mobility transition towards the growing use of bicycles at the expense of the presence of cars is already increasing this attractiveness to a large extent, since cars will no longer be the standard picture in the Hoefkade. Further social and economic spin-offs of greening the Hoefkade will be investigated by another student consultancy called SustainabiliBuddies Consultancy. This research by ECOnsultancy, however, will be limited to how green spaces can improve the living environment in the Hoefkade. By tackling the two challenges of heat stress and flooding, the Hoefkade will most likely already experience an upgrade in liveability as a result of an increase in green spaces.

However, liveability is a subjective concept (Box 1) and different people may have different views of what a pleasant living environment looks like. It is therefore important to take stakeholders' perceptions into account and not make assumptions about their interests. The main stakeholders, besides the municipality, who are most affected by changes made in the Hoefkade, are residents and local employees. Not only are they most influenced by the greening of the Hoefkade, they are also important contributors to the development of the Hoefkade as a whole. Being aware of their interests is a big step towards creating inclusive solutions that benefit as many people as possible.

2.2. Strategy

In the next chapter of this report we explain how the research was approached. We discuss the various methods we used, including qualitative interviews and the Tygron Geodesign platform which was used to create different scenarios towards a greener Hoefkade. After this, chapter 4 elaborates on the results of our research and chapter 5 provides a discussion on the results. We consequently give our recommendations to the Municipality of The Hague in chapter 6. The remaining sections consist of our acknowledgements, references, and the appendices.

This research will provide the Municipality of The Hague with valuable information that is both scientifically supported and practically applicable. With this research we aim to contribute to a safer, more liveable, and more sustainable Hoefkade, which might even set a precedent for other streets in The Hague and in the Netherlands.

3. Methods

Our methodology consists of two main parts. First of all, we have interviewed the main stakeholders of the Hoefkade, namely residents and local employees, in order to obtain a more comprehensive overview of what they believe the problems in the Hoefkade are. This method will be further explained in chapter 3.1. Secondly, we have created scenarios with different combinations of green spaces in order to see what their effects are on heat stress and flooding. These scenarios and the calculations have been made using the Tygron Geodesign platform. This programme and its functions will further be elaborated on in chapter 3.2. Chapter 3.3. will subsequently provide a justification of the scenarios we have chosen.

3.1. Interviews with Residents and Employees

We conducted semi-structured street interviews in the Hoefkade with the main stakeholders; residents and local employees. We interviewed eleven people in total during nine different interviews. Four interviewees worked in the Hoefkade, the rest of them lived in or in the immediate vicinity of the street. Three of the employees we interviewed were also residents of the Hoefkade. Appendix A provides the notes we took during and right after every interview.

We have interviewed only a small number of people. We did this because our goal was to become aware of some of the different opinions of the main stakeholders and not to statistically analyse a large amount of data. The aim was to interview a variety of people in the street and in shops and businesses of the Hoefkade to reflect the opinions of residents and employees. We have chosen these stakeholders specifically because they are the people who currently face the issues of the Hoefkade every day and who are likewise most influenced by the redevelopment of the Hoefkade. The interviews have been used to stay open-minded and to gain more insight into the problems the Hoefkade's residents and employees face, and the solutions they propose or agree with. The questions we asked were prepared in advance (Appendix A). Sometimes the order in which we asked them varied. At times we left out or added a question if that seemed appropriate. We started with a broad question about improving the Hoefkade in general, then we moved to the topic of greenery, after which we asked about interviewees' perceptions on heat stress and flooding specifically. Because the interviews were conducted with random people in the street who remained anonymous, we could not send them our notes afterwards to have them validated.

3.2. Tygron Geodesign platform

For the quantisation of heat stress and flooding, we have been granted access to the Tygron Geodesign platform. This platform allows its users to generate a 3D map environment in which one can model and predict specific effects of certain factors on an area (Tygron, 2020). We have used this programme to predict the effects of adding green spaces to the Hoefkade on heat stress and flooding. This has been done by creating several scenarios, including a baseline scenario, a maximum green scenario, the current redevelopment plan of the municipality, and two new scenarios. The scenarios differ in scope and impact in order to present various alternatives to the currently planned redevelopment. We used the Tygron platform specifically because it allowed us to model alterations to the present state of the Hoefkade regarding infrastructure and green spaces, as well as execute simulations to find out the effects of different scenarios. This made the Tygron platform the perfect tool to reach our research objectives. In this section, we provide an explanation on how the programme works and how we used it to quantise heat stress and flooding using overlays and indicators, as well as how we created specialised functions. After this, we will elaborate on the different scenarios we will generate.

3.2.1. Heat Stress Overlay

Heat stress is visualised in Tygron as a grid-based overlay. The data shown in the programme is not based on measured, fixed data, but calculated based on a module called the Deltaprogramma Ruimtelijk Adaptatie (DPRA) module ("DPRA Heat Module", 2018). With this module, one can perform stress tests that are standardised to the Dutch Delta Programme guidelines. These stress tests allow for the identification of potential vulnerabilities within an area by calculating the possible future effects of climate change on this area ("Bijsluiter gestandaardiseerde stresstest Ruimtelijke adaptatie", 2019). The heat stress grid-based overlay in Tygron provides the heat stress within an area with a grid size of 0.5 m * 0.5 m and takes several factors into account, including but not limited to the wind direction, heat radiation, humidity, and the Bowen ratio of objects, which describes the type of heat transfer for a surface with moisture ("Bowen ratio result type", 2019). In order to set a useful reference temperature, the standard day and time of the DPRA module in Tygron is used (02-08-2013 at 14:00). The Tygron platform describes this day as a hot day with a humidity of 60%, a temperature of 33 °C, and a sun radiation of 700 W/m^2. The heat stress overlay can provide several types of results, such as temperature of the atmosphere, amount of shade, and the physiological equivalent temperature (PET). In this research we calculated heat stress in PET, for the reason that this measurement is a form of perceived temperature, which is the most relevant temperature when it comes to heat stress.

3.2.2. Water Overlay

Similar to the heat stress overlay, the water overlay is also a grid-based overlay within the Tygron platform. It is a built-in water module which can be used for rainfall, groundwater, flooding, and hydraulic structures. In our research, the rainfall event is the only one used, as we only focus on pluvial flooding. We decided to set the rainfall to 100 mm of rain within a time span of 120 minutes, because this is the same type of rain shower that is often used by municipalities and water boards in the Netherlands, as well as by the Klimaatatlas (n.d.). Although 100 mm within two hours is an extreme and thus far rare type of rainfall in the Netherlands, it is expected to occur more often in the near future as a result of climate change ("Klimaatontwikkeling extreme neerslag", 2019). Because the time span of this rain shower is only two hours, evaporation of water will be negligible and most water will either infiltrate in the ground, be drained away by the sewer system, or otherwise stay on the street and cause flooding. The sewer system is automatically generated by Tygron, based on the factor of urbanisation and the size of the neighbourhood. Since this is automatically generated, it is not an exact representation of the real situation in the Hoefkade.

3.2.3. Indicators

In order to generate quantitative results, Tygron uses indicators. Indicators are measurements of change, which can be used to evaluate potential progress within the scenarios. We used four indicators to evaluate the scenarios. These are indicators on the amount of green space, the reduction of heat stress, the reduction of water stress, and the number of parking spaces in the Hoefkade.

The first indicator, which designates the relative amount of greenery in the area, takes the following data from Tygron concerning the Hoefkade area:

- Total surface area (in m^2).
- Total grass or fallow surface area (in m^2).
- Total surface area with the so-called M2 attribute (in m^2). The M2 attribute represents the 'greenness' of an object. This includes trees, hedges, green roofs, etc.

A total area of green space is calculated by summing the grass, fallow, and M2 areas. No distinction is made specifically between the ground types grass and fallow land and both will be interpreted as grassland in Tygron. As a maintained plot of grass is of better quality in regards to growth and size compared to an empty field, the ground types grass and fallow lands - which do not possess any objects on top - are multiplied with the standard factor of 0.7 for the total green surface area.

The second indicator is a modified version of the Tygron heat stress indicator. This indicator compares the average temperatures in the area before and after the implementation of greenery. The indicator generates the average decrease in temperature for the Hoefkade. A maximum cooling capacity of 7.6 °C is assumed, due to the fact that this is the highest improvement found if the whole area is forested (see results scenario 1 chapter 4.2.2.).

Indicator three, the water indicator, makes use of the water overlay within Tygron. In order to provide a clear overview of the flooding situation, three different fractions of the total area are calculated and presented to the user. These fractions show the part of land that has been flooded by more than 0, 100, and 200 mm of water. These are calculated by taking the land area that has been flooded by at least any amount of water, 100 mm of water, and 200 mm of water, and dividing these numbers by the total area of the Hoefkade (21,200 m^2).

Fourthly, to calculate the number of parking spaces within the Hoefkade area, we used the parking space indicator. This indicator calculates both the planned number of parking spaces, as well as the original number, so that they can easily be compared.

3.2.4. Specialised Functions in Tygron

As Tygron does not possess every type of object or green space that is required by our research, we had to make some of our own objects.

First of all, in order to simulate facade gardens, which have been used in scenario 4 (chapter 3.3.5. and 4.2.5.), we decided to use the shrubbery object from the Nature database of Tygron. The guidelines of the municipality for facade gardens ("geveltuintjes" in Dutch) are as follows: The maximum breadth of the garden can be 45 cm and there must be at least 1.5 m of clear walkway left between the edge of the garden and the curb (Den Haag, 2016). We tried to adhere to these measurements as much as possible, but since the smallest possible grid size in Tygron is 50 cm * 50 cm, we used a breadth of 50 cm.

Furthermore, in order to represent green parking spaces, which have been used in scenario 3 and 4 (chapter 3.3.4., 3.3.5., 4.2.4., and 4.2.5.), we created a duplicate of the permeable parking spaces from the paved areas. This duplicate has been edited in order to provide a heat reduction by changing its Bowen Ratio to 0.4 (based on grass). As the green parking space is half grass and half brick, some water can be stored in the grass part. In order to simulate this in Tygron, we further edited the parking space to make it able to store a small amount of water - 0.04 m^3/m^2 - based on the value for permeable parking spaces in Tygron.

3.3. Scenarios

In order to create the scenarios, we first had to create measures within Tygron. A measure is a premade list of changes that override the original spatial data. Measures can for example include the introduction of green spaces or the replacement of parking spaces. Our scenarios are based on the plans of the municipality and on greenery measures that affect temperatures and stormwater storage potential. The implementation of each measure was consequently compared to the original situation (scenario 0) to show the improvement or deterioration of the indicators. In addition, we evaluated to what extent the measures comply with the wishes of the residents and employees of the Hoefkade. With the help of these measures we could easily compare the different scenarios to each other and identify the advantages and disadvantages of each scenario.

For each scenario we made multiple maps and a table. The maps are figures of the Hoefkade in Tygron which display the levels of heat stress and flooding. The tables show the related values, including data on land use and green surface area, heat stress, water stress, and the number of parking spaces in this scenario. In total we created four scenarios in addition to the baseline scenario (scenario 0), which we compared to each other in the discussion. Again, this made it possible to easily see and compare the effects of different green measures on heat stress and flooding.

3.3.1. Scenario 0 - Baseline

At present, the Hoefkade area is experiencing high levels of heat stress and flooding and there is little greenery in the street (Gemeente Den Haag, n.d.). It is important to be aware of the current situation in order to see where in the Hoefkade the biggest problems occur and to have an idea of what the main opportunities towards a greener Hoefkade are. To achieve this, we first created a scenario 0 in Tygron, which displays the current scenery and the levels of heat stress and flooding. This scenario 0 is necessary, as it functions as a reference for the other scenarios. We expected this scenario to be very similar to the situation of the Hoefkade displayed in figure 1 and figure 2, because even though we used a different tool than the Klimaatatlas (n.d.), we did not yet change anything about the Hoefkade.

3.3.2. Scenario 1 - All Green

The first scenario we made ourselves is a fully green scenario. This scenario does not take into account any of the current infrastructure or the future plans, but rather empties the whole street to introduce as many trees as possible. We used this scenario to achieve better insight into the maximum possibilities for improvement. Although this scenario is not realistic, it was a useful means to investigate what the maximum heat stress and flooding reduction in the Hoefkade can be. This way we could form an idea of what results would be feasible in the other scenarios, and it may further help the municipality to set clear targets for stress reduction. In this scenario, we filled the whole Hoefkade area with standard deciduous trees (Tygron Nature database) and no roads or other utilities remained.

3.3.3. Scenario 2 - Plan Municipality

The second scenario was not created by us, but was already planned by the Municipality of The Hague (GDH DSO Verkeer, 2018). We transferred this plan into ArcGis, and then loaded it into Tygron. The current plan of the municipality aims to improve liveability and resilience in the Hoefkade. The main changes in this plan are related to mobility.

The traffic situation is different: roads are narrower at certain points and some roads are blocked by rising bollards, which will result in less traffic. Interestingly, the number of parking spots is hardly reduced. Although this redevelopment plan already includes the introduction of more trees, there is still space for more greenery. Modelling this scenario helped us gain insight into what the current redevelopment plan would do to the level of heat stress and flooding in the Hoefkade.

3.3.4. Scenario 3 - A Greener Plan

For scenario 3, we examined what the possibilities for additional greenery are within the current redevelopment plan of the Municipality of The Hague. We decided to stay within the limits of this street design to show the possibilities of introducing more greenery in the Hoefkade without having to drastically change the structure of the street. This way, we simultaneously took into account the municipality's views and wishes, as well as the call of residents and local employees to make the street a lot greener.

Three different factors have been changed in this scenario. Firstly, some extra trees were added to areas in which there is space. Secondly, the subsurface of all the parking spaces has been changed from a brick surface to the green parking spaces (figure 3). Green parking spaces should ensure better water infiltration and a slightly lower temperature in the Hoefkade area ("Groene parkeerplaatsen", 2020). The parking spaces also provide a small amount of water storage (0.04 m^3/m^2). Thirdly, in some areas of the street, the sidewalks are currently very wide. In order to make use of this vacant space, we replaced these areas with 1 m high hedges.

Figure 3. A green parking space (Art Gallery Courtyard/Parking Lot, 2018).

3.3.5. Scenario 4 - Even Greener

For scenario 4, we investigated the opportunities for more green spaces outside of the current plans of the municipality. This means that rather than staying within the current structure of the street, we studied the possibilities of transforming more of the stony street into green spaces. This included for example giving up parking spaces or narrowing pavements to make room for greenery. This scenario takes into account the opinion of some of the residents and local employees that green spaces should come at the expense of mobility and infrastructure, and it shows the municipality what these trade-offs will yield in terms of climate resilience. In other words, this scenario shows a more drastic alteration to the current features of the Hoefkade, allowing for more green spaces than scenario 3, but being more realistic than the all-green scenario 1.

The first major change in this scenario was the replacement of the brick roads by special water permeable bricks. These bricks allow better water penetration into the ground and can store a small amount of water (0.14 m^3/m^2). However, they possess less strength and are more expensive than regular bricks ("Permeable Pavement - Green Building Alliance", n.d.).

In conjunction with these changes to the road, several underground water storage facilities were placed. These are a variation to the normal water permeable bricks, yet with an increased storage capacity of 1 m^3/m^2. These would be placed roughly 80 m apart and have a surface size around 64 m^2.

Moreover, as mentioned in chapter 3.2.4., we created a specialised function in Tygron for facade gardens. In this scenario, these have been introduced. Next to buildings where the sidewalk is wide, facade gardens have been inserted with a breadth of around 0.5 m. Since the Tygron grid has a size of 0.5 m * 0.5 m, facade gardens were relatively difficult to implement, as the grid lacked the proper precision to give small gardens the correct shape. Therefore, the facade gardens in this scenario should only be seen as a rough approximation.

Furthermore, another change was made to the parking spaces, besides making them green. We shortened several longer parking spaces and completely removed others in order to make room for hedges or more trees. This was done proportionally around the Hoefkade, resulting in a decrease in parking spots from 268 to 241. We made a special plan for the square between the Doedijnstraat and the Jacob Catsstraat. In the municipality's redevelopment plan, a small green area of 4 m wide was planned in this location. In order to enlarge this area, we removed the parking spaces in front of the square and we shifted the sidewalk into the old location of the parking spaces. This provided around 2 m of extra space, making the green area 6 m wide. This extra width provided the space for a second line of trees and for a bigger green square.

4. Results

4.1. Opinions of Residents and Employees

When interviewing the residents and employees of the Hoefkade, the first question was aimed at finding out interviewees' opinions on how to improve the Hoefkade in general. At first, most people seemed content with the Hoefkade as a living environment, and some could not even think of any problems that need to be solved. However, once asked whether there was really nothing they would change, most of the interviewees admitted that there are various issues that could use improvement. According to most residents and employees, the main problem of the Hoefkade is traffic. The traffic situation is being regarded as very unsafe. The speed limits, as well as other traffic rules, are ignored. Multiple interviewees explained that they fear for their children's safety in the street. This issue of traffic is already addressed by the Municipality of The Hague (Gemeente Den Haag, n.d.). Some interviewees were aware of this; others were not.

When asked, almost all interviewees were very positive about the idea of adding more greenery to the Hoefkade. Most of them thought the current amount of greenery is insufficient. "The more the better" is something we heard a lot. The most frequently named advantages of adding greenery include that it would improve the look and atmosphere of the street, reduce stress, and make the street and the people in it more peaceful. In other words, interviewees overwhelmingly thought that more greenery would improve liveability. Before we asked anything about heat stress, one interviewee already mentioned that more shade would be an advantage, because it would cool the street.

When asking about potential downsides of introducing more greenery in the Hoefkade, the answers varied. The lack of space and the danger of branches falling on the street were both said once. Something that came up more often was the potential problem of people littering, trampling the greenery, picking flowers, and other antisocial behaviour. People also believed that the costs would be too high for the municipality. Some interviewees said they hoped that the municipality would allocate more money to the introduction and maintenance of greenery. On being asked what absolutely cannot be replaced by greenery, most interviewees said they could not think of anything or that they did not mind. One interviewee answered that footpaths and bicycle lanes should not be eliminated to make space for more greenery, and another interviewee said that playing areas for children should be prioritised.

Interviewees came up with some ideas for further introducing greenery in the Hoefkade. Flower baskets and facade gardens were mentioned as a good way to improve the attractiveness of the street. One person mentioned that a park where children can play would make the street better. When asked what type of greenery the interviewees preferred, most of them answered trees and flowers. Introducing more colour to the street is something we heard a lot. Other interviewees did not mind.

Figure 4. A hanging flower basket ("Fotoboek hanging baskets", n.d.).

Figure 5. A facade garden ("Geveltuintje aanleggen? Dat mag!", 2018).

We asked specifically about the interviewees' experience of heat stress and flooding. Some residents said they definitely experience heat stress as a problem. Others said that in summer it can be extremely hot, but that they did not think it was a problem specific to the Hoefkade. Interestingly, none of the interviewees recollected having experienced inconvenience of flooding after a heavy rain shower.

Worth mentioning is that many of the residents and employees we questioned spoke negatively of the municipality. They mentioned that they feel like they are not listened to or that they do not get sufficient opportunities to hear about and potentially add or object to the municipality's plans. The argument that the municipality implements ideas from their ivory tower was given a lot. "Come and see what goes on here" exclaimed one shopkeeper. Another resident suggested more regular information meetings at the community centre where the municipality can discuss its plans for the Hoefkade with residents and other stakeholders.

When asked, quite a lot of the interviewees said they would be interested in participating in initiatives or projects related to greenery. However, some of them thought that only few others would be interested as well, and some expressed concern about making residents responsible for anything at all. One person said that she would be interested, but only if many other residents participate. A collective action problem seems to arise here.

4.2. Scenarios

4.2.1. Scenario 0 – Baseline

Table 1. Overview results scenario 0.

Land use and green		Heat stress		Water stress	
m^2 of green	788 m^2	Heat stress reduction compared to maximum	0%	More than 0 mm water	94%
Percentage of green	4%	Degrees of reduction	0 °C	More than 100 mm water	78%
m^2 of green objects	72 m^2	Mean PET temperature	42.9 °C	More than 200 mm water	51%
m^2 of grass	824 m^2	Maximum reduction	0 °C	Other	
m^2 of fallow	199 m^2	Maximum increase	0 °C	Parking spaces	268

In the current situation of the Hoefkade, the amount of urban greenery is very low. We calculated that only 4% of the total area (21,200 m^2) is classified as green. This 4% is made up by 72 m^2 of M2 objects (trees, green roofs, hedges, etc.), 824 m^2 of grass and 199 m^2 of fallow lands.

As can be seen in figure 6, the heat stress map of the Hoefkade shows a combination of high and low temperatures. Upon closer analysis, we found out that the low temperature areas only exist in places surrounded by trees and in the shadows of the buildings (figure 7). As the number of trees in the Hoefkade is currently low, the areas with low temperatures are small in comparison with high temperature areas. Furthermore, we calculated that the average temperature of the whole Hoefkade area is 42.9 °C PET, while the average of the hot zones is 48.8 °C PET and the average of the cooler zones is 35.2 °C PET. Hot days like the one that this scenario is based on (02-08-2013, 33 °C) are occurring increasingly often in the Netherlands (Klimaatatlas, n.d.). Residents in the Hoefkade already experience them as problematic, and they remember the heatwave of last summer (2019) well (Appendix A). To mitigate discomfort and prevent illness and death related to heat stress in the future, the situation in the Hoefkade needs to change.

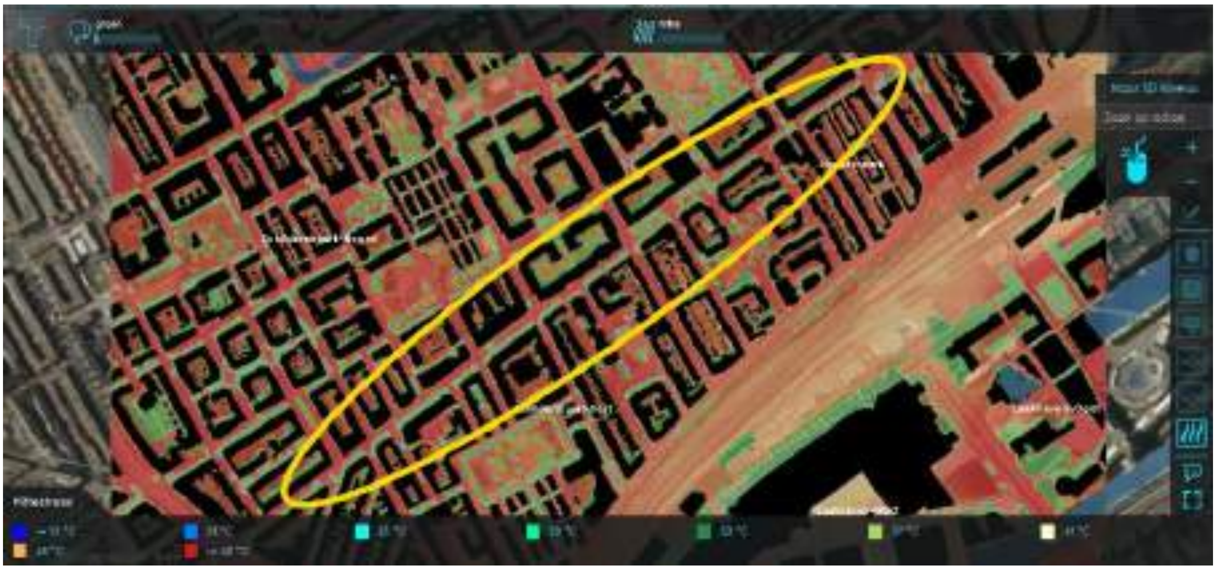

Figure 6. The absolute heat stress levels for scenario 0.

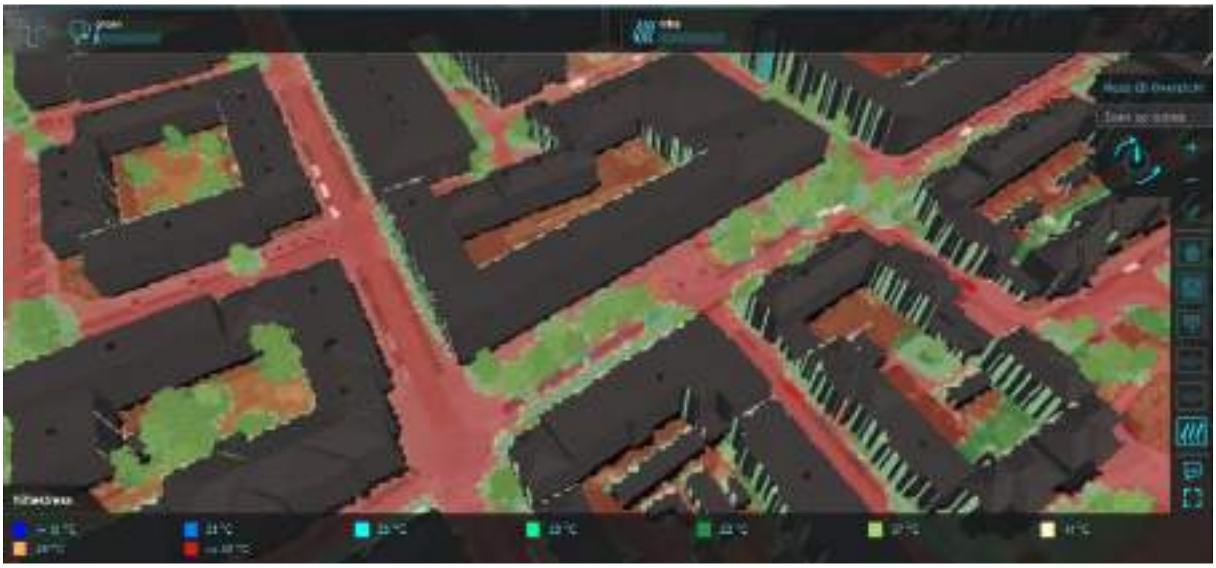

Figure 7. A zoomed-in figure of the heat stress levels for scenario 0.

The current situation regarding flooding is also problematic. This is not surprising, as the current sewer system was not built to sustain the level of rainfall modelled (H. Pilot, personal communication, December 9, 2019). The rainfall that is used in this model (100 mm in 120 minutes) is an extreme case, which does not occur often. This also becomes clear from the interviews, in which none of the interviewees remembered experiencing any inconvenience as a result of flooding (Appendix A). However, with a changing climate, rainfall at this scale will occur increasingly often in the future ("Klimaatontwikkeling extreme neerslag", 2019). It is therefore vital that the municipality and the Hoefkade are prepared for this. The images below show that, in the current situation, this is not the case. As figure 8 and 9 show, almost no area within the Hoefkade exists that is completely dry (only 6%). We calculated that roughly 78% of the area is flooded by at least 100 mm and 51% is flooded by at least 200 mm. As the situation is currently problematic, the possibility exists that extra greenery might not be sufficient and more drastic measures are needed.

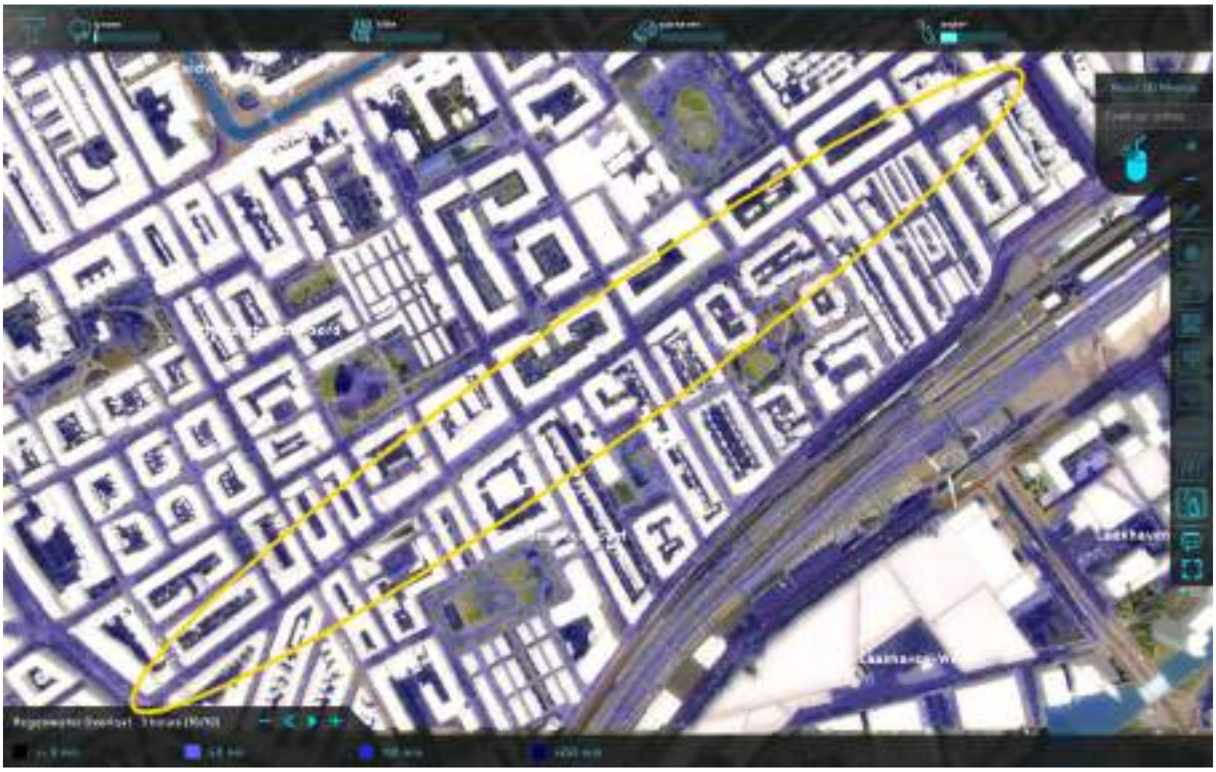

Figure 8. The water levels after two hours of rain for scenario 0.

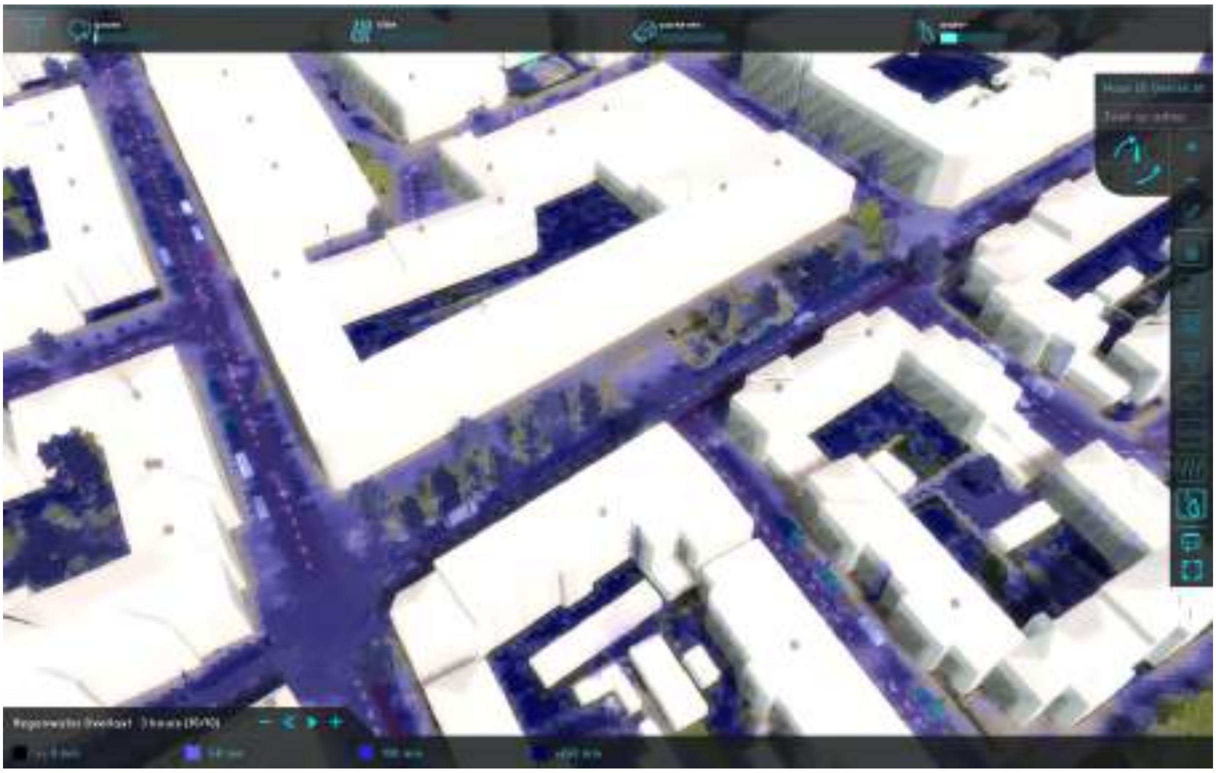

Figure 9. A zoomed-in figure of the water levels after two hours of rain for scenario 0.

The results were validated with the images from Klimaatatlas (n.d.) which showed similar results.

4.2.2. Scenario 1 - All Green

Table 2. Overview results scenario 1.

Land use and green		Heat stress		Water stress	
m^2 of green	20022.6 m^2	Heat stress reduction compared to maximum	99%	More than 0 mm water	100%
Percentage of green	98%	Degrees of reduction	-7.6 °C	More than 100 mm water	83%
m^2 of green objects	20022.6 m^2	Mean PET temperature	35.3 °C	More than 200 mm water	55%
m^2 of grass	0	Maximum reduction	-13.7 °C	Other	
m^2 of fallow	0	Maximum increase	0.3 °C	Parking spaces	0

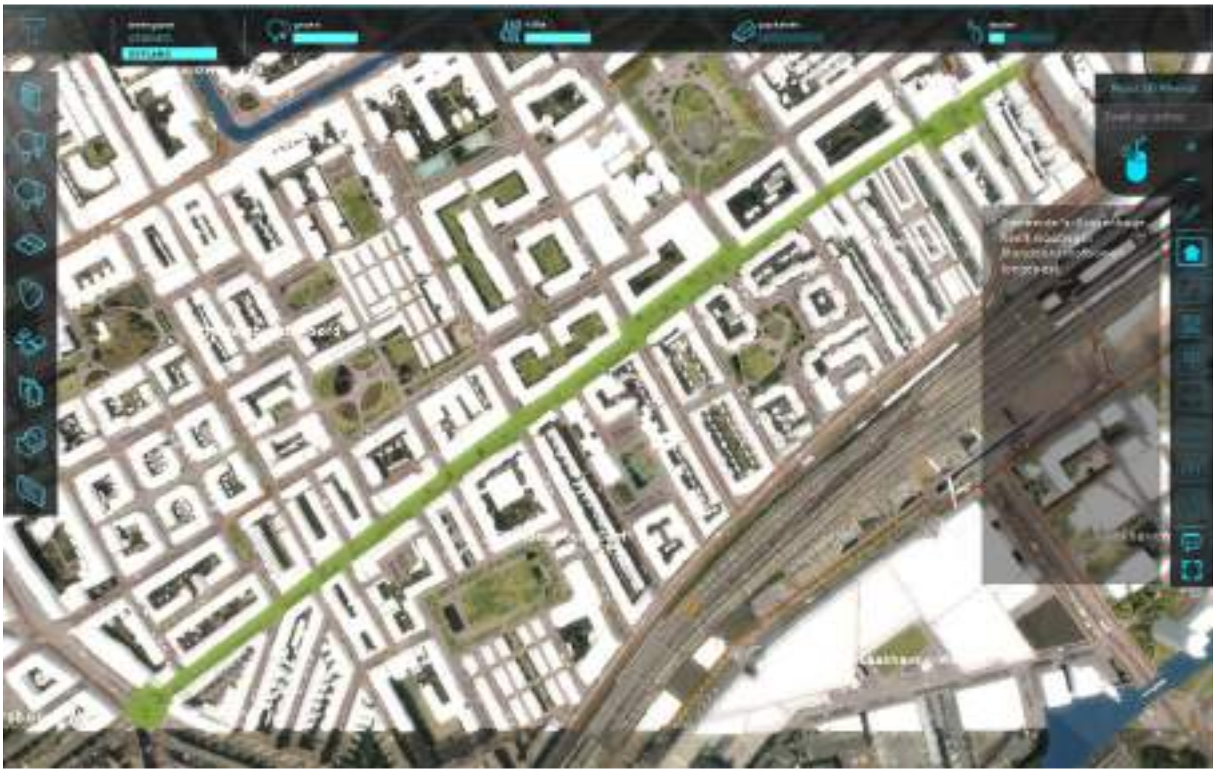

Figure 10. The Hoefkade full of trees in scenario 1.

For scenario 1 we covered the whole street with trees (figure 10). In Tygron, it was possible to green 98% of the street. When examining the effects of the maximum value of greenery, we found the biggest improvement in the reduction of heat stress (figure 11). By filling the street with trees, the maximum temperature reduction value was reached. We calculated an average reduction in temperature of 7.6 °C PET. This can best be seen in figure 11, which displays the changes in PET, showing considerable improvements. These improvements are largest in areas where previously no trees or shadows from buildings existed.

Figure 11. The changes in PET in scenario 1.

Besides heat stress, we obtained some interesting results from the water overlay in scenario 1. The areas flooded by any amount of water have increased with 3% (from 94% to 97%), the areas that are flooded by more than 100 mm have increased with 5% (from 78% to 83%) and the areas flooded by more than 200 mm have increased with 4% (from 51% to 55%). As can be seen in figure 12, the areas in the north-east side of the street are improved, whereas at the other end the situation has worsened. As the north-east area is lower-lying, the water would normally flow to this area but is now slowed down, thus improving the situation in the north-east while deteriorating the situation at the other end. The water is likely slowed down by the trees as these have a higher friction factor compared to asphalt (F. Witsenburg, personal communication, January 22, 2020). We do not know for sure whether this explanation is correct. For the Hoefkade overall, the water situation worsens.

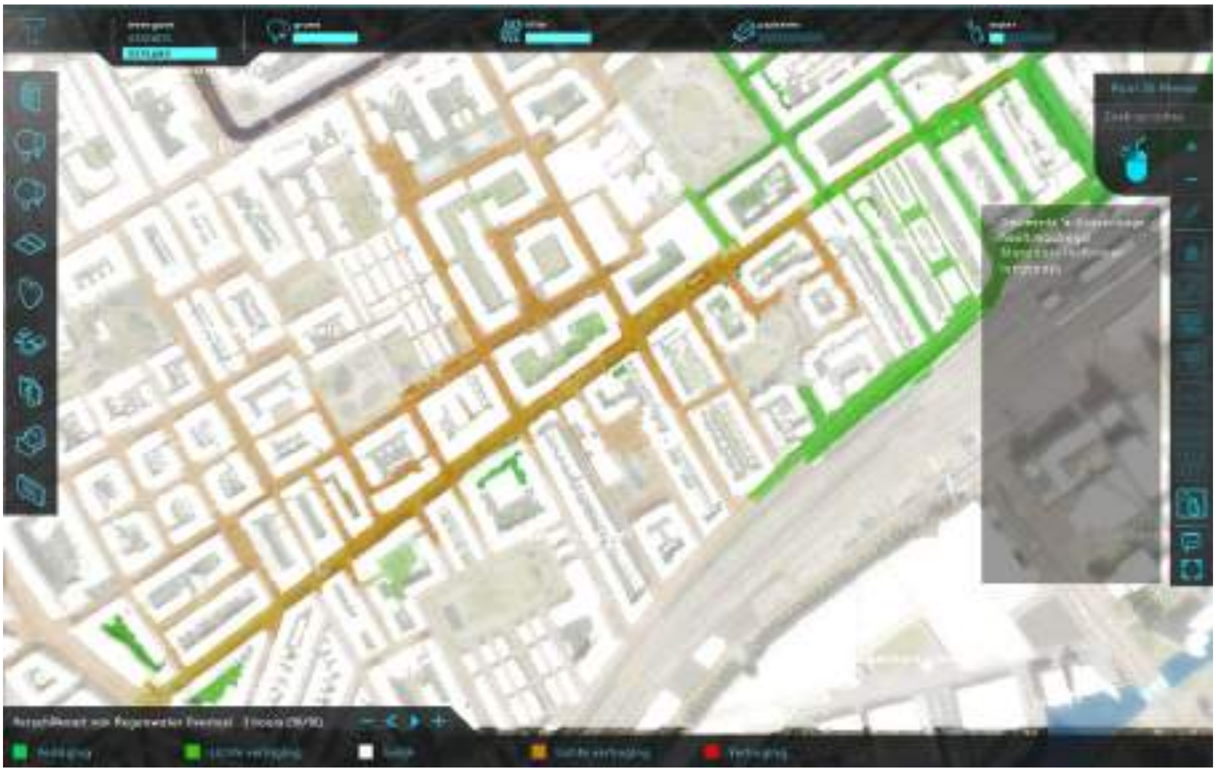

Figure 12. The improvement and deterioration of the water levels for scenario 2.

4.2.3. Scenario 2 - Plan Municipality

Table 3. Overview results scenario 2.

Land use and green		Heat stress		Water stress	
m^2 of green	1317 m^2	Heat stress reduction compared to maximum	68%	More than 0 mm water	94%
Percentage of green	6%	Degrees of reduction	-5.2 °C	More than 100 mm water	78%
m^2 of green objects	614 m^2	Mean PET temperature	37.7 °C	More than 200 mm water	51%
m^2 of grass	818 m^2	Maximum reduction	-13.9 °C	Other	
m^2 of fallow	186 m^2	Maximum increase	0.3 °C	Parking spaces	267

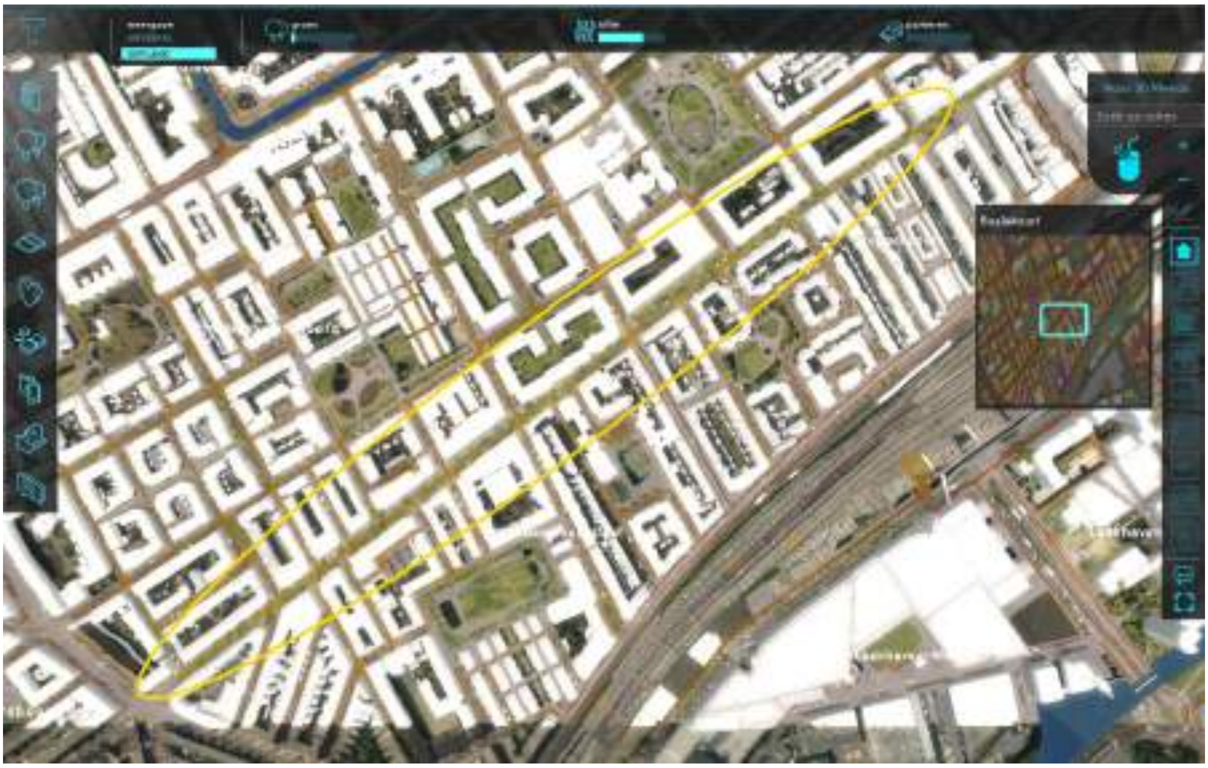

Figure 13. The new look of the Hoefkade in scenario 2.

Looking at greenery, this scenario is an improvement of the current situation, with an extra 542 m^2 of M2 area. This increase of green spaces has a significant effect on heat stress. Namely, the average temperature in the street is reduced by 5.2 °C PET, with the largest decrease in PET being 13.9 °C (figure 14).

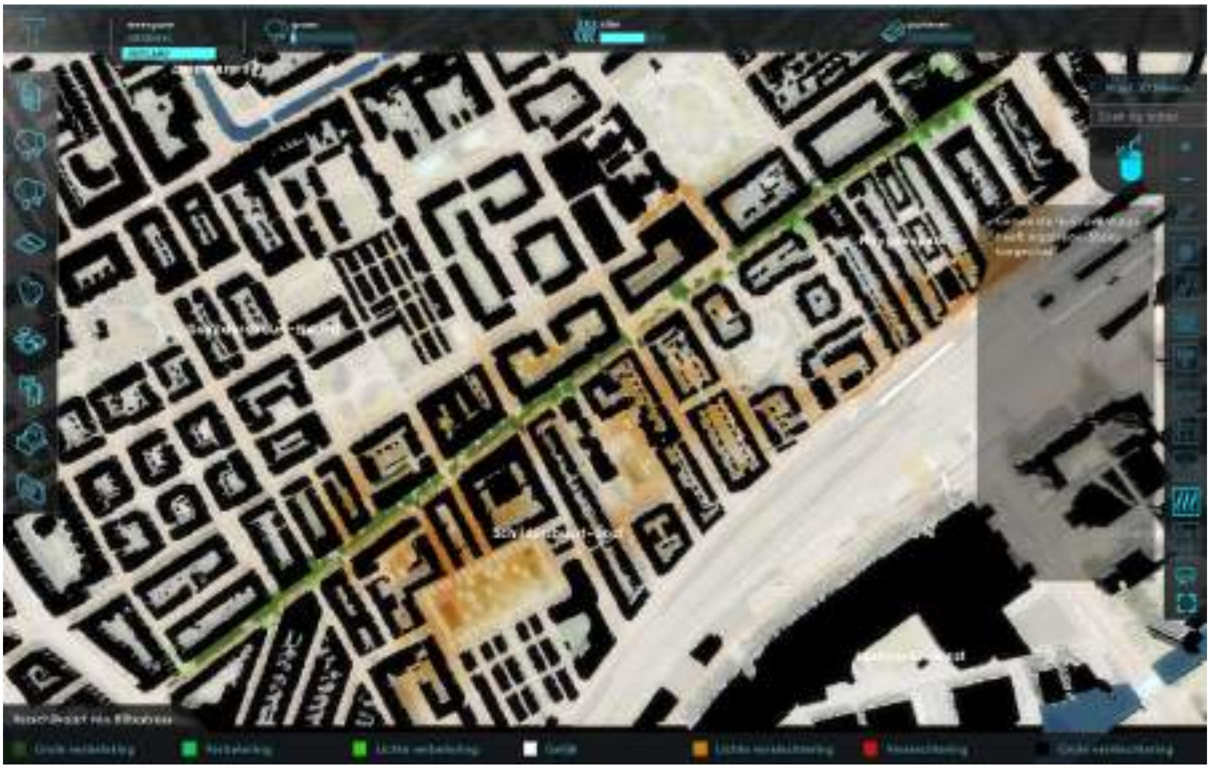

Figure 14. The changes in PET in scenario 2.

The water situation after the two-hour shower does not show much overall improvement or deterioration compared to the current situation (figure 15). The same fraction of land is flooded by all of the three water levels (0, 100, and 200 mm).

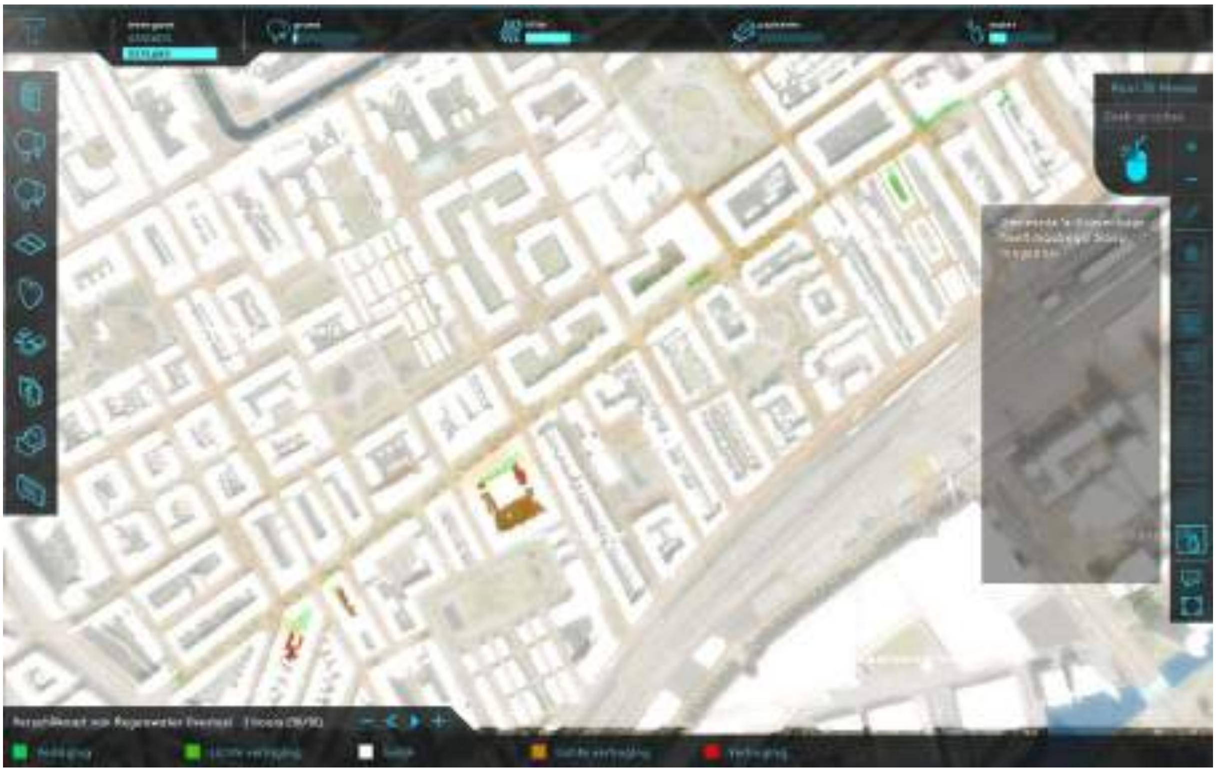

Figure 15. The improvement and deterioration of the water levels for scenario 2.

4.2.4. Scenario 3 - A Greener Plan

Table 4. Overview results scenario 3.

Land use and green		Heat stress		Water stress	
m^2 of green	2085 m^2	Heat stress reduction compared to maximum	68%	More than 0 mm water	91%
Percentage of green	10%	Degrees of reduction	-5.3 °C	More than 100 mm water	73%
m^2 of green objects	1382 m^2	Mean PET temperature	37.6 °C	More than 200 mm water	52%
m^2 of grass	818 m^2	Maximum reduction	-13.9 °C	Other	
m^2 of fallow	186 m^2	Maximum increase	0.3 °C	Parking spaces	267

Scenario 3 has a green percentage of 10%. This is a relatively high amount of greenery, but still fits within the boundaries of the municipality plan, meaning that the shape of the street stays intact and that no concessions were made concerning parking space. Through the creation of greener semi-paved parking spaces, the total amount of greenery has improved without having to cut down the number of parking spaces. In addition, the 1 m high hedges between the trees added more greenery even to places where extra trees were not possible.

We found that heat stress is decreased greatly compared to the baseline scenario, and a little bit more than in the municipality plan. Compared to scenario 0, the PET is reduced by 5.3 °C, but compared to scenario 2, the reduction is only 0.1 °C. Like scenario 2, the largest decrease in PET in scenario 3 is 13.9 °C.

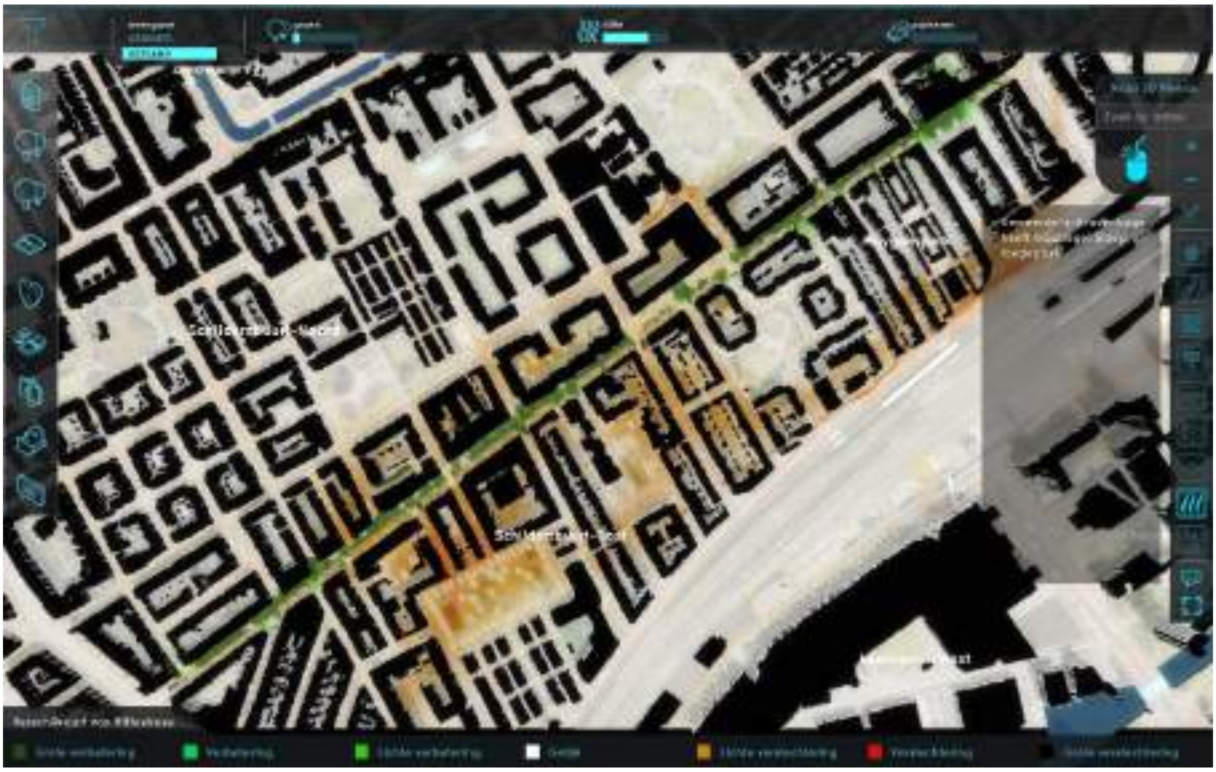

Figure 16. The changes in PET in scenario 3.

The water situation is a different story. Whereas in scenario 2 we found that the consequences of the downpour were evenly spread around the street, in scenario 3 there is a larger difference between the two sides of the Hoefkade (figure 17). The semi-paved parking spaces and the hedges are able to retain some water, slowing down the runoff. The lower-lying part of the Hoefkade (near Hollands Spoor train station) shows a lower capacity to store rainwater, while the higher part (south-west) has a slightly higher capacity. The flooding fractions of scenario 3 are 0.91, 0.73, and 0.52 respectively for 0 mm, 100 mm, and 200 mm.

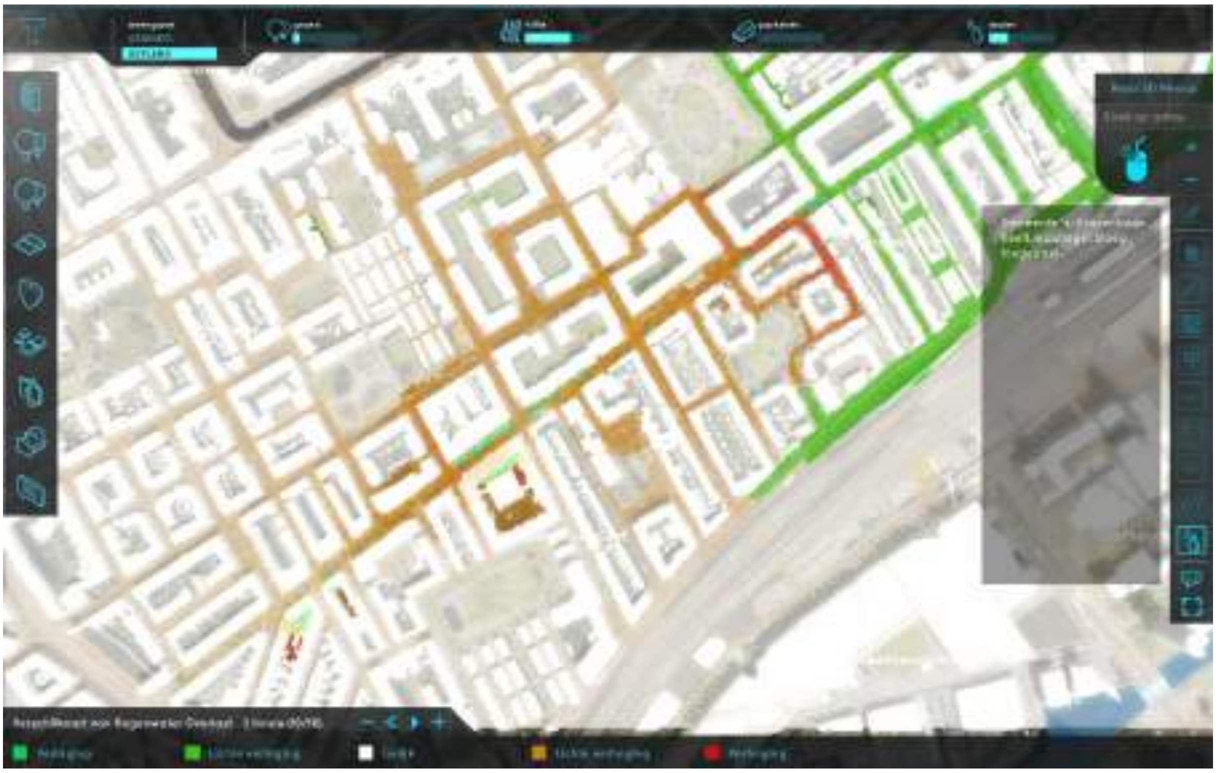

Figure 17. The improvement and deterioration of the water levels for scenario 3.

4.2.5. Scenario 4 - Even Greener

Table 5. Overview results scenario 4.

Land use and green		Heat stress		Water stress	
m^2 of green	2632 m^2	Heat stress reduction compared to maximum	69%	More than 0 mm water	91%
Percentage of green	12%	Degrees of reduction	-5.3 °C	More than 100 mm water	73%
m^2 of green objects	2059 m^2	Mean PET temperature	37.6 °C	More than 200 mm water	48%
m^2 of grass	818 m^2	Maximum reduction	-13.9 °C	Other	
m^2 of fallow	0 m^2	Maximum increase	0.3 °C	Parking spaces	241

Our last scenario is our most ambitious, yet still realistic scenario. As mentioned in 3.3.6., we have changed some of the basic infrastructure of the municipality plan. This resulted in an increase of the total amount of M2 green spaces by 594 m^2 compared to scenario 3 for a total area of 2059 m^2. The amount of fallow land has decreased to zero, thus creating a total green area of 2631.6 m^2 or 12.4% of the total land area in the Hoefkade.

The average heat stress reduction is the same as in scenario 3, namely 5.3 °C PET. The maximum temperature reduction of scenario 3 and 4 is also the same at 13.9 °C PET (figure 18).

Figure 18. The changes in PET in scenario 4.

We found an interesting development in the water situation. From the Tygron water model it was clear that two distinct regimes take place: one short-term (one hour) and one long-term (two hours). For the first hour, we saw considerable improvements in the water levels (figure 19) due to the extra storage capacity of the permeable roads and the underground tanks. However, after the first hour, the overall improvement in the water level disappeared and in some places the water levels even rose (figure 20). This is likely due to the storage tanks being full, thus not allowing any extra storage. Still, we saw a small general improvement even during the second hour. The fraction of dry areas increased from 6% to 9%, the areas flooded by 100 mm decreased from 78% to 73% and the areas flooded by 200 mm decreased from 51% to 48%.

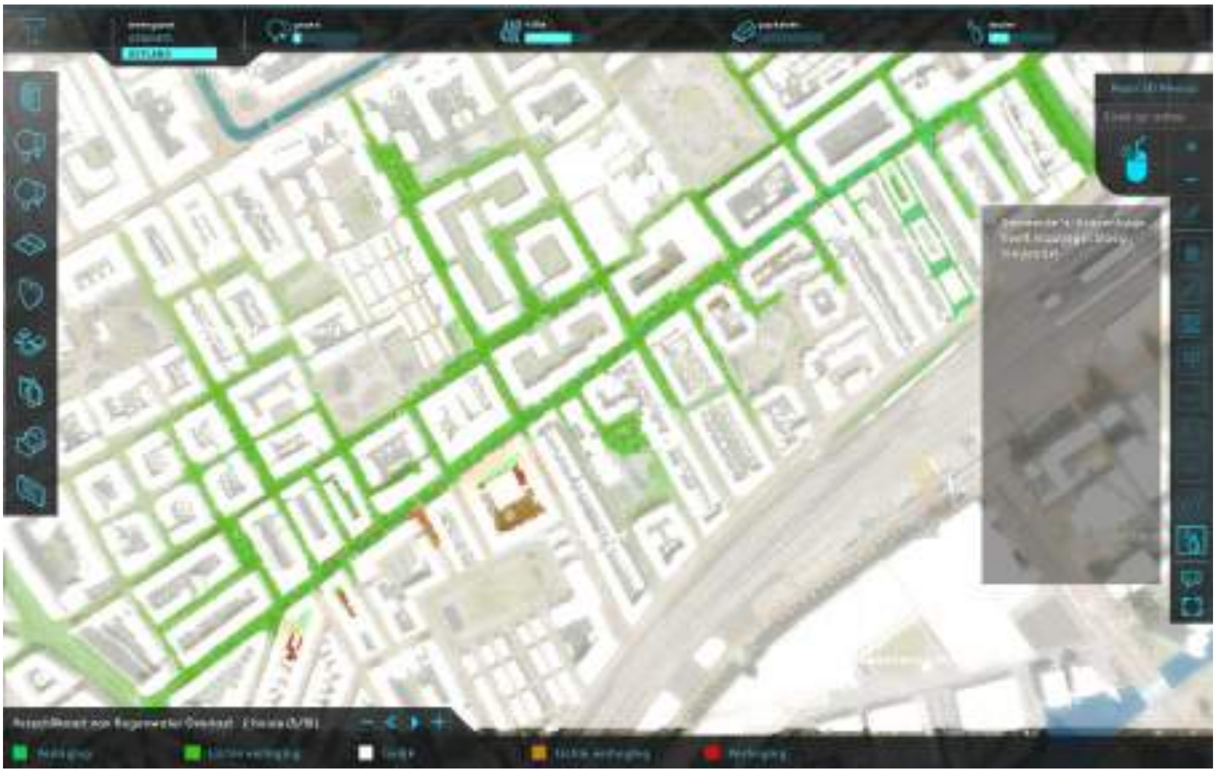

Figure 19. The improvement and deterioration of the water levels for scenario 4 after one hour.

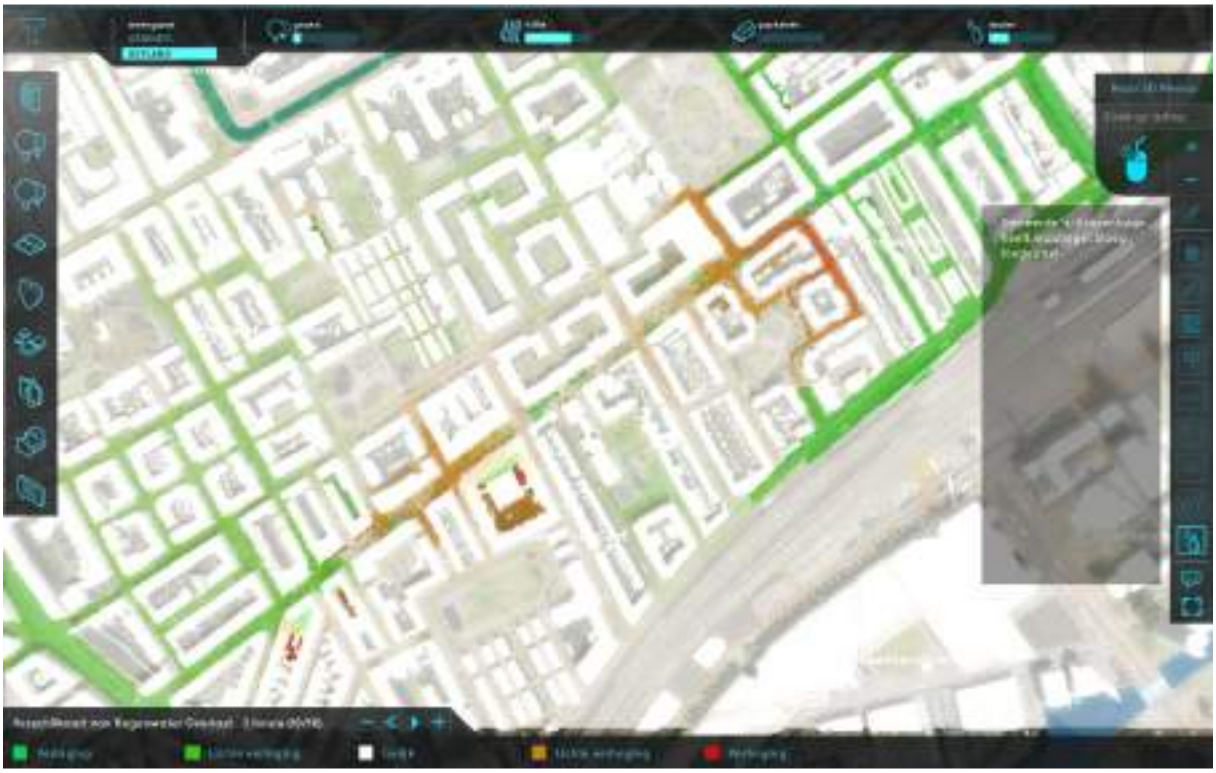

Figure 20. The improvements and deterioration of the water levels for scenario 3 after two hours.

5. Discussion

In this chapter, we discuss our results by first comparing the different scenarios and their outcomes, and consequently linking this analysis back to the stakeholder interviews. In addition, we elaborate on some of the limitations of our research.

In this research, we examined how climate-adaptation measures, especially the introduction of green spaces, can help mitigate heat stress and flooding while taking into account the wishes of residents and local employees of the Hoefkade. The five scenarios all show a different percentage of greenery, ranging from a mere 4% in the current Hoefkade, to 12% in our greenest realistic scenario, to 98% in an all-green, yet unrealistic situation. Given that the Hoefkade is a densely built-up street in an urban area, 12% greenery is quite a lot. In our research, we investigated what the effects of greenery are on heat stress and flooding, while taking into account the wishes and opinions of the main stakeholders; residents and local employees.

Table 6. Overview results of different scenarios.

	Scenario 0	Scenario 1	Scenario 2	Scenario 3	Scenario 4
Percentage of green	4%	98%	6%	10%	12%
Degrees of reduction	0 °C	-7.6 °C	-5.2 °C	-5.3 °C	-5.3 °C
More than 200 mm water	51%	55%	51%	52%	48%
Parking spaces	268	0	267	267	241

When analysing heat stress, we found that adding greenery to the extent that the municipality proposes is already highly effective, as it results in a PET reduction of 5.2 °C. This is a substantial improvement, especially when taking into account that the maximum possible reduction with greenery is 7.6 °C. Interestingly, we also found that adding more greenery than in scenario 2 will most likely not result in a much larger temperature reduction. We found no large differences between heat stress reduction in scenarios 2, 3, and 4. This can be explained by the fact that the temperature remains high in areas where it is not possible to place any more trees, such as at intersections. In other words, heat stress could further be reduced in the Hoefkade through greenery, but only by planting an enormous number of trees at unrealistic locations. If the municipality wants a higher heat stress reduction, other climate-adaptation measures need to be taken into consideration. Further research into these measures could be considered.

It should be noted that in most of our scenarios, a slight deterioration of heat stress can be seen in the streets around the Hoefkade, even though the Hoefkade itself is cooler. The PET slightly worsens in these areas, with a maximum of +0.8 °C. These increases in temperature could be the result of changes in wind speed or direction due to the new trees, as the roughness of trees can prevent cool winds from blowing freely (Santamouris et al, 2018). However, we cannot say this for certain. Nonetheless, this temperature increase is very small compared to the decrease within the Hoefkade, and could perhaps be solved by planting more trees in these areas as well.

For flooding, our results look a little less promising than for heat stress. No substantial reductions in flooding are achieved by any of the scenarios. However, the scenarios do show that the distribution of water in flooded areas shifts. An improvement can be found in the lower-lying area of the Hoefkade, while deterioration is found in the higher areas. We suspect that this difference is caused by the increase in friction factor of the street due to an increase in greenery (F. Witsenburg, personal communication, January 22, 2020). Thus, the introduction of more trees and other greenery enhances this effect, leading to a shift in the flooded areas, while not actually decreasing the total amount of flooded areas.

Furthermore, in scenario 4, the water storage tanks underneath the street cause noteworthy improvements during shorter rain showers (50 mm over the course of an hour). However, this effect does not hold for the heavy, longer-lasting downpour (100 mm in two hours). The results of this longer shower illustrate that with a combination of greenery and other climate-adaptation measures like storage tanks, the flooding problem in the Hoefkade cannot be solved. Other more radical solutions must be implemented to make the Hoefkade resilient to extreme weather events.

With regards to the opinions of stakeholders, the main takeaway from the interviews with residents and employees in the Hoefkade was that the Hoefkade could definitely use more greenery. Since all our scenarios (1-4) have more greenery than the baseline scenario (0), implementing any one of them would already be an improvement. However, many interviewees mentioned that the municipality should introduce as much green as possible. Additionally, the wish for more colour in the street was also expressed by many of the stakeholders in the Hoefkade. This is not specifically shown in our scenarios. However, scenario 4 includes facade gardens, which could hold as many flowers as desired. Even though they are not a decisive factor when it comes to heat stress or flooding, flowers can greatly add to the liveability in the Hoefkade.

We did not interview a statistically relevant number of people, because we used the interviews to gather a varied spectre of opinions. However, we cannot conclude that the opinions heard in our interviews are representative for all residents and employees in the Hoefkade. If the municipality wants to be able to quantify the stakeholders' opinions, another research is could be conducted in which a much larger sample of people is interviewed.

There are a number of limitations to our research. Some of them are a consequence of the way Tygron works. One of the biggest limitations for us was the different grid sizes in Tygron. Some objects possess great precision, such as buildings loaded in from the plan of the municipality, while the heat and water overlays were limited to 0.5 m x 0.5 m. This made it difficult to accurately draw other objects into the programme, such as facade gardens or trees. The way Tygron calculates and uses different terrain types also caused some problems, forcing us to treat grass and fallow land as the same. Moreover, the biggest limitation with regards to calculating water stress was the automatically generated sewer system, as Tygron did not load in any sewer data. More research into the sewer of the Hoefkade is certainly recommended to find out if our water stress calculations are accurate.

Moreover, the limited time we had to conduct this research led to us making certain assumptions in Tygron without having researched them thoroughly. Examples of this include tree size, locations of facade gardens, and the location of parking spots we chose to delete. This is something for the municipality to look into more precisely.

Nonetheless, this research has set the foundation for a greener, cooler, and drier Hoefkade. The next section provides concrete steps that the municipality can take in order to build this more liveable and resilient Hoefkade.

6. Recommendations

Table 7. Advantages and disadvantages of the different scenarios.

	Scenario 0 Current situation	Scenario 1 Full of trees	Scenario 2 Plan municipality	Scenario 3 Scenario 2 + green parking spaces, hedges, more trees	Scenario 4 Scenario 3 + facade gardens, water storage, permeable bricks
Amount of greenery	-	+++	+/-	+	++
Heat stress reduction	+/-	+++	++	++	++
Flooding alleviation	+/-	-	+/-	+/-	+
Parking spaces	+/-	- -	+/-	+/-	-
Stakeholder opinions	-	-	+	+	++
Simplicity of solutions	++	- -	+	+/-	-

The table above shows the advantages and disadvantages of the various scenarios. The municipality can weigh the costs and benefits of each scenario based on this table. One of the scenarios or a combination of a few measures within the different scenarios can be chosen to make the Hoefkade more liveable and resilient. Based on where the priorities of the municipality lie, different decisions can be made. Table 7 helps make this informed decision by weighing each scenario's amount of greenery, heat stress reduction, flooding alleviation, parking spaces, stakeholder opinions, and simplicity of solutions. A list of recommendations follows, and can be seen summarised in figure 21.

6.1. Heat Stress Reduction

If the main priority is combating heat stress, the current redevelopment plan of the municipality is almost as effective as the greener scenarios (scenario 3 and 4). However, there are some factors regarding heat stress that should be taken into account, regardless of which scenario is implemented. First of all, in this research, the standard Tygron deciduous tree has been used. However, when planting trees to lower heat stress, some trees are better than others. To optimise the cooling effect, large trees that are tall and have small leaves should be planted (Santamouris et al, 2018). When placed in a shadowy area, the less dense trees cool most effectively, whereas in open areas trees with high foliage density cool better. In general, trees placed in open areas without shadow have most effect on the surrounding temperature. The municipality should look into the optimal tree for the specific case of the Hoefkade.

Because residents of the Hoefkade explained that they experience heat stress especially inside their houses, green roofs could be a good complementary measure to trees. Because the buildings in the Hoefkade are mostly not owned by the municipality, the municipality cannot place green roofs on them. However, the municipality could make an effort to steer the housing associations that own most of the buildings to implement green roofs. Green roofs can make a big difference on the temperature inside these houses. Moreover, research has shown that if green roofs are implemented throughout the city, they can cool the area between 0.3 to 3.0 °C on average (Santamouris, 2018). We recommend looking further into green roofs for the Hoefkade.

6.2. Flooding Alleviation

With regards to flooding, the current municipality plan does not suffice. Scenario 4 seems to be the best solution to water stress, as it is highly effective for shorter rain showers (50 mm in one hour). However, for heavy downpours of 100 mm in two hours, none of the scenarios are effective. If the sewer information in Tygron is right, there is no other solution than changing the sewer system in the Hoefkade. Therefore, we recommend more research on the sewer system of the Hoefkade and on the possibilities of improving this. This is especially important to make the Hoefkade flood-proof for the future, in which downpours like the one modelled in Tygron will occur increasingly often.

6.3. Liveability

With regards to liveability, almost all the new scenarios will most likely result in an upgrade in liveability. The stakeholders we interviewed expressed the wish for more green in the street. Since scenario 1 fills the whole street with trees, we suspect that this will not lead to an improvement in liveability, as the total structure of the street is demolished. Of the other scenarios, scenario 4 will probably improve liveability the most, as the percentage of green is the greatest and the wishes of the stakeholders are taken into account most. In this scenario, we introduced facade gardens. In The Hague, residents are free to create a facade garden in front of their house without a permit as it is ("Maak een geveltuin voor uw huis", 2016), but we suspect there is little awareness on this among residents. Therefore, we recommend that the municipality makes more of an effort to make residents aware of this possibility. This could for example be done through open information meetings in community centres, as was proposed by one of the residents in an interview (Appendix A). The interviews showed that many residents are interested in green projects or initiatives. Facade gardens could be a great first initiative.

Another recommendation is one that was brought up by a few residents, namely hanging flower baskets (figure 4). In general, many residents asked for flowers and more colour. We think flower baskets hanging from street lanterns will fit in the Hoefkade perfectly, as they will greatly improve the look and atmosphere of the street. Additionally, because the baskets are hanging high from lanterns, the opportunity for vandalism that would exist for flower pots on the ground is greatly diminished. This takes away the fear of some residents that flowers would be trampled or littered in by other residents.

6.4. Simplicity of Solutions

Last, but not least, we provide the municipality with a guideline for the simplicity of the implementation of the scenarios. Scenario 1 is not feasible, as it calls for an alteration of the entire street. Scenario 2 and 3, on the other hand, require a moderate change in the structure of the street and the introduction of greenery. Scenario 4 is the most complex scenario, as it requires larger moderations to the street and the introduction of an abundance of greenery.

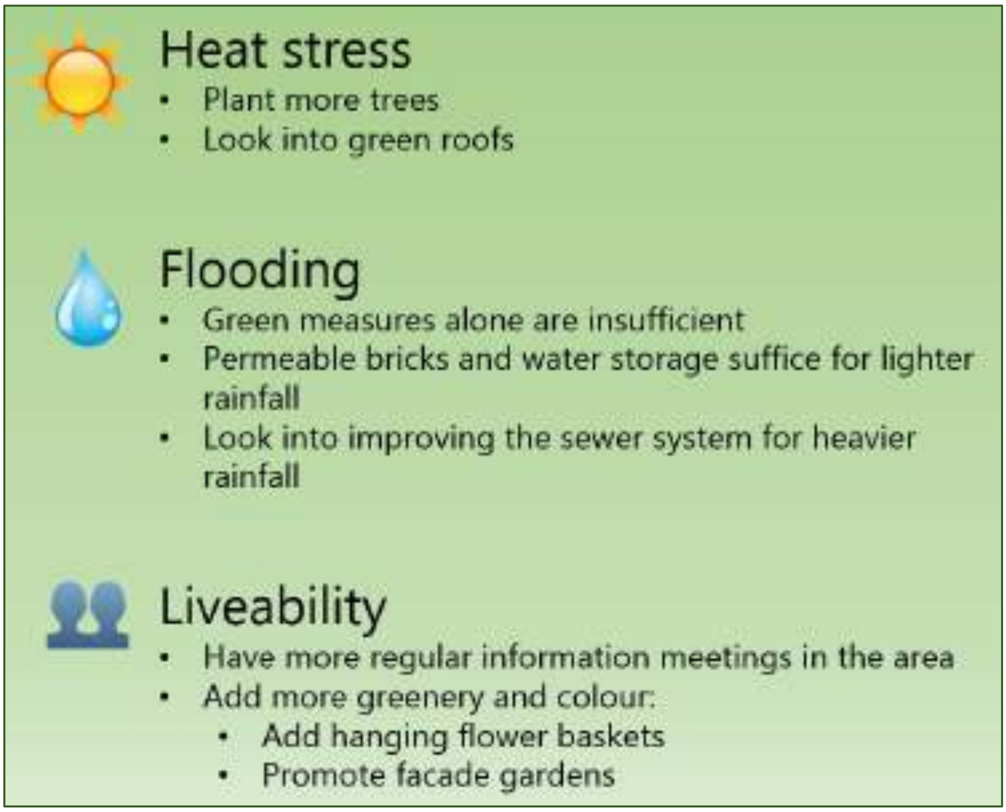

Figure 21. Summarised recommendations for the Hoefkade.

All in all, this research has provided the Municipality of the Hague with copious amounts of new knowledge, gathered from scientific literature, models in Tygron, and stakeholders in the Hoefkade. Based on this information, we have made various recommendations to make the Hoefkade more liveable and climate resilient. It is up to the municipality to decide how they want to use this research. An attractive and climate-resilient Hoefkade will serve as an example for many other streets in The Hague and the Netherlands.

7. Acknowledgements

Many people contributed to this project. We could not have succeeded without their help.

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Appendix A. Interviews

We conducted semi-structured interviews in the Hoefkade on Tuesday 14 January 2020 between 10:30 AM and 3:30 PM.

Interview questions

We asked the following questions in Dutch:

We are students from Leiden University and we are researching the Hoefkade street. May we ask you some questions? This will be anonymous.

- Do you live/work here?
- Are you here often?

- If you could change anything about the Hoefkade, what would it be?
- What do you think of the idea of making the Hoefkade greener?
    - What do you think would be the biggest advantage of more greenery?
    - What do you think would be the biggest disadvantage of more greenery?
- What is present in the Hoefkade now that cannot be replaced by greenery?
- Did you ever experience inconvenience due to heat stress in summer? (we explained what this meant)
- Did you ever experience inconvenience due to flooding after a rain shower?
- What type of greenery would you prefer to see in the Hoefkade?
- Would you like to be involved in a project/initiative on greenery in the Hoefkade?

Interview Answers

Shopkeeper 1

- This man is quite okay with the situation as it is; he initially is not really pro-change.
- He finds traffic in the Hoefkade dangerous, especially at the Wolterbeekstraat-Hoefkade crossing since people do not properly look around them before they cross the street and right of way is not granted by automobilists.
- He suggests that the main thing that needs to change is the traffic flow so that the Hoefkade becomes safer.
- He would like to see more green, preferably trees.
- Flooding is not perceived as a problem by this shopkeeper.
- Heat stress has been experienced; his shop was incredibly warm in summer.
- He is interested in being involved in a green project in the future.

Man walking dog

- This man does not actually live in the Hoefkade but he lives near and he passes it every now and then.
- The main problem this man mentions is traffic. He finds it way too busy in the Hoefkade. He jokingly answers that the municipality should ban all cars, but on further inquiry he mentions that he does not think that banning all cars will be possible because there are so many people who need to enter or pass the Hoefkade.
- He doubtfully answers the question about heat stress and states that it was indeed warm in the houses last summer. He suggests that this is because of the flat roofs of most houses.
- He mentions that the main advantage of more greenery will be the more positive experience people have in the Hoefkade. In addition, it would reduce stress, because he believes that people feel better in the neighbourhood when there is more green.
- However, he thinks that more green will probably not really have a huge effect on other variables like heat stress and flooding.
- More green everywhere would be best, according to this interviewee. He claims that greenery may replace anything - even parking spaces - because it is already hard to find a parking spot anyway.

Shopkeeper 2

- He begins by saying that the Hoefkade is a beautiful street. He was born and raised there.
- He believes that traffic is the biggest problem in the Hoefkade that needs to change, but he disagrees with the current plans of the municipality.
    - He does not agree with the reduction of cars in the street.
    - He does not agree with a one-way street.
    - He claims that there will be traffic jams anyway because it is just a busy part of the neighbourhood. And if you do not allow cars in the Hoefkade, they will go to other streets and cause problems there. Right now, for example, there are many traffic issues at Hollands Spoor.
    - He says that a two-way street is preferable because then the flow of traffic is much better.
- He explains that the municipality cut down many big trees two years ago and replaced them with smaller ones. He thinks they did this because of birds causing too much inconvenience, but he did not agree with that. The new trees still need a lot of time to grow, so a lot of greenery was taken out without a proper replacement. Current trees do not have the same effects yet, which he regrets.
- Heat stress is perceived as a big problem, but not necessarily more in the Hoefkade than anywhere else in The Hague.

- He mentions that the municipality planned to make small football fields, invested in them, but consequently did not finish the plan. Now these fields are just small parks of grass without anything on them. Our interviewee says that grass is not enough; it does not live, there is nothing pleasant about it.
- He wants more green and more flowers, shrubs, etc.
- He thinks there is not more green because of the costs, but he thinks the municipality can cut back on other things and should prioritise green.
- He says that trees are very important for life.
- He mentions newly placed underground bins and a mouse problem that is caused by them. He thinks the municipality should place more greenery instead, and just pick up the trash once a week. This is also an example of how the municipality, in his opinion, makes the wrong tradeoffs that only benefit itself and have bad effects on shopkeepers and residents.
- He thinks that the municipality is only working against entrepreneurs and shopkeepers. He mentions the fines he got for - in his view - unimportant things, like having things outside on the street. He explains that he does not really cooperate with the municipality anymore and that he lost his faith in politics.
- He thinks that in renewing the Hollands Spoor area, too little greenery was introduced.
- "Come and see what goes on here" he wants to tell the municipality. He claims that right now, they have no clue what the opinions of the people are.
- He would definitely be interested in participating in green projects.

Resident 1

- This woman lives in the Hoefkade.
- As a main problem she mentions the traffic and the chaos on the street. Everyone drives too fast and no one follows the rules.
- She is a mother of little children and does not dare to let her children walk in the street or even on the pavement without holding their hands tightly.
- She knows about the plans of the municipality to change the traffic situation and eagerly awaits them being executed. She explains that if the plans had not been there, she would have filed a complaint about traffic safety already.
- She says that the municipality already told the community about their plans a while ago, but after that, she has not heard anything from them and she is annoyed by that, for she wishes to receive more information or updates on the plans.
- Another problem she mentions is criminality. However, this is not a problem she faces through her own experiences, but rather through stories in the street and in the media about stabbings which scare her.
- She thinks that there is not enough greenery in the street.
- She says that she values the good atmosphere in the Hoefkade and the fact that there are always people in the streets.

- She is worried that there is not much space to add greenery.
- The main advantage of more greenery is more shade, which would improve heat stress. Without us mentioning it she mentions heat stress as a problem and says that the Hoefkade neighbourhood is the hottest of The Hague.
- She wants a safer environment for children and is in favour of more parks for children to play in. More green would make the environment safer for kids.
- She thinks that residents could be listened to more and she is in favour of exchanging ideas. She suggests regular information meetings/presentations in the community centre (De Mussen) and claims that many residents - especially women - would show up.
- She thinks the municipality should take more initiative in reaching out to the community. She is afraid that the plans will not work if the community is not properly notified and listened to. Residents should be encouraged to join the redevelopment of the Hoefkade, and then they will probably be motivated to keep positive change going.

Shopkeeper 3

- This adolescent grew up in the Hoefkade.
- He first says that there is nothing to improve, but then mentions trash in the streets. He does not know the causes or a solution to this.
- He does not think traffic could change. He claims that the traffic situation has always been like this and will stay like this in the future.
- He says that more greenery is always good.
- For the rest, he does not have much of an opinion on things. We did not ask all our questions.

Resident 2

- This woman lives in the Hoefkade and says it is a nice street to live in.
- The main problem in this street she mentions is traffic. People do not follow the rules and drive too fast.
- Another problem she mentions is the disturbances by youth playing (football) till late in the night. They cause too much noise, sometimes there are fights, and they often leave their trash.
- She thinks that there is enough greenery in the Hoefkade as it is now. She is afraid that more trees would cause problems with falling branches.
- In addition, she mentions that the community is not really open to more greenery; she expects that people, especially youngsters, will pick flowers or damage things.

- Although she would like to see more flowers, she thinks that people first need to learn how to manage them. Right now she expects they would be trampled, picked and littered on.
- She would be interested in green projects, but is a little apprehensive because she doubts other people would join, and she does not want to be responsible on her own.

Library employee

- This man is not a resident but comes to work by bike every day.
- He says that cycling in the Hoefkade is awful because the traffic is one big chaos.
- He says that he cannot believe that accidents do not occur more often.
- He claims that the police never checks or writes fines when it comes to traffic, but that he understands that they are very busy.
- He knows the plans of the Municipality of The Hague with regards to mobility.
- He wishes to have a lot more green in the Hoefkade but he says that residents do not take initiative so the government must do that.
- Greenery would make the street a lot more liveable (he mentions this term himself).
- However, he is sceptical because of the amount of trash in the street. He says it is depressing and tells us that people sometimes throw entire trash bags out of their windows in the street.
- He claims that some people in the Hoefkade are problematic and gives the example of homeless people who sometimes wander and deal with psychological problems.
- There is a mindset issue in the street, which is clearly visible in relation to traffic, but also to trash and damage. He is afraid that this is something you will always face because the mentality of the people needs to change.
- His ideas towards improving the Hoefkade:
    - "Geveltuintjes", which would make the street more liveable.
    - Flower pots on street lanterns would make the street a lot prettier.
    - More colour is needed! More colour in the street will make it much more attractive.
- He would not mind if parking places disappeared (but he does not use a car himself). He is not sure what other residents think of this. As a problem, he mentions that a lot of people do not know how to cycle or do not come from cultures in which cycling is a habit, so they either take the car or public transport or they walk.
- He does not think heat stress is a bigger problem in the Hoefkade than in the rest of The Hague, but he does mention that it always smells funny in the Hoefkade in spring and summer (when it is not raining and a bit warmer, so not necessarily during heat waves, but during the whole season). He says it is a bad

smell, but he does not know where it comes from. He suggests that maybe it is a combination of car fumes, trash and food.

- He thinks a big advantage of greenery would be an improvement in the atmosphere, look, and liveability of the Hoefkade.
- A main disadvantage of greenery are the costs it brings.
- He mentions that there has been mold in houses, but no flooding in the street.
- He mentions that the people from the Hoefkade often feel like they are not heard or listened to, but that residents should also take an effort themselves into becoming a part of the redevelopment of the Hoefkade.
- He explains that in the library there have been projects and information meetings, but in the first three weeks everyone was always very enthusiastic and after that they stop showing up.
    - So the residents are wanting to be heard, but they also do not really bother to show up after a while. He does not know why this is exactly.
- He would like to hear back from us once we finish the project.

Three women in community centre De Mussen

- They say that there are not many problems in the Hoefkade. However, after asking again they mention that the main problem is the busy traffic.
- They think that there is too little greenery and they would like to see more.
- They want more beauty and more cleanliness in the street.
- They argue that if people see pretty things they will not bother to litter as much.
- No heat stress or flooding problems are perceived by them.
- They would like more areas where their kids can play. These areas should be greener and safer than the current pavements.
- They would like to join initiatives and they think more people would like to join as well.
- They do not really mind if the municipality would introduce trees or plants or flowers; the more the better.

Student resident Rode Dorp

- The main problem this student mentions is security. He thinks more policing and law enforcement is needed.
- He thinks that there should be more greenery and he argues that it would make the street more peaceful and visually more attractive. He thinks that it would calm people down. He does not see any disadvantages to more greenery.
- He thinks that the footpaths and cycle paths are important and should stay.
- When asked whether he experiences heat stress in summer, he says: “No, of course not, I’m from Thailand.”

- He does not perceive more flooding in the Hoefkade than elsewhere in The Hague.
- He says that more trees are necessary.
- He is not interested in joining a green project, because law and order should have a first priority in the Hoefkade.

Appendix B. Tygron sources

Tygron uses various sources in order to create the 3D-model:

- Satellite background data.
  This data from ESRI is used to see the shape and colour and therefore estimates what kind of buildings there are.
- Height (both construction and landscape).
  In order to create a 3D-model, Tygron uses the height data from both ESRI (Digital Elevation Model (landscape) and RWS AHN3 maps (construction)).
- Land use and objects
  Data BGT (basic registration topography on a large scale).
- Risk assessment (Risico kaart).
- Ownership plots (Kadaster).
- Infrastructure (BGT, NWB, TOP10NL).
- Water (TOP10NL).
- Neighbourhoods and zoning (Ruimtelijke plannen and CBS data).

Appendix C. Absolute heat stress

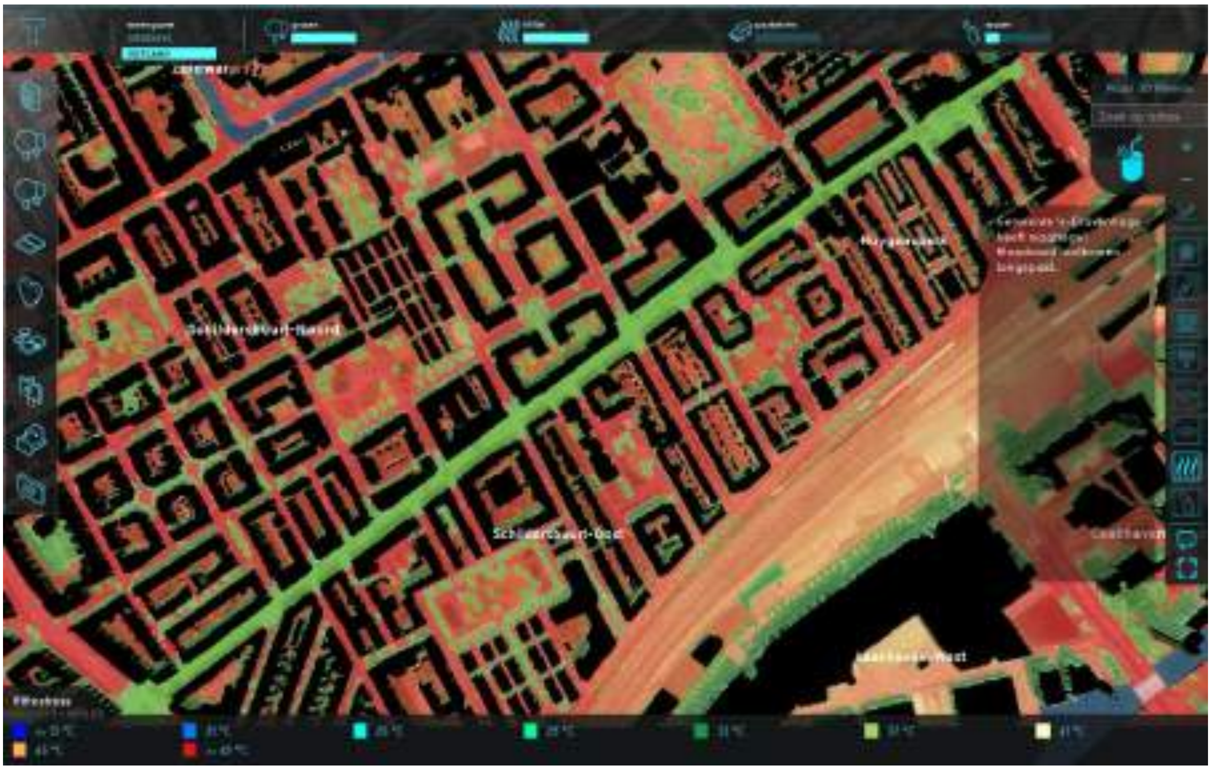

Figure C.1. The absolute PET heat stress levels for scenario 1.

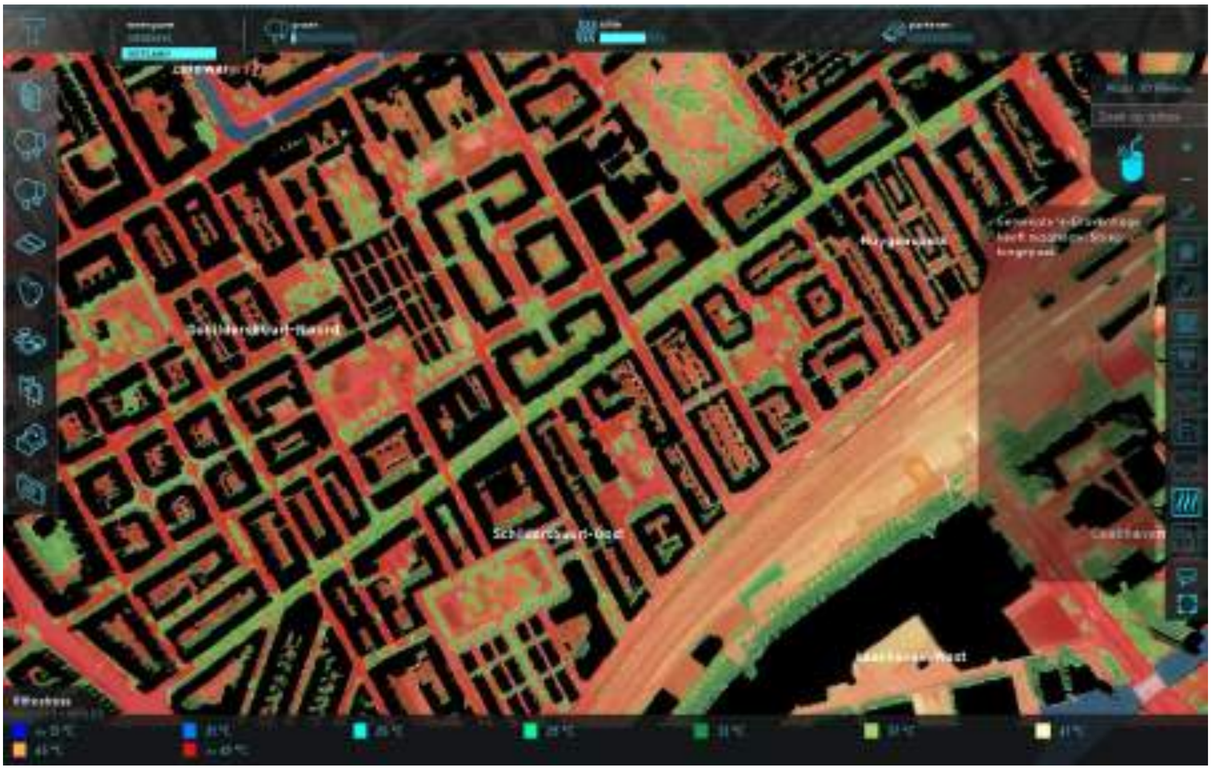

Figure C.2. The absolute PET heat stress levels for scenario 2.

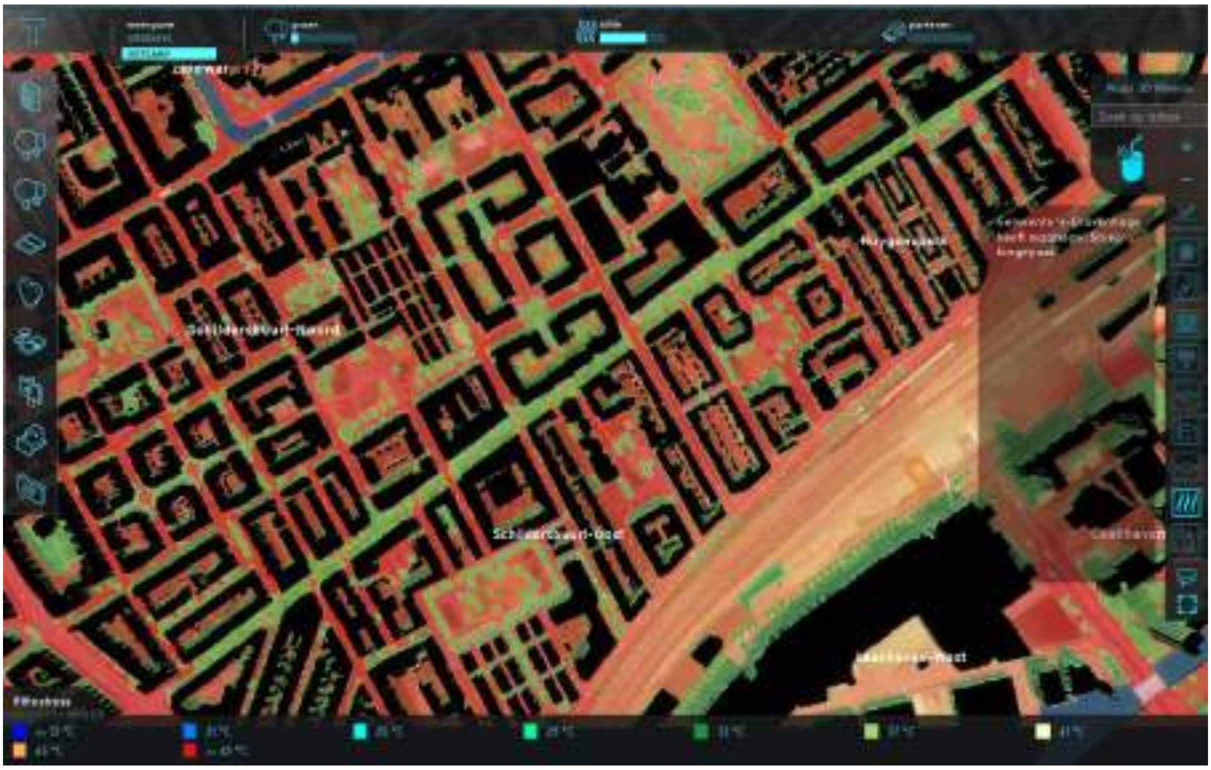

Figure C.3. The absolute PET heat stress levels for scenario 3.

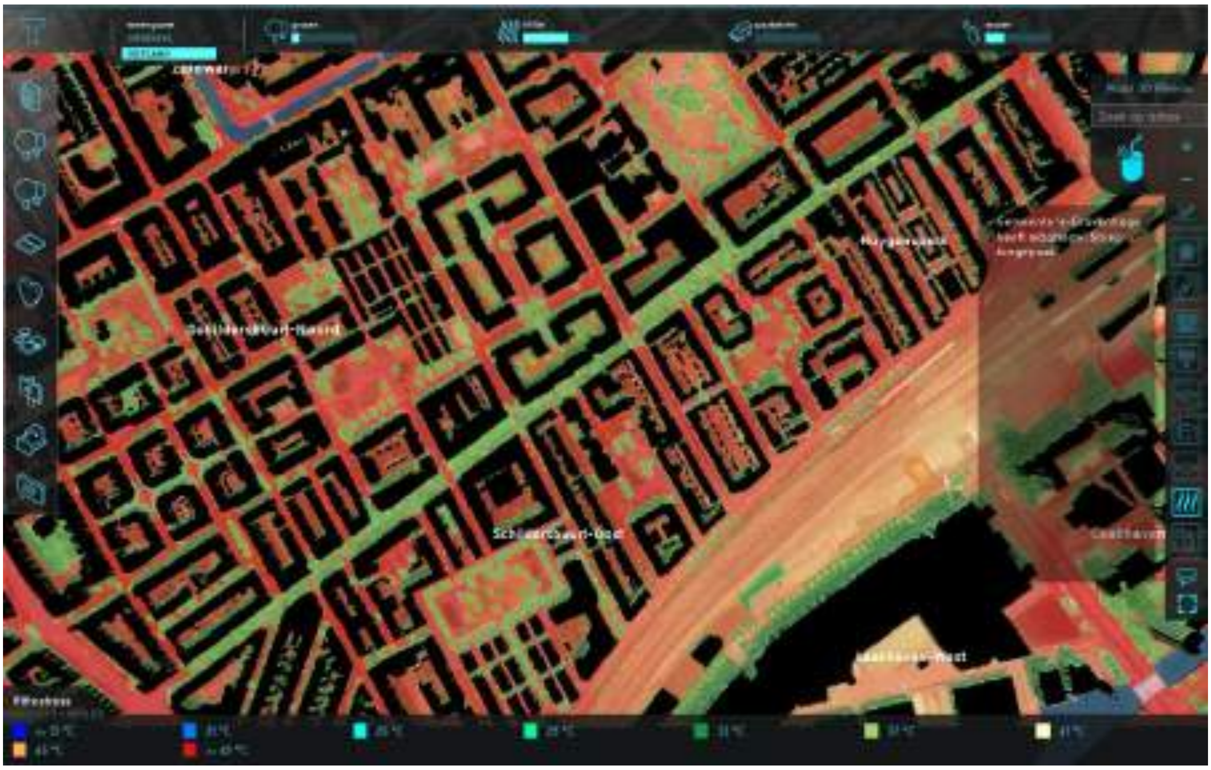

Figure C.4. The absolute PET heat stress levels for scenario 4.