Presenting temperature measurements of public spaces in Enschede

GRADUATION PROJECT

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Abstract

With most of the world's population living in urban areas, the Urban Heat Island effect is becoming a progressively larger issue. This effect causes a buildup of heat in cities, mostly due to anthropogenic heat, the limiting of redistribution of heat due to the geometry of cities, and excess solar radiation captured by roads and buildings. To investigate the extent of the Urban Heat Island in Enschede, the Municipality of Enschede has enlisted the help of students and researchers at the University of Twente to build a network of sensors to measure and monitor the problem.

This graduation project focuses on using this sensor network to create a system that presents the temperature data, so that conclusions can be made about the extent of the problem. Research was done into possible ways of presenting the data, which lead to the creation of multiple concepts. The final system was a data visualization web application consisting of a map visualization with a heatmap, along with a line chart to display historic data.

The system was evaluated with multiple test users and stakeholders, and met many of the requirements. However, due to a lack of time, the system could not be connected to a database with measurements, instead it used an external data file. Many improvements still must be made to the system, however if the Urban Heat Island is a problem for the citizens of Enschede, it will be observable through these visualizations of data.

Acknowledgments

There are several people without whom this project could not be possible. First, I would like to thank Hans Scholten, my supervisor, and Richard Bults, my critical observer, for all the input, feedback and guidance they provided.

Next, I would like to thank Hendrik-Jan Teekens from the Municipality of Enschede. He visited the university many times to give his feedback and input on many concepts and prototypes we worked on, and even though the meetings were very long a strenuous, he was always happy to work with us and very patient.

Next, I would like to thank Laura Kester, Joeri Planting, Thijs Dortmann, Jeroen Waterink, and Sefora Tunç who were the members of the climate adaptive city Enschede group. We met often to discuss our projects together and give feedback to one another, working together to hopefully improve the city of Enschede.

Finally, I would like to thank Yoann Latzer, who worked on the proof of concept version of this project. He provided information on how I could approach the problem and explained how he created his project, he also explained the challenges he faced and what recommendations he drew from the experience.

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1. Introduction

In this chapter the project and its challenges will be introduced, the research questions will be formed, and the outline of the report will be given.

1.1 Situation

By their nature cities are warmer than their rural surroundings, this is due to many factors. Firstly, the materials urban areas are constructed from: concrete, asphalt, and bricks all absorb incoming solar radiation more than fields and forests in rural areas [1]. Secondly, anthropogenic heat, heat caused by human activity, such as industry exhaust, heating, or air-conditioning also increase the temperatures of cities [2]. Finally, the 3D geometry of a city influences the wind flow and the rate at which solar radiation is reflected back to the atmosphere and space [1]. This phenomenon is called the Urban Heat Island (UHI) effect and has been documented since 1818 [3]. However, the intensity of the UHI varies from city to city.

The Urban Heat Island in cities is not only a discomfort for the population but can be dangerous and possibly deadly for the elderly and very young [4]. Apart from its impact on the health of citizens, high temperatures in cities also increase energy consumption, due to the necessary cooling of building interiors, which also leads to higher emissions [5]. Aware of these possible risks, the municipality of Enschede has shown interest in monitoring its possible UHI and investigating the scale of the current and possible future problems in the area.

1.2 Challenges

The municipality of Enschede has set up a small network of six temperature sensing nodes across the city in collaboration with students of the University of Twente. The sensor nodes have been gathering data since January 2018. The challenge of this project will be to present the captured temperature data in a way, that if existing, the Urban Heat Island of Enschede will be identified. The municipality of Enschede desires a way to easily monitor the temperature throughout the city and the possible trends of change, so if necessary, they can take action to mitigate the consequences before they are severe.

1.3 Research questions

To tackle the challenge described in section 1.2 , a research question must be formed. The overarching research question to be answered is:

Main RQ: ***How to present temperature measurements of public spaces in Enschede in an insightful manner?***

To help guide the research towards the investigation of the Urban Heat Island, a sub question will also be researched:

Sub RQ: ***How to use these insights to present a possible Urban Heat Island effect?***

1.4 Report outline

First an analysis of the state of the art will be made. Following this, the methods and techniques that will be used in the project will be discussed. Next, the creation of concepts and analysis of stakeholders will be explained in the Ideation phase chapter. The final system will be specified in detail and the requirements for the system will be listed in the Specification phase chapter. Next the system will be implemented and discussed in the Execution phase chapter. Followed by an evaluation of the system via user testing and testing with the stakeholders. Finally, a conclusion about the project will be made in the conclusions and recommendations chapter.

2. State of the art

In this chapter the current state of art will be investigated. First the advantages of visualization will be discussed. Following this, the current visualization of the data will be discussed. The third section will focus on possible visualizations of the data that could be interesting for visualizing temperature data. The fourth section will focus on novel ways of presenting data. Similar projects to this one will be discussed in the fifth section. Following this, the UHI will be discussed in more detail, so the data can be presented in a way, that would manifest the UHI. Finally, a conclusion on the findings of the state of the art in this chapter will be made.

2.1 Advantages of data visualization

Data visualization is the transformation of a set of data into a graphical representation. The possibilities of graphical representation are vast: from standard bar graphs, to heat maps and complex parallel coordinate graphs. The type of data visualization will be dictated by the type of data to be represented. When used correctly, data visualization can give insights that might be overlooked in a table of data points. Data visualization can also save time when investigating the data set, as humans can process and remember visualized data far faster than data in tables. Processing and analyzing complex data sets can be easier due to the visual representation of patterns and abnormalities in the data [6]. However, if the data is not represented in the correct way, for example when using too many different colors or objects, the data visualization might not bring any benefit [7]. As well as bringing the possibility of skewing data with biased intentions, for example by manipulating the intensity at which differences in data are represented to manipulate the viewer's conclusions. To conclude, data visualization can give valuable insights while investigating a data set if represented correctly.

In the scope of the Urban Heat Island, data visualization can be a useful tool as well. With the use of a heat map, the problematic areas with the highest temperatures can be easily pinpointed. The use of maps in data visualization can lead to more engagement from the viewer, if they can view the data that is relevant to them. Maps may also lead to the discovery of distributions in the data set that might not be apparent from a non-mapped data set [8]. Most researchers who investigate the urban heat island end up visualizing their data using 2D or 3D heat maps, however other possible presentations must be investigated.

Information dashboards are a type of aggregation of data visualizations about a single topic. Stephen Few describes the information dashboard as a "visual display of the most information needed to achieve one or more objectives which fits entirely on a single computer screen, so it can be monitored at a glance." [9]. A dashboard could be used to analyze current and past data to investigate trends of change as well as monitoring problematic areas of the city.

2.2 Previous years project

This graduation project is a continuation of the work of a previous graduation project. Last year a network of six sensor nodes was deployed across Enschede to investigate the UHI, along with a visualization of the data. Figure 1 shows the visualization implemented.

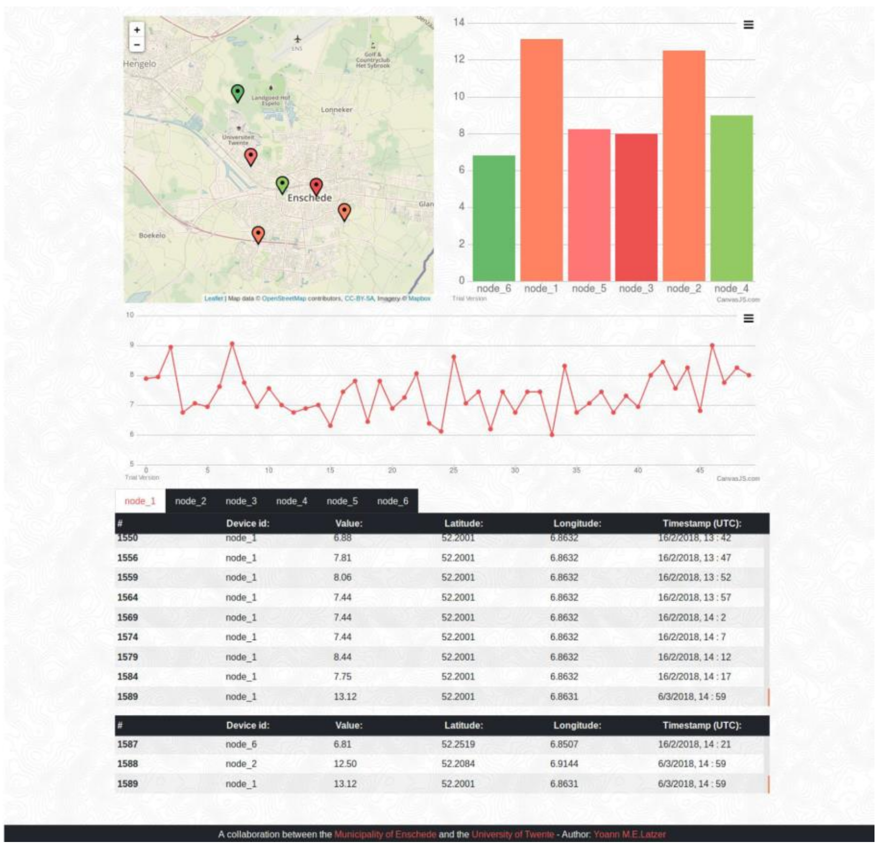

Figure 1: Data visualization of previous years project [10]

There are four main elements implemented in the dashboard created. The first is the visualization of the location of sensors on the map of Enschede. The second is a bar graph to show the temperatures recorded at each node. The third is a line graph that presents the trend of the temperature recorded at a single sensor node. Finally, all the data recorded is available in a table at the bottom of the visualization.

The purpose of the current project is to possibly build onto this visualization to make it more effective or introduce a new way to present the data. To do this, the issues of the previous project must be addressed. The main issue with the visualization was that due to technical problems, it took far too long to load the visualization on the website. Some of the issues concerning the visualization itself were the misunderstanding of what the visualization was representing. People with no knowledge of the context did not immediately understand the visualization was about temperature. Another issue was the misunderstandings about the use of the colors on the map, and what they represent. And finally, the visualization of the data from separate nodes in a bar graph could skew the understanding of the data. The recommendations proposed by the project was for the visualizations to distinguish between the urban and rural areas more clearly. As well as making the purpose of the visualization itself more apparent.

2.3 Possible visualizations of the temperature data

In this section, possible visualizations will be presented, from mapped data to more simple data visualizations. Some of these visualizations could be grouped together to form a temperature monitoring dashboard.

2.3.1 Maps

2.3.1.1 *Heat map on a map*

The heat map is commonly used to present the temperature data across a certain area. Figure 2 shows a standard heat map with a range of colors to visualize a scale of different temperatures. A legend which presents the range of colors and their corresponding values must always be available.

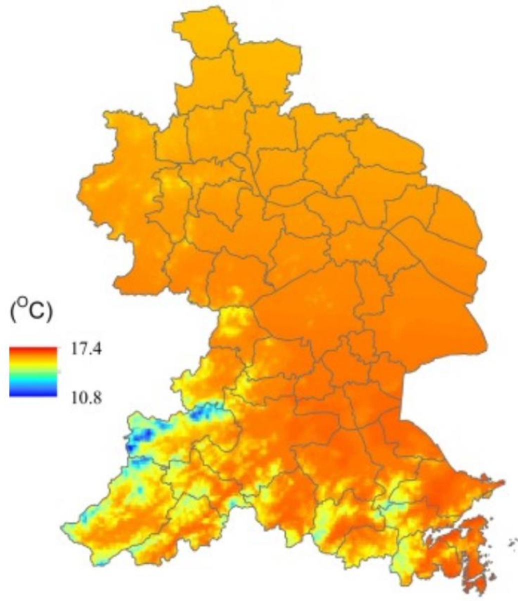

Figure 2 : Heat map of temperatures in East China [11]

A heat map can be used to investigate patterns and find areas which exhibit extreme values. A heat map is not used to investigate exact values as the colors seen cannot be linked back to their exact values, only estimations can be made. A 3D heat map, shown in Figure 3, can be used to display data more truthfully, as temperatures will vary at different elevations.

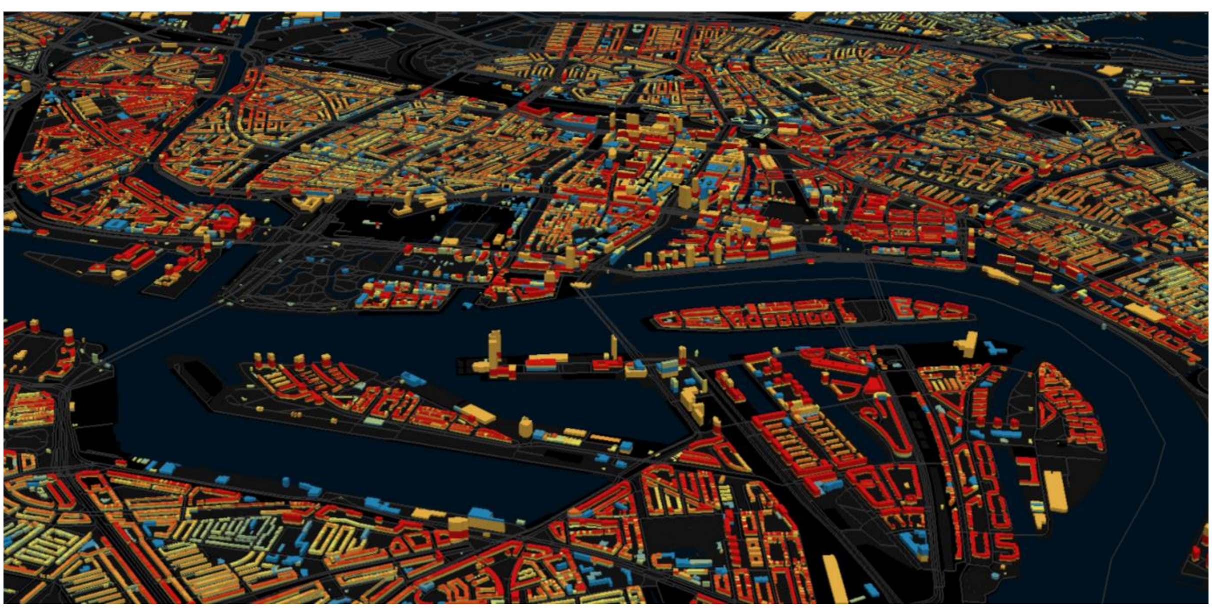

Figure 3 : 3D heat map of Rotterdam [12]

2.3.1.2 Cartogram

A cartogram is a more unconventional way to present mapped data. It warps the map and its separate areas to different sizes according to the data set. Three main types of cartograms are shown in Figure 4.

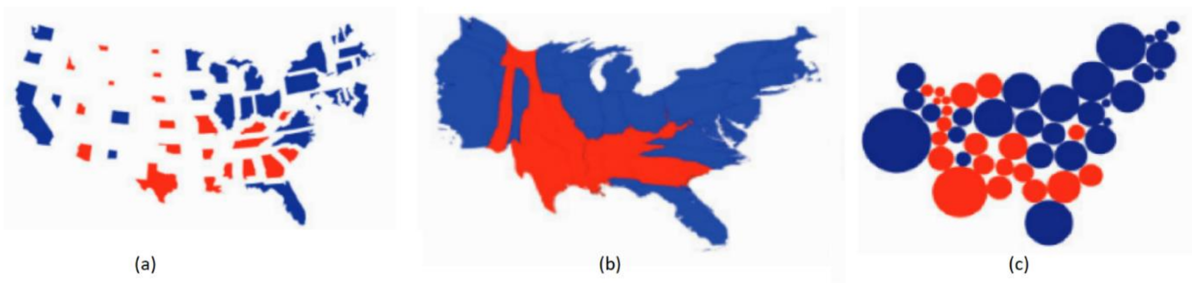

Figure 4 : Three main types of cartograms (a) Non-continuous Cartogram (b) Gastner-Newman Cartogram (c) Circular (Dorling) Cartogram [13]

The cartogram is most useful when illustrating global or country wide data, where the separate countries or regions are easily distinguishable. This might cause an issue with representing data in Enschede, as some might not understand the initial segmentation of the city, and therefore will not understand what insights the cartogram is presenting.

2.3.1.3 Choropleth map

This type of map visualization is very similar to the heat map. However, the colors or shades of colors representing values are not continuous but set per areas or regions. A standard Choropleth map is shown in Figure 5 ranging from white to black. Most commonly colors are not used as a spectrum, but certain colors are set to a certain range of values. This can possibly skew data if regions are not selected properly.

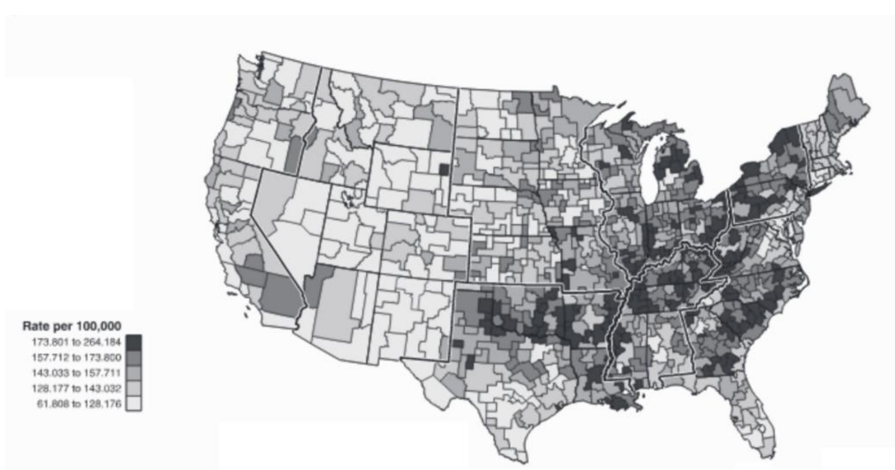

Figure 5 : Choropleth map showing rates of mortality caused by a certain factor [14]

This type of visualization could possibly be used in visualizing the temperature in Enschede if regions are selected properly. There is a possibility to then describe each region with a certain area label, for example: park, residential area, or public square.

2.3.1.4 Contour map

The contour map is most commonly used to visualize temperature or elevation. Contours, or curved lines, are used to represent when certain areas on a map reach a certain threshold. A simple contour map is shown in Figure 6.

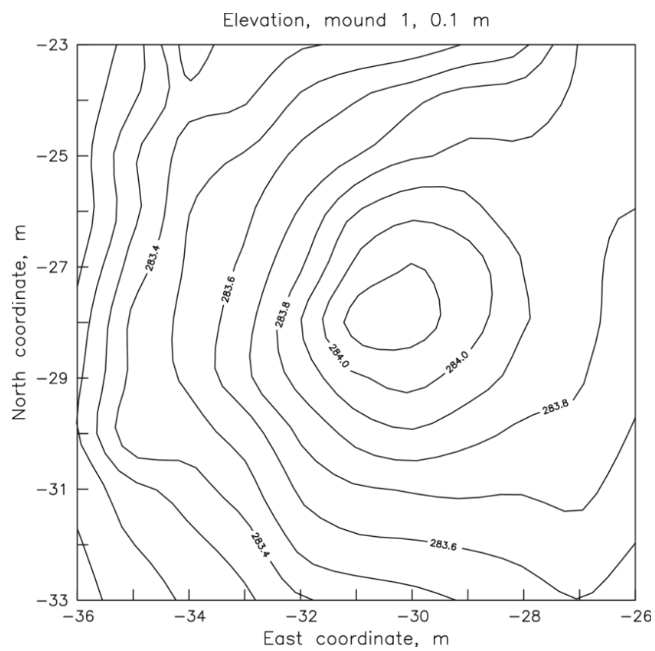

Figure 6 : Contour map of mound [15]

These 2D contour maps can be developed into 3D models that can be used to visualize the temperature landscape, and possibly present the Urban Heat Island and where its peaks are present. A project in London, that visualized the air pollution in the city (Figure 7) is a good example of how the contour map could be transformed into a 3D model.

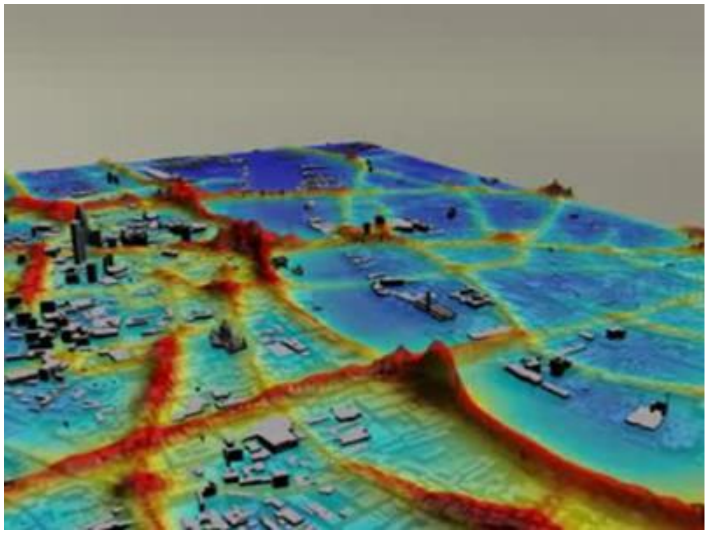

Figure 7 : Air pollution mapped over London [16]

2.3.2 Heat tile map

The heat tile map is a type of visualization used to show time-oriented data. A color spectrum is used to visualize the value per tile, that represents a certain time range. A standard heat tile map can be seen in Figure 8.

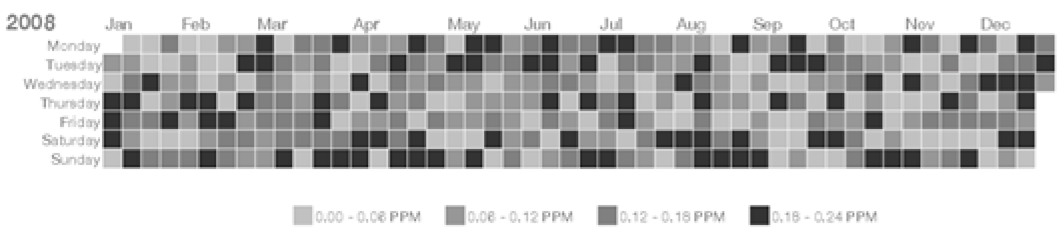

Figure 8 : Heat tile map of the intensity of pollutants in the ozone [17]

The heat tile map is used to investigate extremes over time or certain patterns over time. In the case of the Urban Heat Island it could be used to investigate times of the year when the UHI is most intense or the possible trends of change of intensity over time.

2.3.3 Line chart

The line chart is a simple visualization to show time-oriented data of a variable. A standard line chart is shown in Figure 9.

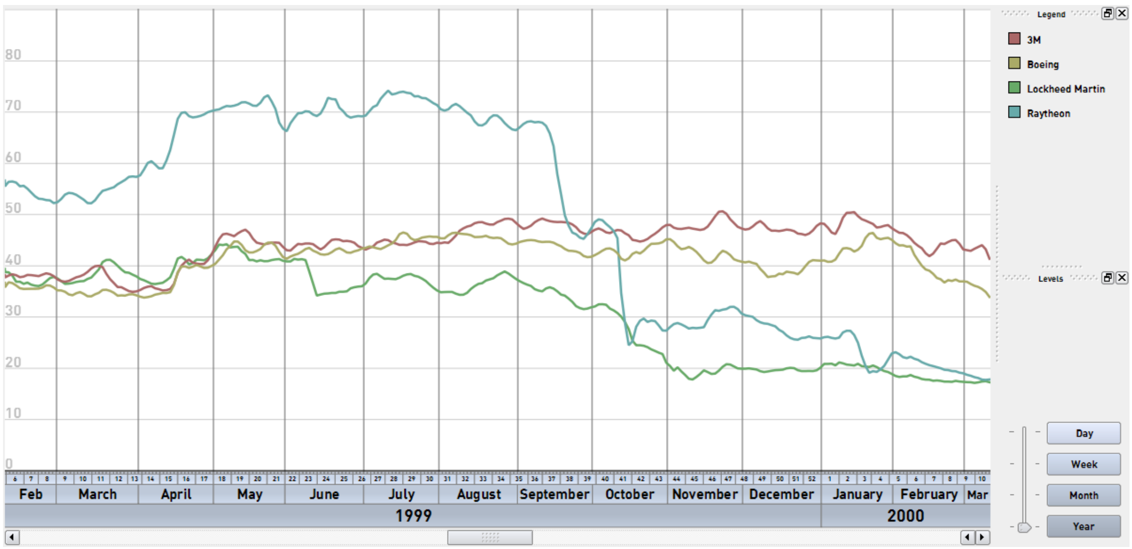

Figure 9 : Standard line chart [17]

In the scope of the Urban Heat Island, the line chart can be used to compare the temperature of multiple nodes over a certain timeframe to see if there is a trend of change or when the UHI intensity is the largest.

2.3.4 Bar chart

A bar chart is a simple visualization of multiple values of a variable. Two standard bar charts are shown in Figure 10. A 3D bar chart, seen in Figure 11, can present multiple variables and their values in a 3D space or display a landscape similar to that of a 3D contour map.

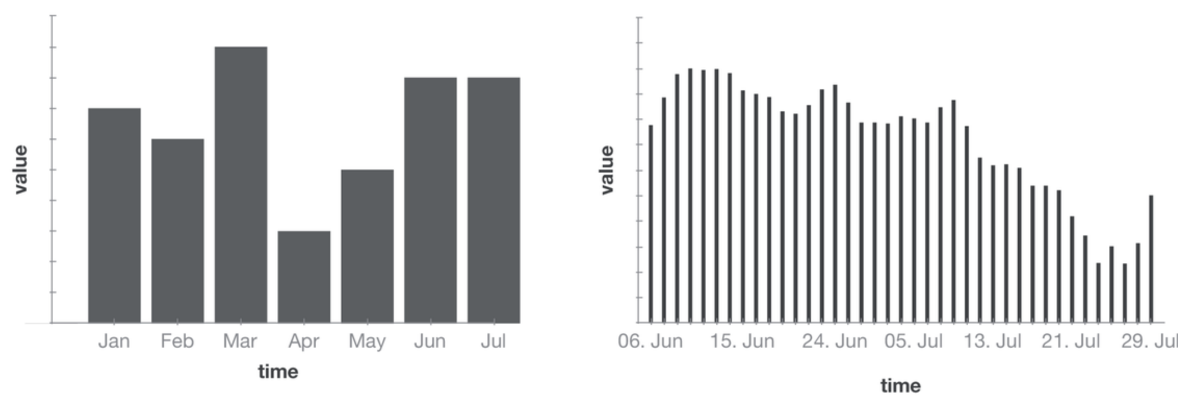

Figure 10 : Standard bar charts with different thicknesses [17]

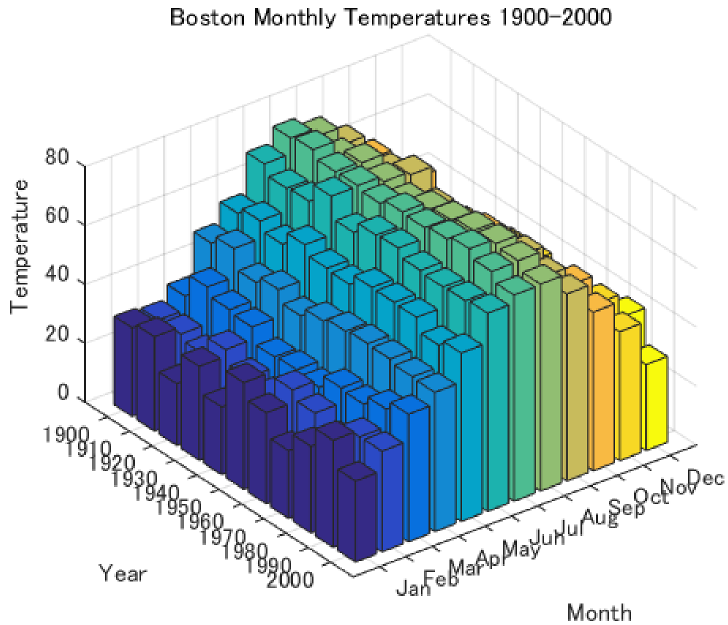

Figure 11 : 3D bar chart of temperatures [18]

In the scope of the Urban Heat Island the bar chart can only be used to display the current temperatures of individual sensor nodes, the challenge will be to decide in which order the nodes are placed. This is where the 3D bar chart can be more honest in displaying the data gathered at certain points in a 3D area.

2.4 Novel data presentation techniques

2.4.1 Virtual and augmented reality data presentation

With new emerging technologies, it would be a waste to not examine the possibilities that they offer for the field of data visualization. The new trend of Virtual Reality (VR) and Augmented Reality (AR) has already shown to be useful in many fields, but still has not been established in visualizing data. However, companies have ben emerging that merge the two. Figure 12 and Figure 13 show the visualization that the company Nirvaniq Labs created to present the data of Canada's energy demand. However, these two screenshots do not propose a unique solution through VR, but rather reproduce standard visualizations that are more useful on a web application than in virtual or augmented reality.

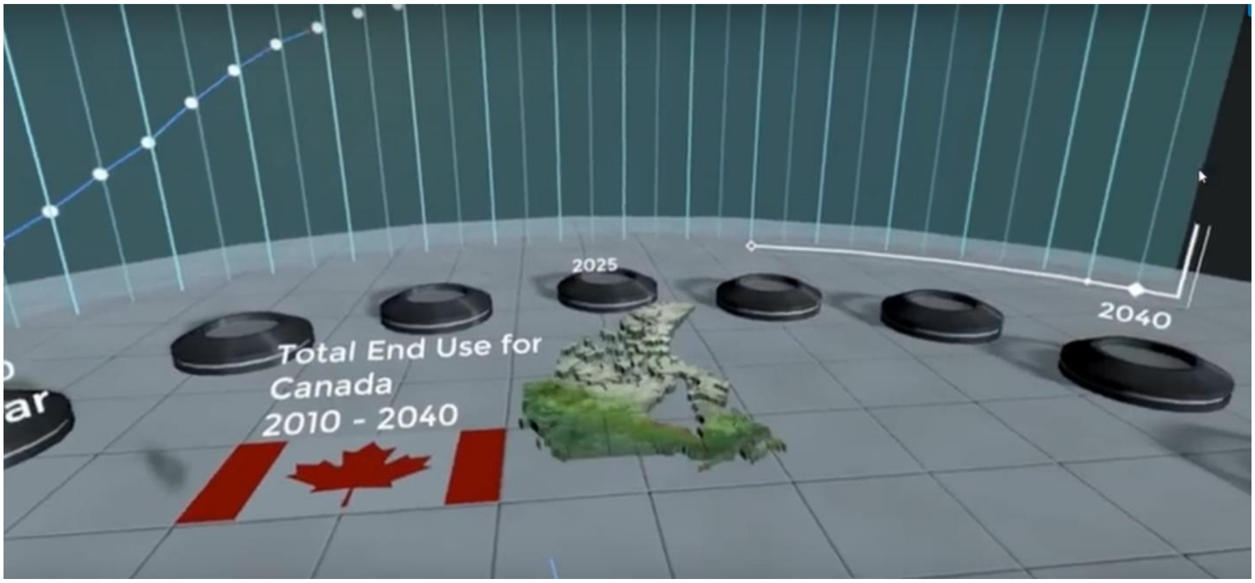

Figure 12 : VR data visualization of Canada's energy demand [19]

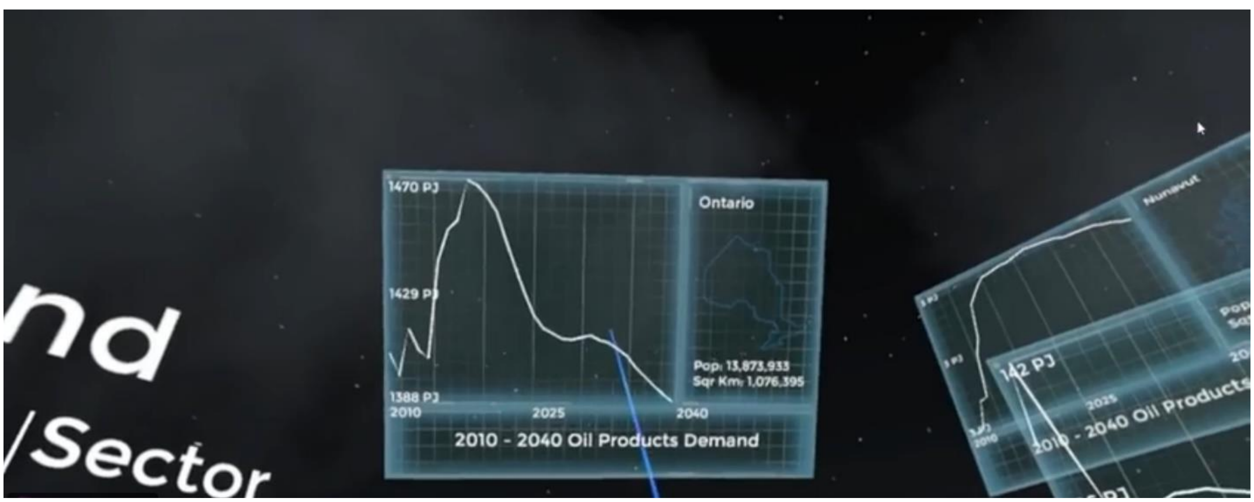

Figure 13 : VR data visualization of Canada's energy demand [19]

A more creative VR visualization was created by the Wall Street Journal, using a line chart and visualizing it in 3D to take the viewer on a Guided tour of the history of the stock exchange Nasdaq. However, this visualization is not used as an exploratory or analytical tool for VR but could be rather considered an educational and entertainment tool.

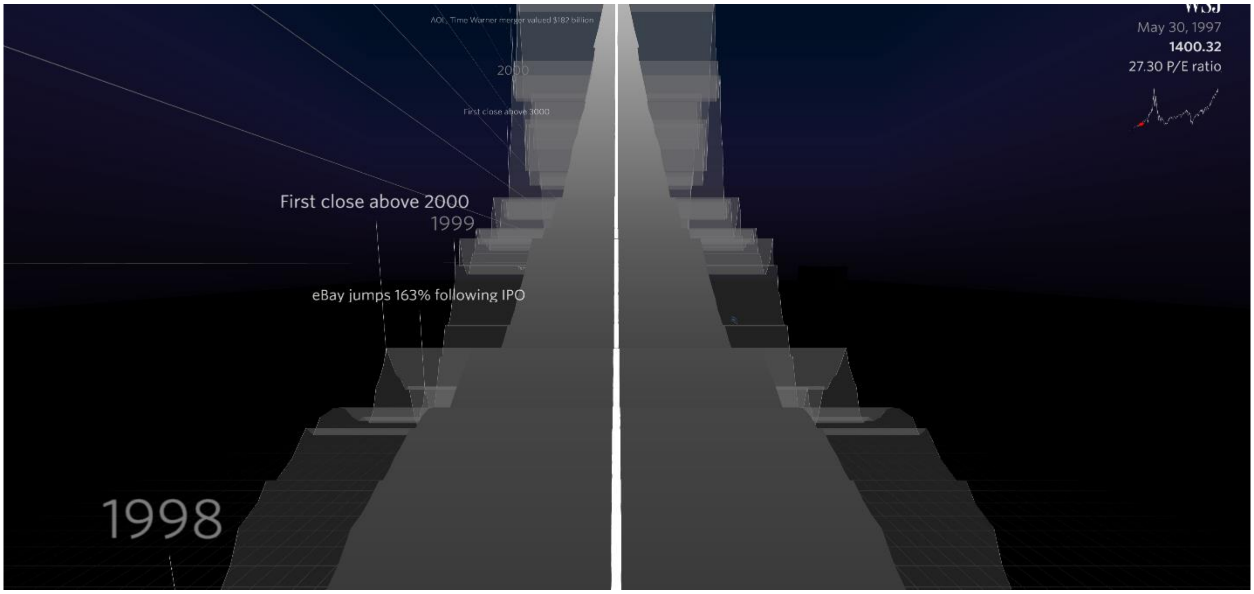

Figure 14 : Wall Street Journal's VR guided tour of 21 years of the Nasdaq [20]

Most current VR or AR visualizations only focus on transposing standard data visualizations into 3D space. This might be useful in the case of 3D bar charts or 3D scatter plots to get a clearer picture of the data. However, it remains to be seen whether or not there are unique data visualizations for exploration and analysis of data that could only be possible in VR or AR.

2.4.2 Data physicalization

Data physicalization takes data and represents it in the physical world. This section will discuss dynamic data physicalization, which uses motors or projections to change the data presented, as the temperature data will be a time-oriented and dynamic data set. The first and most simple, is the dynamic physical bar chart shown in Figure 15, where the bars can adjust height based on the data. However, this suffers from the same faults as the VR solution shown in Figure 13, where the data visualization does not uniquely present the data but uses an already standard visualization and just transforms it into a new form, not adding, but subtracting from the usefulness of the data visualization.

Figure 15 : Wable - dynamic physical bar chart [21]

A more interesting data physicalization is shown in Figure 16, where regions of Italy can elevate to present data sets about the country. The corresponding data visualization to this physicalization would be the Choropleth map, but in this case elevation is used to represent the data value, not color. In this case the physicalization could be used educationaly, obtaining more attention due to a more intersting interaction than with standard visualizations.

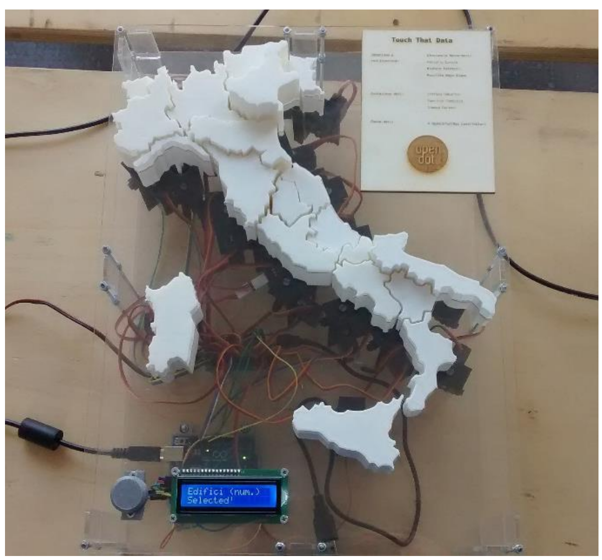

Figure 16 : Actuated Prism Map of Italy [22]

Finally, a more abstract way to make a data set physical is shown in Figure 17, with the Point Cloud. This data physicalization warps the large mesh installation to represents weather data. The types of movement explain the current weather situation, the author describes it as: “Point Cloud performs the data, dynamically shifting between stability and turbulence, expansion and contraction” [23]. However, this physicalization is more of an art exhibition than an effective analytical tool, the data interpretation is very abstract.

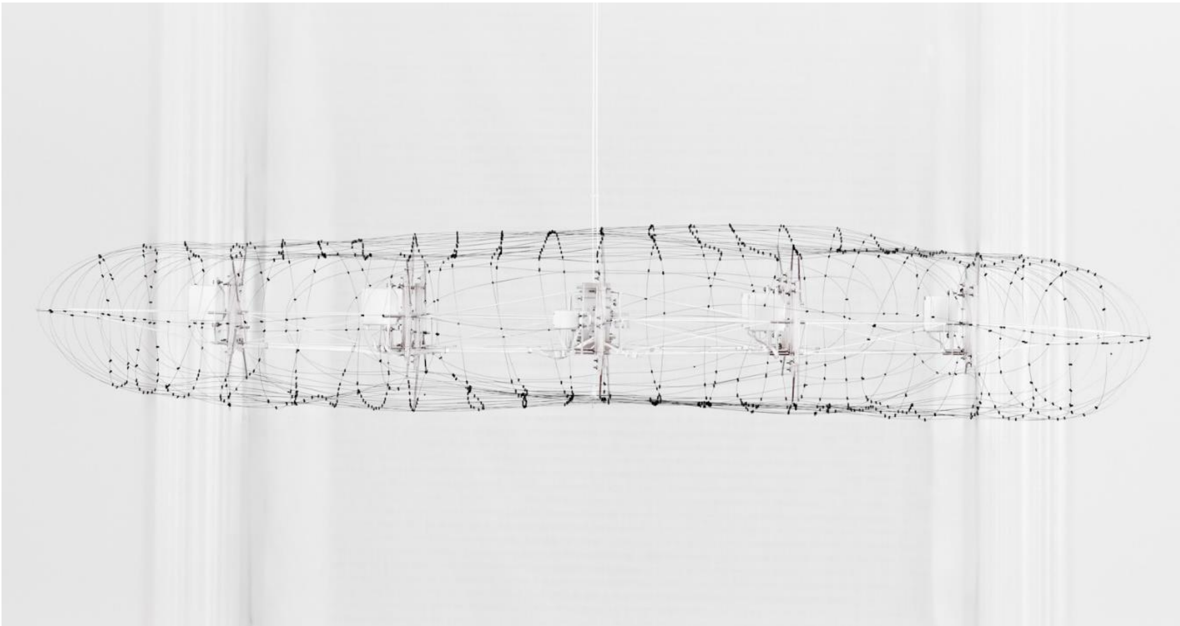

Figure 17 : Point Cloud - kinetic weather interpreter [23]

To conclude, data physicalization could be used to create a more intense feeling of interaction by the viewer or create interest in the topic of the data. However, it remains to be seen if it could be used as a complex analytical or investigative tool to represent the UHI. It could possibly be used to inform the citizens of the issue with an installation in the city of Enschede.

2.5 Similar projects

2.5.1 Climate Ready Boston Map Explorer

The Boston map explorer [24] is one of the many heat maps that are available for citizens of cities to investigate their UHI. Some other cities that have a similar visualization are the city of Parramatta [25] or Los Angeles [26]. In the Netherlands, Rotterdam had a project called Hotterdam [12] that lead to a pamphlet for its citizens to warn them about the health risks of high temperatures and the UHI in Rotterdam. Almost all these projects use temperature data from satellites and map the temperatures of a single time. The visualizations are not continuous and do not show trends. The Boston climate ready map explorer, seen in Figure 18, is the clearest from all other cities. It has a multitude of different layers that can be toggled by the viewer to compare the areas of the UHI and socially vulnerable areas, for example where a large population of elderly live. Development projects in the area can also be highlighted.

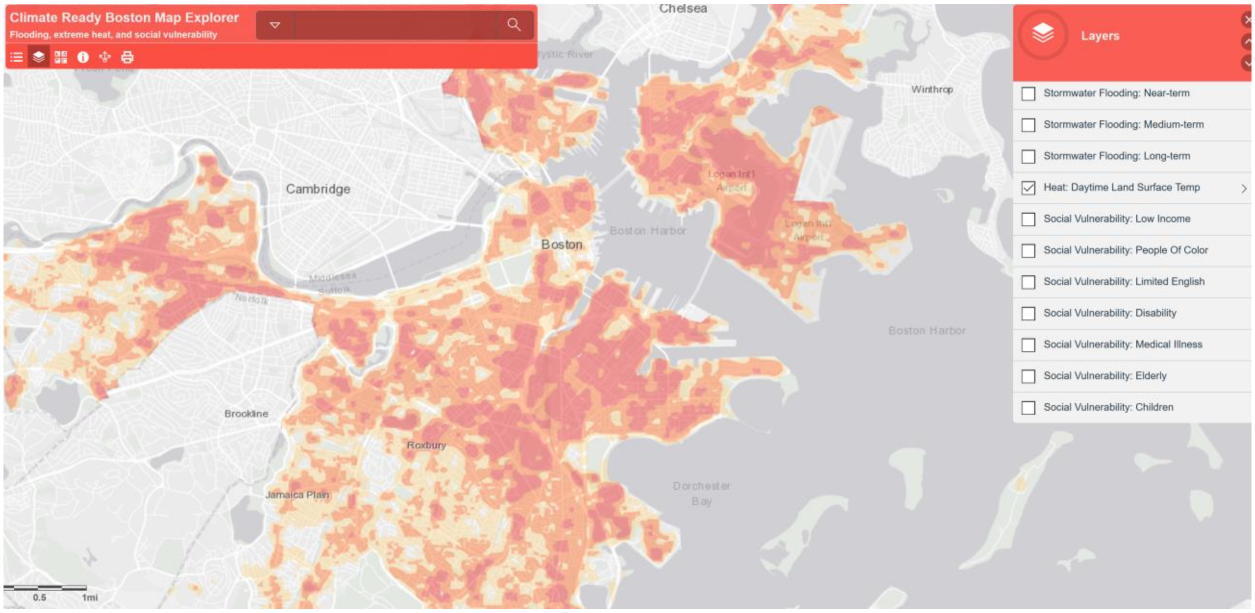

Figure 18 : The climate ready Boston map explorer [24]

The main issue of the Boston map explorer is the lack of a legend to explain what range of values corresponds to certain colors. Apart from this, the visualization is not dynamic and only shows the data of a certain day, this limits the interaction of the users with the visualization and hinders further exploration into the data.

2.5.2 Chicago array of things

The Chicago array of things network [27]is different from the projects described in section 2.5.1, in that it does not use satellite data, but data from a network of sensors, like this graduation project. The city of Chicago has been adding many sensors around the center to monitor many different variables along with the temperature. The map in Figure 19 shows the distribution of the sensor nodes. However, this is the only visualization that is available at the moment. The actual data has not been visualized but is available for the public to download and explore.

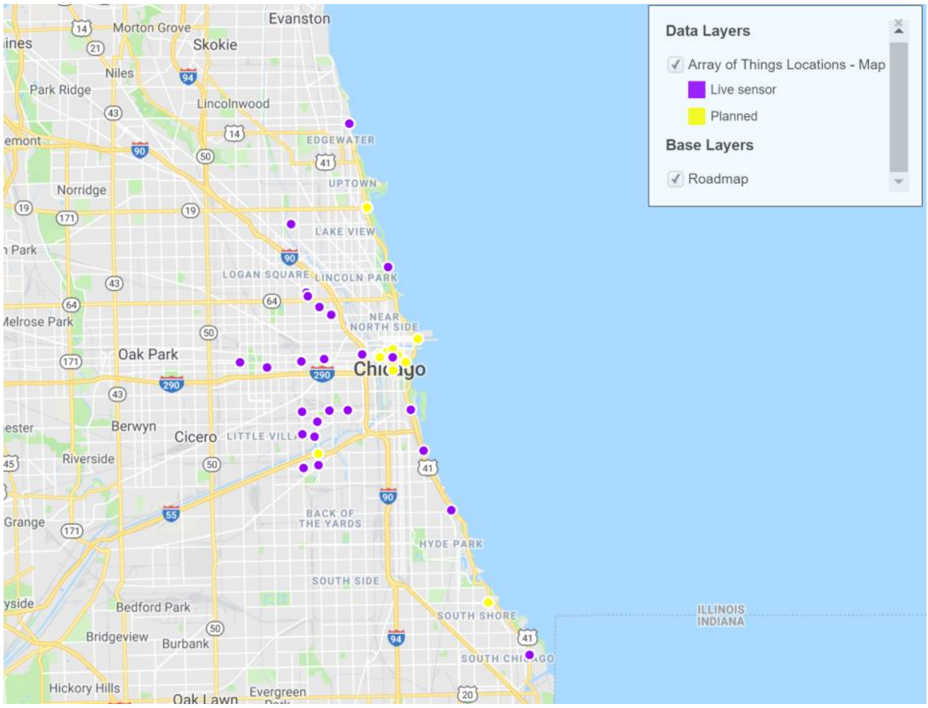

Figure 19 : Chicago array of things sensor network [27]

The way in which the data is available to the public could help guide this graduation project. As parts of the community in Enschede, along with students and researchers at the education facilities in Enschede could make use of this data in their own visualizations or projects.

2.6 Classification of an Urban Heat Island

The Urban Heat Island was described shortly in the introduction and will be discussed in more depth in this section. The UHI, based on sources, can increase the temperature of a city by anywhere from 2°C to 15°C [28] and can be identified by this rise of temperature while moving into the center of the city, and a decrease while moving to rural areas. The cause and factors that contribute to the UHI will be discussed in the subsection 2.5.1 below, to get a better idea on the origin of the UHI.

2.5.1 Relevant variables

There are two types of factors that can influence the UHI [29]. The first are the urban factors: sizes of urban areas, types of building materials, the structure of the urban areas (number of parks, size of parks, sizes of buildings, building density etc.) and the population density. The second type of factors are the climatological factors, these can be: the intensity of solar radiation, wind speed and direction, and seasons. The urban factors will change how the climatological factors of the region effect the city, which then affect the temperature of the city.

The structure of cities influences the amount of solar radiation being absorbed. Firstly, the types of materials influence how easily solar radiation is absorbed and emitted, this is due to the higher heat capacity of concrete, asphalt and fabric [1] . Second, clusters of buildings in a city can cause solar radiation to be reflected between buildings instead of being reflected to space [1], which causes more of the heat that would normally be reflected to space instantly, to stay in the city for longer. The variable that defines the amount of solar radiation reflected is called the albedo (the higher the albedo, the more reflective). Finally, the structure of the city can influence the wind speeds and directions, which will decrease the redistribution of heat in and outside of the city [2] [29]. Therefore, measuring the temperature along with the intensity of solar radiation and wind speed and direction can help with identifying the problematic area of the city that is more prone to high temperatures.

Apart from the variables that can directly influence the UHI, there are also variables that affect the human perception of the UHI effect. Humidity can widely affect humans and how their bodies react to the temperature, at a higher humidity, higher temperatures can have more strain on the body [30]. So, if the city of Enschede were to have an interest in seeing the effect that the UHI might have on its citizens, monitoring the humidity could be very useful.

Therefore, solar radiation, wind speed and direction, and humidity would be interesting variables to measure. However, the focus of this project will be investigating the extent of the UHI in Enschede, so the temperature is the main variable that needs to be investigated. If the UHI is proven to exist, then other variables could be monitored and visualized to help with the investigation of the causes of the problem.

2.6 Conclusion

The focus of this chapter was to gain insight on the possibilities of data presentation in the scope of the UHI, but also in the broader spectrum of data visualization and physicalization. Similar projects have shown to mostly depend on heat maps, however it remains to be seen if this is the only and best solution. Many different possibilities to explore data have been investigated and should be filtered based on the requirements of this project.

The first topic discussed in this state of the art were the advantages of visualizing data. The main advantages was a faster and more efficient understanding of the data set, along with simpler pattern and anomaly detection in the data. Therefore, visualizing the data on a screen, or in 3D space can give useful insight into the search for Enschede's UHI.

The second topic discussed were different types of visualizations that could possibly be used. These need to be filtered based on the requirements of the final product, to see which ones are the most useful and could possibly be combined into a temperature monitoring dashboard that could be used by the municipality.

The third topic discussed surrounded novel ways of presenting data. The first approach was using VR or AR technology to bring data into the 3D space. However, none of the used novel and interesting data visualizations. And the data visualizations that were interesting and novel, were used mostly as an educational and entertainment tool rather than an analytical tool. The only useful utilization of VR and AR visualizations is in displaying 3D visualizations that are normally skewed in 2D but show their true scale in the 3D space. The second novel way to present data discussed was data physicalization. However, this approach suffered from the same problems as VR and AR approaches, in that it mostly took standard visualizations and transformed them into a physical model, which does not add much to data analysis. The only positive this approach garners, is the more interesting human interaction involved in physical models. More interesting and novels data physicalizations found, were more art than analysis. It remains to be seen whether these novel data presentation techniques could bring more value than standard 2D approaches.

The fourth topic investigated similar projects to this one. Where most cities used satellite data and heat maps to present their UHI. These visualizations had a lack of interaction and investigations into the trend of the UHI, due to the fact that they only had data of a certain day at a certain time. The Chicago Array of Things was similar to this project in the fact that it used sensor data but did not present any visualization. This section showed that there needs to be more thought put into the presentation of temperature data, however it might be shown through testing, that heat maps are indeed the most efficient in identifying the UHI of Enschede.

Finally, the UHI effect itself was investigated further to increase the understanding of the topic, which could lead to more effective visualizations. The variables of solar radiation intensity, wind speed and direction, and humidity were shown to either influence the intensity or perception of the UHI. However, before these variables are monitored, the temperature data should show a clear UHI.

The research questions proposed in Chapter 1 of this report could not be explicitly answered and need to be tested specifically. Many different possibilities were outlined but filtering them and coming up with additional ideas will be the focus of the Ideation chapter.

3. Methods and techniques

In this chapter the methods and techniques that will be used in the project will be discussed.

3.1 Creative Technology Design Process

The Creative Technology Design Process [31] is a flexible multistep process of arriving at a final product or system through many prototypes and testing. There are four main phases of the process: The Ideation phase, The Specification phase, The Realization phase, and The Evaluation phase, each discussed in their specific sub sections. Each phase ends with an evaluation and leads to the following phase. However, the phases can occur multiple times after one another, for example there can be further specification after the execution of a first prototype due to new insights gained.

3.1.1 Ideation phase

In the ideation phase, many ideas are created using brainstorming and the knowledge gained from the state of the art research, while considering the preliminary requirements from the stakeholders. It is important to use the technique of divergence and convergence when creating ideas for a solution to a problem. In the divergence stage, all the possibilities are considered, and many different ideas are brought forth to the stakeholders. After this the convergence stage comes to play, and the design space is narrowed down based on feedback from the stakeholders. The chosen type of product or system is then brainstormed on further to create a final idea from the Ideation phase.

3.1.2 Specification phase

In the Specification phase, the preliminary requirements will be extended based on the conclusions made in the Ideation phase. The functional architecture of the product or system should be described in this phase, so that the realization phase can be properly segmented, and each part can be tested individually. Prototypes could be made to further investigate requirements and the functional architecture.

3.1.3 Realization phase

In the Realization phase the requirements and functional architecture described in the Specification phase are implemented into a product or system. First the necessary technology must be found, and then realized in parts, so each part can be tested and evaluated separately.

3.1.4 Evaluation phase

In the Evaluation phase the product is evaluated with all the requirements that were described in the Specification phase. Although many requirements should be checked along the way during the realization, the final evaluation should be executed in this phase of the project. User testing should be performed to test non-functional requirements and evaluate the user experience. Finally, a reflection about the project will be made, along with descriptions of possible improvements to the product or system.

3.2 Stakeholder identification and analysis

To identify and describe all stakeholders involved in this project the methods of Sharp et. al [32] will be used. Using this method, stakeholders are divided into four groups:

- Users
- Developers
- Legislators
- Decision-makers

Users will be the ones that use the system or product in the end. Developers are stakeholders when creating the system and the requirements, but will not be the end users of the system. Legislators are government agencies, quality assurance auditors, or any professional bodies that have a say in the development of the system or product due to quality or legal reasons. Finally, decision-makers are the people in charge of managing the development, like team managers or supervisors.

To help describe the powers and interests of certain stakeholders, the power versus interest grid will be used, based on the grid of Eden and Ackermann [33]. Where the individual stakeholders are mapped to the grid based on their individual power over the project and their interest in the system.

3.3 PACT and scenarios

Once stakeholders are identified, most importantly the users, then a PACT analysis [34] along with scenarios will help visualize the product and think about the requirements. PACT stands for:

- People
- Actions
- Context
- Technology

In each part of PACT, a different view of the product is taken into consideration. With people, the different users are taken into consideration, who they are, their physical differences, their abilities, their disabilities, and different psychological states. With actions, the types of actions and their characteristics are taken into consideration, the frequency of actions, the response times of the system, well defined vs. vague actions, and the data necessary to carry out the actions. With the contexts, the social and environmental contexts should be taken into consideration, where and why the product or system is in use. Finally, with technologies, the different necessary technologies for the system to work are taken into consideration.

Once all the parts of the PACT analysis are described, then a scenario can be made easily. Where a persona is put into the context of the system or product, and a use of the system in the real world is described. If there are different groups of users interacting with the system or product, then multiple scenarios should be made.

3.4 Requirement elicitation and analysis

Through preliminary semi-structured interviews with the stakeholders, the preliminary requirements are drafted. These preliminary requirements are then used for creating concepts, which are discussed with the stakeholders to reach more defined requirements of the stakeholders. After the second round of discussing the requirements with the stakeholders, the stakeholder analysis, PACT analysis, and scenarios will give insight into what requirements need to be met for all the scenarios. Once these requirements are discovered they must be analyzed and documented. First a distinction between functional and non-functional should be made, followed by the MoSCoW ranking of the requirements, and finally the requirements should be documented in a clear notation.

3.4.1 Functional and Non-Functional

Functional requirements are requirements that describe certain functions of the system, or services it should deliver. Non-functional requirements are requirements that describe the quality of those functions or services, for example performance, usability, security, safety, customizability, etc. [35]. Both types of requirements should be described in a way that can be tested and evaluated based on pre-established criteria.

3.4.2 MoSCoW ranking

The MoSCoW ranking is an acronym that entails the following terms:

- Must have
- Should have
- Could have
- Won't have

Requirements that are essential to the system will be marked as Must have. Requirements that are not so important to the system but are necessary to have a useful system are marked as Should have. Requirements that would be good to have in the system but should only be implemented if time allows it are marked as Could have. And finally, requirements that can be implemented in future versions of the system but are not in the scope of the current version are marked as Won't have.

3.5 Usability Heuristics

To help with the design and usability of the system, the 10 usability heuristics by Jacob Nielsen will be followed [36]:

1. Visibility of system status

The users should always know what is going on with the system through appropriate feedback.

2. Match between system and the real world

The system's phrasing should match real-world conventions and speak the language of the user, not using technical terms if the users will not be familiar with them.

3. User control and freedom

Supporting users when they make mistakes, mostly by using redo and undo buttons.

4. Consistency and standards

Phrases, words, and symbols are consistent and always mean the same things.

5. Error prevention

Reduce error prone conditions to make sure errors do not occur instead of giving error messages.

6. Recognition rather than recall

Make sure all information is available when it is needed. Make sure instructions are always available.

7. Flexibility and efficiency of use

Accelerators, which make tasks faster for more experienced users are available and do not confuse novices.

8. Aesthetic and minimalist design

All information available should be simple and relevant, no unnecessary additions.

9. Help users recognize, diagnose, and recover from errors

The system should show simple error messages.

10. Help and documentation

Although the system should be self-explanatory it is always a good idea to have documentation for when users do not understand certain functions. This documentation should be easy to find.

4. Ideation

4.1 Stakeholder analysis

Using the method of Sharp, the stakeholders in Table 1 have been identified. The table contains the stakeholder group, along with the contact person and the specific type of stakeholder. Their specific roles, and influence are described in the specific subsections of each stakeholder.

Stakeholder	Contact person(s)	Type
Municipality of Enschede	H.J. Teekens	Users, Decision-Makers
ITC	Wim Timmermans	Users, Decision-Makers
University of Twente	H. Scholten, R.G.A. Bults	Decision-Makers
Heat stress team	J. Planting, L. Kester	Developers
Citizens of Enschede		(possible) Users

Table 1: Stakeholders, their contact persons, and type

These stakeholders can be mapped to the power versus interest grid, Figure 20 to better explain their influences.

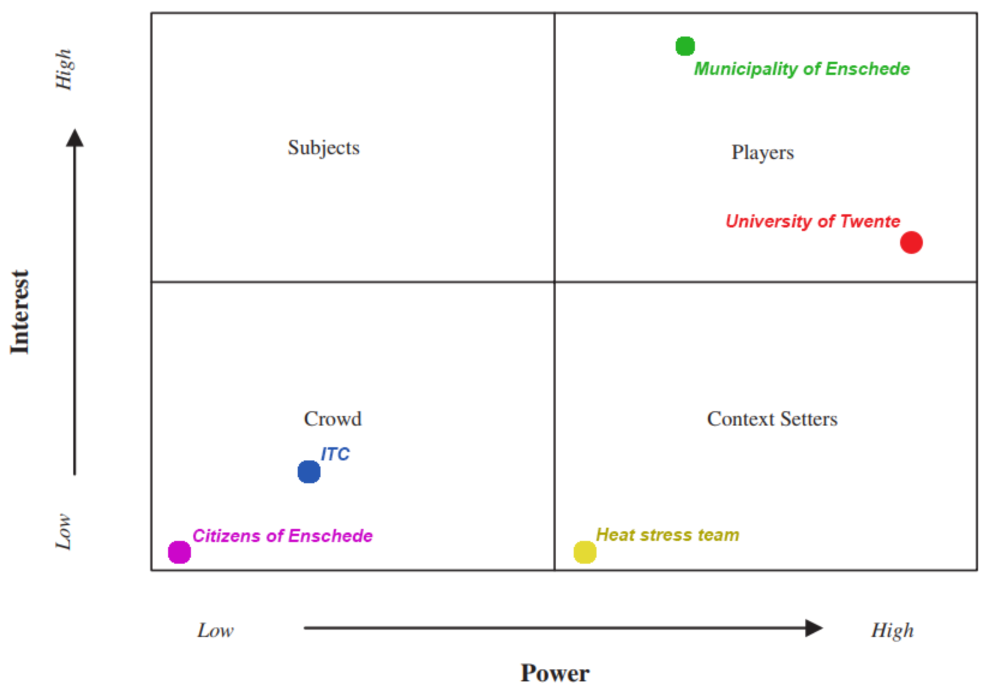

Figure 20: Power versus influence grid

4.1.1 Municipality of Enschede

The municipality of Enschede is an important stakeholder, being one of the main end users of the data presentation and being a decision-maker. The municipality is looking for a way to monitor the temperature measurements that are happening across the city. They wish to classify the extent of the UHI in Enschede, along with the trends of its development. Many meetings were set up with the municipalities contact person H.J. Teekens to ellicit the requirements of the municipality, where concepts of the first and second stage of ideation were presented and discussed.

4.1.2 ITC

The Faculty of Geo-Information Science and Earth Observation (ITC) of the University of Twente has shown interest in the data that is collected in Enschede. The contact person, Wim Timmermans, is working on a meteorological model for the city and needs data to calibrate and validate his models. The presentation of the data is not of importance for the ITC, rather the access to the data.

4.1.3 University of Twente

The University of Twente is overseeing the project and is a decision maker in the final result of the project. They will oversee the progress of the project and make sure all necessary requirements are met.

4.1.4 Heat stress team

The Heat stress team is comprised of L. Kester and J. Planting. L. Kester is working on the meteorological sensor network in Enschede. Close communication must be had, so that the sensors send the correct data, and that the data presentation presents the correct data. J. Planting is working on the database that will store the data of the heat stress project. The development of the database will be guided by the needs of this project, so the requirements must be well communicated.

4.1.5 Citizens of Enschede

The citizens of Enschede are a possible user of the final system, therefore the system should be user friendly. However, for now the municipality wants to monitor the UHI on their own.

4.2 Preliminary requirements

4.2.1 Requirements of the Municipality of Enschede

From the initial meeting with H.J. Teekens from the municipality of Enschede, the following requirements were discussed:

- The system should monitor the temperature from all the sensor nodes
- The system should be able to display whether a UHI is present
- The system should help monitor the possible increase of the UHI over time

Where the system will be used internally for the municipality. However, it is not decided whether the public would get access to the system or the data.

4.2.2 Requirements of the ITC faculty

From the initial meeting with Wim Timmermans from the ITC, the following requirements were discussed:

- The system should allow the ITC to download the data from the sensors in a simple data file

4.3 Concept creation

The concept creation phase is split into two parts. In the first, all possibilities from the background research were taken into consideration and used in the concept creation to satisfy the preliminary requirements. These concepts were then presented to the stakeholders of the Municipality of Enschede and the University of Enschede to choose the direction in which this project should go. In the second phase, where the main type of data presentation was chosen, a narrower set of concepts was generated to come to the final idea of the ideation phase and its main requirements.

4.3.1 First round concepts

4.3.1.1 Online dashboard

The online dashboard would be accessible through the web. It would be comprised of multiple data visualizations that give insights into different aspects of the data, like in Figure 21. There could be a map with the locations and current data of each sensor node. There could be a line chart that would be used to monitor single or multiple sensor nodes over time. There could also be a heat tile map to help discern patterns in the UHI intensity.

Figure 21: Dashboard concept

4.3.1.2 Physical dashboard

The physical dashboard could be a physical map that hangs in an office or public space of the municipality building in Enschede. The map would have LEDs that would represent sensor nodes and their location, along with the color representing the temperature that they measure (see Figure 22). Finally, a line chart and legend could be presented on a smaller screen underneath the map.

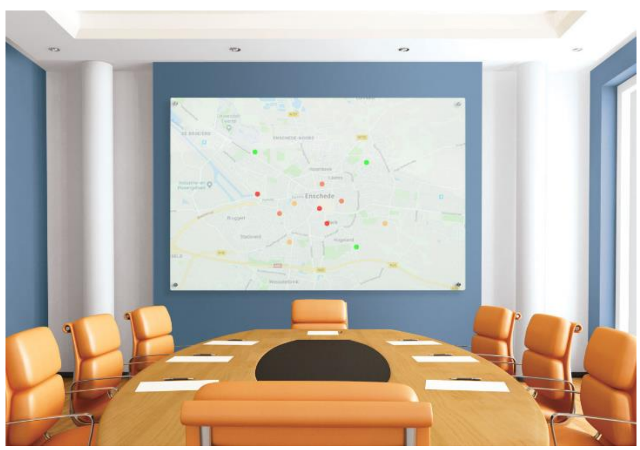

Figure 22: Physical dashboard

4.3.1.3 Virtual Reality tool

The Virtual Reality data exploration tool could be comprised of 3D bar charts or a heat map. The advantage of the Virtual Reality tool over a 2D representation could be a more accurate view of the spatial distribution of the data. A possible view can be seen in Figure 23.

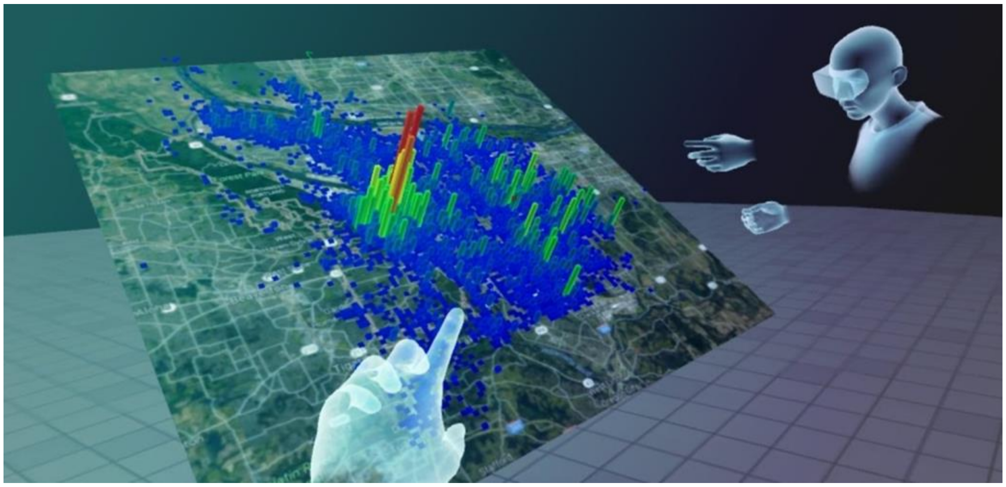

Figure 23: VR data visualization [37]

4.3.1.4 Augmented Reality map

The Augmented reality map could be a more affordable implementation of the Virtual Reality tool, as multiple people could interact with the map at the same time. A heat map from the sensor data could be projected over the physical map of Enschede, like in Figure 24 .

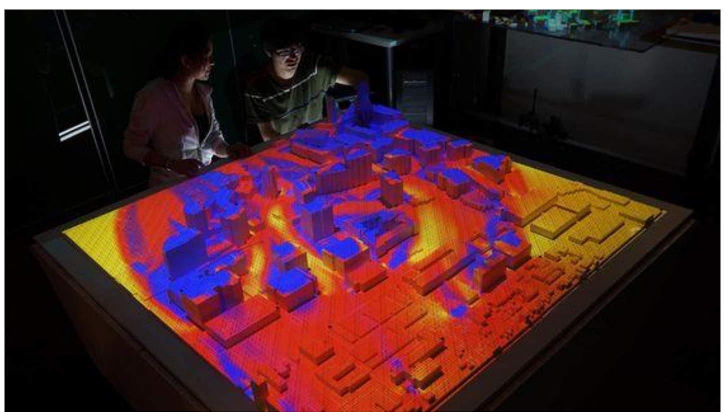

Figure 24: Augmented reality heatmap [38]

4.3.1.5 Visualizations inside of Google Earth

Using the Google Earth exploration tool, data could be added to a layer overlay, so a 3D bar chart or a heat map could be projected over the 3D model of Enschede, like in Figure 25.

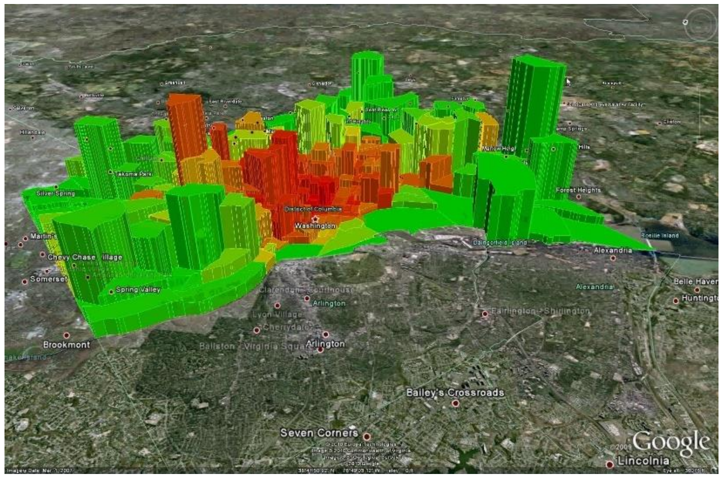

Figure 25: Google Earth choropleth map [39]

4.3.1.6 Choropleth map physicalization

The area of Enschede would be split into many different areas, which would be recreated by physical models and raised up or down based on their temperature by actuators. This physicalization could be used in the public spaces to inform the citizens about the project, like in Figure 16.

4.3.2 Conclusion of the first round of concepts

After all concepts were discussed the direction of the online dashboard comprised of multiple data visualizations for analysis was chosen. With the feedback being, that a map with points representing the sensor nodes should be chosen over the heat map, as the heat map could possibly interpolate a heat map that could lead to an incorrect conclusion due to the limitation of the number of nodes.

4.2.2 Second round concepts

In the second round of concepts, the specific data visualizations that would appear in the dashboard were discussed. The following visualizations were proposed:

- Map with nodes represented by small points, and their temperature values represented by a color scale
- An interpolated heat map, that could be separate, or overlay the existing map with nodes
- A line chart with each line representing a separate node
- A heat tile map
- A bar chart/ 3d bar chart

4.2.2.1 Conclusion of second round of concepts

The main required data visualizations for the municipality are the map containing points that represent sensor nodes and the line chart. The other visualizations are not so important for the municipality, but if time allows for more visualizations, the tile heat map would be of interest. An important feature of all visualizations will be time manipulation, setting certain dates and times for the map visualization and setting date and time frames for the line chart.

4.3 Ideation phase concept

The final concept will be a web-based dashboard with multiple data visualizations. The first of the visualizations being a map with nodes and their temperature, with a possibility to toggle an interpolated heatmap overlay. The second visualization being a line chart, in which each line can represent the temperature of a node over a timeframe. The third visualization being a heat tile map, where the tiles can represent temperatures or the differences between two nodes.

4.4 PACT analysis

As described in the Methods and Techniques chapter, the PACT analysis will give insight into the requirements of the system from the users.

4.4.1 People

The main users of the system will be employees of the Municipality of Enschede. This is a wide range of users of different ages, however all adults. There are physiological differences from person to person, however the only important one in this context is vision. People with color blindness should be taken into consideration, and the system should accommodate them. However, the system will not be accessible to the blind. The people of the municipality already work with similar tools to monitor ground water levels, and therefore a close look at these tools will provide insight on how to develop the temperature measurement tool. The people working for the Municipality are mostly Dutch, therefore the system should be available in the Dutch language.

Researchers from the ITC are also going to use a small part of the system to get data from the website. The researchers will have the skill with computers to download a file from a website.

4.4.2 Activities

The activities the system will perform have been discussed in section 4.3 of the report. The visualizations will probably not be checked daily but could possibly be displayed on a screen in the office continuously. The system should accommodate many users, and the response time of the system should be fast.

The researchers from the ITC will access the data once in a while, the system should allow them to download the data of a certain time frame.

4.4.3 Context

The system will be accessible through a website online. The employees of the Municipality of Enschede and researchers from the ITC will access it during work hours or from their home if necessary. In the context of the work environment the employees will want to download certain visualizations to share with their colleagues.

4.4.4 Technologies

The technologies used will be the server that holds the data along with a web interface that presents the data visualizations and a link to download the data from the server. The users will need a computer with internet access to reach the web interface.

4.5 Use scenarios

4.5.1 Scenario of an employee of the municipality

Thijs is a 36-year-old employee for the municipality of Enschede. He works on improving the cities infrastructure with extra focus on sustainability. It is August, and the weather in the city is making a lot of people uncomfortable due to the immense heat. Thijs's mother, who is 61, has been dealing with a lot of issues due to the hot weather and even endured a heat stroke one month ago. Thijs knows about the phenomenon of the Urban Heat Island Effect and how it effects other cities but does not know how it changes the temperature in Enschede. He wants to investigate the issue further, because if he can find reliable evidence that the urban heat island is causing the immense heat, then he could possibly convince his colleagues at the municipality to work on strategies to reduce the heat in the city.

In the afternoon Thijs went to the web application that displays the temperature across the city. He has heard of the project of the sensor network and wants to see if it can be useful. He opens up the map visualization and turns on the heatmap, "wow" he said to himself, the temperature is actually much higher in the city center. He checks how the temperature was in the morning and sees that most of the temperatures are similar. He decides to switch over to the line chart visualization and compare three locations, one in the city center, one in the outskirts of the city and one in a more residential area. The line chart shows quite a difference in the temperature of the sensor in the city during the afternoon.

Thijs decides to download a picture of the line chart and the heatmap and discuss his findings with his colleagues and will also bring it up when he meets up with his friend Alexis which works as a researcher at the University of Twente to see what her take on the situation is.

4.5.2 Scenario of a researcher at the ITC

Alexis works as a researcher for the ITC faculty of the University of Twente. Last year she finished her PHD were she looked into the alterations of wind patterns in cities. At the ITC she is now tasked with working on meteorological models and how they affect local agriculture. She has a hunch that farms and fields close to the city are being impacted by the Urban Heat Island effect and wants to find out how exactly. She wants to investigate how the possible heat build up in the city might alter the micro climate and local precipitation.

This morning she finally finished her model to see how the city affects the farms and is finally ready to validate her model and see if her work is successful. She goes to the website of the web application and finds the tab where she can download the data she needs. She fills in the short form and decides she wants the data from all sensors this current month. She clicks download and is ready to work with it.

During the day she runs the simulation of her model and starts investigating the results. The research she is working on will be very important for the local farmers but might also be helpful for people all across the world. She sees some slight errors in her model and will focus her work now on fixing them and will hopefully be ready to present her findings at a conference in two months.

5. Specification

In this chapter, the specifications of the system will be explored. The system architecture will be discussed first, showing how the system will function with the data source. Next, the functional and non-functional requirements will be described and sorted using the MoSCoW method. Finally, the multiple rounds of prototypes will be explained.

5.1 System architecture

The system can be described in the following figures, from a high-level abstraction to a clearer representation of functions. In Figure 26 the complete system architecture is shown. The website with visualization is the scope of this project but the importance of all other parts of the system must be related as well. There are two sources of data from which the system will gather data, but in the final system the “measurements file” will not be used.

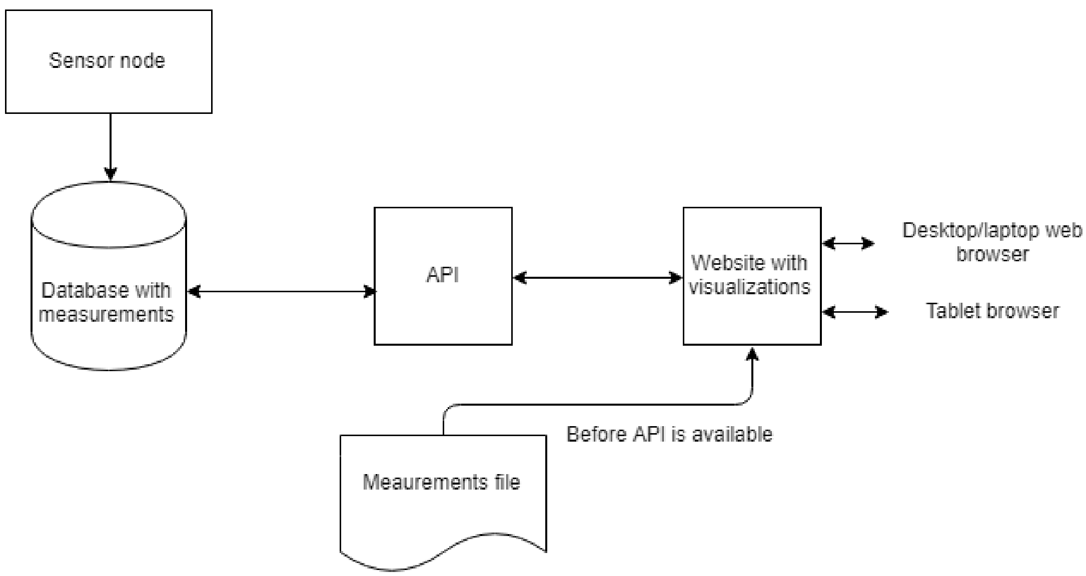

Figure 26 : Complete system architecture

Figure 27 describes the interaction between the website with visualizations and the API, along with the necessary functions of the API corresponding to the blocks of the website.

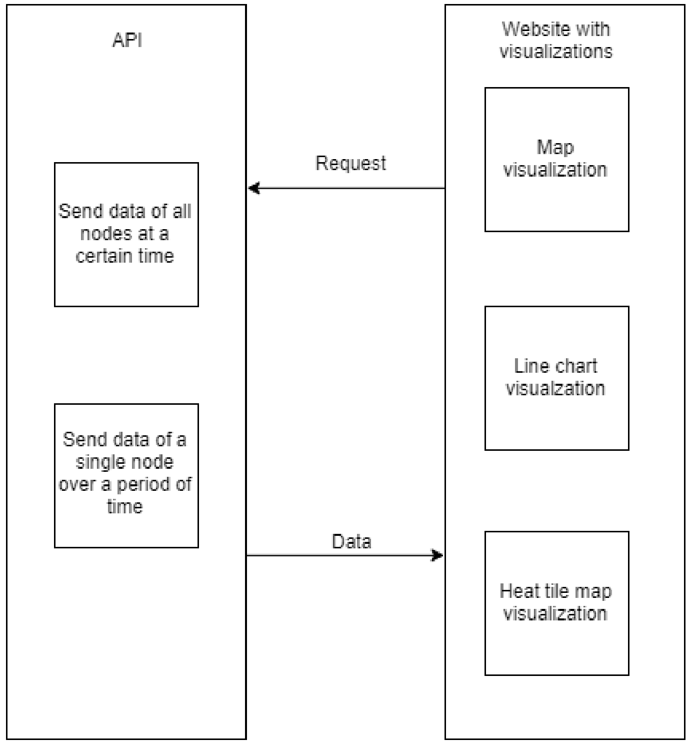

Figure 27: Interaction between web and API

Figure 28 breaks down the essential functions of each visualization which should be implemented gradually and tested step by step.

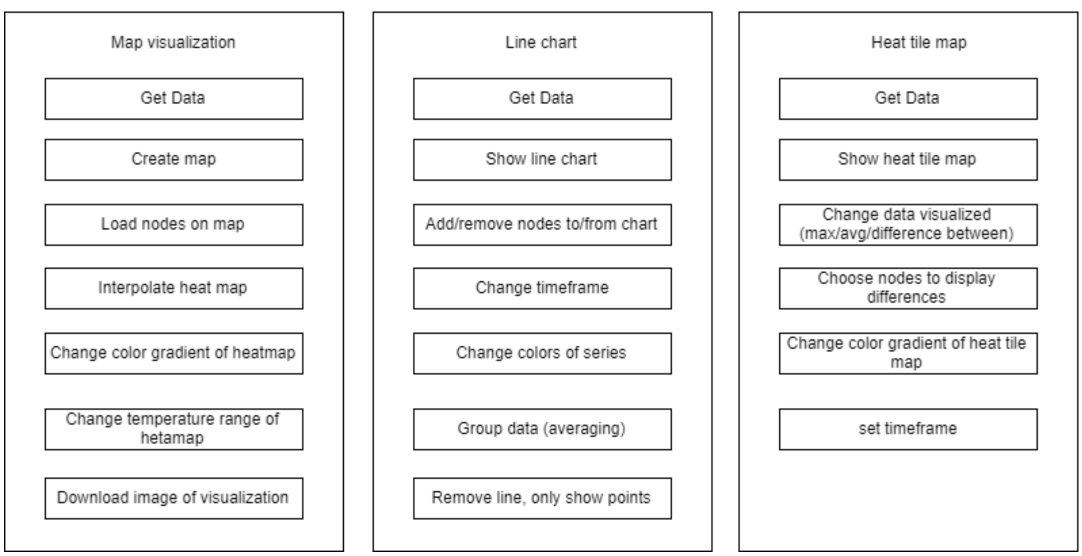

Figure 28 : Breakdown of different visualizations and their necessary functions

5.2 Requirements

5.2.1 Functional requirements

F1: The system can request data from a database with measurements using a dedicated API (M)

F2: The system can display the positions and data points of the nodes on a satellite map (M)

F3: The system can display a heatmap overlay over the map by interpolating the data from all the sensor nodes (M)

F4: The system can display the data of a certain date and time, set by the user, on the map (M)

F5: The system can change the color gradient of the heatmap overlay (S)

F6: The system can change the temperature range that is mapped to the color gradient (S)

F7: The system can display the data of nodes on a line chart, where each node is represented by a single line (M)

F8: The system can alter the timeframe of the line chart (M)

F9: The system can change the line chart to just display the individual data points (S)

F10: The colors of the series on the line chart can be set by the user

F11: The system can display the maximum over a set timeframe on a heat tile map (C)

F12: The system can display the average temperatures over a set timeframe on a heat tile map (C)

F13: The system can display the difference between 2 nodes over a set timeframe on a heat tile map (C)

F14: The system can provide a downloadable image of each data visualization (M)

F15: The system allows the user to download data from the database over a set time period (M)

5.2.2 Non-functional requirements

NF1: The system is available in Dutch and English (M)

NF2: The system can be viewed from a desktop or laptop computer and a tablet device (M)

NF3: The system should load data from the database in a fast manner (M)

NF4: The system should display the data visualizations in a fast manner (M)

NF5: The system should correspond to the 10 heuristic principles described in chapter 3 (S)

NF6: The interpolated heat map should be toggled with the press of 1 button (S)

NF7: The temperature values and node IDs of the sensor nodes on the map should be displayed when hovered over (S)

NF8: Additional sensor data should be displayed when sensor nodes on the map are clicked (S)

NF9: The time and date of the map should be altered in simple drop-down menus (M)

NF10: The timeframe of the line chart should be altered in a simple drop-down menu (M)

NF11: The timeframe of the line chart should be constrained by brushing a rectangle over the line chart (S)

NF12: The system should show a loading animation when loading will take time (S)

5.3 Prototypes

5.3.1 First round

In the first round the basic functionality of individual visualizations will be created with data coming from a static file instead of through an API and database. Once each individual visualization is created, they will be combined into a single web interface, with attention going into reactive design, so the web interface can be comfortably used from a computer and a tablet.

5.3.2 Second round

In the second round the visualizations will be connected to the API so that all their data comes from the database. All final testing will be done after this phase to see if all of the necessary functions have been implemented. After this user testing will be done to see if the non-functional requirements have been met as well.

6. Realization

In this chapter the realization phase will be described, first the tools used to create the web interface and visualizations will be discussed. After this, the final prototype will be discussed in detail.

6.1 Choice of technologies

6.1.1 Web interface

To create the web interface as a whole, the Bootstrap framework was used together with HTML. It is a very simple library that is used to create responsive websites, therefore both the computer and tablets will be supported. The library allows the page to be segmented into rows and columns of certain sizes, that can resize based on the proportions and size of the screen the website is accessed through. Additional styling was made with CSS.

6.1.2 Map visualization

Many tools for creating the map visualization were examined, namely; Carto, Google Maps API, Leaflet, Mapbox, and ArcGis API. Most tools had the same problem, where the heat map generated was not based on values at certain points on the map which would be used to interpolate values at all the other points on the map, but rather by calculating how many points are in a certain area and creating a heatmap based on point density. The only tool that had the possibility to do this was ArcGIS, but this tool was more for scientific analysis, than simple web interfaces, and was therefore complicated to work with and a quick prototype could not be made. The easiest solution was made using the Google Maps API which has the option to create individual heatmap layers for each node, color each individually based on the value, and then group the layers on top of each other, creating a heatmap. All functions for filtering of data and settings were made with JavaScript.

6.1.3 Line chart

There are a large quantity of tools and libraries that can create line charts. The only requirements were, that the charts must be able to update dynamically and there must be an option to zoom in, as requested by the stakeholders. The libraries examined were: D3, Highcharts, Canvas JS, Google charts, and Vega. The stakeholders were however already used to their data visualization of the ground water levels which used the Highcharts data visualization library. As the Highcharts library also fulfilled all the requirements necessary and was easy to work with, it was chosen to be used in the visualization. All functions for filtering of data and settings were made with JavaScript.

6.2 Realization of prototype

6.2.1 Web interface

The final web interface of the system can be seen in Figure 29 and Figure 30.

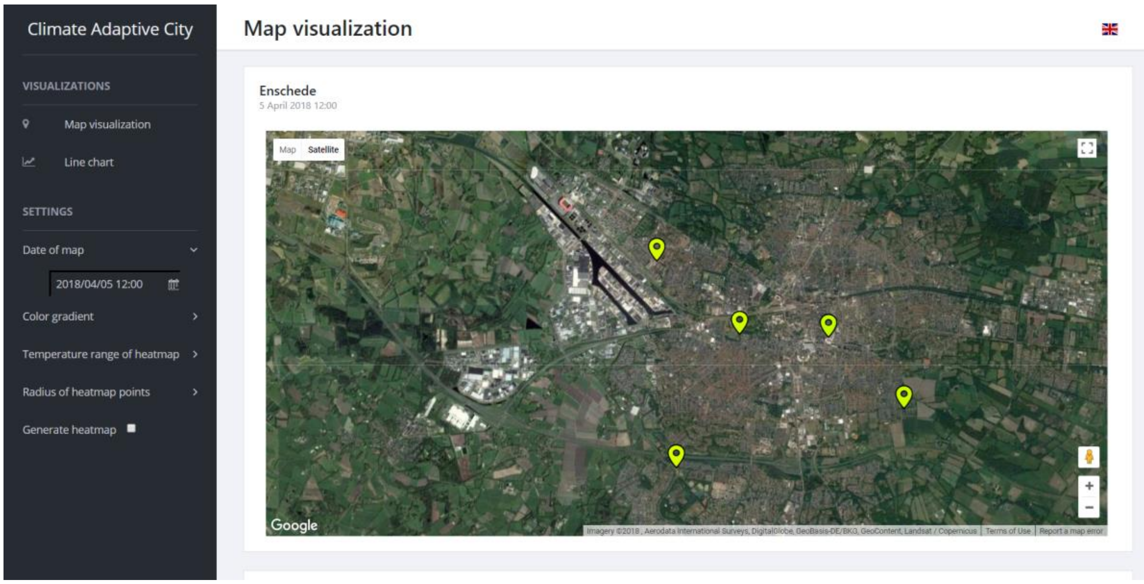

Figure 29: Web interface of the map visualization

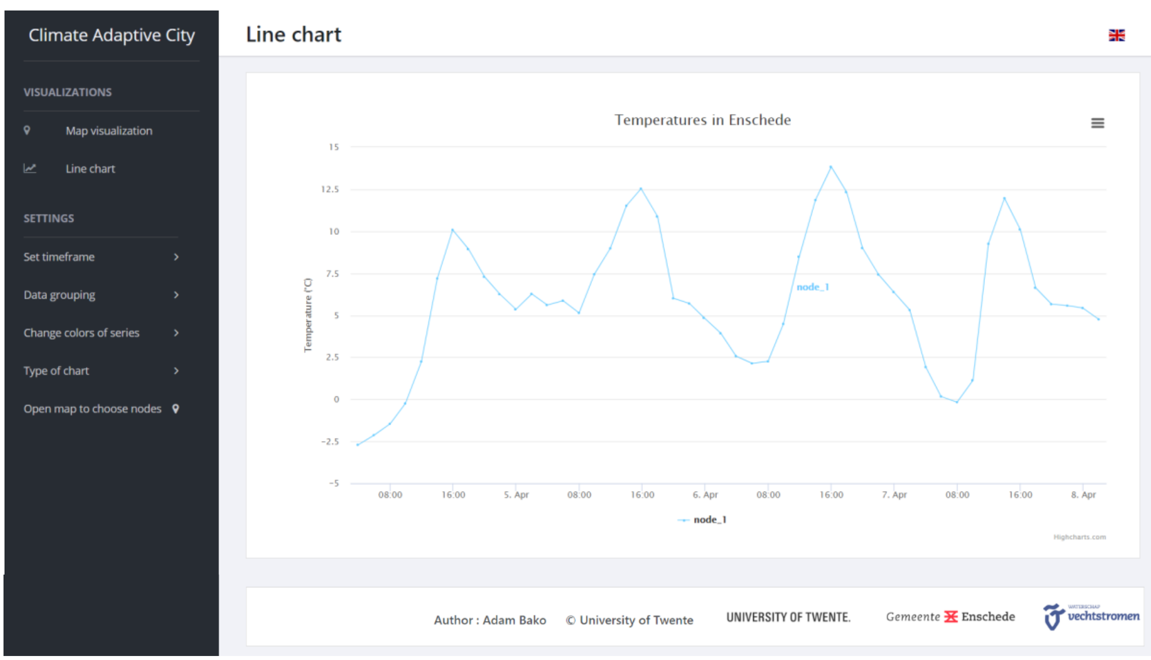

Figure 30: Web interface of line chart with logo area

The choices that resulted in this final interface were led by discoveries in preliminary user testing and discussions with stakeholders, as well as from the standards of the industry and usability heuristics. The interface is divided into two pages, one for the map visualization and the second for the line chart. The visualizations are separated because there is no interaction between them, and therefore it is clearer to show them as two distinct visualizations. There was a concept in which the user can interact with one visualization, which would lead to a direct change in the other, however the stakeholders wished to keep the visualizations separate as combining them together might cause confusion and not be as user friendly.

The page of each visualization is segmented into four parts, the title bar, the side bar with settings, the visualization area, and the area with logos. This was the cleanest design made in the realization phase and was preferred by the stakeholders. In a previous design the choice of visualizations was available in the title bar, as seen in Figure 31, however the stakeholders found it confusing in this location and wanted all the settings of the visualization area to be in the same place.

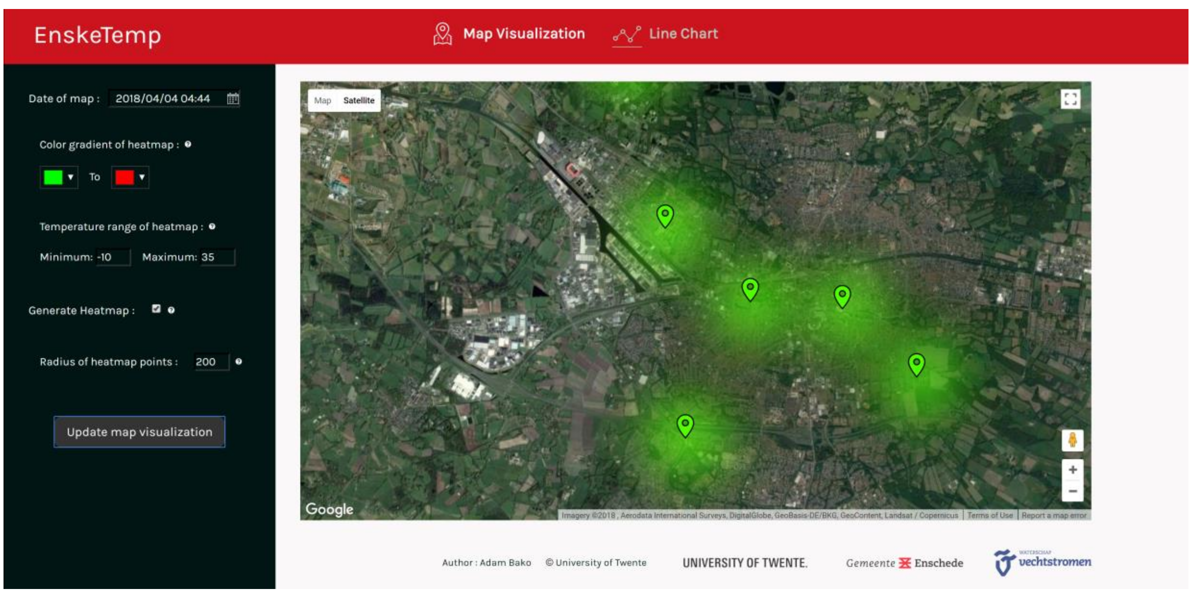

Figure 31: Previous web interface design

Each setting can be changed by clicking on the text of the setting, this opens all the options surrounding that setting, for example in Figure 29 it can be seen that the date setting is being changed. Once the setting has been changed, the visualization updates automatically. In a previous version there was an update button, as can be seen in Figure 31, however the users seemed to find this step unnecessary and wished for an automatic update of the visualizations.

In the final version of the web interface there were no info messages or error messages. In a previous prototype info messages could be found by hovering over an information icon on the side of the setting, as can be seen in Figure 32. However, no one seemed to need these info messages during testing and therefore to make the design more minimalistic and clean, they were removed. Error messages, very similar to the info windows, were also removed, as all the errors made by the users could be prevented by limiting some of the settings, following the error prevention user heuristic.

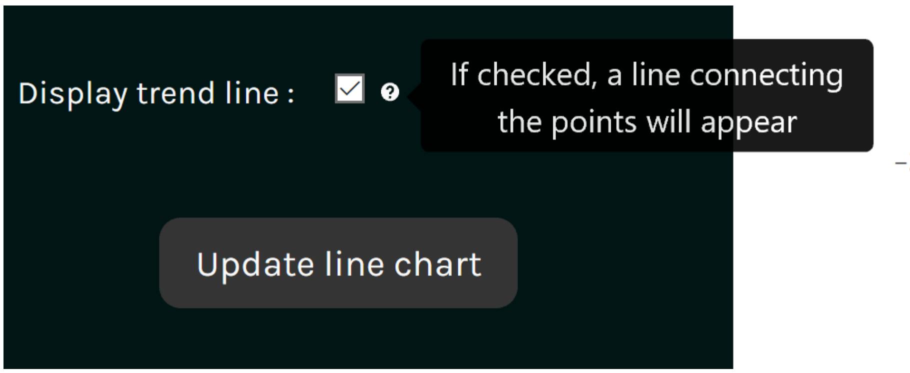

Figure 32: Info window

Finally, the color scheme was chosen as a very minimalistic and simple pallet. When using the colors shown in Figure 31 some users found the side panel too dark and therefore it was made lighter.

6.2.2 Map visualization

The map visualization is the combination of a map with sensor nodes represented by markers along with a heatmap overlay. The map visualization has many settings, where after a user alters a setting, the map visualization updates as a whole. The data is gathered from the measurements file, as there was not enough time in the project to connect it to the database. The function that gets the data, checks the date set by the user, for example 4/4/2018 at 12:00 and gathers all the data half an hour before this datetime and half an hour after this datetime, then it filters out all unique nodes with the closest datetime to the user set datetime. This is necessary because all sensors can be sending data at the same intervals but at different times, so this function makes sure that all the nodes that have data around the user set datetime are displayed in the visualization.

Another important function of this visualization is the heatmap overlay, this is also created with the Google Maps API. Each location is assigned a color based on its value, then each location gets a separate heatmap layer that draws this color onto the map with a specific radius. The colors that are mapped to the values can be changed in two ways by the user. First, there is the option to change the color gradient using the pop-up color picker in Figure 33 . Initially it is set from green to red but can also be set to another gradient that the user might want, for example yellow to orange. The second way in which the user can change the color used to represent the values is to set the temperature range that is mapped to the color gradient. The minimum temperature set will be mapped to the first color and the maximum temperature set will be mapped to the second color. For example, if the temperature range is set from 10°C to 15°C, and the color gradient is set from green to red, then 10°C will be mapped as green 12.5°C will be mapped as yellow and 15°C will be mapped as red. The temperature range is adjusted in simple text boxes taking only numbers as input. Finally, the user can also set the radius of the heatmap points. This will be useful once there are more nodes on the map and the heatmap gradients can be smaller. This setting is also altered in a simple text box which only takes numbers as input.

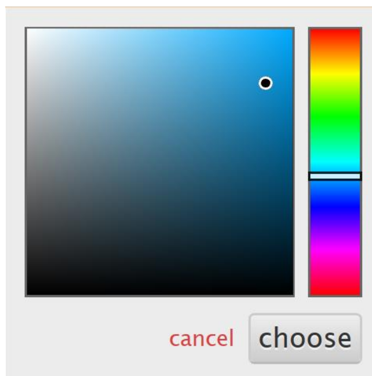

Figure 33: Color picker pop-up

6.2.3 Line chart

The line chart was made with the help of the Highcharts library. The main settings of this visualization will be selecting nodes to be presented on the line chart and changing the timeframe of the line chart. The nodes will be selected through a pop-up window that opens a map. On this map users can click to toggle specific locations where sensors are placed, once selected they will become green and appear in the line chart, Figure 34 shows a single node selected from the map that also appears on the line chart. The nodes that are selected are green due to standard conventions where green usually means correct or selected.

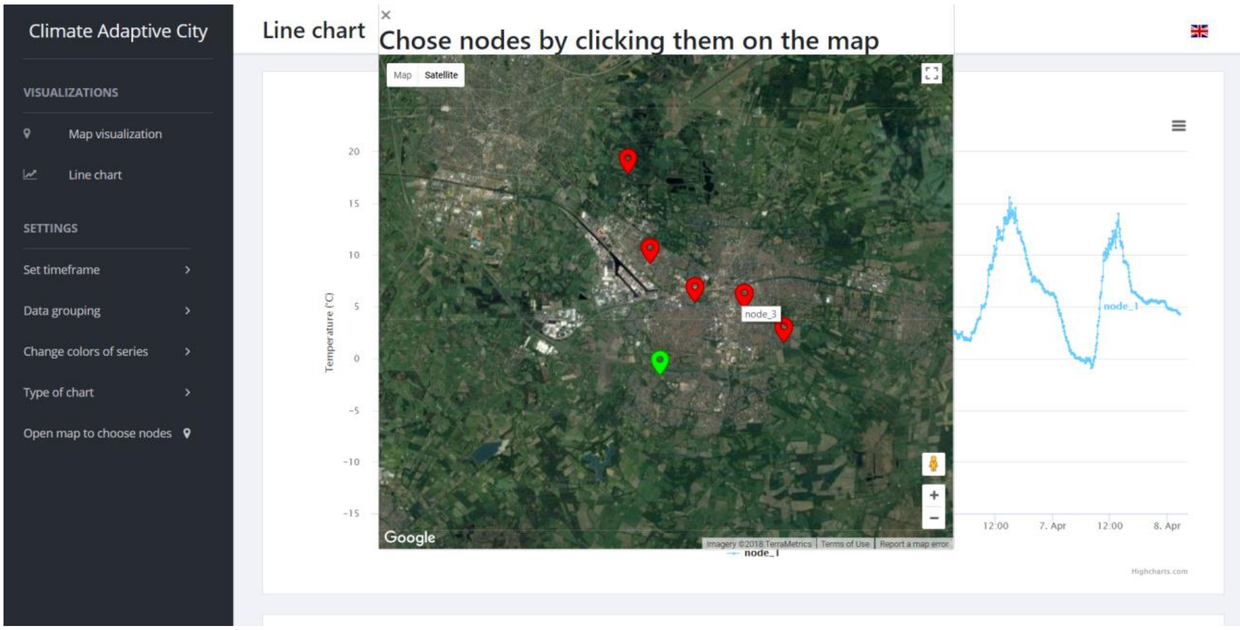

Figure 34: Selecting nodes for line chart

The timeframe can be set by opening the timeframe settings and altering the start and end date through a datetime selection window, which is shown in Figure 35. This datetime picker was taken from the jQuery DateTime picker library. If the end date is before the start date, then this was automatically corrected by the web interface to a timeframe of a day. Once successfully changed, the line chart would get the data of all nodes in that timeframe and update the line chart automatically. The user can also zoom in to the graph by holding their right mouse button and dragging across an area of the chart, which adjusts the timeframe to the area selected.

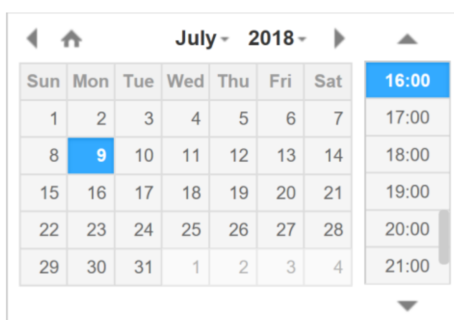

Figure 35: Datetime picker

Apart from these two major settings, some other ones are also available to the user. First, there is the option to group data, this means averaging the data on certain intervals to reduce the loading time. The data can be grouped by hour, by two hours, by six hours, by half a day, by day, and not grouped at all (displaying all data), this setting is just a list of radio buttons, where only one can be selected. When loading large amounts of data, a loading animation is shown to make sure the user understands that the chart is loading. Another setting that the user can adjust is the colors of the series. This is helpful when the user wants to see each node clearly on the chart, highlight one specific line on the chart, or if the user is color blind, they can adjust the colors so that the chart is clear for them. This color setting is made with the color picker pop-up from Figure 33. Another setting that the user can adjust is the type of the chart, the two types of charts available are a line and a point chart. The point chart is simply the line chart without the lines that connect the points. This setting is only two radio buttons, where only one can be selected. Finally, the user is able to download the chart onto his computer in various formats, including PDF, JPEG and PNG.

7. Evaluation

In this chapter, the final system is evaluated. First,. the functional requirements are evaluated. Next. the user testing is described, followed by the evaluation of the non-functional requirements. Next. the evaluation and feedback from the stakeholders is described. Finally, a conclusion on the evaluation chapter is made.

7.1 Evaluation of functional requirements

In this section, each functional requirement will be presented again and evaluated.

F1: *The system can request data from a database with measurements using a dedicated API (M)*

Unfortunately, this must-have requirement was not implemented in time for the presentation of the final prototype to the stakeholders. The development of the interface took longer than expected due to the difficulty of working with the Google Maps API and generating the individual heatmaps. However even if the system was ready on time, the final version of the database API could not be integrated in time either, as it was being developed at the same time as this web application and was finished a few days before the final meeting with the stakeholders.

F2: *The system can display the positions and data points of the nodes on a satellite map (M)*

This requirement was clearly met, as can be seen in the realization phase.

F3: *The system can display a heatmap overlay over the map by interpolating the data from all the sensor nodes (M)*

This requirement was clearly met, as can be seen in the realization phase.

F4: *The system can display the data of a certain date and time, set by the user, on the map (M)*

This requirement was clearly met, as can be seen in the realization phase.

F5: *The system can change the color gradient of the heatmap overlay (S)*

This requirement was clearly met, as can be seen in the realization phase.

F6: *The system can change the temperature range that is mapped to the color gradient (S)*

This requirement was clearly met, as can be seen in the realization phase.

F7: *The system can display the data of nodes on a line chart, where each node is represented by a single line (M)*

This requirement was clearly met, as can be seen in the realization phase.

F8: *The system can alter the timeframe of the line chart (M)*

This requirement was clearly met, as can be seen in the realization phase.

F9: *The system can change the line chart to just display the individual data points (S)*

This requirement was clearly met, as can be seen in the realization phase.

F10: *The colors of the series on the line chart can be set by the user*

This requirement was clearly met, as can be seen in the realization phase.

F11: *The system can display the maximum over a set timeframe on a heat tile map (C)*

F12: *The system can display the average temperatures over a set timeframe on a heat tile map (C)*

F13: *The system can display the difference between 2 nodes over a set timeframe on a heat tile map (C)*

The requirements pertaining to the heat tile map have not been met. As the addition of the heat tile map was only a could-have requirement and there was a very limited time for realization.

F14: *The system can provide a downloadable image of each data visualization (M)*

This requirement has been met for the line chart visualization but not for the map visualization. This is due to problems with the way screenshots can be made with JavaScript. Attempts were made with different libraries to take screenshots of the current map visualization displayed, however the canvas was always blank, this is due to the Google Maps API not allowing for screenshots of dynamic maps. There is a possibility to request screenshots of static maps from the API, however these would be without the heatmap. A work around of this problem is possible based on suggestions from internet forums, however the contributors to this solution explicitly say this breaches the terms of service of the Google Maps API.

F15: *The system allows the user to download data from the database over a set time period (M)*

This requirement was not met due to the lack of connection to the database. However, in further discussions with the stakeholders this requirement was made unnecessary, as this would become a function of the database's API.

7.2 User testing

User testing on the final prototype was done with a testing questionnaire that focused the users on using all the functionalities of the web application (questionnaire can be found in Appendix A), and later asked the users questions pertaining to the usability heuristics described in chapter 3. Before going through the user test, each subject had to sign a consent form (available in Appendix B). The user testing was performed with university students of various backgrounds (namely Creative Technology, Psychology, and Electrical Engineering) with ages ranging from 20 to 25.

In the first part of the user test, where users went through all the functionalities of the web application the feedback was gathered by observing the users and what they were doing, where users were instructed to talk through what they were doing. All user seemed to understand the task and quickly ran through them in 8 to 15 minutes. There were two main issues found during the user test. The most problematic task was adjusting the temperature range of the color gradient, where some people took some time to understand what this setting meant. The second issue pertained to the color picker pop-up setting, where the color was automatically set to black sometimes and users did not understand they had to change the brightness of the colors as well as the hue. Every user managed to correctly answer the question of where they were supposed to find the temperature of a specific node on the heatmap visualization. The only functionality that no one used was zooming into the line chart by selecting an area on the chart and instead manually adjusted the time frame using the DateTime picker pop-up.

The answers to the questionnaire dealing with the usability heuristics are shown below in Figure 36 to Figure 45.

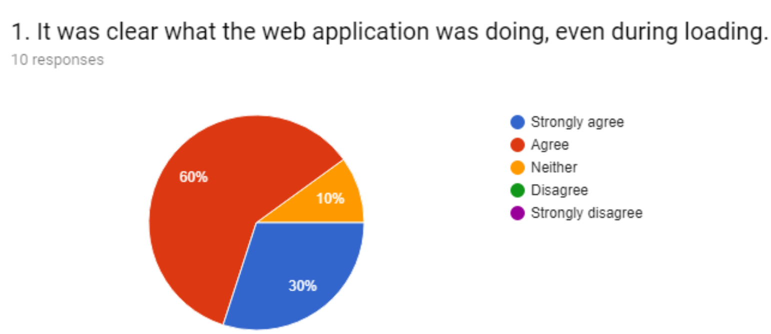

Figure 36: Answers to usability heuristic question 1

2. The meanings of the icons and symbols used are clear.

10 responses

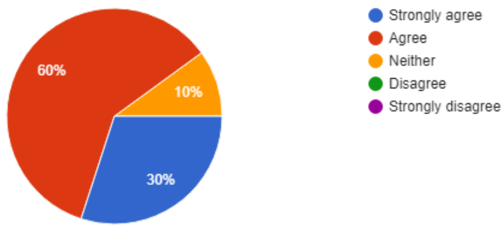

Figure 37: Answers to usability heuristic question 2

3. The map visualization and the information displayed in it was clear.

10 responses

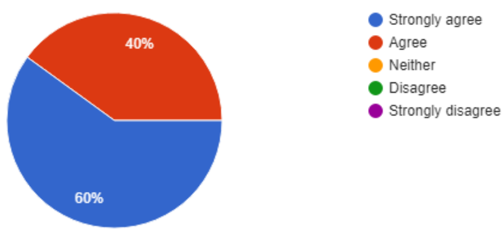

Figure 38: Answers to usability heuristic question 3

4. The line chart and the information displayed in it was clear.

10 responses

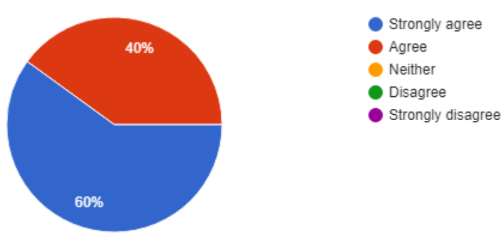

Figure 39: Answers to usability heuristic question 4

5. If you made a mistake during a task, it was clear what the error was and how to fix it. If you made no error this could be left blank.

7 responses

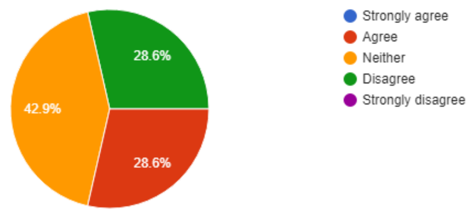

Figure 40: Answers to usability heuristic question 5

6. The design of the web application is consistent.

10 responses

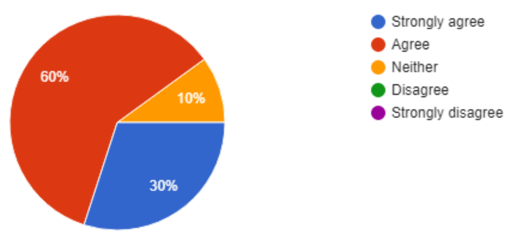

Figure 41: Answers to usability heuristic question 6

7. I could accomplish the tasks quickly and efficiently, there were no unnecessary or complicated steps.

10 responses

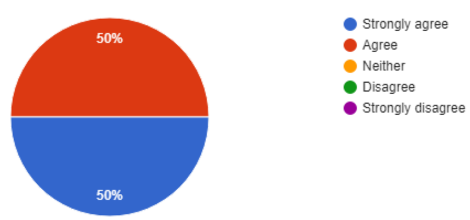

Figure 42: Answers to usability heuristic question 7

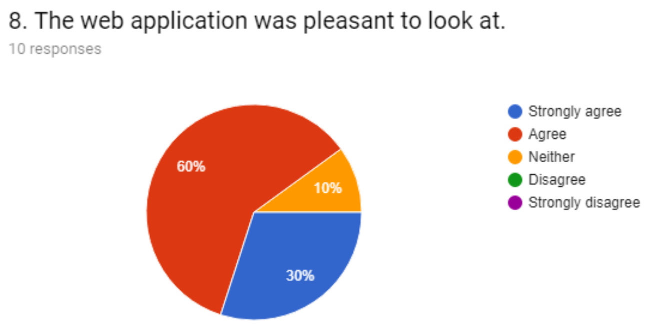

Figure 43: Answers to usability heuristic question 8

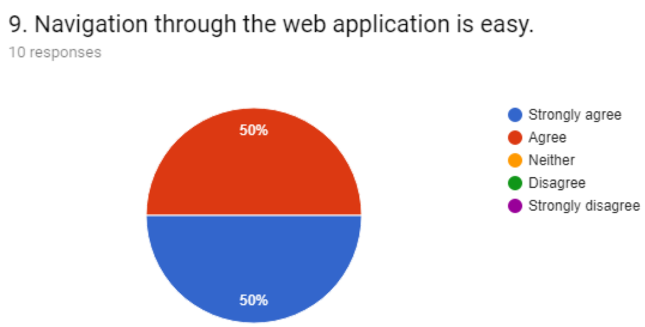

Figure 44: Answers to usability heuristic question 9

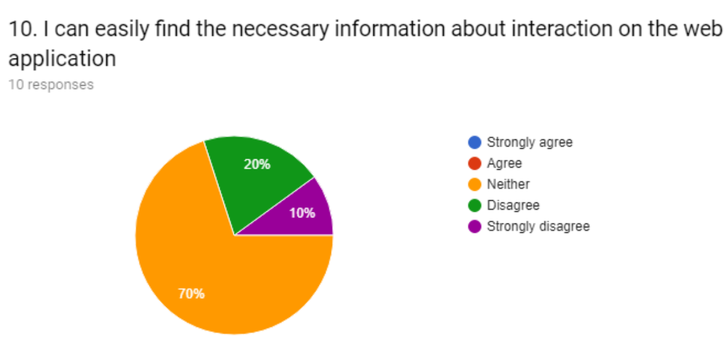

Figure 45: Answers to usability heuristic question 10

Evaluating the responses, the only real problem was with error messages and additional information about the visualizations. Since there were no information windows the users could look at, the usability heuristic of help and documentation was not sufficiently addressed. All users clearly understood what data each visualization was displaying. The design of the visualization seemed to be also well received with some minor feedback on particular parts.

Some users requested there to be a legend that matched the temperature range to the color gradient of the heatmap, which would be a very important addition to the visualization. The color picker pop-up should be simplified to only deal with hue and not brightness, as the brightness picker confused some people.

7.3 Evaluation of non-functional requirements

With the user testing evaluated, the non-functional requirements can be reviewed and evaluated as well.

NF1: *The system is available in Dutch and English (M)*

The system was only made in the English language as there was no time to find a person to help with the translation into Dutch during the realization phase.

NF2: *The system can be viewed from a desktop or laptop computer and a tablet device (M)*

The system was tested on a laptop during the evaluation and resized into different aspect ratios through google chromes developer options. This requirement was met.

NF3: *The system should load data from the database in a fast manner (M)*

The data was loaded from an external file during the user testing, so it is not possible to make a clear conclusion. However, if the speed of the database would not be an issue, then the requirement would have been met.

NF4: *The system should display the data visualizations in a fast manner (M)*

This requirement was met during the user testing.

NF5: *The system should correspond to the 10 heuristic principles described in chapter 3 (S)*

This requirement was mostly met during the user testing, only the help and documentation and helping users recognize, diagnose, and recover from errors heuristics were not completely met.

NF6: *The interpolated heat map should be toggled with the press of 1 button (S)*

This requirement was technically met, as the user only had to press one check box to toggle the heatmap.

NF7: *The temperature values and node IDs of the sensor nodes on the map should be displayed when hovered over (S)*

This requirement was met.

NF8: *Additional sensor data should be displayed when sensor nodes on the map are clicked (S)*

As there was no additional information available, this requirement was not met.

NF9: *The time and date of the map should be altered in simple drop-down menus (M)*

This requirement was met.

NF10: *The timeframe of the line chart should be altered in a simple drop-down menu (M)*

This requirement was met

NF11: *The timeframe of the line chart should be constrained by brushing a rectangle over the line chart (S)*

This requirement was met, however not used by the users.

NF12: *The system should show a loading animation when loading will take time (S)*

This requirement was met.

7.3 Evaluation with stakeholders

The stakeholders were given the same testing questionnaire as in the user testing to show them all the possibilities of the web application, as well as to give feedback on the usability heuristics involved. The stakeholders were pleased with the final prototype presented, however they did have some feedback for improvement. First, it will be very important to connect the web application to the database, this is the most important issue. Next the phrasing used in some of the settings must be adjusted to a less technical vocabulary, changing nodes to sensors, or changing data grouping to averaging of data. The stakeholders also found it difficult to use the color picker, when the brightness was set low, they would prefer a picker that only adjusts the hue. Finally, they would prefer if the web application had additional info windows to help novice users.

7.4 Conclusion

Overall the system performs well, and the users could perform all necessary actions in a fast manner. Most requirements were met, however the connection to the database is still a very important part of the system that needs to be implemented. Apart from this, information windows need to be added to the system to help people with possible issues. The color picker must be adapted to a less complicated way of selecting colors for the heatmap gradient and series colors on the line chart. The language needs to be adapted to less technical terms and a translation to Dutch must be made. Finally, a legend that maps the temperature range of the heatmap to the colors of the heat map must be shown in the visualization area. The possibility of downloading an image of the map visualization is the only requirement that is not easily feasible while using the Google Maps API.

8. Conclusion and recommendations

In this final chapter a conclusion will be made about the project pertaining to the final system and the research questions stated in the first chapter.

Through the Creative Technology Design process, multiple possibilities for the implementation of the system were presented to the stakeholders. A direction was chosen, and the specific requirements of this system were listed. In the execution phase of this project, a web application with data visualizations was created. The two main parts of this web application were the map visualization and the line chart. The map visualization presented the locations and temperatures of all nodes at a certain date and time in Enschede. A heatmap could be mapped over this map to make the temperatures of all nodes more visible. The line chart presented the temperature data of selected nodes over a user set time period.

The research questions specified in the introductory chapter were:

Main RQ: ***How to present temperature measurements of public spaces in Enschede in an insightful manner?***

Sub RQ : ***How to use these insights to present a possible Urban Heat Island effect?***

With the system created, the temperatures are presented in a way, that it is possible to gain many insights into the reality of the situation in Enschede. And if present the Urban Heat Island effect of Enschede should be visible through the visualizations. The map visualization will give insights into the distribution of heat at certain points in time, where it will be visible how strong the UHI of Enschede is. The line chart will give insights into how the temperature of certain locations change over time, so it is also possible to monitor the change of the UHI over time. Of course, for these insights to be correct, more sensors need to be added to the system. However, this is not a problem of the web application, but of the sensor network.

Some things did not go according to plan during this project, and improvements still must be made to the system. First, the web application must be connected to the database holding the data of the sensor network, as the final prototype worked off an external data file. Next, the system must be translated to Dutch and use more standard vocabulary. Next, some of the technologies used to change certain settings must be changed to more user-friendly ones, for example the color picker that changes the colors of series on the line chart. Finally, a legend must be added to the map visualization when displaying a heatmap, so that users can see which temperatures correspond to which colors

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Appendix

Appendix A

Evaluation Questionnaire

First you will run through a set of tasks to try working with the interface, then you will fill out a short questionnaire about your experience.

Tasks:

1. Open the web application of the map visualization. Take a look at all of the options.
2. Find the temperature of node_3 (located in the H.J. van Heekplein) on the 7th of May 2018 at 20:00. Write it below

   _ _ _ _ _ _ _ _

3. Create a heatmap of the current map.
4. Adjust the color gradient of the map from yellow to red, with the radius of the heatmap points being 300.
5. Adjust the temperature range to make the largest temperature appear red and the lowest to be orange or yellow.

6. Go to the line chart tab of the web application. Take a look at all of the options.
7. Create a line chart of node_3 (located in the H.J. van Heekplein) from the 10th of April till the 17th of April.
8. Add another node to compare it to (any node on the map).
9. Change the colors of the nodes displayed on the line chart to red and green.
10. Find a smaller time frame in which there is a difference between the nodes and zoom in or make a separate chart of this.
11. Change the data displayed on the chart to not be grouped (display all the data available)
12. Remove the trendline to see all the data points

Questionnaire:

Mark the bubble you agree with on the scale to indicate whether you agree or disagree with the statement.

1. It was clear what the web application was doing, even during loading.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

2. The meanings of the icons and symbols used are clear.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

3. The map visualization and the information displayed in it was clear.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

4. The line chart and the information displayed in it was clear.

○ Strongly disagree ○ Disagree ○ Neither ○ Agree ○ Strongly agree

5. If you made a mistake during a task, it was clear what the error was and how to fix it. If you made no error this could be left blank.

○ Strongly disagree ○ Disagree ○ Neither ○ Agree ○ Strongly agree

6. The design of the web application is consistent.

○ Strongly disagree ○ Disagree ○ Neither ○ Agree ○ Strongly agree

7. I could accomplish the tasks quickly and efficiently, there were no unnecessary or complicated steps.

○ Strongly disagree ○ Disagree ○ Neither ○ Agree ○ Strongly agree

8. The web application was pleasant to look at.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

9. Navigation through the web application is easy.

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

10. I can easily find the necessary information about interaction on the web application

○	○	○	○	○
Strongly disagree	Disagree	Neither	Agree	Strongly agree

Do you have any recommendations to improve the line chart visualization?

Do you have any recommendations to improve the map visualization?

Do you have any recommendations to improve the web application as a whole?

Appendix B

Consent form for the user evaluation of a data visualization web application

In this user evaluation test, you will be evaluating a web application visualizing temperature data collected from a sensor network spread across Enschede. You will be asked to go through tasks working with the web application followed by a short questionnaire where you will answer questions about your experience with the web application. The data collected will be used to improve the visualizations and the web application as a whole. Your name or personal details will be made anonymous in the evaluation of this project and not be shared with anyone.

Please tick the appropriate boxes	**Yes**	**No**
Taking part in the study		
I have read and understood the study information, or it has been read to me. I have been able to ask questions about the study and my questions have been answered to my satisfaction.	○	○
I consent voluntarily to be a participant in this study and understand that I can refuse to answer questions and I can withdraw from the study at any time, without having to give a reason.	○	○
I understand that information I provide will be used for improving the user experience of the web application	○	○
I understand that personal information collected about me that can identify me, such as [e.g. my name or where I live], will not be shared beyond the researcher.	○	○

Signatures

_______________________ _______________________ _________

Name of participant Signature Date

I have accurately read out the information sheet to the potential participant and, to the best of my ability, ensured that the participant understands to what they are freely consenting.

__________________________ ____________________ _________

Researcher name Signature Date

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