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Visualizing social sustainability: use case Linköping

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Abstract

Fostering social sustainability has become a paramount concern for decision makers seeking to create inclusive and equitable communities. 3D visualizations offer promising opportunities for enhancing decision making processes by providing intuitive and interactive representations of urban data.

This study investigates the potential of 3D visualization techniques, facilitated through digital twins as a medium, to support decision making related to social sustainability within urban contexts. The goal is to provide the stakeholders and relevant parties with visualizations that can support their work with social sustainability decisions. This is achieved through a 3D visualization technique akin to 3D choropleth maps, in which colors and 3D staples with varying heights are used to represent data across geographical areas.

Through a case study focused on the city of Linköping, Sweden, we examine the usability of the visualization tool in aiding the decision making process. The evaluation was done with user testings and surveys, and the observations and received feedback was analyzed through thematic coding.

The results highlight the importance of usability, color management, and making 3D elements more differentiable in order to reduce visual clutter. While the 3D visualizations were not well received in densely partitioned areas, less dense areas received positive feedback, implying that 3D visualization techniques are more useful on maps with larger partitions. Another finding was the complexity of the usage of colors in visualizations. The findings show that colors divided into quantiles were preferred and that the classic red-to-green color scale was discouraged.

The goal of creating visualizations to support decision making regarding social sustainability was not entirely fulfilled, but valuable insights and feedback that is crucial for future iterations have been gained throughout the work. Moving forward, if the flaws are addressed, the visualizations could support decision making regarding social sustainability.

Keywords

Social sustainability, Digital twin, Visualization, Usability.

Sammanfattning

Att främja social hållbarhet har blivit en avgörande fråga för beslutstagare som vill skapa inkluderande och rättvisa samhällen. 3D visualisering erbjuder lovande möjligheter för att förbättra beslutsfattande processer genom att erbjuda intuitiva och interaktiva representationer av stadsdata.

Denna studie undersöker potentialen som 3D visualiseringstekniker i digitala tvillingar har för att stödja beslutsfattande relaterat till social hållbarhet i stadssammanhang. Målet är att erbjuda intressenterna och berörda parter med visualiseringar som kan stödja deras arbete med beslutsfattande inom social hållbarhet. Detta uppnås genom en 3D visualiseringsteknik som liknar 3D choropleth-kartor, i vilket färger och 3D staplar med varierande höjder används för att representera data över geografiska områden.

Genom en fallstudie fokuserad på staden Linköping, Sverige, examinerar vi användbarheten av visualiseringsverktyget som ett stöd för beslutsprocesser. Evalueringen var gjord med användartester och enkäter, och observationer samt den mottagna återkopplingen var analyserad genom tematisk kodning.

Resultaten framhäver hur viktigt det är med användbarhet, färghantering, och att göra 3D element mer differentierbara för att undvika visuell röra. 3D visualiseringarna möttes inte jättebra i täta områden, men mindre täta områden fick bemöttes bättre vilket antyder att 3D visualiseringstekniker kan vara mer användbara för kartor med större indelningar. En annan upptäckt var komplexiteten i användningen av färger i visualiseringar. Fynden visar att färger uppdelade i kvantiler var att föredra, och att den klassiska färgskalan från röd till grön inte var att föredra.

Målet att skapa visualiseringar som kan stödja beslutsfattningar inom social hållbarhet var inte helt uppfyllda, men värdefulla insikter samt återkopplingar som är avgörande för framtida iterationer har förvärvats genom arbetets gång. Inför framtiden, ifall bristerna åtgärdas, skulle visualiseringarna kunna stödja beslutsfattningar gällande social hållbarhet.

Nyckelord

Social hållbarhet, Digital tvilling, Visualisering, Användbarhet.

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List of acronyms and abbreviations

DT	Digital Twin
FSSD	Framework for Strategic Sustainable Development
GDPR	General Data Protection Regulation
ICT	Information and Communication Technology
IoT	Internet of Things
NYKO	Nyckelkod (Key Code)
RISE	Research Institutes of Sweden
SDG	Sustainable Development Goal
UI	User Interface

Chapter 1

Introduction

Social sustainability can be used to define the welfare of individuals in society, and ensuring that may require decisions on a societal level to be made [1]. Making decisions about social sustainability can be complicated, since there are many factors to take into account when considering decisions in urban cities. Information and Communication Technology (ICT) solutions can however provide decision makers with help regarding their work, but the question is what technique to apply, since some may be more suitable than others depending on the area of application [2]. The usage of digital twins (DT) is one such approach, and are utilized to create virtual copies of real-world objects such as cities and countries to evaluate, plan and simulate development of different perspectives.

1.1 Research Context

Data visualization is an essential step in the data science methodology, and is the process in which data is visually represented in the form of graphical elements [3]. The process is especially useful for presenting data to decision makers [3]. There are different forms of visualizations, ranging from 2D charts and graphs to more complex 3D visualizations that can provide information on multiple layers and perspectives.

During the recent years, DT technology have received a significant amount of attention. DTs describe connections between physical and virtual objects. They can be conceptualized by describing as something that must have a physical asset, a digital asset, and an information flow between both assets, which is in most cases made possible by the Internet of Things (IoT) [4] [5]. The term IoT refers to networks of physical objects with sensors and other hardware that allow them to collect and send data [6]. The digital asset represents the physical asset through the use of data, algorithms and simplified models. DTs can be used to simulate the physical counterpart and thus, through analyzing the simulation, predictions and inefficiencies can be found without the need to spend too much time and resources [7]. Today, DTs are used in a wide array of fields such as in healthcare, aeronautics and in urban city planning [8]. In the case of urban city planning, DTs of entire cities can support stakeholders by making their decision making process more illustrative and comprehensible [9].

Decision making is the process of taking an action when multiple possibilities are present, and the choice is made in relation to data that has been gathered [10]. The choices that are made could for instance relate to concepts such as urban city planning. Since choices are made in relation to data, the decision making process is directly linked to the amount of and complexity of data that is available to the decision makers, and that data should therefore be as easy to comprehend as possible. Many decisions include an ethical component [10], and one such component could relate to social sustainability. To make decisions that improve social sustainability, data and a sharp focus on one of the definitions of social sustainability may be required, since there are multiple definitions of the latter [11].

Social sustainability in itself is often seen as a vague concept, and there have been many attempts to define the term throughout history [12]. One such attempt is the Framework For Strategic Sustainable Development (FSSD), which has been developed and refined since the early 1990s. Today, FSSD consists of eight basic defining aspects for both social and ecological sustainability, where five of them define social sustainability. These five aspects are health, influence, competence, impartiality and meaning-making [13].

1.2 Stakeholders

The stakeholder for this degree project is the company Action For Society Sweden AB. Action For Society is a company that has the aim of building better shared futures, and a socially sustainable society. They want to gather a variety of perspectives, make analyses and help make decisions for improvements. This degree project will investigate visualization as a way of showing data from different perspectives [14].

1.3 Problem

To improve social sustainability in cities, important decisions may have to be made. The decision makers in Linköping need a method of data perception that can support their work process and help them make decisions for a more socially sustainable Linköping. An example of a method of data perception is visualization technology. The thesis aims to answer the following question:

Q: How can visualization of social sustainability support decision making?

The question will be answered and discussed following visualizations in Research Institutes of Sweden's (RISE) DT prototype of Linköping, and by conducting a survey directly with relevant stakeholders and decision makers. Moreover, by using the theory of Jakob Nielsen's Usability, user testings will be performed with the stakeholders and their interactions with the visualized data in the DT will be analyzed. The results of this project can provide future researchers with insights on how one should, or should not, visualize social sustainability in order to support the decision making process.

1.4 Purpose

The purpose of the thesis is to present an investigation on how visualization technologies can support stakeholders and decision makers in their work regarding social issues and sustainability.

The purpose of the project is to investigate how digital tools can support the decision making process in Linköping. The company Action For Society needs an evaluation of what visualizations in a DT could contribute with in the context of social sustainability, because they want to know if it is a technology worth committing to for their work.

1.5 Goals

The aim with this thesis is to provide stakeholders and decision makers in Linköping with visualizations that support their work process, namely the decision making process. The visualizations will be made on sustainability data that the decision makers and stakeholders will be able to utilize.

1.6 Research Approach

In this Section, the research methods and methodologies presented in Anne Håkansson's *Portal of Research Methods and Methodologies for Research Projects and Degree Projects* is described [15].

This project will aid in the development of a tool and thus, opinions, perspectives and feedback from the future user base will be central. This means that the nature of this project will be qualitative and will also be based on the philosophical assumption of interpretivism, which means that the people's perspective of this project will be explored.

The research method will be non-experimental and study users' behavior in certain representative scenarios. An inductive approach will be made, since the opinions gathered from the representative user base will be propagated for the entire target group aimed by this tool. The research strategy will mainly consist of a cross-sectional survey due to the limited amount of meetings available with the target group. Combined with the survey, action research will also aim to study the users during specific tasks when using the tool. The methods for collecting the research data will be through surveys and observations. The data analysis will be done through coding, which will quantify the qualitative data collected. Since the project is of a qualitative nature, the quality control will consist of an evaluation of validity, reliability, and ethics, which together with an evaluation of the methods themselves will be presented.

1.7 Delimitations

During the project, new data will not be gathered through contact with the municipality or other sources. This is because the organization already has gathered data with a variety in granularity, and also because the time budget is not large enough for collecting new information. Collecting direct information and feedback from residents in Linköping would be ideal as that would grant a new perspective, but is unfortunately not possible within the scope of this project. Also, the thesis project will be focused only on the city of Linköping, and there will not be any focus set on other cities in Sweden or elsewhere in the world.

1.8 Structure of the Thesis

Chapter 2 presents relevant background information about visualization, digital twins and usability. Chapter 3 presents the scientific methodology used for the investigation. Chapter 4 presents the data collection, visualization and testing process with the target group. Chapter 5 presents the results gathered from the chosen methodology while also discussing the study's reliability and validity. Chapter 6 presents a discussion on the results and their implications, while also discussing potential improvements. Finally, Chapter 7 summarizes the thesis and presents conclusions, future work and reflections regarding the study.

Chapter 2

Background

In this Chapter, the concepts of visualization and DTs are introduced and explained in more detail. Social sustainability is also introduced, alongside a framework that can be used. Lastly, related work is presented.

2.1 Visualization

Data visualization is about placing data in a visual context and communicating patterns to the observing party [3]. In this Section, the concept of visualization is described further and types, techniques, tools, and principles that should be upheld when visualizing data are explained. Lastly, redlining is brought up as an ethical aspect of visualization.

2.1.1 Visualization Types

There are different types of visualizations that can be used to visualize data. These types include tables, pie charts, line charts, histograms, scatterplots, heat maps, and tree maps. These all have their use cases, as they have different properties that make them more applicable depending on the use case [3]. The properties of the types of visualizations mentioned above are listed below:

- Tables: Good for structuring and providing information, but can be overwhelming when looking for general themes.
- Pie charts: Good for organizing data and comparing components by size.
- Line charts: Good for showing change over time by plotting data against time.

- Histograms: Good for finding anomalies and outliers.
- Scatter plots: Good for finding a relation between two variables.
- Heat maps: Good for visualizing data on different locations, such as a map.
- Tree maps: Good for displaying hierarchical data.

The properties are listed above [3]. As can be seen, the visualization types all have different properties and are applicable for different types of data and use cases. Choropleth maps are also of interest and further explained in Section 2.2.3.

2.1.2 Visualization Techniques

Successful visualizations can grant the user insights on the structure of the data as a whole or different characteristics of the dataset. Adding color to such visualizations can enhance the understanding of the information [16]. According to the University of California, one should pick a color scheme or Brewer palette with 6 - 12 colors, which can be categorized as either qualitative, sequential or diverging [17]. A qualitative Brewer palette lacks a perceived order among colors and is suitable for categorical data representation. In contrast, sequential palettes exhibit a perceived order, with colors increasing or decreasing uniformly in strength, making them ideal for ordered or continuous data. Diverging palettes, on the other hand, are specifically designed to highlight extreme values by using two distinct sequential palettes on opposite ends of the spectrum [18].

When choosing the palette, there are certain considerations that needs to be made. One is to be mindful of the audience's potential color-deficiencies and the other is to take into account how the colors are interpreted and what they are associated with in the culture of the target population [17].

When visualizing time dependent data, the scale divisions of the continuous series should be consistent [17]. In other words, if the data is divided into time periods, such as a time period of 5 years, all data should be divided into periods of 5 years. Unequal divisions can lead to misinterpretations.

Besides these techniques there are several other methods to that can be specifically applied to visualizations of spatio-temporal data on maps. These include using pencil and helix icons [19], and the usage of disks forming glyphs [20], which will be further explained in Section 2.5.3.

2.1.3 Visualization Tools

There are various tools that can be used for data visualization. Python and R are commonly used in data science, and different packages can be used to visualize the data of interest [21]. Other visualization tools include D3.js, which is used for making visualizations on browsers that are dynamic and interactable [3]. Kepler.gl is yet another tool that can be used for making geospatial visualizations on maps [22]. It allows different techniques to be used, such as the use of heat maps, points, and buildings.

2.1.4 Visualization Principles

In order to assure visual communication, the visualizations have to be clear. Otherwise, observers cannot retrieve the necessary information through the visualizations [3].

The visualization type has to be chosen carefully, as they all have different properties. If the right type is not chosen, then the observer will have difficulties trying to interpret what they are seeing. However, using the right visualization type can assist the observer in understanding patterns and information [3].

Simplicity is also an important principle to follow [3]. The observer should only focus on what they are intended to see, and adding too many elements can make it overwhelming for the observer. Elements that can distract users should therefore be minimized [3]. The visualizations should also be appropriate for different groups of users. Some users may be color blind, and the colors used in the visualizations must therefore be chosen appropriately so they can understand the visualizations as well [3].

2.1.5 Redlining in Visualizations

Redlining is a practice where areas of a map visualization get red lines drawn over them or are shaded red [23]. Catherine D'Ignazio and Lauren Klein state in Chapter 2 of *Data Feminism* that areas that usually are redlined include a specific group of people, which become targeted by these visualizations. This can cause implicit consequences such as discrimination toward the people of those areas. One example drawn by D'Ignazio and Klein is how insurance companies use these map visualizations to grant or deny policies based on the demographics shown on those areas, which can lead to unjust treatment of certain groups of people.

2.2 Digital Twins

DTs are technologies that have been developing for the last 20 years and are tools that can support decision making in various industries [24]. The concept of the DT was first introduced by Michael Grieves in 2002, who stated that the DT consists of three components. The three components are a physical asset, a virtual asset, and an information flow between them [4].

2.2.1 Main Components of a Digital Twin

Further expanding on the three main components, the model of a DT includes a physical world and a digital world [25]. The physical world holds the physical entity, which is the real-world object that is to be twinned in the DT. The digital world of the model holds the virtual asset, which is the copy of the real-world object. The information flow occurs between the two worlds in the form of a bidirectional path [25].

The virtual to physical, and physical to virtual connection are critical principles in DTs [24]. The physical to virtual connection is one of the directions of information flow, and is used to update the status of the virtual asset in the DT [24]. This step is done by collecting data from the physical asset, and updating the data currently in the virtual asset [24]. The data in question can optimally be collected through IoT sensors, since they can return data with a higher frequency [24][25]. Consequently, the virtual asset would be closer to its real life counterpart. The requirements are however dependent on the specific implementation. The virtual to physical connection describes the process in which information from the virtual world is transferred to the physical world [24]. The physical world is affected as a consequence of the insights gained from the visuals and information in the DT, because actions can be taken based on the gained insights [24]. Decision makers are an example of a user group that can gain insights from the virtual world and apply actions in the real world to solve problems.

2.2.2 Digital Twins in Urban Planning and Sustainability

Cities are very complex systems with connections to economical, ecological and social aspects [26]. Different types of problems can occur in cities with regards to economical, ecological and social standards if the city is not taken care of and planned properly. Recently, the solutions to these problems have been presented in the form of ICT solutions that aim to solve and avoid the problems that could occur. The term smart cities refers to digitalization in cities [27] and they can provide IoT technology that DTs can utilize for their simulations and visualizations. Urban issues that relate to sustainability can therefore be tackled by DTs, provided that there are visualizations from which conclusions can be drawn [26].

2.2.3 Visualization Techniques for Digital Twins

For better perception of data, the data in the DT has to be visualized [25]. In the context of decision making, it is important that the decision makers do not have trouble reading and interpreting the visualizations. Therefore, it is important to focus on a technique that is focused on completeness of data presentation, which is an aspect of visualization in DTs [25]. The aspect is focused on how comprehensive the visualized data is. Also, for visualizations on DTs, completeness of data presentation is an aspect that is possible to achieve [25].

Choropleth maps is one such technique that can be used to visualize social sustainability. In a choropleth map, the region is divided into several areas and each area can be displayed with a color that is determined according to the value of some data variable [28]. Linköping is already divided into areas and regions, so provided a color grading option, choropleth maps can be utilized as a technique for visualizing social sustainability.

Spatio-temporal visualization is a technique that can be employed for visualizing social sustainability as well. By combining the dimensions of both space and time, this technique provides information on patterns and changes that occur on the data, thus making it an important tool for decision-makers [29]. By collecting social sustainability data throughout different years, this technique can be used by decision makers to make analyses, predictions and decisions accordingly.

Another useful technique is incorporating heat maps that can be used for visualizing differences in data [3]. Heat maps are useful for representing data by location, and can be further utilized with colors to show differences between the different locations [30]. Darker colors are usually used to represent higher values [30]. Within the context of decision making, heat maps can be very useful since they show key trends, and are relatively easy to gather insights from [30].

2.2.4 Challenges for Digital Twins

The third component of Grieves' definition of DTs describes the connections of data and information that tie the real and virtual product together [24]. The DT of Linköping does not possess live data transfer regarding social sustainability between the real and the virtual city, and it can therefore happen that the virtual asset does not have the most up to date data. This violates the third component of Grieves' definition, but is also problematic since basing decisions on data that is old is not optimal. A possible way to achieve the dynamic information flow is given in Chapter 7.

2.2.5 Insight Portal and Mobile Application

Action For Society's mobile application prototype serves as a tool for collecting live data from residents in the city of Linköping. The organization's insight portal is currently used for mirroring the data provided through the app. In later stages, both the mobile application and insight portal will be used together with the DT as a package.

2.3 Nielsen's Usability

Usability is a term that describes how easy it is to use a user interface (UI). The main components that define what usability is are the following five [31]:

- **Learnability**: This component measures how easy it is for a user to finish basic tasks, given that they have not interacted with the design previously.
- **Efficiency**: This component measures how quickly a user can finish tasks after having gained experience with the design.
- **Memorability**: This component measures how easy it is for a user to restore their proficiency after having not used it for a period of time.
- **Errors**: This component measures the count of and severity of errors that the user makes during their interaction with the interface, and measures how easily they recover from the errors.
- **Satisfaction**: This component measures how pleasant the design is to use for the user.

The above components are related to how easy the UI is to use. One should also factor in if the UI does what the user needs it to do, namely utility. Usability and utility are two equally important aspects, and without either of them, the usefulness of the interface plummets [31].

2.3.1 Nielsen's 10 Usability Heuristics

Nielsen's 10 heuristics can be used as a general guide for creating and maintaining a good UI [32]. Nielsen's 10 usability heuristics are the following [32]:

1. **Visibility of System Status**: System status should be available to the users at all times, so they are informed on what is going on. This can for example be achieved through continuous feedback.

2. **Match Between the System and the Real World**: The language of the design should not differ from the language of the user. Words, phrases and concepts that are unfamiliar to users should not be used.

3. **User Control and Freedom**: The user should have the ability to quickly undo mistakes, or redo actions, without going through an extensive process.

4. **Consistency and Standards**: Concepts, words and actions should be following industry conventions and standards in order to reduce cognitive load on users.

5. **Error Prevention**: Error-prone conditions should either be eliminated, or the action of the user should be confirmed in case there is a risk for errors to occur.

6. **Recognition Rather than Recall**: Humans have limited short time memory and recognition is therefore more optimal than recall. If components are made visible to the users, their cognitive load is relieved because they can act upon recognition and not recall.

7. **Flexibility and Efficiency of Use**: The UI should provide shortcuts that can speed up the interaction for experienced users, so it has to be made with thought to both experienced and inexperienced users.

8. **Aesthetic and Minimalist Design**: UI should not include irrelevant information, since they will compete with relevant information and

reduce the visibility of relevant information. The focus has to be on the essential parts of the UI.

9. **Help Users Recognize, Diagnose and Recover from Errors**: Errors should be visualized for the user, and be expressed in language that describes the problem and suggests a solution.

10. **Help and Documentation**: If necessary, documentation could be required if users need help regarding how to complete their work.

2.3.2 Importance of Usability

Usability is important for software tools and web applications since low usability may lead to the user being confused or having difficulties, which would make them leave and look for better options [31]. In the context of decision making however, leaving and looking for better options may not be as simple since the tool is adopted by the organization. To ensure that workers are comfortable with their work environments, it is essential to make sure that the digital tools have high usability. The usability of a tool is however not set in stone and can become worse, or better over time.

2.3.3 Improving Usability

The importance of usability is apparent from Section 2.3, and it is therefore crucial to know how usability in UIs and digital tools can be improved upon. A simple way of improving usability is to apply user testing [31]. User testing is a methodology that consists of three main steps, notably finding representative users, asking them to do representative tasks, followed by an observation of their interaction with the UI [31]. Nielsen states that running tests with five users is enough for finding the most important aspects and that is because putting the time and project budget on many small tests is desirable, rather than one large study [33]. After adding more than three users, it is likely that less and less will be learned from each new person. The second step is to ask the user to do tasks within the UI. The purpose of this is to observe what they do to solve the task, the challenges they face and how they attempt to solve the challenges [31]. The users can be instructed to think aloud to gain additional insights on their thought process throughout the user testing [34]. By observing the challenges they face, it is possible to find issues within the UI that should be solved for better usability.

2.4 Social Sustainability

Social sustainability is an important aspect regarding development of urban cities and societies. It describes the well-being and longevity of societies, communities, and the individuals who reside within them [1].

2.4.1 Brief History of Social Sustainability

Before social sustainability was coined as a concept, the more general term sustainable development was introduced in the Brundtland Report [35] published 1987 by the World Commission on Environment and Development. In that report, sustainable development was defined as “development that meets the needs of the present without compromising the needs of future generations to meet their own needs” [12].

Fast forward to today and we commonly use sustainable development as an umbrella term for three major areas: environmental, economic and social sustainability. The relations between the three pillars and sustainable development is presented in Figure 2.1.

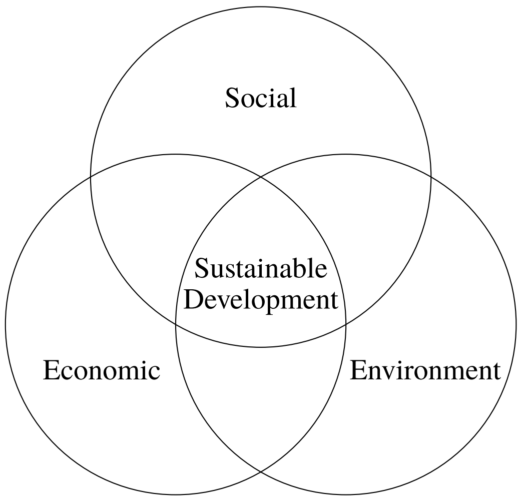

Figure 2.1: The three pillars of sustainable development.

Since the United Nations Conference on Environment and Development in 1992, social and economical sustainability have been growing in importance in respect to environmental sustainability and have during the 2000s to 2010s become as important as environmental sustainability [12].

During the entire lifespan of social sustainability, the term itself has remained relatively vague. There are five aspects of FSSD that can be used to define social sustainability indicators.

2.4.2 Framework for Strategic Sustainable Development

FSSD is a framework that was created in the 1990s and has been under development ever since [36]. It has eight core aspects, five of which are related to social issues and social sustainability. Together, the aspects describe how a sustainable future could look like [36], but since this report is focused on social aspects, only five of the aspects will be explained. Below are the five aspects that there should be no obstacles for in order to have a socially sustainable future [13].

- **Health**: All individuals in society should have the ability to avoid physical, mental and emotional damage in their day to day lives.
- **Influence**: All individuals in society should have the ability to express themselves and influence social systems, such as the government and work environment.
- **Competence**: All individuals in society should be able to learn and gain expertise and competence, regardless if they are alone or with others. There should be no obstacles for education.
- **Impartiality**: No individual should be handled differently through any form or shape of discrimination. Everyone is equal, and should be given the same opportunities in society.
- **Meaning**: All individuals should be able to create meaning, for example cultural meaning without anyone suppressing their ability to do so.

The above five aspects have been derived and developed with five criterions, and those criterions have been created so a balanced definition could be made [13]. The five criterions are that the aspects must be:

- **Necessary**: The aspects should avoid unnecessities since those may pose unwanted restrictions.
- **Sufficient**: The aspects should allow further elaboration, which is a consequence of gaps not occurring while thinking.

- **General**: The aspects should be general and therefore applicable to different areas. The reason for this is to for example allow cross-sector collaboration.
- **Concrete**: The aspects should be concrete and can be used for creating a step-by-step guide for improvements.
- **Non-overlapping**: The aspects should not be overlapping in order to simplify the development of indicators that can be used for identifying progress and development.

If there are no obstacles for the five aspects, then it can be concluded according to FSSD that development is going towards a socially sustainable future [36].

2.5 Related Work

In this Section, similar and related work will be presented and discussed. A short introduction of their context will be given, followed by a short discussion of similarities and differences between their work and this thesis project.

2.5.1 Previous Work on Visualization Techniques and Color Representation

Cynthia A. Brewer *et al.* present an evaluation of color schemes on choropleth maps in their work *Mapping Mortality: Evaluating Color Schemes for Choropleth Maps* [37]. Their study found that color can add greater accuracy when reading maps, and that purple and green hues are preferred overall. For our work, we can use green hues to visualize aspects that are doing well, but a light green hue may not be optimal for visualizing an aspect that is doing worse for some area, as green can be associated with doing well overall. Decision makers have to feel a sense of urgency for areas that are doing worse, and a green color may give the wrong message to the decision makers. Some areas will do well in certain aspects, while others will do worse. Their condition can be described as good, neither, and critical. It is therefore of utmost importance that colors to represent these three conditions are chosen, such as red for critical, green for good and yellow for neither. Alternatively, stronger and lighter hues of green and yellow can be chosen as a transition between good and critical condition.

Natalia Andrienko *et al.* present spatio-temporal visualization techniques, one of them being map animation [38]. Map animation is the process of updating the visuals as changes in data occur [38]. The technique can be used on time-series data, with different characteristics such as speed, direction and smoothness [38]. For our project, this technique can be combined with colors and hues in order to show how social sustainability aspects have changed over a period of time. It is therefore an important technique that can be incorporated in this project.

2.5.2 Evaluation of Visualization Methods for Population Statistics on Choropleth Maps

In a study conducted by Lonni Besançon *et al.*, the accuracy and efficiency for a number of different visualization methods on population statistics based on choropleth maps were evaluated [39]. The final subset of methods to evaluate for user testing after receiving input from visualization experts were juxtaposed univariate maps, choropleth bertillon maps, 3D choropleth maps, and deformed cartograms. In the results, the 3D choropleth map was ranked as the favorite visualization method by a majority of testers, which can imply that this technique is the most user friendly. However, the 3D effect of altering the height of each area could also be disadvantageous to the tester if the areas are dense, which could reduce the accuracy of an analyst trying to interpret the data. Despite this drawback, Besançon et al. speculate that this might not be a huge problem if the user has the possibility to drag and rotate the map, but they are still cautious as this might pose other interpretation problems for a user. This project will visualize data using a 3D choropleth map since it seems to be the most well-received according to the findings of Besançon *et al.* Since the DT can allow users to rotate and drag the map, the issues with accuracy might not be as bad as described.

2.5.3 Previous Work on 3D Information Visualization for Time Dependent Data on Maps

Christian Tominski *et al.* proposed two approaches for visualizing spatio-temporal data onto maps, pencil and helix icons. A pencil has many faces and each face can be used to represent different data parameters. The natural shape of the pencil can also be used to visualize each parameter's change over linear time. As a convention, the earliest time begins at the common tip. Each face or parameter should be color coded, and a ”tunnel view” should be able to be selected, meaning that the user can select a specific pencil to get a better overview look of the parameters. The idea is that each of the areas on the map should have a pencil over them. The same idea applies to the helix icons. The natural shape of the helix allows for easier visualization of data over cyclic time, for example, recurring temporal primitives, like seasons or months over several years. However, at the same time, the helix allows less room for different parameters. Just like the pencils, the tunnel view mode should also work with the helix icons [19].

Sidharth Thakur and Andrew J. Hanson proposed a visualization method in their study using 3D glyphs for representing spatio-temporal data [20]. The technique involves depicting each time step as a disk, with varying width and color gradient corresponding to the data value for that particular moment. The final assembled glyph resembles the figure of a vase and each area on the map should have its own glyph over it. The technique is intended to assist analysts in exploring and quickly grasping multiple time-varying quantities on a map, which can be relevant for this project. However, due to time constraints this technique might not be able to be implemented to the DT.

Since the pencil technique is able to show multiple data aspects in one visualization, it is of interest for this project.

2.5.4 The Digital Twin of Karlskrona and the Karlskrona Analysis

Karlskrona has conducted work regarding a DT of the municipality in conjunction with the Karlskrona analysis, and proposes that they can together promote sustainable development in societies [40]. The Karlskrona analysis shows differences and similarities between different areas in Karlskrona, and focuses on various social factors. The DT is their tool for simulating future developments, and together they can be used to make decisions about the municipality's development [40]. However, it still remains unclear if they visualize different aspects of social sustainability specifically, as this project aims to do.

2.5.5 Other Similar Work

Other related work that were found during the literature review include the DT of Singapore, DT of Zurich, and the DT of Gothenburg. Virtual Singapore is a DT of the entire country of Singapore, available for various sectors that work within the context of for example planning and decision making [41]. It is stated that the DT of Singapore can be used for decision making, virtual experimentation, and for research and development [42]. Another similar project is the DT of the city of Zurich in Switzerland. The main aim of the project is to deal with the predicted drastic population increase in Zurich until 2040, which will pose a plethora of challenges for the city [9]. The DT of Gothenburg is a tool used for visualizing and simulating projects regarding the city [43]. Moreover, they explain that the tool can be used for improving decision making by letting users make sharper decisions [43].

2.6 Summary

In summary, visualization is a concept in data science that can be utilized with different techniques and tools with principles that should be followed. Visualization can be incorporated in different tools and solutions, one of them being the DT, which is a virtual copy of a real world object. Different aspects regarding the object could be visualized in the virtual version, in order to gain insights and consequently make decisions regarding the real world object. However, as any digital tool, usability is an important aspect since low usability will make people leave the application. Therefore, it is important to keep the main five components of usability in mind when creating visualizations. Moreover, an understanding of social sustainability and a limitation with regards to FSSD is important, as there are many definitions of social sustainability. Lastly, viable visualization techniques such as the pencil technique and the usage of choropleth maps are presented and discussed.

Chapter 3

Methodology

This Chapter provides an overview of the research methodology. Section 3.1 presents an overview of the research process. Section 3.2 describes the research paradigm for this work. Section 3.3 describes data collection, sampling and ethics. Section 3.4 outlines the test environment and the required software. Section 3.5 discusses the reliability and validity of the collected data and Section 3.6 describes an analysis and evaluation framework for qualitative data.

3.1 Research Process

The research process is the foundation of how the research will be conducted. For this study, the research process is structured as in Figure 3.1.

Figure 3.1: Research process of the study.

The literature review serves as the foundation of the entire project. It provides a comprehensive understanding of the existing research relevant to the topics. By conducting this literature review, the researchers gain insights into the current state of knowledge, key themes, gaps and debates within the fields. The gaps in the fields then guide the identification of areas in need of further investigation and exploration, which not only help refine the research focus but also the formulation of research questions.

The design of the research plan follows after the completion of the literature review. Here, methodologies that are suitable are selected for the project and an outline for how the research will be conducted is made. For this work, a qualitative research methodology was deemed appropriate.

The data collection step is the phase where the chosen research methodology will be used to gather data for the research, and the data analysis step is the phase where the collected data will be analyzed, interpreted and discussed before the final presentation.

3.2 Research Paradigm

To steer and drive the research, a philosophical assumption has to be made. One can choose from the core paradigms that are positivism, realism, interpretivism, and criticalism. Positivism is the philosophical assumption that reality is objective, while realism describes that objects in the world are independent of observers and known. Criticalism means that reality is reproduced by humanity [15]. The philosophical assumption chosen for this work is interpretivism, which is the philosophical assumption that reality is subjective and socially constructed. Approaches with interpretivism generally rely on subjective results through user surveys and interviews that are used to gain insights and deeper understandings [44]. In essence, those approaches consist of qualitative methods that apply to non-numerical results and projects. Qualitative research methods regard subjective concepts such as meanings and behaviors in order to draw conclusions concerning different hypotheses [15].

3.3 Data Collection

This Section brings up how data is sampled, the sample size, and the intended target population for the data. Section 3.3.1 discusses data collection methods. Section 3.3.2 explains sampling and Section 3.3.3 brings up ethical aspects related to the collected data.

3.3.1 Data Collection Methods

Data collection is the process of gathering data that is of interest for a particular research. There are various methods for collecting different types of data, but the common point between them all is honest and accurate data collection [45]. Two such methods are quantitative and qualitative methods. The choice of methodology is dependent on the nature of the project. If the project or work is about proving phenomena in society by using extensive datasets together with experiments, then the work is quantitative. Research is qualitative if phenomena are studied in order to create theories, thereby being more subjective [15]. Since this project is of qualitative nature, qualitative methods will be explained in more detail.

Qualitative methods are based on subjective elements such as a collection of opinions and meanings, to gain insights, analyze and evaluate hypotheses. Qualitative data collection methods are questionnaires, case studies, observations and interviews, from which subjective data can be gained and analyzed. For surveys, the questions can be formulated to retrieve quantified data, or to retrieve qualified data, and this is dependent on if the question is close- or open ended. While quantitative methods require extensive and large datasets, qualitative methods require smaller datasets, in which data collection continues until enough data has been collected [15].

Collected data can also be categorized into primary and secondary data. Primary data refers to data that has been collected directly from the researcher through for example interviews and surveys, while secondary data refers to data that has been collected by someone else [46].

3.3.2 Sampling and Sampling Size

For large populations, it may not be applicable to test and collect data from every person within the population. Therefore, a sample of the original population can be tested instead with a sample size that is relevant to the research methodology of the project. Qualitative methods do not require as large datasets as quantitative methods and a smaller sample size can therefore be more applicable for this kind of methodology [15]. The sampling and sample size is dependent on the nature of the project, and the people who make up a relevant target population.

3.3.3 Ethical Considerations

Ethical considerations regard interaction with the participants during the data collection phase. The participants have to be informed about the research project to all its extent and have knowledge regarding the potential risks that could arise during and after the data collection. They should be able to walk away and not be forced into participating in the data collection phase. Moreover, anonymity has to be respected, and participants must be able to stay confidential and anonymous [47].

3.4 Experimental Design and Planned Measurements

In this Section, the test environment is outlined and the required software to conduct the testing is described.

3.4.1 Test Environment

The user testing is conducted directly with stakeholders and decision makers online. They are given the same tasks to work with in the DT. Their experiences with the DT are observed and there is no verbal communication unless required. Thus, all of the tests are conducted with the same, or very similar conditions that are required to gather fair and accurate results.

3.4.2 Software

The software required to conduct the testing is the DT of Linköping. Because of how crucial the visualizations in the twin are for this project, the project is not possible to replicate without them.

3.5 Reliability and Validity

This Section presents a discussion of reliability and validity with regards to data and data collection methods. For qualitative measurements, validity refers to trustworthiness of the work, which denotes to what extent the work has been conducted according to rules [15]. Reliability however, refers to how consistent responses are from multiple respondents [48].

3.5.1 Validity of Methods

Making sure that the chosen method is valid is crucial in order to retrieve correct answers. To retrieve the correct answers, the right questions have to be asked, and the right practical methods and strategies have to be chosen. This is achieved with an extensive study into the field, and most importantly, by choosing a methodology that is appropriate and relevant to the research question. A qualitative method will lack validity for a research question that requires a quantified answer, while it could be very valid for a qualitative research question. Moreover, to ensure validity, one can let the testers and participants confirm that the findings are correct [15].

3.5.2 Reliability of Methods

In order to make sure that the chosen method is reliable, there should be strict guidelines that make sure that the experiment is conducted in the same manner for all tests. This way, consistency between all test runs can be ensured and consequently the method will be more reliable.

3.5.3 Validity of Data

To make sure that the collected data is valid, the relevance of the data in relation to the research question has to be evaluated. For qualitative studies, this could mean setting up questions either as open ended questions, or closed questions, depending on what the requirements are to answer the research question.

3.5.4 Reliability of Data

To make sure that the data that has been collected is reliable, external factors should be minimized so that results over multiple tests are consistent. The size of the target population can also be increased, so outliers and anomalies can be identified and handled properly.

3.5.5 Rejected Methods

Quantitative methods were considered in combination with qualitative methods to gain perspectives on aspects such as time taken to complete tasks. The quantifications would however not hold much significance, since there are no other values to compare and draw conclusions with. The quantitative methodology was therefore rejected and the study is therefore focused on qualitative results through surveys and observations.

Another data collection method beyond observations that was considered in the beginning was to conduct interviews in order to acquire more qualitative data. The idea was to let testers freely express themselves in order to maximize opinions and feedback. However, this data collection method was rejected due to time and resource constraints. Questionnaires and user testing were selected instead. The questionnaire still includes questions that dive deeper, letting the testers explain themselves in depth. By doing so, the initial intention of including interviews for more in-depth insights is still fulfilled with less resource and time use.

3.6 Planned Data Analysis and Evaluation

This Section presents an outline of a data analysis strategy that can be used to analyze datasets. An evaluation framework for evaluating the data and deriving results is presented, alongside a description of the software tools for managing the data.

3.6.1 Evaluation Framework

Thematic analysis is an evaluation framework that can be applied to analyze data. Thematic analysis is a way of uncovering themes in qualitative data, and makes it possible to see important aspects within the data [49]. This way, qualitative data can be evaluated and analysed, and conclusions regarding the collected data can be drawn.

The process includes several steps that have to be conducted. The steps are [49]:

1. **Gather data**: In this step, the data on which thematic analysis will be applied on is gathered through studies such as interviews or notes.

2. **Familiarization**: In this step, all data is read from beginning to end in order to gain an understanding about the data. Interesting and key points are highlighted.

3. **Coding**: In this step, the highlighted sections have to be categorized. This is done by coding, which is the process of giving labels to fragments of text. The categories, or groups, consist of fragments with similar codes.

4. **Find themes**: In this step, possible relationships such as similarities and differences between the different codes in each group are explored. Consequently, underlying themes can be discovered. Also, their relation to the research question is explored.

5. **Break**: In this step, a break is taken for a day in order to return with a fresh mindset that could yield different, or missed insights.

6. **Evaluate themes**: In this step, the themes are evaluated with respect to how much support they have from the data. If the themes are badly supported, then the analysis can start over from step four until satisfactory themes have been found.

This way, data can be analysed to find underlying themes connected to the data, from which results can be derived and discussed.

3.6.2 Software Tools

In this thesis, Google Sheets is used for storing data that is retrieved through the use of Google Forms. The DT is developed in Unity and runs scripts written in C#.

Chapter 4

Implementation

The previous Chapters in this paper laid the basis for the project with a focus on visualization methods and methodologies. In this Chapter, requirements and the collected social sustainability data is presented. Also, the DT is explained in more detail alongside the visualizations that were made. Thereafter, the implementation and procedure of the user surveys and user testings are presented.

4.1 Requirements

This section outlines the functional, non-functional, and ethical requirements that have been defined by the host company.

4.1.1 Functional Requirements

The functional requirements for this project are to experiment and create different visualizations, and conduct user testings and surveys to evaluate them with relevant stakeholders. Moreover, another functional requirement is to conduct user testing on the company's insight portal and mobile application.

4.1.2 Non-Functional Requirements

The non-functional requirements for this project is that the data used for the visualizations should be publicly available and be useful, and the data should be over several time periods. The visualized data should also respect the provided framework, which in this case is FSSD. Lastly, the data should be on NYKO-level.

4.1.3 Ethical Requirements

The data collection process has to be unbiased and conducted in a fair manner that to avoid misinterpretations and wrong analyses. Also, the data should adhere to the General Data Protection Regulation (GDPR). GDPR is crucial for the rights of individuals to have their personal data protected, and all use of data should therefore adhere to it.

4.2 Data

Before visualizing data in the DT, social sustainability data connected to the FSSD must be collected.

4.2.1 Data Indicators

The setup before the visualizations is about collecting relevant data for each FSSD aspect by finding indicators. By using FSSD as a framework, the non-functional requirement of using FSSD is achieved. The indicator for the health aspect is ”ohälsotal” (sickness absence rate), which represents the yearly number of paid compensation days per person on average. The influence aspect is represented by data regarding election participation in the different areas of Linköping. Competence is described by data surrounding education levels in the local areas of Linköping, and the impartiality aspect is represented by the wage gap between men and women. Lastly, the meaning aspect is represented by data regarding low economical standards, since conducting activities and extra curricular activities becomes difficult with low economy.

4.2.2 Collected Data

The data comes directly from Linköping municipality’s statistical database, which is publicly available. Linköping’s database provides detailed statistics on basal-, or in other words, key code (NYKO) areas over different years. Since the database is publicly available and has data over different years, all non-functional requirements are achieved. Table 4.1 presents the data sources for the five FSSD aspects. Observe that there is no collected data for the influence aspect, which is because data on NYKO-level could not be found.

Table 4.1: Data Sources for FSSD Aspects.

FSSD Aspect	Indicator	Data Period	Data Source
Health	Sickness absence rate for men (days)	2005 - 2022	Linköping Municipality
	Sickness absence rate for women (days)	2005 - 2022	Linköping Municipality
	Sickness absence rate for men and women (days)	2005 - 2022	Linköping Municipality
Influence	-	-	-
Competence	% with low education	2005 - 2022	Linköping Municipality
	% with post-secondary education	2005 - 2022	Linköping Municipality
	% with short post-secondary education	2005 - 2022	Linköping Municipality
	% with long post-secondary education	2005 - 2022	Linköping Municipality
Impartiality	Income of women in proportion to income of men (%)	2005 - 2021	Linköping Municipality
Meaning	% with low economic standard	2015 - 2021	Linköping Municipality

4.3 Digital Twin of Linköping

The usage of the DT satisfies one of the functional requirements of creating visualizations. The DT of Linköping is developed by RISE in Unity and C#. It is a part of a larger project containing several other DTs of different cities in Sweden. The DT already offers support for a time series function, a color gradient ranging from green to red with yellow in between, and the functionality to show data values when hovering over areas.

4.3.1 Data Management

The data is uploaded through a server that dynamically keeps the DT updated during runtime. This link serves as the information flow between the physical and virtual entities. The collected data for the visualizations in this project is static, as they do not change.

4.3.2 Preparing Visualizations and Areas

The DT offers Linköping with NYKO areas already set, but additional preparations for the visualizations were necessary. The shapes seen in 4.2 are the meshes of each area, shrunk in x and y dimensions. To create those, a copy of each area is set as a child object of the original area, and the position of the copy is set to the origin (0, 0, 0) in relation to the original area object. The child copies are stripped of their parents' functionalities, as only their z-dimension and color are changed based on the values that the parents receive from the data. In other words, they do not need any functionality as they are directly changed through the parent.

The original material that the areas used was shiny and transparent, and they lost their color when the camera zoomed out too far. Therefore, an opaque material that maintains its color regardless of the zoom level was designed and is applied instead.

4.3.3 Propagate Function

A script, `Propagate`, was written and is applied for the parent objects as seen in Listing 1. Its functionality is to access the child object and change its values based on the parameters of the function that consist of a `Color` object and a float value denoting the new height scale of the visualization. The function picks the child object that is the copy of the parent and sets the color by utilizing material properties, and the height by directly changing the z scale of the object.

Listing 1 Code for propagating properties to 3D staples

```
public void Propagate(Color color, float normalized_height)
{
    foreach (Transform child in transform)
    {
        if (child.name.Equals("PopUp"))
        {
            Renderer childRenderer = child.GetComponent<Renderer>();

            if (childRenderer != null)
            {
                childRenderer.material.SetColor("_baseColorFactor", color);
            }

            Vector3 childLocalScale = child.localScale;

            childLocalScale.z = normalized_height;

            child.localScale = childLocalScale;

            break;
        }
    }
}
```

`Propagate` is used for setting the material color and staple heights. The object with name `PopUp` refers to the 3D staple in the engine and is accessed with its name in the code. `Propagate` is applied to all NYKO areas in the DT. The function goes through every child object of an area and modifies the object named `PopUp`.

4.4 Visualizations

As discussed in Section 2.5, there are many different techniques that can be employed to visualize data. The DT used in this work offers Linköping with NYKO areas already set. The collected data is therefore visualized on NYKO areas by utilizing the concept of choropleth maps and 3D objects that show the magnitude of the data. Figure 4.1 shows an image without visualization applied, and Figure 4.2 shows the same area where data is being visualized with colors and staples.

Figure 4.1: The inner city of Linköping in the DT with no visualization applied.

Figure 4.2: Visualizations in the DT on the proportion of people with long post-secondary education.

4.4.1 Colors

As stated in Section 4.3, the DT of Linköping already has a color gradient ranging from green to red with yellow in between, which we used for the visualizations. The color for the visualizations are determined by calculating the data's position within the gradient with regards to the maximum and the minimum value in the current dataset. A normalization function yielding a value between zero and one is used in order to achieve this. The value being zero indicates that the current value is the minimum value in the dataset, and one indicates that the current value is the maximum value. Thus, a position within the gradient can be found and set for the data. However, for certain datasets, the colors are inverted since low values indicate good circumstances, while for other datasets, low values indicate worse circumstances. Examples of such data are education levels where higher values are desired, and sickness absence rates where lower values are desired.

4.4.2 3D Objects - Staples

Beyond the coloring, 3D staples with varying heights, colors, and shapes that pop up from the areas are implemented. The coordinate system in the DT is defined as in Figure 4.3.

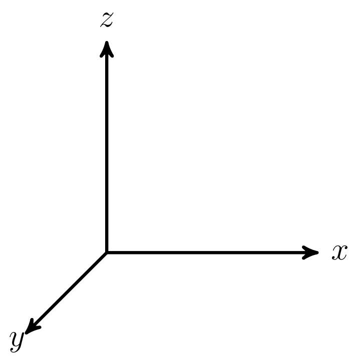

Figure 4.3: Axis orientation of the DT.

A sample of the staples can be seen in Figure 4.2 They retain the shape of the area, although downscaled in both x- and y-axes so boundaries between the staples are more present and to avoid a situation where the objects are melding into each other. For setting the colors of the staples, the normalization function is used to calculate a value between zero and one, and the color is retrieved and set by using the color gradient. For the heights, the 3D objects are scaled up in the z-axis with a value between 1 and 15, which we achieved by using the normalization function and using the normalized value in equation 4.1.

$$\text{z-scale} = 1 + \text{normalizedHeight} \times 14 \tag{4.1}$$

Since normalizedHeight is a value between zero and one, the lowest possible scale is set to 1, and the highest to 15, which yields the desired scaling interval. Following this, the z axis is scaled with the calculated value to set the height of the staple.

4.5 Usability Testing

Due to external factors, the mobile application and insight portal were unavailable, and user testings were only conducted on the visualizations in the DT. Consequently, the functional requirement of testing the mobile application and insight portal was not achieved. The results of the user testing are anonymous, and the privacy of the participants is respected and thus the ethical requirement is satisfied. To achieve the requirement regarding the visualizations in the DT, the user testing was conducted with five different testers that are all from the relevant target population consisting of stakeholders and decision makers from Linköping. Due to complications, the group was split in two and only two of the testers interacted directly with the visualizations. The other three participants were given a thorough presentation of the DT, during which we went through each task together and gathered feedback and comments from them with regards to the visualizations, colors, and usability after each and every task. The usability testing and presentation consisted of the following tasks:

1. Find the NYKO area *Kanberget*.
2. Decide if *Kanberget* has a high proportion of individuals with low economic standard.
3. Try to use the visualizations to decide which NYKO areas are the worst and best in regards to the average paid sick leave days in a year for both men and women.
4. Investigate the wage gap between men and women in the NYKO area *Berg södra glesbygd*. How is the area performing? A time limit of two minutes for this task is set.
5. Investigate the NYKO area *Innerstaden nordväst* in regards to the average paid sick leave days in a year for women in 2018.
6. Investigate the proportion of individuals with post-secondary education in both *Innerstaden nordväst* and *Innerstaden sydväst*. Compare both NYKO areas' development between 2018-2021.

There was a goal behind each task. The goal for each task is listed below:

1. The goal with task one was to understand how difficult it is to navigate the virtual version of Linköping.

2. The goal with task two was to understand how difficult it is to navigate the data menu, and how easy it is to understand and give meaning to the data.

3. The goal with task three was to understand how the staples could support, or hinder, the testers from making comparisons between areas on first inspection.

4. The goal with task four was to understand how easy it is to find areas in the virtual version of Linköping, since areas cannot be evaluated if they cannot be found. The chosen area for this task was localised in the outskirts of the city.

5. The goal with task five was to understand if the user learns how to use the twin. The task is similar to task two, and investigates data navigation and data understanding.

6. The goal with task six was to understand if the tool could be used to solve more complex problems and make comparisons between two chosen areas and their development throughout time.

Thus, data to understand the visualizations and usability was collected by evaluating the experiences and observations of the different participants.

4.6 Survey

As explained in the previous section, the mobile application and insight portal were unavailable, and consequently the survey is only focused on the visualizations in the DT. The survey is anonymous, and the privacy of the participants is respected and thus the ethical requirement is satisfied. A survey was used to gain direct feedback on the visualizations from all of the participants. The survey questions are listed below:

1. Have you used a similar tool before? (two options)
    - Yes
    - No

2. After the usability testing, what was your opinion on the ease of use for the digital twin? (three options)
    - Difficult to use

   - Neither difficult nor easy to use
   - Easy to use

3. Please elaborate your answer from the last question.
4. What are your thoughts regarding the 3D staples that are adding an extra dimension to the visualizations?
5. How easy was it to understand the visualizations?
6. On a scale from 1-10, how difficult was it to find the NYKO areas specified in the tasks?
7. Was there anything that was especially good?
8. Is there anything to improve upon?
9. What would you like to see in this digital twin that is not implemented yet and could support working with social sustainability?
10. Could this digital twin assist in working with social sustainability in Linköping? Do you think it would have helped you with your work?

The survey was sent to each participant after the usability test was done, and the answers are anonymous. Each participant was prompted to answer the survey within two days to ensure that they answered it with fresh impressions.

Just like the tasks in the usability testing, each question in the survey was designed to understand certain objectives. The general aim for the survey was to collect written feedback regarding the visualizations and the usability of the tool, and also gather data on what needs to be added to solve the problems.

Chapter 5

Results and Analysis

This Chapter presents the results acquired from the conducted user testings, presentations and surveys, and also provides a reliability and validity analysis of the used methods and collected data. Discussions and conclusions follow based on the results in Chapters 6 and 7 respectively.

5.1 User Testing

The results from the user testing can be categorized into a per-task format, in which different aspects of the visualizations have been given feedback from the participants. Two testers were able to run the application on their own computer, while three testers were not and were needed to be shown these tasks instead.

5.1.1 Task One & Task Two

T1: Find the NYKO area Kanberget.

T2: Decide if Kanberget has a high proportion of individuals with low economic standard.

The observations and feedback gathered during task one and two can be categorized into these major categories below. The testers:

- managed to solve the problem without complications (two testers).
- questioned the meaning of the colors, since there was no legend (three testers).

- thought that the visualizations looked better when the camera was zoomed out (two testers).
- pointed out that the view can become cluttered when visualizing data in dense areas (two testers).
- felt the absence of a search functionality to find areas (two testers).

Aside from the main themes, there was one tester who pointed out that the visualizations differed more in height than they did in color. Also, finding data below the FSSD categories was difficult for most of the testers, as they were not familiar with the framework beforehand. One tester explicitly stated that it was beneficial that they could see the status of neighboring areas.

5.1.2 Task Three

T3: Try to use the visualizations to decide which NYKO areas are the worst and best in regards to the average paid sick leave days in a year for both men and women.

For task three, the testers:

- wanted to see more variance for the colors and not only a spectrum from red to green (four testers).
- pointed out that a color grading legend would be good (two testers).
- felt that it was hard to determine what ”good” and ”bad” was (two testers).

Other minor comments include that the colors should not be limited to green and red since the testers could be color blind, which would limit the use of the visualizations. Two testers also pointed out that industrial areas should be excluded entirely from the visualizations, since the amount of residents usually are limited to a few people. Thus, industrial areas can often appear as anomalies. Other feedback received during the testing regarded dividing the data into quantiles, where each color belongs to a quantile instead. Another idea received from a tester was to add edges to each staple in order to make them more distinguishable.

5.1.3 Task Four

T4: Investigate the wage gap between men and women in the NYKO area Berg södra glesbygd. How is the area performing? A time limit of two minutes is set for this task.

For task four, the testers:

- noted that the visualizations were cluttered when zoomed in (two testers).
- noted that the visualizations were better when zoomed out and viewed from a certain angle (three testers).

Aside from the main points above, one tester noted that it was hard to see differences between small adjacent areas that had minor yet significant differences in data values. Another tester said that a camera reset function would be of great help in case the user becomes disoriented. The same tester noted the absence of a compass function, which made it harder to navigate and find areas in Linköping when the camera had been rotated. In addition, one tester mentioned how adding a search function would speed up the search process. This tester was not among the people who mentioned the search function in task one and two earlier.

5.1.4 Task Five

T5: Investigate the NYKO area Innerstaden nordväst in regards to the average paid sick leave days in a year for women in 2018.

Not all testers reached task five, but task five was shown to two participants and they:

- saw no issues for using the time series function for the datasets (two testers).

One tester noted however that the timeline was a little too detailed for the time series function, since the timeline included time down to seconds, while the data represented values for each year only.

5.1.5 Task Six

T6: Investigate the proportion of individuals with post-secondary education in both Innerstaden nordväst and Innerstaden sydväst. Compare both NYKO areas' development between 2018-2021.

Not all testers reached task six, but the task was presented to three participants and they:

- noted the absence of a memory function, since in its current state, the twin would require one to take notes between years (three testers).

There were split opinions on whether the visualizations could be used to solve such a task. One tester said that they could do it, while another said that they could not. Also, the tester that could use the visualizations to solve such a task suggested that one should be able to lock the areas, and only visualize the ones that are locked.

5.2 User Survey

Four of the five participants answered the user survey, and they gave feedback regarding the visualizations and their interactions. Summaries of the answers to each question are shown below.

5.2.1 Survey Question One

Q: Have you used a similar tool before?

The responses to survey question one are as shown below in Figure 5.1. The numbers in the pie chart represent the count of participants who chose each specific option.

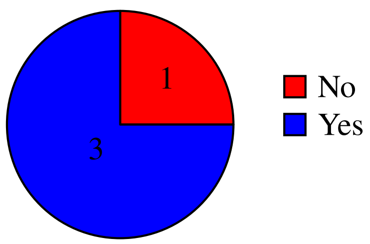

Figure 5.1: Number of respondents that have and have not used a similar tool before.

As shown in Figure 5.1, three respondents answered that they have used a similar tool before, while one respondent answered that they have not. That one respondent elaborated that they have used similar 2D tools before, but not any tool utilizing 3D like this one.

5.2.2 Survey Question Two

Q: After the usability testing, what was your opinion on the ease of use for the digital twin?

The responses to survey question two are as shown below in Figure 5.2.

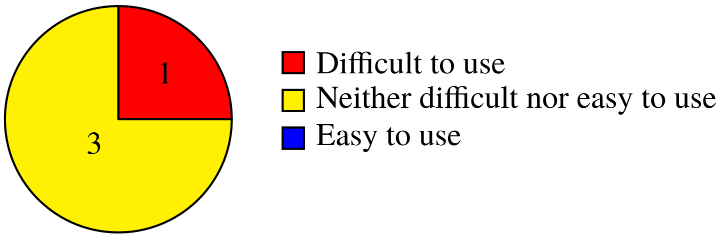

Figure 5.2: Reported difficulty of using the DT.

As shown in Figure 5.2, three respondents answered that the DT was neither difficult nor easy to use, while one respondent found it difficult to use. No respondents answered that the tool was easy to use.

5.2.3 Survey Question Three

Q: Please elaborate your answer from the last question.

The answers to survey question three can be summarized with the following points:

- The staples led to visible clutter, which hindered the user from gaining a quick overview.
- The staples were unclear in shape and location.
- The colors were hard to interpret, since there was no legend.

One tester noted that one has to learn to utilize the camera to maximize the efficiency of the staples. Another tester mentioned that a search function would be useful for finding areas.

5.2.4 Survey Question Four

Q: What are your thoughts regarding the 3D staples that are adding an extra dimension to the visualizations?

The answers to survey question four can be summarized with the following points:

- The 3D effects were hard to see.
- The staples did not feel entirely centered in each NYKO area.
- To ensure better functionality, the color gradient has to be adjusted.
- The visualizations gave a clear picture over the area.
- Frames were recommended for the staples to make them easier to differentiate.

One user noted that the staples were in the way, and they did not see any purpose for them to exist. They also said that they did not have any 3D effect, but instead looked like flat plates on the screen. The user would have rather seen highlighted areas. Another user answered that the color gradient should be more varied.

5.2.5 Survey Question Five

Q: How easy was it to understand the visualizations?

The answers to survey question five can be summarized with the following points:

- Two testers answered positively while two testers answered negatively.
- While it was possible to gain an overview of areas, it could have been better if the colors were not so similar.

5.2.6 Survey Question Six

Q: On a scale from 1-10, how difficult was it to find the NYKO areas specified in the tasks?

The responses to survey question six are as shown below in Figure 5.3.

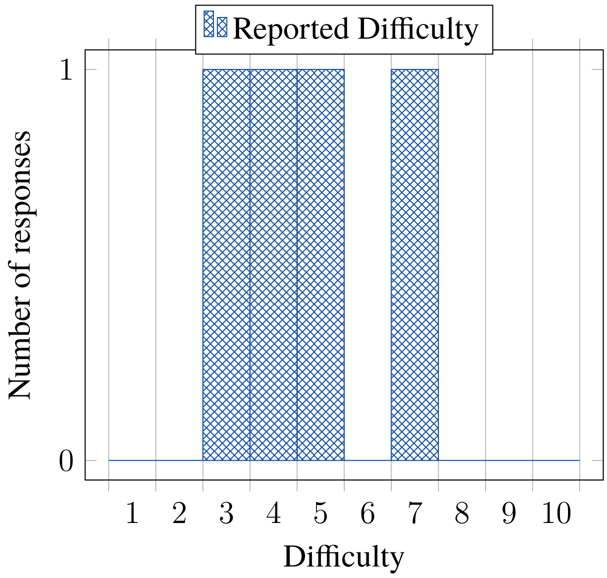

Figure 5.3: Reported difficulty for finding relevant areas in the DT.

As shown in Figure 5.3, two of the respondents answered that the difficulty was somewhat on the easier side (3 - 4), one respondent answered that it was neither difficult nor easy (5), and one respondent answered that it was slightly difficult (7).

5.2.7 Survey Question Seven

Q: Was there anything that was especially good?

The answers to survey question seven can be summarized with the following points:

- The idea of using staples for each area was good.
- Using percentual values to represent data was good.
- The resolution of the DT looks great.

One user wrote that the DT still is in its early development stages and that it is too early to say.

5.2.8 Survey Question Eight

Q: Is there anything to improve upon?

The answers to survey question eight can be summarized with the following points:

- Navigating in the DT without prior local knowledge may be challenging, so adding a search function is recommended.
- Improving clarity for the staples is necessary.
- Adding a reset function for the camera would enhance usability.
- A menu allowing more customization for the visualizations was suggested.

Regarding what could be improved, the testers wanted search functionality for those without local knowledge and wanted additional clarity and customization on the visualizations, with easier navigation.

5.2.9 Survey Question Nine

Q: What would you like to see in this digital twin that is not implemented yet and could support working with social sustainability?

The answers to survey question nine can be summarized with the following points:

- Adding data for statistics from public safety surveys could help decision makers identify more vulnerable areas in general.
- Showing data from multiple perspectives by utilizing the height of the staples. For instance, showing how things look on ground level and showing the development on property level as the height increases.

Two participants said that the question was hard to answer. One wrote that social sustainability is a wide area and that the answer depends on what one wants to achieve with the DT. The other participant said that their inability to answer is a consequence of them not working with social sustainability issues specifically.

5.2.10 Survey Question Ten

Q: Could this digital twin assist in working with social sustainability in Linköping? Do you think it would have helped you with your work?

Two participants answered that the DT could be a part of the workflow in the long term if more development is put into it. Aside from the two participants, one participant did not answer the question since they do not work with social sustainability specifically. Another participant said that the twin cannot be used for such work in its current state.

5.3 Reliability Analysis

To make sure that the method is reliable, strict guidelines to follow were set up. As mentioned earlier, the target group consisting of testers was split into two smaller groups, one of which interacted with the visualizations, while the other observed the visualizations.

Before the user testings began, the two participants were given a brief introduction to the DT and how they should navigate the data. This was done the same way for both of them, to make sure that they have the same background information before the interaction began. Following that, the participants of the user testings were given the same set of tasks sequentially and began interacting with the visualizations. Once one task was finished, the next was introduced. By following these guidelines, the consistency of the user testing could be upheld. Moreover, the user testing is possible to replicate with decision makers from other municipalities as well, since they are not limited to Linköping. Changing the names of the areas in the tasks are all that is necessary for similar tests in other cities.

The other group of participants were given a presentation of the visualizations. Similarly to the user testings, the presentations were guided by the tasks. The presentation consisted of a mock user testing scenario, in which questions were asked and feedback was gathered after every task. To ensure consistency, the same person gave the presentation and the same questions were asked to every person after a task was finished. The presentations can also be replicated, as they were strictly adhering to the tasks and list of questions that should be asked after every task.

All participants were given the chance to participate in the user survey. They all received the same questions and were reflecting on the same experiences. The questions were given in the same sequence to ensure consistent data collection and the survey questions were designed to be simple and clear to avoid misinterpretations. Moreover, the survey was conducted after the user testing and presentations to make sure that all participants had the knowledge and experience required to give relevant and insightful answers. By making sure that the user testings, presentations, and user survey were consistent, we tried to ensure reliable results.

Despite the participants following the same rules and guidelines provided during the user testing and survey, the results, consisting of observations, feedback, and opinions cannot be described as very consistent. This is due to each participant's own background and experiences, which is the reason to why some react strongly to some elements while others take notice of other elements, thus resulting in varied feedback. However, the results in general still have some level of consistency as later participants were producing similar feedback as earlier participants, which is expected according to Nielsen's usability theory. The participants were expected to bring up previously mentioned opinions and feedback while also providing at least something new, which was true for entirety of the testing. The same thing held true for both user groups, as both of the answers hold similar themes between the groups.

The results for the survey were more inconsistent than the user testing observations and feedback. The participants were given 2 days to complete the survey after the user testing, which may imply that the participants' memory of the user testing were not equally fresh. Some of the survey questions were also written to be more general, thus giving the participants a wide array of options to write about. Both of these factors combined, could be the reason to why the answers were more unique in this phase than in the user testing. However, the answers were still connected to the findings from the user testing, which shows a form of consistency between the results of the conducted user testings and user surveys.

5.4 Validity Analysis

To measure meaningful data, the right methods had to be used. The method required subjective data, comprising feedback and opinions on the visualizations, as well as an evaluation of the participants' experiences with the software. To achieve this, user testings and surveys were used.

The user group for the user testings was split in two halves, where one half used the DT and the other received a thorough presentation of the DT that was guided by the tasks. Despite the split that had to occur, validity of the method was ensured by using the tasks as a guideline to achieve the goal of receiving measurable data from the participants. Since the original target group was five people, the split resulted in two very small groups consisting of two and three people each. This could have resulted in skewed data since for instance, the two people that interacted with the twin could have liked the visualizations, or the reverse, by chance.

The participants that partook in the user testings were given the tasks sequentially and their experiences were observed and analyzed. They were instructed to think aloud during the test, from which results were derived. The think aloud protocol yields unfiltered and direct feedback regarding what the testers see and interact with, which was useful for analyzing genuine user interaction and measuring the intended data. The other participants received a presentation that sequentially followed the tasks and their feedback was collected after every task. This way, it was ensured that measurable data was collected from both groups. Relevant results to answer the research question were collected from the participants despite the difference in method for the two target groups, because the visualizations were the source of relevant feedback. Since they are of visual nature, the participants in the user testing only had the privilege of making them appear and moving around them. In essence, both target groups gave feedback on the visualizations by evaluating what they observed.

The user group for the survey was however not split and they all participated in the same survey. Since they participated in the same survey, they were all reflecting on the same experiences, which means the same measurements were being assessed. The survey provided additional insights and opinions, and gave the participants a chance to develop their feedback regarding their experiences and observations further. Consequently, both their subjective experiences and subjective thoughts were analyzed in the form of user testings and user surveys respectively.

To ensure data validity, the survey and tasks were focused on the visualizations and usability of the DT, as both are crucial for social sustainability work. Consequently, the collected data was centered on the color gradient, visual clutter and complexity, all of which are directly related to the visualizations and how they can be used in practice.

Chapter 6

Discussion

The previous Chapters have presented the implementation and results of this project with regards to how visualization can support decision making regarding social sustainability. The results of the study indicate that while 3D visualization methods can mediate the necessary information for evaluating areas, there are factors such as color choice, color variety, and visual clutter that have to be considered.

6.1 Color Gradient

A main recurring theme throughout the feedback of the participants is revolving around the color gradient and that it does not show differences between areas with similar, yet differing data. The significance of this finding is that it hinders the user from making comparisons between an area and other adjacent or nearby areas that may have similar data. Only being able to see differences between areas that are doing really good and really bad is not really useful, as nuances between the areas in the middle of those two extremes are lost. To support decision making in Linköping, one should be able to identify differences between arbitrary areas, and not only areas that are on extreme opposites of the color spectrum since that is very delimiting and drastically lowers the use of the visualizations.

However, the results are still in line with the findings of Brewer *et al.*, who found that color can add accuracy when reading maps. As the user testing and presentations show, users are able to see differences between areas with larger difference in data due to color changes, but have difficulties interpreting whether the areas are doing good or bad due to the absence of a color legend. The meaning of the visualizations can be made more apparent by implementing a color legend.

6.1.1 Using Quantiles to Determine Color

A suggestion from the feedback to remedy the problem with the color gradient is to use quantiles that each have a color representing them. This way, if a data value is within a certain interval it receives a specific color, just like the Brewer palette presented in Section 2.1.2. Assuming that there are multiple intervals and color that differ enough for each interval, differences between arbitrary areas can be shown. However, a similar problem to the one explained in 6.1 persists in this implementation, which is that two data values in the opposite sides of the same quantile are given the same color despite not being equal to each other. Thus, this solution can lead to misinterpretations as it can be assumed that two areas in the opposite sides of a quantile do similarly with respect to data. This is of course dependent on the size of the intervals. Having many but small intervals lowers the probability of misinterpretations occurring, but shortening the intervals leans more towards the color gradient implementation since the colors are distributed over a larger number of quantiles.

6.1.2 Solving the Color Gradient Problem

A possible solution to solve the presented problems is to combine the color gradient with the implementation using quantiles. A color gradient can be implemented into each quantile, thus showing differences within each quantile as well as between all quantiles. This also requires a jump in color between each interval, so the problem with the color gradient implementation does not persist. A problem that could occur with this implementation is that a larger set of colors may be required, which can add visual clutter in the form of colors. Consequently, the visualizations can be harder to interpret, depending on how many different colors there are in use. Even so, this solution has the capability to show nuances between areas with minor and major differences in data values. With a choice of an optimal amount of colors, this implementation can solve the problem of not seeing differences between areas with slightly differing data values and thereby give relevant users the necessary information to understand and make decisions based on the visualizations.

Another possible solution to ensure simplicity is to only use a color palette with one color for each quantile. Despite there being no differences between different data within the quantile, this approach could help with clarity and gaining an understanding of the dataset in large without introducing too many colors.

6.2 3D Staples

In the implementation, staples are used to show the status of each area with respect to data. While some participants noted that the idea with the staples is good, most believe that they still need more work before they can be utilized properly. Besançon *et al.* found in their study regarding accuracy and efficiency for visualization methods on population statistics that 3D choropleth maps is ranked as the favorite visualization method. They also speculated that 3D objects may be disadvantageous if the visualized areas are dense, but that this can be solved by allowing the user to move and rotate around the areas. Contrary to their findings, the staples are not very well received by the testers as many say that they add visual clutter, and become a hindrance when one wants to view areas from up close. This is a surprising finding, since we were originally confident that our results would be in line with the findings of their study on 3D effects. However, important to note is that our implementation scales down the staples in x and y dimensions with aim to make the staples more differentiable. The visualized areas are also dense, and those might be the factors that led to the differing findings on the 3D effects between our and Besançon *et al.*'s implementation.

6.2.1 Cause of Visual Clutter

As some of the testers noted, the staples do not have frames and are therefore hard to differentiate. Also, two testers pointed out that the view becomes cluttered when data is being visualized in dense areas, which might be the main contributor to the visual clutter. The inner city is partitioned into many NYKO areas, and the density of areas being visualized in the inner city was large thus leading to a large number of staples next to each other. The usage of staples might therefore be a better idea for maps and areas that are partitioned into fewer but larger areas so the clutter is minimized, as the results of our findings indicate that largely dense areas might be the root cause of visual clutter.

6.2.2 Improving the Staples

Based on the feedback, the staples may not be contributing with as much meaning to users as initially expected. The visual clutter is hindering users from gaining an overview and interpreting what they see, which directly impacts the use of the visualizations. A potential improvement that can remedy this was given by one of the participants. They mentioned that locking areas and only showing staples for locked areas can reduce visual clutter, and show visualizations only for areas of interest. This can be a significant improvement, as a major theme in the results revolves around the visual clutter as a consequence of the staples. We also speculate that adding frames or edges to the staples can remedy the problem as well, by making them easier to differentiate.

While those improvements can alleviate the problem, one must still consider the use cases when staples are appropriate to implement. Our implementation only utilizes small partitions, but large partitions can potentially be where staples are appropriate, since the clutter would be minimal. Additionally, one of the participants noted that it is hard to see differences between small adjacent areas that have slight differences in data values. Similar to the color gradient problem, there are areas that have similar heights in the inner city, which makes it hard for users to interpret the visualizations based on heights. The issue may have been that the z scale should have been larger than 15, as it might be too small to show a significant difference between data values that are close to each other. The visualizations have to be easy to read and find meaning in, since without that decision makers cannot gain the necessary overview and detail to make decisions to improve social sustainability. To ensure that the staples are useful, the heights have to be calculated with values that show the necessary nuance and difference in data.

6.3 Disconnection between Colors and Staple Heights

A participant noticed that the visualizations vary more in height than they do in color. This finding is significant despite only one participant noting this, because it shows an inconsistency between the two visualization methods. Colors are used to represent the state of the area, and heights as well. They must therefore be scaled the same way, so the difference in color represents the difference in height. Otherwise, the visualizations can be misleading and hard to interpret since a situation where the height is showing a bad state, and the color a good state can occur.

6.3.1 Connecting Colors and Heights

The problem can be solved by using a modified version of the proposed solution to the color gradient problem presented in Section 6.1.2. The proposed solution uses quantiles to determine color, and a color gradient within each quantile to show differences between data. That solution can be built upon further, so each quantile also determines the height of the staple. This way, two values are retrieved. A height value and a color to represent the state of data with regards to other data within the same quantile.

Determining both the height and color of the staple by using this method creates a connection between colors and heights. This solution reduces the variance in height however, and many areas are given the same height. This may not be problematic, since that can reduce the overall visual complexity of the visualizations. Under the assumption that the color gradients are varied enough, making comparisons between two adjacent areas within the same quantile is still possible with this solution, since a color gradient is applied to every quantile. This method can lower the probability of misinterpretations happening, and may make it easier to gain an overview over the state of areas since visual clutter is mitigated and the disconnection between colors and heights is minimized.

6.4 The Meaning of the Visualizations

Testers gave feedback that questioned the meaning and accuracy behind the visualizations. Their feedback is explained in more detail in Section 6.4.1. In Section 6.4.2, the potential for misinterpreted messages behind the visualizations are explained, with a foundation based on Chapter 2 of *Data Feminism* by D'Ignazio and Klein.

6.4.1 Area Treatment

Some testers mentioned that visualizations on some areas are slightly inaccurate, or convey the wrong message. Some areas have extreme values, either very high or very low depending on the chosen dataset. Those areas are mostly industrial and university areas, and the common theme between them is a very low population. The main point of the visualizations in this project is to convey a status for each area, but as the results show, some are inaccurately represented. To solve this, it is important to consider that all areas should not be treated the same. The areas can for instance be grouped into categories such as industrial and urban areas, and each group should be treated differently depending on the requirements. In the current state of the DT, visualizations are being compared directly with no consideration for the type of area. Therefore, it is important to consider the type of area that is being visualized and to calculate values, heights, and colors accordingly. Otherwise, misinterpretations and inaccuracies may occur.

6.4.2 Potential for Misinterpretations

Reflecting over D'Ignazio and Klein's explanations in Chapter 2 of *Data Feminism*, it is important that the visualizations do not convey wrong messages that could lead to bias. The target group for the visualizations made in this work consists of people that are relevant and connected to Linköping, and they are likely familiar with the state of each area. For instance, if an area is represented with a red color to show a critical state and if the user knows that the area has a high concentration of people not from Sweden, the user can make connections that were not originally intended to be made. What we aim to say with this is that the visualizations on a surface level show the status of areas with relation to data, but their meaning on a deeper level has to be considered as well. It is therefore important to make sure that the tool cannot be used for the wrong purposes that could lead to racism, sexism and discrimination.

6.5 Usability

While visualization is one core aspect, the usability aspect is another, since the meaning of the visualizations may not be mediated effectively if the software is not user friendly. One of the main points brought up by the testers regarding usability is the complexity of the tool. The meaning of this is that the DT would have been very difficult to use and navigate in without the instructions given at the beginning of the user testings. A complex tool requires extra time and resources for stakeholders to learn and master. Thus, reducing the complexity by adding instructions or simplifying the interface is vital before releasing the tool.

6.5.1 Lack of Search and Navigation

Other more specific usability issues found in the results are the lack of a search function and lack of a camera resetting function. The addition of a search function would indeed lower the time to find specific areas, making the tool more efficient to use in general. It would also completely remove the necessity of knowing the geography of the city, which could greatly broaden the tool's accessibility to users that are not locals of the specific city in the tool. A camera resetting function could help users who are lost or disoriented to return to the default camera position. However, if a search function is implemented, the need for a camera resetting function is diminished as users can easily navigate to specific areas without relying on manual adjustments.

6.5.2 User Freedom

While some testers have no issues with the staples, other testers prefer the visualizations to be flat. Different people prefer different things, so this is a natural response. The key is to respect both parties wishes by giving the users the option to toggle between different modes. This could increase the user's freedom with the tool. Another similar functionality that was brought up by a tester in Section 6.2.2 is the power to let users choose what areas to visualize. In this manner, only areas of interest are displayed, effectively minimizing visual clutter that has been a major issue significantly impacting the visualizations.

6.5.3 Memory Functionality

A memory function was also suggested by three testers. This suggestion originates from task six, in which users were given the task to compare data between different years. Not being able to see the comparisons within the DT made the tool feel less valuable, as looking at raw data and taking physical notes is effectively the same process. One possible solution is to include the comparisons within the visualizations themselves. For example, if the user wants a comparison between 2010 and 2020, a visible chunk of the staple can be of another color, symbolizing the difference between 2010 and 2020. This can reduce the need for the user to compare the data by manually visiting each year. Combined with the ability to lock what areas to visualize, this improvement can yield the user the functionality to observe how specific areas have changed throughout the years, and thereby simplify the workflow.

Chapter 7

Conclusions and Future Work

This Chapter describes our conclusions and presents limitations, reflections, and key points that future work can focus on.

7.1 Conclusions

In conclusion, the problem was to evaluate and find out how visualization of social sustainability can support decision making. The problem was evaluated by implementing different visualization methods in a DT of Linköping and by conducting user testings and user surveys with a relevant target group in order to gain feedback and insights.

As seen in Chapter 5, the visualizations were not received as well as expected, but very useful insights regarding visualization were gained throughout the work process. After evaluating the results, we found that subjects that may seem simple such as colors and staples, are indeed very complex and one has to be very careful of how they are implemented to avoid misinterpretations, misinformation and visual clutter.

Our goal was to provide stakeholders and the relevant target group with visualizations that can support their work process, and this goal was not entirely fulfilled due to extreme time constraints. The implementation can be useful and supportive for the target group, but in its current state, it is not very user friendly and revisions have to be made before we can conclude that the goal was fulfilled. Despite not fulfilling the goal, we gained the necessary insights and feedback required to make sure that the visualizations reach the goal in future iterations of development. For the tool to be used in a decision making context, the visualizations need to be revised as discussed in Chapter 6, until the tool is in a state where it becomes a supporting tool.

While our initial goal of creating visualizations to support decision making was not entirely fulfilled due to time constraints, our work has yielded valuable insights and feedback that is crucial for future development. Moving forward, the flaws we have identified have to be addressed, in order to ensure that the tool becomes a supportive tool.

7.1.1 Positive Effects and Drawbacks

As the testers were exploring the visualizations, some noted that the staple heights made it easy to compare adjacent areas. This was the intention of the staples. However, they did contribute to quite a bit of visual clutter that made it hard for the testers to interpret and differentiate between the different objects that they were seeing.

7.1.2 Evaluation of Results

The results show that visualizations should not be overly complicated and kept simple enough for the user to understand and interpret what they are seeing, with UI elements to support the meanings behind the visualizations. Also, the colors were hard to interpret due to the lack of a color legend and very small differences between colors. While the intention of staples was to add additional clarity in the form of height comparisons, they led to visual clutter in dense areas. The goal of providing relevant stakeholders with visualizations that support the decision making process was not entirely achieved, since there are some drawbacks to the visualizations that hinder the users from gaining well-defined understandings that decisions can be based upon.

7.1.3 Gained Insights

A valuable insight is the importance of coherence between different visualization techniques if multiple are used at the same time. It was noted that colors varied less than heights, which led to an inconsistency and potential misinterpretations.

Also, the importance of legends and guides were recognized. It cannot be assumed that everyone will interpret different aspects of visualizations the same way, as everyone is different. For any visualization, there has to be a guide or legend that describes how the visualization should be interpreted.

The usage of colors was much more complex than we had anticipated. One should be cautious when using gradients and consider using color palettes with a specific number of colors instead, as suggested by some testers who preferred the data to be divided into quantiles. The selection of colors is also an important matter, as one must consider the cultural connotations associated with the colors and also the potential color-deficiencies in the target population.

7.1.4 Suggestions for Others

Suggestions to others working in the same area are to firstly minimize the visual clutter that may hinder interpretation, but to also try different methods that can communicate meaning to observers. Moreover, conducting continuous tests and revising the visualizations in an iterative manner is recommended for finding and making optimal visualizations.

7.1.5 What We Would Have Done Differently

If there was enough time, we would have liked to add information in the DT that explains what the visualizations mean and also add a function for enabling and disabling either, or both, of the visualization techniques that were incorporated in the DT. Also, it would have been beneficial to incorporate more techniques and implementations, so a more nuanced analysis of several techniques could be made. This would also contribute to gaining a more comprehensive understanding of visualization.

7.2 Limitations

While working on this project, there were several factors that set limits on our efforts. First of all, the data used for the project was required to be on NYKO-level in Linköping while also respecting the FSSD aspects. This in itself was quite limiting, especially for certain aspects such as meaning, since the found data did not have a very clear connection to the aspect. To ensure a clear connection between the data and the aspects, more data had to be found. However, due to the previously mentioned problem regarding data and NYKO, this was not possible to achieve.

Secondly, the project was also limited in the form of time and resources. Access to the DT was not granted to us until very late into the project. This severely limited our potential to implement our work better as the access was granted only several days before our first scheduled user test. If more time was granted, the visualizations could have been more polished, look more 3D, and other new functions could have been explored and implemented within the project.

Thirdly, the lack of information flow between the DT and our data limits this project as the real potential of the DT was never realized. Instead, static data was used. If some dynamic form of information flow was achieved, the experience during the user tests could have been more immersive and the discussions regarding the DT could have been more relevant, despite making each user test a little different.

7.3 Future Work

The next steps for this project would be to further develop the DT of Linköping while keeping in contact with the decision makers. This will ensure that the DT's functionalities and usability are aligned with the interest of the decision makers. One way of achieving this could be to work on the DT iteratively, implementing features or fixes to test with users, gain feedback, consider the feedback and repeat until both parties are satisfied.

As for the information flow between the DT and the physical component, Action For Society's mobile app is planned to facilitate that connection as it will be aiming to collect different types of data in real time. Consequently, the information flow component of Grieves' definition would be upheld. After such a connection is established, the DT might be able to move on to the next step and actually simulate and predict FSSD data.

More work regarding combinations of the FSSD aspects are expected to be developed. The aim is to easier find correlations between each FSSD aspect in the different areas of Linköping, which might make patterns easier to find. Furthermore, machine learning could be incorporated to improve data analysis and prediction, and the underlying data sources for the FSSD aspects are also expected to be expanded upon further than what has been done during the course of this project.

7.3.1 What Has Been Left Undone?

Due to time constraints, the prototype was slightly lacking in usability because the time budget was mainly given to the visualizations.

Also, due to the same constraints, we were unable to look into different color gradients and see if there were any better options. The work was severely limited by time constraints, and more experimentation with colors and staples would have been beneficial to ensure readability.

Lastly, there were other visualization techniques such as the pencil technique presented in Section 2.5.3 that would have been beneficial to implement and evaluate in the DT.

7.3.2 Next Obvious Things to be Done

The next obvious thing to be done is to revise the DT and the visualizations based on the feedback from the user testings, presentations, and survey questions. Following this, the visualizations should be tested again to see if there are any improvements and new issues that have to be solved. The visualizations and usability can be improved by doing this iteratively.

7.4 Reflections

The work can be evaluated with respect to ethical and social aspects.

7.4.1 Ethical

The gathered data that the visualizations are built upon do not show any information on any individuals living in Linköping and they are all anonymous. To further improve the anonymity, visualizations on areas with very low inhabitants such as industrial areas should be omitted so the results cannot be traced back to people that may be living there.

7.4.2 Social

If the DT is further enhanced after this project, the goal of visualizing social sustainability will be reached and decision makers will be able to make use of the DT as a tool for analysis for social sustainability. This should improve the general welfare of the people inhabiting the relevant city of the DT. If the project is successful for Linköping, the same idea could be propagated to other cities (not limited to Swedish cities), potentially also improving other cities' social sustainability in the long run.

Lastly, the project has contributed to the following Sustainable Development Goals (SDG) [50]:

- SDG 3 (Good Health and Well-Being): The visualizations provide the opportunity to find and improve areas where people are less healthy on average.

- SDG 4 (Quality Education): The visualizations provide the opportunity to find and improve areas with low education levels.
- SDG 5 and 10 (Gender Equality and Reduced Inequalities): The visualizations provide the opportunity to find and improve areas where inequalities exist.
- SDG 11 (Sustainable Cities and Communities): The visualizations provide the opportunity to improve the social sustainability of urban cities and communities.

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