Accessible Analytic Dashboards

Guidelines and Requirements for an Accessible Visual Analytics Experience

Master's thesis in Computer science and engineering

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Gothenburg, Sweden 2023

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Cover: Illustration of an accessible visualisation with a tooltip on an interactive component

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ABSTRACT

In order for everyone to be able to consume content, it is vital to consider accessibility. With this in mind and in collaboration with a visual analytics company, the purpose of this thesis was to answer the following research question: “What should data visualisation authors consider when building dashboards and applications with the intent to produce more accessible experiences for users?”. This was accomplished by conducting a pre-study and iterative design process consisting of five phases: empathise, define, ideate, prototype and test. The process resulted in 15 Guidelines for Authors and 42 Requirements for Development of Visual Analytics Platforms, that were iterated throughout the project. The Guidelines for Authors are meant to help authors make accessible choices when building visual analytics dashboards. The Requirements for Development of Visual Analytics Platforms however, are meant to inform, and enable the author to make those choices. Moreover, they also provide several aspects that are essential to the accessibility of visual analytics platforms, that cannot be affected by the author. These requirements are meant to be used for those who design and develop visual analytics platforms. Eight of the requirements were also chosen for design. The solution to these acts as examples of how those requirements could be fulfilled.

Keywords: accessibility, information visualisation, interaction design, visual analytics

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CONTENTS

1
INTRODUCTION

In pace with society becoming more digital, more data is also produced (Keim et al., 2008). The amount of data collected is increasing faster than the ability to analyse it, creating a gap in its usefulness. The goal of *visual analytics* is to take these large amounts of data and represent it in a perceivable way, allowing extraction of knowledge and insights. Ware (2021) explains that *data visualisations* are the most efficient way to communicate large amounts of information from computer to human, by representing the data visually, for example in graphs. Furthermore, several software tools have been developed with the aim of aiding the process of creating and sharing data visualisations. Ware explains that these software tools often present their visualisations in composites called *dashboards*, a collection of visualisations and information that create a context for the representations.

The Company expressed that great focus has been to develop efficient and intuitive controls for building and sharing dashboards and analytical applications, less emphasis has been put on *accessibility features*, i.e. support for screen-readers, keyboard navigation and similar, in the resulting dashboards and analytic applications. This is an important subject that would mean that more users can consume the data in these dashboards and applications. Therefore, web accessibility is a vital focus and in many instances it is required by law. WCAG is an acknowledged accessibility standard that provides guidelines for how to design web content (WAI, 2023-b). It is a helpful standard to ensure that all users are able to contribute, perceive, understand, navigate and interact with the information presented.

This thesis is conducted in collaboration with a visual analytics company and this report will describe the background for the project, theory regarding design and accessibility, as well as methodology. Furthermore, this project will evaluate and identify areas of improvement regarding the features of the product, resulting in more accessible dashboards.

1.1 Research Question

Communication with the company involved led to several different subjects within interaction design being discussed, from those the following research question was formulated:

What should data visualisation authors consider when building dashboards and applications with the intent to produce more accessible experiences for users?

1.2 Goals

Guidelines for authors, requirements for developers of visual analytic platforms, and prototypes will be produced based on critical evaluation of previous research to answer the research question. The purpose of the guidelines is to guide the authors in the right direction. However, to be able to follow the guidelines as an author, the requirements for development of a visual analytics platform need to be considered in the first place. Lastly, the prototypes will act as examples of how the guidelines can be implemented. The prototypes will also be used to explore supportive, or alternative means of designing and consuming insights. Another goal is also to evaluate the accesiblity from all aspects and not only focus on a specific impariment.

1.3 Delimitations

A limitation of this project is that it will not investigate the accessibility of the creation of visualisations and dashboards, rather ensure that the resulting visualisations and dashboards are more accessible.

Another limitation is that this project will mainly conduct user studies using The Company's software. However, benchmarking will be conducted and since the competitors softwares are similar to The Company´s, conclusions will to a great extent also be applicable to data visualisation in general.

Since the time frame of this project is short and the aim of the process is to create guidelines and prototypes that support them, formative evaluations will be primarily used for this phase of the design process. This is with the intent of creating a design solution that is as optimised as possible.

1.4 Ethical Considerations

A potential ethical issue that may arise, could be the limited number of reachable users in the target group; users who are familiar with analytics today and are in need of accessibility features. However, since this work does not solely focus on expert users with impairments, it could partly be evaluated independent of the previous knowledge of analytics. Another ethical aspect is that information regarding impairments can be sensitive and therefore as little personal details as possible will be collected, to preserve anonymity. While this is always the case for interaction design projects, extra care will be taken to preserve this.

Furthermore, a potential ethical issue could be that the limited time frame will not allow us to focus on all aspects of accessibility. Meaning that guidelines would be made to support some impairments but not all. While this would still mean an increase in accessibility it would not mean a complete accessibility analysis.

Lastly, an ethical issue to consider is how the screener questions are formulated when conducting interviews and questionnaires. It could be experienced as sensitive or offensive and therefore the formulation needs to be planned by an accessibility approach. To ensure this project will fulfil these requirements, a template with inclusive screener questions will be used as a guide to the greatest extent possible (UserTesting, 2023).

2
BACKGROUND

This section will include background information about the company, the product, the users and the competitors of the company. Throughout this report the company involved will be referred to as The Company and their product as The Product, at the company's request.

2.1 The Company

The Company where this thesis will be conducted was founded in 1997, has over 10 000 employees and offers several different software tools specialised in data analysis. This thesis will be conducted with support from The Company's Gothenburg office but they also have offices in Asia, North America, South America as well as other locations in Europe.

2.2 The Product

The product analysed in this thesis is an end-to-end analytics platform where data analytics authors can create dashboards with immersive interactive visualisations that enable efficient processing of information (Figure 1).

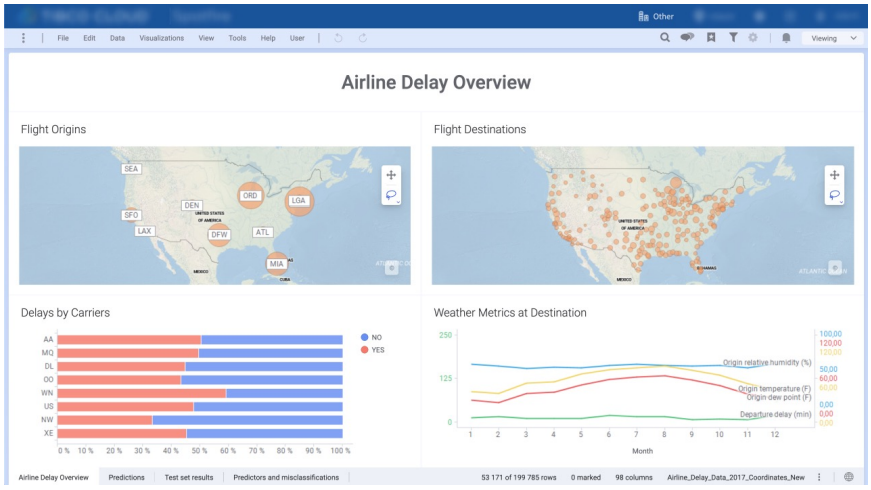

Figure 1: Example of a Dashboard in The Product

It has capabilities such as predictive analytics, streaming analytics, geolocation analytics and AI-powered recommendations and insights, to aid the exploration of information. The Product primarily uses PCs as its platform but there exists mobile and tablet versions as well. There is also a web client for The Product that is becoming more and more capable. The Product is used as a business analytics tool in many different sectors, however the use varies depending on the needs of the customer.

2.3 The Product's Users

The product has two different main types of users, *authors* and *consumers*. Firstly, the product is used to build and design dashboards by authors. This is accomplished by bringing data into the system and using existing visualisations to generate insights. The authors are able to customise the dashboard in order to fit the consumers needs. Secondly, the consumers use the dashboard to gain insights. The product is often used by companies for business intelligence to enable effective and informed decisions.

2.4 Competitors

The Company competes with a number of other companies on the market. The following sections will present the most relevant competitors. The presentation will be followed by the company's accessibility features. Furthermore, Microstrategy (MicroStrategy, n.d) and IBM Watson AIops (IBM Watson AIOps, 2022) are additional competitors but these companies will not be mentioned in the selection below due to non-relevance for this report, since they are not main competitiors and slightly different than The Product.

2.4.1 Tableau

The software company Tableau provides a data analysis platform with focus on facilitating data exploration and data management for their users (Figure 2). The platform is used to make understanding and discovery of insights more effective (Tableau, n.d.-c). It is possible to build accessible data views for consumers with braille keyboards, keyboard-only navigation and screen readers etc. The user can create a view with elements that is WCAG-conformant, once the view is published, it needs to be embedded in a web page that conforms to WCAG (Tableau, n.d.-a).

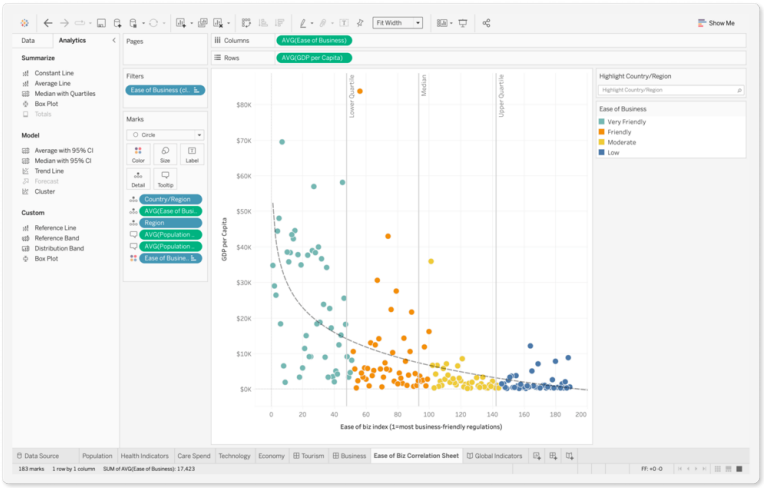

Figure 2: Example of visualisation in Tableau

2.4.2 Qlik

The software Qlik provides data analytic tools. An example of a visualisation created in Qlik is shown in Figure 3 (Qlik. n.d-b). Their platform Qlik Sense is WCAG-conformant and these accessibility features are available in the standard software packages. Qlink's latest improvements within the topic includes enhanced keyboard navigation and screen reader tags. To optimise the accessibility features on their website, Qlik has a collaboration with ADA Site Compliance which is a third-party that tests, remediates and monitors the website (Qlik. n.d-a).

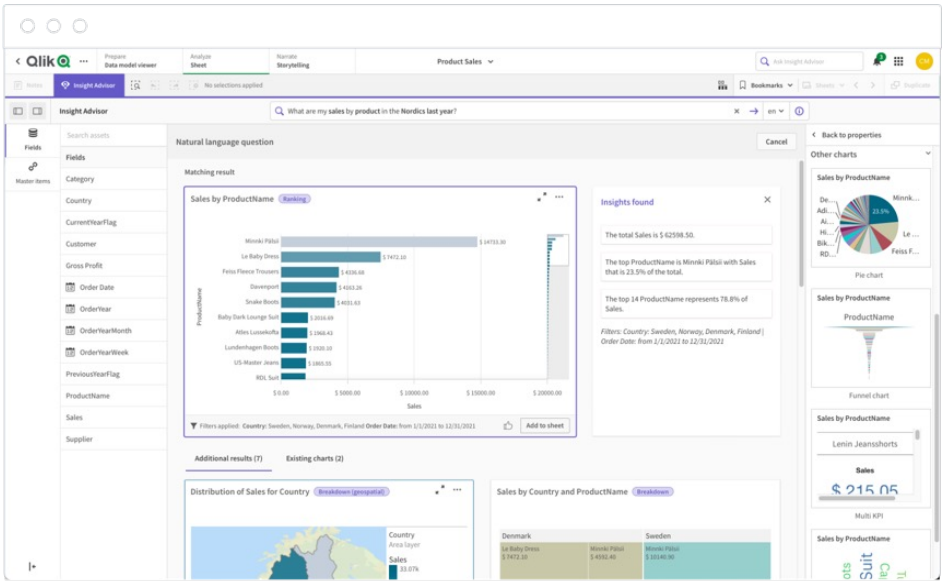

Figure 3: Example of a visualisation in the application Qlik.

2.4.3 Power BI

Power BI is a data visualisation software used primarily for business analytics (Figure 4). The software is developed by Microsoft and allows users to create interactive visualisations from large amounts of data and share them with their teams (Microsoft, n.d.).

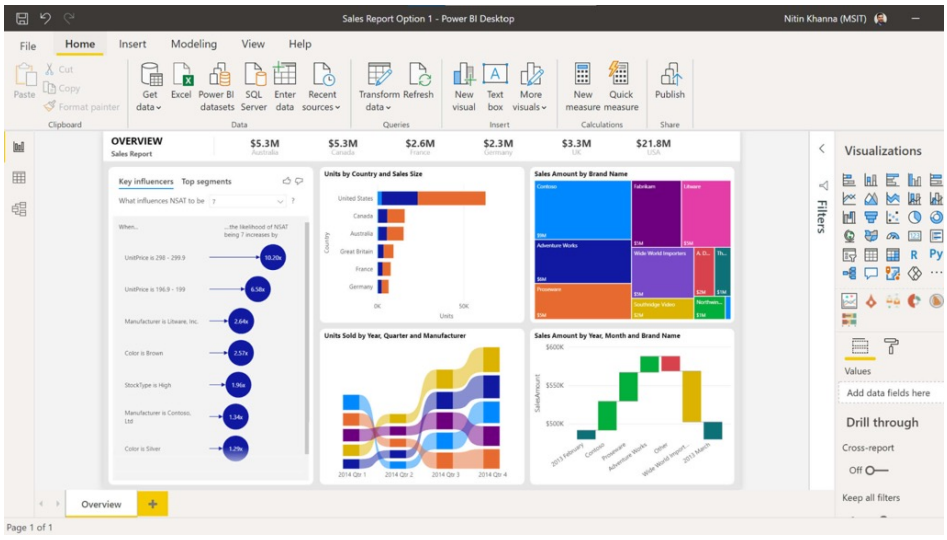

Figure 4: An example dashboard from the software Power BI

Power BI provides the analytics authors with some tools to create accessible dashboards. The software contains several built-in accessibility features, such as: keyboard navigation, screen reader compatibility, high contrast colours view, focus mode and showing data tables in a way that is screen reader friendly. Power BI also includes several keyboard shortcuts for navigating the interface, both when creating and consuming dashboards (Microsoft, 2023). Furthermore Iseminger et al. claims that the accessibility functions are generally only available for consumers using mobile devices.

3
THEORY

This chapter will explain the relevant theories and concepts for this project. Firstly, information visualisation and analytics will be explained. Thereafter, important design aspects will be emphasised and lastly focus will be on several standards with guidelines describing how to design accessible solutions.

3.1 Information Visualisation & Visual Analytics

Information visualisation is defined broadly as the use of interactive interfaces to convey abstract data that is actionable, such as statistics (Kem et al., 2008). Ware (2021) explains that when large amounts of data needs to be communicated from computer to human, visualisations can be used as a tool to make the data perceivable. He explains that this is the most efficient way to transfer large amounts of information since our visual senses acquire more information than any other senses. Furthermore, humans are exceptional pattern finders, meaning that if visualisations are created in a well structured way, we are likely to perceive the data successfully. Spence (2001) states that three aspects need to be considered before creating visualisations; the type of data that is to be represented, the dimension of it and the user that has to interpret the visualisation. He emphasises that acknowledging these factors can help the designer create visualisations that correspond to the user's mental model. Ware states that effective information visualisations should also provide interactions that allow the user to explore the data and reveal more information where desired. He suggests that modern visualisations should be viewed as an interface that supports meaningful interactive exploration of data, rather than a static visualisation.

Visual analytics is a more specific field where interactive visual interfaces are used to support analytic reasoning (Kem et al., 2008). The purpose of the practice is to create visualisations that allow users to read and process large amounts of information in an efficient way. The visualisations and the platform in which they are displayed are often interactive. Therefore it is important to design them in such a way that they can be understood, and that the data can be navigated. Furthermore, Kem et al. continues to explain that visual analytics is used to draw conclusions and make informed decisions. By providing timely, convincing and understandable assessments, people use visual analytics tools to make derivations from extensive, dynamic and frequently conflicting data. The aim of visual analytics is to make the most out of information overload. However, human involvement is still a key factor in the data analysis process to combine the computational power with creativity, flexibility and previous knowledge.

3.2 Universal Design

Universal design aims to come up with a design solution that can be used by all without the need for assistive technologies (Nielsen Norman Group, n.d.). That is, a solution that is created in a way that fits all people independent of mental and physical abilities. Universal design has seven principles that should be considered and integrated during the design process (Babic, 2021; Story, 1998):

1. Equitable use
The goal of the designer should be to create a solution that is useful for people with diverse abilities to the greatest extent possible.

2. Flexible use
The design solution should be able to adapt to how different users interact with it. It should be flexible and easy to use regardless if you are left- or right- handed.

3. Simple and intuitive use
It is important that the solution is intuitive and usable independently of the user's earlier knowledge, language, experiences or skills. The designer should put emphasis on appropriate feedback and a minimalistic visual design to eliminate the complexity.

Perceptible information
4. The solution should aim for communication and interaction through multiple modalities. This is important since it makes it more effective for users with different sensory abilities.

5. Tolerance for error
The designer should aim for a design solution that minimises the possible mistakes and use protective barriers to prevent the risk of irreversible actions.

6. Minimal physical effort
The physical effort needed should be minimised. The interaction that is necessary should have good ergonomics and be comfortable for the user.

7. Size and space for approach and use
The solution should be appropriate to use regardless of the user's body-size or mobility. The interaction should be within reach and possible to manipulate.

There are two related concepts to universal design; *inclusive design* and *accessible design*. These concepts are often mixed since the three concepts have its core in reducing obstacles for human-technology interaction, as well as contribute to an inclusive experience (Nielsen Norman Group, n.d.).

3.2.1 Inclusive Design

Compared to universal design, Inclusive design emphasises the uniqueness of individuals and that one solution does not have to fit all, instead there can be different versions for different needs. Some areas inclusive design addresses are education, gender, culture, age, geographic location, language, race, economic situation and accessibility. If inclusive design is prioritised in digital interfaces, the overall user experience could be positively impacted, due to the promoted sense of belonging. The main focus is empathising with

the users and understanding their needs when designing interfaces (Nielsen Norman Group, n.d.).

Inclusive design can be divided into three dimensions described below:

1. Recognize diversity and uniqueness
Most of the users deviate from the average in some aspect of their goals or needs. It is important to be aware of every individual's diversity and uniqueness and therefore, to achieve an inclusive design, a mass solution will not be the best option. Instead the inclusive designer should strive for one-size-fit-one solutions. Furthermore, since segregated solutions are both not economically or technically sustainable, the system needs to be flexible and adaptable (Inclusive design research centre, n.d.).

2. Inclusive process and tools
To have a team that is as diverse as possible in the inclusive design process is valuable. Both the process and the tools used should be inclusive. This will be beneficial since their previous experiences will guide the process. These perspectives are of high value since it is difficult to imagine the perceived experience (Inclusive design research centre, n.d.).

3. Broader beneficial impact
The context and wider implications of any design need to be considered by the inclusive designer. It should be a positive influence that goes beyond the designer's intended beneficiary (Inclusive design research centre, n.d.).

3.2.2 Accessible Design

Accessible design is a rising subject and aims for ensuring the possibility for people with disabilities to use technologies and interfaces (Nielsen Norman Group, n.d.). The difference between accessible design, universal design and inclusive design is that accessible design focuses more on adapting already existing solutions while universal and inclusive focus more on designing solutions from scratch. Nielsen Norman Group continues to explain that adapting solutions so that they can be operated, perceived and understood in an accessible manner has become a vital focus when designing technology.

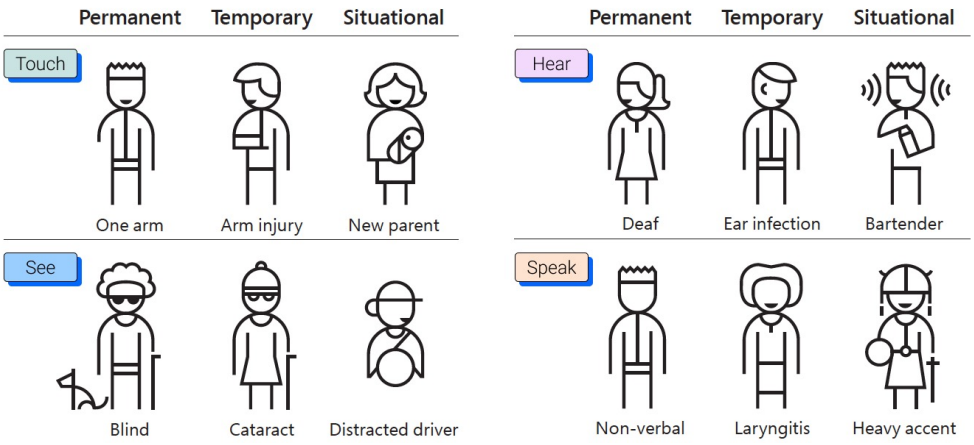

Figure 5: States of disability (Knaflic, 2019)

The term disabilities includes visual, auditory, cognitive and physical impairments. Even though there are multiple assistive technologies for people with impairments, the interaction with the technology or interface is not always designed with the accessibility features needed. Furthermore, Figure 5 suggests states that extend beyond permanent impairments (Knaflic, 2019). One should keep in mind that it is a spectrum and not a fixed status.

3.2.3 Assistive Technologies

Keyboard navigation is possible because of the HTML structure of a webpage and is used by a variety of people. It may be due to blindness, motor limitations or that the individual prefers keyboard navigation instead of a mouse. Screen readers also make use of the HTML, but this tool takes the information embedded and reads it out loud (Organ, 2022). A previous study regarding data visualisations indicates that three key design dimensions can be identified for expressive screen reader accessibility; *structure, navigation* and *description*. Firstly, structure is important to facilitate the navigation of the user. Secondly, the navigation needs to be considered so that the user can perform the required actions to navigate through the structure. Lastly, the description of the elements is important since this is what the screen readers will read, which makes it a key dimension to the whole experience (Zong et al., 2022). Findings from an additional study shows that people who use screen readers interact with data visualisations 211% longer and have an accuracy of 61% lower when extracting the information compared with non-screen readers (Sharif, 2021). This is due to the lack of accessibility of data visualisations in general. Furthermore, the results also indicate that online data visualisations are most often not discoverable for people using screen readers.

Colour blind people struggle with differentiating certain colours (Organ, 2022). Furthermore, it is the designers responsibility to choose colours from an accessible colour palette (Figure 6). A common misunderstanding, according to Organ, is that if red or green are used, the work will be disqualified from usability. However, if the colours are slightly changed, they will be accessible and you can still take advantage of the high-association and culturally-relevant meaning behind the colours. Organ continues to explain that this is also relevant for example when printing a visualisation and only a black and white printer is accessible. Furthermore, Ware (2021) explains that when choosing colours it is preferable to pick colours that differ in the blue-yellow spectrum rather than red-green (Figure X). They argue that the majority of the colour blind population are able to distinguish colours in that direction. However, Ware also reflects that this vastly reduces the amount of viable colours, and that there should therefore be another means of distinguishing elements, in addition to colour.

Figure 6: Example of an accessible colour palette generated at Venngage.com (n.d.).

3.3 Accessibility Standards

There are several standards for checking the accessibility of technology. The following section will describe the standards and also suggest guidelines beyond the standards. Except for the selection there are several other standards such as US section 508 (US access board, n.d.) and Webb-Direktivet (Vägledning för webbutveckling, n.d.). However, these will not be described in this report, since they are built on WCAG but tailored to another context. For example, Webb-Direktivet is specifically adapted to Swedish law.

3.3.1 Web Content Accessibility Guidelines

Web Content Accessibility Guidelines (WCAG) is a widely accepted standard developed by organisations and individuals around the globe. It contains guidelines for how to design web content in an accessible manner, to ensure all needs are met from both individuals and organisations. The guidelines are primarily intended for designers and developers and outline how to improve the accessibility of web content for people with impairments. In general, web content is described as information on a web application or page such as text, sound and images. Another example is code that specifies the structure of the page (WAI, 2023-b). WCAG is divided into four main principles: *perceivable*, the presented content must be perceivable for some of the user's senses, *operable,* the user needs to be able to interact with the content in a way that is possible for them, *understandable*, the user must understand the content and the expected operation in the interface, and lastly *robust,* the information needs to be reliable enough over time to be understood by several user agents, including assistive technology (WCAG 2.1 Understanding Docs, 2022).There are testable success criteria with three levels for every guideline: A, AA, and AAA. The conformance with WCAG is determined by the success criteria and therefore the material must pass the success criterion to comply with WCAG (WAI, 2023-b).

3.3.2 WAI-ARIA

Compared with WCAG, Accessible Rich Internet Applications suite (WAI-ARIA) focuses on advanced user interface controls and dynamic content developed with HTML, JavaScript or other technologies. WAI-ARIA enables the possibility for some users to access certain functionalities on the web. Especially some assistive technologies such as screen readers and those who are unable to use a mouse (WAI, 2023-a).

3.3.3 Beyond the Guidelines

According to previous studies, the web content accessibility guidelines are incomplete. The issues encountered by people with impairment can not all be covered by the guidelines. The following problems were highlighted by Calvo et al. (2016):

1. Hides information incorrectly
It can be beneficial with additional information to promote understanding for screen readers. However, it is important that the information is relevant to not confuse the user.

2. Does not use common design patterns
If the design pattern for the website is common or close to the standard, the users are familiar with navigating in the interface. This promotes inclusiveness and facilitates understanding. If not, it might not correspond to the user's mental model.

3. Uses wide gaps between related information
Users may have difficulties interacting and seeing relationships between elements due to wide gaps.

4. Use of custom components
It could cause accessibility issues if the components are customised since the users behaviour could differ from the expected behaviour.

5. Buttons and text size are small
If the size is not considered it could be difficult for the user to identify buttons or read the text.

6. Colour contrast ratio between icons and background is not enough
WCAG specifies that the colour contrast ratio should be higher than 4.5:1 between the background and foreground. The same specification needs to be pointed out for the colour contrast ratio between the background and the interactive buttons.

7. Important information is not shown at the top
If the information is not structured in a proper way, this will increase the complexity of the comprehension.

3.4 Nudging Theory

Mirsch et al. (2018) states that the concept of *Nudging* was founded by Thaler and Sunstein based on insight in the behavioural economics field. The concept is focused on how to influence human choices in a more sustainable way. The decision maker should perceive the nudge as transparent, beneficial, easy to avoid.

Thaler (2018) describes nudging as wiser choices without forbidding other options. Furthermore, Thaler explains the importance of having the decision maker judge the choice as better than the alternatives available, rather than forcing them to do so (Quote 1). Moreover, Thaler (2018) also provides an example of a nudge that is beneficial for the human; if people are automatically enrolled in savings plans for retirement, which is easy to terminate, this will be beneficial for the ones that always meant to enrol a plan but never got around to do it. Thaler (2018) also puts emphasis on the risk of using the concept for less benevolent purposes and how it may discourage people from acting in their best interests.

"...the goal... is to help people make better choices 'as judged by themselves' ."

Quote 1: Quote by Thaler (2018)

4
METHODOLOGY

The following chapter describes an approach to design research and wicked problems, as well as a description of various iterative design processes and the phases of the process chosen for this project. It also describes various relevant software tools.

4.1 Design Research

Design research can be divided into three types: Research *into* art and design, research *through* art and design and research *for* art and design (Frayling, 1994). Frayling suggests that the first constitutes research about the design subject; it can be historical, theoretical or aesthetical. The second is explained as being research about the design process itself, for example communicating the necessary steps of a process. The last is explained as being the most open for interpretation and it emphasises research less than the others. For example, it can be gathering inspiration for creating art. Hanington and Martin (2019) states that research through design is necessary for the design process to be validated as a research activity. They continue to explain that models and theories of design can be integrated into the design process, using the approach of research through design. Zimmerman et al. (2007) also argue that research through design can be used as a method for human-computer interaction designers to research and engage wicked problems. Furthermore, Hanington and Martin also suggest that such research should result in a documentation of the process and the result, in order to contextualise the design.

4.2 Wicked Problems

Problems that are seemingly impossible to solve because of a myriad of independent factors can be called *Wicked Problems* (Interaction Design Foundation, n.d.-b). The term was introduced by Horst Rittel (1973) where he explains that wicked problems can be characterised by not having a stopping rule, that there is no definitive formula, the solution is not true or false and that testing the solution is not immediate. Furthermore, in order to solve these problems, the linear design process is insufficient. Buchanan (1992) proposed that an iterative design process would be more suitable for attacking wicked problems since it allows the designer to come back to the problem and redefine it later in the process. Furthermore, it allows the designers to adapt the process to the problem (Buchanan, 1992), which is of importance since wicked problems are never the same (Rittel, 1973). Buchanan also argues that most design problems are wicked, since there is

no definitive solution to a problem, rather many different variations could have fulfilled the same requirements, but in different ways. However, tackling these problems with an iterative process ensures that the solution space will be explored and that an adequate solution can be found (Interaction Design Foundation).

4.3 Iterative Design Process

There are many different models of the design process, each with their own strengths and weaknesses (Wikberg-Nilsson et al., 2015). Furthermore, the common goal of these models is to facilitate the process in order to reach a result that has explored the solution space thoroughly, while still being as efficient as possible. The different models also have a lot in common, however they differ in how they explain the process. In order to tackle wicked problems the Interaction design Foundation suggests (2021) an agile methodology and give an iterative design process as an example. Wikberg-Nilsson et al. explains that most design process-models are divided into different phases. They continue to explain that conducting a design process iteratively means that the phases are not executed linearly, rather they are executed repeatedly, as deemed necessary. They propose that a successful design does not stem from a successfully conducted process, rather that success stems from meeting the needs of the user. This is in turn accomplished by properly understanding the user's situation, which they argue can be most effectively done with an iterative design process.

An iterative design process is usually also more efficient and cheaper than a traditional waterfall model, since it does not require a product to be developed fully to receive feedback from the user (Interaction Design Foundation, 2021). Instead prototypes can be created and evaluated with users throughout the process, ensuring a more user-centred result. Bevan and Petri (2009) emphasises that using an iterative design process when designing for accessibility is especially important since it allows the inclusion of users with impairments throughout the process, instead of just the beginning, making it easier to understand their needs.

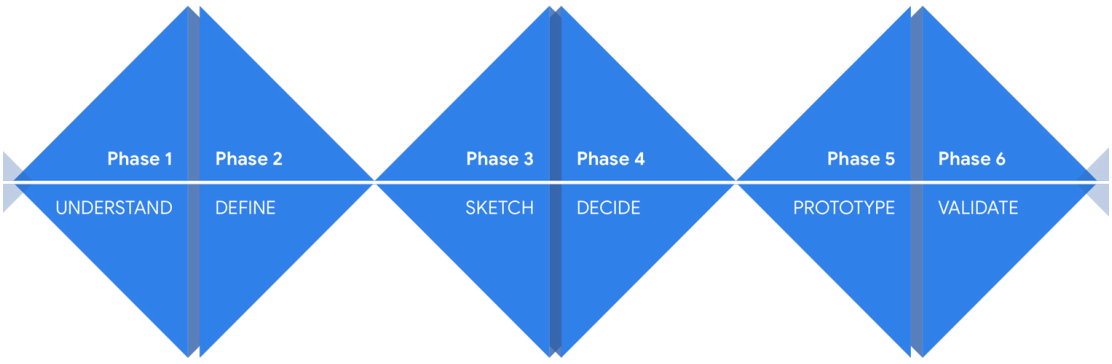

Figure 7: Triple diamond process from google design

Google design (n.d.-a) proposes a *Triple diamond* structure for their design process (Figure 7). The diamonds are supposed to illustrate the approach to design. The process is divided

into six phases: understand, define, sketch, decide, prototype and validate where the shape of the diamonds represents what that phase is for. For example, understand is about expanding your knowledge and exploring the user's situation, therefore it is visualised as an expanding triangle. Define on the other hand, is represented as a shrinking triangle, this is because here you are supposed to take the vast knowledge gained and distil it to a problem definition. A similar design process is presented by the Interaction Design Foundation (n.d.) in their model *Design Thinking*. Instead of having six phases, they propose using five: empathise, define, ideate, prototype and test. The difference between these two models is that phase three and four from the triple diamond has been combined to the step ideate in Design Thinking. Wikberg-Nilsson et al. (2015) presents a *four phase model*: plan, explore, ideate and prototype. Each of these phases are divided into two stages, creating eight phases: explore project & define project, explore context & define needs, explore ideas & evaluate ideas, prototype concepts & evaluate concepts. The three last phases and their stages are more or less equivalent to the other presented models, however Wikberg-Nilsson et al. has expanded those by including the project planning phase in the model.

While the presented methods are similar they still complement each other well by providing slightly different approaches to the process. Interaction Design Foundation (n.d.) explains that the Design Thinking process is especially effective when designing for wicked problems, since it focuses on reframing the problem in terms of the user's needs. Therefore, Design Thinking has been chosen as the primary process model for this project, however, with some additions from the triple diamond and Wikberg-Nilsson et al.'s model as well. The process will consist of the following phases: *Empathise*, *Define*, *Ideate*, *Prototype* and *Test* (Figure 8).

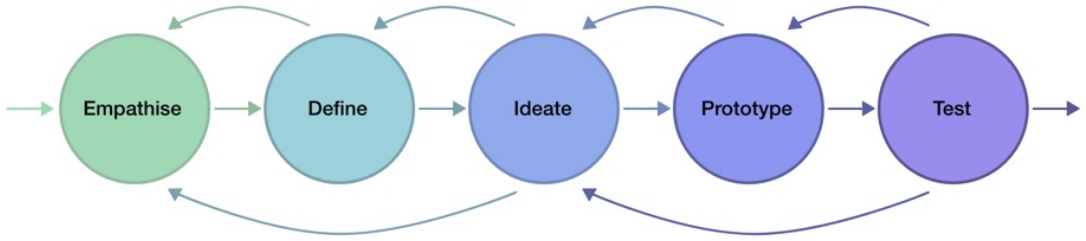

Figure 8: Triple diamond process from google design

4.3.1 Empathise

The first phase of the design process is Empathise. The focus of this phase is to understand the users and their situation (Dam, 2022). The Interaction Design foundation (n.d.) explains that the empathise phase is about gathering as much information about the users as possible. The goal is to get an empathetic understanding of the user's situation and their problems. Wikberg-Nilsson et al. (2015) explain that this is usually most effectively accomplished by immersing yourself in the users' environment by conducting observation studies and interviews.

Hanington and Martin (2019) suggest *Literature reviews* as a method for gathering and analysing existing literature. The purpose of this method is to capture the most important aspects of existing literature within the subject of interest. This is accomplished by creating structure of the sources and categorising them. The relevance a given source has for the project should also be defined, together with its relation to other sources. Hanington and Martin suggest that conducting a literature review is an efficient way of gathering and analysing information, however it can be quite time consuming. They also explain that literature reviews are beneficial for getting an understanding of the current state of a research subject and gives insights into what other researchers have found. Similarly, the method *Benchmarking* can be used to gain insights into existing solutions from other companies by studying the flows, experiences and functions of other designs (Da Silva, 2020).

Another method that is used to understand the users' situations and problems is *Interviews* (Wikberg-Nilsson et al., 2015; Hanington & Martin, 2019; Pernice, 2018). Pernice explains that conducting interviews is an effective way of gathering qualitative information from the user by asking them questions about a topic of interest. Furthermore, Hanington and Martin suggest that there are two different main types of interviews: structured and unstructured. The difference between these is the degree to which the questions have been prepared. In a structured interview, a list of questions is followed, that has been prepared by the design team beforehand. Hanington and Martin suggest that the benefits of this is that the interview is easier to control and it is more likely that the desired questions will be answered. However, they also explain that structured interviews can be experienced as limiting and formal. In contrast, they describe unstructured interviews as having few pre-prepared questions. Instead, relevant topics have been selected and are discussed with the interview subject loosely. They explain that this allows for detours from discussions that may result in valuable knowledge, but it also creates less control. Wikberg-Nilsson et al. presents semi-structured interviews as a combination of the two types where there is control from structure but it still allows for detours when necessary.

Questionnaires can also be used as a qualitative user study to gain empathy and understanding of the users' situations and problems (Hanington & Martin, 2019). Hanington and Martin also stress that questionnaires can be used on their own, but are best utilised in addition to interviews and observation. Furthermore, doing this means that the qualitative data from those methods can be strengthened by the quantitative results from the questionnaire.

Smith (2001) explains that there are two different types of knowledge: *explicit* and *tacit*. Explicit knowledge is explained as knowledge that can easily be expressed and can therefore be gathered from interview studies. Contrary to this, tacit knowledge is described as a subconscious know-how that is hard to define. Smith explains that it is often connected to skill and mastering something, and that the specifics of the knowledge is hard to express, since the actions happen automatically, without much thought. Furthermore, it is knowledge that the individual might not know that they possess in the first place. Bligård (2015) explains that observation studies are an efficient method of uncovering tacit knowledge, since they allow the designer to observe the actions of the user and get a deeper understanding of what might be a problem. Furthermore, Hanington and

Martin (2019) describes observation as a method, often used in addition to interviews, for gathering qualitative data. They explain that the method consists of observing the user as they conduct a task for analysis. Ciesielska et al. (2018) distinguishes three different levels of participation in observational studies, *participating*, *partially-participating* and *non-participating*. These refer to the level of presence the observer has in the situation. Participating is when the observer is fully part of the experience and fully immerses themselves. Partially-participating is the most common and is when the observer partakes in the environment but does not intervene in the actions performed by the users. The last, non-participant, is when the observer is completely hidden to the users and has no effect on the situation. Ciesielska et al. describe (2018) that the level of participation can have an effect on the results. Not participating, means that you will not alter the situation and therefore get the data with least noise, however, it also means that you will be detached from the user and cannot ask them questions when something is unclear. The fully-participating study can be efficient in getting a deep understanding for the environment and situation, but risks a loss of analytical attitude. Partially participating is therefore seen as a compromise between the two extremes and an efficient way of revealing tacit knowledge.

Another method for gaining understanding of the user's situations is the *Hierarchical Task Analysis* (HTA) (Bligård, 2015). This method is used for gaining insight into the specific steps taken by the user and in which order a task is performed. This is accomplished by creating an overarching goal that is divided into sub-tasks. These subtasks form the process to reach the goal. This is an efficient method for understanding, analysing and structuring a set of actions.

4.3.2 Define

The Interaction Design Foundation (n.d.) explains the purpose of the define phase in Design Thinking as structuring the information gathered during the previous step. The goal is to define the problem and create a problem-statement that encapsulates the issue in a human-centric way (Dam, 2022). Wikberg-Nilsson et al. (2015) adds to this by stating that a design specification should also be produced containing a list of the users' needs and requirements. They explain that the list can be divided into *requirements*; something that the concept must fulfil in order to reach its goal, and *wishes*; something that the concept does not necessarily need to fulfil, but doing so will create a better experience. This list of requirements will act as a base for the ideation phase as it maps the necessary functions of the design. Furthermore, Bligård (2015), explains that the list of requirements should be revisited throughout the project and updated as the understanding of the users' problems increases.

Bligård (2015) argues that in order to arrive at a list of requirements the knowledge gained from the collected data needs to be structured and analysed. He proposes the method *KJ-analysis* as a method to accomplish this. The design team takes insights from the collected data and writes it on post-it notes. These are then discussed and categorised in groups that are given a title. The idea is that the titles and units of data on the post-its will be a starting point for a list of requirements. Hanington and Martin (2019) describes that the method is efficient for analysing data and provides a framework for comparing and discussing data.

Bligård also explains that the KJ-analysis uses *bottom-up* processing, meaning that the method first studies the details and then overview. Hanington and Martin describe this as an effective and natural way of processing the data and finding overarching themes.

Wikberg-Nilsson et al. (2015) describes that creating a persona and user scenario can be an efficient way to express the list of requirements. The persona is meant to symbolise a typical user and its description can be good supporting material for the ideation phase. Hanington and Martin (2019) describe scenarios as a narrative of a user's journey. This can then be used to include steps that are included in the list of requirements, creating an additional representation of it (Wikberg-Nilsson et al., 2015).

4.3.3 Ideate

The third phase of the Design Thinking process is ideate (Interaction Design Foundation, n.d.). In the beginning of this phase the purpose is to generate ideas that will solve the problem (Dam, 2022). Brainstorming is often described as a common initial method for generating ideas (Dam, 2022; Wikberg-Nilsson et al., 2015). However, Wikberg-Nilsson et al. describes this as a way of thinking, rather than a specific method. The purpose of ideation methods is to generate creative out of the box ideas and explore the solution space thoroughly (Wikberg-Nilsson et al., 2015). Many methods are designed to encourage creativity and stress the importance of not being critical to your own, or others' ideas (Hanington & Marin, 2019; Wikberg-Nilsson et al., 2015). Some popular ideation methods are: Brainwriting 6-3-5, Braindrawing (Wikberg-Nilsson et al., 2015), Crazy 8's (Google Design, n.d.-b), morphological matrix (Hanington & Marin, 2019; Wikberg-Nilsson et al., 2015). These methods propose different ways of stimulating creativity and generating ideas. They also provide means to discuss and build on each other's ideas.

Later in the phase it is beneficial to select other ideation methods with the purpose of evaluating the ideas and modifying, combining or removing them (Dam, 2022). Wikberg-Nilsson (2015) describes the ideation phase as a series of *diverging* and *converging* stages. In the diverging stages, the goal is to generate as many ideas as possible and in the converging stages the goal is to take those ideas and remove those that don't fulfil the list of requirements. Several solutions can also be merged into one greater solution. Wikberg-Nilsson et al. continues to explain that this will be followed by a diverging phase where the solution space is explored further. This is repeated until the solution space has been explored thoroughly. Several methods are proposed to help the designers in the converging phases: six thinking hats (The de Bono Group, n.d. ; Wikberg-Nilsson et al., 2015), Scamper (Wikberg-Nilsson et al., 2015) and Occams Razor (Wikberg-Nilsson et al., 2015).

Another approach for ideation is co-design. Sanders and Stappers (2008) explains that co-design is when designers and users participate simultaneously and cooperate in the design-process activities. This can, for example, be in workshop settings where different ideation methods are performed with both designers and users. Eriksson et al. (2021) suggest that co-design allows for a deeper understanding of the problem, since new discoveries will be made during the activities. They also explain that including the users in the design process allows their expert views on the design. However, Eriksson et al. also emphasise

that care must be taken to create a creative environment where everyone can be heard for the co-designing activities, since the participants are most likely inexperienced in design. Wikberg-Nilsson et al. (2015) explains that a suitable method for this is workshops.

4.3.4 Prototype

The fourth phase of the Design Thinking process is prototype. The purpose of this phase is to create prototypes with the intent to identify the best possible idea from the previous stage (Dam, 2022). Finding the best solution means combining or developing ideas into concepts that are slightly more refined than those in the previous design phase (Wikberg-Nilsson et al. 2015). Hanington and Martin (2019) describes prototyping as a method where models of the product are created with the purpose of testing and communicating design. They separate two distinct kinds of prototypes, based on their level of fidelity; high and low. *Low-fidelity* prototypes are common in the ideation phase, where quick prototypes are created to explore or communicate design ideas (Hanington & Martin, 2019). For example, this can be simple paper prototypes or sketches (Wikberg-Nilsson et al., 2015). Wikberg-Nilsson et al. also distinguishes different purposes of prototypes. For example, *experience prototypes* are explained as having the purpose of communicating the user experience rather than function. They also propose the opposite, *function prototypes*, meant to only evaluate and communicate a function, rather than the experience or form.

High-fidelity prototypes are more refined and are often created to communicate the final concepts of the design. (Hanington & Martin, 2019). A common use for these is evaluation with users. Hanington and Martin also describe that high fidelity prototypes can be both physical and digital, depending on the project, and should express the same look and feel as the concept. Furthermore, they often include some degree of interactivity to aid the evaluation process. They also explain that the method *Wizard of Oz* can be used to simulate a function. This is accomplished by having a designer behind the scenes that simulates functionality and makes the user believe that they are interacting with a functional prototype. This enables the designers to evaluate a function that otherwise might be expensive or time consuming to implement (Hanington & Martin, 2019).

4.3.5 Test

The final phase of the Design Thinking process is Test. The purpose of this phase is for the designer to evaluate their design (Dam, 2022). However since this is an iterative process, the evaluations are not the end of the process, instead the results are used to refine the concept further (Dam, 2022; Wikberg-Nilsson et al., 2015). The concept should also be continuously compared with the list of requirements (Bligård, 2015). Dam expresses that the ultimate goal of this phase is to gain as much information as possible about the concept and the user experience. Joyce (2019) explains that there are two different kinds of evaluation, *summative* and *formative*. Furthermore, formative evaluations occur throughout the design process with the purpose of determining the problems and positive aspects of the design. Joyce argues that this approach is well suited for the design process since it concerns evaluating and improving the design iteratively. Summative evaluations often compare the design solution with a benchmark, with the purpose of analysing how well the solution performs. This is often done late in the design process with a refined prototype and is often conducted to get an overview of the performance rather than detailed interactions (Joyce, 2019).

Nielsen (2000) explains that in order to discover most usability problems with a design, only five test subjects are needed. He presents a model that shows that you will learn less and less with each user you test with, as the responses and findings begin to converge. Furthermore, he argues that five subjects should be enough to discover 85% of the usability problems present. Instead of spending more resources and time on testing with more subjects to find the remaining 15%, he proposes that the team focuses on creating a design solution that aims to fix those 85%. Then, another test can be conducted in order to evaluate the design, which in turn will analyse whether or not the usability problems were solved, as well as help the designers to discover the remaining 15%.

Hanington and Marin (2019) suggests *A/B testing* as a summative evaluation method. The method is meant to compare different design concepts against the existing solution. A difficulty with A/B testing however, is to get a selection of participants that is fair. If the same people are used to test both designs, they might have learned from the first design, if instead different people are used, they might differ in previous knowledge (Sova & Nielsen, 2010). To minimise this risk, a mix of the two could be used. However Sova and Nielsen also explains that if the learnability of the product is to be evaluated, it is important that only new participants are selected, since the effect of learning might be misleading otherwise.

An example of a formative evaluation method is *usability testing*, where tasks have been prepared beforehand and participants are asked to perform them (Hanington & Martin, 2019; Joyce, 2019). Hanington & Martin explains that the goal of this method is to identify pain points and parts of the interface that frustrate users. Wikberg-Nilsson et al. (2015) suggests that interviews, questionnaires and observations can also be used as evaluation methods. They also suggest *cognitive walkthrough* as a method to evaluate the interface, a method where the participant is given tasks to perform and is asked to think aloud while doing them.

4.4 Software Tools

This section contains descriptions of some of the main software tools that could be used in this project.

4.4.1 Adobe XD

Adobe XD (Figure 9) is a vector based design tool for creating interactive prototypes (Rae, 2020). The tool is part of the Adobe creative cloud service and shares many functionalities with their other programs. It is best suited for creating prototypes of digital user interfaces that can be of varying fidelity, for example wireframes or highly interactive high-fidelity prototypes. Adobe XD also allows users to collaborate in the same file simultaneously. XD also contains several accessibility features, such as support for screen readers and keyboard navigation.

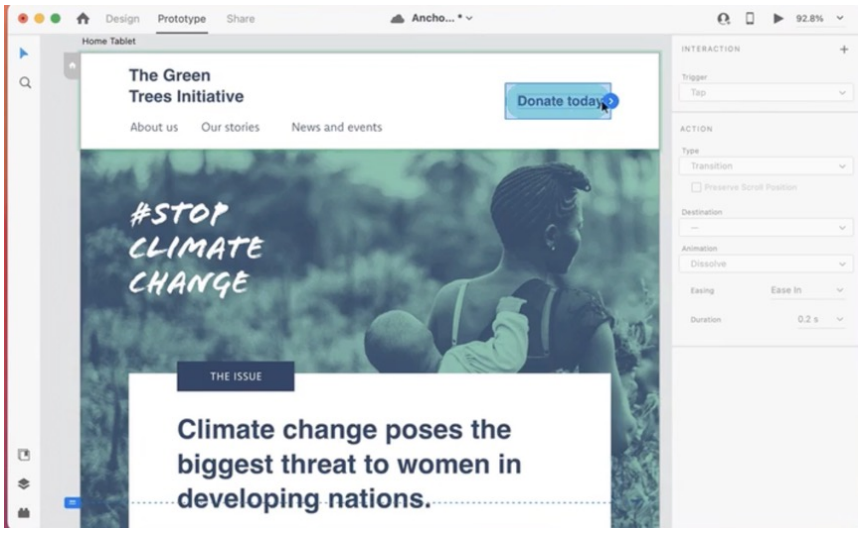

Figure 9: Example of a design in Adobe XD

4.4.2 Figma

Figma (Figure 10) is another prototyping tool used for creating digital user interface designs (Figma, n.d.). However, unlike Adobe XD Figma is primarily web based and is optimised for collaboration. Similar to XD, it also supports the creation of interactive low– and high-fidelity prototypes and has several tools to make this easier. Furthermore, Figma also houses some accessibility features, such as a screen-reader support and colour contrast modes (Miller & Oh, 2022).

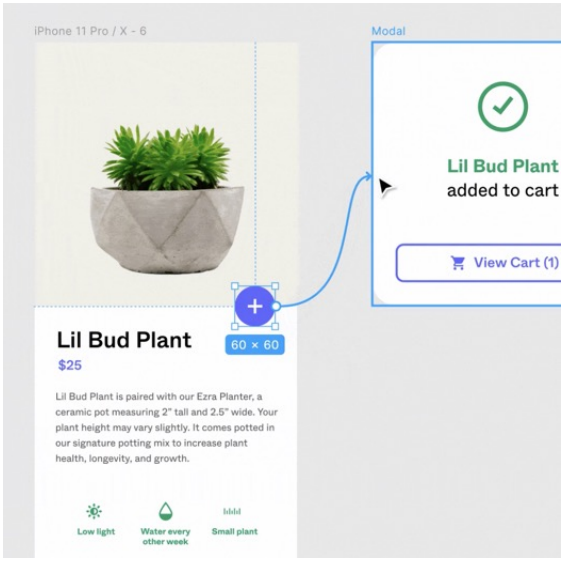

Figure 10: Example of a design in Figma

4.4.3 Axure RP

Axure RP (Figure 11) is an advanced digital prototyping tool for creating interactive user interface prototypes (Axure, n.d.-a). The tool specialises in the creation of high-fidelity prototypes with advanced interactions and realistic navigations, without the need to code. However, the tool also allows the creation of low-fidelity prototypes, such as wireframes. Axure also outputs the prototypes in HTML. Moreover, Axure includes some accessibility features, such as navigating using keyboard and screen readers (Axure, n.d.-b).

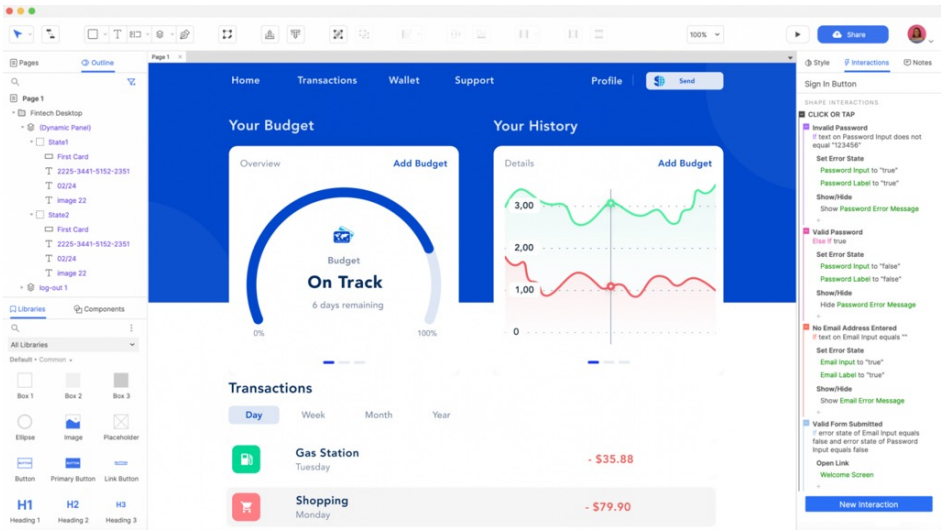

Figure 11: Example of a design in Axure RP

4.4.4 UserTesting

This service is for recruiting participants and conducting user studies (UserTesting, n.d.). The tool allows the design team to create a user study with tasks and questions for the participants (Figure 13) and then filter which attributes they should have to take the test (Figure 12). The test will then be sent to the appropriate participants who can conduct the test in exchange for payment. The tests can either be conducted live in a video call or by the participant recording their screen and voice.

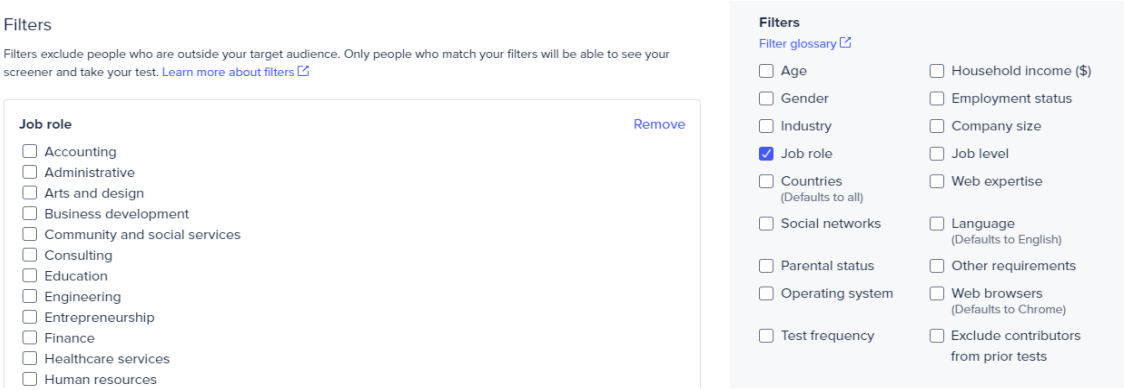

Figure 12: Example from filtering in the service UserTesting

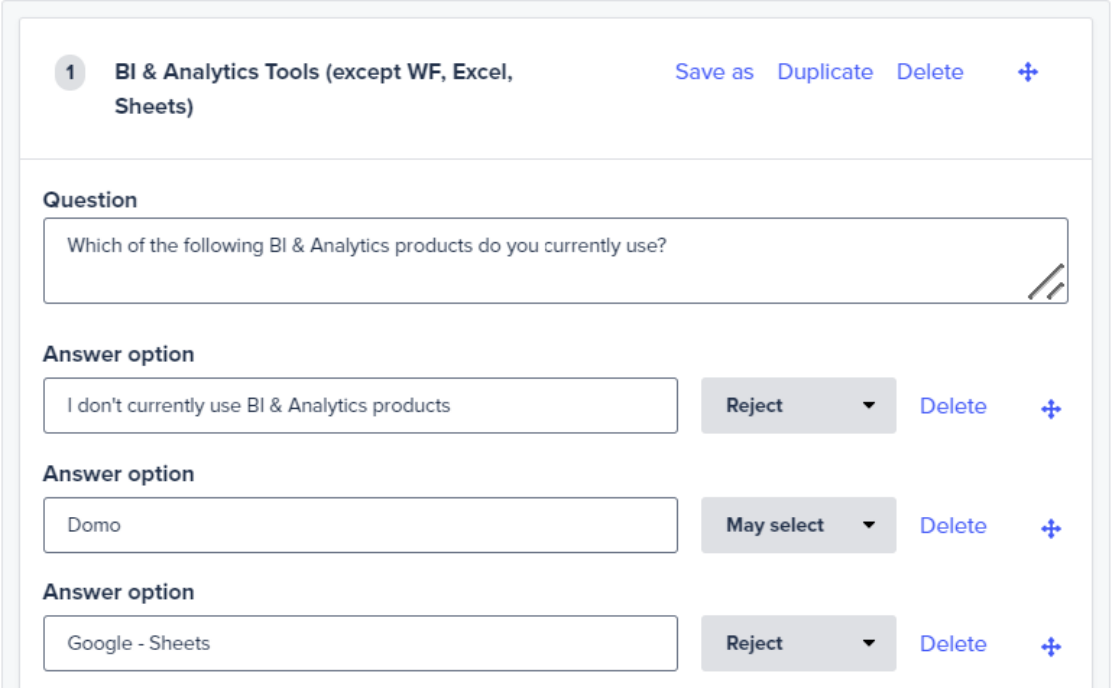

Figure 13: Example screening question in the service UserTesting

4.4.5 Accessibility Evaluation Tools

There are several accessibility evaluation tools that help designers evaluate web pages with the WCAG guidelines, such as: Wave (Wave Web accessibility evaluation tool, n.d.) and WCAG-EM Report Tool (Figure 14) (WCAG-EM Report Tool, n.d.).

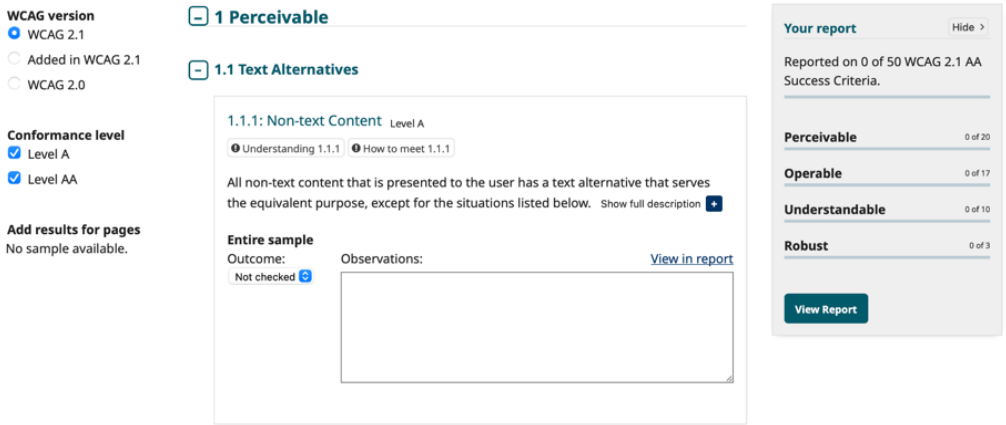

Figure 14: Example from WCAG-EM Report Tool. The user is provided with a success criteria to evaluate and note their findings.

These tools can both help the designer check a webpage with the guidelines, but they also facilitate discussion (WAI, 2020). These tools have different ways of assisting the process of evaluation, such as: *reports*, *step-by-step evaluations*, *in-page feedback* and *page transformation* (WAI, 2020). Reports help the evaluators to structure the evaluation by providing a template for checking the accessibility of the website. Step-by-step evaluation

tools help guide the evaluators through the accessibility checks and evaluate some aspects automatically, for example colour contrast of certain elements. In-page feedback tools evaluate a page automatically and pinpoint the elements that failed a check with symbols on the page. Lastly, page transformation tools help provide a different context for the evaluators by changing certain aspects of the page. For example, changing the page to text-only to help the designers evaluate further.

5
PLANNING

The work will be divided into several sub-parts. The initial weeks will be dedicated to the planning report and literature study. The following weeks, the design process will be the focus. This part of the project will be divided into three major iterations, with the purpose of tackling a few smaller problems at a time instead of all at once. It will also ensure that the design is iterated upon and therefore more likely to fulfil the requirements.

Weekly meetings will also be planned with both the stakeholder and the supervisor to ensure the goals are met. This time frame will allow for an extensive analysis to base the creation of the guidelines and prototypes upon. Lastly, the conclusive weeks will be dedicated to finalising the report. The time plan that was created in the project planning stages is summarised in Table 1.

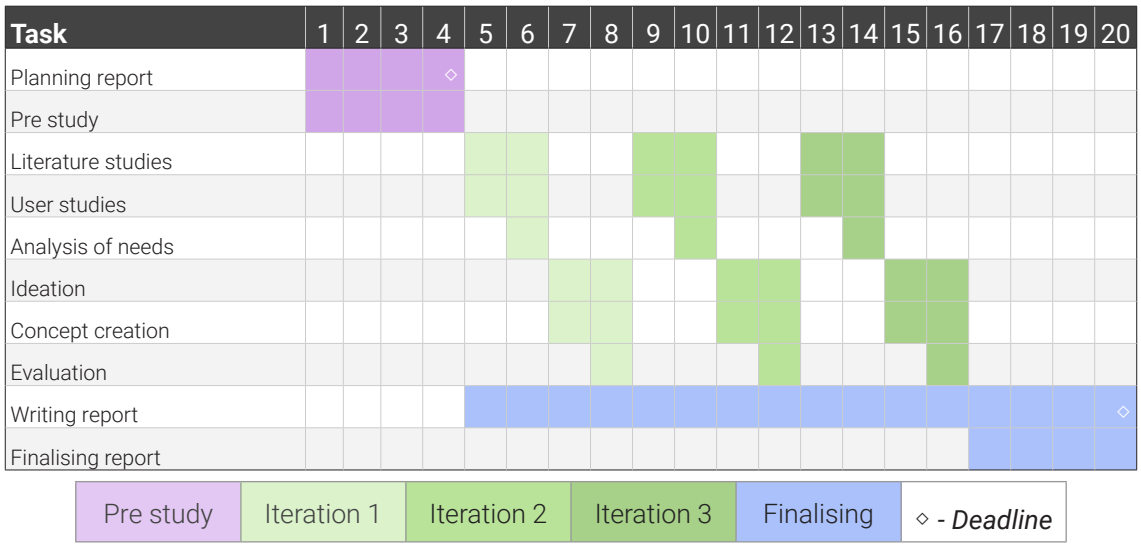

Table 1: Initial time plan

The time plan was then refined during the pre-study phase of the project. This was done with the aim of making it more precise, detailed and understandable. The revised time plan is divided into three phases shown in Table 2. The majority of the literature studies will be conducted in phase one and thereafter the literature will be studied when necessary. This will ensure there is a foundation when iteration one starts and thereafter

the gaps will be filled along the way. During phase two, the focus will be to design and conduct the practical work. The iterations are meant to divide the problem into smaller parts, making them more approachable. This will also ensure that results are generated throughout the process, and therefore create an even workflow. During each iteration the iterative design process chosen will be conducted with its five phases, Empathise, Define, Ideate, Prototype and Test. Here, the methods described in the methodology chapter will be conducted in an iterative manner. The plan is to conduct the process as follows but it may change depending on the situations that arise: Interviews and observations will be carried out to empathise with the user, this data will then be analysed to define the problem, using a KJ-analysis. With the definition in mind, Brain Drawing will be used to ideate solutions. If, during the ideation, it is discovered that there are uncovered aspects of the problem, a questionnaire would be created and sent to gather more data. Crazy'8s will be conducted to ideate further and then the Six thinking hats method will be used to evaluate and create concepts. These concepts will then be prototyped and evaluated with users and refined based on their feedback. This will be repeated until the solution space has been explored thoroughly and it is time for the next main iteration.

Troughout the project, a combination of universal, inclusive and accessible design apporaches, as described in 3.2, will be adapted depending on the situaitions and context. Lastly, a daily diary will be written regarding the progress of the project. This will later be used as support when writing the execution chapter for the report.

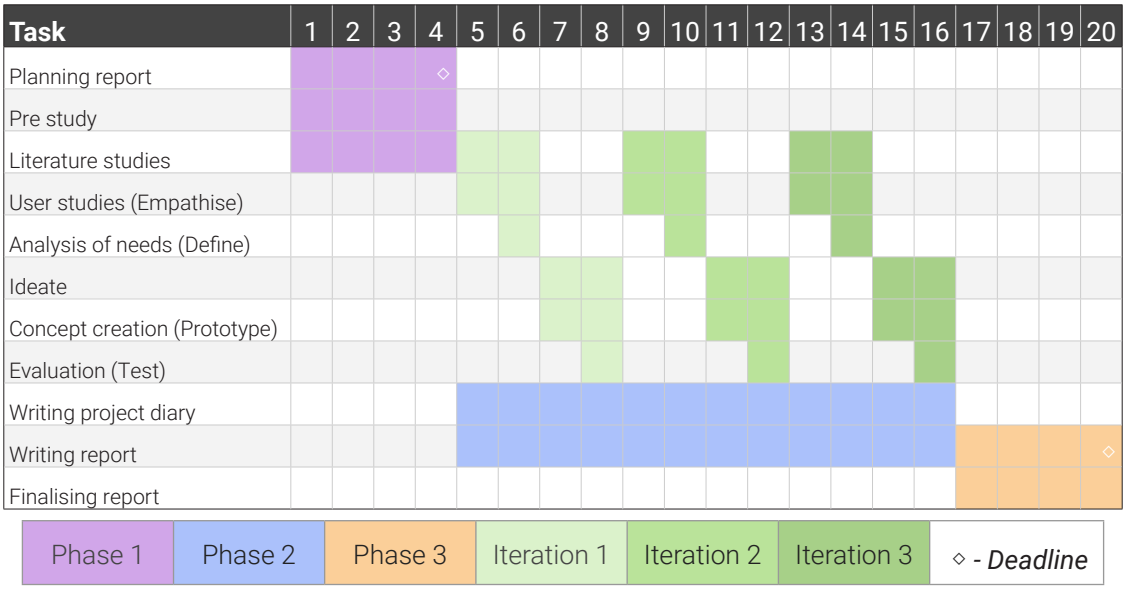

Table 2: Revised time plan

6
EXECUTION

This chapter will describe the process in a chronological order. Firstly, the pre-study will be covered, thereafter the design process with the five phases will be presented. In addition to this, the focus and design areas will be accompanied with a results and reflection section.

6.1 Phase 1 - Pre-Study

A pre-study involving a literature review, benchmarking and WCAG evaluations was conducted at the beginning of the project. The result of the pre-study was a deeper understanding of the field, insights about how well The Product scores in WCAG evaluations and an initial list of requirements.

6.1.1 Literature Review

A literature review was conducted in order to gain insights into digital accessibility and define possible directions for the thesis. To find relevant articles and information Google Scholar[1], ACM library[2], course literature and official websites for accessibility standards were used to search for information. When an article or resource holding relevant information was found, it was added to a document where its topic, title, APA reference, searched keywords, important pages and a short description was stored for future reference. Some of the keywords used were: Web Accessibility, Inclusive Design, Accessible Design, Universal Design, Multimodal Interactions and Accessibility in Data Visualisation. The insights gained were used to create a theoretical framework that the thesis could be based upon, as well as resources and methods that would be helpful later in the process. This can be seen in chapter 3.

6.1.2 Benchmarking

In addition to the literature review, benchmarking was conducted to analyse how competitors to The Company had approached accessibility for data visualisations. The benchmarking served as inspiration of what problems other companies had identified and what solutions they had implemented to solve them. The companies researched were

1 https://scholar.google.com/

2 https://dl.acm.org/

Tableau[3], Power BI[4], Qlik[5], Microsoft Excel[6], IBM Watson AIOps[7] and Alteryx[8]. The results from the benchmarking were added to the library created for the literature review, to store all useful information in one place, the results are also presented in chapter 2.4. Later in the process benchmarking was also used to research solutions to specific problems. For example, Google.com and SvtPlay.se were used as inspiration for "skip to main content" functions and Apple.com was used for inspiration of captions for visualisations.

6.1.3 General Accessibility Interviews

In order to get a better understanding of the subject of accessibility, two general interviews were conducted. One of the interviews was conducted with a participant who had minor accessibility needs, becuase of decreased fine motor skills, visual impariment and a slight cognitive impariment. This indivual also lectured about accessibility. This interview had the aim of getting a deeper understanding of how life can be with accessibility needs. The participants themself had only minor impairments but had worked with many who had greater accessibility needs and could explain how browsing the web was experienced from their point of view.

A second interview was held with an accessibility expert who both teaches and researches accessibility. This participant was asked questions regarding accessible design and what to consider when conducting a project within accessibility. They were also asked if they could provide resources that could prove useful for the project.

The interviews were semi-structured to both allow the participants to explain freely on topics that they thought were important. But also so that questions that had arisen during the literature review could be answered. The interviews resulted in an expanded understanding of accessibility and the challenges designing for it. However, some of the results were also used for the empathise phases in chapter 6.2.4-6.2.6, as well as the initial list of requirements presented in 6.1.5.

6.1.4 WCAG Evaluations

During the pre-study, four different dashboards created in The Product were evaluated. The two first dashboards were evaluated in the webclient, the third dashboard was extracted to PDF and the fourth was a website with embedded visualisations from The Product. This could be found in Table 3 together with the results from all evaluations. All evaluations were examined using the assistive technology ChromeVox and the guidelines from WCAG 2.1, which is described in chapter 3.2.3 and 3.3.1. This was accomplished by using the WCAG-EM Report tool, described in chapter 4.4.5. The tool provided a step-by-step guide on how to evaluate the dashboards (Figure 14). The tool did not evaluate anything automatically, rather supported the process by presenting the WCAG 2.1 guidelines in a more understandable manner. Furthermore it also helped to display an overview of the results when the evaluations were finished.

3 https://www.tableau.com/
4 https://powerbi.microsoft.com/en-au/
5 https://www.qlik.com/us/
6 https://www.microsoft.com/en-us/microsoft-365/excel
7 https://www.ibm.com/aiops
8 https://www.alteryx.com/

The following summary could be extracted from the first evaluation:
Keyboard navigation is not possible. The screen-reader cannot understand what it is looking at, especially the visualisations. There is no information about visualisations (captions) and there are no captions for insights. It is not possible to drill down into visualisations in order to select or have the screen-reader read the content. The screen-reader navigation has no clear flow, it jumps all over the page when tabbing. The author can add captions and titles, however this might not always be done. Colour contrasts are not sufficient for text or UI-components.

The following summary could be extracted from the second evaluation:
Same conclusions as before regarding levels up to AA. New things: Some AAA passed. Issue with components receiving focus not displayed. Titles could be more clear on pages. Scroll is an issue when zoomed in. Implementing shortcuts for the web would be beneficial for navigation. Context-sensitive help would be beneficial. Screen-readers can identify buttons, but it is not clear what they will do. They are also not expressed as buttons, but as groups.

The following summary could be extracted from the third evaluation:
Same as before. However the lower level of interaction in the PDF means that more criteria were not present.

The following summary could be extracted from the fourth evaluation:
While keyboard navigation is possible to an extent it is not sufficient to gain any insights into the data.

Dash. nr.	Format	Success criteria	Passed	Failed	Couldn't tell	Not present	Not checked
1	Web client	AA	11	13	13	13	0
2	Web client	AAA	12	35	10	21	0
3	PDF	AA	9	18	11	12	0
4	Embedded	AA	8	14	6	22	0

Table 3: Results of the four dashboard evaluations from WCAG-EM Report tool

From the evaluations, conclusions could also be drawn regarding which areas to focus on. Many of the failed criteria were in the first WCAG principle called Perceivable and some in the second called Operable. This resulted in the first principle being split into two focus areas, Distinguishable and Interpretable. Operable was kept as its own area of focus and the remaining criteria of importance were divided into the areas where they fit the best. It was discussed that when Perceivable and Operable are solved, the third principle called Understandable is, to a great extent, also covered since it is believed that the solutions required are similar to the ones required for principle one and two. The last principle called Robust ends up outside the scope of this thesis since it is focused on the programmatic interpretation by user agents and not the consumers. The areas of focus are presented in Table 4 below.

Distinguishable	Operable	Interpretable
This area of focus will regard how information is distinguished and thereby perceived. It will handle contrasts, colours, patterns and images of text.	This area focuses on navigating the interface without a mouse. Specifically, it will look at focus states, interactions, the structure of the pages for keyboard navigation and screen-reader navigation.	This area covers captions and insights. It will ensure that there are text alternatives for visualisations that could be interpreted by screen readers and also shown/ hidden for everyone. Order of content and the relationship between them will also be covered.

Table 4: Areas of focus

6.1.5 Results and Reflections of Pre-study

After the pre-study the time plan was revised as shown in chapter 5 (Table 2). This was due to the fact that more knowledge of accessibility had been gathered and therefore the process could be altered slightly. Furthermore, the time plan was structured differently to create a more clear overview of the different phases of the project.

From the literature review, general accessibility interviews and WCAG evaluations, some initial requirements could be defined. The requirements were divided into the focus areas Distinguishable, Operable and Interpretable. They were also divided into R - Requirements and W- Wishes. A requirement is something that has to be fulfilled to solve the problem and a wish is something that does not have to be fulfilled to solve the problem but should be in order to create a better solution. The initial requirements are presented below.

Initial list of requirements

Distinguishable
R - Contrast for interface components is at least 3:1
R - Contrast for text is at least 4.5:1
R - Understand relationships between filter and visualisation
R - Provide interactive components larger than 44x44 pixels
R - In addition to colour, other visual means are provided to differentiate information
R - Text is vector based

Operable
R - Allow keyboard navigation
R - Navigation should be sequential
R - Allow keyboard navigation between headings
R - Provide a way to skip repetitive content
R - Provide alternative to path-based gestures for selecting in visualisations
R - Provide different heading levels
R - Allow use of keyboard shortcuts
R - Provide focus indicators
W - Tooltip should stay when mouse is hovered over it

Interpretable
R - Provide descriptive visualisation headings
R - Provide text alternative for visualisations
R - Provide clear page titles
R - Allow screen-readers to access tooltip information
W - Provide input labels
R - Provide names of the components for screen-readers
W - Provide a contextual help function
R - Provide information to screen-readers of how interactions will affect other visualisations

6.2 Phase 2 - Design Process

In this section, the design process will be presented, involving the three focus areas and the three design areas. The three focus areas are all divided into three parts: 'empathise', 'define' and 'results and reflections'. Moreover, the three focus areas are divided into three parts: 'ideate', 'prototype' and 'test'. The design phases and their methods were carried out based on the methodology presented in chapter 4.

6.2.1 Focus Area 1: Distinguishable

This area focuses on how information is distinguished and perceived. More specifically it will tackle issues with perceiving contrasts, colours, patterns and images of text. Furthermore, this focus area is mainly formulated based on parts of the first principle in WCAG's Guidelines called Perceivable (WAI, 2018).

Empathise

In order to understand the problem connected to the first focus area a total of nine interviews were conducted. The purpose of these interviews was to find problem areas in The Product encountered by those with low vision.

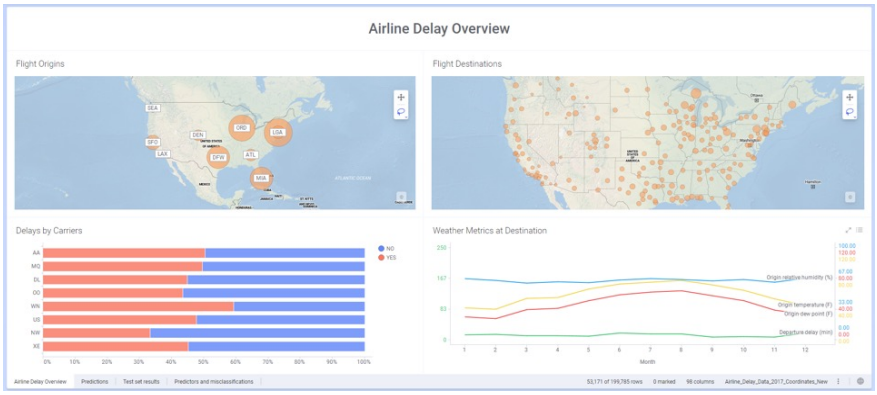

Figure 15: Dashboard used as example for interviews in focus area one

Eight of the interviews were conducted using the service UserTesting and one was held over zoom with a representative from Synskadades Riksförbund[9] (SRF), Swedish Association of the Visually Impaired. The latter was a semi-structured interview with general, specific and task-related questions where the participant was asked questions regarding how their visual impairment affected their use of the computer and was asked

9 https://www.srf.nu/

to demonstrate this. They were also asked to try to navigate and interpret a dashboard created in The Product (Figure 15) and answer questions about how they experienced it.

The interviews conducted with UserTesting were structured and pre-recorded. Meaning that there was no direct contact with the participants, rather they recorded themself completing pre-determined tasks and answered questions about them. The test was created using UserTesting's software, described in 4.4.4, where questions, tasks and other other relevant probes can be added to the test. A number of screening questions (Appendix A) were also added to make sure that the right target group was reached. These questions regarded the participants web experience, experience with visual analytics tools and the severity of their visual impairment. For this specific test only participants who had a high web experience, had used some visual analytics tools and had low-vision were allowed to take the test. If the participant fulfilled these requirements they could continue with the test and recorded themselves, and their screen, while completing it. After the test had been completed they were transcribed to allow for further analysis.

Define

In order to define the problem the data had to be analysed further. This was accomplished with the KJ-analysis method, described in chapter 4.3.2. Important quotes and data was written down on post-it notes and put on a whiteboard. When all nine interviews had been analysed the post-its were grouped into several categories. This was done in an iterative manner, meaning that they were grouped, discussed and then regrouped several times in order to find groups that best highlighted the important aspects and problems. When the final groups had been formed, they were given a title that described their content (Figure 16).

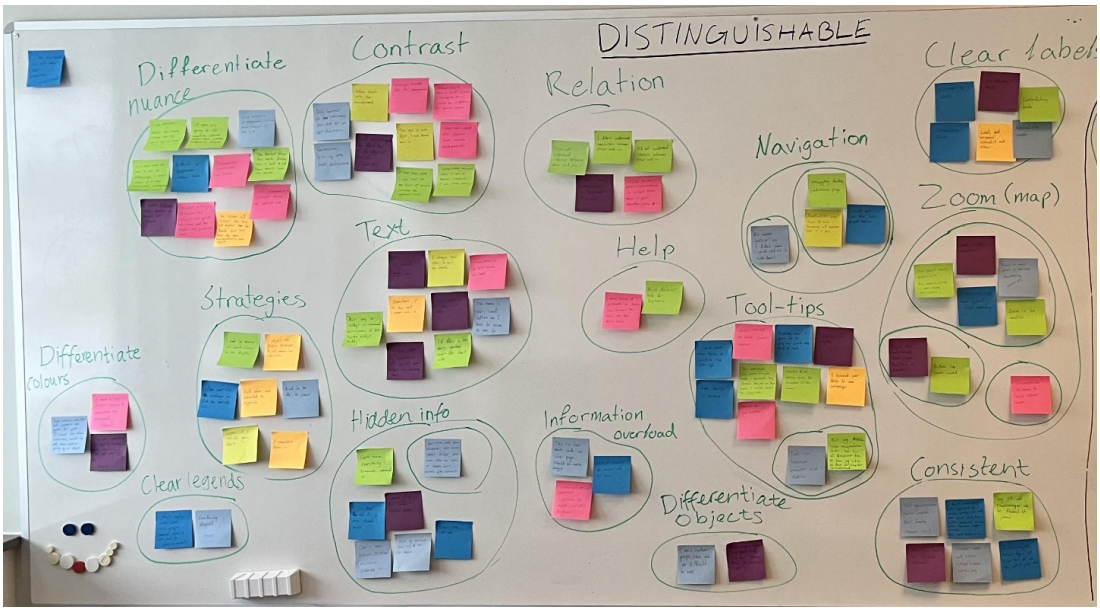

Figure 16: Overview of KJ-Analysis for Focus Area 1: Distinguishable

These were:

- Differentiate nuances
- Differentiate colours
- Contrast
- Strategies
- Clear legends
- Text
- Hidden information
- Relation
- Help
- Information overload
- Navigation
- Tool-tips
- Clear labels
- Zoom (maps)
- Consistent
- Differentiate objects

The results from the KJ-analysis were then used to create requirements and wishes. These were then added to the list of requirements.

Results and Reflections of Focus Area 1

In the final stage of the first focus area, the time plan was discussed and changed. The benefit with the new time plan was that the list of requirements was complete before areas to design were chosen. This ensured that time was prioritised on the requirements deemed most critical and valuable. It also provided an overview of the list of requirements before the prioritisation was made which ensured that the focus areas were not deemed equally important before data was available to support this. The final time plan is shown in Table 5.

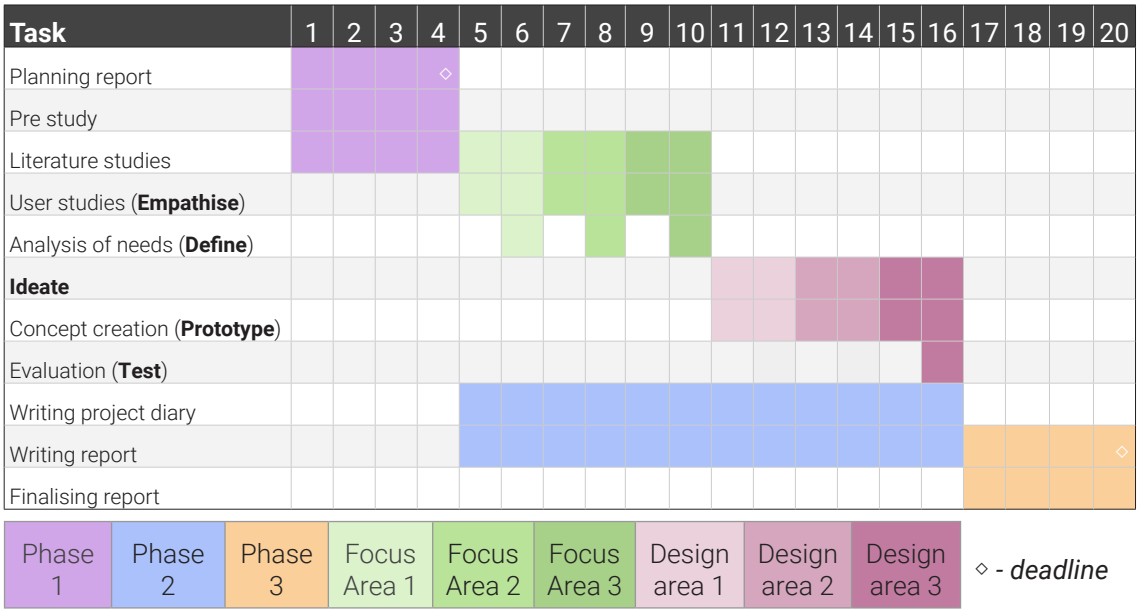

Table 5: Final time plan

A visual representation of the categorisation and prioritisation of the requirements is shown in Figure 17. The plan was that the results from the three focus areas would be compiled in a list of requirements. Thereafter the requirements could be divided into groups of either Recommendations for product, Guidelines for authors or Design/prototype.

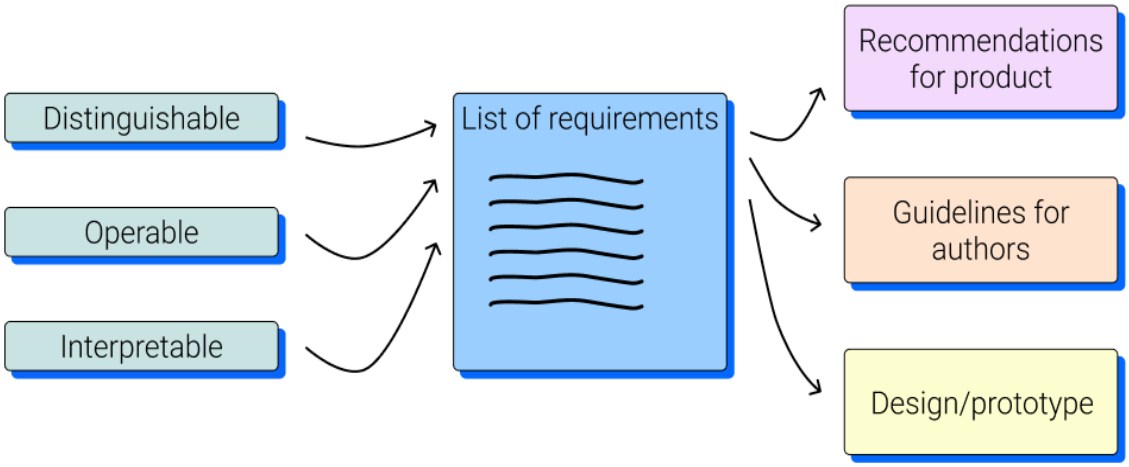

Figure 17: Illustration of the categorisation and prioritisation of the requirements

Below the requirements from focus area one are presented:

R - Provide colour palettes that are colour-blind friendly
R - Provide consistent colours
R - Provide consistent nuances in visualisation
W - Provide text larger than 16 pixels
R - Provide spacing between elements/components
R - Provide tool-tips
R - Allow zoom with buttons (Maps)
W - Allow more precise zoom with trackpad
W - Avoid hidden content
R - Allow the use of zoom or screen magnifiers without loss of content
W - Avoid background animations
R - Components with different interactions should be differentiable
R - Provide clear visual hierarchy
R - Provide spacing around labels
R - Use San-Serif fonts

6.2.2 Focus Area 2: Operable

This area focuses on navigating the interface without a mouse. Specifically, it explores focus states, interactions, the structure of the pages for keyboard navigation and screen-reader navigation. Furthermore, this focus area is mainly formulated based on parts of the second principle in WCAG's Guidelines called Operable (WAI, 2018).

Empathise

For focus area two, a total of eleven interviews were conducted. Eight interviews were conducted with the service UserTesting (Appendix B), as described in 4.4.4, two over Zoom and one in person. For these interviews the target group was individuals that cannot use a mouse or other pointing devices to navigate their computer. Therefore the screening questions were changed with the intent to only accept these users. However, this proved to be difficult as it was challenging to reach those specific users. Moreover, the screening

questions about prerequisites for visual analytics tools, as described in 6.2.1, had to be removed as the target group was too small. Furthermore, many participants misunderstood what a pointing device was and therefore selected that they did not use any, while completing the test with a trackpad. Despite trying several different variations of screening questions, the intended target group was not reached. Instead people who sometimes used keyboard navigation were reached. At this point it was also reflected whether or not the desired target group was possible to reach with UserTesting, as the platform might not allow participants to use only their keyboard to progress tests. While the target group was not exactly as intended, it was close enough that meaningful tests could be conducted.

Figure 18: Dashboard used as example for interviews in focus area two

The interviews were structured in the same manner as the first focus area, however, the questions and tasks were changed to better investigate the navigation of The Product. After completing the screener questions, the participants were presented with a test dashboard with a dataset from Kaggle (2019). This dashboard had been constructed specifically for testing different elements of navigation of the product (see Figure 18). The tests were also structured to a greater extent and had guided tasks for the participant to complete. For these tests, the ability to navigate the dashboard was of interest, rather than the participants ability to interpret information. Therefore they were asked to look at specific visualisations, rather than having to find the correct visualisation themselves. The tasks were also designed in this manner since The Product had been evaluated as difficult to navigate with a keyboard-only setup in the pre-study.

The difficulties in finding the intended target group with UserTesting resulted in more emphasis being placed on the regular interviews. These tests were a bit less structured than the UserTesting counterpart since the real-time interactions allowed for more control and adaptability. Two of the participants were completely blind, and could therefore not use a pointing device and one had cerebral palsy meaning that their ability to perform fine-motor skills tasks with their right arm was reduced. Like the UserTesting tests, the participants were asked to perform certain tasks and answer questions related to those in a test dashboard, however, they were also asked more general questions regarding how they wanted navigation to work. Furthermore, they were implored to show us an example of a website they thought had good navigation, and explain why they thought so.

Define

In order to pinpoint problem areas for focus area two, transcripts of the interviews were made. These transcripts were then used to conduct the KJ-analysis method (Figure 19) similar to the previous focus area in chapter 6.2.1.

Results and Reflections of Focus Area 2

The KJ-analysis resulted in several groups that described important aspects of operability. These where:

- Complexity
- Structure
- Navigation

From these, requirements and wishes were formulated and added to the list of requirements. The additions can be seen below:

Figure 19: Overview of KJ-Analysis for Focus Area 2, and Focus Area 3

W - Provide accessibility help function and page
R - Provide natural structure in lists and tables (alphabetical, north-south etc)
R - Provide focus on content that is relevant to the user
R - Use common design patterns for navigational elements
R - Interactive components should have different hover, click and focus states
R - Allow text input in addition to sliders
R - Text field should move with slider handle

6.2.3 Focus Area 3: Interpretable

This area covers captions and insights. It will explore the interpretability of visualisations for users with varied abilities. For instance, how a visualisation can be interpreted for someone who cannot see. Order of content and the relationship between them will also be covered. Furthermore, this focus area is mainly formulated based on parts of the first principle in WCAG's 2.1 Guidelines called Perceivable (WAI, 2018).

Empathise

During the last focus area, nine interviews were conducted. Seven interviews were conducted using UserTesting, one over Zoom with an expert user and one in person. The aim for this test was to interpret the content on the dashboard hence the name of this focus area. Also, the interaction between the participant and the visualisations were of interest.

In UserTesting, the screener questions were meant to only accept participants who had a substantial loss of vision. Thereafter, the participants were asked to fill out what, if any, assistive devices or softwares they used with their computer, and also if they could verbally describe their visual impairment. The remainder of the questions and tasks were about how they interpreted different visualisations and can be found in Appendix C. The dashboard used for this test is shown in Figure 20. However, once again it was difficult to

reach the intended user group with UserTesting, as the interpretation of “blindness” and “substantial loss of vision” differed dramatically between participants. Even though the screening questions were modified during the time of responses, it was difficult to find the intended target group. None of the participants turned out to be completely blind. Once again, as brought up in 6.2.1, it was reflected about whether or not it was possible to reach the target group through the service, since the platform might not support the specific needs of those users.

Figure 20: Dashboard used as example for interviews in focus area three

The zoom and in person interviews, with participants that were completely blind, made up for the lacking UserTesting responses from the intended target group. The participants were asked general questions about how they navigate a computer, common issues on websites and how they would like visualisations to be presented. Thereafter, they were asked to show how they navigate the web and an example dashboard.

Define

To analyse the user studies, a KJ-analysis was conducted, similar to chapter 6.2.1 and 6.2.2. The goal was to find out insights through categorisation of data points.

Results and Reflections of Focus Area 3

The problem areas identified with the KJ-analysis (Figure 19) were:

- Overview
- Descriptive titles/tags
- Alternative representations
- Complexity

After this, the newly formulated requirements and wishes were added to the list of requirements:

R - Provide descriptive legends
R - Provide overview of visualisation
W - Minimise visual and navigational complexity in dashboards
W - Provide alternative representations for visualisations
R - Enable marking of text

W - Visualisations of the same type, in a dashboard, should be consistent
R - Provide visual indication that a tooltip has appeared
W - Dashboards should be constructed with a natural flow
R - Provide overview of dashboard

6.2.4 Design area 1: Accessible Perception

After the three focus areas, it was time to decide which requirements in the list that would be most important to prototype. Since the prototypes acted as examples for how to tackle the issues it was important that the requirements chosen were central and valuable for The Product. Another aspect when choosing the requirements to prototype was that they needed to have a significant design space. In total, eight requirements were chosen for design, these were then grouped into three design areas. This chapter describes the first of the areas and regards the following design requirements:

D1. Provide contrast for interface components, at least 3:1 - The visualisations need to be created based on this requirement to facilitate for people having difficulties with contrasts.

D2. Provide contrast for text, at least 4.5:1 - The visualisations need to be created based on this requirement to facilitate for people having difficulties with contrasts. An example is labels that are not black/dark grey on white but in yellow on white or similar.

D3. Provide text larger than 16 pixels - This is not as much of a problem if the text is vector based, since it allows zoom. However there is still a limit to how small the text can be.

D4. Avoid hidden content - For some window sizes, the dashboards are not resized properly and therefore some visualisations are not shown. Also, if the screen is too small it might cause axis-labels to be hidden.

Ideate

In order to contextualise the requirements connected to the first design area, two personas were created, with two respective scenarios. The pictures of the personas were AI generated. The personas and scenarios were meant to aid the ideation process by making the requirements more tangible. The creation of the scenarios also entailed that a typical workflow had to be explored, creating a greater understanding of the product. The two personas and scenarios were also meant to contextualise the problem from the perspectives of both the author and the consumer, since these differ a lot. This was also important as the project investigated what the authors should consider in order to create more accessible dashboards.

Author

Name: Jane Murphy
Age: 34
Occupation: Data analyst
Impairment: None

Jane is a data analyst working for Food4Me&U, a large chain selling groceries. The chain has over a 1000 stores in Sweden and Jane is provided with data regarding their customers' shopping behaviours in different stores.

Consumer

Name: Douglas Smith
Age: 45
Occupation: Shop owner
Impairment: Low vision

Douglas has been a shop owner since 5 years back. His store is part of a large grocery-chain in Sweden, Food4Me&U. Douglas receives visualisations from Food4Me&U every month regarding the sales for his store.

Scenario - Author

Jane prepares the monthly data analysis dashboard with the visualisations for Douglas shop. She imports the data into The Product and creates a new dashboard. Her aim is to enable Douglas to gain insights into trends and habits of his shoppers, as well as information of what has sold well that month and what has not. The insights are used to plan strategies in the store. Jane wants the data to be as easily digestible as possible for Douglas, so that he can make smart decisions based on the insights he gains. Therefore, Jane picks visualisations that best present the data. She picks a bar chart and a tree-map with a drill down that is linked to a pie chart. She also includes a "home-page" where a text-summary is added on top of an image of the company's logo. Overall, Jane keeps the properties of the visualisations close to default but changes the font size to be a bit smaller in one visualisation to fit the axis-labels. When she is finished, she shares this dashboard with Douglas.

Scenario - Consumer

Douglas receives the monthly analysis with the dashboard made by Jane. Since Dougals has blurry vision, he has his web-page zoomed-in to 150%. When opening the dashboard he has difficulties reading the text on the "home-page" since the contrast is low. It requires great effort and extensive use of his screen-magnifier for Douglas to read this summary. Furthermore, according to the summary from Jane, there should be a tree-map at the bottom of the next page that Douglas cannot find. Since he cannot find it, he assumes that Jane has made a mistake and that there is no such visualisation included, and therefore he moves on. He starts by reading the title on the page and then continues to analyse the different visualisations. He begins with the bar chart and immediately encounters more problems. The labels are very small and require him to zoom-in and out extensively to see which bar is what. Jane has also used a light blue colour for one of the bars, paired with the white background of the dashboard, there is very little contrast between these elements. This results in him missing that category and his interpretation of the dashboard leads to him making inaccurate decisions.

With the Personas and scenarios in place, the process of generating ideas could begin. The first method used for generating ideas was Crazy 8's, described in 4.3.3. It yielded quick and dirty sketches of several solutions (Figure 21).

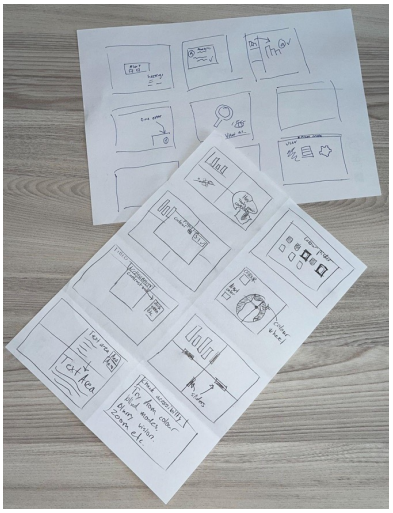

Figure 21: Overview of the resulting sketches from the method Crazy 8's in design area one

However, while there were many different options, it was determined that the solution space had not yet been thoroughly explored. Therefore, a morphological matrix was created as described in 4.3.3. The problem was divided into sub-problems, stemming from the requirements. These were: Contrast for components, contrast for text, text size and hidden content. A brainstorming session was then conducted where solutions to the different sub-problems were explored. These were then written down into a list to create the morphological matrix (Table 6).

Contrast component	Contrast text	Text Size	Hidden content
Check	Check	Check	Auto adjust size
Blurred	Blurred	Blurred	Paper clip
View as	View as	View as	View as
Number (3:1)	Number (3:1)	Size buttons	Resize handles
Alert	Alert	Alert	Alert
Default	Default	Default	One vis at a time
Theme (whole)	Theme (whole)	Theme (whole)	Mini window
Analysis	Analysis	Analysis	Guided tour
Eye squeeze	Eye squeeze	Eye squeeze	Label explosion
Suggestions	Suggestions		Suggestions
Themes c.	Themes c.		Max-button attention
B & W	B & W		
Contrast mode (U)	Contrast mode (U)		
	Text box (image)		

Table 6: Morphological matrix for design area one

An insight from the morphological matrix was that three of the sub-problems had very similar solutions, with a few exceptions. This led to the conclusion that these three could probably be solved by a single solution. However, this also meant that the value of the morphological matrix was somewhat shifted. Initially the idea was that a randomised selection of the solutions to the sub-problems could create a single solution that would

solve the overarching problem. Instead, it acted more as a structured brainstorming session without the combining of solutions, as this would have meant that problems that could be solved with the same idea, would have been solved with different ideas.

The ideas from the Crazy 8's and morphological matrix were then discussed and sorted, so that similar designs were combined into one solution. They were also discussed with two designers from The Company and the supervisor for this project. This resulted in 14 different ideas that were sketched on the whiteboard. In order to evaluate these ideas, a Six thinking hats session was conducted (Figure 22), as described in 4.3.3. The ideas were analysed from the different perspectives (hats) of: facts (white), positivity (yellow), negativity (black), feelings (red) and creativity (green). The final hat (blue) regarded the future development of the idea. This hat took the result from the other hats into account in order to decide what should be done with each respective idea.

Figure 22: Overview of results from the method Six Thinking Hats for design area one

The six thinking hats session resulted in a few ideas being dropped and several ideas being developed and combined in different ways, to create five concepts. These were developed further by sketching on the whiteboard and brainstorming new additions that could enhance the ideas. These ideas were then integrated into the concepts and given a short text summary of important aspects of the design. Thereafter, the concepts were evaluated using a pros and cons methodology where the concepts were discussed by listing their positive and negative aspects (Figure 23).

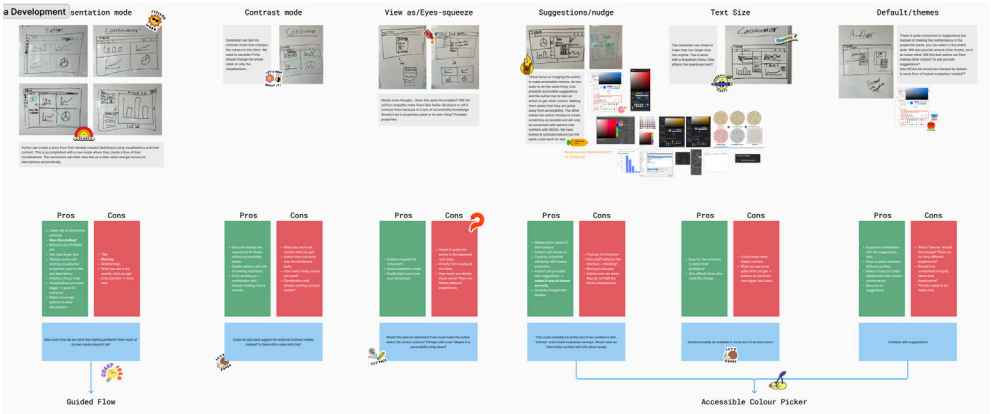

Figure 23: Overview of results from analysis of the ideas for design area one

However, in order to specify what should be done with the concepts a third aspect was introduced, where the future of the concepts were described. For example, “suggestion/ nudge” and “default/themes’’ were combined into one since they built on the same idea, and “text size” was dropped as a concept, but was instead included as both a guideline for authors and a requirement for developers of visual analytics platforms. This was due to it not requiring any design, rather just the implementation of a WCAG guideline.

Some ideas were dropped in this phase, for example the idea about having a function that enabled the author to view the dashboard like someone with colour blindness etc. However, this idea was more about creating empathy and did not solve the problem on its own. Other ideas that were dropped were the possibility to change text size and change contrast mode, since the design space was limited. It was considered that these should rather be a product recommendation, than design suggestions. The remaining ideas were discussed and refined by sketching and brainstorming on a whiteboard (Figure 24).

Figure 24: Overview of whiteboard sketches of the remaining ideas in design area one

Workshop

A workshop was then conducted with the purpose of further exploring the solution space and creating inspiration to the already existing ideas, by creating discussion about the subject. The workshop was conducted with nine UX designers at The Company and lasted about 60 minutes. The participants were divided into three groups of three, were presented with the personas and scenarios described earlier, as well as given two problems to try and solve by ideating. The questions can be seen below in Figure 25, along with some tips for ideation methods.

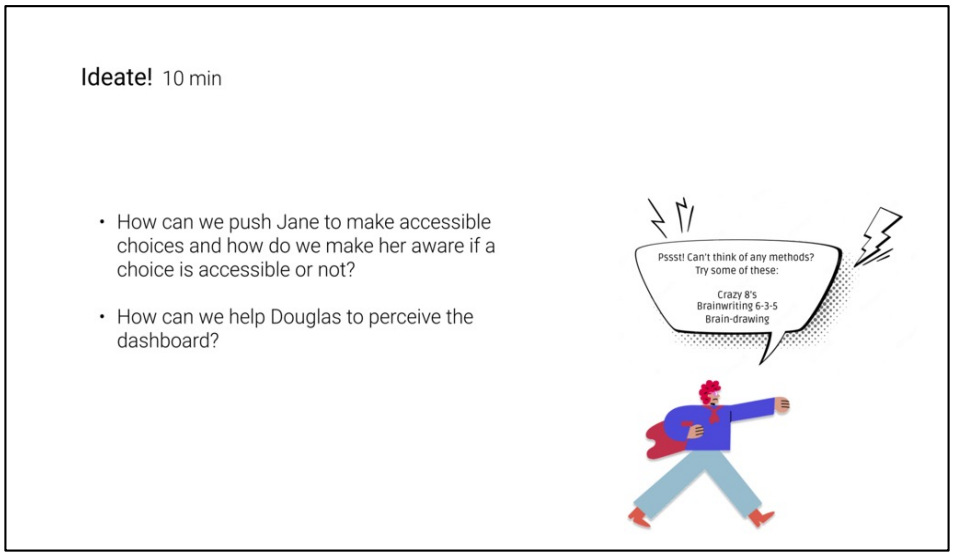

Figure 25: Slide from workshop one presentation, showing the instructions for ideation

The plan was to give the participants ten minutes to ideate and then ten more minutes to refine their ideas. However, during the workshop the ideation phase was extended to 15 minutes since the groups expressed that they had not yet been able to formulate ideas. After they had ideated and refined their ideas they were asked to present their ideas (Figure 26) to the other participants and discuss with them. The presentation/discussion phase lasted for the remaining 20 minutes of the workshop.

Overall the workshop was successful in fulfilling its purpose. Since the time was quite short the ideas produced by the participants were of quite low refinement and abstract. However, since the aim of the workshop was not to receive direct input into the ideation process, rather serve as inspiration to the process, it was well suited. However, the participants should have been given a bit more time, five minutes or so, to allow for deeper reflections, as they expressed that it was quite stressful. Furthermore, the participants expressed that the scenario was a bit too specific as they felt that it limited their freedom. They also thought it was a bit hard to understand the use case. In addition to this, they also expressed that it would have been helpful to have an example image of the dashboard that had been designed by the person in the scenarios. Without it, they struggled with visualising the problem and had to keep everything in their head. The participants were, however, satisfied with the workshop as a whole and thought it was interesting, and challenging, to design with accessibility in mind.

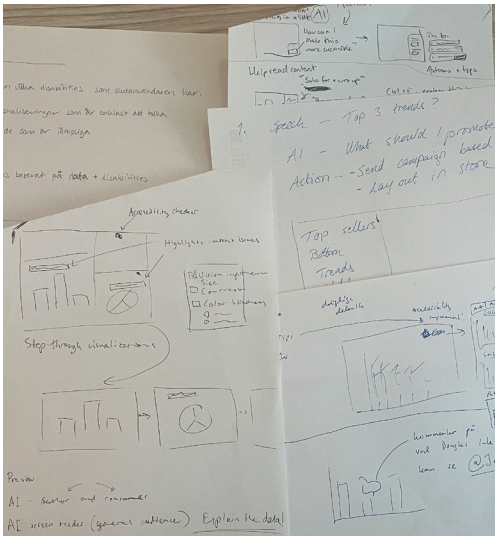

Figure 26: Overview of notes and sketches from workshop one

With the input from the workshop the ideas were discussed regarding if any of the workshop-ideas could be incorporated into them. Many of

the workshop-ideas were similar to the existing ideas however, all the groups thought it would be useful to not only get instant feedback regarding the accessibility of your choices but also some mode where a dashboard could be checked for accessibility issues, after completing it. Therefore, an "accessibility checker" idea was brought back and developed.

Low-Fidelity Prototype

The ideas remaining were grouped into three concepts: *Colour- and font picker* (Figure 27, 28), *accessibility checker* (Figure 27) and *Guided Flow* (Figure 28). The first is a revision of the current colour and font selection pickers in The Product. The concept helps the author make accessible choices by providing instant feedback. Generally, this was accomplished by introducing an accessibility symbol, with an accompanying tooltip displaying relevant information about why their choice is not accessible, and what they could do to improve it, when a non-accessible choice was made. For the colour picker, it also meant showing the contrast ratio between the fore- and background colours. The Chrome colour picker was one of several that served as inspiration to the design. The second concept, the accessibility checker, helps the author evaluate their decisions retroactively by showing them all the issues in a single place, and providing a suggestive solution as well as a way to open the relevant properties panel. The Guided Flow concept, on the other hand, was focused on the consumer experience. It is a mode where the visualisations are presented one at a time, alongside their description.

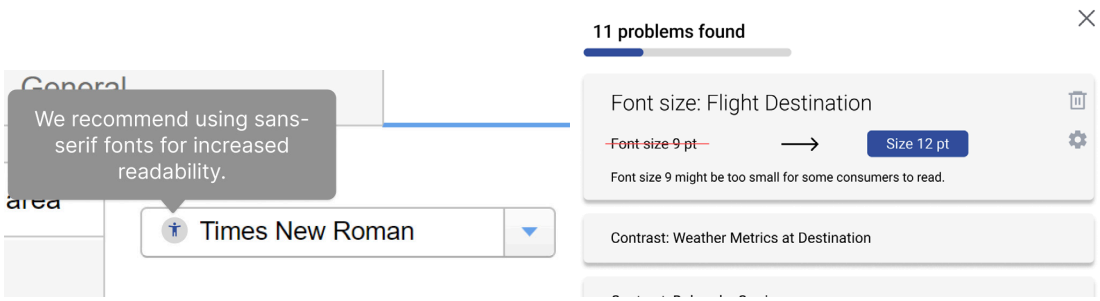

Figure 27: Low fidelity prototypes of the concepts font picker (left) and accessibility checker (right)

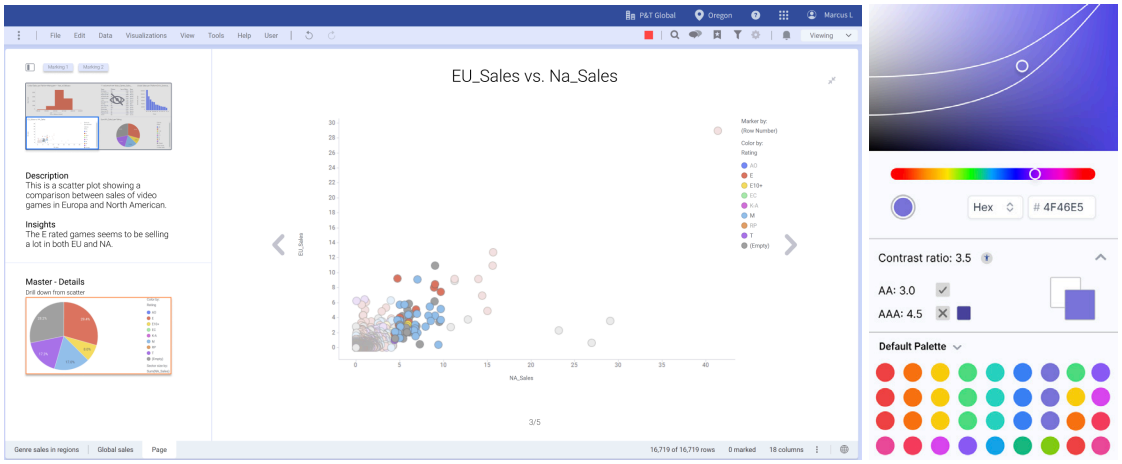

Figure 28: Low fidelity prototypes of the concepts Guided Flow (left) and colour picker (right)

These concepts were created as low-fidelity prototypes in Figma (Figure 29). The purpose of these prototypes was not to evaluate by letting users try them, rather they served as means to communicate the design and implore discussions. Therefore, the prototypes were constructed to be interacted with in a specific flow. Meaning, that interactions had to be made in a specific order for it to work. The purpose of the prototypes was also not to evaluate aesthetics of the solutions, rather the core ideas and how they could be applied in The Product. While creating the prototypes several minor changes were also made to the concepts as new aspects were found while constructing them.

Overall the prototypes were made by taking screenshots of already existing dashboards in The Product and adding the design concepts on top of those. The main idea behind creating the prototypes in this way was that it was time efficient and yielded realistic looking results. However, it also meant that the ideas looked more "finished" than they were, which in turn may have affected to which degree participants expressed negative thoughts on the concepts. Therefore, it was made sure that the additions to the screenshots remained quite low in their level of detail, to compensate for this factor.

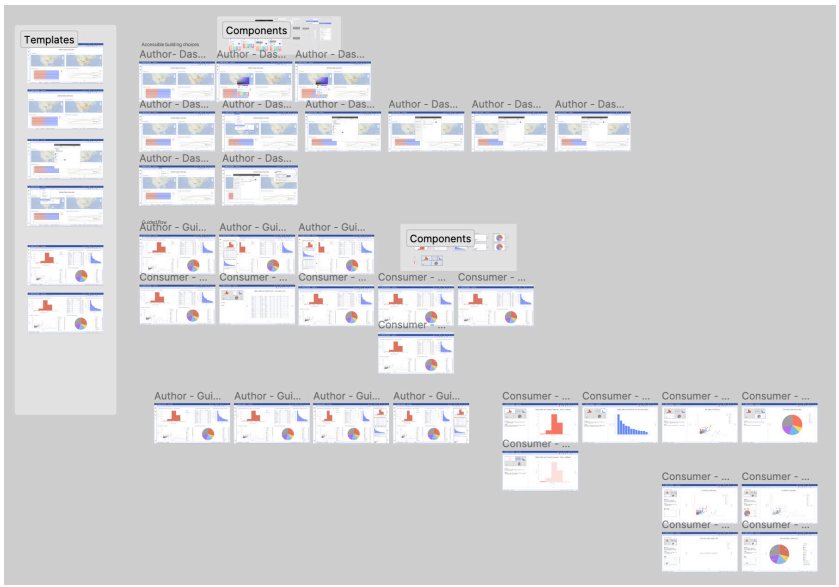

Figure 29: Overview of low fidelity prototypes in Figma for design area one

Expert Discussion

An expert discussion was organised to develop the ideas further. Since the time frame was limited, these kinds of smaller discussions were used for continuous feedback and an extensive evaluation was instead prioritised at the end of the design process, for more in depth evaluations.

In order to evaluate the concepts an expert discussion was conducted where three UX designers from The Company were invited. While these experts knew the product well and were experienced designers, they did not have any expert knowledge in accessible design. This meant that no outside input was given regarding the accessibility of the concepts, but several usability problems were discussed, as well as how the ideas would work with the data analytics workflow. While it would have been optimal to complement these

discussions with either user tests or including an accessibility expert in the discussions, it still yielded useful results for the designs.

The main problem discussed was how to design the drill down visualisations in the Guided Flow in an intuitive way. How marking in one visualisation affects another visualisation and making that understandable and easy to use for the consumer. Another issue brought up was that the overview of the dashboard shown in the left sidebar, was too small (Figure 28). It was also discussed where to find this functionality, since the participants did not experience the author bar to be the most suitable placement. Lastly, additional functionality was discussed about how to change settings manually in the checker. Perhaps the consumer would like to follow the suggestions presented, but tweak it slightly in order to make the dashboard more accessible. By adding an icon for enabling a shortcut to change the settings manually, it would make it possible to fit the author's needs in a more usable way.

6.2.5 Design Area 2: Alternative Marking

This chapter describes the process for design area two which is based on the following design requirement:

D5. Provide alternative to path-based gestures for selecting in visualisations - For marking in visualisations there needs to exist a gesture that is not click-and-drag since all users might not be able to do this.

Ideate

This phase was structured in a similar way as the previous design area. Firstly, a persona was created and a scenario was written based on the requirement for this design area. This time only one persona was required in order to conceptualise the consumers' needs, as the design requirement was not relevant for authors. This aspect was important in order to understand the consumer's experience when marking in visualisations.

Consumer

Name: Camille Martin
Age: 32
Occupation: Manager at a tech company
Impairment: Carpal tunnel syndrome

Camille has been working in a stressful office environment since she graduated college. A lot of time spent in front of a computer in a poor ergonomic seating position has led to her developing carpal tunnel syndrome. The condition has progressed quite far and she has problems with performing fine motor skill tasks.

Scenario - Consumer

Camille receives a weekly dashboard from the data analytics department containing insights into how her department has performed during the last week. In this week's dashboard, Camille spots three data points in a scatter plot that are disconnected from the others. She wants to find out more about these data points and would like to mark them to reveal them in other visualisations as well. However since the marking tool requires path-based gestures, Camille struggles to perform the task.

Thereafter, the Crazy 8's method was conducted to start the ideation based on the persona and scenario. It resulted in several low level sketches shown in Figure 30. However, many of the ideas were similar and a decision was made to develop these sketches by brainstorming and drawing the concepts on the whiteboard.

When the ideas from the Crazy 8's method were developed further , the sketches were inserted in Figma where the method Six Thinking Hats was conducted in the same way as described in 6.2.4. Different ways of perceiving the ideas were discussed and summarised as shown in Figure 31. The ideas were also discussed with two UX-designers at The Company.

Figure 30: Overview of the resulting sketches from the method Crazy 8's in design area two

Figure 31: Overview of results from the method Six Thinking Hats for design area two

Thereafter, decisions were made regarding which ideas to move on with. Some of the ideas were combined and some ideas were dropped in this phase. Pros and cons were discussed for the respective solutions (Figure 32) which resulted in two ideas that made it to the low fidelity prototype phase, "Pen/click-tool", and "Keyboard marking", which was combined with the idea "Move/adjust marking". The idea "AI/Author insights" was about having buttons based on insights in the visualisations, and if the consumer clicked that button, the specific data was marked. However, this idea was dropped since a decision to step away from AI was made. This was due to the fact that the author can not be completely sure about if the AI generates truthful content. Furthermore, another reason why this idea was dropped was because it does not solve the entire problem, since some path based gestures would still be needed for more free marking.

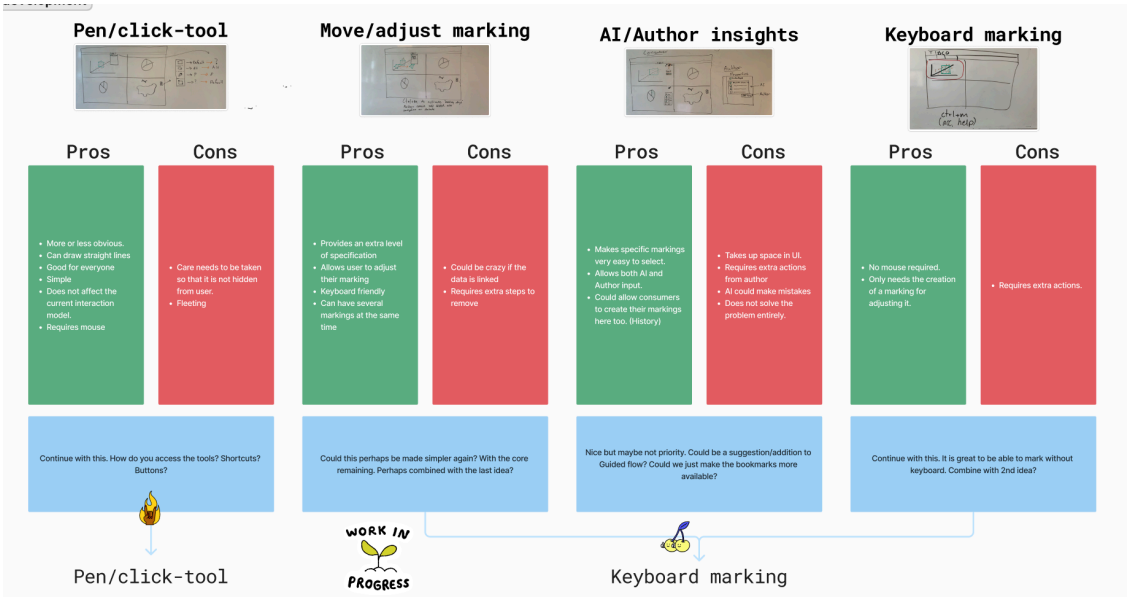

Figure 32: Overview of results from analysis of the ideas for design area two

Lastly, before the low fidelity prototyping started, the ideas were developed and the concepts were iterated one more time (Figure 33).

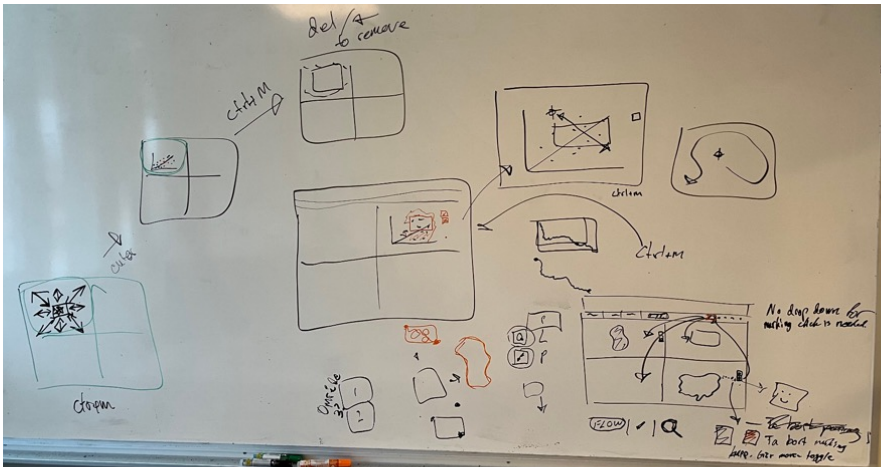

Figure 33: Overview of whiteboard sketches of the remaining ideas in design area two

Low-Fidelity Prototype

The two ideas *Pen/click-tool* (Figure 34) and *Keyboard marking* (Figure 35) were further developed into a low fidelity prototype. The Pen/click-tool was an idea about using mouse down, mouse up multiple times to create an area to mark. It could be different states such as changing to only requiring two clicks to create a rectangle, or multiple times to create a more flexible area, similar to how pen-tools are used in softwares such as Figma. These alternatives to mark could either be changed globally, for the whole dashboard, or locally, for a specific visualisation.

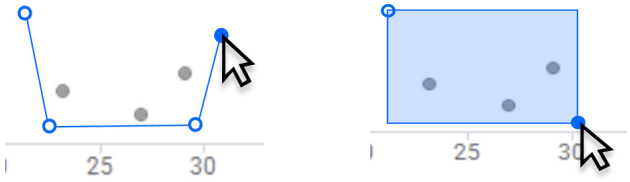

Figure 34: Low fidelity prototypes of Marking alternative Pen-tool (left) and click-tool (right)

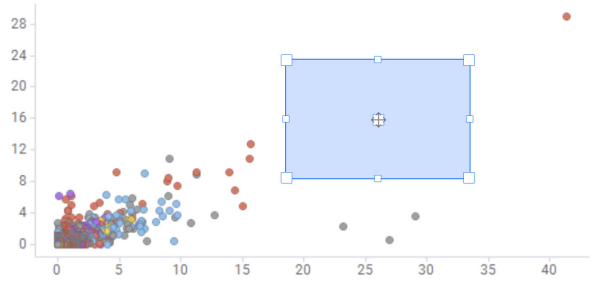

Figure 35: Low fidelity prototype of Keyboard-only marking alternative

The Keyboard marking alternative is accessed through a keyboard shortcut when focused on a specific visualisation. When the shortcut is used, a rectangle is created in the middle of the visualisation. This area could be moved and adjusted with the arrow keys. To navigate to the specific corner the consumer would like to adjust, the tab key is used. This way of marking is an accessible alternative since it does not require any pointing device. All of the prototypes were created in Figma (Figure 36).

Figure 36: Overview of low fidelity prototypes in Figma for design area two

Expert Discussion

In this design area, no workshop was conducted. This was due to the area being too narrow. Instead the next step was to organise an expert discussion. The group consisted of one UX-designer and two developers at The Company. Questions such as the interaction models of the concepts were discussed. The participants expressed positive attitudes toward having the making function global and placed in the toolbar, since it is possible to customise the functions in the bar. Another insight from the discussion was that it would be enough to have only four adjusting dots in the keyboard marking function since that

would be a good balance between efficiency and specificity. It was also brought up that it is important to have the possibility to create and change shortcuts in The Product.

6.2.6 Design Area 3: Alternative Representation

This chapter describes the process for design area three which is based on the following design requirements:

D6. Provide text alternative for visualisations - There needs to be a text alternative present for all visualisation to aid those that cannot see or for some other reason cannot comprehend the visualisation. This should not only include a description of the visualisation, rather focus on the insights it could give.

D7. Provide overview of visualisations - Before the user can dive into the data they need to be able to get an overview first. This can be accomplished with text alternatives or some other way.

D8. Provide alternative representations for visualisations - A visualisations needs to be presented in more than one way. Text is required but it is also desirable to utilise another sense, such as sound.

Ideate

Similarly to the previous two design areas, personas and scenarios were created in order to frame the requirements and put them into context. This time, the context was that a data analyst from a Finnish environmental agency wanted to create a public dashboard that would be accessible to everyone. Specifically, it needed to be accessible to Lucía, an artist with complete blindness.

Author

Name: Eino Mäkelä
Age: 32
Occupation: A Finnish environmental agency
Impairment: None

Consumer

Name: Lucía Fernández
Age: 38
Occupation: Artist
Impairment: Complete blindness, from birth

Author

Eino works for a Finnish environment agency that publishes reports about environment changes for the public using visual analytics dashboards. They publish everything from how the quality of drinking water has changed over time to change in the outdoor climate in different regions. Lately, Eino has received a lot of requests that the dashboards should be accessible, both from the government and the public.

Consumer

Lucía is curious about different environmental changes in her region and therefore she visits one of the dashboards created by Eino. Since Lucía is blind, she uses a screen reader and keyboard navigation when using her computer. Lucía has no problem navigating the dashboard as she is able to access the different functionalities as well as the content. However, she is unable to grasp what the dashboard contains and what the different visualisations are. She also struggles with understanding the content of the visualisations and is unable to get any insights or draw any conclusions from the data.

With the personas and scenarios in consid-eration, a Crazy 8's session was conducted in order to produce many lowlevel ideas in a short amount of time (Figure 37). While there were many different ideas, some of them were also similar, causing the results to diverge quickly. However, it was determined that there was more exploring to do before diverging the ideas into concepts.

Therefore, all the different ideas were sketched on the whiteboard, and were then discussed and iterated in a brain-storming session. The session resulted in some ideas being changed and the creation of additional ones. These were also discussed with two UX-designers at the company before being condensed, so that ideas that were similar were merged, and that ideas that made no sense were removed. These ideas were then evaluated using the six thinking hats method, similar to the previous two design areas described in 6.2.4 and 6.2.5 (Figure 38).

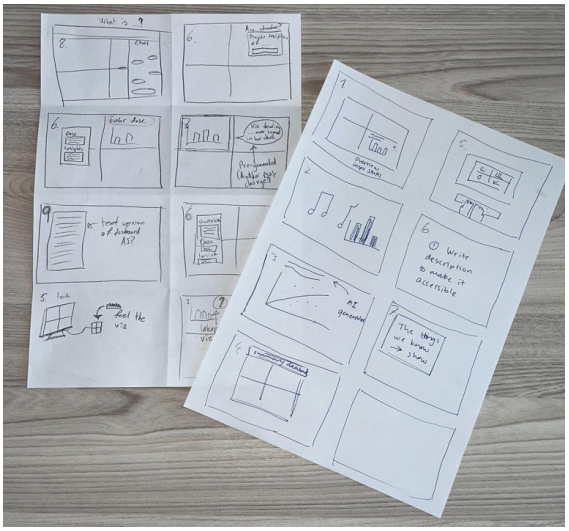

Figure 37: Overview of the resulting sketches from the method Crazy 8's in design area three

Figure 38: Overview of results from the method Six Thinking Hats for design area three

Similar to the previous design iterations, the method resulted in some ideas being dropped and some being combined. For example, a design that meant that the user could chat with an AI and ask them questions about the data and visualisations, was dropped. Mainly this was because AI can be mistaken, and if the user has no other way of processing the data to confirm what the AI states, they would have no other choice but to believe it. An example would be a user that cannot see, as they could not confirm the accuracy of the AI's statement visually. Also, a decision was made about stepping away from external products, for example touch control or a braille 2D screen, since it requires additional features which are specific for the product. Lastly The Products' mobile application was explored regarding how visualisations are presented on a smaller screen, however it was

discovered that the experience is different from the Products desktop as well as Web clients and is rather a less extensive version of it. The six thinking hats resulted in there being three ideas left, *Accessible dash description*, *accessible visualisation descriptions* and *aggregated tables*. The first two regard how to provide text alternatives and get an overview of the content while the latter is an alternate way of presenting the data in a visualisation. The concepts were sketched again and several new ideas were added that had emerged from the six thinking hats method. They were then evaluated again with the pros and cons method (Figure 39), similar to the two previous design areas, described in 6.2.4 and 6.2.5, and were discussed with two UX designers at The Company.

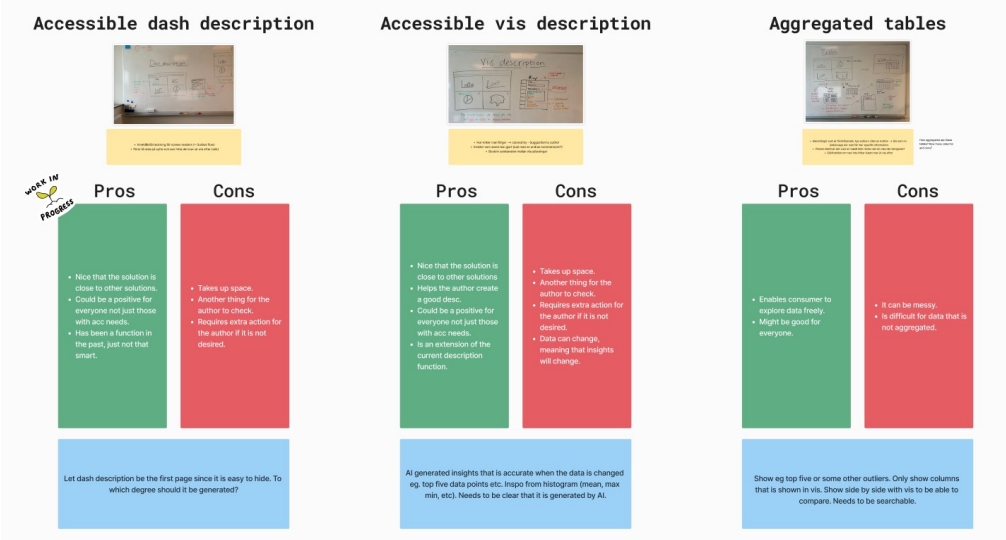

Figure 39: Overview of results from analysis of the ideas for design area three

The method did not result in the removal of any ideas since all of them were considered to serve a different purpose in providing an accessible experience. However, they were developed in different ways to make the ideas more refined. For example, adjustments were made so that they would follow similar patterns as the designs in the first design area, to provide consistency in the author-experience. The ideas were then sketched again and are shown in Figure 40.

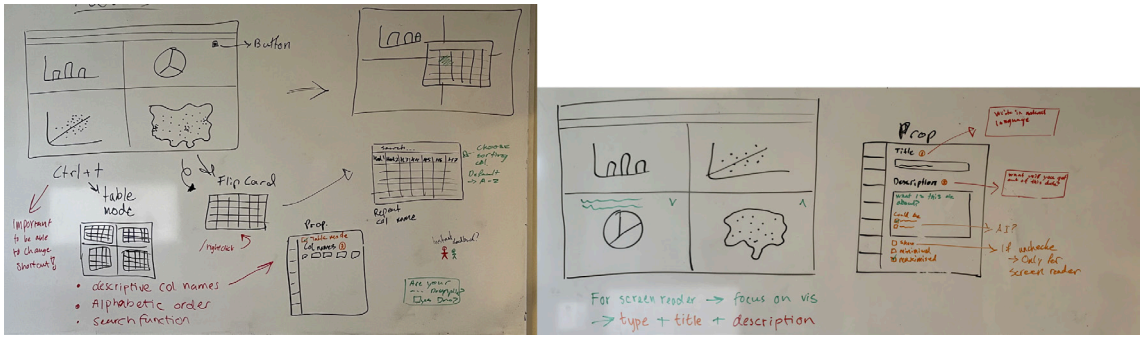

Figure 40: Overview of whiteboard sketches of the remaining ideas in design area three

While sketching the ideas, another iteration of brainstorming was conducted where new ideas were added to the concepts.

Workshop

Another workshop was then conducted with the purpose of gaining new fresh ideas for the concepts. The workshop was conducted with six UX designers at The Company and lasted 60 minutes. Before being divided into two groups, the designers were presented with the scenarios and provided with an introduction about what the workshop would contain (Figure 41).

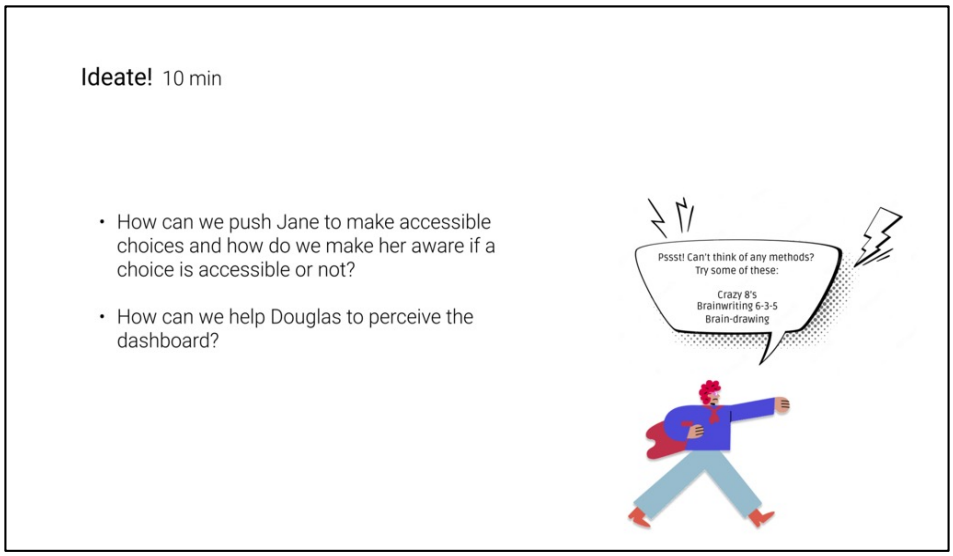

Figure 41: Slide from workshop two presentation, showing the instructions for ideation

A change to this workshop from the previous was that instead of having two ten minute intervals, one for ideate and one for refine, these were combined and extended to a single 30 minute ideation session. This seemed to be more beneficial and suitable for the purpose as the ideas were a bit more refined and therefore could spark more discussion. Another change was the addition of a printed out dashboard that was provided to the participants, as they expressed in the previous workshop that it would be helpful and make it easier to frame the problem. The results of the dashboards can be seen in Figure 42.

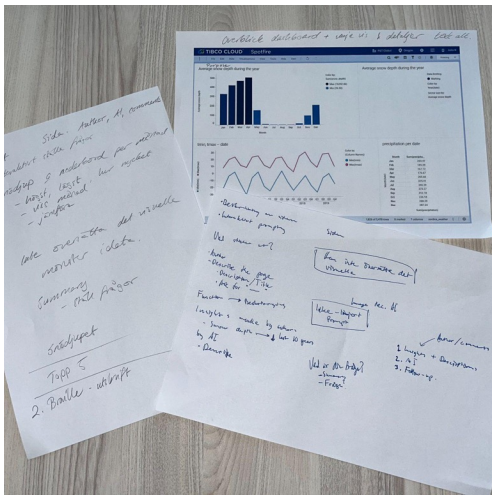

Figure 42: Overview of notes and sketches from workshop two

Like the previous workshop, the purpose of the workshop was not to create ideas that would be considered their own concepts in the process. Rather, it was to collect small, clever parts of the ideas, and implement those. Furthermore, hearing other designers discuss the subject allowed for new inspiration and insights into what might be important and what different solutions might require from The Product. Therefore, the ideas were discussed again and were enriched by some ideas from the workshop before starting the process of creating Low-fidelity prototypes.

Low-Fidelity Prototype

At this stage, the remaining ideas were *Dashboard description*, *Visualisation description* and *Tables*. The first concept introduces a new first page to every analysis-file that contains a dashboard description and a new Table of contents function (Figure 43). This page is meant to provide the consumer with an overview of what the dashboard will contain and what the purpose is. Furthermore, the author will be aided when writing the description by encountering a probe in the text entry field saying "What is the purpose of this dashboard". In addition to this, the author will also be provided with suggestions based on what the dashboard contains. The second concept is similar to the first but is specific to each visualisation (Figure 43). The concept is about helping the author describe the visualisation in a meaningful way. This is once again accomplished by providing a probe and suggestions. These suggestions are based on the content of the visualisation, its type and the category names. The final concept is about providing a table mode as an alternative way of viewing visualisations (Figure 44). The table will be specific to each visualisation but will have the same kind of interactivity as normal visualisations, i.e. marking in the table will mark the data points in the visualisation. Furthermore, the table mode will only contain the columns and rows present in the visualisation and will be searchable for quick retrieval of information. These concepts were then made into Low-fidelity prototypes in figma (Figure 44).

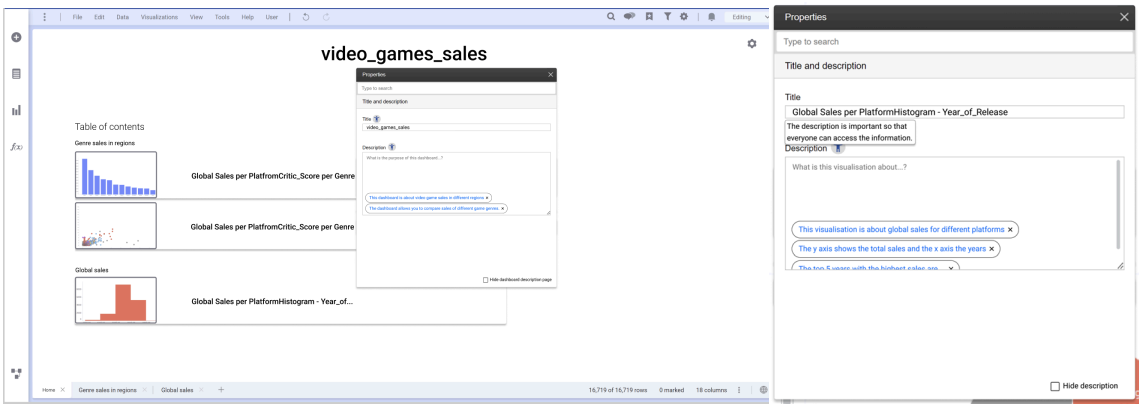

Figure 43: Low fidelity prototypes of the concepts Dashboard description (left) and Visualisation description (right)

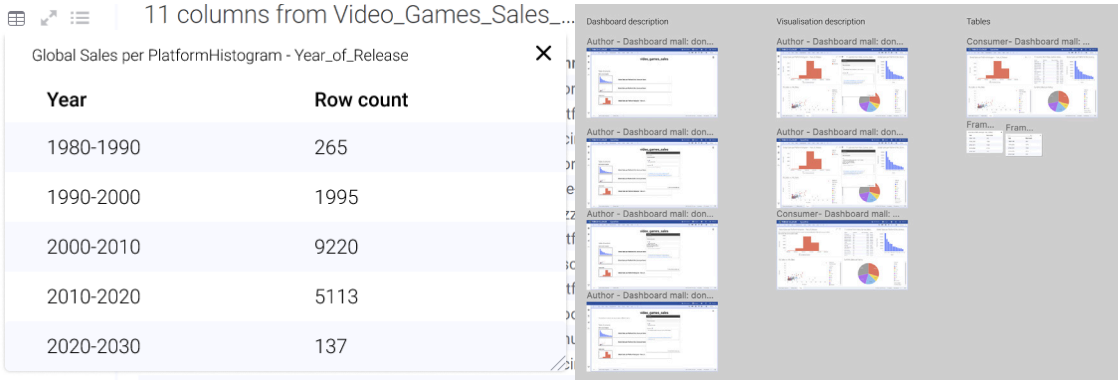

Figure 44: Low fidelity prototype of the concept Table view as an addition to the graphs (left) and Overview of low fidelity prototypes (right)

The prototypes were made with the purpose of communicating the designs and probe discussion with experts. They were created in a similar way as the previous ideas, with screenshots of The Product and revisions added on top.

Expert Discussion

A third expert discussion was organised with two UX designers and one developer. It had the same structure and purpose as the previous ones, described in 6.2.4 and 6.2.5. The discussion resulted in several changes being made to the concepts. For example, the dashboard description page was removed and instead fitted into a new drawer that could be toggled, as this would mean that the user could be more flexible with it. The contents section was also enriched by adding pages as a heading and its visualisations below it, creating a more natural hierarchy. Another very central discussion was that of how dynamic dashboards are. The experts explained that for the visualisation descriptions to be valuable, they would need to be dynamic, as the visualisations may change over time. They explained that this is because many authors have dashboards that are sent to consumers and have the same structure but the underlying data from the database may change, which in turn will change the visualisations. One solution to this that was discussed was having a more general description that would be true even if the data changed. However, this would mean that the text alternative would be less valuable, and the experts thought that insights were a key to making the visualisations accessible through text. Therefore a change was made that the description was divided into two parts, a static general overview and an insights part that is meant to be dynamic and highlights aspects of the data that the author deems important, for example the top three.

Finally, the experts explained that the table mode could be very valuable however it is a challenge to implement for certain visualisation types. For example, it is not a problem for aggregated plots, such as pie charts, however if there is a scatter plot with 2000 data points it might get confusing. Furthermore, visualisation can have properties such as colour that is not apparent in the data. They expressed, however, that the concept is promising and has big benefits for everyone. While this problem had no apparent solutions it was deemed that if it works for some visualisation types, it is better than none.

6.2.7 Test

This chapter will describe the final phase of the design process, where the concepts were evaluated with users.

High-fidelity prototype

The high-fidelity prototypes were created similarly to the low-fidelity, however, they were not made with screenshots, rather all components in The Product were re-created as Figma components. The design area Alternative Marking, was not developed further in this phase due to limitations in Figma. The interaction models needed for allowing the user to mark freely were not possible to simulate, hence the purpose for further tests was lost. Furthermore, as experienced in previous user tests, it was difficult finding the intended target group of keyboard-only users. Therefore, the focus was primarily on the other two design areas; Accessible Perception and Alternative Representation.

Mainly, the Guided flow from the first design area was meant to be tested. The concept bound together all parts of the consumer experience in an efficient manner. Including description, insights, table format and the flow of navigating through the visualisations one by one.

User test

Formative evaluations of the high-fidelity prototypes were conducted with ten participants. The participant characteristics are described in Table 7.

Nr	Characteristics	Impairment	Flow
1	External participant from SRF	Total blindness	Consumer experience
2	Internal participants from The Company	None	Author experience
7	External participants from UserTesting	Low vision	Consumer experience

Table 7: Participants characteristics in the user tests for the high fidelity prototype

For the external participant from SRF, a prototype was prepared in Figma and presented by a screen reader. The prototype was simplified compared to the original prototype since the screen reader was not compatible enough with Figma. This also meant that the navigation had to be carried out by the test leader, as the prototype was very fragile when using the screen-reader. The purpose with this test (Appendix D) was to analyse the consumer-experience of the Guided Flow for someone that is completely blind. The screen reader described what the dashboard was about, its visualisations, insights and how to mark to be able to drill down. Overall, the participant was told that visualisations would be presented one at a time and were then guided through the flow. The participant expressed a positive attitude towards the design solutions and experienced them as intuitive. Most of the feedback was regarding the navigation. However, this was not an area that was looked into due to the limited timeframe of the project.

Another test was prepared for two internal participants from The Company (Appendix E). This time, both the author experience and the consumer experience was evaluated, where all the design solutions were included. The first participant expressed a positive attitude towards the new concepts. A potential improvement the participant mentioned was the lack of feedback when adding insights to the visualisation. Furthermore, the tables were discussed and an aspect that was highlighted was if a table was generated with a high number of rows, it could quickly make it complex and difficult to use. The concepts tested were described as helpful and supportive when considering accessibility in dashboard building. The second internal participant from The Company expressed a general positivity towards the concepts. However, they pointed out a lack of feedback when creating insights and descriptions, similar to the first participant's comments. They also suggested some minor improvements, for example showing font suggestions in the respective fonts, to improve usability in the accessibility checker. Furthermore they also wished that it would be more clear what had been marked in the master-details visualisations. They also expressed that they felt that the dashboard was more accessible after the tasks and that the concepts had

helped in making the correct choices. Furthermore, it was also communicated that they did not feel disturbed by the new symbols, rather intrigued.

Lastly, the consumer experience was also tested on seven external participants on the service UserTesting. This test was similar to the first test with the external participant from SRF. However, this time, the participants did not use a screen reader but they navigated through the Guided flow themselves where they received tasks to complete throughout the test (Appendix F). The participants described the Guided flow as *"accessible", "interpretable", "useful", "informative", "explanatory", "precise", "promising"* and *"easy to use"*. They appreciated the Guided flow and the mode met their expectations. One participant thought the text was too small in the axis of some visualisations, however, overall, the participants expressed that the mode was helpful and found the design accessible, especially for people with visual impairments. They thought it was beneficial to have a general description but also specific insights and a table mode that gave them more specific values. The majority of the participants understood the drill down model when marking without issue.

Final Refinements

From the user test some final refinements were made in the high fidelity prototypes:

- Increased the text size in Guided Flow, since it was perceived as too small.
- Increased the contrast for the text in Guided Flow, since it was perceived as too low.
- Placed the Accessibility symbol in the Accessibility checker to increase consistency.
- Made the visualisation description visible in the prototype to simulate how The Product works today.
- In the Accessibility checker, the suggestion of changing font was set to the specific font to facilitate comprehension of what is about to happen.
- Suggestions were added to the function of writing the dashboard description, similar to the suggestions found in the settings for the visualisation description, to increase consistency.

Furthermore, the list of requirements were iterated continuously but some final changes were made. Firstly the groupings of the requirements were changed and a more structured way of dividing them were created. Secondly, a requirement was rephrased to make it more understandable:

- (W) Avoid hidden content → Provide resizing without loss of content

Lastly, a few requirements were removed due to either lack of argument or redundancy:

- **Provide consistent colours** - If a colour is associated with a specific value or type, all other elements of that value or type should have the same colour. Also, no other value or type should have that colour.

This requirement was removed due to the fact that this does not always have to be true, rather it can depend on the dashboard. The requirement was meant to make data more understandable by always having “banana” as yellow, for example. However if a dashboard only analyses bananas, it could be beneficial to use distinct colours, in order to visualise that it is different aspects of the banana.

- **Provide consistent nuances in visualisation** - In a specific visualisation; if a nuance in a colour gradient is associated with a specific value and type, all other elements of that exact value and type should have the same nuance. Also, no other value or type should have that nuance.

This requirement was removed due to the same reasons as described above. The only difference with these requirements were that one concerned hues, and the other nuances of a specific hue.

- **Allow zoom with buttons (Maps)** - Users need to be able to zoom with buttons in maps. They might not have the dexterity to perform gentle movements of the scroll wheel.

This requirement was removed due to it being too specific. While there should exist additional ways of zooming in maps, it does not specifically have to be buttons in the UI.

- **Allow more precise zoom with trackpad** - The zoom on the trackpad works poorly in the product today and it needs to be easier to zoom in on the map with a trackpad.

This requirement was removed due to it being judged as a usability issue of The Product and not as an accessibility issue in general.

- **Allow keyboard navigation between headings** - It should be possible to get an overview by navigating between HTML headings. Screen readers have a keyboard shortcut for this, but there needs to be different levels of html headings to work.

While it is true that users need to be able to navigate by headings with their screen-readers, this should not be dictated by the product. Rather, the product should only provide headings with different HTML levels, so that the screen reader can navigate them. In other words, the screen readers solve this requirement as long as there exists HTML headings in a product, which is another requirement.

- **Provide focus indicators** - In order for the user to see where they are in the interface when navigating with the keyboard, components need to have focus indicators.

This requirement was removed due to redundancy. Another requirement specifies that there should exist different and distinguishable focus, hover and select states for each component, thereby rendering this requirement unnecessary.

- **Provide an overview of the visualisation** - Include a description of visualisation. What is the purpose of it, what should the consumer look for and what does it show?

This requirement was removed as an author guideline since it was redundant. Another guideline already specifies that they should provide text alternatives with descriptions.

7
RESULT

This section will present the results for this thesis. The results are divided into different sections. First, the guidelines and requirements will be described. Thereafter, the guidelines for authors will be presented and motivated followed by the requirements for development of visual analytics platforms. Lastly, the final designs will be presented and described.

7.1 Guidelines & Requirements

The following chapter will present the guidelines and requirements that the evaluations, research, user studies and interviews resulted in. The list of requirements was created throughout the project and has been updated regularly to accommodate new findings. Several of the guidelines and requirements stem from the WCAG 2.1 list (WAI, 2018), however they have been slightly adjusted to fit visual analytics better. The requirements have been divided into two main parts, *guidelines for authors* and *requirements for development of visual analytics platforms*. The two parts have also been divided into several sections that hold requirements or guidelines that relate to the same subjects. These sections have been used to create a general list of requirements that can be seen below.

To be able to follow the guidelines as an author, the requirements for development of a visual analytics platform need to be considered in the first place. Therefore a list for both parties will be presented in this thesis since it is believed that one list can not stand alone to answer the research question. Moreover, the final design acts as examples of how some of the requirements could be solved to enable authors to create more accessible dashboards.

Guidelines for Authors:

- Use colours with high contrast and be consistent
- Make your content descriptive and readable
- Minimise complexity of your visualisations, and dashboard as a whole

Requirements for Development of Visual Analytics Platforms:

- Provide distinguishable colours
- Provide distinguishable text
- Provide assistive information
- Support assistive technologies
- Minimise visual and navigational complexity
- Support alternative interaction
- Provide alternative representations

7.1.1 Guidelines for Authors

Presented below are the guidelines suitable for authors that create visual analytics dashboards. These guidelines aim to provide the author with support regarding how they should design and construct their dashboards for them to be accessible.

Use colours with high contrast and be consistent

A1. Provide contrast for interface components, at least 3:1 - For colours in your visualisations and elements the user will interact with, pick colours that have a contrast ratio of at least 3:1 against the background colour.

A2. Provide contrast for text, at least 4.5:1 - For colours of text elements in your dashboard, pick colours that have a contrast ratio of at least 4.5:1 against the background colour.

A3. Pick colours that are colour-blind-friendly - For coloured elements that are to be compared, pick colours that are colour blind friendly. Use colour-blind-friendly palettes and avoid using red and green together.

A4. Visualisations of the same type, in a dashboard, should be consistent - If there are two or more visualisations of the same type in a dashboard (two pie charts, for example) these should be consistent. Meaning that they should have similar properties as well as "look and feel". However they do not necessarily need to have the same colours.

A5. In addition to colour, use other visual means to differentiate information - Avoid relying on only colour for differentiating elements in visualisations. Consider adding differences in size, shape and pattern of elements, so that they can be distinguished from one-another.

The first guidelines are about informing the author about how to pick their colours and style their visualisations. The first two (A1, A2) refer to the WCAG 2.1 (WAI, 2018) success criterion 1.4.11 and 1.4.3 respectively. They state that user interface components and graphical objects should have a contrast ratio of 3:1 or higher, than their adjacent, or background colours, and that text should have a contrast ratio of at least 4.5:1. The intent with these criteria is that enough contrast is provided in order for people with low vision to still be able to distinguish the content from the background. It also became apparent through the user studies conducted in the beginning of the design process that the participants with low vision struggled with distinguishing elements that had a lower contrast ratio than 3:1 (Quote 2). Power BI and Tableau also include these guidelines in their help documents for authors, explaining that it is essential for making the content distinguishable (Microsoft, 2023; Tableau, n.d.-a).

> *"I can definitely distinguish the heavy colors but the light, not so much."*

Quote 2: Regarding low contrast

In addition to contrast, some participants also struggled with discerning different colours. For example, one of the visualisations in the test had green and red bars, symbolising yes and no respectively. Some participants that stated that they were colour blind expressed that they had problems with this. For example one participant stated that they could not see

a difference in those colours at all, and became very stressed as a result of it. Furthermore, Organ (2022) argues that it is the responsibility of the creator to pick colours that are accessible, both considering contrast and colour-blind-friendliness. Therefore, the third guideline (A3) is to pick colours from a palette that is colour-blind-friendly.

The fourth guideline (A4) is about minimising the mental workload of the user by decreasing the amount of elements that has to be learned. Several participants in the user studies explained that they found it difficult processing large amounts of information at once, and that consistency helps in reducing that workload. Calvo et al. (2016) confirms this as they argue that consistency in interfaces promotes inclusiveness as it lessens the mental workload.

The fifth guideline (A5) for this section is motivated both by WCAG 2.1 (WAI, 2018) and user tests. WCAG 2.1 success criterion 1.4.1 states that colour should not be the only visual way of displaying information. Furthermore, according to the early user studies conducted, a participant expressed difficulties separating red and green and understanding the enclosed meaning behind the colours. The participant wished for additional indications like arrows going up or down. Furthermore, Ware (2021) argues that if colours are picked to be colour- blind-friendly, additional means is needed to distinguish elements, since it limits the amount of unique colours that can be picked. The importance of using more than just colours to convey information is also stressed by both Microsoft (2023) and Tableau (n.d.-a). Therefore, the fifth guideline was developed.

Make your content descriptive and readable

A6. Provide descriptive visualisation headings - Headings need to describe the content in the visualisation. Name them something that introduces the consumer to the visualisation.

A7. Provide descriptive legends - Legends in visualisations need to describe the values clearly.

A8. Provide descriptive page titles - Page titles need to be descriptive of the content that the consumer can expect on the page.

A9. Provide text alternative for visualisations - There needs to be a text alternative present for all visualisation to aid those that cannot see or for some other reason cannot comprehend the visualisation. This should include a description of the visualisation and its purpose, as well as potential insights.

A10. Provide an overview of the dashboard - Include a description of your entire dashboard. What is the purpose of it, how should it be navigated and what should the consumer expect?

A12. Use San-Serif fonts - Pick fonts such as Roboto or Arial. Avoid fonts such as Times New Roman since it is difficult to read for some users.

A13. Provide text larger than 16 pixels - If possible, use text that is at least 16 pixels tall. If smaller text is used it requires higher contrast than G2 suggests.

This section of the guidelines is about helping the author create dashboards that are easier for the consumer to understand. Guidelines five, six and seven (A6, A7, A8) are about providing headings, legends and page titles that describe the content. These guidelines are motivated by WCAG 2.1 (WAI, 2018) success criterion 2.4.6 that states that headings and labels should describe the topic or purpose. The intention being that the consumer is helped to understand what the content will be about, which helps them find the desired topic. Furthermore this is motivated by the user tests conducted as several users showed issues in identifying what the visualisation was about when the heading was non-descriptive. However, when care had been taken to write a descriptive heading, participants showed an increased understanding of the visualisations and found it easier to find specific content. The guidelines are also included in author guidelines made by both Power BI and Tableau, stating that descriptions of content provides the consumer with understanding where they are and what they are doing (Microsoft, 2023; Tableau, n.d.-a). Furthermore, Zong et al. (2022) also describes that descriptions also play a vital role for screen-reader users as that is what it will read.

From interviews with people who were blind it became clear that all non-text content that holds information must have a text alternative, unless the content is purely decorative (Quote 3). This is also supported by WCAG 2.1 (WAI, 2018) success criterion 1.1.1 that states the same. The participants explained that this is necessary for them because they would otherwise miss that content. Another participant also explained that text-alternatives can support those with cognitive impairments since it allows them to process the information in a different manner. It is also specified by Babic (2021) and Story (1998) in universal design principle four, that multiple modalities should be used to convey information. In this instance, text is that alternate modality and to help authors remember and follow this, guideline nine (A9) was created. Similarly, the blind participants also described that for them to process information they first need to get an overview of the data, and then be able to go into the details (Quote 4). Therefore, guideline ten (A10) was created, informing the author that a general description needs to exist for the dashboard as a whole.

A: "Your screen-reader is focused on a map."

B: "I didn't get that."

Quote 3: Regarding text alternatives for visualisations

"I don't get the same sense of overview, since I'm blind."

Quote 4: Regarding overview of visualisation and dashboard

Guidelines eleven (A11) and twelve (A12) aim to help the author make accessible choices when it comes to fonts and text size. Calvo et al. (2016) argues that if the size of the text is not considered it might be difficult for the user to identify and read. Furthermore, one of the participants in an interview for focus area one, who was a representative for SRF explained that there is a debate in the vision impairment community whether or not there should be any guidelines of text size in web content. SRF currently suggests that text sizes larger than 12 points, corresponding to 16 pixels, should be used. However, since screen magnification is available, it was argued by the participant that this might not be necessary. For that reason,

it was implemented as a guideline for the author, but not recommended as a limiting factor for the program. Several participants with low vision also stated that small text made it difficult for them to read and they had to lean in close to the screen. Similarly, it was also specified by participants that serifs make text harder to read as it can make the characters appear as they are blending together or look like other letters. Therefore it is recommended for the author to use sans-serif fonts if possible.

Minimise complexity of your visualisations, and dashboard as a whole

A13. Provide natural structure in lists and tables - Tables and lists should be structured so that it is easy for the consumer to navigate them. Use natural structures such as alphabetical order, or north-south for geographical data.

A14. Minimise visual and navigational complexity in dashboards - Strive for a clear and simple dashboard to minimise complexity. If visualisations are meant to be viewed together, put them on the same page and in the order they are meant to be viewed.

A15. Dashboards should be constructed with a natural flow - Design your dashboards so that they are easy to perceive and navigate sequentially. Meaning that there is a natural flow, for example from top-bottom and left-right. Also, important information should be placed at the top.

This section provides the author with guidelines regarding how they can create dashboards that are easier to digest and navigate. It builds on the third Universal design principle, *simple and intuitive use*, that states that the design should be intuitive independent of skill or knowledge (Babic, 2021; Story, 1998). Further, it also specifies that complexity should be minimised. In addition to this, Tableau (n.d.-a) also emphasises that it is important for the author to "keep it simple" when they build dashboards.

A13 was created after interviews with people with blindness that specified that it is common to get lost in tables or lists if they do not have a predictable structure. Similarly, another interview participant described that people with cognitive impairments may find it easier to digest dashboards when the content has a natural flow, for example read from left to right, top to bottom. Furthermore, one of the participants that were blind also stated that it is important that essential information is presented first, which is also argued by Calvo et al. (2016). Therefore, A15 was created. In addition to this, A14 was created to encourage authors to build dashboards that are as simple as possible, to minimise the mental workload on the consumer. This will help consumers with cognitive impairments, or other impairments that reduce the demand of their pool of cognitive resources, to comprehend the dashboard (Babic, 2021). Furthermore, participants expressed during the user studies that they found it difficult to process large amounts of information at once (Quote 5) and that they need the dashboard to be as simplistic as possible.

"I can't process too much info at once."

Quote 5: Regarding information overload

7.1.2 Requirements for Development of Visual Analytics Platforms

Presented below are the list of requirements for development of visual analytics platforms. The purpose with these requirements is to enlighten the designers and developers, make

them aware when designing and developing accessible visual analytics platforms. The list contains both requirements (R) and wishes (W).

Provide distinguishable colours

R1. Provide contrast for interface components, at least 3:1 - The contrast between the foreground and the background needs to be at least 3:1 since some users experience difficulties distinguishing the component if the contrast ratio is too low.

R2. Provide contrast for text, at least 4.5:1 - The contrast between the text element and the background needs to be at least 4.5:1 since some users experience difficulties distinguishing the text if the contrast ratio is too low.

R3. Provide colour palettes that are colour-blind friendly - Help the authors create visualisations that are colour-blind-friendly by providing pre-made palettes.

R4. In addition to colour, provide other visual means to differentiate information - Avoid relying on only colour for differentiating elements in visualisations. Provide ways for authors to change size, shape and pattern of elements.

All of the requirements in this section (R1, R2, R3, R4) are also present as guidelines for the author and are motivated the same way as in section 7.1.1 above. The difference between these and the guidelines is that the platform needs to make it possible for the author to follow the guidelines. For example the author needs to make sure to pick colour-blind-friendly colours, while the platform needs to ensure that there exists premade palettes with accessible colours. For example, these palettes can consist of colours that differ in the yellow-blue spectrum, as explained by Ware (2021).

Provide distinguishable text

R5. Provide vector based text - The text should be vector based to improve the quality when zooming.

R6. Use San-Serif fonts - Text in the interface should be in San-Serif fonts to eliminate the risk that some letters could be mistaken for others.

R7. (W) Provide text larger than 16 pixels - If possible, use text that is at least 16 pixels tall. If smaller text is used it requires higher contrast than R2 suggests.

Requirement R5 was motivated by WCAG (WAI, 2018) Success Criterion 1.4.5 since it stresses the importance of using text instead of images of text. This was also brought up in one of the early user tests when a participant zoomed in with their screen magnifier and the quality of the images of text drastically decreased (Quote 6). Furthermore, R6 and R7 are motivated in the same way as described in section 7.1.1 but are directed to developers of the visual analytics platforms instead. In addition, Calvo et al. (2016) also stated that it could be difficult to read the text if the size is not considerable.

"The numbers become pixelated and the contrast is poor when I'm this zoomed in."

Quote 6: Regarding images of text

Provide assistive information

R8. Provide tooltips for interactive components - That gives the user more information about the component.

R9. Tooltips should stay on hover - If a user is zoomed in so that they can only see a small portion of the screen, the tooltip may be mostly outside their field of view. The user needs to be able to hover over the tooltip in order to navigate to it and read.

R10. Provide visual indication that a tooltip has appeared - Tooltips need to be attached to, overlap the hovered component or in some other way communicate that it has appeared. If not, users with a high level of zoom on their screen-magnifiers can miss that they have appeared.

R11. Allow screen-readers to access tooltip information - All tooltips in the interface should be accessible by screen-readers.

R12. (W) Provide accessibility-help page - If a user with accessibility-needs opens the page they might need help regarding, for instance, how keyboard navigation is performed or how contrast modes are activated. Information about this should be available in an accessibility page that can be reached easily. A page should also be available to the author with guidelines for building accessible dashboards.

R13. (W) Provide contextual help - Contextual help is help that is relevant to the user in a specific instance. It can be in the form of tooltips or some other help function.

During the user tests, participants expressed appreciation for tooltips that enabled the possibility to convey more detailed information. Furthermore, when the tooltips were absent, they requested this functionality.

According to WCAG 2.1 (WAI, 2018) success criterion 1.4.13 it is required that the tooltip should stay when hovering over it. This was also confirmed in an early user test when the participant stated that it was impossible to read the tooltip since they were zoomed in with their screen magnifier (Figure 45), and when the mouse was moved, the tooltip disappeared (Quote 7). Also, the participant stated that the tooltip could even be missed since there was no visual indication that a tooltip had appeared. From that R9 and R10 were developed. The information in the tooltips is important for understanding the content, as expressed in several user tests, and should therefore also be accessible when using screen readers. Furthermore, it is also important to state that, as explained by Microsoft (2023), information that is important to the navigation or interaction of the content should not only be available as tooltips, as people with dexterity issues might have difficulties accessing these. Instead, tooltips should contain information that is ancillary. Due to that, R11 was added to the list of requirements.

"When I tried to move the mouse over the tooltip, it disappeared.Then I can't read it when I'm zoomed in ."

Quote 7: Regarding disappearing tooltips

Figure 45: Example of Tooltip that is not readable

R12 was created based on comments from the workshops. The participants expressed that accessibility can feel overwhelming and that help is needed both for the author and the consumer. For example, there needs to exist a page where the author can access the guidelines written in 7.1.1. Similarly, some accessibility features may be hidden by default and might require an action to activate. In order to discover these functionalities there needs to exist a page where the consumer can explore their options.

R13 is based on the success Criterion 3.3.5 in WCAG 2.1 (WAI, 2018) that stresses the importance of providing context-sensitive help to the users. This is to reduce the risk for the user to make mistakes or not understand the interaction required. For example, "Link" reveals that a user will navigate to another page. Also, the user should be able to understand how the actions will affect other connected visualisations.

Support assistive technologies

R14. Allow the use of zoom or screen magnifiers without loss of content - The visualisations need to reshape and rearrange when zooming without disappearing.

R15. Text field should move with slider handle - If a user zooms in while using a slider handle, the text field might fall outside the view, which makes it impossible for the user to know when the target value is reached. Therefore, the text field that displays the current value should move with the handle.

R16. Enable marking of text - All text needs to be markable since some users use screen readers that will read marked text.

R17. Provide descriptive tags of components for screen-readers - If an icon or other component is present, that icon or component should have a tag that describes its purpose.

R18. Provide information to screen-readers regarding how interactions will affect the interface - Screen-readers need to access information about the consequences of an action.

R14 and R15 were developed after early user tests when the participant from SRF expressed concerns about the loss of content when zoomed in. The participant also stated if zoomed it was not possible to see the text field when using the slider handle (Figure 46). Furthermore, R16 was created after the same participant explained that the text in the interface is locked and not markable, which is a problem since many people mark text to get it read by their screen reader (Quote 8). Lastly R15 could also be motivated by Calvo et al. (2016) since they stated that problems might occur if custom components are used. In this case, if

"When I tried to move the mouse over the tooltip, it disappeared.Then I can't read it when I'm zoomed in ."

Quote 8: Regarding disappearing tooltips

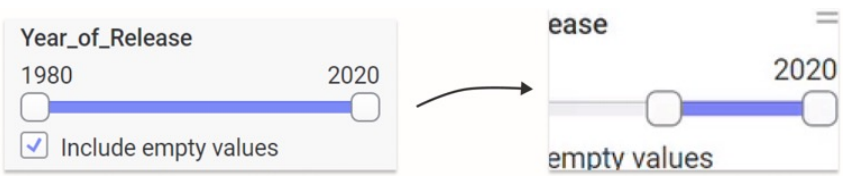

Figure 46: Example of issue: Text field does not move with slider handle

the consumer is zoomed in, it is a behaviour that differs from the expected. Therefore, accessibility issues occur, due to the text field not moving with the slider, which entails that it falls outside the consumers view.

The Success criterion 2.4.4 in WCAG 2.1 (WAI, 2018) emphasises that it is important to be able to determine the purpose of each link as a user. Furthermore, success criterion 1.3.6 states that it is crucial that it is possible to identify the purpose of interface components such as icons. This success criterion also received support in early user tests since several participants expressed negative attitudes against websites that did not provide information to the screen reader regarding tags of components and consequences of the interactions. Lastly, Zong et al. (2022) argued that the description of the elements is a key dimension in the whole experience when using a screen reader. Therefore requirement R17 and R18 was formulated.

Minimise visual and navigational complexity

R19. Provide clear visual hierarchy - It is important that the user understands the relationships between heading and content, where one heading starts, ends and the connected subheadings. There needs to be a clear visual hierarchy.

R20. Provide relationship indication between filter and visualisation - There needs to exist visual indication that a filter is connected to a certain visualisation.

R21. Provide spacing around labels - Labels need to have spacing around them so that they are readable. Also, avoid labels placed on top of other labels. If labels are on top of content, make sure it has proper contrast.

R22. Provide spacing between elements/components - Dashboards need to have "breathing-room"/white-space in order to better allow processing of information. If there is too much information at once it gets difficult to process.

R23. Provide input labels - If input is required, labels should specify what is expected.

R24. Components with different interactions should be differentiable - It should be easy to differentiate the different components' interactions. The user should be able to understand the specific interaction without examination.

R25. Interactive components should have different hover, click and focus states - It should be easy to differentiate the different states. The user should be able to understand the specific state without great effort.

R26. Use common design patterns for navigational elements - Use common design patterns in order to promote consistency, familiarity and to make the navigation efficient.

R27. Interactive components should be larger than 44x44 pixels - Components that are clickable need to have an appropriate sizing, at least 44x44 pixels.

R28. Provide natural structure in lists and tables - Tables and lists should be structured in a natural order, such as alphabetical order, or north-south for geographical data, to make navigation easier.

R29. (W) Provide resizing without loss of content - If the window size is changed the content needs to adapt without hiding vital information.

R30. (W) Avoid background animations - Background animations should be avoided to decrease the complexity and mental workload for the consumer.

This section of the requirements is about minimising the visual and navigational complexity of the dashboards. R19 is about understanding which content belongs to which section, something that was expressed as an issue by many participants in our user studies. Specifically, a participant with low vision argued that it was difficult for them to understand where one section ended and another began when the headings were so similar to the contents. Therefore, there needs to be a greater visual hierarchy between the heading and its contents. Furthermore, it was also frequently expressed that it was difficult to understand which elements were connected to what in a dashboard. For example, which filter was connected to which visualisation and which visualisation was a drill down from which master visualisation. Participants expressed that this increased their mental workload and therefore also their perceived effort. As an effect of this, R20 was added. Both requirements R19 and R20 are conformant with what Calvo et al. (2016) argues, since they emphasise the importance of making the relationship between elements understandable.

Another requirement that was added to minimise visual complexity was R21. This requirement is about providing sufficient spacing around labels to increase their readability and make them more distinguishable for consumers with low vision. This requirement was created after several of the participants expressed that the labels that were cramped in a small space were difficult to distinguish from one another. They also communicated that it made it more difficult for them to understand which label corresponded to which element, further increasing their mental workload. Similarly, a participant expressed that providing spacing around components and visualisation is essential for making the information processing easier. They argued that it is especially true for people with cognitive impairments as they can require more effort to focus. Therefore, R22 was introduced.

WCAG 2.1 (WAI, 2018) states in the criterion 3.3.2 that when content requires user input, labels or other instructions need to be present. Since this occurs in visual analytics, for example when searching or filtering information, it also applies here, which is why R23 was created. In addition to this, it is stated in criterion 2.4.7 that a focus state should be visible for components. Furthermore, it was clear from user tests that consumers appreciated when there were distinct focus, hover and click states for components, as it made it easier for users to navigate. Therefore, R25 was introduced.

R24 and R26 were introduced as it was explained by users in the tests conducted that components that looked similar, but had different interaction models were confusing (Quote 9). Furthermore, it is stated by Calvo et al. (2016) that a common mistake that causes accessibility issues is using your own components, instead of standardised. This increases mental workload for the user and can also create confusion. For example, if someone with low vision places their focus on a checkbox, they might expect it to behave a certain way, but then when it

"Slider looks like checkbox, it's confusing."

Quote 9: Regarding differentiating components

does not, because the pattern has been changed, they might fail to complete the desired interaction.

WCAG 2.1 (WAI, 2018) criterion 2.5.5 states that targets that require input from pointing devices should be at least 44x44 pixels in size. This holds true for visual analytics as well, except for when the size of the object is essential to the data. An example of this could be that having a scatter plot with thousands of data points where all of them are 44x44 pixels in size would not make interaction easier. All other components should have appropriate sizing as it, for example, makes it easier for those with dexterity problems to click their targets. This is also motivated by Calvo et al. (2016) since they emphasise the importance of size to ensure all consumers can identify the components. This is why R27 was introduced.

R28 was introduced for the same reasons as for the author counterpart. However, this requirement focuses more on making it possible for the author to make such a choice and that natural structure should be the default.

R29 was created as it was discovered in the user tests with individuals with low vision that when they had a high level of zoom in their browser, certain visualisations disappeared or did not resize properly. The consequence was that they missed information and could not complete certain tasks.

A participant in the general accessibility interviews explained that background animations could cause great difficulty when trying to digest information on a web page. They stated that this issue is amplified for those with cognitive impairments and should therefore be avoided, which is why R30 was created.

Finally, Babic (2021) and Story (1998) validate requirement R19-R30 when they state that the design should be intuitive and simple to use. Hence, it is important to minimise visual complexity so the consumers can independently use the product.

Support alternative interaction

R31. Allow keyboard navigation - Everything should be navigationable using only keyboard.

R32. Navigation should be sequential - Keyboard navigation should be organised in a clear natural flow, for example from top-bottom, left-right.

R33. Provide a way to skip repetitive content - There needs to exist a way for users to skip content such as menu bars and go straight to the main content.

R34. Provide different heading levels - In order for the user to navigate between headings, there needs to be different HTML-levels of them.

R35. Provide focus on content that is relevant to the user - Consider what the user wants to see. When interacting with content that will change the state and move the user's focus, it is important that it lands on something that is relevant to the user. For example if there is an alert, the focus needs to go to that alert, or the user will miss it.

R36. Allow use and change of keyboard shortcuts - To simplify use with a keyboard only setup, there needs to be some standard keyboard shortcuts present that does not clash with the shortcuts of the screen reader. These could be for frequent actions, such as opening the filters panel. These shortcuts need to be presented to the user so that they can learn them. Furthermore, it should be possible to change the shortcuts to fit the user's needs.

R37. Allow text input in addition to sliders - An alternative way of selecting instead of path-based gestures. Also, input allows for a more precise choice.

R38. Provide alternative to path-based gestures for marking in visualisations - For marking in visualisations, there needs to exist a gesture that is not click-and-drag, since not all users are able to do this.

Requirement R31 is motivated by success criterion 2.1.1 in WCAG 2.1 (WAI, 2018). The criterion states that all functionality should be operable using keyboard-only navigation. Furthermore, success criterion 2.4.3 argues for a sequential navigation with the keyboard, so that the elements receive focus in an order that creates meaning for the user. From this argument, R32 was added to the list of requirements. These navigation issues were also encountered during early user tests with external participants from SRF. They brought up the struggles they had experienced when the keyboard navigation was not organised, which led to the webpage being impossible to understand. R33 is also formulated based on early user tests where an external participant from SRF explained the benefit of being able to navigate directly to the main content, without needing to navigate past repetitive information, such as menu bars. This is also confirmed in success criterion 2.4.1 in WCAG 2.1 (WAI, 2018) where it is stated that it is important that users are able to bypass blocks of content when this content is repeated on several web pages. The participant also mentioned the appreciation towards being able to navigate between heading levels with their screen reader, which led to R34 being added. They explained it as an efficient way of navigating that saves time, effort and favour the understanding of the user.

Moreover, requirement R35 was added to the list after early user testing with another external participant from SRF. The participant stated that if the focus is not accurate to what the user wants to see, it loses its purpose. This could be crucial if the user gets an alert but is zoomed-in which entails that the user misses the important information (Quote 10). Furthermore, R31-R35 are also motivated by Zong et al. in their argument about the importance of considering the navigation to enable the consumers to perform the required actions.

"If I, for example, fill out a form, an alert pops up and the screen reader focuses somewhere else, then I will miss it."

Quote 10: Regarding focus on relevant content

WCAG 2.1 (WAI, 2018) success criterion 2.1.4 describes that keyboard shortcuts need to be possible to turn off, remap or only be active on focus. This was also confirmed from participants in early user tests which is why requirement R36 was added to the list.

Requirement R37 was motivated by early user tests where it was argued that the possibility of allowing text input as an alternative to sliders is appreciated when zooming in with screen magnifiers, and getting a limited view.

Lastly, R38 was motivated by success criterion 2.5.1 in WCAG 2.1 (WAI, 2018) since it is stated that all functionality that requires path-based gestures need to have an alternative interaction model.

Provide alternative representations

R39. Provide overview of dashboard - Before the user can dive into the visualisations, they need to be able to get an overview of the dashboard. This can be accomplished with for example text alternatives describing the content.

R40. Provide overview of visualisation - Before the user can dive into the data, they need to be able to get an overview of the visualisation. This can be accomplished with for example text alternatives describing the visualisation.

R41. Provide text alternatives for visualisations - There needs to be text alternatives present for all visualisations to aid those that cannot see or for some other reason cannot comprehend the visualisations. These should not only include a description of the visualisation, rather also focus on the insights it could give.

R42. (W) Provide alternative representations for visualisations - A visualisations needs to be presented in more than one way. Text is required but it is also desirable to utilise another sense, such as sound.

R39-R41 are motivated as their author counterparts, described in section 7.1.1. Furthermore, the requirements R39-R41 are also communicated by Babic (2021) and Story (1998) in their arguments regarding the importance of using multiple modalities. Therefore, alternative representations play a key role when considering universal design. Lastly, the final requirement is based on an early user test with a blind participant where they emphasised the benefits of using other senses when interpreting graphs. For example, the participant mentioned audio feedback as an interesting alternative, with different pitches depending on the height of the bar in a bar chart.

7.2 Final Designs

This chapter describes the design suggestions created as examples of how the following requirements might be fulfilled. The requirements selected for design were based on the arguments stated in 6.2.4 and the connected requirement, from the full list, is found in the parentheses.

D1. Provide contrast for interface components, at least 3:1 (R1)
D2. Provide contrast for text, at least 4.5:1 (R2)
D3. Provide text larger than 16 pixels (R7)
D4. Provide resizing without loss of content (R29)
D5. Provide alternative to path-based gestures for marking in visualisations (R38)
D6. Provide text alternative for visualisations (R41)
D7. Provide overview of dashboard (R39)
D8. Provide alternative representations for visualisation (R42)

7.2.1 Accessibility Symbol

The first design suggestion is an "Accessibility Symbol" (Figure 47) that is available for the author-experience. This design, at its core, is about nudging the author to make accessible choices. However, as explained by Thaler (2018) it is important that nudging is transparent. Furthermore, the design is also meant to be a tool to help the author learn why their choice was not accessible so that they can make better choices in the future.

Figure 47: Accessibility Symbol concept without tooltip

The idea has two aspects, one is meant to direct attention to important aspects of accessibility and the other about informing the author. The first is that a symbol will appear whenever there is an aspect of their dashboard that does not meet the accessibility requirements and needs to be improved. The colour is subtle so as not to annoy the author, however, it has enough contrast that it is distinguishable from the rest of the content. When asked, several of the participants in the evaluations expressed that the symbol was visible and immediately directed their attention, however it did not feel intrusive or annoying. The symbol is also the most commonly used accessibility icon, and all participants understood that it had something to do with accessibility, suggesting that it corresponds to their mental model. The second aspect of the design, that is meant to inform and educate the author, is a tooltip that appears on hover (Figure 48). The tooltip is meant to guide the author towards more accessible choices and inform them why this is important, in a concise and discrete manner.

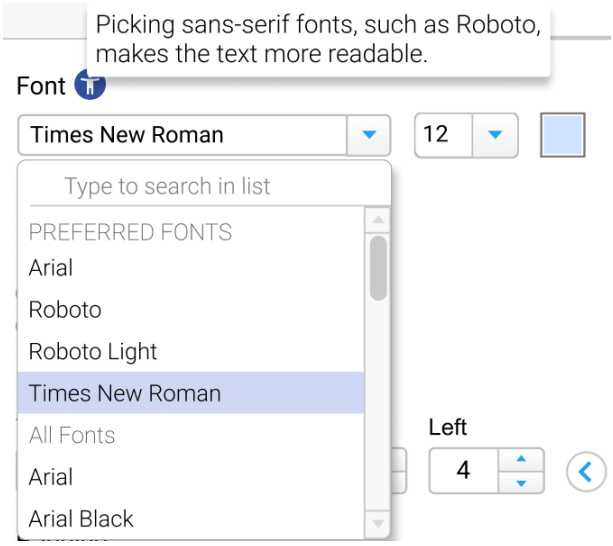

Figure 48: Accessibility Symbol concept with tooltip in font picker

Several aspects of this design were important during development. Firstly, accessibility might not always be necessary, depending on the consumers targeted. However, creating accessible dashboards will not only be positive for those with accessibility needs, but also improve the overall user experience, as suggested by Nielsen Norman Group (n.d.). Similarly, it might not always be possible to make accessible choices because the choice may be important for the data representation. Therefore, instead of limiting the authors

to fonts, colours etc that are accessible, a contextual help is provided that can inspire and help the author to make the accessible choice themselves, building on Thaler's (2018) theories of nudging. Furthermore, several participants in the evaluation expressed that it was satisfying to learn and correct the non-accessible choices they had made. In addition to this, they also expressed that they appreciated that the tooltips focused on suggestive improvements rather than criticising their choice, since it created a more positive experience. Finally, another important aspect of this design is the versatility of it. The same symbol and pattern can be used in all places where there is a potential of making accessible choices, creating consistency in the interface. Therefore, this solution was aimed at fulfilling all design requirements except for D5 and D8.

7.2.2 Colour Picker

This concept is very similar, in its core principles, to the previous design in that it is trying to nudge the author to make accessible choices in a discrete way, however it is more specific and extensive. The aim with this design is to fulfil D1 and D2 by informing the authors of their choices, the WCAG 2.1 (WAI, 2018) contrast criteria, and making it easy for them to select conformant colours. By default, the colour picker is the same as in many platforms, in that it has a picker field, hue-slider, input for hex and RGB as well as some premade palettes. What is new with this picker is that it has a contrast ratio field in addition to those features (Figure 49).

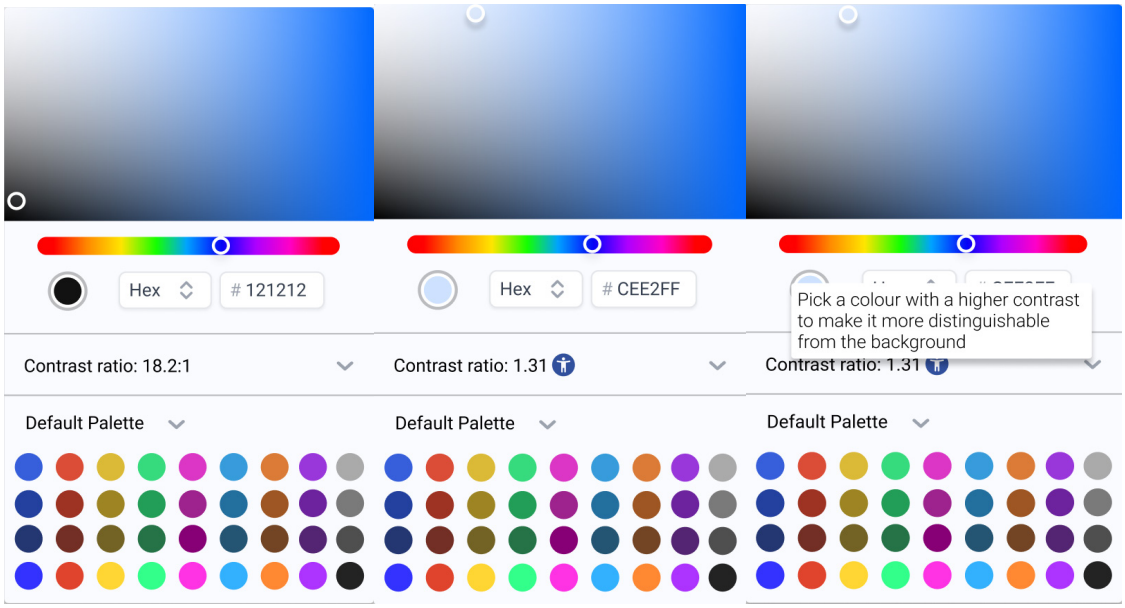

Figure 49: Colour picker concept with high contrast (left), colour picker concept with low contrast (middle), colour picker concept with Accessibility Symbol hovered (right).

This field shows the contrast ratio between the foreground and background colours and displays the Accessibility Symbol from the previous design when the contrast ratio is below the WCAG 2.1 (WAI, 2018) threshold (Figure 49). The Symbol can be hovered to reveal more information about the issue and what the author can do to improve the accessibility (Figure 49), as explained in 7.2.1 above.

The contrast field can also be expanded to reveal more information (Figure 50). The picker field at the top now has two lines in it, representing the limits for WCAG AA and AAA respectively (WAI, 2018). The user can also see the AA and AAA requirements for contrast and whether or not it has been fulfilled in the expanded version of the contrast field (Figure 50). Hovering over either of them will highlight the respective area corresponding to that WCAG level in the picker field (Figure 50). Furthermore, it also provides a tooltip informing about the WCAG levels, to help the author if they are unaware of what AA and AAA means. The author is also presented with a suggested colour for each respective WCAG level. These colours are the closest possible to the one they have selected that is conformant with WCAG. The author can also see a preview of how their selected colour would look on the background to the right in the contrast field (Figure 50).

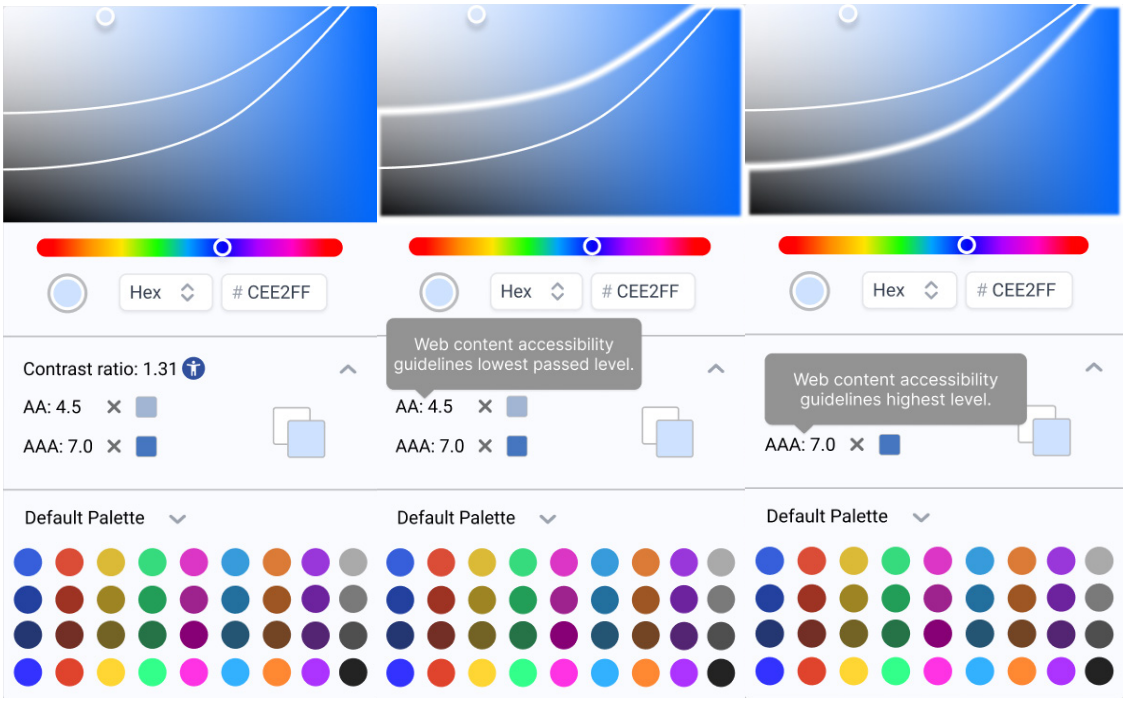

Figure 50: Colour picker concept with contrast field expanded (left), colour picker concept with AA hovered (middle), colour picker concept with AAA hovered (right).

Another functionality of the Colour picker is the ability to switch between different colour-palettes. This is important as it was expressed during the expert discussions for design area one, that many authors want to be able to select colours quickly. Furthermore, it could also be a way of fulfilling R3 by implementing colour-blind-friendly palettes in this drop down. During user evaluations it was expressed that, similar to the previous concept, the design was not annoying or distracting, rather helpful and natural.

7.2.3 Description and Insights

The third design aims at meeting requirement D6, providing text alternatives for visualisation. The design is based on the same concepts of nudging as the previous designs, and includes the Accessibility symbol seen in 7.2.1 (Figure 51).

Firstly, it tries to encourage the author to write a text description of the visualisation. In order to help the author get started, they are provided with a probe in the form of a question: *"What is the purpose of this visualisation?"*. The purpose of this probe is to get the author going and also explain what the description should contain. The same pattern is commonly used in UI design and is present both in the search field of The Product, and in several other applications (Figure 52).

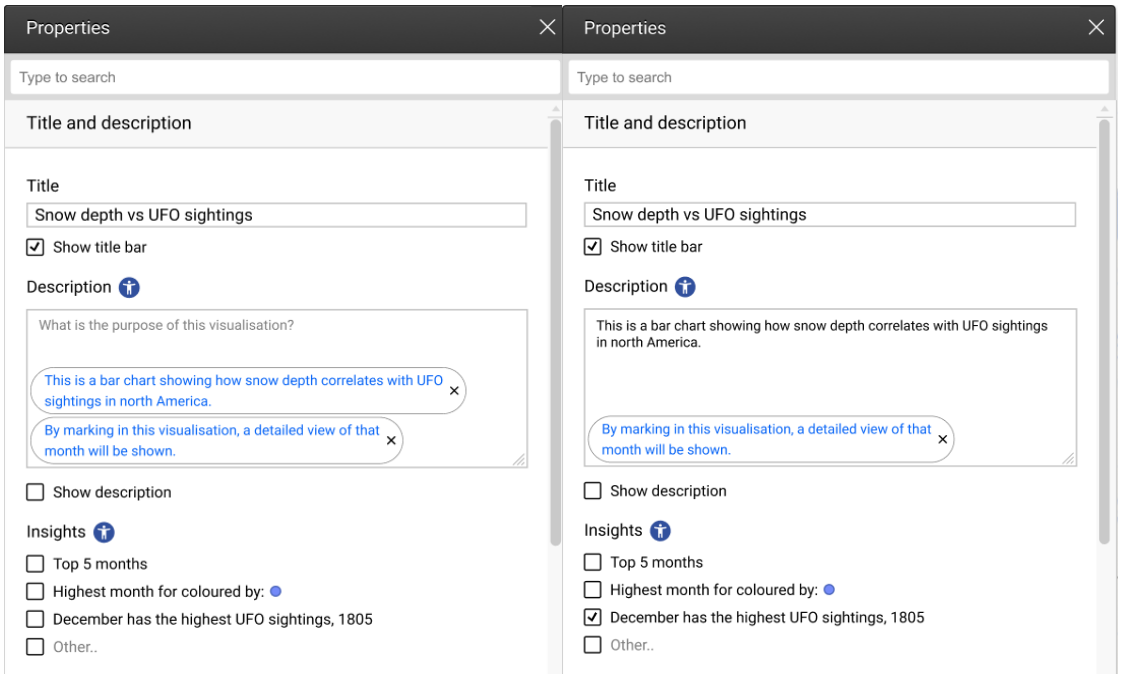

Figure 51: The properties panel showing suggestions for what to write in the description. It also shows how to add dynamic insights to a specific visualisation.

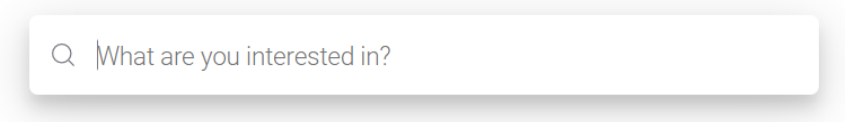

Figure 52: The search input field with a probe

In addition to the probe there are also auto generated suggestions present for the description that the author can click to create that text (Figure 51). This allows the author to create their general overview of the visualisation in an efficient way. The suggestions are generated with already existing knowledge of the visualisation, such as its type (i.e. bar chart, scatter plot etc), the column names that it contains, and what connections it has with other visualisations. This could also be made more advanced by including AI with natural language generators, that could interpret the purpose of the selected visualisation.

During the workshop for design area three and the last expert discussion, it was discussed that many visualisations can change over time because the dataset they are built on is updated. Therefore, the text alternatives must also contain a dynamic aspect that can change as the data is updated. For this purpose, the insights section was created (Figure 51). It is similar to the description in that it is supposed to be a text alternative for the visualisation, however it is meant to be more specific by highlighting interesting aspects

of the data. This can be outliers, the highest values, values the author has chosen to colour a specific way or other aspects tied to a parameter. The idea is that the application will suggest potential points to highlight as insights, and the author can then determine which should be shown to the consumer. Furthermore, the authors are also able to define their own insights, if they wish. An example of how the descriptions and insights could be displayed can be seen in chapter 7.2.6.

7.2.4 Dashboard Description and Table of Contents

The fourth design was created to accommodate D7, provide overview of dashboard (Figure 53). This is accomplished by providing a dashboard description that behaves like the visualisation descriptions as described in 7.2.3. Furthermore, it contains the same concept of including a probe and suggestion, as in the previous design. However, it also contains a new *content* area that acts as a Table of Contents for the dashboard. It shows the content on a page- and visualisation-level, meaning that the consumer can see on which page a visualisation is located and get an overview of what they can expect on each page. The table is updated automatically as the author adds new visualisations, and uses the page titles and visualisation titles as its headings.

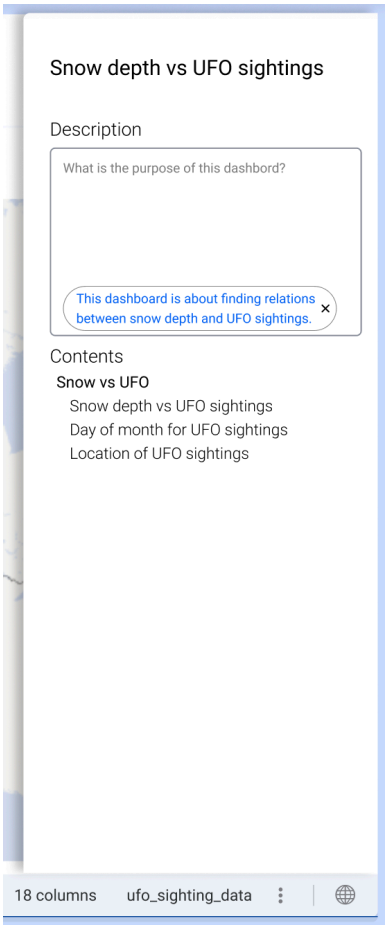

Figure 53: The dashboard description and table of content concept

This function can be opened as a drawer by clicking a button in the toolbar in The Product. The description entered will also be available to screen-readers before opening the analysis-file, so that those users may get a better understanding of what that file will contain, and its purpose.

When tested with users, they expressed that it provided a sufficient overview of the dashboard that created an expectation of what they would find. Therefore making it easier to grasp the connections between visualisations. Specifically, a blind participant expressed that the function increased their ability to comprehend the dashboard, as it provided a necessary overview.

7.2.5 Accessibility Checker

The concept called Accessibility checker is a design solution for requirement D1-D3, D6 and D7. When using this function, the author can easily discover aspects to improve in order to make the dashboard more accessible. All accessibility problems found in the dashboard are marked with the accessibility symbol, described in 7.2.1. Furthermore, the checker shows a summary (Figure 54) of all those issues. In the checker, the author can easily change the settings automatically by clicking the suggested alternative. However, the author can also change the settings manually by pressing the settings icon, as well as

removing the suggestion by clicking the trash can if they feel that it is not relevant.

While the author could fix all of the issues present by navigating different menus and properties windows in The Product, the purpose of the checker is to collect and summarise all of them in a single place. The goal is that the author will fix all issues highlighted by the accessibility symbol as they encounter them, however they might not go into all menus that have settings necessary for creating accessible experiences, and therefore they might miss some critical aspects. By providing an accessibility checker, the author can methodically adjust all necessary settings one by one, without having to navigate through all the menus. Furthermore, authors may also use this function to make old dashboards more accessible.

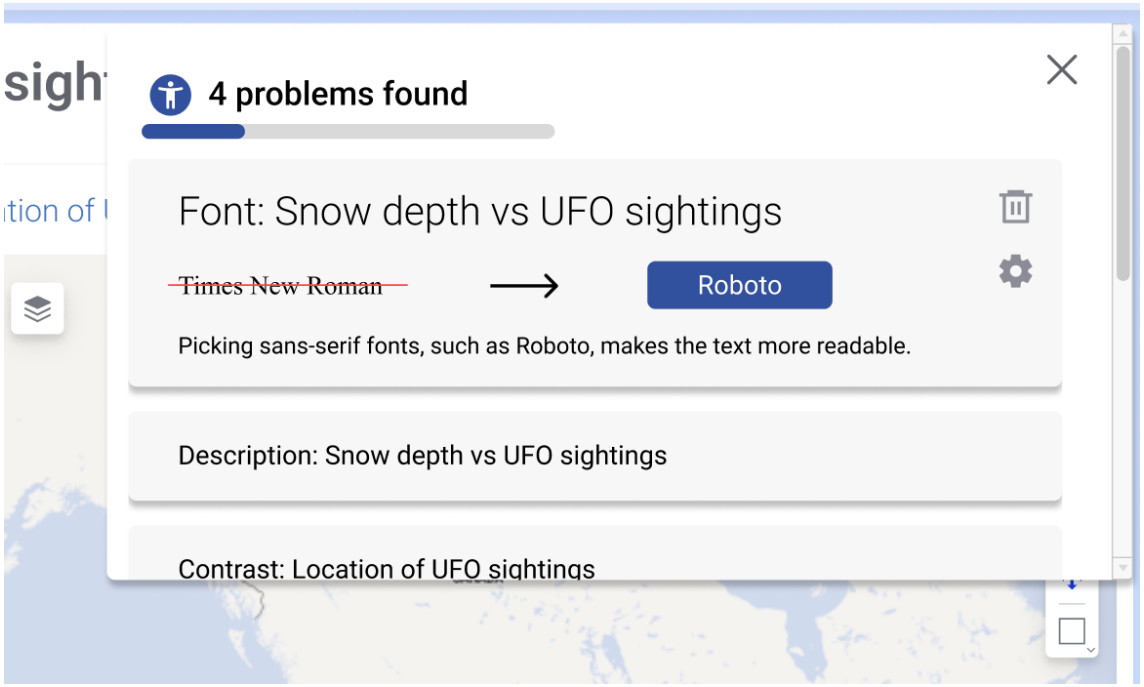

Figure 54: Accessibility checker concept, meant to help authors when designing dashboards

Similar to the colour picker described in 7.2.2, Thaler's (2018) theories of nudging have been applied by making the accessible choice easiest to make, as it stands out from the background and only requires one click. Furthermore, the same principles used in 7.2.1 have been used here in that the author is provided with information regarding why there is an accessibility issue and what they should do instead, creating a learning experience.

The concept received positive attitudes from the user tests and the participants stated that they appreciated having this as a summary. They also mentioned that the interaction was intuitive and rewarding.

7.2.6 Guided Flow

The sixth design is aimed at solving D4 and D6 by expanding on the already existing maximised view in The Product. The core of the design is that it has the author creating a flow of their dashboards and that can then be digested one visualisation at a time, by the

consumers. It also provides some of the most vital information, in text format, alongside the visualisation, creating an experience that is easier to understand.

From the author's perspective, the Guided Flow is auto generated when a dashboard is created. The default order of the visualisations in the flow is left-right, top-bottom in the analysis-file and if it contains several pages, then all the pages are present in the flow. However, the author can choose to hide visualisations in the flow based on their needs. An example of a situation where the hide function could be useful is when a text area is used as a title in the dashboard, or if there is a visualisation that should not be in the flow. Figure 55 shows what it looks like when an author opens the "edit Guided Flow" panel. Another function available is reordering the visualisations in the flow by dragging and dropping them to another place in the order.

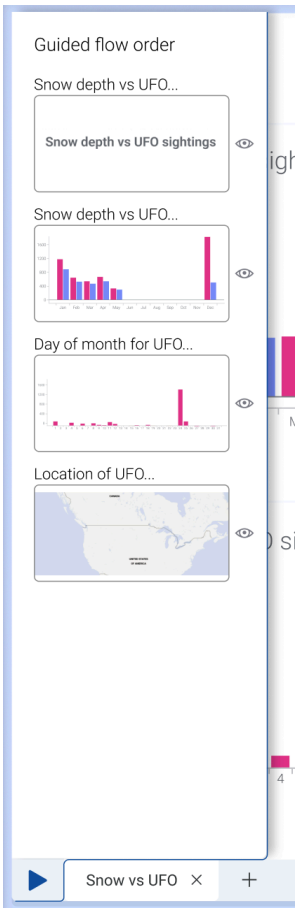

Figure 55: Edit Guided Flow panel

Figure 56 shows the consumer experience of Guided Flow. When using this mode, one visualisation is presented at a time, as described earlier. The consumer can also see an overview of the dashboard in the side panel to the left, accompanied by a description and interactive insights. Moreover, it is possible to mark data in the visualisation, however since the mode only displays one visualisation at a time the connection to other visualisations is not as clear. Therefore, the consumer can see the connected drill-down visualisations in the side panel to the left, to simplify the navigation and make those connections clearer. However, if the consumer moves on to a drill down visualisation without marking anything in the master visualisation, the consumer will encounter an empty visual-

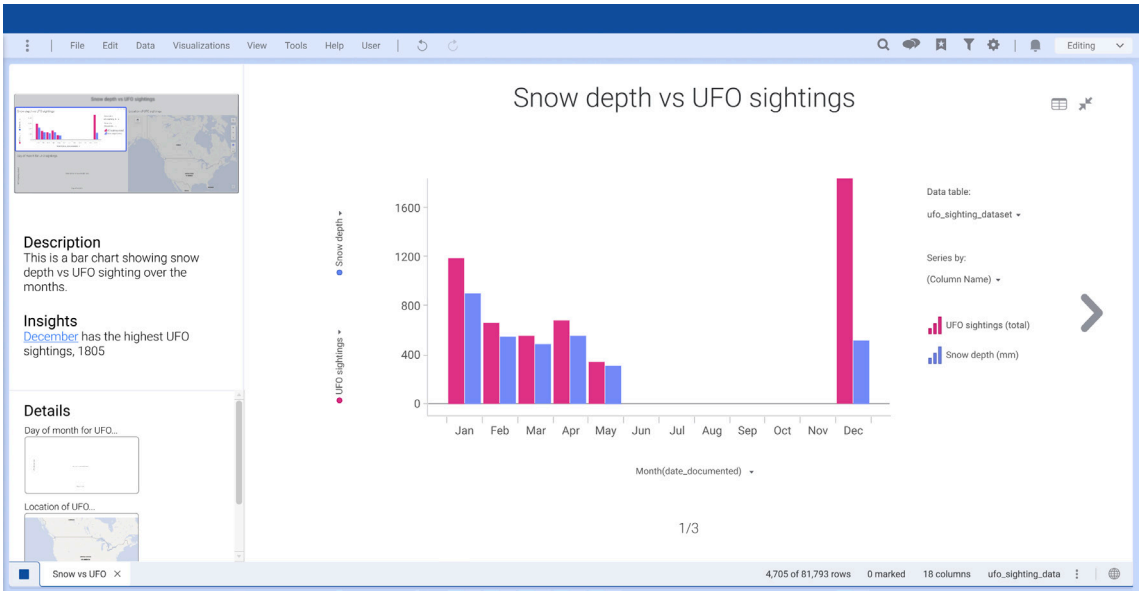

Figure 56: Guided Flow showing one visualisation at a time

isation with a text suggesting the consumer to mark data in the master visualisation. They will also be able to navigate to the connected master visualisation by using the same side panel area where the drill-downs appeared.

The Guided Flow-view minimises the cognitive load by minimising the superfluous content present on the screen, and provides additional modalities alongside the visualisation. Meaning that while the design is aimed primarily towards solving D4 and D6, it may also solve R22 (Provide spacing between elements/components) by minimising the amount of visualisations present at one time, R32 (Navigation should be sequential) by providing a navigational structure and an order that could also be used as a focus order, and R41 (Provide text alternatives for visualisations) by making text alternatives easily accessible for consumers.

In the consumer evaluations of this concept, several participants expressed that they experienced the concepts as intuitive and simple, while still remaining informative. The participants were also positive about having the insights visible in this view. Specifically, a participant with total blindness expressed that they could get an overview of the data as well as explore it in detail. They also stated that they felt that it was a natural flow and that it corresponded well with how they desired to explore the dashboard.

7.2.7 Marking

Three different marking alternatives without path based gestures were conceptualised to meet D5. Two of them only require mouse down and mouse up, whereas the last marking alternative is suitable for consumers who are using a keyboard-only setup. As mentioned previously, in 6.2.7, these concepts were not evaluated in the high fidelity prototype.

Pen Tool

The pen tool is widely used in other programs, such as Figma and the Adobe Suite. With the pen tool, the user is marking an area by creating the outline when left-clicking. The tool makes marking flexible and could, for example, be effective for map charts where the selection requires more precise markings (Figure 57).

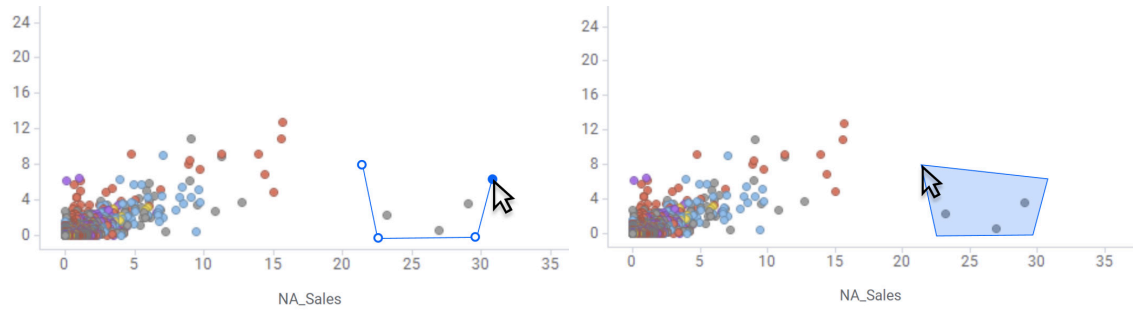

Figure 57: Illustration of how it would look like using Pen-tool concept to mark

Rectangle-click

This tool is similar to the existing rectangle marking tool but instead of using a click, hold and release interaction model to create areas it uses only mouse down. Meaning that the benefits with this tool is that a path based gesture is not required, since the user only needs to click twice to create the marking (Figure 58).

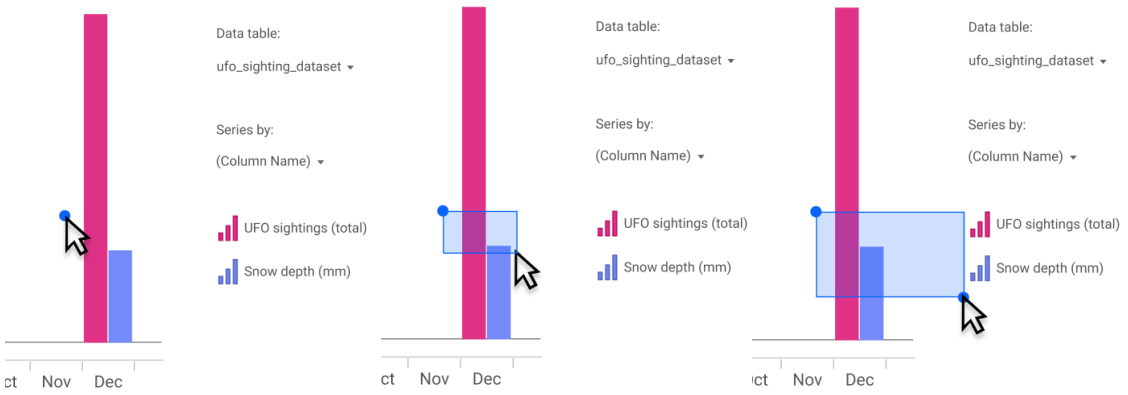

Figure 58: Illustration of how it would look like using rectangle-click concept to mark

Keyboard Marking

The third and last marking alternative only requires a keyboard (Figure 59). By using a shortcut when focused on a visualisation, a rectangle appears in the middle of the visualisation. The user can move the rectangle by using the arrow keys and can adjust its shape by tabbing to the desired corner, and then use the arrow keys (Figure 59). When the user is satisfied with the area, the enter-key is used to confirm the selection.

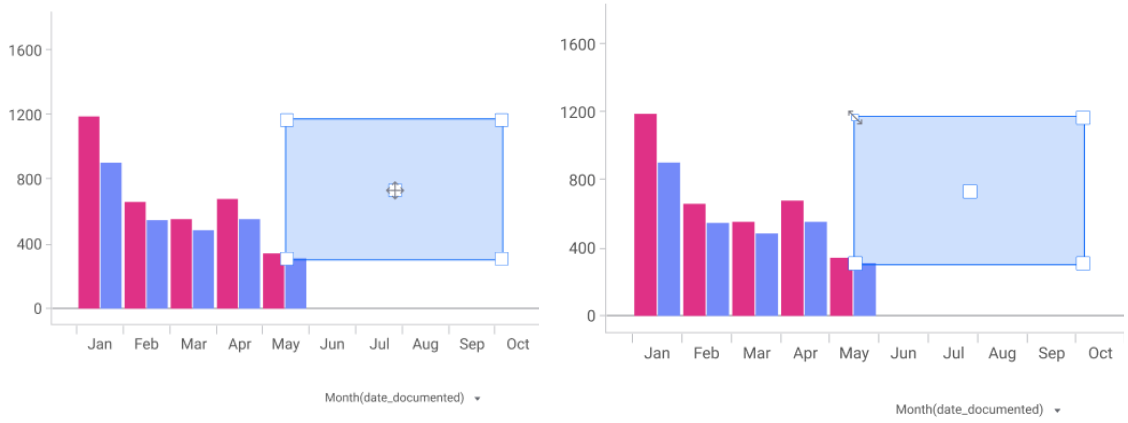

Figure 59: Illustration of how it would look like marking with the keyboard-only concept

7.2.8 Table View

This design is aimed at providing alternative representations for visualisations (D8), by providing an aggregated table view that is automatically created for all visualisations (Figure 60). It is contained in a popover that makes it possible to see and compare both the visualisation and the table at the same time. The function is accessed by clicking a table-icon and is useful if the user would like to dive into the details of the data. Furthermore, this is a way of making the data accessible to screen readers. It is also possible to search in the table if the user is looking for something specific.

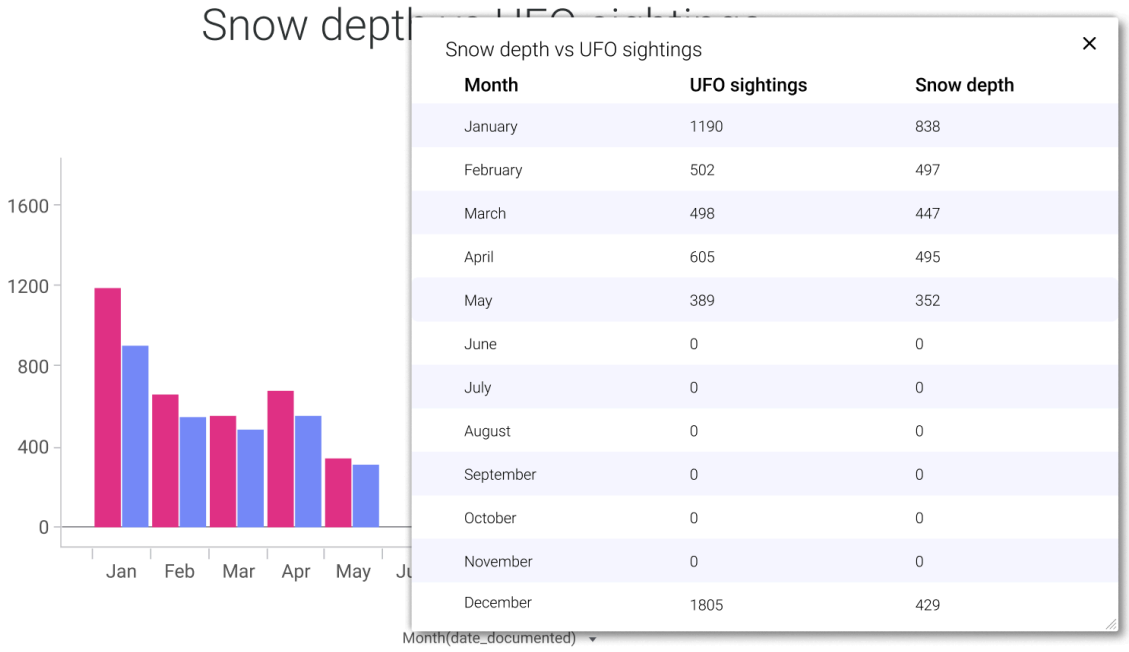

Figure 60: Shows the Table view concept of the visualisation

A similar function is also suggested by Microsoft (2023) and Qlik (n.d-a) as a way of making the visualisations more accessible, since it is screen reader friendly. Furthermore, the table view received positive reactions from evaluations. For example, a blind participant expressed that the table function made the data more approachable to them as they could explore it cell by cell with their screen reader.

8
DISCUSSION

This section will discuss the process of this thesis and the findings it resulted in. The validity and generalisation of the results will also be discussed, along with potential ethical issues and future work.

8.1 Execution and Process

The goal of the process was to answer the following research question:

> *What should data visualisation authors consider when building dashboards and applications with the intent to produce more accessible experiences for users?*

To accomplish this, the process began with a literature review, benchmarking, WCAG evaluations of The Product, and general accessibility interviews. These parts of the process were vital since they created a foundation of knowledge that the rest of the project could build upon. The literature was revisited throughout the project and the library was expanded as new areas of interest were discovered. For example, nudging was explored during a later stage of the project since many of the designs built upon those theories. While the benchmarking was revisited in the later stages of the project, the process could have benefited from exploring it continuously throughout the project, as it would have allowed for a deeper understanding of the competitor's design choices.

Both the WCAG evaluations and the general accessibility interviews were crucial to the process since they created a fundamental understanding of accessibility. The WCAG evaluations served as an introduction to the WCAG criteria, which many of the requirements are based on. The evaluations and the WCAG 2.1 (WAI, 2018) criteria were also revisited throughout the process as more knowledge was gained, allowing for deeper reflections. Furthermore, the general accessibility interviews played an even more important role for the process, as it served as a contact link to individuals with great knowledge about accessibility, both from their own experiences but also from working with these issues. The interviews started a learning process that continued throughout the project. Not only about how to design for accessibility, but also general knowledge about how individuals with different abilities go about life. These lessons have been invaluable,

and could most certainly only have been gained through talking and interacting with the actual individuals. However, this learning curve also meant that the time plan had to change several times. This was because when the project started, it was treated as a traditional interaction design project ,and while creating accessible designs is possible with largely the same methodologies, it puts emphasis on certain aspects of the project, interviews and evaluations for example. Furthermore, it was decided from the beginning that the project would try to have as broad a scope as possible, and not to focus on only one aspect, for example "visual analytics for people with cognitive variations", meaning that the plan had to change from a standard project, to one that had a more shallow approach but instead had a more general perspective of accessibility.

After the first phase of the process it was decided that the main focus would be on the first and second principles of WCAG 2.1 (WAI, 2018), Perceivable and Operable, mainly due to the fact that this was where most issues were found in the evaluations. However, it was also due to the relationship between the principles. While some criteria from the third principle were considered, many of them were regarded as more programmatic counterparts to the criteria in principles one and two. It was also discussed that solving some of the criteria in principles one and two would automatically solve some in three and four. Since, the project was chosen to view accessibility widely, but on a surface level, the third and fourth principles were mostly skipped.

For phase two of the process the methodology was mainly successful. Since it had been understood from the first phase that interviews were crucial for designing accessible solutions, as many as possible were conducted, especially in the empathise and test phases. However, it was quickly discovered that finding participants with accessibility needs was challenging. Many organisations for people with different kinds of impairments were contacted but only the organisation for the visually impaired (SRF) had individuals that wanted to partake in the studies. Furthermore, while UserTesting was efficient in finding participants quickly, it was difficult to screen for participants with different impairments. This entailed that more time had to be spent to find the desired target group. These issues were amplified for focus area two and three as finding the suitable users for those areas required compromising on the prerequisite of visual analytics experience. Therefore, only participants who were inexperienced with visual analytics were reached, which meant that some participants got stuck on things that were not relevant for the test. Potential explanations for the difficulties finding participants with blindness or who only navigate with a keyboard, could be that it is not supported by UserTesting. For example, they might not have implemented support for screen readers or keyboard navigation, thereby excluding those users from the pool of participants. The same issues were then also encountered for the evaluation phase of the design process.

The entire process was conducted iteratively, which was especially apparent for the define phases. During the first and second focus areas, information was collected that also applied to the first focus area. Later, it was also discovered that data that had been collected in the first focus area could be applied in the latter ones. Because of the fluidity of the process, it was also possible to conduct the define phase for area two and three simultaneously. This was because it was realised that they had important correlations between one another. For the remainder of the design process the fluidity was preserved,

which meant that designs from design area one could be iterated while focusing on design area two, because something that could benefit those designs was discovered.

It is possible that the prototypes created in both the low and high fidelity stages had too much of a "polished" look. Since screenshots of the product were used for the low fidelity prototype and a dashboard had been replicated for the high, it meant that the prototypes looked close to The Product. Therefore, several discussions were had on detailed aspects of the designs, such as icon placements, while the interest was on the concepts as a whole. Therefore, the level of detail of the prototypes should reflect the level of the concepts, to communicate the purpose of them. While this probably did not affect the result greatly, it required more effort to explain the purpose of the evaluations.

8.2 Results

The following section will discuss and reflect the results of the process. First the guidelines and requirements will be discussed followed by the final designs, validity and generalisation of the result.

8.2.1 Guidelines & Requirements

A difficulty when analysing the data from the user studies was deciding if a problem was of an accessibility nature or if it was a usability problem. These are quite often linked in some way but there are exceptions to this. While the list of requirements is supposed to be used for developing accessible visual analytics platforms, it is possible that some of the requirements have no connection to accessibility at all, instead they stem from usability issues that were picked up by all participants. However, one could also argue that if a platform has usability issues that creates barriers in the interaction, it is not accessible to anyone. In addition to this, impairments come in many different kinds and durations, as explained by Knaflic (2019). For instance, if someone talks on their phone they have an accessibility need, since they only have one arm available for other interactions. While the most evident individuals with accessibility needs are those with different kinds of impairments, it is easy to forget the temporal aspect. Organ (2022) makes a similar example as he explains that creating colour schemes that are colour-blind-friendly, for example, can help those times when only a black and white printer is available.

Another important aspect is that the List of Requirements was split into two categories, *Guidelines for Authors* and *Requirements for Development of Visual Analytics Platforms*. The main reason being that they have different targets, authors and designers. The research question for this thesis however, is mainly focused on what the authors should consider when creating dashboards. The reason for including design requirements in addition to the author guidelines is that they are meant to enable the author to consider those guidelines. An example of this is that a guideline for authors is "provide text alternatives for visualisations". However, this requires that there is an option in the platform to add the alternative text in the first place, otherwise the guideline is useless. However, all of the requirements do not have such a clear correlation to the guidelines, instead they include important aspects for creating accessible visual analytics experiences, that the author should not have to consider. For example, that tooltips should stay on hover; it is

essential to the accessibility of the product but it is not something that the author can or should control.

8.2.2 Final Designs

Firstly, it is important to discuss the approach to design for the project. As explained in chapter 3.2, Universal design is about creating designs that works for everyone (Nielsen Norman Group, n.d.) and inclusive design is about recognising that all individuals have different abilities. Therefore, the design should be flexible enough to accommodate that (Nielsen Norman Group, n.d.). Lastly, accessible design is about adapting an already existing design so that it becomes accessible (Nielsen Norman Group, n.d.). For this project, the approach has been a mix of all of them, but mainly inclusive and accessible design. This is because instead of changing the design of The Product, new solutions were produced that made it more flexible. Thereby a mix of both adapting an already existing design by incorporating accessible solutions, and making it more flexible was used. However, those solutions were also made with universality in mind, meaning that they should have a benefit for everyone, not just those with accessibility needs. For example, everyone can benefit from having text alternatives, depending on the surrounding factors, impacting the user experience positively for everyone. Furthermore, the additional accessibility features were created with the intent that they would not negatively impact the existing user experience by making it bloated. Rather, emphasis was put on making it discreet, but still effective.

Since the project approached accessibility in general, it meant that the design process also focused on accessibility as generally as possible. While only a few requirements were chosen for design, it still meant that time was short and that the concepts had to be on a low level. In addition to this, the early ideas managed to solve different aspects of the problems presented by the design requirements. This meant that a decision had to be made to either develop some ideas extensively or keep them all, and refine them as much as time allowed. Only choosing a few would mean that not all aspects of the design requirements would be solved, which is why it was chosen to move forward with many concepts instead. As a result, the concepts presented in 7.2 are on a quite low level and should be viewed more as inspiration for future work or a starting point, rather than finished designs.

8.2.3 Validity and Generalisation of the Result

From the literature review and interviews with accessibility experts it became apparent that dialogue with the users are critical when it comes to creating accessible designs. However it was also discovered that since the user group was quite specific, it was difficult to find suitable participants. While the user studies conducted were extensive and done with as varied a pool of participants as possible, the validity of the result could be greatly increased if more resources could be spent on finding the right participants. For example, the marking designs, described in 7.2.7, could not be evaluated because of a lack of access to participants that those designs are intended for. This is not because they do not exist, however, they make up a small part of the entire population, which makes it difficult to find them. Most of the interviews and tests were conducted with individuals with visual impairments, since they were the easiest to find. Efforts were made to find

participants with other impariments, for example physical and cognitive, by contacting swedish associations for individuals with those impairments, but none responded.

In combination with this, it was also desired that the participants had experience with visual analytics, which made the target group even smaller. Furthermore, the platform UserTesting was used extensively since it allowed screening for specific attributes, which made it possible to explore their pool for individuals with accessibility needs. However, one limitation with using this platform is that it could be excluding some users. For example, UserTesting is built around the participant conducting tasks and speaking aloud. But those kinds of tasks ultimately exclude those who are unable to speak. Meaning that some aspect might have been missed. One could argue that the ability to speak does not affect one's ability to analyse data, however it is possible that a similar user group could have been excluded unknowingly.

Another aspect is that finding authors was difficult, even though they did not need to have any accessibility needs. As an effect of this, the final designs were evaluated with two participants who were experts in The Product, but not the intended authors. It is therefore possible that there are some aspects of the author's experience that might have been missed. For consumers however, it was not a problem, since everyone could be a consumer. Contrary to this however, the test participants were given a scenario and a dashboard to explore, meaning that they did not choose to do it themselves, and therefore were not involved or cared too much about the data they were exploring. While this is almost always an issue in design evaluations, it might have entailed that the results are less valid, since the participants might have felt more eager to explore if they cared about their tasks.

An additional effect of the difficulty of finding the right participants is that the expert discussion had to be conducted with experts within design and of The Product. Optimally, these discussions would also have included at least one participant with accessibility needs, creating a deeper understanding of the accessibility aspects. While the expert discussions still yielded results, they could have been even more valuable with that kind of setup. Additionally, the lack of subjects also entailed that the two representatives from the organisation for visually impaired (SRF), were regarded as "expert-users", since they had both great knowledge and experience of accessibility, but also about design. This meant that their feedback was regarded highly in the process, while still not being considered as the only possible solutions.

An important aspect to consider is that the design process aimed at finding a solution to a wicked problem, as described in 4.2. While it can be argued that the design suggestions in this thesis solve the problem, the wickedness entails that the problem has no definitive solution and could therefore have other solutions that were not discovered through this process. In adition to this, the thesis also exemplifies that trying to solve one wicked problem, will create several new wicked problems. Furthermore, it also entails that the solutions can be refined indefinetly, since the problem has no stopping point. For example, when designing a solution where there needs to be an icon present, a new wicked problem is the placement of that icon, as it has no definitive solution.

Lastly, this project concerned evaluations of The Product, and not any of the competitors. The competitors' products were explored in the benchmarking, however they were not tested further. While the guidelines and requirements have been expressed generally to apply to all visual analytics platforms, it is important to acknowledge that some other platforms might not have those issues. The goal was however, that if someone would want to create a new visual analytics product, they could use those requirements to create one that is accessible. Furthermore, the benchmarking was not used to gain inspiration to the designs or guidelines, rather understand the underlying issues of accessibility in visual analytics. However, it is possible that the benchmarking affected the results unconsiously.

8.3 Ethical Issues

As explained by Knaflic (2019) accessibility is broad with many variations and states of impairment. Therefore, it is an area that could not be completely covered in this short amount of time. To analyse the accessibility of design, large sample sizes are required, and if the size is not sufficient, it is difficult to motivate that the solution is accessible to everyone. For this thesis, it meant limiting the scope to a general accessibility overview.

Another ethical issue encountered was that the result will not be completely accessible due to the limited number of reachable users in the target group; users in need of accessibility features that are familiar with analytics platforms. However, one can argue that focus area one, about how information is distinguished and perceived, concerns the highest number of users. Luckily, the target group for that area was also the easiest to find, meaning that the validity of that area is the highest. Furthermore, another ethical aspect is that quotes from the participants were used to exemplify the issues found in the user test and studies. The participants were not explicitly asked for permission for this, however, they were asked if the interviews could be recorded. Therefore, the quotes are anonymous and were chosen so that they did not concern the participants, rather about accessibility issues. Similarly, conducting accessibility interviews meant asking personal questions that might have been sensitive to the participants, therefore they were informed that they did not have to answer the questions if they did not feel comfortable. For example, questions were formualted as "if it is okay with you..." or "if you feel comortable, would you like to tell us about..." for questions regarding sensitive information. They were also informed before the interview that it would regard accessibility aspects and could therefore be personal to them, and had to opt-in to participate.

Lastly, the nudges in the designs were developed with care, to minimise the risk of being unethical. The aim was a helpful, transparent nudge that did not feel intrusive or limiting for the author. As confirmed in the user test, the nudge was experienced as a guide for the author to make better choices.

8.4 Future Work

Due to a limited time frame for this project, some topics of interest remain for future work. A couple of more extensive topics include researching keyboard navigation and contrast for gradients. To cover the topic of keyboard navigation, the commonly used strategies need to be investigated and mapped. Further interviews also need to be conducted to be able

to understand the users' needs properly. Moreover, the use of gradients quickly becomes a complex issue when high contrast is required, requiring more extensive research to find the proper guidelines and requirements Furthermore, the marking alternatives needs to be evaluated further since it was not possible to include this in this thesis, as described in 6.2.7. The desired target group needs to be addressed and their experience must be evaluated to be able to verify the accessibility of the design. In addition to this, WAI-ARIA (WAI, 2023-a) needs to be explored further to invistigate how to implement the requirements, from a developers perspective, as described in 6.3.2.

Another aspect for future work that would not need as much research is making it clearer what is marked in Guided Flow. For instance, if a master visualisation containing a bar chart with one bar for each month is viewed, and December is marked. Then, if the user proceeds to the drill down, there should exist some indication of what it is that the consumer marked, to minimise navigational excise. Furthermore, another small adjustment would be to give the author feedback when creating insights in the visualisations, such as a preview or similar in the properties panel. Moreover, more research is also needed to determine the best way to display both the descriptions and insights to the consumer.

Additionally, the guidelines for authors need to be evaluated on the intended user group, since the experience of interpreting the guidelines have not yet been investigated. This is a vital aspect to test since it will reveal if the guidelines are possible to understand and use when creating dashboards with the intent to make it more accessible. Furthermore, a summative evaluation needs to be conducted in order to compare the performance of the new design prototypes with The Product.

Finally, emphasis should be on a more extensive accessibility research overall since it is difficult to capture all accessibility needs at once. It is important to analyse all different types of impairments to be able to make a product completely accessible.

9
CONCLUSION

This thesis was conducted in collaboration with The company with the purpose to answer the following research question:

What should data visualisation authors consider when building dashboards and applications with the intent to produce more accessible experiences for users?

To answer the research question, a pre-study and an iterative design process was executed. The pre-study consisted of literature reviews, general accessibility interviews and WCAG evaluations of The Product. The design process consisted of five phases; empathise, define, ideate, prototype and test. The two first phases were conducted for three different focus areas: Distinguishable, Operable and Interpretable. During these phases, several interviews, and a KJ-analysis for each respective focus area, were conducted. The phases resulted in 15 guidelines for authors and 42 requirements for developers of visual analytics platforms. The guidelines are meant to aid the author in making accessible choices when creating dashboards in visual analytics applications. The requirements are meant to enable the author to make accessible choices by providing suitable functionality. The requirements and guidelines were divided into ten sections that made up a general list of requirements and guidelines, meant to provide an overview. These are summarised in the list below:

Guidelines for Authors:

- Use colours with high contrast and be consistent
- Make your content descriptive and readable
- Minimise complexity of your visualisations, and dashboard as a whole

Requirements for Development of Visual Analytics Platforms:

- Provide distinguishable colours
- Provide distinguishable text
- Provide assistive information
- Support assistive technologies
- Minimise visual and navigational complexity
- Support alternative interaction
- Provide alternative representations

From the 42 requirements, the following eight requirements were chosen for design. The decisions were based on the value of the requirement for The Company as well the size of the design space.

- Provide contrast for interface components, at least 3:1
- Provide contrast for text, at least 4.5:1
- Provide text larger than 16 pixels
- Provide resizing without loss of content
- Provide alternative to path-based gestures for marking in visualisations
- Provide text alternative for visualisations
- Provide overview of dashboard
- Provide alternative representations for visualisation

These were divided into three design areas: Accessible Perception, Alternative Marking and Alternative Representation. To create designs that would fulfil these requirements the remainder of the phases of the design process were conducted. The ideate and prototype phases were conducted in three iterations, one for each design area, and consisted of ideation, evaluation and prototyping methods. Finally, the test phase was conducted for all of the ideas. It consisted of a formative evaluation with ten participants, where two tested both the author experience together with the consumer experience, and eight solely the consumer experience. The tests resulted in some minor improvements of the prototypes as well as some aspects for future work. However, the participants expressed an overall positivity toward the final designs. The purpose of these designs were to give examples of how visual analytics platforms can be designed to enable authors to make accessible choices, as well as show some functions that make the platform more accessible overall.

Lastly, more extensive research needs to be conducted to be able to capture all accessibility needs. Specifically, keyboard navigation, contrast of gradients and the marking alternatives presented need to be investigated further. However, this research was an eye-opener for The company since there are great opportunities for improvement in The Product. The Company also expressed that they are satisfied with the final results and emphasised the importance of this topic for The Product.

10
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APPENDIX

Appendix A - UserTesting Interview Template, Focus Area 1

Single choice	Multiple Choice	Written response	Verbal response
Task	Rating	Scenario	Reject

Screening filter

Single choice - Web experience

Screening questions

Single choice - We are collecting perspectives about experiences related to contributors' mental and physical status that includes Personal Health Information (PHI). We will use this information to understand your needs and preferences. None of this information will be shared publicly; it will only be used by the teams who are working on projects related to the topics covered in this test. Are you willing to participate in this study?(single select)

- Yes, I am willing to participate in this study
- No, I am not willing to participate in this study

Multiple choice - Are you familiar with any of the following data visualisation software?

- Domo
- IBM
- Looker
- MicroStrategy
- Microsoft PowerBI
- Oracle
- Qlik
- SAP
- Sisense
- Tableau
- ToughSpot
- TIBCO Spotfire
- Yellowin
- None of the above

Single Choice - What, if any, difficulties do you have seeing?

- I prefer not to answer
- I have no visual difficulties
- Low vision (e.g., blurry vision, seeing only the middle of the visual field, seeing only the edges of the visual field, clouded vision, glaucoma, light sensitivity or night blindness)
- Blindness (i.e., substantial loss of vision in both eyes.)
- Colour blindness (i.e., difficulty distinguishing between colours generally red and green, or yellow and blue, and sometimes the inability to perceive any colour.)

Test

Verbal - If it's okay with you, would you like to tell us a bit about your visual impairment?

Verbal - Does your visual impairment affect how you use the computer? Please explain.

Multiple Choice - What, if any, assistive devices or software do you use with your computer? (choose all that apply)

- I prefer not to answer.
- I do not use an assistive device.
- I use a screen reader (e.g., VoiceOver, JAWS, ZoomText, etc.).
- I use a monitor magnifier.
- I use a Braille translator.
- I use electronic glasses (e.g., eSight).
- I zoom in or use other software options.
- I use a device or technology that is not included in this list. (You must be willing to demonstrate or describe how it works during the test) Other…

Scenario - Imagine you are about to fly from Los Angeles (LAX) to Miami (MIA) for a vacation. Since your cousin is going to pick you up at the airport in Miami, you would like to inform them about the average airline delay so they know when to expect you. Therefore, you are looking at an analysis to find the desired information.

Task - Go to the folder (---) and open the visualisation called "Predicting Airline Delays Cleaned".

Verbal - If you look at delays by carriers, what is the percentage of delayed flights for DL?

Verbal - How did you experience finding this data?

Verbal - If you look at the "Flight Destinations" map, how many airports can you find in or the vicinity of Miami?

Rating scale - How did you experience finding this data?

Verbal - If you look at the "Weather metrics at destination". What are the highest values of the vertical axis to the right?

Verbal - How did you experience finding this data?

Verbal - Navigate to the predictions page. Select LAX as the airport. Which days of the month have the most delayed flights?

Verbal - How did you experience finding this data?

Verbal - Navigate to page called “Predictors and misclassifications” and look at the visualisation for misclassification rate vs predictor values for CART, Random forest, Boosted trees. Change the filter on the left to “DayofMonth”. For Random forest, which days have the lowest misclassification rate?

Verbal - How did you experience finding this data?

Verbal - For CART, which days have the lowest misclassification rate?

Verbal - How did you experience finding this data?

Verbal - For Boosted trees, which day has the highest misclassification rate?

Rating - How did you experience finding this data?

Appendix B - UserTesting Interview Template, Focus Area 2

Single choice	Multiple Choice	Written response	Verbal response
Task	Rating	Scenario	Reject

Screening filter

Single choice - Web experience

Screening questions

Single choice - We are collecting perspectives about experiences related to contributors' mental and physical status that includes Personal Health Information (PHI). We will use this information to understand your needs and preferences. None of this information will be shared publicly; it will only be used by the teams who are working on projects related to the topics covered in this test. Are you willing to participate in this study?(single select)

- Yes, I am willing to participate in this study
- No, I am not willing to participate in this study

Multiple choice - Are you familiar with any of the following data visualisation software?

- Domo
- IBM
- Looker
- MicroStrategy
- Microsoft PowerBI
- Oracle
- Qlik
- SAP
- Sisense
- Tableau
- ToughSpot
- TIBCO Spotfire
- Yellowin
- None of the above

Single Choice - What, if any, difficulties do you have seeing?

- I prefer not to answer
- I have no visual difficulties
- Low vision (e.g., blurry vision, seeing only the middle of the visual field, seeing only the edges of the visual field, clouded vision, glaucoma, light sensitivity or night blindness)
- Blindness (i.e., substantial loss of vision in both eyes.)
- Colour blindness (i.e., difficulty distinguishing between colours generally red and green, or yellow and blue, and sometimes the inability to perceive any colour.)

Multiple Choice - What do you use to navigate your computer?

- I prefer not to answer
- I use a mouse
- I use trackpad
- I use mouse and keyboard
- I use only keyboard (No pointer devices)
- I use some other assistive devices (i.e. joystick, mouth-stick etc.)

Information

Some of the tasks in this test might not be possible to complete. If you get stuck for too long, don't hesitate to move on to the next task. However, please express why you got stuck and what you would have wanted to happen instead.

Credits for dataset: https://www.kaggle.com/datasets/sidtwr/videogames-sales-dataset

Test

Multiple Choice - What, if any, assistive devices do you use with or in place of your keyboard?

- I do not use any assistive devices
- Intellikeys
- KeyGuards
- KeyWizard [reject - misdirect]
- BigKeys
- KidGlove
- On-Screen keyboard
- Chording keyboard
- Speech to text software
- I use a device or technology that is not included in this list (You must be willing to demonstrate or describe how it works during the test)

Verbal - If it's okay with you, would you like to tell us why you have chosen to navigate your computer that way?

Multiple Choice - What, if any, assistive devices do you use with or in place of your mouse?

- I do not use any assistive devices
- Adaptive keyboard
- Joystick
- Trackball
- Trackpad
- Switch interface
- Sip and puff
- Mouth-stick
- I use a device or technology that is not included in this list (You must be willing to demonstrate or describe how it works during the test)

Verbal - If it's okay with you, would you like to tell us why you have chosen to navigate your computer that way?

Multiple Choice - What, if any, other assistive devices or software do you use with your computer?

- I prefer not to answer.
- I do not use an assistive device.
- I use a screen reader (e.g., VoiceOver, JAWS, ZoomText, etc.).
- I use a monitor magnifier.
- I use a Braille translator.
- I use electronic glasses (e.g., eSight).
- I zoom in or use other software options.
- I use a device or technology that is not included in this list. (You must be willing to demonstrate or describe how it works during the test)

Verbal - If it's okay with you, would you like to tell us why you have chosen to navigate your computer that way?

Scenario - Imagine that you are a videogame designer and are about to start a new game project. In order to decide what your new game should be, you need to get an overview of different trends in the gaming community. Therefore you will have a look at an analysis to find this data.

Task - Go to the folder (---) and open the visualisation called "Video Games".

Verbal - In the Visualisation "Global Sales per Platform", mark Playstation, Nintendo and Microsoft. What was the most popular genre for these consoles in Japan?

Rating scale - How did you experience finding this data?

Verbal - In the "Filters" panel, select the Publisher "1C Company". What were the Global sales for PC?

Verbal - How did you experience finding this data?

Verbal - Navigate to the page called "Global sales". If you are not able to do this, please use the following link (...) and open the analysis called "Page 2".

Verbal - How did you experience finding this data?

Verbal - Click the button "Adventure" in the filters panel to the right. Please navigate to the table "Sales per Genre". What is the total global sales for this genre?

Verbal - How did you experience finding this data?

Verbal - Click the button "Role-playing" in the filters panel to the right. Please navigate to the bar chart "Global Sales per Game Title". Use the zoom-slider below the visualisation to find the game with the highest Global Sales.

Rating - How did you experience finding this data?

Appendix C - UserTesting Interview Template, Focus Area 3

Single choice	Multiple Choice	Written response	Verbal response
Task	Rating	Scenario	Reject

Screening filter

Single choice - Web experience

Screening questions

Single choice - We are collecting perspectives about experiences related to contributors' mental and physical status that includes Personal Health Information (PHI). We will use this information to understand your needs and preferences. None of this information will be shared publicly; it will only be used by the teams who are working on projects related to the topics covered in this test. Are you willing to participate in this study?(single select)

- Yes, I am willing to participate in this study
- No, I am not willing to participate in this study

Information

Some of the tasks in this test might not be possible to complete. If you get stuck for too long, don't hesitate to move on to the next task. However, please express why you got stuck and what you would have wanted to happen instead.

Credits for dataset: https://www.kaggle.com/datasets/sidtwr/videogames-sales-dataset

Test

Multiple Choice - What, if any, other assistive devices or software do you use with your computer?

- I prefer not to answer.
- I do not use an assistive device.
- I use a screen reader (e.g., VoiceOver, JAWS, ZoomText, etc.).
- I use a monitor magnifier.
- I use a Braille translator.
- I use electronic glasses (e.g., eSight).
- I zoom in or use other software options.
- I use a device or technology that is not included in this list. (You must be willing to demonstrate or describe how it works during the test)

Verbal - If it's okay with you, would you like to tell us a bit about your visual impairment?

Scenario - Imagine that you are a videogame designer and are about to start a new game project. In order to decide what your new game should be, you need to get an overview of different trends in the gaming community. Therefore you will analyse the data to find insights.

Task - Go to the folder (---) and open the visualisation called "Video Games 1".

Verbal - What platform had the highest global sales?

Verbal - How did you experience finding this data?

Verbal - In the Visualisation "Global Sales per Platform", mark Playsation, Nintendo and Microsoft. What was the most popular genre for these consoles in Japan?

Rating scale - How did you experience finding this data?

Verbal - In the “Filters” panel, select the Publisher “1C Company”. What were the Global sales for PC?

Verbal - How did you experience finding this data?

Verbal - Navigate to the page called “Global sales”. If you are not able to do this, please use the following link (---) and open the analysis called “Video Games 2”.

Verbal - How did you experience navigating here?

Verbal - Click the button “Adventure” in the selections panel to the right. Please navigate to the table “Sales per Genre”. What is the total global sales for this genre?

Verbal - How did you experience finding this data?

Verbal - Click the button “Role-playing” in the selections panel to the right. Please navigate to the bar chart “Global Sales per Game Title”. Use the zoom-slider below the visualisation to find the game with the highest Global Sales.

Rating - How did you experience doing this?

Appendix D - Final test: SRF

- Is it OK if we record this interview?

Scenario:
You are a data enthusiast that likes to find connections in data that might not be apparent at first sight. You have found an analysis that compares snow depth and UFO sightings in North America. The analysis is created by someone in the forum that you found it in and you are now ready to deep dive into the analysis to explore it!

Task 1: Start Guided Flow
Start with opening the analysis file. As a first step, tab and can hear the following instructions from the screen-reader:

```
Start guided flow
Skip to main content
Accessibility help
Accessibility feedback
```

- How do you interpret this information?
- What do you expect from each function?

Task 2: Table of Content
Choose Guided Flow and listen to the following:

`Table of content / dash description`

- How do you interpret this information?
- What kind of function do you think this is?

Task 3: Snow depth vs UFO sightings
Tab to the next visualisation, you will hear the following:

```
Titel
Description
Insights
```

- What was this visualisation about?
- Vilket är det högsta värdet för UFO sightings och vilken månad var det? What is the highest value for UFO sightings and which month was it?
    - When did you hear that info?

Task 4: Table
Navigate to the function “table view”, to get a representation of the visualisation as a table.

```
Table
```

- What do you think of this functionality?
- Are you able to understand the data using this function?
- If you would like to find the month with the highest snow level, how would you do that?

Task 5: Day of month for UFO sightings
Close table view in order to explore the analysis further. Navigate to the next visualisation and listen, you will hear the following:

```
There is nothing displayed in this visualisation. This is a details
visualisation of visualisation 1, mark items to view details here.
Click to go to master visualisation.
```

- What do you do now?

Navigate to the previous visualisation and mark data by using insights. Listen for the following:

```
Titel
Description
December has the highest UFO sightings, 1805
```

Click the link and navigate to the next visualisation.

```
Titel
Description
Insights
```

- What is this visualisation about?
- Which day in december has the most UFO sightings

Questions for discussion:

- How did you experience interpreting the visualisations?
  - What worked well?
  - What did not work well?
- What did you think of the flow?
  - You were presented with the visualisations one at a time, what did you think of this?
- Any final thoughts?

Appendix E - Final test: The Company

- Is it OK if we record this interview?
- Do you have any visual impairment?

Scenario:
You are a data enthusiast that likes to find connections in data that might not be apparent at first sight. You have found an analysis that compares snow depth and UFO sightings in North America. The analysis is created by someone in the forum that you found it in and you are now ready to deep dive into the analysis to explore it!

Author
Task 1: Colour picker
You feel almost ready with the dashboard and are in the settings for visualisation titles. You want to try a light blue colour that is more discreet because you want the visualisations to be in focus.

- Do you think this colour is accessible?
    - Why/why not??
- How did you experience this function?
    - How do you think this function works?
- How do you interpret the symbol that appeared?
    - Did you notice the symbol?

Instead you choose the colour that is suggested as the closest alternative that is AAA conformant.

Task 2: Description visualisation
The final change will be to add a description to your first visualisation because you want to help consumers get an overview and insights from it. Therefore, you go into properties to fix this. You also think that it is important that the consumer realises that December is the month with the most UFO sightings.

- How did you experience this function?
- Did the symbol support you?
- What do you think the insight function is about and how does it work?
- What do you expect from the interaction model for description/insights?

Task 3: Accessibility Checker
Now you feel happy with the dashboard and want to double check that it is accessible for everyone. Navigate to the menu bar, and further to “Accessibility checker”.

- What do you think this is and what do you expect?

Task 4: Font Picker
You quickly want to adjust your font settings on your text for “column selectors” according to what is suggested in the checker.

- How did you experience this?
- If you would like to change to another font, where would you have pressed instead?
    - What do you expect from this interaction?

Task 5: Description dashboard
You see that the next line in the checker is about the dashboard description and therefore you want to add one.

- How do you add a description from here?

You are in a new function that acts as a table of contents.

- What do you expect from a table of contents?
- Can you interact with things here? How?

Task 6: Guided Flow
There is another new function called “Guided flow” where the author can create a flow that then shows the visualisations one by one to consumers. Right-click on the icon in the page-bar to access the editing flow panel. You do not want the title box to be visible in your flow and therefore you press the “Hide icon”.

- How did you experience this function?

You would like to change the order of the first and second visualisations.

- How would you do it?

You change your mind and swap it back.

Consumer

Task 1: Guided Flow

You want to start Guided Flow as a consumer.

- Where do you find this function?

Task 2: Description visualisation

- How did you feel about descriptions/insights presented in this way?
- Do you see any connection between UFO sightings and Snow depth?

You want to see the data in detail and open the visualisation in a table

- What do you think of this format?

Navigate to the second visualisation in the flow.

- How would you do it?

It is a details-visualisation.

- If you want to find out more about December, how would you do to show this here?

Navigate to the third and final visualisation. To get a more specific selection of markers in the map, mark December 1st.

- Can you draw any conclusion? Is there any connection between snow depth and UFO sightings?

Check December 24 instead.

- Can you draw any conclusion?
- Why do you think there were so many UFO sightings that day?

Questions for discussion:

- As an author, how did you experience creating a dashboard that is more accessible?
- Did you experience that the dashboard became more accessible?
- Did you experience that the tools available guided you to create a more accessible dashboard?
    - What did you like?
    - What did you like less?

Do you have anything to add?

Appendix F - Final test: UserTesting

Single choice	Multiple Choice	Written response	Verbal response
Task	Rating	Scenario	Reject

Screening filter

Single choice - Web experience

Screening questions

Single choice - We are collecting perspectives about experiences related to contributors' mental and physical status that includes Personal Health Information (PHI). We will use this information to understand your needs and preferences. None of this information will be shared publicly; it will only be used by the teams who are working on projects related to the topics covered in this test. Are you willing to participate in this study?(single select)

- Yes, I am willing to participate in this study
- No, I am not willing to participate in this study

Multiple choice - Are you familiar with any of the following data visualisation software?

- Domo
- IBM
- Looker
- MicroStrategy
- Microsoft PowerBI
- Oracle
- Qlik
- SAP
- Sisense
- Tableau
- ToughSpot
- TIBCO Spotfire
- Yellowin
- None of the above

Single Choice - What, if any, difficulties do you have seeing?

- I prefer not to answer
- I have no visual difficulties
- Low vision (e.g., blurry vision, seeing only the middle of the visual field, seeing only the edges of the visual field, clouded vision, glaucoma, light sensitivity or night blindness)
- Blindness (i.e., substantial loss of vision in both eyes.)
- Colour blindness (i.e., difficulty distinguishing between colours generally red and green, or yellow and blue, and sometimes the inability to perceive any colour.)

Single choice - Are you able to correct your visual impairment with glasses?

- Yes, I can see quite clearly when I use my glasses
- No, my vision is still impaired when I wear glasses.
- I don't wear glasses.

Scenario - You are a data enthusiast that likes to find connections in data that might not be apparent at first sight. You have found an analysis that compares snow depth and UFO sightings in North America. The analysis is created by someone in the forum that you found it in and you are now ready to deep dive into the analysis to explore it!

Test

Verbal - If it’s okay with you, would you like to tell us a bit about your visual impairment?

Task - What you're seeing right now is the analysis that you will explore. You are now going to test a mode called Guided flow. Press the play button in the lower left corner.

Task - Without leaving this page, in your own words, describe what you think you can do in this mode? Be specific.

Verbal - You are now presented with a visualisation. What is this visualisation about?

Verbal - Do you see any relation between snow depth and UFO sightings?

Verbal - What month had the highest UFO sightings? How many?

Rating scale - How did you experience finding this data?

Task - Open the visualisation in a table format by pressing the icon in the top right.

Verbal - Do you think this format would help you interpret the data?

Task - Close the table by pressing the "x" in the top right.

Task - Navigate to the next visualisation.

Task - This visualisation shows a day by day view for the current month selected. Which days had no UFO sightings in december?

Rating scale - How did you experience completing this task?

Task - In the "Day of month for UFO sightings visualisation", mark the 1st of December and navigate to the next visualisation.

Verbal - Can you see any relation between UFO sightings and Snow depth?

Task - In the "Day of month for UFO sightings visualisation", mark the 24th of December and navigate to the next visualisation.

Verbal - Can you draw any conclusions? Why do you think there are so many UFO sightings on the 24th of December?

Verbal - How did you experience the Guided Flow?

Verbal - Did you find this prototype accessible? Why? Why not?

Task - What 3 words would you use to describe this mode? Explain your answer.