JÖNKÖPING UNIVERSITY
School of Engineering

Improving Graphical User Interfaces for Visual, Physical and Hearing Disabilities

Main Subject area: *Computer Engineering*
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JÖNKÖPING 2024/02

This final thesis has been carried out at the School of Engineering at Jönköping University within Computer Engineering. The authors are responsible for the presented opinions, conclusions and results.

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Scope: 15 hp (first-cycle education)

Date: 2024-06-05

I. Abstract

This bachelor thesis investigates the accessibility challenges faced by individuals with visual, physical, and hearing disabilities when interacting with the ticketing application of public transport, focusing on Zbiletem. Drawing on a thematic analysis methodology, data was collected through interviews and literature review. The study aligns with the Web Content Accessibility Guidelines (WCAG) and emphasises a user-centred design approach. Findings reveal significant challenges for visually impaired users due to lack of alternative text. Users with physical disabilities encountered navigation difficulties, while those with hearing impairments faced fewer challenges. The study underscores the importance of inclusive design practices and highlights the need for developers to consider diverse user needs. Recommendations include enhancing alternative text for images and textual elements to help technological tools such as VoiceOver read relevant information. Overall, this research contributes valuable insights into enhancing accessibility in public transport applications, aiming to create more inclusive digital environments for users with disabilities.

Keywords:

Graphical User Interfaces (GUIs), Accessibility, Disabilities, Thematic Analysis, Web Content Accessibility Guidelines (WCAG), Public Transport Applications, Inclusive Design, Assistive Technologies, Usability Testing, Infospread

II. Table of contents

1 Introduction

In today's rapidly evolving digital world, accessibility has emerged as a fundamental aspect of product development. This study, conducted in partnership with Infospread AB, examines the complicated world of digital accessibility and usability solutions. They provided their bus ticketing application as a practical case study for the research. The purpose of choosing a bus ticketing application for this research is because public transportation services are important for ensuring inclusivity and accessibility in public environments. By focusing on improving the accessibility of this specific digital interface, the aim is to address real-world challenges faced by individuals with disabilities in their daily lives.

Infospread is an entrepreneur-driven product development company based in Jönköping. Since its inception in 2005, Infospread has been at the forefront of innovation in the field of public transport and mobility solutions. With a mission to simplify the delivery of information to people on the move, Infospread focuses on collective, ground travel within and between regions (Infospread, n.d.).

“Designing products that are accessible means creating them in such a way that individuals with a wide range of abilities can use them.” (EDL, 2023). Accessibility is important today, where technology plays a significant role. By ensuring that digital platforms are accessible to individuals with disabilities, digital products can gain more users over time. Moreover, accessible digital solutions do not only benefit users with disabilities but also enhance the overall user experience for all individuals, thereby driving users’ satisfaction and loyalty.

Building upon the established foundation, the focus of this study is on improving Graphical User Interfaces (GUIs) to fulfil the needs of individuals with visual, physical, and hearing disabilities. As technology continues to evolve, the opportunities to enhance accessibility and inclusivity in digital interfaces follow. The intersection of design and disability presents unique challenges and opportunities for innovation. By addressing the specific needs and preferences of users with visual, physical, and hearing disabilities, the aim is to contribute to make the world more accessible for everyone.

The significance of this research extends beyond theoretical discussion, it has real-world implications for individuals with disabilities who rely on digital interfaces for communication, information access, and social participation. By bringing together different areas of knowledge and expertise, this research can foster the creation of user-friendly digital products and services. It aspires to create meaningful outcomes that benefit users with visual, physical, and hearing disabilities and contribute to the overall digital world.

Furthermore, this study aligns with broader aspirations towards inclusivity and diversity. As organisations increasingly recognize the value of diversity in their workers' and customers' base, there is a growing demand for accessible and inclusive design solutions. By embedding accessibility principles into the core of GUI design processes, these solutions can cater to a wider range of users, ultimately fostering a more inclusive and equitable society.

In this chapter, the background for the report is presented, and the problem area the study is addressing. Further, the purpose and the research questions are presented. The scope and delimitations of the study are also described. Lastly, the disposition of the thesis is outlined.

1.1 Problem statement

GUIs are the interaction solution between the users and the computer, yet many websites or mobile applications overlook the needs of individuals with disabilities, which leads to preventing them from full societal participation. With an estimated 1.3 billion people experiencing a significant disability today, which is roughly around 16% of the global population (World Health Organization, 2023), creating inclusive digital environments is something crucial.

This study aims to address a gap in GUIs design for individuals with disabilities. This gap specifically refers to the oversight of the needs of individuals with disabilities in many websites or mobile applications, resulting in their exclusion from full societal participation. The focus is on examining the general shortcomings in GUI designs for individuals with disabilities, with specific consideration given to three types: visual disability, physical disability, and hearing disability. The reason for selecting these three disabilities is grounded in their prevalence, as they represent among the most common disabilities (University of Rochester, n.d.).

This study aims to address a significant gap in GUI design, namely, the oversight of the needs of individuals with disabilities in many websites or mobile applications. By examining GUI design for individuals with disabilities, specifically, three disabilities will be considered in this study: visual disability, physical disability, and hearing disability. The reason for selecting these three are grounded in their prevalence, as they represent among the most common disabilities (University of Rochester, n.d.).

The problem is regarding the design limitations of GUIs, specifically for individuals with the previously mentioned disabilities. While accessibility guidelines such as the Web Content Accessibility Guidelines (WCAG) exist, the ongoing issue persists. The current design standards may not fully meet the needs of individuals with visual, physical, and hearing disabilities, highlighting a gap between existing guidelines and practical implementation.

Based on past research, it is evident that few studies have really investigated making GUIs more user-friendly for people with visual, physical, and hearing disabilities. This will act as the foundation of this study, its aim being to fill in the research gap regarding improving the GUIs for people with the previously mentioned disabilities.

By identifying the needs of individuals who suffer from the earlier mentioned disabilities and addressing them, it is not just going to solve a problem for one or two groups, but also it will contribute to an extended conversation about making digital interfaces accessible for everyone.

This thesis is grounded on established design guidelines and standards, such as the WCAG and the International Organization for Standardization (ISO) accessibility standards. As the World Wide Web Consortium (W3C) emphasises,

> Web accessibility means that websites, tools, and technologies are designed and developed so that people with disabilities can use them. More specifically, people can perceive, understand, navigate, interact, and contribute to the Web.

(World Wide Web Consortium, 2023).

Incorporating these standards into the research ensures a commitment to universal accessibility, promoting an inclusive digital experience for users of all abilities.

1.2 Purpose and research questions

The goal of this research is to improve the usability and accessibility of the User Interfaces (UIs), and the User Experience (UX) for people with visual, physical, and hearing disabilities. The focus is on creating guidelines and finding solutions to enhance the accessibility of UIs for individuals affected by these specific disabilities.

The purpose of selecting a bus ticketing application for this research was to focus on improving the usability and accessibility of digital interfaces specifically tailored to individuals with visual, physical, and hearing disabilities. By utilising a bus ticketing application as the case study, the aim is to develop guidelines and solutions that enhance accessibility for users facing these particular challenges. This choice allows for a practical examination of real-world scenarios encountered by individuals with disabilities in their daily interactions with digital interfaces.

To investigate the differences in designing GUIs for individuals with a singular disability compared to the individuals with a combination of disabilities, the first question delves into the specific challenges and requirements associated with each disability category. This comparison aims to uncover the key differences, providing valuable insights when it comes to designing GUIs for each disability category, thereby promoting inclusivity in digital interfaces.

Therefore, the study’s first question is:

1. *What are the key differences in designing graphical user interfaces for individuals with singular disabilities compared to those with combinations of disabilities?*

To explore the interactions that individuals with visual, physical, and hearing disabilities have with the bus application, the second question delves into understanding the key differences of each disability group when using the application. By examining the differences in their interactions, the study aims to uncover insights into the usability and accessibility requirements specific to each disability category. This comparative analysis will provide valuable information for designing more inclusive applications that cater to the diverse needs of users with the previous mentioned disabilities.

Therefore, the study's second question is:

2. *How do individuals with visual, physical, and hearing disabilities differ in their interaction with the ticketing application of public transport?*

1.3 Scope and limitations

Even though the ambition is substantial, it is important to outline the scope of this research. The primary focus will be on GUIs, investigating their usability for people with the earlier mentioned disabilities. The aim is to offer valuable solutions for these specific disabilities, recognizing the importance of making digital interfaces accessible for all.

However, it is crucial to acknowledge the complexity of addressing every aspect of visual, physical, and hearing disabilities. While the research strives to provide meaningful solutions, it may not cover every potential aspect of these disabilities. The goal is to establish a robust foundation for future work in improving GUIs for individuals with visual, physical, and hearing disabilities, which will hopefully lead to more comprehensive solutions in the future.

Furthermore, it is also important to acknowledge the practical challenges associated with finding suitable participants for interviews. Individuals with specific disabilities, such as visual, physical, or hearing impairments, may be relatively few, which makes recruitment for interviews a potential challenge. Despite these practical difficulties, every effort will be made to engage with individuals with these specific disabilities to gather valuable insights.

1.4 Disposition

To guide through the exploration of Improving GUIs for Visual, Physical and Hearing Disabilities, this report is organised as follows:

Chapter 1: Introduction

The introduction chapter presents the report's background, problem area, purpose, and research questions. It outlines the study's scope and limitations while providing a preview of the overall thesis structure.

Chapter 2: Method and Implementation

This chapter outlines the study's work process, detailing the approach, design, and methodological considerations. It explains data collection and data analysis, emphasising validity and reliability. The chapter clarifies the study type, whether qualitative, quantitative, or a combination, and the specific methods employed.

Chapter 3: Theoretical Framework

This chapter identifies and evaluates relevant theories integral to achieving learning outcomes. Serving as a foundation for empirical work, it guides the development of tools and integrates seamlessly into the analysis. Providing a robust theoretical base for the research.

Chapter 4: Results

This chapter presents the collected data objectively and coherently, without personal interpretations. It also includes the analysis of the data, answering the research questions and fulfilling the study's purpose.

Chapter 5: Discussion

This chapter explains the study's findings and compares them with existing research. This chapter critically analyses the results in the context of previous studies, highlighting similarities, differences, and potential areas for further investigation. Moreover, it addresses the broader implications of the study's outcomes and any limitations encountered during the research process.

Chapter 6: Conclusions and Future Research

This chapter brings together the key findings of the study and proposes areas for future research. It summarises the main points discovered and suggests potential areas for further exploration in this field.

2 Method and implementation

In this chapter, the work process for this study is described and motivated through outlining the approach and design, considering methodology, and making well-validated decisions regarding the study. In addition to this, the chapter also describes how the data collection and data analysis will be conducted. The chapter ends with a description of how to secure validity and reliability in the study.

This chapter outlines the methodologies employed to gather data in the study. It discusses the different strategies used to ensure reliability and ethical conduct in the research.

Specific methods were selected for the research questions to effectively address the objectives and goals. The approach for reviewing existing accessibility guidelines, conducting user interviews, and analysing data collected from different users is described.

The chapter mentions the importance of inclusivity in data collection, highlighting the measures that have been taken to help participants with disabilities during interviews. There will also be an overview of the data analysis methods, including thematic analysis and content analysis, which will be used to analyse the results and data from the interviews.

To enhance the validity of the findings, the research is grounded in previous research, providing a robust foundation. Furthermore, the discussion will encompass the utilisation of various tools, such as a bus ticket purchasing application, provided by Infospread, throughout the research process, contributing to a comprehensive exploration of the topic.

The ethical considerations during the research process are vital. The discussion about the different measures will be in place to reach the ethical guidelines, such as informed consent, maintaining confidentiality, and minimising biases. The chapter ends by focusing on the importance of collaboration with Infospread during the research process. They will help validate findings and ensure real-world applicability of the research outcomes.

2.1 Data collection

To collect correct data to facilitate answering the research questions. These specific methods have been chosen for the questions.

Research question 1: *What are the key differences in designing graphical user interfaces for individuals with singular disabilities compared to those with combinations of disabilities?*

Research question 2: *How do individuals with visual, physical, and hearing disabilities differ in their interaction with the ticketing application of public transport?*

The research questions address two different things, which have a high relevance in how the accessibility guidelines are applied and used. The first one focuses on the difference between the behaviour of individuals with a singular disability compared to individuals with a combination of disabilities. The second question focuses on the differences in interaction with the bus application between individuals that have one of visual, hearing, or physical disability.

To answer the questions, semi-structured interviews were conducted, as well as a literature study. The interviews were conducted with users of the application who suffer from disabilities. This was done to gather insights into their experiences and challenges when interacting with the application interface. By combining interviews and relevant literature, the specific requirements for digital products to fulfil were identified for individuals with visual, physical, and hearing disabilities.

To make sure to include the details of the information, the interviews with some participants with visibility, hard of hearing, or physical disabilities were recorded. Consent to recording of voice was asked before the interview. If the participant was not comfortable and did not give consent to recording, the answers that were provided by the participant were written down instead. These interviews' aim was to get insights from users regarding the application's accessibility features.

Specific measures were implemented to facilitate a smooth process for participants. For users with visibility impairments, verbal descriptions of visual elements were provided, with the request for users to reciprocate in aiding the gathering of insights. For those who are hard of hearing, clear audio quality was ensured, supplemented by written communication when necessary. Lastly, participants with physical disabilities had their needs accommodated through flexible response formats, patience, and provisions for breaks if needed.

These interviews applied a semi-structured approach that allows flexibility in exploring the topics while also maintaining a focused discussion on accessibility. Participants were encouraged to share their honest opinions, insights, and experiences about the application freely.

Another method involved user testing tasks within the application to make it easy to evaluate the usability and accessibility first-hand. With this approach, the aim was to gather qualitative data that will offer valuable insights into user interaction and experience within the application's GUI.

Some experts that work with qualitative research avoid the topic of the number of interviews that are enough. Many articles, book chapters, and books suggest a minimum of five participants in qualitative research. However, most of these references mention that it is a vague response to the number of participants that should be included, and that it depends on numerous factors such as the quality of data, the scope of the study, the nature of the topic, the amount of useful information from each participant. (Dworkin, 2012) The emphasis was on receiving informative responses rather than meeting a numerical threshold. The commitment was made to prioritise quality over quantity in the research.

Qualitative methods were chosen because they allow for a deeper understanding of the needs and perspectives of individuals with disabilities. By engaging in qualitative interviews, the aim was to hear directly from those affected and prioritise their voices and experiences over simply collecting numerical data.

2.2 Prototype

The application chosen for the testing phase is called Zbiletem (*Zbiletem*, n.d.), a bus ticket purchasing application developed by Infospread specifically for users in Poland. Infospread provided the prototype for testing and no modifications or additional features have been made to it. This is to ensure impartiality during testing. The application is developed in Polish, but there is an option for the user to switch the interface language to English, however, it does not translate every text on the screen to English. For the usability tests, the application language will be set to English. It is important to note that the version provided by Infospread is a Demo version, distinguishable by its inclusion of developer functionality such as the ability to add simulated funds and purchase non-functional tickets. These tickets are solely intended for testing purposes and are not valid for use on actual buses. Except for these differences, the Demo version is identical to the application used in Poland.

2.3 Usability tests and interviews

During a session of usability testing, a researcher guides a participant through various tasks using specific user interfaces. Throughout the session, the researcher observes the participant's actions and later listens to their feedback about their experience. Usability testing is often referred to interchangeably as user testing.

The primary objectives of user testing are to point out the design issues within a product or interface, discover opportunities for improvement, and gain insights into the behaviour and preferences of the target users. The modern user interfaces today are complicated and require a lot of attention. Testing is therefore crucial to ensure an optimal user interface, given the complexity of human cognition.

Qualitative usability testing focuses on gathering insights and observations regarding how individuals interact with a product or service. This approach is effective for identifying user experience problems and is more powerful than quantitative usability testing, making it suitable for this specific research.

The number of participants required for a usability test varies depending on the nature of the study. For a qualitative usability study targeting a single user group, approximately five participants are recommended to uncover most common issues. (Moran, 2019)

While there are several types of usability testing, most tests incorporate essential components: the facilitator, tasks, and participant. The facilitator guides the participant through tasks, observes their actions, and asks for feedback. Follow-up questions may be asked to gather additional insights from the participant. This process is demonstrated in Figure 1 below.

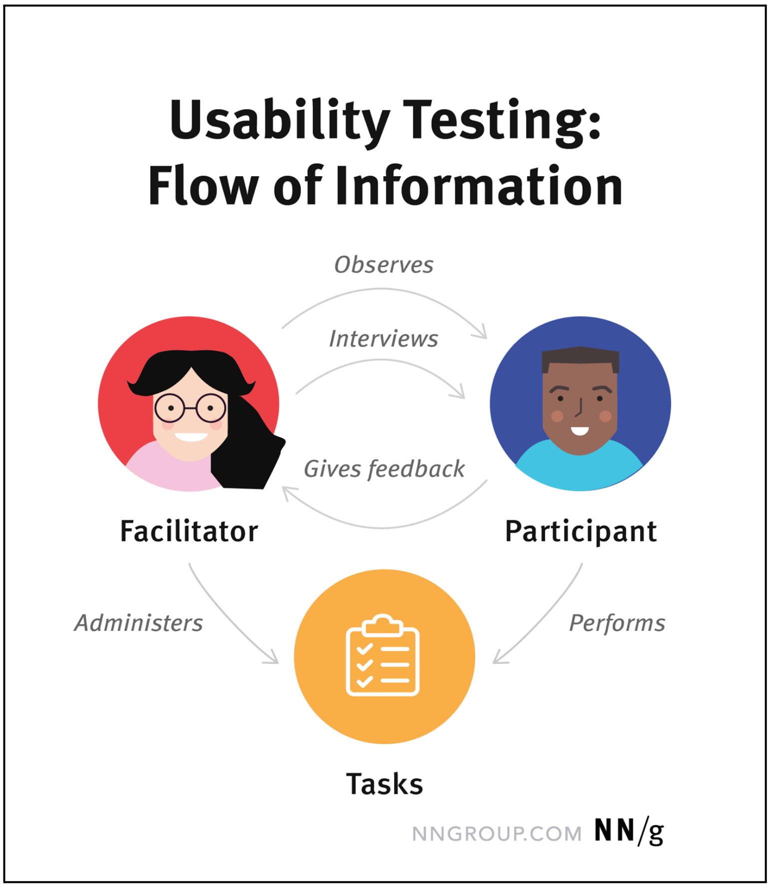

Figure 1: *The flow of information during usability testing (Moran, 2019)*

2.3.1 Limitations during testing

Initially, the plan was to conduct testing using Maze (*Maze*, n.d.), a platform for user testing and analysis. However, this became infeasible due to a lack of wireframes provided by Infospread, the company that owns the prototype application. Without wireframes, Maze could not be effectively utilised. Maze would have provided insights into user interaction. With Maze, researchers can analyse user behaviour by identifying areas of confusion and usability issues. One key feature that would have facilitated result analysis is the Maze heatmap functionality, where Maze visually represents where users are clicking the most within the prototype. Maze also provides detailed analytics on task completion rates. As a result of not being able to use Maze, manual testing methods were resorted to, where completion times for each task were recorded, and any miss clicks were documented as well by writing them down. Something that counts as miss-click was when the participant did something that was not part of the task, for instance if the participant bought the wrong ticket, or navigated to an irrelevant screen that was not needed during the specific task.

Additionally, Zoom (*Zoom*, n.d.) was intended to be utilised for testing sessions with users of the application from Poland to ensure accurate results. However, Infospread was unable to provide suitable participants for the testing and interviews. As a result, participants with disabilities had to be found locally in Sweden to avoid further complications. This rendered Zoom unnecessary, as participants could appear in person for the testing sessions.

2.3.2 The interview and testing process

The interview process was divided into two parts. Firstly, the participants engaged in tasks involving purchasing a ticket, viewing it, and scanning it within the application interface. Following completion, the time taken for each task was manually recorded to facilitate post-test evaluation and data analysis. The second part of the interview involved asking questions to participants about their overall experience with the application and receiving feedback on areas for improvement. From the tests and answers that were received, a thorough data analysis was made, and conclusions were drawn.

During the usability testing, participants were guided through a series of tasks within the application. Firstly, they were tasked with purchasing a ticket valued at 4.40 PLN (Polish zloty / currency). Once the ticket was successfully purchased, this task was considered complete. Following this, the next task involved the participants navigating to locate the recently purchased ticket within the application interface and clicking on it. Upon clicking on the correct ticket, this task was marked as completed. The final task involved locating the QR code corresponding to the purchased ticket. When the QR code for the correct ticket was displayed on the phone screen, the task was concluded.

The usability test is described below with screenshots from the application. In Figure 2 the home screen of the application shows where the participants will start the usability test.

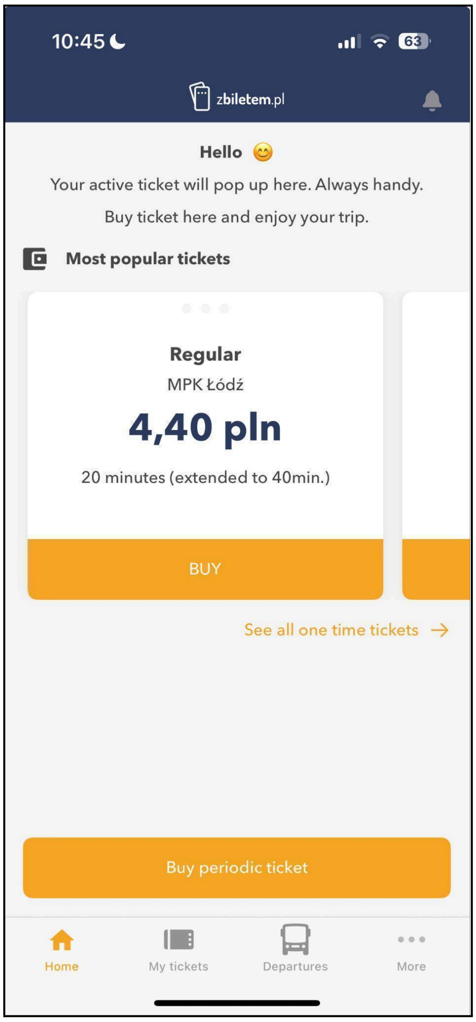

Figure 2: *home screen of the application*

In Figure 3 below is the screen that the participant will see when they click to buy a ticket. They can choose the quantity of tickets, payment method, and lastly to buy the ticket. When the user clicks on “Buy and activate”, the confirmation pop-up appears to verify the payment. After clicking “Yes” on the pop-up, the ticket will be bought, and funds will be drawn from the wallet.

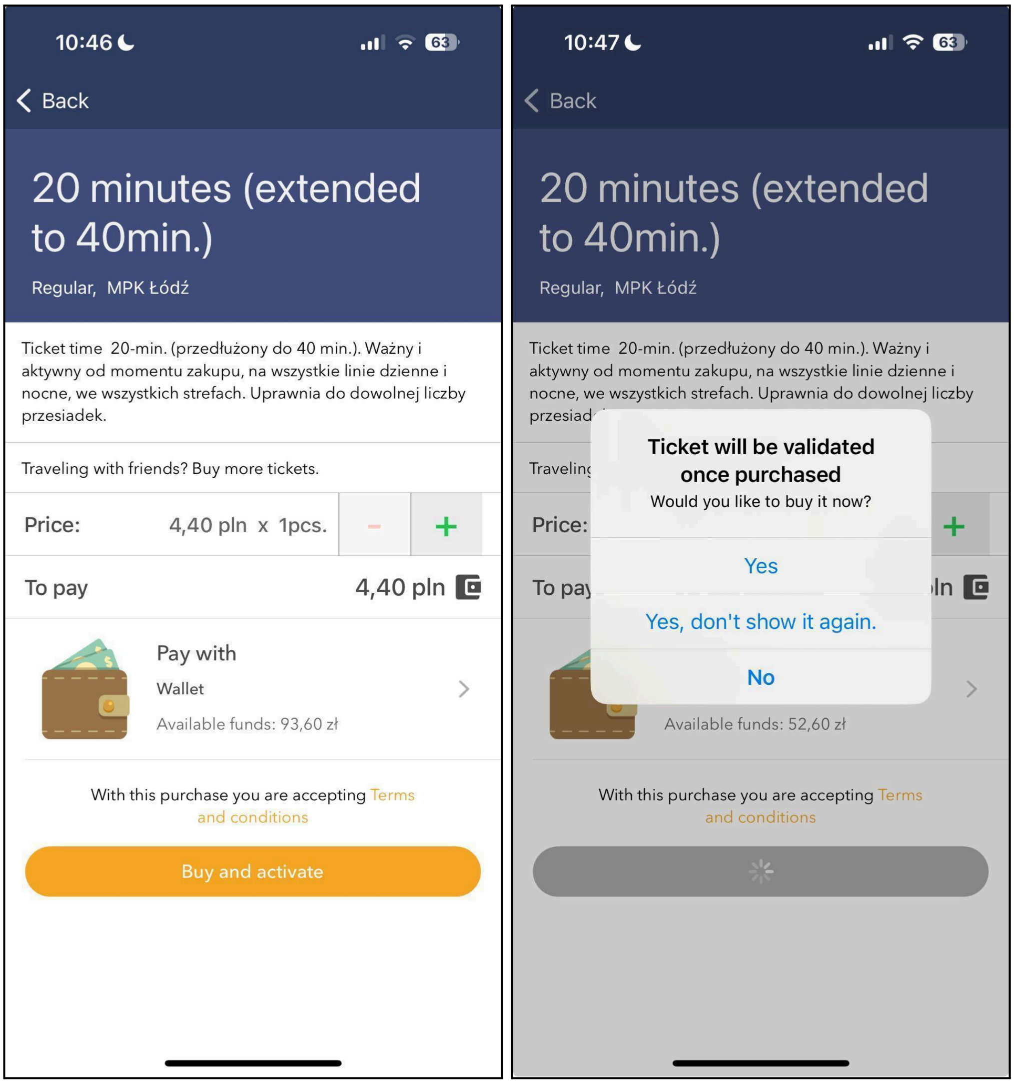

Figure 3: *ticket buying and confirmation screen.*

In Figure 4 below is the "My tickets" screen where the user can see all their active tickets that have been purchased. The participant will need to select the ticket that was recently bought on this screen.

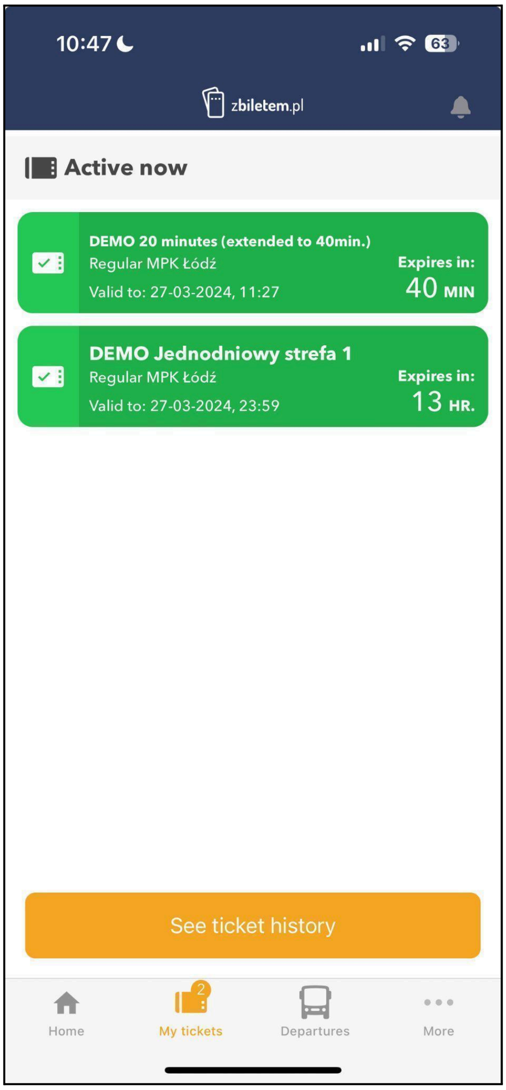

Figure 4: *"My tickets" screen with all active tickets*

Figure 5 showcases the screen for selecting an active ticket that has been purchased. The participant will need to select the ticket and click on “Show QR code” to scan the ticket and complete the usability test.

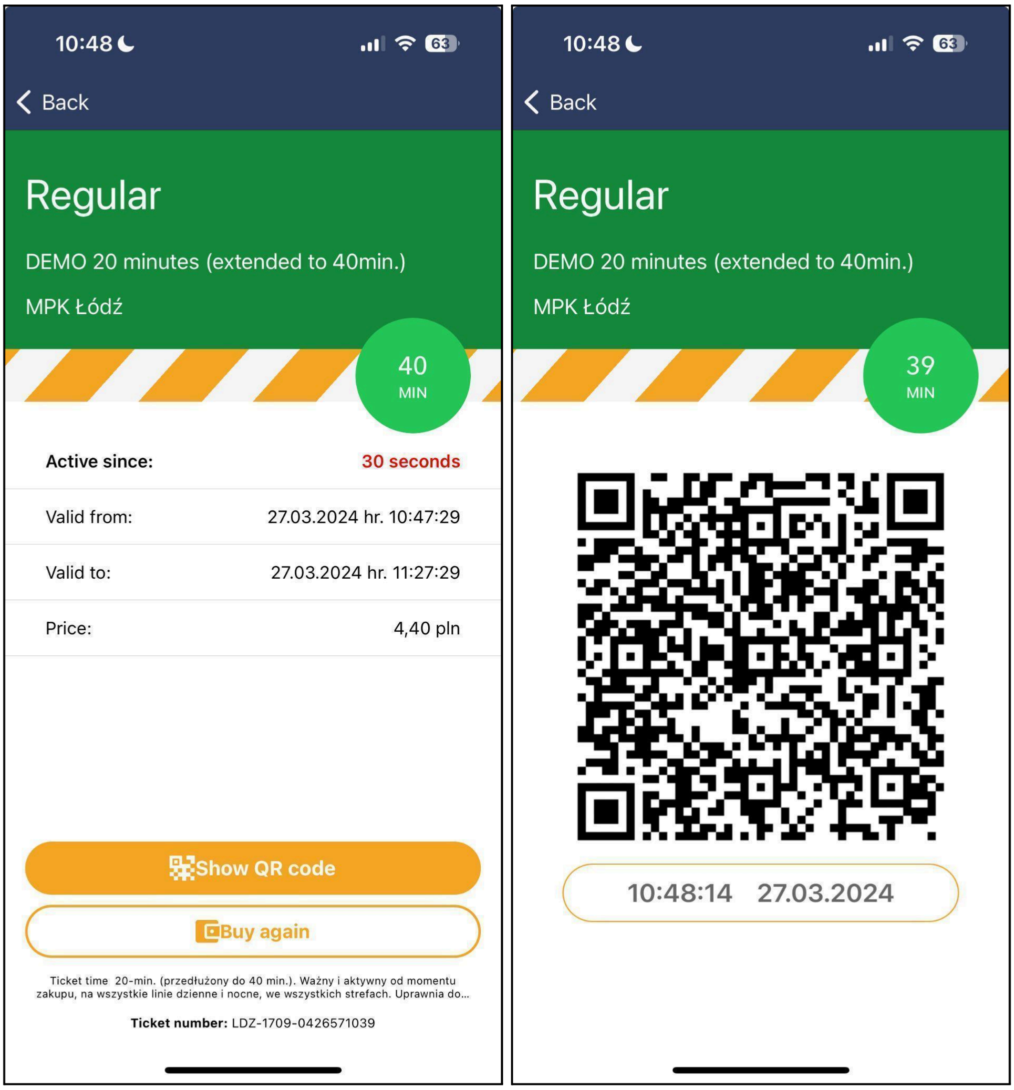

Figure 5: *specific ticket screen and QR code for ticket*

The recruitment of the participants for the testing and interviews was coordinated with Jönköping Läns Funktionsrätt (Jönköpings Län Funktionsrätt, n.d.). They asked for participants with the selection of disabilities. The interviews were conducted at their office in the city, to avoid any complications. While participants had a general idea of the testing and interviews, specifics were not disclosed initially. This was to ensure that participants approach the process without any biases. This also aided to maintain the integrity and validity of the research by ensuring that participants’ responses were not influenced by prior knowledge or expectations. The details of testing and interviews were disclosed a few minutes before the testing began and were disclosed in a group environment to give everyone a chance to ask if there are any unclear instructions, or if there was something the participants were not comfortable with. Once the testing commenced, each participant was accommodated in a separate room to ensure a comfortable environment. The testing was done with one participant at a time with both authors being present in the room. The user testing was supervised to ensure no mistakes were made and to answer any questions that were asked during the testing by participants. Participants then proceeded with the application testing and answered predefined questions. The questions were structured as follows:

1. How would you rate the ease of use of the application on a scale from 1 to 5, if 1 is the worst and 5 is the best?
2. Did you face any challenges during the testing? If yes, please elaborate.
3. Could you share your overall experience of the application and the tasks performed?
4. Are there any specific improvements or additions you suggest enhancing the application's user-friendliness for people with disabilities?

These questions were formulated uniformly to prevent any personal bias in responses. If the questions were formulated differently, participants may understand them differently and give biassed answers. Uniformity when formulating questions, ensures consistency in understanding and removes the risk of skewed responses influenced by individual biases. Completion time and encountered difficulties during the application usability tests will be documented. This data will be analysed alongside existing research to draw conclusions. During the interview phase, participant responses will be recorded using a phone, with their consent. If consent is not given, the responses will be documented by writing it on the phone note application. Participants will be assured of anonymity to respect their privacy, as only their disability information is of interest for the study, therefore no names or other personal data of participants will be mentioned in this report. Participants will be asked to describe their specific disability before the testing and interviews commence, if they feel comfortable to do so.

Detailed instructions will be provided to participants for each task, such as “purchase a ticket priced at 4.40 PLN (Polish zloty / currency) in the application.” Once the participant has the phone, the timer will start, and it will stop once they have completed the task by purchasing the correct ticket. The participant will be given the chance to ask questions during the tasks in case they need assistance with the task. The questions and assistance required will be noted down.

2.3.3 Pilot testing

Conducting a pilot test prior to the main testing serves a few beneficial purposes. Firstly, it allows for the identification of any potential issues in the testing process, such as unclear instructions or ambiguous tasks. The pilot tests were made with people that do not have any disability. By doing pilot testing, necessary adjustments can be made before proceeding to the full-scale testing part. It will help with knowing how much average time it should take for a specific task for a person to complete.

The testing involved two non-disabled individuals, each tasked with completing three specific actions within a bus ticketing application. Participant 1 took approximately 25 seconds to complete the first task, which involved purchasing a specific bus ticket within the application. The second task, locating the purchased ticket, took them around 10 seconds, while the third and last task, finding the ticket's QR code, took about 5 seconds. In contrast, participant 2 completed the first task in approximately 10 seconds, the second task in 5 seconds, and the third task in 3 seconds.

The purpose of conducting these pilot tests with non-disabled individuals is to establish a baseline for results comparison between non-disabled and disabled participants in using the application. Through this comparative analysis, potential areas where the application's usability may present challenges for individuals with disabilities may be identified, ultimately informing the development of more accessible design features and functionalities.

2.4 Data analysis

There are different methods that were used to analyse the collected data. The methods used are as follows:

1. Reviewing Literature

   Through the examination of books, articles, and scientific papers, a broader understanding of the problem was gained, explaining common issues that require solutions when individuals with disabilities use digital interfaces on applications.

2. Analysing interviews

   Thematic analysis was used to get deeper into the responses gathered from the interviews. Thematic analysis includes identifying common themes or patterns across the answers to uncover the main issue users encounter with the application interface (Villegas, n.d.). This method will allow organising the qualitative data received, which will help to understand the underlying meanings that are expressed by the participants.

Thematic analysis involves different steps. First, the interview responses and the notes were read carefully to better understand the data. Afterwards, key phrases, ideas, or concepts representing different patterns were identified. Next, the findings were organised, and overarching themes were identified to gain a deeper understanding of the challenges the users faced with application interfaces.

However, thematic analysis is not the only method that was used to analyse the data. Some elements of content analysis were incorporated into the approach. This involves quantifying specific characteristics within the data. (*Content Analysis*, n.d.)

The primary focus was on thematic analysis, but content analysis helped to supplement the findings by finding trends within the interview responses. The combination of thematic and content analysis would provide an understanding of the issues surrounding application interface usability.

The analysis involved examining two different metrics. Firstly, the assessment of completion time for each task among participants with different disabilities was done. Secondly, the responses that were gathered during the interviews were used to identify any recurring patterns or themes. For instance, some participants may find it challenging on some screens or tasks. Based on the answers and feedback from the participants and additional information from past research, some effective guidelines will be made.

It is important to ensure that the guidelines do not result in subjective guidelines. Efforts were made to minimise the influence of personal thoughts and feelings on the analysis process. This helped the results at the end stay fair and honest.

2.5 Validity and reliability

2.5.1 Methodological Approach

This thesis has a qualitative approach. This means that the research explores the challenges faced by people with disabilities who use application interfaces more deeply. Interviews were conducted to gather insights directly from individuals with the previously mentioned disabilities, using the Infospread's application. This accurately represented the experiences and struggles of users with disabilities.

2.5.2 Grounding in Existing Knowledge

By grounding the research in existing knowledge from literature and scientific papers, guidelines and results were ensured to be backed up by theories. This enhances the validity of the study by providing a solid foundation for the chosen approach.

2.5.3 Collaboration with Infospread

By validating the findings and solutions with Infospread, another layer of reliability was added to this study. This ensured that the research outcomes were relevant and applicable in real-world contexts.

2.5.4 Ethical Considerations

Ethical considerations have been considered throughout the research process. Ensuring informed consent from all participants, maintaining confidentiality and anonymity, and adhering to ethical guidelines for research involving human subjects are essential. Efforts have also been made to not involve any potential biases, both in the data collection process and in the interpretation of findings. This led to a stronger validity and reliability in the research study.

2.6 Considerations

It is crucial to consider the long-term impact of this research. The goal is to develop sustainable solutions that promote equal access to application interfaces for users with disabilities. This involves many things, including designing interfaces that are scalable, adaptable, and environmentally sustainable, while also making sure they meet the needs of users.

The collaboration with Infospread presents opportunities for this research to work closely within the industry and together with partners to ensure that the study outcomes are aligned with real-world needs and challenges. Working alongside the company's developers enables validation of findings and the incorporation of diverse perspectives to foster positive change in digital accessibility. Transparency and impartiality has been maintained throughout the collaboration to uphold research integrity and credibility.

3 Theoretical framework

The following chapter will discuss the different theoretical frameworks that are needed for this research. By exploring theoretical frameworks, the aim is to make the relationship between accessibility and GUI design clear, particularly when it comes to individuals with disabilities. The goal is to get an understanding of the specific requirements that are important for creating accessible GUIs tailored to the needs of users with visual, hearing, and physical impairments by examining existing literature. By discovering multiple theoretical perspectives and insights, the objective is to find key concepts and principles that make the approach more informative when addressing accessibility challenges. The aspiration is to contribute valuable insights to the field and advance the understanding of how theoretical frameworks can enhance the development of inclusive digital environments.

3.1 Web Content Accessibility Guidelines (WCAG)

The WCAG are a set of internationally recognized standards developed by the W3C to make sure that digital content on the web is accessible to all users, including those with disabilities. WCAG provides a framework for web developers and designers to follow when creating websites and evaluating the accessibility for the web applications. “WCAG is the universally accepted set of technical standards that, when followed, make digital experiences more accessible.” (WCAG, 2021)

The guidelines are organised in four different principles that lay the foundation necessary for anyone to access and use web content. The four principles are as follows: (*World Wide Web Consortium,* 2023).

- Perceivable - Information and user interface components must be presentable to users in ways they can perceive. This means that users must be able to perceive the information being presented.
- Operable - User interface components and navigation must be operable. This means that users must be able to operate the interface.
- Understandable - Information and the operation of the user interface must be understandable. This means that users must be able to understand the information as well as the operation of the user interface.
- Robust - Content must be robust enough that it can be interpreted reliably by a wide variety of user agents, including assistive technologies. This means that users must be able to access the content as technologies advance.

According to W3.org (2023), if any of these principles are not met, users with disabilities will not be able to use the web. These principles form the foundation for accessibility and are broken down into specific guidelines. Each guideline addresses a different aspect of accessibility, such as providing alternative text for images, ensuring keyboard accessibility, and creating understandable content.

Designers and developers should follow the different principles of the criteria that are outlined by WCAG. For designers, ensuring adequate colour contrast is crucial to enhance readability on web pages or in mobile applications. Insufficient contrast can pose challenges, particularly for individuals with low vision, as it makes it difficult to read text. Similarly, incorporating alternative text for all non-text content, such as images and graphics, is crucial. Alternative text descriptions work to convey the meaning of visual elements and facilitate screen reader accessibility, especially for decorative images.

In addition, developers have another set of criteria to follow compared to designers. One key requirement is to accurately identify the language used on each web page and any language changes within the content. Plain language identification helps both regular users and those relying on screen readers to read the text accurately. Furthermore, making sure the alignment between visual and programmatic labels is important. Interactive elements like buttons and form fields may have programmatic labels that differ from the visual representation on a website or a mobile phone. Aligning and adjusting these labels will ensure consistency and will improve accessibility for all users. One approach that is effective to address the problem of labels is to ensure they begin with the same few words and have guidelines for these among the coders. This will help to maintain consistency between visual and programmatic elements.

Accessibility considerations do not begin with designers and end with coders though. Authors, or content creators, can also impact the accessibility and usability of websites and other digital assets. The goal for content creators is to make the content that is created easy to find and most importantly, to understand. Effective use of alternative text, headers, and plain language are among the key factors in making the content accessible to as many people as possible. Just like designers and developers, there are also different criteria for content creators.

The priority of content creators and authors should be to use informative and distinctive page titles. Each page title should be clearly expressed and short, but descriptive of the content of the page. It is essential to place unique and relevant information at the beginning of the title. Another criterion is to have meaningful link texts to enhance accessibility. Link texts should provide relevant information about the destination and describe the content users can expect upon clicking the link. It is important to avoid using vague or ambiguous text like “read more” or “click here”, if it is not clear what content will be displayed after the user clicks on the link (WCAG, 2021).

3.2 Accessibility Guidelines in Mobile Applications

Mars Ballantyne (2018) discusses the critical issues of mobile application accessibility. The authors present their findings from an evaluation of popular mobile applications and propose guidelines to improve accessibility.

The evaluation revealed significant deficiencies in applications that follow accessibility guidelines, particularly in the areas of video content and text presentation. The most frequently violated guideline was the lack of providing textual descriptions for video content and making sure text is readable and resizable. A lot of social media applications that focused on user-generated content lacked textual descriptions. This made the content inaccessible to users with disabilities.

Additionally, the evaluation highlighted some issues with screen reader interaction and task completion for users with disabilities. For example, GrubHub's application met some accessibility guidelines in the design. However, it was found to be nearly impossible to navigate and use with a screen reader for ordering food due to unpredictable ordering and incorrect representation of text elements.

This study emphasises the need for increased awareness about accessibility requirements among application designers. Social media platforms should make the content accessible to ensure inclusivity for all users. However, one thing that remains a challenge for developers and designers is the integration of accessibility principles into application design without compromising usability (Ballantyne et al., 2018).

In Figure 6 below, the different accessibility guidelines that were measured and tested are listed. The right column displays how many times these specific guidelines were violated in the different applications that were tested.

Accessibility Guideline	Total Number of Violations
All text elements are visible to screen reader	37
Contrast ratio between background and text is at least 7:1	35
Images have an alternate text description	31
UI elements (buttons, divs, etc) have descriptive labeling	48
Touch targets are 9mm high and 9 mm wide	25
Touch targets close to minimum size are surrounded by inactive space	18
Link / button purpose can be determined from link / button text only	5
Identify and explain any errors that can be automatically detected	5
Normal-size (< 18 pt / 14pt bold) text: Contrast ratio of 4.5:1	3
Form fields are below (not beside) labels	2

Figure 6: *Accessibility guidelines and total number of violations*

Appendix 1 is from the article by Ballantyne (2018) and outlines the "Benefit" of each category of guidelines. This refers to the type of user who would benefit the most from following the accessibility guidelines and how it would help them. For instance, a benefit regarding text in a design is to allow users with vision impairments to read, hear, feel, or otherwise perceive content. Another benefit is to allow users with cognitive disabilities to read and hear content at the same time.

Below in Figures 7, 8, and 9 are some accessibility guideline violations found in the most popular applications.

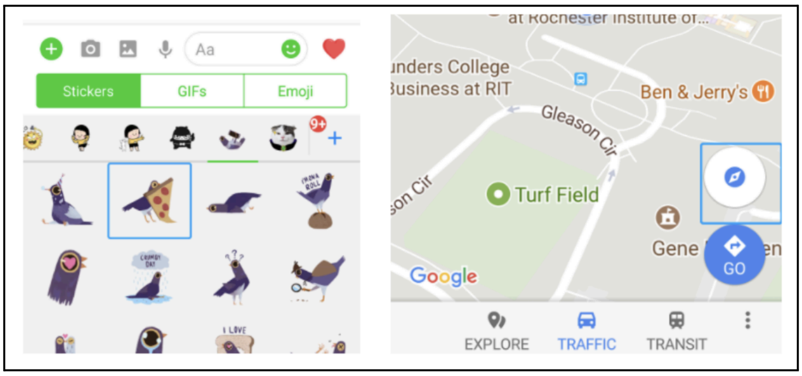

Figure 7: *Screen reader ignores most sticker names on Messenger (left) and text on Google Maps (right)*

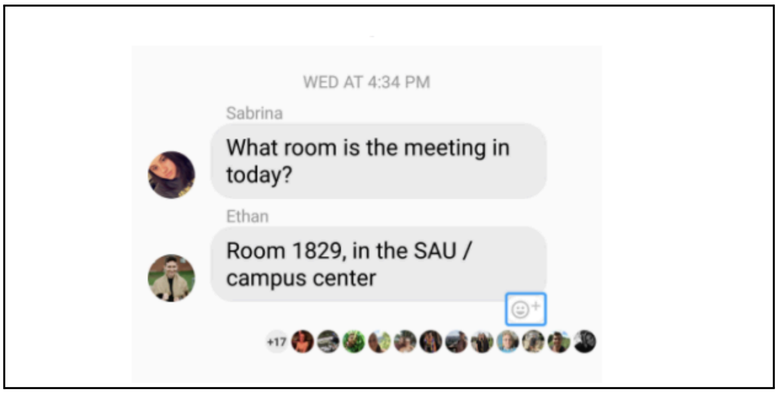

Figure 8: *Facebook Messenger emoji reaction button for individual messages does not meet touch size recommendation.*

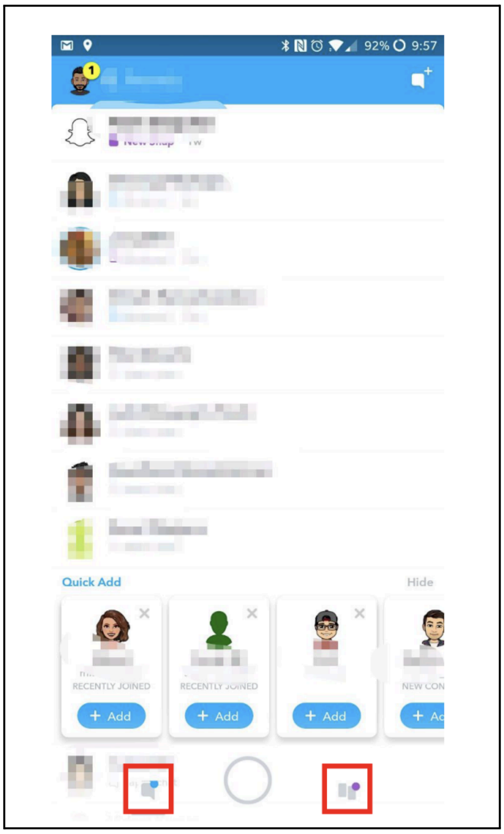

Figure 9: *Snapchat navigation buttons and indicators are not labelled and do not contain text.*

The accessibility guidelines that are mentioned in this article provides clear guidelines to follow during the research that will be conducted. The results from this article are essential for the research because they help paint a picture of what is specifically lacking in the most popular applications today.

3.3 iFree

The iFree article (Angellotti et al., 2020) introduces a novel pointing method designed for individuals with disabilities that makes it easier to interact with mobile devices like smartphones and tablets. The pointing method is called iFree. It was developed by researchers at the University of Salerno, Italy.

The method iFree uses face recognition technology, specifically the front camera of the device, to control a cursor on the screen. It offers two modes for target selection, mouth click, and sound click. Mouth click occurs when a user opens and closes their mouth, and sound click occurs when a vocalisation triggers the selection.

The authors conducted an experiment with 14 non-disabled participants to evaluate iFree's performance. In the experiment, the two different target selection modes were compared. Results demonstrated that while both modes were good and viable, the sound click mode showed higher throughput, accuracy, and faster movement time, making it the preferred choice among participants.

According to the article, various technologies, including tongue or lip-controlled systems and muscle electromyography, have been explored in the past for individuals with disabilities. The article also discusses other related work on assistive input methods (Angellotti et al., 2020).

The iFree pointing method will be considered as a reference to explore innovative assistive technologies aimed at improving accessibility for users with disabilities.

3.4 User-Centered Approach

A theoretical framework that is connected to the subject is the framework specified in the research paper by Rezaei, Heisenberg, and Heiden (2014). In the paper, they focus on the importance when considering users with disabilities, specifically users with more than one disability. They mention challenges that arise from singular-focused designs, where only one disability is considered by the designer.

The main point of the paper is to introduce the three interdependent spaces which are the user space, need space, and application space. The approach is named User Centered Design (UCD), and this framework aligns with Human-Computer Interaction (HCI) theories. The point is to focus on who is using the GUI, what they need on the GUI, and different tailored applications.

The paper by Rezaei, Heisenberg, and Heiden (2014) suggests a need for future research in this topic, and to explore real-life applications following the UCD approach and guidelines. The theory and model mention that accessible technology is vital for inclusivity in the modern technology society. By using the research conducted in the paper as an insight, it will help build and test theories in this research.

In Figure 10 below is a substitutional table from the research paper. The table displays how technology can be used to replace lost or damaged senses and actuators. For example, eye gaze tracking can be a replacement to sight, and speech-to-text can be a replacement to hearing, according to the table.

		Sight	Hearing	Touch	Taste	Speech	Upper limb	Lower Limb	Skeletal muscles	Tactile graphic display	Tactile sensors	Text to Braille	Braille to Text	Eye gaze tracking	Head tracking	Facial gesture detection	Hand gesture detection	Text to Speech	Speech to Text	Sign language to Speech	ERP-based Control (EEG)	ERD/ERS-based Control (EEG)	Neuro-prosthetic /EMG-based	Manipulator arm	Non | Autonomous wheelchair	Environment mapping
Actuator	Skeletal muscles					*								*		*			*		*	*	*			
	Lower limb						*		*								*		*		*	*	*		*	
	Upper Limb					*		*	*					*	*				*		*	*	*	*		
	Speech	*		*			*		*							*	*	*	*	*						
Sense	Taste	*																								
	Touch	*									*															
	Hearing	*					*		*									*	*	*	*	*				
	Sight		*	*		*	*	*	*	*		*	*					*	*		*	*				*

Figure 10: *Substitutional table for human body senses*

The article presents an algorithmic guideline for minimising interdependencies between interaction modalities to improve user interface usability for disabled individuals. (Rezaei et al., 2014)

Notable that the results from this research article are around ten years old, and therefore may be outdated today when designing new interfaces for applications. However, Rezaei, Heisenberg, and Heiden (2014) offer a comprehensive theoretical framework and a few practical guidelines when addressing accessibility requirements in GUI design. This makes it a valuable resource for this research study.

3.5 Home Automation Mobile Applications

Gabriela de Oliveira (2022) writes about an in-depth exploration of Casa Assistiva. Casa Assistiva is a home automation application designed specifically for individuals with visual impairments. Through iterative improvements guided by user feedback, Casa Assistiva became a better, simpler, and more comfortable experience for its users. The final version of Casa Assistiva empowered users to navigate their home environment independently.

The process had a testing phase where participants, who were visually disabled, provided feedback to try to enhance the quality of life for visually impaired individuals. Despite challenges such as interface inconsistencies and communication delays, the article highlights the adaptability of the Casa Assistiva team in addressing the issues. During the testing phase, the team followed accessibility guidelines and listened to feedback. In the end, the application was refined to meet the needs of visually impaired users.

The application helped and allowed the users who have difficulty seeing to control things in their homes more easily. For example, they could turn the lights on and off or adjust the TV volume using the application instead of needing a remote control. The application used voice assistance to help users control various appliances and devices in their homes (de Oliveira et al., 2022).

The insights provided in the article offers some valuable lessons for designing accessible mobile applications for visually disabled users. This will allow identifying key requirements and best practices when addressing accessibility challenges in GUIs later in the study.

3.6 The obstacle detector application

The article about Machine Learning based computer vision application for visually disabled people (2021) is about the intersection of technology and accessibility, and it is specifically targeting people who are visually disabled. The article proposes a computer vision-based mobile application in a world increasingly influenced by smartphones. The focus is on object direction and depth estimation, which are two essential elements to help visually impaired people in their daily tasks.

Encountering obstacles when navigating indoors and outdoors is one of the common problems that visually impaired people have in their lives. Traditional aids like sticks are rudimentary, highlighting the need for advanced solutions. The application that they talk about in this article aims to provide real-time assistance in obstacle avoidance to prevent unintentional collisions. Object detection becomes important for identifying and locating obstacles, while depth estimation plays a crucial role in measuring the user and these obstacles.

The application's main idea is shown in Figure 11. It highlights how the application helps visually impaired people by detecting objects and estimating distances using the phone’s camera. This visual representation gives a quick overview of how the technology could make a difference in the daily lives of those with visual impairments (Machine Learning Based Computer Vision Application for Visually Disabled People, 2021).

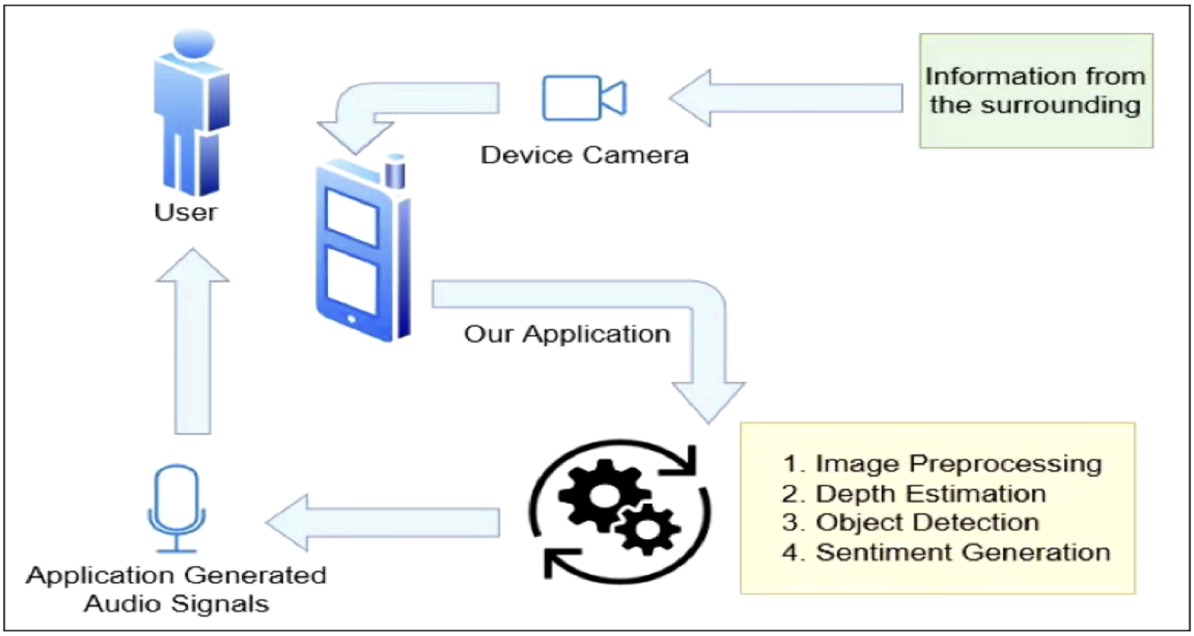

Figure 11: *The application's functionality overview (Machine Learning Based Computer Vision Application for Visually Disabled People, 2021).*

By analysing the technological innovations and accessibility features presented in the article, some valuable insights into the design requirements for GUIs can be gained. The development of accessible GUIs will ensure inclusivity and usability for users with visual disabilities.

3.7 Inclusive content

The article by Rease Rios (2021) talks about the importance of inclusive content creation as a commitment to equity and a safer experience for a broader audience. Focusing on some essential elements of inclusive content on the web, the article delves into accessible web design and inclusive writing.

In the accessible design field, the article highlights the importance of making everything, from navigation to text, accessible to as many people as possible. It highlights key practices, including ensuring screen readers can interact with every page, adding alt text to images, providing captions for videos, and using voice commands for interacting with applications and websites. The article also addresses some potential challenges related to excessive motion in design elements and emphasises the importance of considering colour contrast and avoiding reliance on colour alone to convey information.

The article talks also about the language, references, formatting, and the importance of inclusive writing. It encourages the use of inclusive language beyond pronouns, advising against categorical terms and terms with negative connotations. It also warns against using idioms and ability-specific calls to action that may unintentionally exclude certain audiences.

Providing practical insights and guidelines, the article serves as a valuable resource for content creators striving to create inclusive content that fosters diversity and creates a welcoming environment for everyone (Rios, 2021).

The inclusive content creation principles discussed in this article will guide the study's approach to improve GUIs for individuals with visual, physical, and hearing disabilities. These ideas will help to make the digital environments more accessible and user-friendly.

4 Results

This chapter serves as a comprehensive presentation and analysis of the data collected during the study. Divided into two sections, the first part objectively presents the collected data. Subsequently, the second section delves into the data analysis process outlined in the methodology chapter. Through this analysis, the chapter aims to provide insights that directly address the research questions and fulfil the study's purpose.

4.1 Presentation of collected data

This section will outline the data that was collected from the interviews and usability tests that were conducted. In the following chapter, the data collected from individuals with visual, physical, hearing disabilities will be discussed.

4.1.1 Results of participants with a singular disability

The following chapter will outline the results from participants with a singular disability of either visual, physical, or hearing from the usability testing. Additionally, the answers that the participants provided to the questions will be mentioned here. The results that were gathered are presented in an objective way without any personal interpretations, opinions, and views.

Participant 1 - Physical Disability

A participant with physical disability, who needed a wheelchair to navigate and slight hand dexterity, underwent a series of tasks aimed at assessing the usability of a bus ticketing application. The results of the tasks for participant 1 are shown in Figure 12 below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	38.17 seconds	2.19 seconds	11.64 seconds

Figure 12 : *The results of participant 1*

Upon completion of the tasks, they provided feedback through responses to a series of questions. They rated the ease of use of the application as 4 out of 5, indicating a positive experience. They did not encounter any issues while using the application. Furthermore, they described their overall experience as easy to understand, highlighting the ease of use and navigation through the tickets. Additionally, they suggested improving the contrast within the application and implementing a swipe gesture to search through purchased tickets. They also recommended the ability to adjust text size for better accessibility.

Participant 2 - Physical Disability

Another participant, also with physical disability and a need for a wheelchair to navigate, engaged in a series of tasks to evaluate the usability of a bus ticketing application. They completed all of the tasks, and these results are shown in the Figure 13 below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	16.32 seconds	55.06 seconds	5.83 seconds

Figure 13: *The results of participant 2*

After completing the tasks, they provided insights through responses to a series of questions. They rated the ease of use of the application as 2 out of 5, citing challenges with understanding English text due to language barriers. While they did not encounter significant technical issues, they highlighted difficulty in interpreting the time displayed on the ticket. Despite these challenges, they described their overall experience as positive, expressing a desire for more language options to enhance accessibility for users with language limitations. Specifically, they suggested incorporating additional language choices to cater to diverse linguistic needs.

Participant 3 - Visual Disability

An interview was conducted with an individual experiencing significant visual impairment, characterised by low vision and challenges with contrast perception. This individual relied on speech when interacting with modern applications, and braille when they stumbled upon signs.

This individual needed technological aids to use modern applications, however, initially, a test was conducted without any technological aids, but it proved infeasible due to the severity of the visual impairment. None of the assigned tasks could be completed successfully.

Afterwards, a second test was conducted, this time using the built-in VoiceOver tool on the iOS system, which provides auditory descriptions of on-screen content. While this enabled the participant to complete some of the tasks, there were inaccuracies. The first task was completed, but the participant did however purchase the wrong ticket. During the second task, the participant managed to navigate to the "My Tickets" screen that displays all the purchased tickets but struggled to find the specific ticket due to VoiceOver's inability to read the necessary information in the ticket, adding unnecessary information. Finally, the participant successfully completed the last task. Participant 3's results are shown in Figure 14 below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 33 seconds (Purchased wrong ticket)	Couldn't complete the task	13 seconds

Figure 14: *The results of participant 3*

After the initial test, there was some discussion with the participant regarding their experience with the application. Given their inability to use the application without technological assistance, their feedback was negative and almost non-existent, because they could not use the application at all. The participant rated the experience as 1 out of 5 and expressed that the application was unusable for them without such assistance.

After the second test with technological assistance, the participant provided more insightful feedback. This time, they rated their experience a 2 out of 5. They noted that the VoiceOver feature described irrelevant elements on the screen that should not have been described, which hindered rather than aided the navigation. However, they acknowledged that using technological assistance significantly improved the overall user experience compared to navigating the application unassisted.

Participant 4 - Hearing Disability

The participant that did the test experiences severe hearing impairment in their left ear and complete deafness in their right ear. They use implants in the head for auditory perception, bypassing traditional ear usage. The tasks results of participant 4 are as shown in the Figure 15 Below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	40 seconds	37 seconds	3 seconds

Figure 15: *The results of participant 4*

After the tests, the participant rated the experience as a 4 out of 5. Their primary issue with the application was the untranslated elements. They found the presence of the untranslated Polish text inside the application to hinder the user experience a bit, as they only relied on English. Otherwise, they reported no other difficulties during the tasks, as they thought they were mostly visual-based, and they had no problems visually.

4.1.2 Results of participants with combination of disabilities

Participant 5 - Hearing & Physical Disability

A participant, with both hearing and physical disabilities, actively engaged in a usability test of a bus ticketing application. The participant could not hear distant sounds and faced difficulties in moving both of their hands. This evaluation aimed to evaluate the application's accessibility and usability for users facing challenges related to both hearing and physical impairments. This participant's involvement provided valuable insights into the nuanced experiences and needs of individuals navigating digital interfaces while contending with multiple disabilities. The tasks completed by the participant during the test are detailed in Figure 16 below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 37 seconds	49.12 seconds	31.04 seconds

Figure 16: *The results of participant 5*

Following the completion of the tasks, the participant provided feedback on their experience with the application, addressing various aspects. They rated the application's ease of use as 2 out of 5, indicating some difficulties. The participant noted challenges in understanding certain features, such as the diverse ticket options and the process of locating purchased tickets. Language barriers were identified as a significant issue, with the application primarily available in English and Polish, leading to confusion. Overall, the participant expressed dissatisfaction with the application's usability and suggested improvements, including additional language options and enhanced navigation features for easier ticket management.

Participant 6 - Visual & Physical Disability

An interview was conducted with a participant with a combination of visual and physical disability. This participant experienced significant visual impairments and relied on speech when interacting with mobile applications. The participant had a physical disability and needed a wheelchair to navigate.

Initially, a test without any technological aids was made, in order to see how well they could use the interface. None of the tasks could be finished because the participant struggled with navigating the interface without aid. A second test was made with the VoiceOver tool on the iOS system. The participant could now complete two of the three tasks, and they still struggled on some parts and had to ask for directions. For instance, the participant struggled to find the correct ticket to buy and struggled to find the ticket that was purchased in the "My tickets" screen. The task results of participant 6 are as shown in Figure 17 below.

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 52 seconds	Couldn't complete the task	15.28 seconds

Figure 17: *The results of participant 6*

After the usability testing, the participant rated their experience on the first test a 1 out of 5. The participant could not provide valuable feedback after the first usability test, because they could not experience the main parts of the application without aid. They expressed that the application was not usable for them without tools such as VoiceOver.

Another discussion took place after the second usability test where some technological assistance was used. This time, the participant rated the experience a 3 out of 5. They still had some issues because the VoiceOver tool described irrelevant elements on the screen. However, the participant could use the main functionality of the application this time, and thought that the overall user experience improved by using technological assistance. The participant had a suggestion to enhance the accessibility in the application. The suggestion was to make the screen more basic and filled with more text elements when the user uses the application with accessibility functionality. The participant stated that this could be a setting built in the application that the user can turn on and would make the VoiceOver tool read correct and relevant data.

4.2 Data analysis

In this chapter, the collected data is analysed using thematic analysis to identify patterns in participant responses and challenges across the different disabilities. The analysis process, previously detailed in the method chapter, is now filled with substantial content. Each step of the data analysis procedure is carefully followed to obtain meaningful insights. The results obtained from this analysis are then examined to answer the research questions and fulfil the study's overarching purpose.

Below in Figure 18 is a visualisation of all the task completion times from the usability tests. The completion time for task 1 is visualised by red points, the completion time for task 2 is visualised by purple points, and the completion time for task 3 is visualised by yellow points in the graph. One thing that can be noted from the graph is that the red points (task 1) on average took the longest time, while the yellow points (task 3) on average took the shortest time to complete.

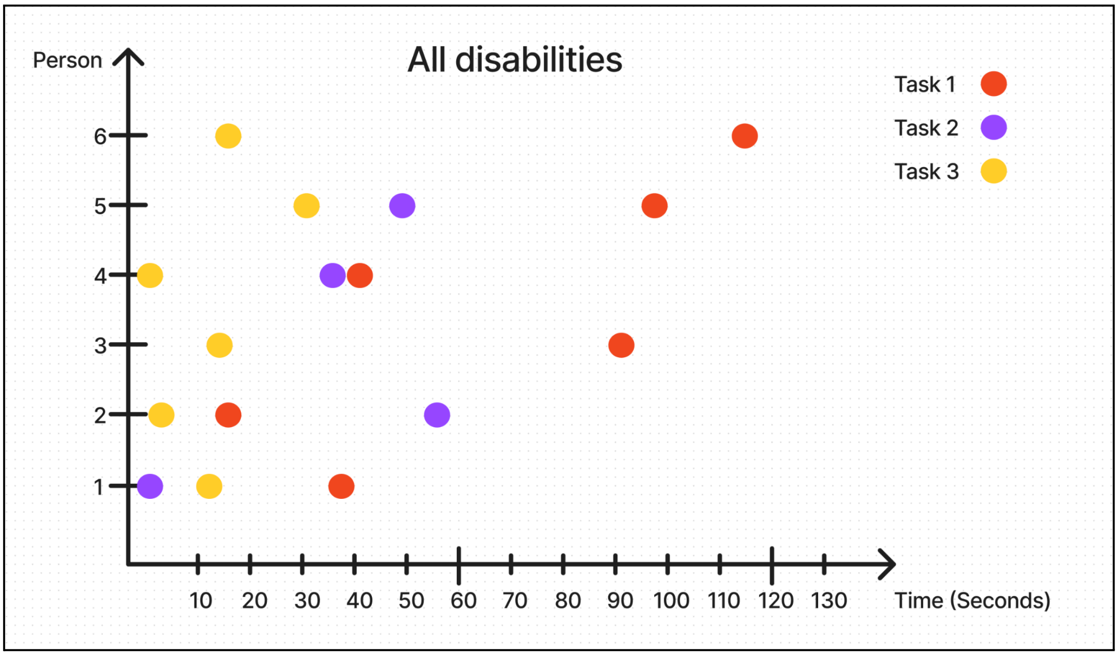

Figure 18: *Visualisation of all task completion times results*

Below in Figure 19 is a visualisation of how all participants rated the application experience after the testing that was concluded. The participants with visual disabilities did the usability tests twice, first without any technological aid, and later with technological aid.

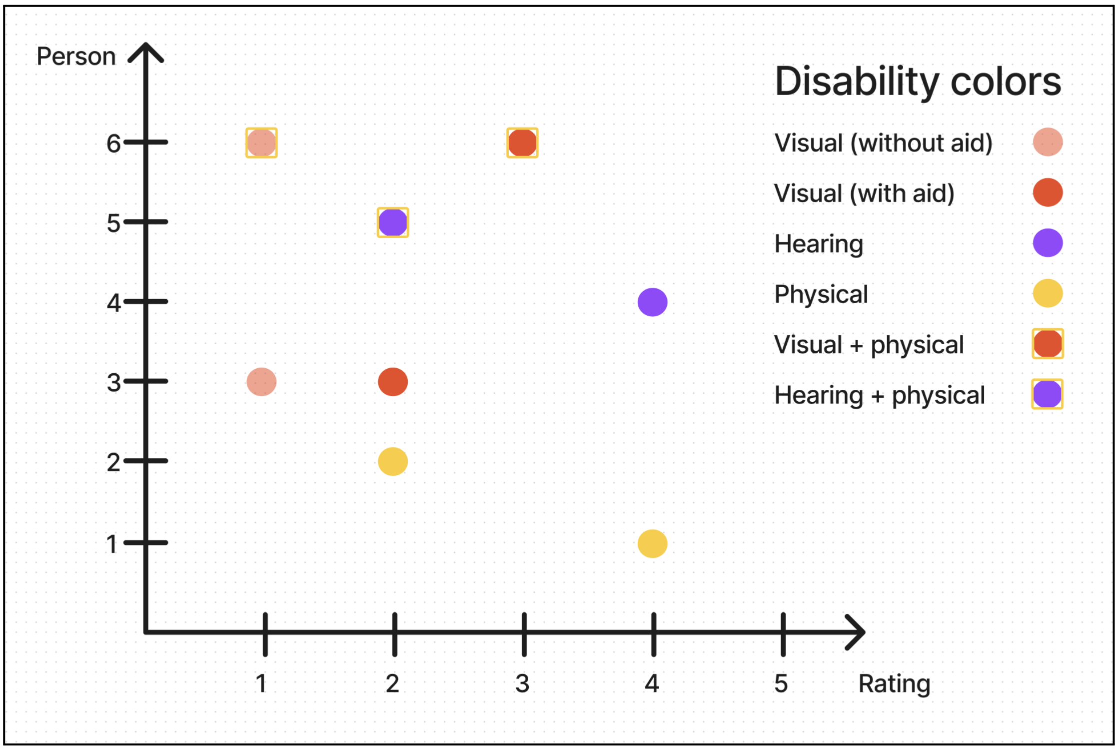

Figure 19: *Visualisation of all ratings of the application*

4.2.1 Analysis of results from participants with visual disability

The first participant that struggled with visual impairment was participant 3. This individual experienced significant visual impairment and could not complete any tasks without technological aid. The participant did the usability test using the VoiceOver tool that is built in the iOS system on the iPhone. This aid helped the participant complete the tasks to some degree, but they still struggled with task 2 which was to find the correct ticket that was recently purchased in the application. They purchased a ticket in task 1, but it was the wrong ticket and not the one that was meant to be purchased during the task. These tasks were not fully completed due to irrelevant VoiceOver descriptions.

The second participant with visual impairment was participant 6, and they also struggled with physical impairment. This individual experienced significant visual impairment similar to participant 3. The participant was not able to complete any of the tasks without technological aid. The aid that was used was the VoiceOver tool similarly to participant 3. The tool facilitated task completion, but the participant still struggled with navigation inside the application due to irrelevant VoiceOver descriptions. The participant had some struggles with finding the correct ticket to purchase in task 1, however, they managed to purchase the correct ticket in the end. During task 2 the participant could not complete the task due to irrelevant VoiceOver descriptions of textual elements inside the application interface.

Something that is relevant to mention here is that participant 3 only had a singular disability of visual impairment, while participant 6 struggled with a combination of visual and physical disability. Despite these differences in disabilities, the results of both participants were similar with shared challenges in navigating the application, therefore there is no indication that the physical impairment of participant 6 influenced the results in any manner. This could be because participant 6 had a physical impairment with walking. The case would probably be different if the participant had a physical disability affecting their hands or arms, as these were crucial for navigating the application interface in this usability test.

Both participants that struggled with a visual disability highlighted the critical role of technological assistance in improving accessibility. None of the participants would be able to do the tests if not for the VoiceOver tool. They also emphasised the need for more accurate and relevant auditory descriptions to enhance the user experience for individuals with visual disabilities. This underscores the importance of considering the various needs in the design and development of GUIs.

Below in Figure 20 is a visualisation of the task completion time results from the participants with a visual impairment. None of the participants with visual impairment managed to complete task 2, therefore there are no purple points visualised in the graph. Both participants had similar task completion times according to the graph. Task 1 took a bit longer for participant 6 to complete, however there is no evidence that the physical disability was the cause for this.

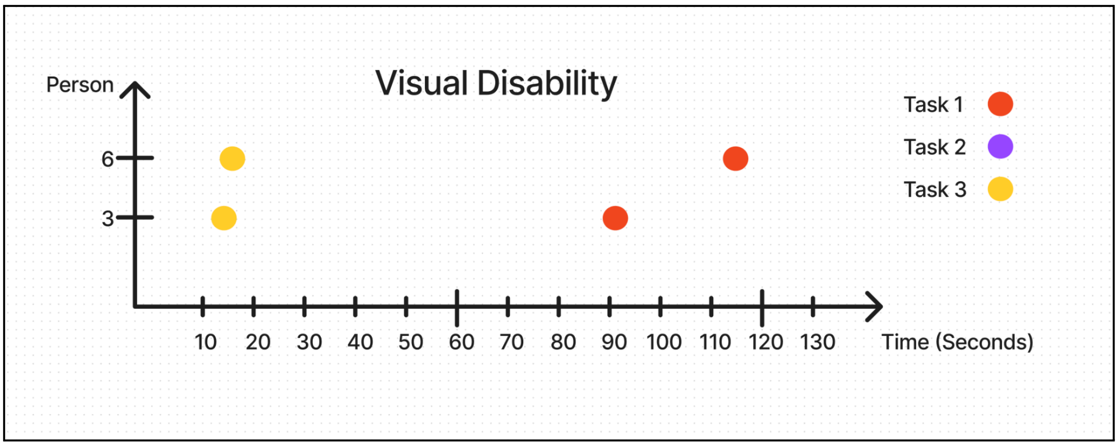

Figure 20: *Visualisation of task completion time results for participants with the visual disability*

4.2.2 Analysis of results from participants with hearing disability

Two participants that contributed to this research had a hearing impairment. The first participant was participant 4 and had a singular hearing disability. This individual had severe hearing impairment in their left ear and complete deafness in their right ear. They used implants in the head for auditory perception, bypassing traditional ear usage. During the tasks, the disability of participant 4 did not hinder the task completion. The main issue the individual had with the application was the untranslated elements on screen. There was still some Polish text on the interface even though the application language was set to English. This is due to the developers that programmed the application.

The second participant with hearing impairment (participant 5) had a combination of physical and hearing disability. The physical disability of the participant resulted in them not being able to move both of their hands. The hearing disability of the participant resulted in them not being able to hear distant sounds. However, the participant could hear someone that was close to them and talked with a clear voice. The results of participant 5 were much slower compared to participant 4, and this is probably due to the physical impairment of participant 5, rather than the hearing impairment. For instance, task 1 showed a disparity of almost one minute between participant 4 and participant 5, and task 3 exhibited a difference of approximately 30 seconds, with participant 5 taking much longer to complete the tasks. The tasks that were chosen, do not need the user to use their hearing ability. The results of the interaction with the application would most likely differ if the application had tasks that required hearing ability.

Both participants mentioned the translation in the application interface. They mentioned that it was difficult to read some textual elements because they were not translated from Polish to English, even though the application language was set to English in the application settings. This problem had nothing to do with their disabilities, but it was a factor when it came to completion time, due to the participants not knowing Polish at all.

The Figure 21 below visualises the results of all the participants who had a hearing disability.

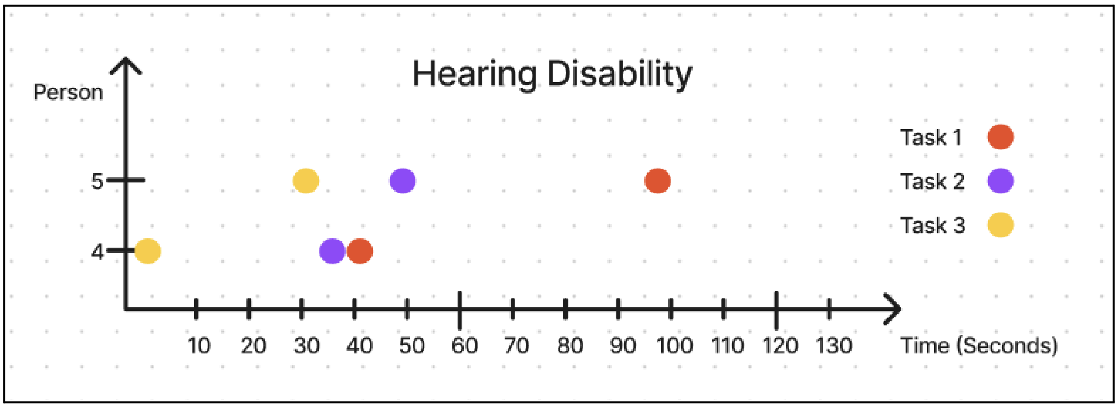

Figure 21: *Visualisation of task completion time results for participants with the hearing disability*

4.2.3 Analysis of results from participants with physical disability

During this research, interviews were conducted with 4 participants experiencing physical disabilities. Among them, 2 suffered from a singular disability (participant 1 and participant 2), which was the physical disability, and the other 2 participants had a combination of disabilities (participant 5 and participant 6), one of those disabilities was the physical disability. The interviews aimed to evaluate their experience with the bus ticketing application.

The two participants, who had a singular disability, completed all the 3 tasks successfully without any issues. The only notable difference in their experience was the time difference in task 2, which was about to find the purchased ticket. It took almost one minute for participant 2 to complete that task due to language difficulties, compared to participant 1 who completed it in 2.19 seconds.

Participant 1 gave their overall experience a 4 out of 5, indicating they did not face major problems with the application. They suggested improvements, particularly in searching through purchased tickets and implementing a swipe gesture instead of scrolling through a list of purchased tickets. As for participant 2, they rated the application's ease of use as 2 out of 5, primarily due to language barriers, otherwise, they did not encounter big technical issues.

The experience of the application for the other two participants (participant 5 and participant 6), who suffered from a combination of disabilities, was different compared to those who had a singular disability. They had more difficulties in using the application, and their completion time for all the tasks was notably higher than the completion time of the participants with one disability. It took both of them over one minute of time to complete the first task, which for participant 5 was due to the challenges they faced in moving their hands, and for participant 6 was more because of their visual disability than the physical one.

Participant 5 rated the ease of using the application as 2 out of 5, indicating some difficulties in using the application. They faced difficulties in moving both of their hands, which was the main reason why it took a long time to purchase a ticket and complete the other tasks, but it was also due to language barriers. Participant 6 rated their overall experience in using the application as 3 out of 5. Most of the difficulties they faced while using the application were because of their visual disability rather than the physical one.

The Figure 22 below visualises the task completion time results of all the participants who were physically disabled.

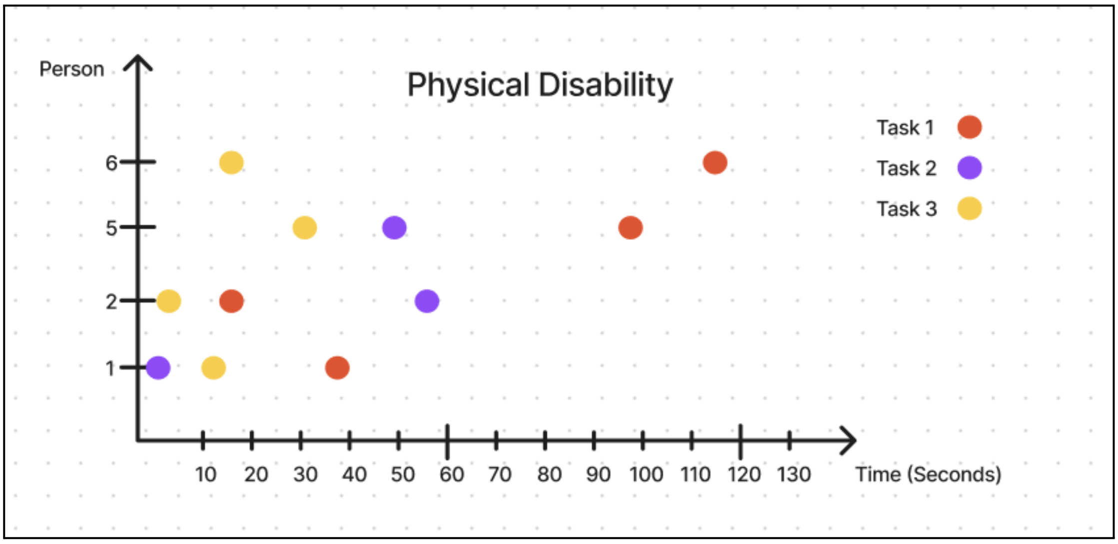

Figure 22: *Visualisation of task completion time results for participants with the physical disability*

4.2.4 Thematic analysis of the results

The thematic analysis reveals several themes throughout the different disabilities related to usability challenges. The thematic analysis process involved both researchers working in separate rooms to identify themes within the participants' answers and challenges from the usability tests and interviews. After the researchers individually discovered some themes related to visual, hearing, and physical disabilities, they joined together to collectively discuss the identified themes. The following themes represent the findings of this collaborative effort.

Visual Disability

The participants that had visual impairments experienced significant challenges in navigating the application interface. They had to do the usability test twice, first without any technological aid, and later with the technological aiding tool VoiceOver that is built in the iOS system. This was the primary tool that helped the visually disabled participants. However, some issues still existed due to irrelevant or inaccurate descriptions of textual elements that hindered task completion. Both of the participants with visual impairment struggled similarly with navigation, specifically with task 2 when the goal was to find the recently purchased ticket in the application.

Hearing Disability

The participants that had the hearing disability faced their biggest challenges in untranslated elements within the interface of the application. The issues with untranslated text affected the completion time for the participants. One participant that had a combination of physical and hearing disability had slower task completion time compared to the other participants with hearing disability. This is likely due to the physical disability of the participant and not the hearing impairment. The participants highlighted the importance of translating textual elements inside the interface.

Physical Disability

The participants that had a physical disability had different results. Some participants with physical disability had a combination of another disability, and this impacted their results. The challenges that were faced included issues related to both physical and visual impairments. While participants that had a singular physical impairment completed the task successfully, one participant still faced some issues with the language barrier, as they were not very fluent in English and the application interface was mostly in English. This impacted their results but had nothing to do with the disability that they had. Those with a combination of disabilities that included physical disability did however experience more significant issues compared to the participants with a singular physical disability. Their completion times were longer and one participant also had problems with their visual impairment. Some participants that had a physical disability had no problems with using their hands, while others did have some difficulties with that part. The usability tests focus on using the hands in order to navigate and complete the tasks inside the interface, therefore the participants with no hand dexterity issues had a better overall experience with the application because their disability did not make it difficult for them during the tests.

5 Discussion

The Discussion chapter will delve into the study's findings and compare them with past research efforts. This thorough examination will shed light on the study's implications and how it contributes to current knowledge. It will also critically assess any limitations encountered during the study, offering a comprehensive understanding of its results. Through these discussions, readers will gain valuable insights into the research's importance and potential applications.

5.1 Result discussion

As previously mentioned in the purpose and research questions chapter, the goal of this study is to provide, if possible, some valuable guidelines and solutions to enhance the usability and accessibility of the GUIs to cater the needs of individuals with visual, physical, and hearing disabilities. In order to fulfil the purpose of the thesis, two questions had to be answered.

The first research question of this study is:

1. *What are the key differences in designing graphical user interfaces for individuals with singular disabilities compared to those with combinations of disabilities?*

By combining the findings from the theoretical frameworks in this study, now we can better understand that creating GUIs has many aspects to consider, especially, when they are for the individuals with a combination of disabilities. These insights will allow developers to create consistent and powerful designs, which in the end will result in a more user-friendly digital interface.

As an answer to the first question, designing GUI designs for people with only one disability includes addressing the challenges that are only related to their singular disability. Insights from the UCD approach by Rezaei, Heisenberg, and Heiden (2014) emphasise considering the unique needs of users with disabilities, ensuring a more inclusive design process. For example, when it comes to individuals with physical disabilities, the focus should be on providing larger touch targets, such as buttons, and text fields, ensuring keyboard accessibility for those who have difficulties moving their hands. These solutions and functionalities will make it easier for people who only suffer from physical disabilities to interact with the UI design.

Theories from the article inclusive content creation by Rease Rios (2021) underscore the importance of compatibility with assistive technologies and providing alternative text, enhancing accessibility for individuals with visual and hearing impairments. Similar to physical disabilities, individuals with visual disabilities require solutions that are only tailored for their specific disability, such as, GUIs with screen readability, contrast sensitivity, and compatibility with assistive technologies like screen readers such as VoiceOver, and other solutions that only cater to visual disabilities needs. The focus should be only on one type of disability. Therefore, it may limit the application's reach and accessibility, potentially excluding users with different disabilities or diverse needs.

On the other hand, individuals with combinations of disabilities face more challenges when interacting with GUIs. Based on insights from both the UCD approach and Web Content Accessibility Guidelines (WCAG, 2021), developers can ensure comprehensive accessibility in GUI design. The UCD approach emphasises considering all the unique needs of users with disabilities, including those with multiple disabilities. Similarly, WCAG provides a strong foundation for accessibility, outlining principles to make GUIs perceivable, operable, and robust for different types of disabilities, including combinations of disabilities.

Unlike singular disabilities, people with a combination of disabilities require considering all types of disabilities, because multiple disabilities make the user experience harder and more complicated. Developers and designers should focus on all different types of disabilities. By considering all the issues that are faced by individuals who suffer from a combination of disabilities and providing a solution for every single one of them, developers can create more inclusive GUIs that cater to the unique needs of every user, and not only the needs of people with a combination of disabilities.

The second research question of this study is:

2. *How do individuals with visual, physical, hearing disabilities differ in their interaction with the ticketing application of public transport?*

To answer the second question, it is crucial to understand and consider the diverse accessibility needs and challenges faced by individuals with these disabilities when interacting with GUIs. Individuals with different disabilities have unique accessibility needs and challenges when interacting with modern day GUIs. In some applications, the accessibility needs can vary depending on what tasks are meant to be completed. In this study, the application that was the focus point was the ticketing application of public transport called Zbiletem (*Zbiletem*, n.d.).

According to the WCAG, it is obvious that people with visual disabilities face challenges in observing information on application interfaces. Inadequate colour contrast and lack of alternative text for images can hinder the ability of visually impaired individuals to navigate effectively (WCAG, 2021). This aligns with the findings from this study, as the participants with visual impairments struggled to complete tasks without technological aids such as VoiceOver, and even with this tool, some tasks could not be completed to their full extent. The reason for this is most likely due to inaccurate alternative text that makes the VoiceOver tool read out wrong or irrelevant information to the user. Another possible reason could be the untranslated elements in the application. Developers have a responsibility to think of these details when developing applications. Textual elements and images should have alternative or descriptive text so tools like the VoiceOver tool can read it out to visually impaired people. It is noticeable that the participants with visual impairments rated the experience higher when they could use technological aid. One noticeable thing is that the participant with visual and physical combination rated the application higher than other participants when they could use technological aid.

Similarly, participants with physical disabilities in the analysis struggled to navigate the interface. The reason for this is most likely not down to their physical disability, even if it could have impacted the results in a way. Some of the participants that had a physical disability could still use their hands normally without any difficulties, therefore they should not have had any problems with completing the tasks, but still encountered problems due to untranslated text in the application. Making sure that text is translated in applications is also a part of the accessibility guidelines that exist. However, in some cases, individuals with physical disabilities may encounter difficulties in interacting with application interfaces due to their mobility limitations. The study by Angellotti et al. (2020) introduces innovative assistive technologies like the iFree pointing method, which can make interaction easier for users with physical impairments.

In this study, the application Zbiletem (*Zbiletem*, n.d.) did not provide any auditory cues to its users, therefore the individuals with hearing disabilities did not face any greater challenges or difficulties when interacting with the application as most of the tasks were visual. This can be said because the completion times were similar to the completion times from the pilot testing that were conducted with participants without any impairments. However, individuals with hearing disabilities may face challenges in understanding auditory cues provided by some applications. According to the (WCAG, 2021), in order to make audio and video media as accessible as possible, the developers should focus on implementing captions / subtitles on all media content. The captions can also be used by people who process written information better than audio, or simply if the person does not fully understand the language that is spoken and needs to read what is being said in order to follow along. If the bus ticketing application Zbiletem introduced some functionality to its users that used auditory cues or video content, then the developers would need to think of an alternative way to use the functionality without being able to hear, for instance by having live captions as soon as the content starts playing, in order to follow the WCAG.

When designing GUIs, it is important that the designer needs to consider the diverse needs of users with disabilities. The framework proposed by Rezaei, Heisenberg, and Heiden (2014) sheds a light on this issue and states that it requires a holistic approach to the problem. The framework emphasises understanding the user space, need space, and application space. By understanding these three different spaces, the development of accessible GUIs is tailored to the specific requirements of individuals with visual, physical, and hearing disabilities.

In this study, it was very clear from the beginning that the participants that would struggle the most would be those with a visual disability. It is even more clear afterwards that it was the case. Individuals with visual impairments need technological tools to navigate and use the application Zbiletem. This was not the case for participants with hearing or physical impairments. The participants with the least problems during the usability tests were the participants with hearing disabilities. These individuals did not need to use their hearing capabilities in order to complete the given tasks within the application interface. The case would probably be different had we given them a task that would need the participant to listen to some auditory cues without any speech to text tools.

This addresses the second question of the study. When it comes to bus ticketing applications, such as Zbiletem (*Zbiletem*, n.d.), those with visual impairments encounter the most significant challenges. The user group with a vision disability rely heavily on their vision to find the correct ticket they wish to purchase, locate it within the application interface, and perform tasks such as scanning the ticket. When the technological tool VoiceOver reads irrelevant or misaligned content, it intensifies the difficulties faced by visually impaired users. The user group with hearing impairments encountered the fewest obstacles within the application. This was because of the absence of auditory cues or need for auditory functionality within the bus ticketing application. The impact of physical impairments on user interaction varies based on the nature of the disability. For instance, users experiencing limitations in hand mobility may encounter difficulties when navigating the application, however, those with lower limb impairments typically do not face any challenges as they do not need their lower limbs in order to interact with the application's interface.

5.2 Method discussion

The methods that were chosen for this study were qualitative. These methods were chosen because they allow for a deeper understanding of the needs and perspectives of individuals with disabilities. By engaging in qualitative interviews, the aim was to hear directly from the participants and those that were affected and prioritise their experiences over simply collecting numerical data from a quantitative analysis.

According to Dworkin (2012), many articles and books recommend and suggest anywhere from 5 to 50 participants as adequate. However, even though the number of participants in this study exceeded the minimum suggestion from Dworkin, the feeling is that the results would improve by having more participants. By increasing the number of participants, particularly those with a combination of disabilities, it would facilitate the identification of themes during the thematic analysis process, and perhaps lead to finding even more specific themes between participants that have the same combination of disabilities. This was difficult to achieve, particularly due to the considerations involved in conducting qualitative research, especially with individuals with disabilities. The most important consideration were the ethical considerations, as participants needed to consent to having their responses and test results documented for research purposes. Additionally, the process of recruiting participants proved to be challenging. With help from Jönköping Läns Funktionsrätt (Jönköpings Län Funktionsrätt, n.d.), some suitable participants with the specific disabilities were identified for the study.

Another method selected for this study involved a review of existing literature. By reviewing existing literature, the findings could be compared with the responses and outcomes from the participant interviews and results from the usability tests. This analysis made it easier to identify the different themes and conduct a thematic analysis because it was clear what challenges were expected from previous research. This method provided insights to inform the study's preparation and interviews process. It was crucial to understand the existing literature prior to starting the research, as it allowed the study to contextualise its contributions within the research landscape and address gaps in the field to fulfil a purpose.

The overall impression is that the criteria for validity and reliability was met. In the validity and reliability chapter, the focus is on the qualitative methodological approach, which included reviewing existing literature, collaboration with Infospread (Infospread, n.d.) by utilising their bus ticketing application for the study, and ethical considerations by above all ensuring participants' consent. All these aspects were effectively addressed and fulfilled, therefore the requirements for validity and reliability were met satisfactorily.

5.3 Study limitations

Due to geographical and ethical reasons, we encountered some difficulties when trying to get Polish customers for the application testing. Therefore, we chose the alternative approach and opted to conduct the testing with users in Sweden. This enabled us to simulate a similar testing process and facilitated potential in-person meetings, which made it easier when providing clear instructions and explanations. During a meeting in-person, it would offer a more conducive environment for effective communication. However, the application was tailored for people that lived in Poland, therefore the ideal thing would be to do the same usability tests in Poland. Many of the Swedish customers complained that the application still had some untranslated textual elements that were in Polish, and that may have caused a distraction during the testing and affected the task completion time results.

Originally, the strategy involved Maze to assess participants' interactions with the application during testing. However, due to the absence of wireframes or Figma designs that were provided by Infospread, some challenges occurred. Maze requires these wireframes to conduct testing. Consequently, an alternative approach had to be devised. The testing was conducted by using phones and manually timed tasks. During the testing process, any miss clicks or difficulties on the tasks encountered by participants were documented. It is important to note that this manual method of measuring time and documenting difficulties without the use of Maze may have introduced some degree of inaccuracy into the test results.

6 Conclusions and further research

In this chapter, the conclusions of the study will be presented to provide insights into the implications of the research, Additionally, potential areas for future research will be outlined to suggest directions for further exploration and development in this field.

6.1 Conclusions

The purpose of this study was to address the challenges faced by individuals with disabilities when using websites and mobile applications. Even though there are many existing guidelines, many digital platforms still are not easy for everyone to use, especially those with visual, physical, or hearing impairments. This research aimed to identify these challenges and find ways to make digital interfaces more accessible for everyone, and making sure that people with disabilities can fully participate in the digital world.

The first research question was:

What are the key differences in designing graphical user interfaces for individuals with singular disabilities compared to those with combinations of disabilities?

This question was answered by examining the usability of GUIs for individuals with both singular and combinations of disabilities. By conducting usability tests and interviews with participants who suffer from different types of disabilities, the study gained insights into the unique challenges that are faced by them. Also, through those interviews and tests, the study identified some design considerations tailored to address the needs of users with singular and combinations of disabilities. Additionally, by comparing the usability experiences of participants with singular disabilities to those with combinations of disabilities, this study found that designing GUIs for individuals with singular disabilities involves addressing challenges specific to their disability type, such as providing larger touch targets for those with physical disabilities and ensuring screen readability for individuals with visual impairments. However, individuals with combinations of disabilities face more complex challenges, requiring consideration of multiple disability types to create inclusive interfaces. And by having this question answered, the study contributes to a deeper understanding of what developers and designers should think about to improve GUIs and facilitate accessibility for individuals with various disability backgrounds.

The second research question was:

How do individuals with visual, physical, hearing disabilities differ in their interaction with the ticketing application of public transport?

This study addressed the research question by examining how individuals with visual, physical, and hearing disabilities interact with the ticketing application of public transport through usability tests. It became clear that various accessibility needs and challenges exist among these user groups when working with GUIs. Participants with visual impairments encountered the most significant challenges, mostly due to lack of alternative text which hindered effective navigation with the help of the VoiceOver tool. The VoiceOver tool was essential for individuals with visual impairment in order to have a chance of completing the tasks that were given within the application. Participants with hearing impairments faced fewer obstacles as the Zbiletem application in this study (*Zbiletem*, n.d.) did not have a need for hearing. However, challenges may arise if auditory functionality is introduced in the application in the future without proper accommodations like live captions in video content for instance. Hand mobility limitations in individuals with physical impairments posed challenges for navigation. The participants with physical disability in their lower limbs did not face any significant challenges. This study underscores the importance of considering diverse user needs in GUI design and emphasises the necessity of adhering to accessibility guidelines to ensure inclusivity for all users, irrespective of their disabilities.

6.1.1 Practical implications

The findings of this study can have some important implications in different sectors. In the industry, following the suggested guidelines and solutions can lead to more accessible and user-friendly GUIs. Thus, it can improve the user experience for individuals with disabilities and makes it easier for them to interact with the digital interfaces. Moreover, in public sectors, implementing the suggested guidelines can promote inclusivity and equal access to services for everyone, which can lead to a more equitable society. Also, prioritising accessibility in design in general can foster a culture of inclusivity and empathy, ultimately benefiting society as a whole.

6.1.2 Scientific implications

This study's results can offer valuable insights into the scientific community's understanding of how accessibility in GUIs can make the life easier for disabled people. By comparing the key differences in designing GUIs between individuals with singular disabilities and individuals with a combination of disabilities, the study sheds light on the challenges they face, and what requirements each group needs in order to make the process of interacting with GUIs easier for them. Additionally, by understanding how individuals with visual, physical, and hearing disabilities interact with public transport ticketing applications, it can offer valuable information for developers and designers when conducting similar research within this field.

6.2 Further research

In case of future exploration within this field, there are some areas to consider improving or continue working on. This study is about improving the GUIs for three singular disabilities. It would be interesting to do the same study, but for individuals who suffer from multiple disabilities, to understand their needs and know how to improve the GUIs for those people.

In the world, individuals with disabilities represent a minority within the broader population. To have more accurate results and to enhance the outcomes of the future research within this field, consider having more participants who suffer from some kind of disability that makes interacting with the GUIs difficult. This way, researchers can gain deeper insights into the different challenges faced by disabled people when interacting with digital interfaces.

Furthermore, a comparative study between applications that comply with the WCAG and those that do not could shed light on the real-world impact of commitment to accessibility standards. This could also lead to exploring more future design guidelines and solutions to enhance the GUIs.

7 References

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8 Appendices

Appendix 1: *Categories of mobile accessibility guidelines*

Category	Purpose	Benefit	Example (Ex.) Guideline
Text	Text is rendered in adequate format, size, and color. Text alternatives such as speech, Braille, or symbols are provided for non-text content.	Allow users with vision impairments to read, hear, feel, or otherwise perceive content that is written in text. Allow users with cognitive disabilities to read and hear content at the same time.	Ex1. Text has a reasonable default size (14pt). Ex2. Text can be resized without assistive technology up to 200 %.
Audio	Apps allow users to control and access audio. Apps provide alternatives to audio content, such as textual transcriptions, or captions.	Allow users with hearing impairments to see a textual transcription and description of content that is communicated through audio.	Ex1. Audio files have text transcript. Ex2. Audio is not played automatically for more than 3 seconds, users are able to pause audio.
Video	Apps provide alternatives to video content, such as captions and audio descriptions of visual content.	Allow users with vision impairments to hear an audio transcription and description of visual content. Allow users with hearing impairment to read the audio transcript.	Ex1. Prerecorded videos have captions. Ex2. Videos have extended audio description that gives the narrator adequate time to describe what is happening in the video.
UI Elements	User interface elements, including images, are clearly labeled, colored, and positioned on screen. Make it easy for users to navigate around the app, find content, perceive it, and determine where they are in the app.	Allow users with visual impairments to navigate the interface and locate controls and links. Allow screen reader users to access and navigate the app interface.	Ex1. UI elements (e.g. buttons, images, etc) have descriptive labels. Ex2. Elements that trigger changes (buttons, links, etc) are clearly indicated.
User Control	Provide users enough time to read and use content. App follows user-changed device settings.	Users with vision impairments or cognitive disabilities who have trouble reading quickly are not restricted to perceive content by time limits. Users with mobile impairments can use the device in their preferred orientation.	Ex1. Both landscape and portrait orientation are supported. Ex2. App complies with OS-level changes to settings e.g. font, and color.
Flexibility and Efficiency	Minimize data entry and maintain user data. Information can be accessed in multiple ways.	Users with mobile impairments or visual impairments will benefit from reducing data entry related tasks. Users with visual impairments or cognitive disabilities will benefit from maintained user data when the asked to re-login.	Ex1. The amount of text entry is reduced thorough the use of select menus, radio buttons, checkboxes, etc. Ex2. Screen has multiple ways to reach it e.g. (search function, menu).
Recognition rather than Recall	Apps must provide users with necessary information to complete task-on-hand, within the same screen.	Users with visual impairments and cognitive disabilities are able to find the information they need to complete a task without going to previous screens or looking up information.	Ex1. Important information can be viewed without scrolling. Ex2. Screen has title that describes the purpose.
Gestures	Gestures must have alternatives, and can be replaced by other interaction options.	Users with mobile impairment can use easy to perform gestures, and do not worry about activating unwanted functionalities if a wrong gesture is made.	Ex1. Gestures can be replaced by keyboard options. Ex2. Touch targets close to minimum size are surrounded by inactive space.
System Visibility	Application appears and operates in predictable ways that users can perceive.	Users are not confused by system's lack of response. Users with visual impairments will benefit from knowing the system status and its response to their gesture or interaction.	Ex1. User is notified of state changes. Ex2. Focus/currently selected element is clearly visible.
Error Prevention	Help users avoid errors and correct mistakes when entering input.	Allow users to easily and quickly find errors in their input. Users with visual impairment, mobile impairment, and cognitive disabilities will save their time when the app finds and corrects errors.	Ex1. Identify and explain errors that can be automatically detected. Ex2. Save correct input, allow user to correct errors and proceed.
Tangible Interaction	Apps have all of its features accessible using tangible device e.g. physical keyboard.	Users with visual impairments or mobile impairments can use keyboards, and switches and will still be able to use the app.	Ex1. User can move focus between all elements using external keyboard. Ex2. All functionality can be accessed by an external keyboard.

9 Figures

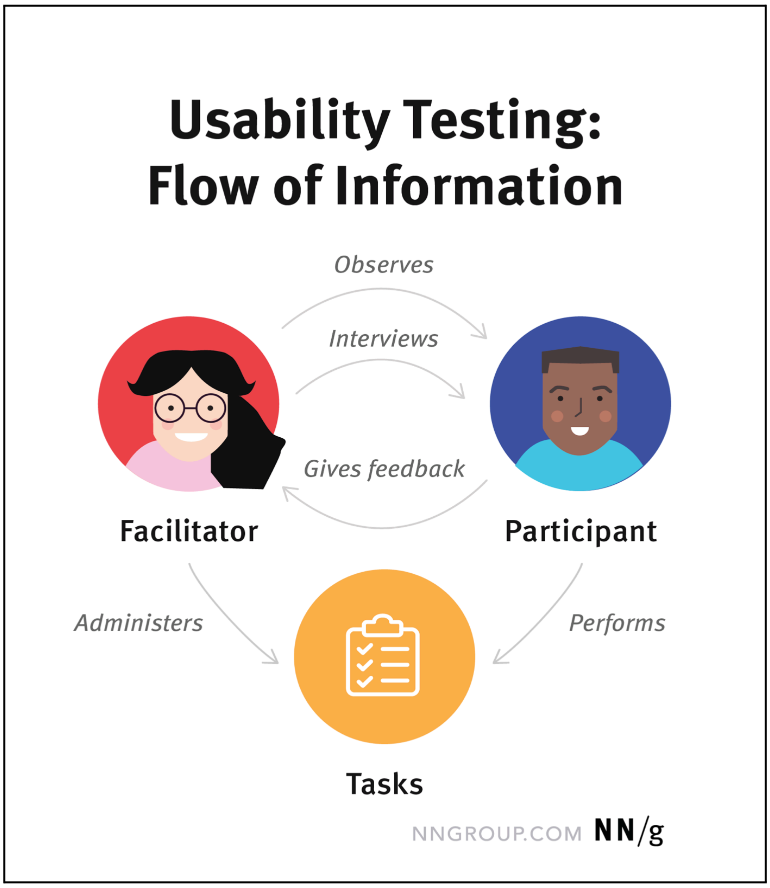

Figure 1: *The flow of information during usability testing (Moran, 2019)*

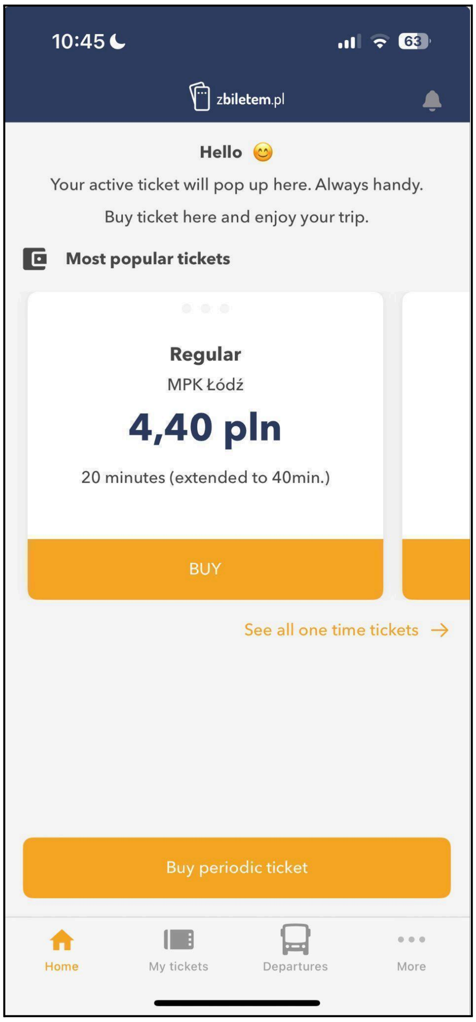

Figure 2: *home screen of the application*

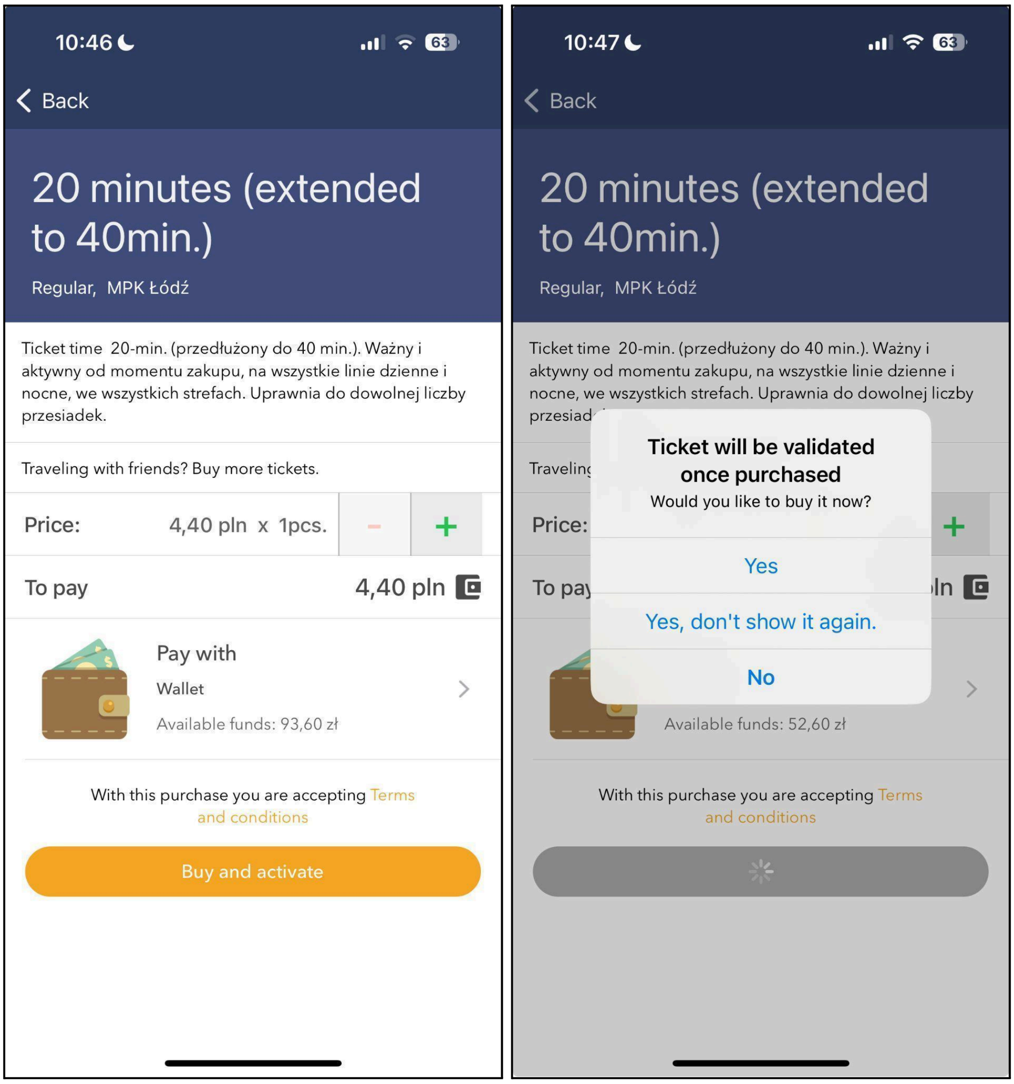

Figure 3: *ticket buying and confirmation screen.*

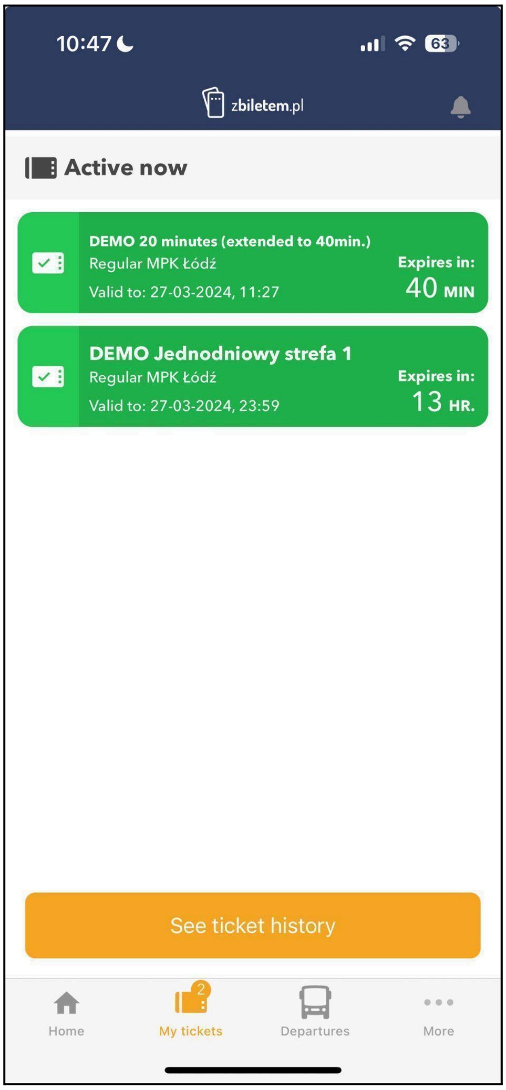

Figure 4: *"My tickets" screen with all active tickets*

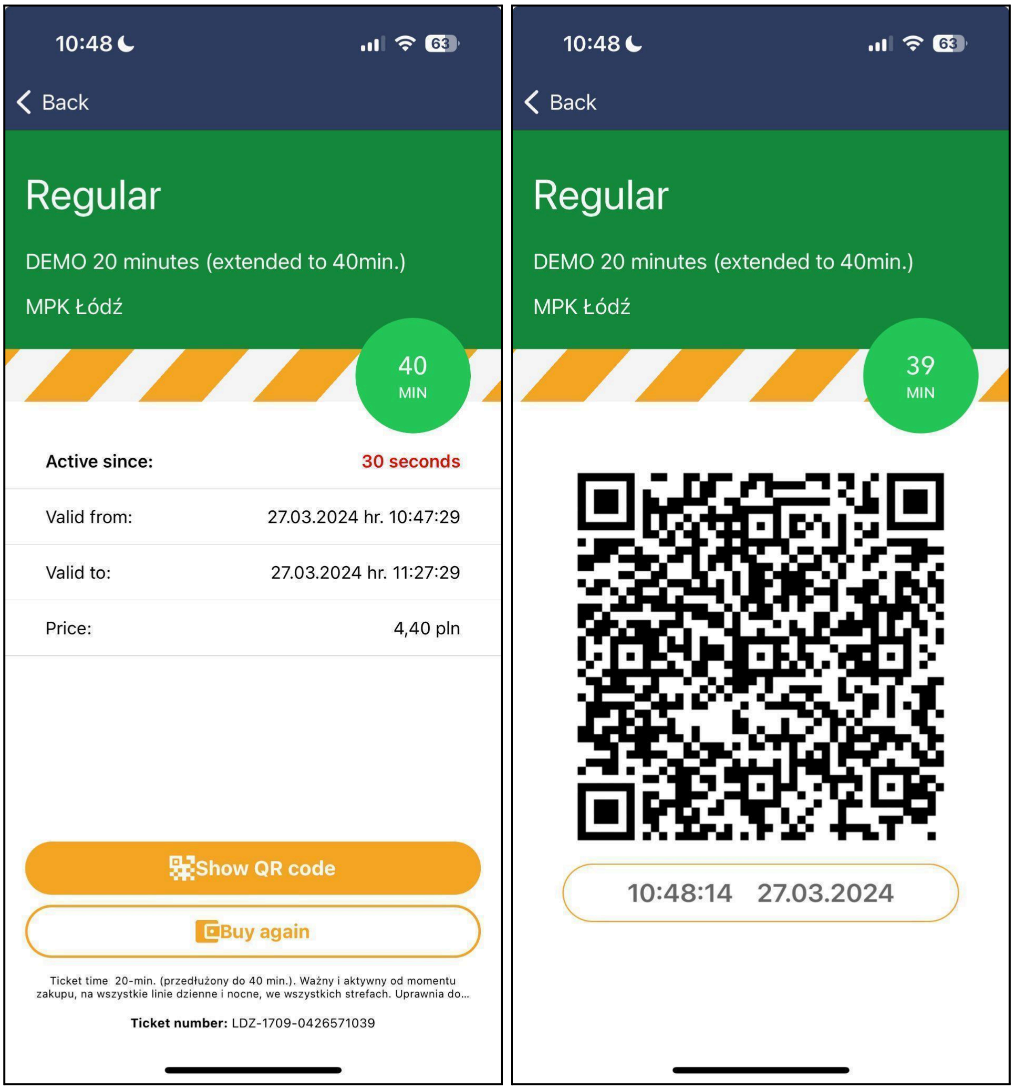

Figure 5: *specific ticket screen and QR code for ticket*

Accessibility Guideline	**Total Number of Violations**
All text elements are visible to screen reader	37
Contrast ratio between background and text is at least 7:1	35
Images have an alternate text description	31
UI elements (buttons, divs, etc) have descriptive labeling	48
Touch targets are 9mm high and 9 mm wide	25
Touch targets close to minimum size are surrounded by inactive space	18
Link / button purpose can be determined from link / button text only	5
Identify and explain any errors that can be automatically detected	5
Normal-size (< 18 pt / 14pt bold) text: Contrast ratio of 4.5:1	3
Form fields are below (not beside) labels	2

Figure 6: *Accessibility guidelines and total number of violations*

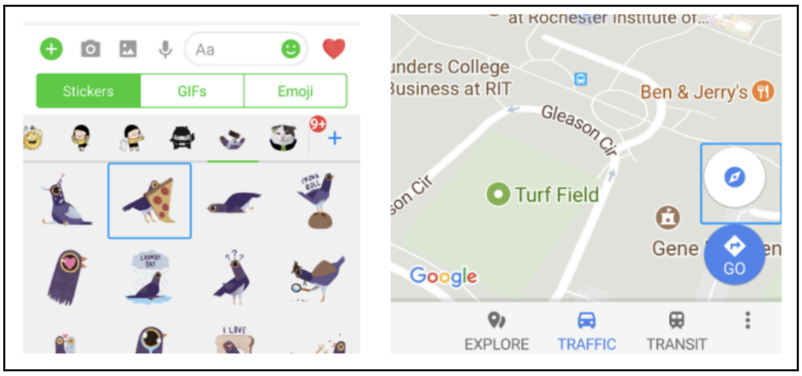

Figure 7: *Screen reader ignores most sticker names on Messenger (left) and text on Google Maps (right)*

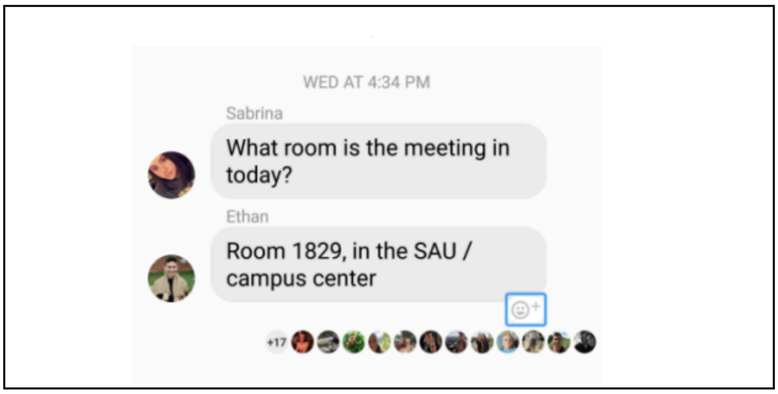

Figure 8: *Facebook Messenger emoji reaction button for individual messages does not meet touch size recommendation.*

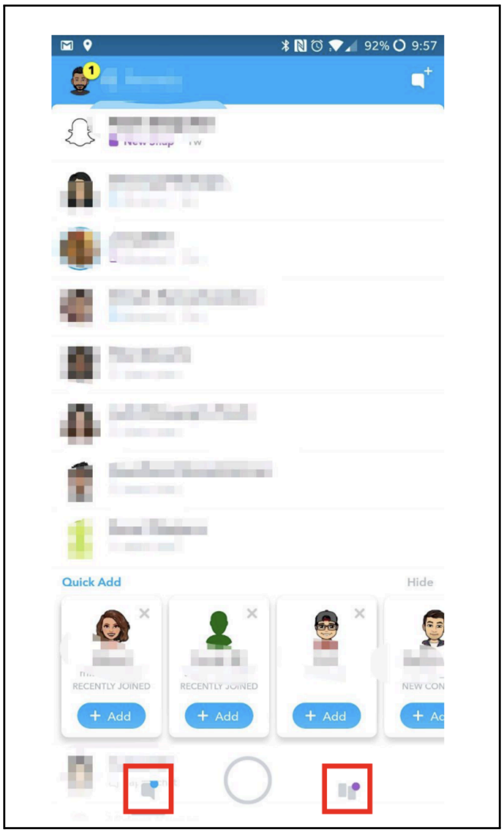

Figure 9: *Snapchat navigation buttons and indicators are not labelled and do not contain text.*

		Sight	Hearing	Touch	Taste	Speech	Upper limb	Lower Limb	Skeletal muscles	Tactile graphic display	Tactile sensors	Text to Braille	Braille to Text	Eye gaze tracking	Head tracking	Facial gesture detection	Hand gesture detection	Text to Speech	Speech to Text	Sign language to Speech	ERP-based Control (EEG)	ERD/ERS-based Control (EEG)	Neuro-prosthetic /EMG-based	Manipulator arm	Non | Autonomous wheelchair	Environment mapping
Actuator	Skeletal muscles					*								*		*			*		*	*	*			
	Lower limb						*		*								*		*		*	*	*		*	
	Upper Limb					*		*	*					*	*				*		*	*	*	*		
	Speech	*		*			*		*							*	*	*	*	*						
Sense	Taste	*																								
	Touch	*									*															
	Hearing	*					*		*									*	*	*	*	*				
	Sight		*	*		*	*	*	*	*		*	*					*	*		*	*				*

Figure 10: *Substitutional table for human body senses*

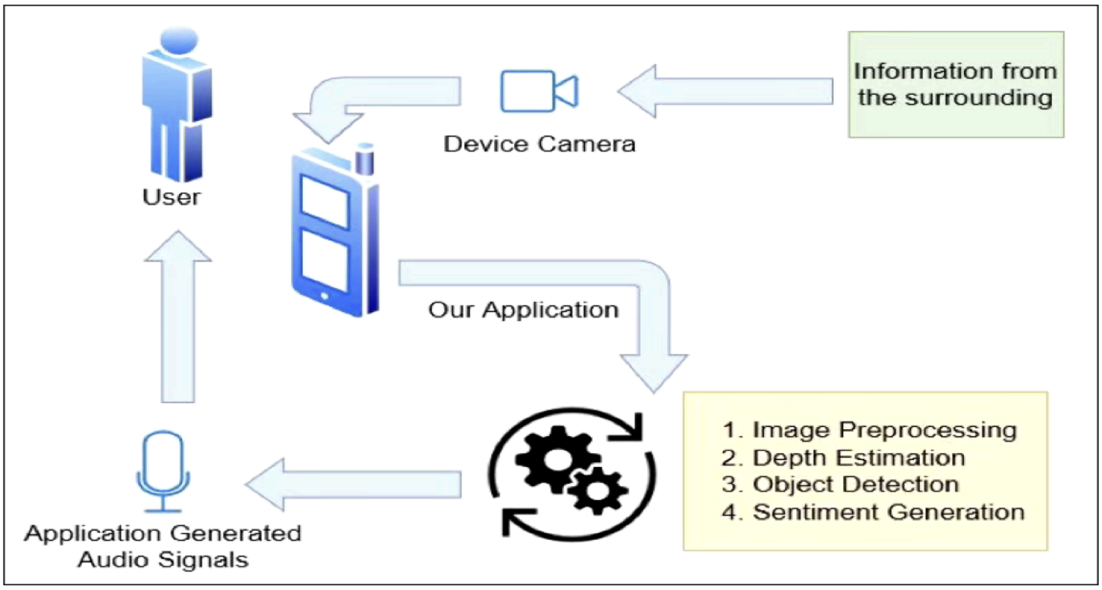

Figure 11: *The application's functionality overview (Machine Learning Based Computer Vision Application for Visually Disabled People, 2021).*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	38.17 seconds	2.19 seconds	11.64 seconds

Figure 12 : *The results of participant 1*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	16.32 seconds	55.06 seconds	5.83 seconds

Figure 13: *The results of participant 2*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 33 seconds (Purchased wrong ticket)	Couldn't complete the task	13 seconds

Figure 14: *The results of participant 3*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	40 seconds	37 seconds	3 seconds

Figure 15: *The results of participant 4*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 37 seconds	49.12 seconds	31.04 seconds

Figure 16: *The results of participant 5*

	Task 1 (purchasing a specific bus ticket)	Task 2 (locating the purchased ticket)	Task 3 (finding the ticket's QR code for scanning)
Time	1 minute and 52 seconds	Couldn't complete the task	15.28 seconds

Figure 17: *The results of participant 6*

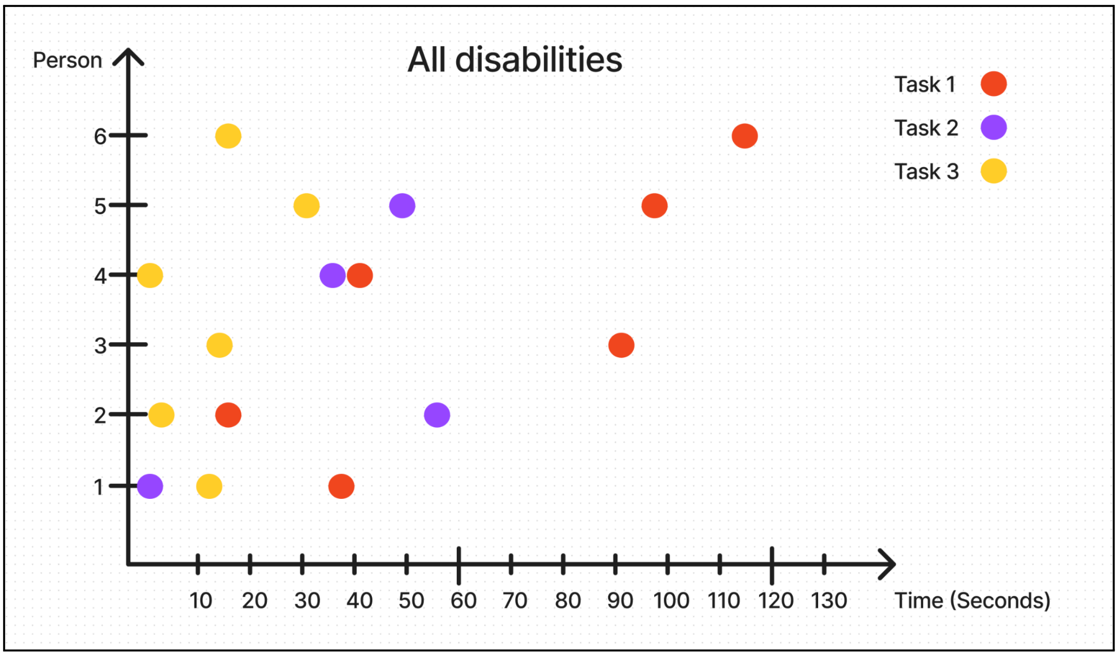

Figure 18: *Visualisation of all task completion times results*

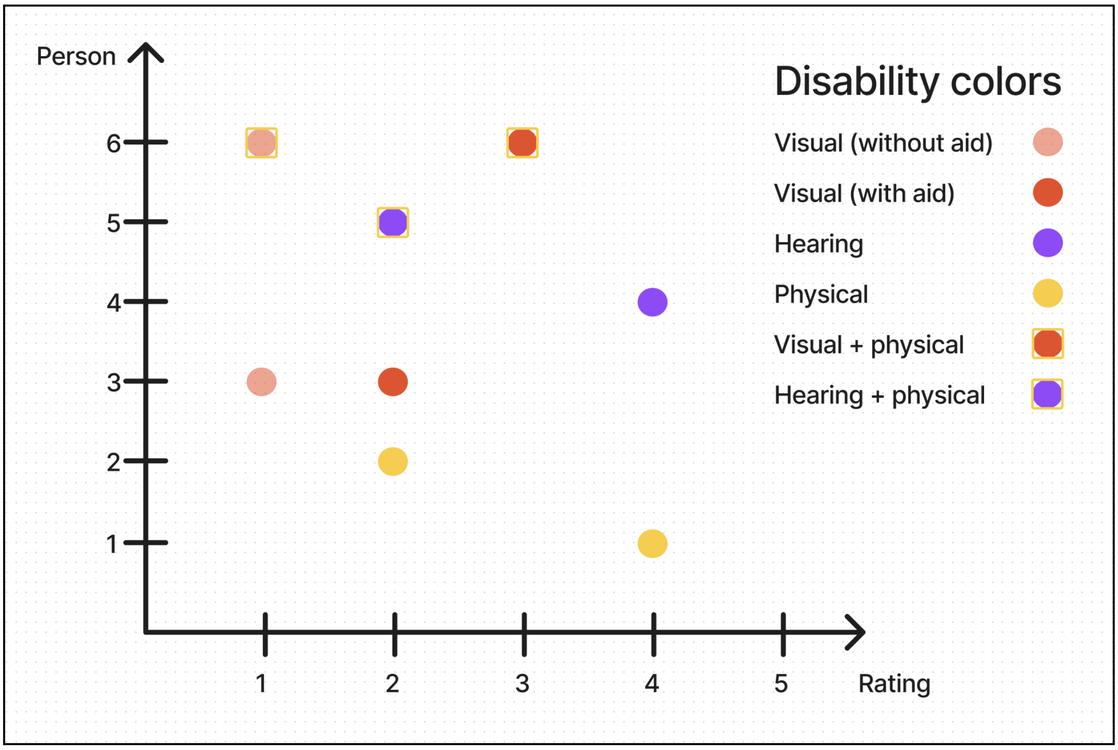

Figure 19: *Visualisation of all ratings of the application*

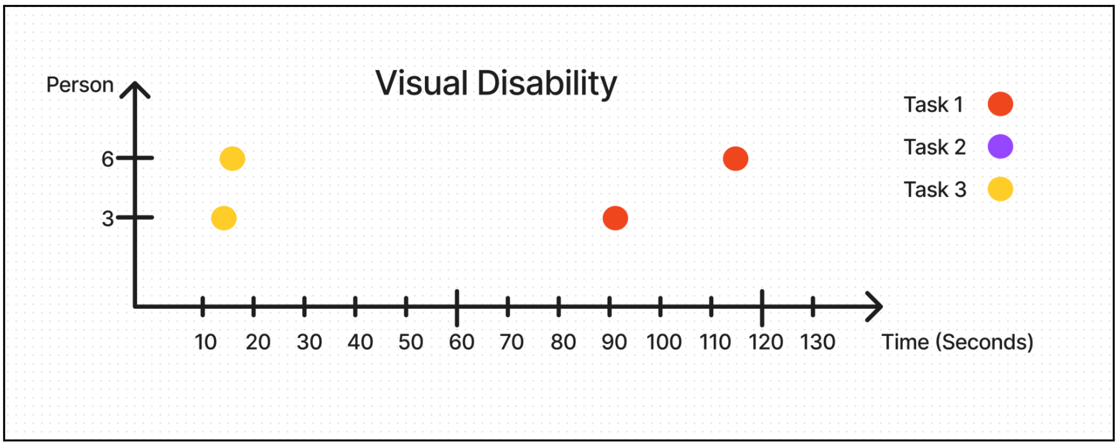

Figure 20: *Visualisation of task completion time results for participants with the visual disability*

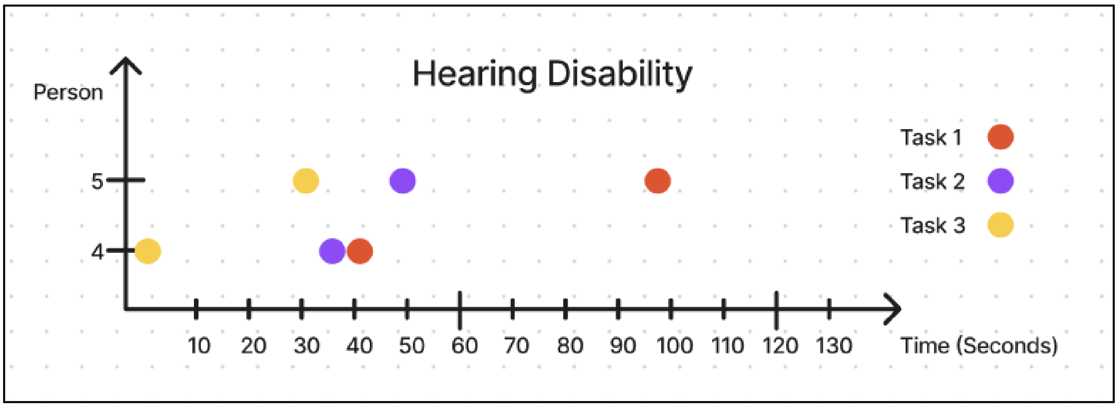

Figure 21: *Visualisation of task completion time results for participants with the hearing disability*

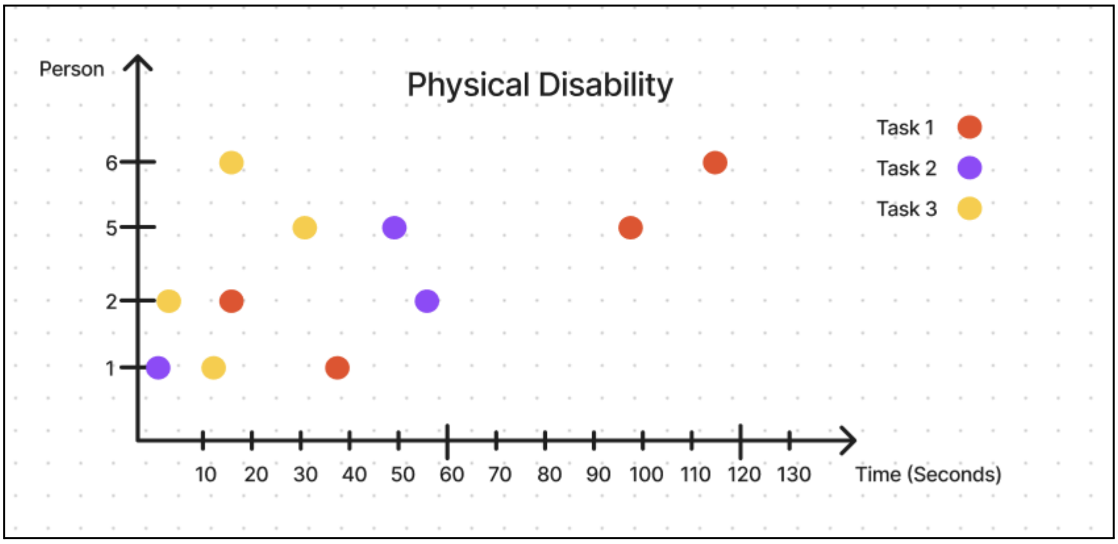

Figure 22: *Visualisation of task completion time results for participants with the physical disability*