Voting Machine for People with Disabilities

Martina Gauci

Supervised by Dr Colin Layfield
Co-Supervised by Dr Conrad Attard

University of Malta
Department of Computer Information Systems

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FACULTY OF INFORMATION AND COMMUNICATION TECHNOLOGY

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Mgauci

Abstract

At present, the only methods of casting a vote in a Maltese election is by paper ballot, braille ballot or an audio guide. If a person is unable to vote on their own using one of these mechanisms, they are provided assistance by an electoral representative in the vote casting process. This procedure blocks the citizens from their right to a secret vote by forcing the citizens to reveal their vote to the representative. Furthermore, people suffering from severe visual impairment have no means of verifying that their intended vote is being cast.

This study's aim is to create an interface for a voting machine located at the polling station which will allow citizens with disabilities to vote unassisted. A participatory design process, which includes the target audience and experts in accessibility, is used to ensure the accessibility of the artefacts. The approach taken is iterative where the designs are refined into more usable and accessible prototypes. The prototypes will also increase in fidelity; hence, the final prototype will look closest to a fully functional interface. The changes are based on feedback provided by the accessibility experts or the results of the user testing. During the user testing, the prototypes are measured in terms of effectiveness, efficiency and user satisfaction. Some issues were encountered when carrying out the user tests, therefore, the number of testers and the conditions under which the tests were held are not ideal.

Using the high-fidelity prototype, the testers were able to cast the intended vote in under five minutes. All testers were also able to make the instructed changes to the vote. All prototypes obtained a good user satisfaction score, the highest mean score being 95.4 for the final prototype. The high-fidelity prototype showed an improvement in effectiveness, efficiency and satisfaction. However, the improvement is not statistically significant. This is possibly due to the small number of participants.

Acknowledgements

I would like to thank my supervisor, Dr Colin Layfield, and co-supervisor, Dr Conrad Attard, for their assistance, input and guidance during the entire process of this project.

I would like to express my heartfelt gratitude towards my parents who have been immensely patient, motivational and have supported me, not only through my academic journey but in all aspects of my life. I also want to thank my girlfriend, Jael, who has helped me keep my focus and encouraged me throughout my degree.

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1 Introduction

The principal method of casting a vote in the Maltese electoral system is the paper ballot. The alternative methods are a braille ballot and an audio guide. If a person is unable to vote using either option, the assistance of an electoral representative is offered when using the paper ballot. This constrains the citizen to reveal their intended vote to the assistant. Under the declaration of the United Nations' Human Rights [1], all citizens are entitled the right of a secret vote. Therefore, it is of the utmost importance to provide a method that enables independent voting for these citizens.

The three main categories of disabilities that hinder the vote casting process are visual, motor and cognitive impairments. In a survey administered by the Foundation for Information Technology Accessibility within the disabled community [2], 55% of respondents remarked that they are unable to vote without third party assistance. 5% of the respondents make use of the available braille ballot paper or audio ballot, while the remaining can vote independently. The second statistic implies that the alternatives to a paper ballot may have usability issues. The results of this survey are visualised in Figure 1.

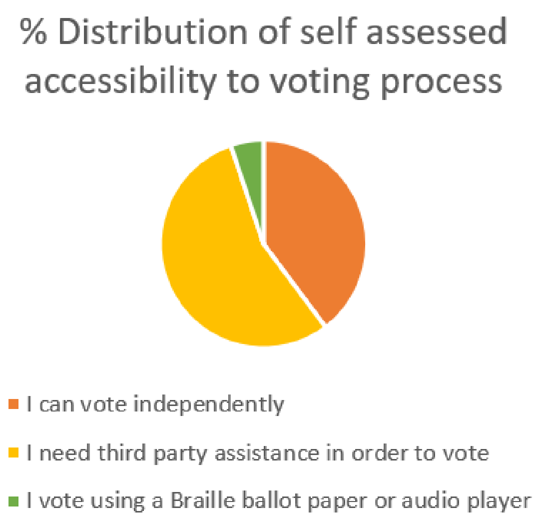


Figure 1- Pie chart illustrating how the disabled respondents in [2] *cast their vote*

There are two main aspects to creating a voting machine: interface design and security. Each aspect needs to be studied in detail in order to implement a system which is accepted by both the electoral commission and the population. Problems that may be caused if the system is not trusted by the citizens include reduced voter turnout and lack of endorsement of the election results. Due to time constraints, this project will target only the interface design with a focus on accessibility. This is a non-trivial task because the interface must be used independently by persons with visual, physical or intellectual impairments. This is further complicated due to the laws which restrict ballot design. Even though amendments to the law can be made, there are a set of principles that the ballot must comply with. For instance, the ballot cannot show any preference to a candidate over another even if this is unintentional.

The aim of this study is to design an interface for a voting machine which will enable the casting of a secret vote by those who are not able to do so using the methods provided presently. To achieve this, the following objectives have been established:

- O1: Create designs for an accessible voting interface based on previous research and accessibility guidelines
- O2: Determine which evaluation techniques will be used to identify issues in the interface
- O3: Identify the measurements which will be used to assess the usability and accessibility of the prototypes
- O4: Attempt to create and evaluate a usable interface for a designated voting machine which disabled persons can use to vote independently

The artefact is developed during three iterations with the involvement of the target audience and domain experts during the design process. Initially, three wireframe designs were created. With the involvement of experts in accessibility, the low-fidelity prototypes were refined into more accessible designs and developed into web applications. A user-centric approach was taken to further improve the prototypes. Users from the target audience evaluated the mid fidelity and high-fidelity prototypes. The measurements extracted from the user testing sessions are effectiveness, efficiency and user satisfaction. These measures enabled the identification of any significant differences between the usability of the prototypes. Feedback provided by the testers was used to support these findings. Since the testing is being carried out by members of the disabled community, the usability measurements will reflect the accessibility of the artefacts.

2 Background and Literature Review

2.1 Voting Machines

2.1.1 An Overview

There exist various voting technologies, such as punch cards and lever machines, being used around the world. Electronic voting machines are a modern alternative to these technologies which were first used in the United States of America in 1976 [3]. Other countries which followed suit are The Netherlands, Brazil and Venezuela [4]. Some countries faced numerous issues while implementing this voting process, namely sociological and ethical [4]. However, electronic voting has the potential to improve voter turnout by making the voting process more accessible.

Voting is explicitly defined as a fundamental human right by the United Nations [1] , therefore, the system must be fine-tuned before it is implemented. Furthermore, The Universal Declaration of Human Rights calls for “universal and equal suffrage” and “secret vote” [1]. This highlights the importance of an accessible voting process where any citizen, regardless of disability, can cast a vote independently.

Usability and security are the core issues of voting machines. The former is the main focus of this research, whereas the latter is outside of the scope of this project. Voters have reported issues regarding reliability and accessibility [5] as well as anonymity and trust [6] towards new voting technologies. Studies show that voters very often refrain from asking for help while casting their vote for many reasons such as embarrassment and compromising the secrecy of their vote [7], [8]. This stresses the importance of usability in the ballot design. The consequences caused by the poor ballot design of the 2000 United States’ Presidential election in Florida is proof of the significance of usability, specifically in this setting. The ballot used in this election is pictured in Figure 2. Voters had to punch a hole in the circle corresponding to their preferred candidates for president and vice president. However, it was unclear which circle was matched to which candidate. This led to voters mistakenly voting for Buchanan and Foster instead of Gore and Lieberman which, in turn, gave a large lead to the Republican Party over the Democratic Party.

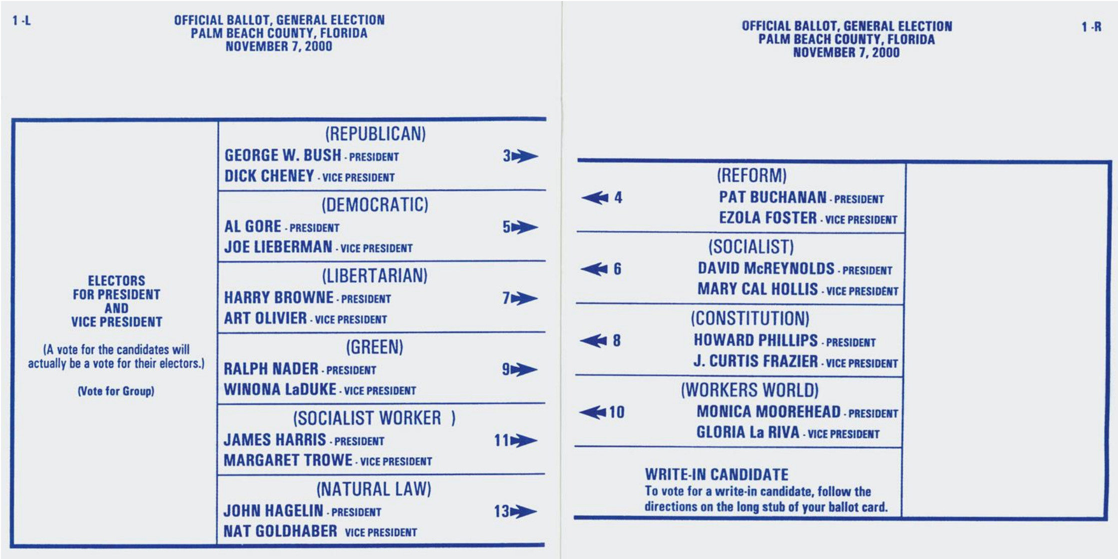


Figure 2 - The ballot used for the 2000 United States' Presidential election in Florida reproduced from[9]

Direct Recording Electronic (DRE) Voting Machines are increasing in popularity as there are many advantages to using this technology. DREs are touchscreen machines which record a vote by tracking what is being pressed by the user and then storing it on an electronic or magnetic medium [10]. The test subjects in [7] found that voting using a DRE is comfortable, text is readable and error correction is easy. Most importantly, the testers were confident that the machine recorded their intended vote. This is a critical factor in any voting technology as it might affect future voter turnout and the endorsement of the election's outcome [8], [10]. Participants in [6] carried out trials on three different prototypes and they felt that the prototype with the least amount of steps was the least reliable because they were not entirely sure that their intended vote was recorded. DREs obtained a higher average usability rating when compared to other voting technologies [10] . Furthermore, testers were faster and more satisfied when using DREs.

2.1.2 Existing Systems

Despite the controversy they attract, voting machines are being set up in countries all over the world such as Japan, the Netherlands and the United States among others [11]. The main concern is security. There are multitudinous possibilities of security violations such as unauthorized access, casting multiple votes and changing votes [12]. In addition to this, voting machines bring worries related to usability. All types of electronic voting machines suffer from a common set of disadvantages when compared to any other electronic machine. For instance, elections occur infrequently and, therefore, users do not have enough practice using the system. Furthermore, it is extremely important to design a system which is usable by all people of voting age. One of the most popular touch screen voting machines is the Diebold AccuVote-TS pictured in Figure 3. This machine had been deployed in 385 counties in the United States by 2006 [13]. It is important to note that elections in the United States do not follow the same process as elections in Malta. An election will ask the citizens to select a candidate for a particular political figure such as president and vice president. The election for each role is called a contest and there are multiple contests in one election. Herrnson et al. [8] observed 47 students using AccuVote-TS and reported that all but one participant managed to cast their intended vote. The participants rated the overall comfort of use 7.7 on a scale from 1 to 9 where 9 is most comfortable. This system was also compared to the Avante Vote-Trakker and a prototype developed at the University of Maryland named Zoomable in [11] and [14]. The most noteworthy difference between the three systems is the navigation structure. AccuVote-TS goes through the contests in an election in a predefined sequence where the user must pick a candidate and tap another button to proceed. Zoomable has an identical advancing mechanism but the contest sequence is flexible. Vote-Trakker is pictured in Figure 4 and it has an automatic advancing mechanism where the user is redirected to the next contest once a candidate is chosen. This made the users feel unsure of who they voted for and, consequently, ballot review time doubled when compared to the other systems [11]. Moreover, users are only allowed to review and change their vote at the end of the candidate selection process which may cause the user to forget the changes that need to be made. 25% of the participants in [14] conveyed their disapproval of this aspect in the system. Changing the vote is easiest on Zoomable because the user simply must tap on the intended candidate to change selection. AccuVote-TS is slightly more complicated because the user must deselect the chosen candidate in order to select another candidate. This was purposefully done to clarify the user's intentions in contests where two candidates must be chosen [11].

Figure 3 - The layout for contests and candidates on Diebold AccuVote-TS (reproduced form [15]*)*

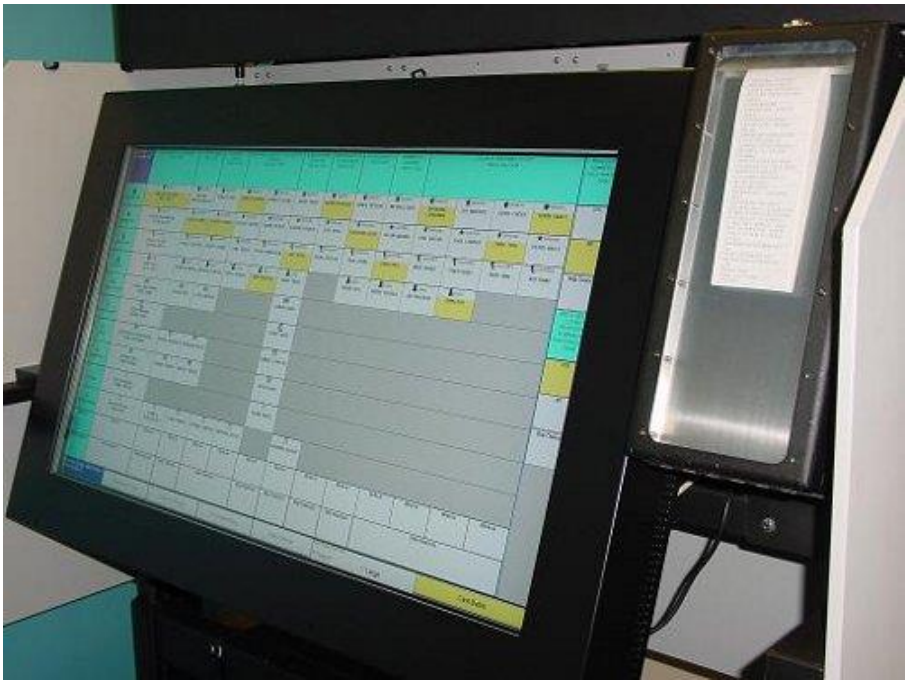


Figure 4 – Avante Vote-Trakker on a 42 inch screen (reproduced from [16]*)*

Vote inaccuracy is the most prominent problem of a voting interface which can result out of bad usability. Especially in close elections, small percentages of erroneous votes can change the election result. It is estimated that between two and three percent of voters cast their unintended vote when tasked with selecting a single candidate for a contest [14]. This percentage increased when the participants were asked to carry out more complicated tasks such as change their vote. AccuVote-TS and Zoomable had similar error percentages whereas Vote-Trakker performed slightly worse [14]. The laboratory study in [14] , found that participants cast unintended votes most using Zoomable. The cause for most of these errors is that the users tapped the “Review and Cast Ballot” button instead of the “Next” button due to their proximity as seen in Figure 5. Overall, [14] found that AccuVote-TS fared best in terms of accuracy.

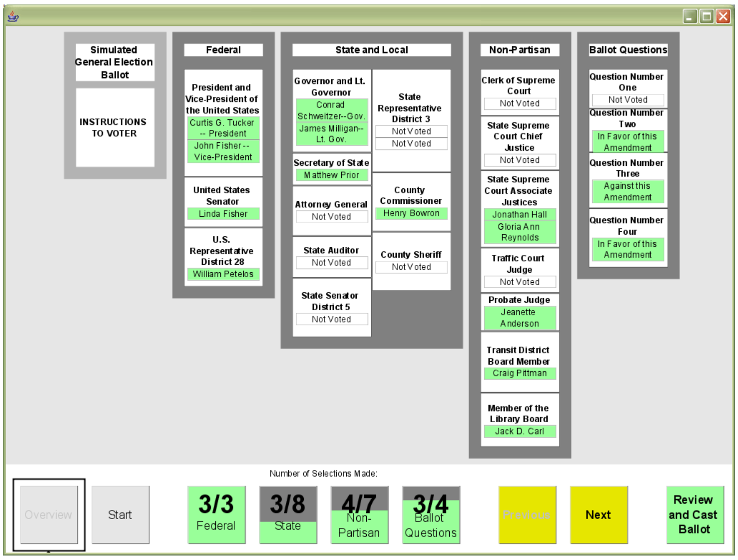


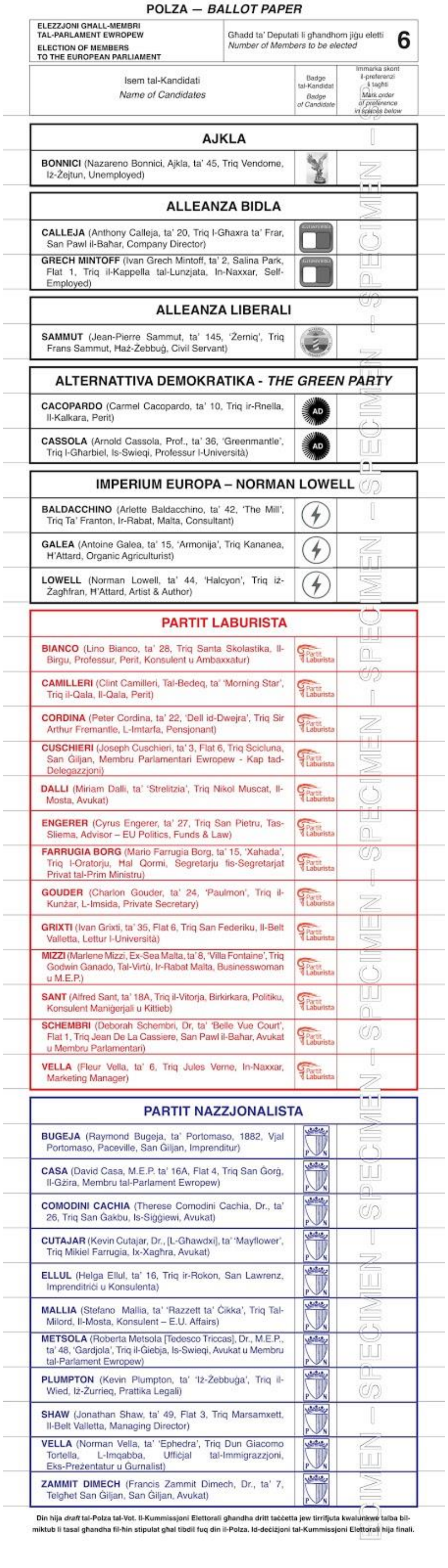
Figure 5 - A screenshot of the Zoomable voting interface

The American Foundation for the Blind tested AccuVote-TS and Vote-Trakker on 13 people who are blind or have low vision [17] . The aim of the study was to check if persons with visual impairment can cast an independent vote using these machines. When using AccuVote-TS, 8 participants required assistance. Most of the participants needed help at the end of the process to cast the vote. Vote-Trakker is even less accessible because 11 of the 13 participants asked for assistance. Users needed assistance when changing the voting selection, scrolling through the ballot hierarchy, and setting the text-to-speech controls. When using this system, users struggled most to set the synthetic speech controls. AccuVote-TS offers a few accessibility features such as magnification, audio and a keypad for navigation [18] . Another voting machine developed by Diebold is AccuVote-TSX and it offers additional accessibility features over AccuVote-TS such as contrast and colour shift. Diebold claims that persons with visual impairments were included in the design of AccuVote-TSX which is why it is more accessible [18]. Some precautions were taken so that physically challenged voters can also make use of this system independently. For instance, voice prompts can be used to complete the ballot [18].

2.1.3 Maltese Elections

The current voting method being used for all Maltese elections is the Single Transferable Vote (STV). Ireland and Australia use STV to elect the Assembly and the Senate respectively [19]. This proportional voting system is also used in a few municipal elections, presidential nominations and party elections in the United States of America [20]. In essence, the STV voting system requires each voter to rank the electoral candidates in his preferred order and, when the vote is being counted, the vote is transferred from one candidate to another based on the voter's preference. There are a set of rules which determine whether the vote can be passed on to the next candidate such as whether the candidate has reached the quota of votes required to be elected [19]. The primary means of casting a vote in Malta is the paper ballot. The voter is given a ballot paper similar to the one in Figure 6. The ballot contains a list of candidates grouped by political party and in alphabetical order by surname. Each candidate is listed in a separate box which contains their full name, address and occupation. In-line with each of the candidate boxes there are another two boxes, one containing a party emblem representing the party the candidate is running for and another blank box. The voter has to locate his preferred candidate and write '1' in the empty box on the right-hand side of the candidate's name. The voter will then proceed to write '2' in box beside his second favourite candidate. The voter will repeat this process, each time assigning the next number to his favourite candidate out of the remaining candidates which are not assigned a number yet. The number of candidates assigned a preference is at the voter's discretion.

Almost 12,000 votes were considered invalid when counting the votes for the Local Councils Election of 2019 [21]. Although one can assume that a fraction of these were purposefully cancelled by the voter, there are some minor mistakes that lead to a large number of votes being nullified. For instance, repeating or skipping a number in the sequence and writing unclear numbers [22].



POLZA — *BALLOT PAPER*

ELEZZJONI GĦALL-MEMBRI TAL-PARLAMENT EWROPEW ELECTION OF MEMBERS TO THE EUROPEAN PARLIAMENT	Għadd ta' Deputati li għandhom jiġu eletti *Number of Members to be elected*	6

Isem tal-Kandidati *Name of Candidates*	Badge tal-Kandidat *Badge of Candidate*	Immarka skont il-preferenzi li tagħti *Mark order of preference in spaces below*
AJKLA		
BONNICI (Nazareno Bonnici, Ajkla, ta' 45, Triq Vendome, Iż-Żejtun, Unemployed)		
ALLEANZA BIDLA		
CALLEJA (Anthony Calleja, ta' 20, Triq l-Għaxra ta' Frar, San Pawl il-Baħar, Company Director)		
GRECH MINTOFF (Ivan Grech Mintoff, ta' 2, Salina Park, Flat 1, Triq il-Kappella tal-Lunzjata, In-Naxxar, Self-Employed)		
ALLEANZA LIBERALI		
SAMMUT (Jean-Pierre Sammut, ta' 145, 'Żerniq', Triq Frans Sammut, Ħaż-Żebbuġ, Civil Servant)		
ALTERNATTIVA DEMOKRATIKA - *THE GREEN PARTY*		
CACOPARDO (Carmel Cacopardo, ta' 10, Triq ir-Rnella, Il-Kalkara, Perit)	AD	
CASSOLA (Arnold Cassola, Prof., ta' 36, 'Greenmantle', Triq l-Għarbiel, Is-Swieqi, Professur l-Università)	AD	
IMPERIUM EUROPA – NORMAN LOWELL		
BALDACCHINO (Arlette Baldacchino, ta' 42, 'The Mill', Triq Ta' Franton, Ir-Rabat, Malta, Consultant)		
GALEA (Antoine Galea, ta' 15, 'Armonija', Triq Kananea, H'Attard, Organic Agriculturist)		
LOWELL (Norman Lowell, ta' 44, 'Halcyon', Triq iż-Żagħfran, H'Attard, Artist & Author)		
PARTIT LABURISTA		
BIANCO (Lino Bianco, ta' 28, Triq Santa Skolastika, Il-Birgu, Professur, Perit, Konsulent u Ambaxxatur)	Partit Laburista	
CAMILLERI (Clint Camilleri, Tal-Bedeq, ta' 'Morning Star', Triq il-Qala, Il-Qala, Perit)	Partit Laburista	
CORDINA (Peter Cordina, ta' 22, 'Dell id-Dwejra', Triq Sir Arthur Fremantle, L-Imtarfa, Pensjonant)	Partit Laburista	
CUSCHIERI (Joseph Cuschieri, ta' 3, Flat 6, Triq Scicluna, San Ġiljan, Membru Parlamentari Ewropew - Kap tad-Delegazzjoni)	Partit Laburista	
DALLI (Miriam Dalli, ta' 'Strelitzia', Triq Nikol Muscat, Il-Mosta, Avukat)	Partit Laburista	
ENGERER (Cyrus Engerer, ta' 27, Triq San Pietru, Tas-Sliema, Advisor – EU Politics, Funds & Law)	Partit Laburista	
FARRUGIA BORG (Mario Farrugia Borg, ta' 15, 'Xahada', Triq l-Oratorju, Ħal Qormi, Segretarju fis-Segretarjat Privat tal-Prim Ministru)	Partit Laburista	
GOUDER (Charlon Gouder, ta' 24, 'Paulmon', Triq il-Kunżar, L-Imsida, Private Secretary)	Partit Laburista	
GRIXTI (Ivan Grixti, ta' 35, Flat 6, Triq San Federiku, Il-Belt Valletta, Lettur l-Università)	Partit Laburista	
MIZZI (Marlene Mizzi, Ex-Sea Malta, ta' 8, 'Villa Fontaine', Triq Godwin Ganado, Tal-Virtù, Ir-Rabat Malta, Businesswoman u M.E.P.)	Partit Laburista	
SANT (Alfred Sant, ta' 18A, Triq il-Vitorja, Birkirkara, Politiku, Konsulent Maniġerjali u Kittieb)	Partit Laburista	
SCHEMBRI (Deborah Schembri, Dr, ta' 'Belle Vue Court', Flat 1, Triq Jean De La Cassiere, San Pawl il-Baħar, Avukat u Membru Parlamentari)	Partit Laburista	
VELLA (Fleur Vella, ta' 6, Triq Jules Verne, In-Naxxar, Marketing Manager)	Partit Laburista	
PARTIT NAZZJONALISTA		
BUGEJA (Raymond Bugeja, ta' Portomaso, 1882, Vjal Portomaso, Paceville, San Ġiljan, Imprenditur)	P N	
CASA (David Casa, M.E.P. ta' 16A, Flat 4, Triq San Ġorġ, Il-Gżira, Membru tal-Parlament Ewropew)	P N	
COMODINI CACHIA (Therese Comodini Cachia, Dr., ta' 26, Triq San Ġakbu, Is-Siġġiewi, Avukat)	P N	
CUTAJAR (Kevin Cutajar, Dr., [L-Għawdxi], ta' 'Mayflower', Triq Mikiel Farrugia, Ix-Xagħra, Avukat)	P N	
ELLUL (Helga Ellul, ta' 16, Triq ir-Rokon, San Lawrenz, Imprenditriċi u Konsulenta)	P N	
MALLIA (Stefano Mallia, ta' 'Razzett ta' Ċikka', Triq Tal-Milord, Il-Mosta, Konsulent – E.U. Affairs)	P N	
METSOLA (Roberta Metsola [Tedesco Triccas], Dr., M.E.P., ta' 48, 'Gardjola', Triq il-Ġiebja, Is-Swieqi, Avukat u Membru tal-Parlament Ewropew)	P N	
PLUMPTON (Kevin Plumpton, ta' 'Iż-Żebbuġa', Triq il-Wied, Iż-Żurrieq, Prattika Legali)	P N	
SHAW (Jonathan Shaw, ta' 49, Flat 3, Triq Marsamxett, Il-Belt Valletta, Managing Director)	P N	
VELLA (Norman Vella, ta' 'Ephedra', Triq Dun Giacomo Tortella, L-Imqabba, Uffiċjal tal-Immigrazzjoni, Eks-Preżentatur u Ġurnalist)	P N	
ZAMMIT DIMECH (Francis Zammit Dimech, Dr., ta' 7, Telgħet San Ġiljan, San Ġiljan, Avukat)	P N	

Din hija *draft* tal-Polza tal-Vot. Il-Kummissjoni Elettorali għandha dritt taċċetta jew tirrifjuta kwalunkwe talba bil-miktub li tasal għandha fil-ħin stipulat għal tibdil fuq din il-Polza. Id-deċiżjoni tal-Kummissjoni Elettorali hija finali.

SPECIMEN – SPECIMEN – SPECIMEN – SPECIMEN – SPECIMEN

Figure 6 - Ballot paper for the election of members to the European Parliament

There are some disabilities, such as visual and physical impairments, that prevent a citizen from casting a vote independently. All citizens have the ability to request the help of an assistant electoral commissioner or a friend to cast their vote. This is the only alternative being offered at present which means that not all persons are being granted a secret vote as instructed in the Universal Declaration of Human Rights. A survey distributed by the Commission for the Rights of Persons with Disabilities showed that 64% of people who do not ask for help would choose to use technology to cast their vote if given the option and 60% of people who make use of another person's assistance prefer to use technology and vote independently. The respondents stressed that if such a tool would be developed, it is important to have an intuitive interface which could be used by persons with various impairments as well as people with low literacy skills. Some people confessed that they resent having to disclose their political opinion to their assistant. However, others explained that they feel more secure having a person help them vote because of their lack of familiarity with technology. The results of this survey show that the current arrangements should not be discontinued but a new alternative which allows independent voting is needed, nonetheless.

2.2 Accessible Interfaces

The following subsections discuss interfaces that cater for the specific types of impairments which will be targeted by the artefact will be discussed.

2.2.1 Visual Impairments

It is estimated that 1.3 billion people around the world are visually impaired, 217 million of which suffer from moderate to severe impairments and 36 million are blind [23]. Touchscreens have become ubiquitous and often lack any physical control panels which can aid a visually impaired person to navigate through the interface. Offering braille buttons is not sufficient as some people are not able to read braille [24]. Furthermore, such buttons cannot indicate when to carry out a certain action and how. For example, when depositing money at an ATM, braille buttons do not indicate when and where to insert cash. Specific types of visual impairments make the operation of devices such as a joystick or a mouse a laborious task [25], therefore, touchscreens are the universal option. The study in [26] revealed that 92% of sighted users can use search engines easily, however only 7% of blind users can. This highlights the existing usability issues that people with visual disabilities face on a daily basis. A main cause of this is that important features are hidden or poorly explained to the blind or visually impaired [26].

Screen readers are a very common type of assistive technology currently being used by people suffering from visual impairments. This technology allows synchronized auditory and graphic interfaces which create a universal design that is accessible to users with different disabilities as well as users without disabilities [27]. Screen Readers translate the interface into a format similar to a text document which the user can traverse to find what he is looking for. Evidently, it is frustrating to listen to all the content preceding what you are looking for. The test subjects in [28] disclosed that there are two ways of discovering if a page includes what they are looking for. They either listen to all the links in a page or listen to the information provided about the contents of the page including headings and number of links. Both of these methods do not fully represent the page and they are still time consuming.

Piner and Byrne [29] surveyed 180 legally blind American citizens of voting age. It was reported that independent voting can increase from 51% to 86% if accessible voting machines are implemented. Although the vast majority said they are comfortable with keypads, only 34% of respondents would prefer using a braille keypad to vote over an auditory interface. 70% of respondents conveyed that they have voted for all the candidates of one party and none from the other parties at least once in the past. This is referred to as straight party voting. The most desired features for an auditory interface to a voting machine were the ability to change volume and change the speed of speech. Ideally, the interface could be provided in multiple languages and make use of a human-recorded voice rather than a synthetic voice.

2.2.2 Motor Impairments

People with motor impairments cannot carry out basic tasks due to their weak muscles, reduced sensation, muscle contracture or spasms [30]. In extreme conditions, it can result in total paralysis and the loss of control of all muscles including the eyes [31]. These conditions can make it impossible to use a typical interface without frustrating or exhausting the user.

Pointing at an on-screen element will take multiple attempts to land within the target space. The study in [32] assigned identical tasks to a group of users with motor disabilities and a comparison group of users without a motor disability. It was revealed that 70% of the users in the first group had an error rate larger than 10% in the pointing tasks. The largest error rate reported from the motor impairments group was 47%, while for the comparison group it was 6.3%. Furthermore, the average time take per task for the motor impairments group was more than double than that of the comparison group.

Similarly, dragging is a demanding process since the user must click, keep pressing, move towards the target and release exactly on the target. 60% of subjects in [32] exhibited greater distress when dragging when compared to clicking or pointing. The same study showed that the most problematic part was releasing the mouse button at the target. The subjects also struggled to hold down the button until the target is reached. Some suffered muscle contracture during the drag which causes the user to stiffen.

2.2.3 Intellectual Impairments

Intellectual disabilities are the cognitive repercussions of developmental impairments which limit the intellectual and adaptive functioning of the individual [33]. There are various causes to these disabilities [33] and it is impossible to cater for all in an interface.

Problems with memory, analytical skills, recognition and focus make it difficult for these people to use a typical interface. Nonetheless, there are a number of best practices that can help make an interface accessible to people suffering from intellectual disabilities. First of all, touchscreen interfaces should always be used since people with intellectual disabilities are not able to see the direct correlation between the cursor on the screen and the movement of the mouse or touchpad [34]. The study conducted in [35] suggests that network navigation structure is more accessible than a hierarchical one. This is because some intellectual disabilities such as Alzheimer's disease complicate the development and retention of mental models. Therefore, a shallower navigation structure is preferable. The common interface often sacrifices its simplicity by offering a wide range of options which require the user to remember long processes. Such interfaces are unusable by people who have problems with memory. The research in [36]–[38] supports this and emphasizes the importance of a simple and intuitive interface. Similar tasks should also have a consistent process to help the user recall the process [34].

Guidelines have been constructed to improve the understandability and accessibility of text presented through a user interface. Text should be plain and concise especially for titles [36], [37]. All non-text content should be paired with a text alternative and, similarly, words can be supported by pictures or icons to minimise the cognitive workload [36], [37]. For instance, a save button should include the standard icon that indicates the button's function. Furthermore, the text colour should contrast its background and all hyperlinks must clearly describe where they lead to [38]. It is also important not to use colour only to denote information [38].

Simulating the use of an interface is extremely helpful for a user with an intellectual disability to understand how to make use of it. This has been proven in [39] where a tool was developed to simulate the use of an ATM. This tool provides a step-by-step guide to the users with synchronized auditory instructions and visual cues. The post-simulation error rates and the help required were drastically lower than the results of the pre-simulation tests. Other research supports this by stating that pictures and auditory cues in general improve task accuracy and independence [34].

Unfortunately, the feedback obtained from user testing of interfaces designed for people with intellectual disabilities are often unreliable due to the nature of the testers. Furthermore, mock-ups cannot be used in the design process as they require abstract thinking which people with intellectual disabilities struggle with [37]. Therefore, alternative methods have to be used when designing such an interface. For instance, the research in [35] is based on behavioural theories. In [38] , expert reviews and observations were used to support a close-ended questionnaire presented to the users.

2.3 User Interface Design

This section contains discussions about various user interface design elements that were crucial to the project. Reference is made to previous studies in order to extract how each element is typically tackled.

2.3.1 Prototyping

Prototyping is the process of creating an abstract design which is iteratively refined until a suitable design is formed. The recent development of tools such as Axure RP and Balsamiq show that the use of prototyping is increasing. This process takes an integrated approach to development as it incorporates a wide range of abstractions as well as a variety of people such as designers, developers and end users.

There are a number of stages within the prototyping process that lead to a final design. The first step is creating a low fidelity mock-up of the interface from the available requirements [40]. 97% of designers start off this process by sketching [41]. Dr. Zant in [42] states that this initial prototype must incorporate the set of high priority features. The prototype must then be refined to a higher fidelity in both appearance and behaviour [40]. Unfortunately, designers find prototyping behaviour much more difficult than prototyping the appearance of an interface. In fact, 86% of designers believe it is much more arduous to model behaviour than appearance while 76% think it is also more burdensome to communicate [41]. The only way to portray complex behaviour in prototypes is to use code. Most times, storyboards are used to visualise both appearance and behaviour, however, this tool only allows linear behaviour to be shown [40]. State machines can be used in conjunction with storyboards in order to explore the behaviour further [40]. Initial designs may only use textual annotations to portray behaviour as it is a simple means of communication which can be understood by everyone [41]. The prototype must be iteratively tested by end users and refined until the customer is satisfied and it complies with user interface standards [40].

Since prototyping involves different people coming from a variety of backgrounds, it creates issues of communication. With the help of annotations, sketches have the potential to become understandable by all parties of the development process. Furthermore, annotations such as small chunks of text can portray requirements which are not directly shown by a non-interactive prototype [43]. 97% of respondents in [41] add annotations to their prototypes at least sometimes. Storyboards and state machines can also be used to bridge the gap between developers and designers during the prototyping process [40].

Prototyping can be used within different development methodologies. It is often used in Agile development to capture and clarify user interface aspects by using mock-ups at each iteration[44]. A mock-up is a sketch of a possible user interface at different levels of fidelity which is non-technical so that it can be understood by all stakeholders [44]. Similarly, Rational Unified Process and Test Driven Development can easily incorporate prototyping for early usability testing within their iterations [44].

2.3.2 Defining Usability, User Experience and Accessibility

The term usability is used in various fields of study and has a range of definitions but these are often too broad and vague [45]. Its definition can differ between people and is often described as "fuzzy" [46]. The International Standards Organisation (ISO) defines usability as the "extent to which a system, product or service can be used by specified users to achieve specified goals with effectiveness, efficiency and satisfaction in a specified context of use" [47]. The 24 international usability professionals in [48] conveyed that their personal interpretation of usability go beyond this definition. The professionals' individual constructs included additional dimensions such as frequency of use and security. Other aspects of usability which are identified in research include learnability and memorability [49]. Defining usability is crucial to the usability of the product being developed [48] and, ideally, the criteria for usability goals should be established at the start of the design process.

User Experience (UX) is another commonly used term in the field of Human-Computer Interaction (HCI). ISO defines it as a "person's perceptions and responses resulting from the use and/or anticipated use of a product, system or service" [47]. UX and usability share common concepts such as user satisfaction. Nonetheless, they are also different. For instance, beauty and aesthetics are important components of UX, however, these factors are deemed irrelevant when measuring usability [50]. Another distinction is that usability focuses on task oriented aspects of a system, but UX takes a more holistic view [49]. In general, UX measures the users' emotional content and pleasure while using a system, whereas usability focuses on the quality of a product.

Accessibility goes hand in hand with usability as it represents whether or not a system is usable by persons with disabilities. Accessibility allows persons with different abilities to perceive, understand, navigate and interact with the Web as well as contribute to it [51]. This definition hints that accessibility is a fragment of usability. ISO defines the term as "usability of a product, service, environment or facility by people with the widest range of capabilities" [47]. Contrasting to the previous explanation, the ISO definition portrays accessibility as a superset of usability since it encompasses a larger range of issues. These arguments show just how closely the two HCI concepts are intertwined. Similar to the previously described terms, accessibility must be considered in the early stages of design [49].

2.3.3 Measures of Usability

As explained in the previous section, ISO breaks down usability into three components: effectiveness, efficiency and satisfaction. These three measures are used in various HCI studies even those regarding voting interfaces. However, different studies calculate these three components in different ways.

Effectiveness measures whether or not a user can complete a task with accuracy in a specific environment [52]. Accuracy is given more importance in voting studies as it is crucial that the outcome is a vote which matches the voter's intentions. One approach to measuring efficiency is counting the number of errors encountered. This method is frequently used in studies regarding voting interfaces [7], [8], [53], [54]. Another way of obtaining this measure is to compare the expected outcome of a task to the actual outcome. This method is often applied to voting studies by verifying that the intended vote is cast [11], [52], [55].

Efficiency is defined as the number of resources utilized to complete a goal [47]. It is of utmost importance that accuracy is not traded for efficiency, especially when using voting systems. This measure is often represented as the time or the number of steps taken to complete a task. Although effectiveness is more important for a voting machine's usability, efficiency may also have a substantial effect. For instance, a citizen may feel pressured to be quick when casting their vote due to the people waiting for their turn to vote [11].

The third element, satisfaction, is defined as the overall comfort and positive attitude towards the use of the system. Satisfaction of voting systems can be interpreted as the voting process being free of stress [52]. This is a qualitative and highly subjective measure. Nonetheless, it offers important input especially in the formative stages of development where the interface is still being improved. In most cases, a questionnaire is used to extract this aspect of a system. A questionnaire can be off-the-shelf or customized. The former offers reliability but it is often too general. On the other hand, customized questionnaires are specific to the system being tested but are unreliable and do not allow comparison to other research [55]. Another method of extracting a system's satisfaction is by conducting an open-ended interview with the users after they have tested the system [53].

2.4 Evaluation

There is a range of evaluation methods to assess the level of usability and accessibility of an interface. However, different methods need different resources, for instance the people available and their level of expertise [49], [56], [57]. This can be the deciding factor for which evaluation method is used to validate an interface in terms of usability or accessibility. Furthermore, different methods often bring to light different subsets of usability and accessibility issues [56], [57]. Although most literature focuses on assessing websites, the concepts can be extracted and applied to other systems such as desktop applications.

2.4.1 Automated Testing

User interface evaluation can be split into two broad sections: automated and manual. The former is often used with the initial implementations of a prototype to verify that the basic accessibility guidelines are being adhered to. Automated accessibility evaluation tools have an underlying checklist of guidelines that the interface is tested for. The results assist developers and designers in what must be fixed in order to improve accessibility. Foundation for Information Technology Accessibility (FITA) recommend using WAVE or Axe for automatic accessibility evaluation [58]. Both of these tools are open source, but they only cater for websites. W3C offer a similar service for website validation. This tool can improve the accessibility of a website as it validates the mark-up which screen readers are highly dependent on. Screen readers are an assistive tool which parse HTML and read out what is displayed on the screen. These tools are very helpful in productivity and effectiveness [57] as well as reliability [59] . However, since they are so heavily reliant on the underlying guidelines, the quality of the evaluation is dependent on the quality of those guidelines. Some authors argue that, by itself, this evaluation method is insufficient as it requires some expertise from the developer's side to understand what is wrong and how to fix it [60] . Even though automated evaluation methods take little time and cost in comparison to other methods, it does not guarantee that the interface is accessible [59], [60].

2.4.2 Expert Evaluation

There are various methods of manual evaluation. Expert evaluation is the most used of these methods [57], [61]. The participants may be experts in the system's domain, usability or accessibility. This method is often used to eliminate some accessibility and usability issues prior to user testing [49] . Some expert evaluations are task-based and these are referred to as walkthroughs while non task-based evaluations are called reviews [49]. When conducting a walkthrough, the expert considers how the users will attempt to complete each task and, using his expertise, attempts to extract potential problems [49]. The most popular type of expert evaluation is heuristic evaluation [49] where the experts use a set of heuristics to help identify issues and rate them in severity.

The research in [59] claims that three experts or fourteen nonexperts can find practically all the problems. In accordance to this, the study in [49] found that each expert finds 30% of the usability problems. However, the problems each expert find might overlap and, hence, three experts are not enough to find all the problems. On the other hand, the study in Comparative Usability Evaluation 3 (CUE-3) [46] found that 79% of the known problems were only reported by one or two experts out of the eleven participants. This suggested that over 10 experts are needed to find as many usability issues as possible. Experts tend to focus on superficial problems and the reliability of the evaluation depends on how similar the experts knowledge and experiences are to a potential user's [49].

A barrier walkthrough is another popular method to evaluate accessibility. In [57] , a barrier is defined as "any condition that makes it difficult for people to achieve a goal when using the website in the specified context". This method assesses accessibility by considering usage scenarios and goals for specific user groups. As opposed to other methods, barrier walkthroughs take context into consideration. Similar to heuristic evaluations, barriers are assigned severity but the severity of a single barrier may vary by context [61]. In comparison to heuristic evaluations, barrier walkthroughs find a larger portion of severe accessibility problems but a smaller portion of all the issues regarding accessibility [57], [61] . Unlike expert evaluations, persons conducting a barrier walkthrough are not necessarily experts. However, expertise has a positive effect on the validity and reliability of the evaluation [59]. Furthermore, a substantially larger group of non-experts are needed to find the same amount of issues as a small group of experts [59].

2.4.3 User Evaluation

User testing is widely used for usability evaluation where the target audience gain hands on experience of the interface by carrying out realistic tasks to help identify any issues that hinder ease of use. Tasks can be predefined as shown in [11] and [14] . These studies in particular tested out voting machines and the tasks assigned to the users during the testing phases included changing their vote, selecting a number of candidates to vote for and abstain from voting. During this procedure, the users may be asked to employ the think aloud protocol where they speak out their thought process so that usability issues can be identified. When the target audience are trying out the interface, they will find 45% of issues that cannot be identified by experts [62]. Moreover, user testing, where the tester suffers from a disability, identifies both usability and accessibility issues at the same time. In fact, [60] found that the problems identified during user testing with disabled participants include general usability issues. It is estimated that 80% of the problems can be found with a group of three to nineteen participants [49].

The outcome of user testing is an evaluation regarding the usability of the interface tested. Conrad [55] states that usability is measured in terms of accuracy, speed and satisfaction. Accuracy measures the number of tasks completed successfully with respect to the total number of tasks. This measure can also take into account the sub steps of each task. Speed of use is the time taken by each user to complete the assigned tasks. These two measures may trade-off each other because to achieve high accuracy, users will probably complete the tasks at a slower pace. Satisfaction, as opposed to accuracy and speed, is a subjective measure of usability. Questionnaires and interviews are often used to evaluate this. Interviews are extremely subjective, and they allow the interviewer to ask additional questions if an issue is encountered. The unstructured format can help the designers understand the problem in more detail and, hence, may be more beneficial for requirement gathering rather than evaluation. On the other hand, questionnaires are more rigid, especially if the respondents must answer using a predefined rating scale. Questionnaires are preferred when trying to reach a wider audience in less time [56]. Designers can create a questionnaire specific to their interface, however, using psychometrically designed questionnaires will yield more reliable results [49]. An example of such a questionnaire is the System Usability Scale (SUS) which contains ten questions half of which are negatively posed in order to reduce bias by forcing the user to put some thought into each question [63].

This method of evaluation can be problematic with special categories of users such as persons with disabilities because particular arrangements must be done in terms of location and time for the testing session [60] . This sometimes causes designers and developers to opt for remote user testing. There are two main methods of remote testing: synchronous and asynchronous.

The former represents testing sessions where the test subject and evaluator participate at the same time while during the latter the subject and the evaluator are temporally separated[64]. The study in [65] found that participants of synchronous remote testing can detect as many usability issues as participants in a controlled environment. There are varying views on asynchronous testing. Some studies have shown that the results of asynchronous remote usability testing are comparable to those of traditional usability testing [66], [67]. Other studies found that remote usability testing finds significantly less issues when compared to lab testing [60], [65]. A common remark in remote testing research is that task times are longer in comparison to other usability testing methods [65], [67], [68].

3 Specification and Design

3.1 Specification of the proposed system

The main aim of this study is to create a voting system that is usable by people who cannot cast a vote independently through the methods currently available in Malta. Therefore, the target users of this system are people who suffer from visual, physical and intellectual disabilities. Nonetheless, this system will also be used by people with temporary disabilities such as a broken arm.

Since this mechanism aims to serve as an alternative method of voting, it must replicate all the functionality being offered by the current methods. It is important to allow the voter to choose the number of preferences to assign. This can range from zero to the total number of candidates on the ballot. When using a paper ballot, one can request a new ballot if a mistake is made. Hence, the system is required to incorporate the functionality of clearing all previously assigned preferences. On top of this, a voting machine can offer the capability to edit a vote. This means that the voter can delete or reassign preferences without having to start over. To do so on a paper ballot would mean that the marked sheet would be cancelled, a new ballot sheet is provided to the voter and all the preferences would have to be assigned once more. Another helpful function is having an additional view containing only candidates who have been assigned a preference. This can be useful if the voter would like to review his vote before casting it. For obvious reasons this is impossible to be implemented when using a paper ballot.

An important functional requirement for this voting machine is to check if the vote is valid before it is cast. A valid vote must either have zero preferences assigned or have a sequence of preferences assigned from one upwards without skipping a number. If a vote is invalid, the user must be notified and given instructions as to how the vote can become valid. This is an important feature which will not allow any invalid votes to be cast.

Citizens can cast a purposefully spoilt vote. This is sometimes used as a protest. This has to be reflected in the functionality of the voting machine. This requirement is complex as it is difficult to replicate the multitudinous ways to spoil a paper ballot. Another intricate requirement of a voting machine is the help page. Undoubtedly, the interface must include a way for the user to be directed how to use the interface. The assistance offered through the help feature must replace a human assistant. Due to the nature of the users, some additional functionality must be added to allow the users to alter text size and colour contrast and to modify the screen reader's settings.

3.2 Initial Designs and Design Decisions

The three initial designs were created as wireframes with text and arrows joining the screens to describe the behaviour of the system. The tool used to visualise the designs is draw.io. This tool is an open-source online diagram software and it provides the user with a number of predesigned elements which can be dragged and dropped onto the illustration.

The initial designs are aimed for a landscape touchscreen interface. A touchscreen was chosen as people with intellectual impairments can easily see the correlation between the element they tapped and the action [34]. This is discussed further in the section *2.2.3 Intellectual impairments*.

The figures shown in the following subsections are only part of the designs. To view the complete low fidelity designs, as shown to the experts in the first evaluation, refer to Appendix E.

3.2.1 Design 1

This design is inspired by the paper ballot currently used in Maltese elections. The blind participants in [69] disclosed that they would prefer an interface similar to what a sighted person would experience. The candidates are grouped by party and sorted in alphabetical order by surname. For each candidate, the full name, address and occupation is displayed. This mirrors the information provided on the Maltese election paper ballot. Voters using the screen reader do not have to listen to all the information provided about the candidate as they can simply move onto the next candidate.

This interface asks the user to choose a candidate for the given preference as seen in Figure 7. Initially, the voter will be asked for the first preference, then the second and so on until all the candidates have been assigned a preference. Each time the user selects a candidate to be assigned a preference, he will be asked to confirm this action. The confirmations were added so that the system would not advance automatically because, as discussed in section *2.1.2 Existing Systems*, such a mechanism would make the voters unsure of who they voted for. This process is visualised in Figure 8. The candidates which are assigned a preference will not be visible on the list of candidates available for selection. This effort aims to reduce the number of invalid votes.

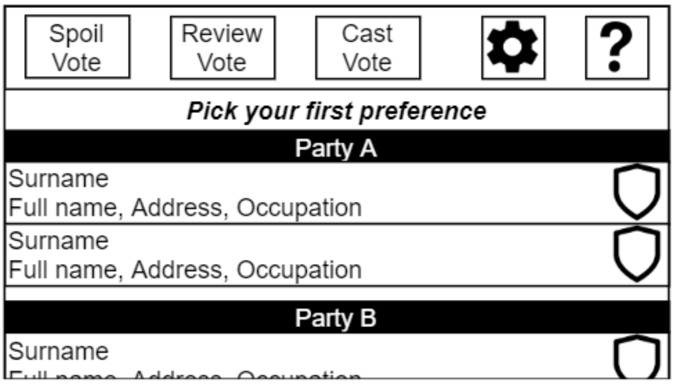


Figure 7 - Ballot design for Design 1

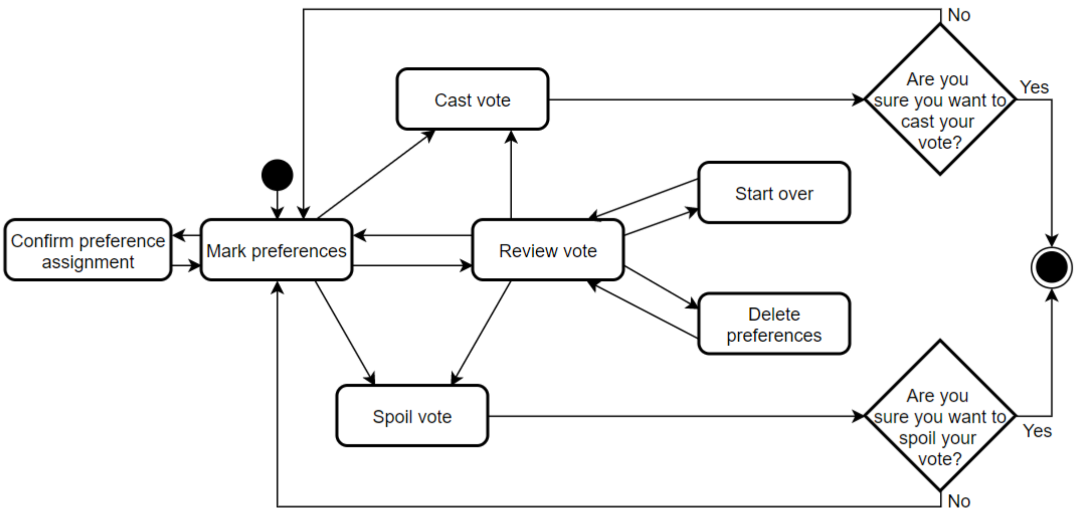


Figure 8 - Activity diagram for Design 1

The design includes a navigation bar at the top of the screen. The first button enables the user to spoil his vote. The user will have to confirm this action to ensure that the button was not tapped accidently. The second button redirects the user to the review page seen in Figure 9. This page contains the list of candidates which have already been assigned a preference. The candidates will be displayed in ascending order of preference. The voter can unassign a preference from a candidate by tapping the cross to the right of the candidate details and the assigned preference. When this happens, the user will be asked to assign the deleted preference again once he returns back to the main screen. The review page also allows the user to delete all preferences assigned through the start over button. The third button in the navigation bar at the top of the screen takes the user to the cast vote page. This page asks for confirmation from the user to cast the vote. The user is also given the option to review his vote or go back to the main page from this screen.

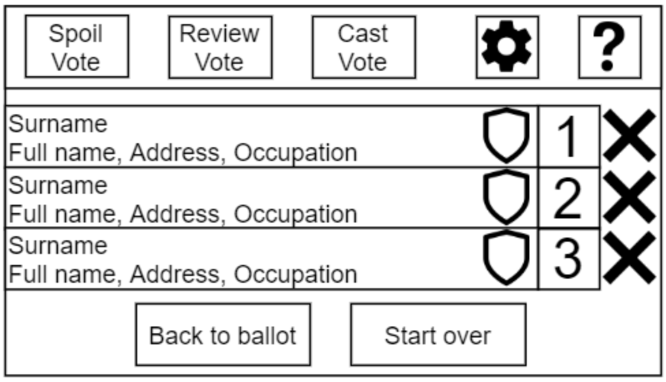


Figure 9 - Review ballot screen for Design 1

The settings page and the help page can be accessed from the gear icon and the question mark in the navigation bar. The settings page contains multiple settings such as enabling the screen reader and the confirmation pages. These can be toggled on or off by the user. The help page consists of a video tutorial showing the user how to cast his vote using the system provided. The tutorial will have synchronous audio for persons with severe visual impairments.

3.2.2 Design 2

This design is based on the paper ballot design for the city council election in Cambridge, Massachusetts shown in Figure 10. The voter is provided with a paper which contains a list of candidates, next to each candidate is a series of circled numbers from 1 to the number of candidates for the election. The voter must find the circled preference to be assigned in-line with the candidate and fill it in. The election in Cambridge made use of paper ballots and, therefore, no validation measures could be implemented to ensure that a candidate will be assigned one preference and that a preference is only assigned to a candidate. This design aims to replicate the basics of the ballot in Figure 10, elevate it to a touchscreen interface and apply it to the Maltese electoral system. The behaviour of this design is explained in Figure 11.

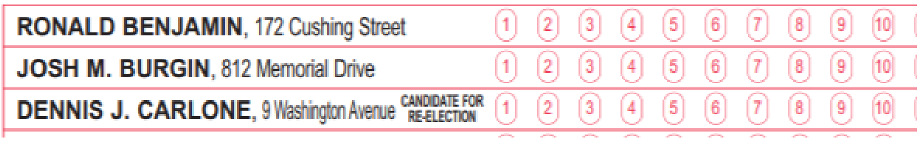


Figure 10 - Part of the ballot for Cambridge, MA city council election of 2017 (reproduced from [70]*)*

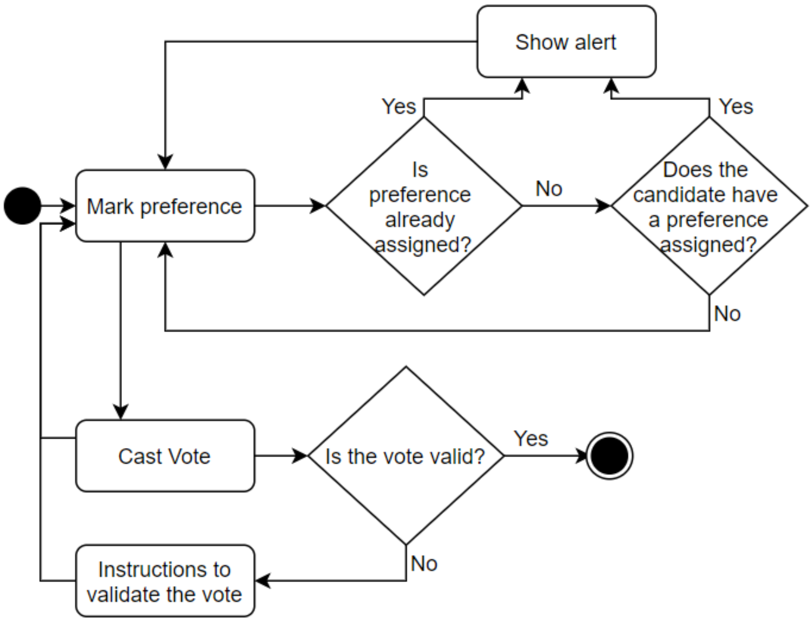


Figure 11 - Activity diagram for Design 2

In the design created, the user assigns a preference to a candidate by tapping one of the circled numbers aligned with the candidate's name. For instance, if the circled 1 is tapped which is in line with candidate A, then candidate A is assigned first preference. To undo the assignment, the user will have to tap on the same circle again. There are three types of circled preference buttons:

- White background with solid black outline; this symbolises that the particular preference has not been assigned to any candidate.
- Black background and white text; this indicated that the preference in the button is assigned to the candidate it is in line with. In Figure 12, the first preference is assigned to the second candidate in the list.
- White background with a dotted black outline; this implies that the preference is assigned to another candidate.

All these button types ensure sufficient contrast for persons with low vision while making it easily distinguishable for people with intellectual disabilities. Another preventive measure for persons with low vision is the ‘Cast vote’ button. This crucial button takes the entire width of the screen and has a black background to contrast the white background of the rest of the screen. These design features are illustrated in Figure 12.

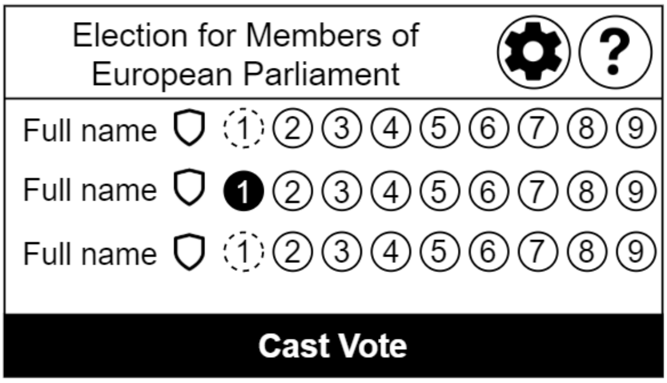


Figure 12 - Ballot design for Design 2

When the user attempts to assign a preference to a candidate who has already been assigned a preference, an alert will be displayed asking to make the user aware of this change and to confirm it. Similarly, an alert will be displayed if the user tries to allocate a preference which has been previously assigned to another candidate. These changes will cancel any previous assignments in order to keep the vote valid. This mechanism will prevent errors in case the user mistakenly taps a preference. The user must tap the black cast vote button at the bottom of the screen to proceed with the process. The user will be presented with a list of assigned candidates in ascending order of preference. If the vote is valid, a green button will occur at the bottom left corner of the screen. This button will officially cast the vote. Otherwise, this button is replaced by a red button which will lead to an explanation on why the vote is invalid. The preferences which need to be assigned in order to validate the vote are highlighted in red. The valid vote screen and the invalid vote screen are shown in Figure 13 and Figure 14 respectively.

Figure 13 - Valid vote screen for Design 2

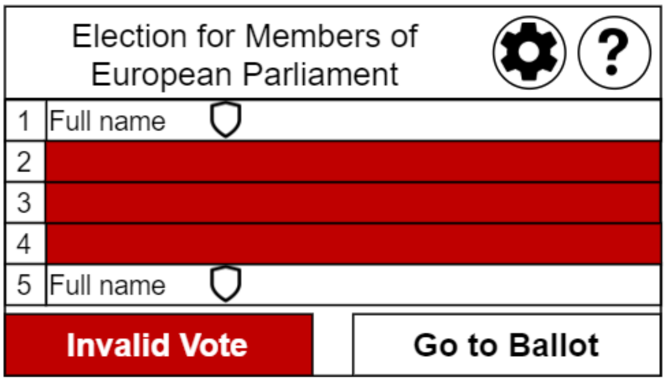


Figure 14 - Invalid vote screen for Design 2

The top bar in every screen will hold the election title, a button to the settings page and a button to the help page. The settings page is designed similarly to the ballot screen where the user must tap on the preferred setting to select it. Selection will turn the button black while all others will have a white background. The help page will be comprised of steps to guide the user to cast a valid vote.

3.2.3 Design 3

The third design incorporates different elements from previous designs and voting research. As discussed in section *2.2.1 Visual Impairments*, a vast majority of voters vote for candidates of the same party. With this in mind, filtering functionality was included in this prototype where the voter can either have all candidates displayed or candidates of a particular party only. This feature will also help persons with motor impairments because they will have a shorter list of candidates list and, hence, they will need to scroll less. This will cause the voter to be less fatigued by the system.

The preference assignment procedure is inspired by one of the designs in [71] where the user must select a candidate and then choose which preference to assign to that candidate. The relevant screens and the transitions between them are illustrated in Figure 15. The behaviour of the system as a whole is pictured in Figure 16. As opposed to Design 1, the users can assign the preferences in any order they want. Zoomable, a prototype developed by the University of Maryland, has a flexible navigation sequence as the user is given an overview of all the contests in an election and the user can navigate freely between contests to choose the preferred candidates. In this design, the flexibility in navigation is applied to the Maltese voting system where the user will be given an overview of the candidates in the election and the ability to choose freely which preference to assign next.

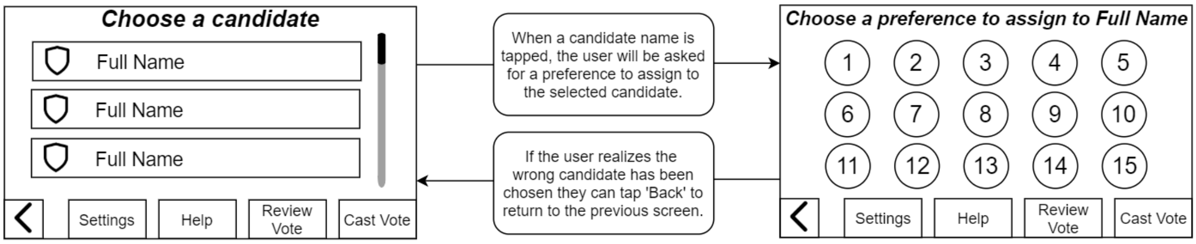


Figure 15 - The screens for candidate and preference selection

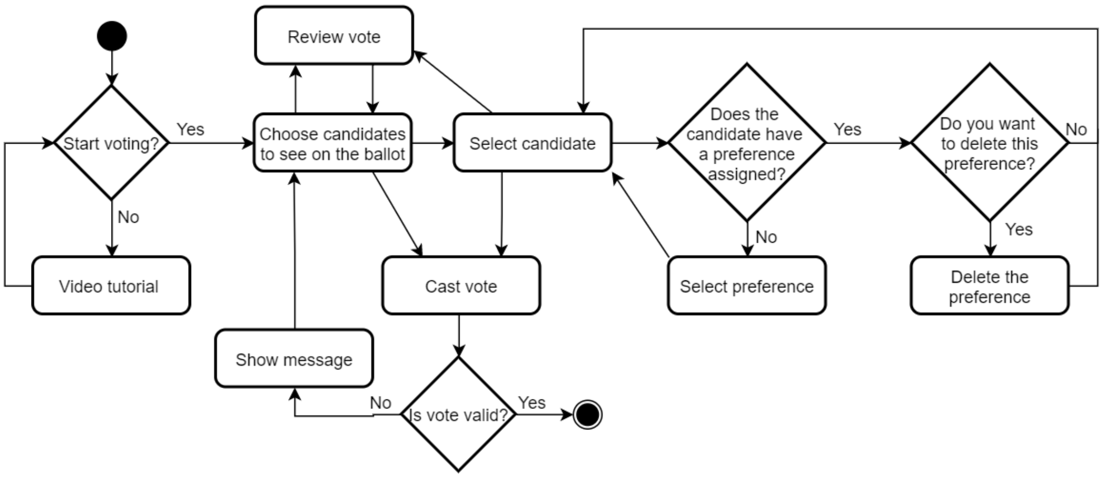


Figure 16 - Activity diagram for design 3

To change a vote, the user must revisit the candidate and tap on the intended preference. This procedure is reflects that of Zoomable. As mentioned in section *2.1.2 Existing Systems*, testers found this method to be easiest when making amendments to their vote. To ensure that a preference is only assigned to one candidate, the preferences which have already assigned will be greyed out and not selectable as shown in Figure 17. Therefore, if the user wants to assign a preference that has already been assigned, they must delete the preference of the candidate currently assigned that particular preference in order to make it available to other candidates.

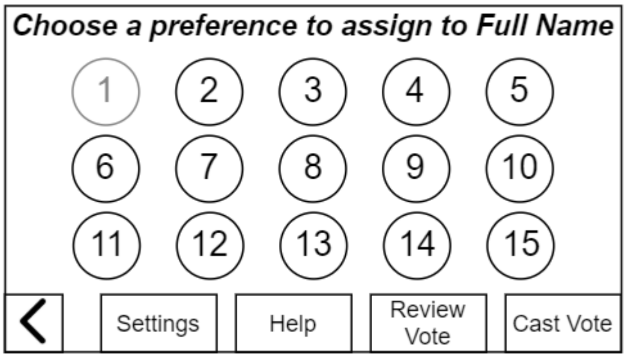


Figure 17 - The preference selection screen where preference number 1 has already been assigned

Contradictory to Design 1, candidates assigned a preference will still be visible on the ballot with the preference assigned visible to the right of their name. The candidates on the ballot will maintain the same order irrelevant of preference. To view the candidates in order of preference, the user must visit the review page from the button in the navigation bar.

A navigation bar has been placed at the bottom of each screen. The first button contains an arrow pointing to the left which will take the user to the previous page. The icon is used in many websites and applications and, hence, its function should be intuitive to all users. The second button redirects the user to the settings page where some aspects of the interface can be altered using sliders. The third button displays the help page which contains a video tutorial instructing the user how to cast a vote using the system. This page can also be accessed from the launch screen shown in Figure 18**Error! Reference source not found.**. This screen contains the title of the election, a button which redirects the user to the help page and another button which will take the user to the filtering option page. The button at the right end of the navigation bar will inform the user whether the vote is valid or not. If so, a button is shown to complete the voting. Otherwise, an informative message is displayed to guide the user to cast a valid vote.

Figure 18 - The launch screen in Design 3

3.3 How the evaluations changed the designs

3.3.1 Expert Reviews

Due to the outcomes which will be discussed in section *5.1.3 Results*, some changes were made to Designs 1 and 3. It was decided that Design 2 would be eliminated due to the poor accessibility and overall usability. The remaining designs were developed into web applications, Prototype A and Prototype B, respectively. Both prototypes were structurally developed for optimal integration with a screen reader and portrait view in order to fit more candidates on the screen. Furthermore, the settings pages had to be removed since most settings could not be applied through a web application. The only way of configuring some crucial accessibility features is through the device's settings. An example of such a feature is turning on or off the screen reader.

The following changes were made to Design 1 when developing it into a web application. The party emblem was replaced with a photo of the candidate as this would help persons with intellectual disabilities remember more clearly who they want to vote for. The candidates are grouped by party and surrounded by the party colour so that it is still evident which candidates belong to which party. Moreover, the confirmation methods for each preference assignment were eliminated. In order to eliminate the automatic advancing mechanism, a next button was added at the bottom of the candidates list. Therefore, the user must choose a candidate and press next to complete the preference assignment. In addition to this, a back button was added beside the next button to serve as an undo button which will cancel the latest preference assignment. Beneath these buttons, two more buttons were added, one to redirect the user to the review page and another to start over. These buttons will only be shown once the user scrolls through all the ballot. The navigation bar at the top of each screen was eliminated from the design as these buttons replaced their functions. The help button was kept at the top right corner of the screen for easy access. The spoil vote button was discarded since the experts deemed it highly unethical to promote a spoiled vote.

These changes were also reflected in the review page. The buttons at the bottom of the list in this page can be used to go to the ballot page, cast the vote or start over. Some changes were made to the candidates shown on this page. Since the party emblem was replaced by an image of the candidate, the border colour of the candidate's box will reflect the party the candidate represents. Furthermore, two buttons were added in line with each candidate. These buttons are used to increase or decrease the preference assigned to each candidate by one. If the new preference is already assigned to another candidate, the preferences will be switched to keep the vote in a valid state. Either way, the user will be informed of the changes made and asked for confirmation. When the current assignments are valid and the cast button is tapped, the user is asked for confirmation to finalize the process. If the vote is not valid, the user is instructed on which preferences must be assigned to validate the vote. The process that checks whether a vote is valid or not is shown in Figure 19. This process is used in all prototypes. All confirmation alerts used in this prototype include green and red coloured buttons with the appropriate icons.

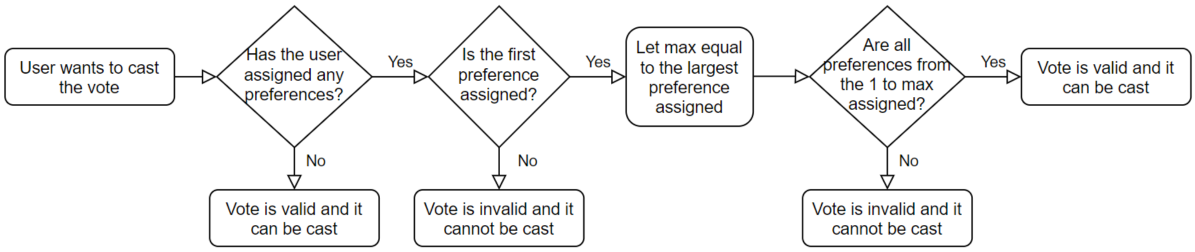


Figure 19 - Flowchart illustrating how a vote is determined to be valid or not

The help page was altered slightly such that instead of one video tutorial, there were multiple video tutorials instructing the user how to complete specific tasks. In addition to this, the videos have synchronized audio with detailed information so that it can help persons who have low vision.

Design 3 went through a similar process of refinement when being developed into a web application. The buttons in the filter page were given coloured borders which reflect the colour of the party. In the preference selection page, preferences which have already been assigned will be hidden rather than just greyed out. Nonetheless, the buttons will not change location in order to be consistent and keep the user oriented. This page will include a delete button when a candidate that already has a preference is chosen. This enables the user to simply unassign the preference rather than forcing the user to give another preference to the candidate. A message will be displayed on top of the preference buttons to inform the user of the current preference assigned to the candidate and that this preference will be replaced if a new one is chosen. A red background is given to this text to attract the users' attention.

The only change made to the navigation bar was that the button redirecting the user to the current page is hidden. For instance, if the user is on the help page, the help button is hidden. The other buttons will keep their original location to be consistent and also to help persons with low vision locate the buttons more easily.

The help page was changed to guide users using steps instead of a video tutorial. The reason for this change is that the experts were unsure of which alternative would be more helpful so one prototype uses video tutorials and the other uses textual steps. The page is partitioned into sections containing steps to complete a specific task such as deleting a preference. To reduce scrolling, the sections are collapsed. When the title is tapped, the steps will be shown under it. The appropriate aria tags were used to ensure that the screen reader would convey a clear mental image of the page.

3.3.2 User Testing

The following decisions are based on the results of the user testing, the feedback provided by the testers and the observation of the tester's interactions. After considering all the elements, it was concluded that one high fidelity prototype would be developed. This artefact will encompass the more usable aspects of the tested prototypes as well as the new or improved elements which the testers revealed would make the artefact more usable.

While observing the users carry out the tasks on Prototype B, it was noticed that the vast majority made use of the filtering feature when assigning preferences. Therefore, this feature will be carried onto the high-fidelity prototype. Furthermore, most users conveyed that they preferred the flow of Prototype B over that of Prototype A. This means that these users preferred selecting a candidate and choosing the preference to assign it to rather than having to choose a candidate for the given preference. There was no clear preference or statistical significance in efficiency between the mechanisms to change the vote, so both were implemented in the high-fidelity prototype.

Buttons were given thicker borders and larger font sizes throughout the prototype to aid users with low vision. Two users found that casting a vote using Prototype B was not intuitive. The main reason behind this was that pressing ‘Cast vote’ in the navigation bar did not cast the vote but only redirected the user to the cast vote page where another button must be pressed to finalize the process. Due to this, the casting process in the high-fidelity prototype will mirror that of Prototype A. Another issues that will be targeted in the final prototype is that the preference is shown before the candidate’s name when reviewing the vote. Furthermore, both blind testers suggested that the heading of each page is announced when the page is loaded. The necessary ARIA attributes were added in the code to have the headings announced once the page loads.

The testers all agreed that the system should incorporate a way of casting a purposefully spoilt vote. While most found the current mechanism sufficient, some hinted that they would like some more options in this regard. After weighing the ethical issue of promoting this, it was decided that at the beginning of the process the user should be offered to cast the protest vote. This option would not be visible on all pages so that it does not seem to be promoted. Regarding the help page, the users had mixed feelings; some preferred the textual steps while others found the video tutorials with synchronized audio more helpful. Therefore, both options will be included in the final prototype. The help page is simply a prototype and the ‘Watch video tutorial’ buttons are used for design purposes. The videos were not added to the prototype since they were not being used by the testers.

4 Implementation

To start with, three low-fidelity prototypes were designed. Each of these designs were portrayed as wireframe screens with arrows between the screens to depict the system's behaviour. To do this, draw.io was used because it includes all the necessary functionalities include drag-and-drop and a large range of predefined shapes. The wireframes were printed and presented to the experts in the first round of evaluation. Having a hardcopy allowed the experts to write notes or draw on the diagrams during the discussion. First, the design decisions, workflow and the accessibility feature of the prototype was explained. Then, the experts expressed their thoughts on the elements that lacked usability and accessibility. Pain points that may be encountered by persons with specific disabilities were also identified. Most times, they also offered insight into how these elements can be improved.

The designs were altered based on the feedback provided by the experts. Web applications were developed from the improved designs. The technologies used were HTML, CSS and JavaScript. React.js is a JavaScript library used for designing user interfaces. This library was utilized as it allows code to be split into components which are rendered when needed and these components update automatically when the data changes. Prototyping tools such as AxureRP and Balsamiq will not be used even though they simplify the design process. The reason for this is that a strict HTML structure is needed for the screen reader to be effective. Writing the markup from scratch will ensure that the control over the code structure is maintained and aria tags can be included whenever necessary.

Due to time constraints, this project will only focus on the interface design of a voting machine. The vote will be stored in the browser's local storage which will be cleared once the user casts the vote. An unexpected problem was encountered when developing the mid-fidelity prototypes. The settings for the screen reader could not be set from the web application. This led to the decision to drop the settings page from the prototypes. When conducting the user testing, the accessibility settings required by the user will be set by the observer. In a real-life scenario, the settings may be set by the electoral commissioner before each citizen starts voting.

Once the mid-fidelity prototypes are developed, the first iteration of user testing can commence. The testers are persons who are IT literate and suffer from visual or motor impairments. Persons with intellectual disabilities were not included in the testing sessions. The reason for this is that feedback provided by these persons may not be reliable as discussed in section *2.2.3 Intellectual Disabilities*. Nonetheless, precautions were taken to make the interface accessible to this user group. For instance, buttons have different colours and icons that make their use intuitive. The candidate's photos have been added to the ballot so that people with intellectual disabilities can identify the candidate without having to read the text. Ideally, the prototypes would be tested by a large number of people but since the eligible testers are a minority group, only a small number of people were found. Each user will be given the same set of tasks to carry out using each prototype. They will be observed during this process so that pain points and unintended votes can be identified. In addition to this, the prototypes will be evaluated by the typical measures of usability: effectiveness, efficiency and satisfaction. After the participant tests out a prototype, the SUS questionnaire will be administered. Participants will also be given the chance to highlight any issues they encountered while casting the vote to support the observed pain points. Additionally, participants can suggest further improvements for the next iteration of prototype development.

The measures and points extracted from the user testing guided the development of the high-fidelity prototype. Once the necessary changes had been made to the prototype, another run of user testing took place. Unfortunately, due to the Covid-19 pandemic, most testers were not willing to meet in person. Therefore, remote testing was the only option to gather some feedback about the prototype. As discussed in section *2.4.3 User Testing*, remote user testing can produce similar outcomes to traditional user testing but, in some cases, it does not.

5 Testing and Evaluation

5.1 Expert Reviews

5.1.1 Procedure

Expert evaluation was used to refine the initial designs. As discussed in section *2.4.2 Expert Evaluation*, this type of evaluation has been used to eliminate general usability and accessibility issues prior to user testing. Expert review was the type of evaluation chosen for this study.

Before commencing with the session, the participants were explained the test procedure, what was expected from them and how their input would affect the study. Subsequently, the users were asked to read and sign the consent form.

The experts were presented with the three wireframe designs, each printed on A3 paper. Arrows and text were used to explain the behaviour and the transitions between the screens. The prototypes were shown one at a time so that they could be described in detail. The experts could intervene with statements and questions during the explanation. Furthermore, after each design and at the end of the session, a discussion was held to identify the elements of the design that are accessible, and which are not. The experts could also provide useful insight regarding how to improve the accessibility of particular screens or the design as a whole.

5.1.2 Participants

Five experts in accessibility took part in the evaluation of the low-fidelity prototypes. The participants were split into two sessions. In the first session, one participant works within the Parliamentary Secretariat for Active Ageing and Persons with Disability and the other works at the Commission for the Rights of Persons with Disability. The second session had three participants all working at the Foundation for Information Technology Accessibility. Two of the participants were blind, therefore, the wireframes were explained in much more detail than the previous session. These experts provided insight into accessible designs from issues they experience at first hand.

5.1.3 Results

The initial designs are discussed with the appropriate figures in section *3.2 Initial Designs and Design Decisions*. To view the low fidelity designs as a whole, refer to Appendix E.

The changes made due to the comments discussed below are listed in section *3.3.1 Expert Reviews* under section *3.3 How the evaluations changed the designs*.

Design 1

Most of the issues brought up were common in both sessions. The most common pain point was the confirmation screens at each candidate selection. All experts found this to be tedious. Nonetheless, a preference should not be assigned at the first tap as this would cause many errors. It was suggested that the confirmations are dropped and instead, a button is added to proceed with the preference assignment. One expert also suggested to add an undo button which would unassign the previous assignment. Another common comment among the experts was the need to add a candidate portrait to the ballot as this helps illiterate people identify the candidate. Furthermore, the experts found it unethical to include a 'Spoil vote' button as this may be considered as promoting the submission of an invalid vote. Despite this, it was agreed that the submission of an invalid vote should be included in some way. One expert expressed that one way of allowing an invalid vote to be cast is to permit the submission of an empty vote.

The participants of the first session drew attention to the electoral law which states that all candidates must be visible at one time. It was discussed how the electoral law would have to be adapted before any voting machines can start being used. One way of minimising this issue is to develop for a portrait device so that more candidates can be visible in a single screen. One of the experts emphasised that the number of buttons on screen should be minimized in order to reduce on screen clutter. It was suggested to put the navigation buttons below the list of candidates.

Two of the participants in the second session had conflicting opinions about whether or not a candidate should still be visible on the candidate list after it is assigned a preference. One expert argued that it would be helpful to remember which candidate have been assigned a preference. Another disagreed, stating that making the list shorter would be helpful since the next candidate could be located in less time. Another issue highlighted in the second session was that video tutorials can be difficult for visually impaired and blind persons to comprehend because the audio is not informative enough. As a general remark, one expert stated that this design would probably be more easily accepted by the Electoral Commission since it closely resembles the design of the paper ballot.

Design 2

This design was strongly disliked by some of the experts. They believed it would be too complex for persons with intellectual disabilities. Moreover, it would be very difficult for a person using the screen reader to comprehend such an interface. Scrolling is stressful for a number of disabilities and should be minimized. In addition, the law states that the voter must be given the chance to assign all candidates a preference. Therefore, if 20 candidates are up for election, the numbers from 1 to 20 must be displayed on screen such that each candidate can be assigned and number from 1 to 20.

The element most liked from this design is the settings page as it is easy to understand. Nonetheless, people using the screen reader may have a problem understanding how to use it.

Design 3

The experts conveyed contradictory views with regards to the filtering functionality of this design. Some thought it would be helpful to have a shorter list of candidates, while others reasoned that all the candidates should always be available to the users. Furthermore, most experts expressed that the sliders in the settings page are easy to use, yet some communicated that it would be difficult to control by users with motor impairments.

Some issues with this design were due to the words used. It was emphasized that buttons should use few words and that important messages such as the invalid vote message should use short sentences and simple English.

Two important comments were made with regards to the preference selection screen. First, that the screen should display a button for each preference from one to the total number of candidates. Second, that the previously chosen preferences should be hidden rather than greyed out. The preferences should also keep their initial location on the screen.

One expert was sceptical about the flow of the candidate-to-preference assignment process. He indicated that it may be too repetitive and may cause the user to be fatigued.

5.2 First iteration of User Testing

5.2.1 Procedure

A one-on-one meeting was set up with each participant to extract as much feedback as possible from the sessions. Prior to conducting the testing, each user was informed about the aim of the study and their role within it. The tasks and the measurements of the study were also explained. The below procedure was carried out on both prototypes for each session. The prototype to test first was randomly chosen in order to eliminate bias.

The participant was given the opportunity to explore the prototype and ask any questions. The following tasks were given to the testers:

1. Cast a specified vote
2. Make changes to a vote
3. Cast a protest vote

For the first task, the candidates and preferences to be cast were predefined in order to replicate the real-life scenario where a voter casts his intended vote. A total of five candidates from different parties were chosen. All testers were given the same list of candidates and preferences to assign. For the second task, three candidates were assigned a preference and the tester was asked to make some changes to the vote including assigning a preference which has already been allocated to another candidate and changing the preferences assigned to candidates on the ballot. The third task required the tester to cast a spoiled vote which in this case meant casting an empty vote. The System Usability Scale (SUS) was administered after the tasks and the users could answer it on their own using a Google Form or have the observer ask the questions and take note of the responses.

5.2.2 Metrics Used

The usability of each prototype is measured in terms of effectiveness, efficiency, and satisfaction. Effectiveness is the number of successfully completed tasks. Efficiency is the time taken in seconds to complete each task. Subjective satisfaction was measured using the SUS questionnaire where the user answers ten questions using a five-point Likert scale. To quantify the result of the questionnaire, one must:

- For each odd numbered question, subtract 1 from the score
- For each even numbered question, subtract the value from 5
- Add the score of each question
- Multiply the total by 2.5

The reason why odd numbered questions are measured differently from even numbered questions is that the first group are positively worded while the second half is negatively worded. This polarity switch between the questions forces the respondents to really think about their answers.

5.2.3 Participants

This iteration of user testing included a total of five participants. Two participants are physically disabled, one has low vision and another two are blind. All the participants are IT literate and make use of technological devices on a daily basis.

The two blind participants used the screen reader when testing the prototypes. The tester with low vision conveyed that he sometimes uses the screen reader but, in most cases, he finds the colour inversion feature sufficient to navigate an interface. When carrying out the tasks, this tester only made use of the colour inversion feature. The two participants with motor impairments did not use any accessibility functions when using the tablet. However, one participant uses a stylus held in her mouth instead of a finger when using touchscreen interfaces. This is due to the immobilization of her arms.

5.2.4 Results

Effectiveness

All tasks across both prototypes were completed successfully except one. A physically impaired user did not manage to make his intended changes to the vote on Prototype B. After deleting the assigned preferences, he forgot to re-assign the preferences.

Efficiency

The time taken per task was measured in seconds. The mean time taken to complete each task using the prototypes is shown in Table 1. A paired T-test was used to extract the statistical significance between the prototypes. Since $p>0.05$ for all cases, there is no statistical significance between prototypes. However, there seems to be some discrepancies between the calculated means especially for Task 2.

	Mean time taken Prototype A	Mean time taken Prototype B	p-value
Task 1	195.4	197.4	.946
Task 2	102.5	153.75	.241
Task 3	18.6	25.2	.133

Table 1- Efficiency results for the first iteration of user testing

There is a notable difference between the time taken by the two blind testers in comparison to the other testers. For instance, when carrying out task 1, the blind users took between 4 minutes and 13 seconds to 5 minutes and 53 seconds. The other users took at least 1 minute and 29 seconds and at most 3 minutes and 19 seconds. One should consider that blind persons make use of the screen reader and, therefore, they must wait for the elements to be announced to them before taking action.

Satisfaction

Similar to the evaluation of efficiency, the significance was calculated using a paired T-test and $p>0.05$, hence, there is no statistical significance between the two prototypes in terms of user satisfaction. Table 2 shows the means and p-value obtained from questionnaire scores. The mean values are out of 100 since the maximum score obtained from the questionnaire used in 100. These results suggest that both prototypes exhibit a similar level of subjective satisfaction. Furthermore, the mean scores indicate that the testers found each of the prototypes usable.

Mean score of Prototype A	Mean score of Prototype B	p-value
92.5	91.5	.794

Table 2 - Satisfaction results for the first iteration of user testing

5.2.5 Comments and observations

This section contains any comments or feedback given by the users as well as any observations made by the evaluator.

Prototype A

Of the five testers, only one stated that this was his preferred prototype. Nonetheless, he discussed that a number of changes can be made to improve this design. He insisted that the candidate should still be visible on the ballot when assigned a preference. Furthermore, he would prefer if the candidates' names and preferences only would be visible on the ballot. One physically impaired tester forgot to press the next button when assigning preferences. Fortunately, she realized this before casting the vote. One cannot exclude that some individuals will make the same mistake and not realize before submitting their vote, thus casting an empty vote instead of the intended vote. In line with this, a blind user suggested having the 'Next' button always visible on screen and at the same location so that the user does not have to scroll to the bottom of the page to find it. It was observed that both blind participants had to traverse all candidates in the ballot in order to reach the 'Next' button which was irritating and time consuming.

Prototype B

Three testers conveyed that this was their preferred prototype. One user explained that she preferred it because the preference assignment order was not predefined as in Prototype A. The other two testers said that the process was closer to that which they employed while casting a vote. The tester with low vision struggled to see some of the pages and he suggested that thicker outlines and larger text size should be used. An important observation made during the sessions was that four of the participants made use of the filter feature when assigning preferences to their vote. This shows that the users preferred seeing shorter lists of candidates. One of the blind participants did not realize straight away that he needed to tap 'Cast Vote' on the Cast Vote page in order to finalize the process. One other participant pointed out that this was not intuitive and may lead to a large percentage of uncast votes. The same participant suggested that the option to cast an empty vote should be added to the Filter page.

General

Some users made comments which were not particular to any prototype. A common concern was whether training would be provided is such a system would be implemented. It would be crucial, especially, for citizens with low IT literacy, to be provided a demo system to train on before election day. Some participants conveyed that they would like the system to include a way which enables them to spoil a vote and add a message. One participant in particular stressed that this is crucial. This user also said that it would be helpful to screen reader users if, on the review page, the preference would be announced before the candidate's name. The blind participants both communicated that having the page's function or title announced on load would be extremely helpful to keep them oriented.

5.3 Second iteration of User Testing

5.3.1 Procedure

The procedure of the second run of user testing was planned to be identical to the procedure of the first run. Unfortunately, due to the Covid-19 pandemic, most people were not willing to meet in person. Therefore, alternative procedures were offered to the testers so that they could still offer some feedback. All the procedures employed are discussed in the following paragraphs.

The first option was to carry out the testing as initially planned. This procedure brings the tester and the evaluator to meet in person. The tester is given the same three tasks as the first iteration of testing. The evaluator observed the user to extract any errors made or any issues encountered. Once all three tasks were completed, the SUS questionnaire was administered. This was the ideal procedure but only two participants opted for this option. The other participants feared this would be too risky given the situation.

The second option was to execute the procedure remotely. Remote user testing is discussed in section *2.4.3 User Evaluation*. As noted in this section, remote user testing has the potential of extracting similar results to traditional methods. Nonetheless, the evaluator did not have as much control as in the initial plan. The participants who chose this procedure had to carry out the same tasks as the first iteration of user testing using a tablet. Since the evaluator was not present, the testers had to record themselves either by a screen recorder or a camera device. This enabled the evaluator to take the necessary measurements for effectiveness and efficiency. After carrying out the tasks, the testers had to fill an online version of the SUS questionnaire. Therefore, this method could extract the same metrics used in the previous procedure using a similar device. Another two participants opted for this procedure as they owned tablets. Other participants were giving the option of being lent an Android tablet for a day; however, this was not accepted for different reasons.

The final option given is the least ideal due to having a different device and the least experimental control, but it was used to collect the feedback of an additional three users. This was used by persons who wished to participate but did not wish to meet in person, did not own a tablet or did not want to borrow one. The interface was adapted to be displayed adequately on a laptop or desktop screen. The URL was sent to any persons willing to participate. The participants were encouraged to rigorously test the interface and carry out tasks similar to those in the previous two alternatives. When each participant felt that they had explored the website enough, they filled in an online survey. The survey asked for what elements were found to be helpful or annoying as well as what they would improve. The participants had to answer the SUS questionnaire too.

5.3.2 Metrics Used

The first and second procedure options allowed the evaluator to gather the effectiveness, efficiency, and satisfaction measurements as per the previous user testing. For the desktop version testing, only the satisfaction was measured. The other measurements were not taken because the devices and methods of interaction were different and, therefore, could not be compared.

5.3.3 Participants

In this iteration of user testing, seven persons from the target audience took part. The distribution of testers with respect to the options chosen and disabilities are shown in Table 3. All but one of the visually impaired participants are blind and made use of screen readers to test the interface. The other visually impaired participant has low vision and made use of high contrast features to see the interface. Some of the participants had taken part in the previous user testing. The physically impaired tester that opted for option 2 and both visually impaired testers that chose option 3 were new participants.

	Visual impairment	Physical impairment
Testing as initially planned	2	0
Remote testing on a tablet	1	1
Remote testing of desktop version	2	1

Table 3 - Distribution of participants in the second user testing

5.3.4 Results

Effectiveness

All four participants eligible for this measurement managed to cast their intended vote. Although this is an excellent outcome, one must consider that the participants are all IT literate. Given a larger number of testers with different levels of IT proficiency, the results may differ.

Efficiency

The time for each task was measured in seconds. Table 4 shows the time taken by each tester to carry out the tasks on the final prototype. Testers 1 and 2 are both blind and they met the evaluator separately and carried out the testing as initially planned. Testers 3 and 4, suffering from low visual and motor impairment respectively, executed the remote testing using their personal tablets. Their results may have been affected by the lack of control in remote user testing.

	Task 1	Task 2	Task 3
Tester 1	266 seconds	126 seconds	43 seconds
Tester 2	260 seconds	81 seconds	88 seconds
Tester 3	185 seconds	88 seconds	53 seconds
Tester 4	54 seconds	43 seconds	21 seconds

Table 4 - Time taken by each participant to carry out each task

As noted in section *5.2.4 Results*, blind persons take longer to perform a task when compared to other persons, including those that have different impairments. The only exception to this observation is the time taken for task 2 by testers 2 and 3. From the video sent in by tester 3 of his interaction with the system, it was noticed that the tester wasted a lot of time going back and forth between the prototype on the tablet and the document explaining the tasks on a separate device. Due to his visual impairment, a substantial amount of time was wasted reading the tasks while executing them.

Table 5 compares the mean task times between the two mid fidelity prototypes, Prototype A and Prototype B, and the final prototype which was tested in this run of user testing. The first task was improved by a few seconds. The second task, making amendments to a vote, on the high-fidelity prototype had a drastic improvement over the previous prototypes. The p-values obtained from One-Way ANOVA are also shown in Table 5 and they exhibit that both these tasks did not improve significantly. However, this may be affected by the small number of testers since the mean task times for task 2 have a substantial difference. Only task 3 took longer to accomplish. This increase is caused by the time taken to add a comment to the protest vote. Although this is not mandatory, all participants opted to add a comment even if it was a set of random characters.

	Task 1	Task 2	Task 3
Mean time taken on Prototype A	195.4 seconds	102.5 seconds	18.6 seconds
Mean time taken on Prototype B	197.4 seconds	153.75 seconds	25.5 seconds
Mean time taken on the final prototype	191.25 seconds	84.5 seconds	51.25 seconds
p-value	.996	.350	.060

Table 5 - Mean time taken per task on the prototypes developed

Satisfaction

All three evaluation alternatives offered to the users extracted the satisfaction measure using the SUS questionnaire. Table 6 shows the SUS scores, impairment and testing alternative chosen for each participant. The scores range from 87.5 to 100. Seeing that two of the participants gave the perfect ratings for the system, one might think that the participants are being too optimistic and not viewing the interface critically enough. This might be affected by their enthusiasm for voting independently. Furthermore, there is no notable difference between the scores of participants with different disabilities or different testing options.

Testing option	Impairment	SUS Score
Testing as initially planned	Visual (Blind)	87.5
Testing as initially planned	Visual (Blind)	100
Remote testing on a tablet	Visual (Low vision)	95
Remote testing on a tablet	Physical	95
Remote testing of desktop version	Visual (Blind)	92.5
Remote testing of desktop version	Visual (Blind)	97.5
Remote testing of desktop version	Physical	100

Table 6 - SUS scores for all testers

The final prototype achieved a higher average rating in user satisfaction when compared to the infidelity prototype. The scores can be viewed in Table 7 along with the statistical significance which was calculated using One-Way ANOVA. Since the p-value is much larger than 0.05, the results do not show significant improvement. However, the means show that there was some improvement between the mid-fidelity prototypes and the high-fidelity prototypes.

Mean SUS score on Prototype A	Mean SUS score on Prototype B	Mean SUS score on the Final Prototype	p-value
92.5	91.5	95.4	.495

Table 7 - SUS scores across prototypes

5.3.5 Comments and observations

One tester who carried out the testing as initially planned and the physically impaired tester who did the testing from home on a tablet had only positive comments on the feedback. Both testers conveyed that they would not change anything about the voting interface's design and gave high satisfaction scores. Nonetheless, the tester with low vision came across some issues that hindered his experience. For instance, the 'Review and Cast' button has a low text to background ratio. This caused the user to waste a lot of time looking for the button especially the first time he needed to use it. Moreover, when he attempted to add a comment to the protest vote, he did not realize whether anything had been typed because the font size was too small. The issue brought out by one of the blind testers is that blind voters will not be able to tell which party a candidate belongs to when reviewing the vote. He noted that an auditory cue would be helpful in this regard. The few negative comments brought out by the tablet testers can be easily fixed. One must consider the small size of the testing group, meaning that if a larger testing group with a wider range of disabilities were available, many more issues may have been found.

The two blind testers that executed the testing as initially planned identified a lot of features which were helpful to them, such as the headings being announce on load and the static navigation bar. The filter feature kept proving useful through these sessions as three of four participants made use of it.

All three testers who carried out the testing on a laptop or desktop computer found the interface instinctual, simple and straight forward. Two of these participants had no issues with the interface. However, one of these testers had concerns which are external to the interface. The first concern was that votes may be identifiable if only a small number of voters make use of it. Secondly, she feared some people would not be willing to use technology to vote. The user who had some issues with the prototype made use of a screen reader and had problems navigating the interface with the keyboard, therefore, he navigated using a mouse. This prototype is intended for touchscreens, however, if a keypad or a keyboard were to be added in the future, the appropriate attributes and tags would have to be added in the code. On a positive note, this user communicated that he was able to cast a vote without any assistance and without referring to the help page. This participant reported that the layout was logical and clear. He also offered a list of items which he found helpful when interacting with the system. This includes the error prevention mechanisms, confirmation alerts and the layout of lists.

7 Conclusion

Throughout this project, an interface was designed for a dedicated voting machine which allows independent voting by persons who cannot do so using a paper ballot. Three initial designs were designed and, through a number of evaluations, were refined to higher fidelity, greater usability, and superior accessibility. Experts in accessibility and users from the target audience were involved in this study to ensure that the final artifact is usable by persons within the disabled community.

At the beginning of this study four objectives were established:

- O1: Create designs for an accessible voting interface based on previous research and accessibility guidelines
    - As already mentioned, three low fidelity designs were created during the early stages. These were drawn as wireframes with additional annotations to express the behaviour of the system. Each design was thoroughly discussed with accessibility experts and developed into mid fidelity web applications. The designs are discussed in section *3.2 Initial Designs and Design Decisions*.
- O2: Determine which evaluation techniques will be used to identify issues in the interface
    - After researching evaluation techniques used in previous voting research and usability studies in general, it was decided that expert reviews and user testing will be used to evaluate the interfaces being designed and developed in this study. The findings can be read in section *2.4 Evaluation.*
- O3: Identify the measurements which will be used to assess the usability and accessibility of the prototypes
    - ISO breaks usability down to three main elements: effectiveness, efficiency and satisfaction [47]. These measures are discussed in section *2.3.3 Measures of Usability* and used to quantify and compare the usability of the mid-fidelity and high-fidelity prototypes.
    - Furthermore, a statistical approach was taken to check whether there was significant improvement between the mid-fidelity prototypes and the high-fidelity prototype. Due to the small number of testers, statistical significance

    - was not found in any case. Therefore, the means were calculated to obtain some insight into which prototypes were most usable.
- O4: Attempt to create and evaluate a usable interface for a designated voting machine which disabled persons can use to vote independently
    - This was the main objective of this project. The results in section *5.3.4 Results* show that when using final prototype, all participants were able to cast their intended vote independently in a few minutes. Furthermore, the SUS scores show that the users were very satisfied using the system. Therefore, the interface designed in this project has been proven usable by the target audience.

Although all the objectives were reached, this is not a finished interface. Further usability testing is required to identify any present accessibility and general usability features for a wider audience.

7.1 Future Work

This project has only kicked off the research needed to reach a fully implementable accessible voting machine. Future research can evaluate the interfaces created in this study with larger groups of target users to get a more holistic view. It is of utmost importance to test with people of low IT literacy skills since all the testers who took part in this study are proficient with touchscreens and different devices since they make use of them on a daily basis. Moreover, usability testing should include people without disability. Some of the participants in this study showed their concern that if only disabled persons make use of this system, their votes will be identifiable. Therefore, a voting machine should be available to all citizens casting their vote.

A major factor which was outside of the scope of this project is the security of such a machine. This is a crucial aspect as it can affect voter turnout and the endorsement of the election's result. In addition to this, studies must also explore the hardware that will be needed and the electoral laws that have to be changed in order to allow this type of voting mechanism. Lastly, future research should delve into the training that should be offered before election day. Many testers brought to light that giving the users time to explore and cast dummy ballots would facilitate casting a vote at the polling station on the day of the election.

Bibliography

[1] United Nation General Assembly, “Universal Declaration of Human Rights,” 1948.

[2] “FITA EVoting - Electoral Research.” .

[3] T. Selker, “Fixing the vote,” 2004.

[4] C. Enguehard, “Transparency in Electronic Voting : the Great Challenge,” 2008.

[5] A. Ward, P. M. A. Baker, and N. Moon, “Ensuring the Enfranchisement of People With Disabilities,” *Artic. J. Disabil. Policy Stud.*, vol. 20, no. 2, pp. 79–92, 2009, doi: 10.1177/1044207308325996.

[6] K. S. Fuglerud, K. Skeide, F. Till, and H. Røssvoll, “An evaluation of Web-based voting usability and accessibility,” *Univers. Access Inf. Soc.*, vol. 11, no. 4, pp. 359–373, 2011, doi: 10.1007/s10209-011-0253-9.

[7] P. S. Herrnson, P. L. Francia, and B. Bederson, “Early appraisals of electronic voting,” *Soc. Sci. Comput. Rev.*, vol. 23, no. 3, pp. 274–292, 2005.

[8] B. B. Bederson, B. Lee, R. M. Sherman, P. S. Herrnson, and R. G. Niemi, “Electronic Voting System Usability Issues,” 2003.

[9] “United States presidential election of 2000 | United States government | Britannica.” [Online]. Available: https://www.britannica.com/event/United-States-presidential-election-of-2000. [Accessed: 18-May-2020].

[10] B. Simons, “Voting and technology: Who gets to count your vote?,” *Artic. Commun. ACM*, 2003, doi: 10.1145/859670.859692.

[11] F. G. Conrad *et al.*, “Electronic voting eliminates hanging chads but introduces new usability challenges,” *Int. J. Human-Computer Stud.*, vol. 67, pp. 111–124, 2009, doi: 10.1016/j.ijhcs.2008.09.010.

[12] J. Bannet, D. W. Price, A. Rudys, J. Singer, and D. S. Wallach, “Hack-a-Vote: Demonstrating Security Issues with Electronic Voting Systems.”

[13] A. J. Feldman, J. A. Halderman, and E. W. Felten, “Security Analysis of the Diebold AccuVote-TS Voting Machine.”

[14] P. S. Herrnson, “THE IMPORTANCE OF USABILITY TESTING OF VOTING SYSTEMS.”

[15] "PA County's Voting Machines Impounded Following Complaints | WIRED." [Online]. Available: https://www.wired.com/2008/11/pa-countys-voti/. [Accessed: 24-Apr-2020].

[16] "Direct Recording Electronic - Avante International Technology, Inc." [Online]. Available: https://www.avantetech.com/products/elections/dre/. [Accessed: 24-Apr-2020].

[17] "The Ballot Ballet: The Usability of Accessible Voting Machines | AccessWorld | American Foundation for the Blind," 2019. [Online]. Available: https://www.afb.org/aw/5/4/14723. [Accessed: 18-Feb-2020].

[18] "Verifiedvoting.org." [Online]. Available: https://www.verifiedvoting.org/downloads/20050816.dieboldresponse.pdf. [Accessed: 18-Feb-2020].

[19] N. Tideman, "The Single Transferable Vote," 1995.

[20] "Ranked Choice Voting / Instant Runoff- FairVote." [Online]. Available: https://www.fairvote.org/rcv#where_is_ranked_choice_voting_used. [Accessed: 03-Mar-2020].

[21] "Electoral Commission of Malta." [Online]. Available: https://electoral.gov.mt/ElectionResults/LocalCouncil?year=246&v=null. [Accessed: 12-Feb-2020].

[22] D. Grech Urpani, "Here's Everything You Need To Know About Voting In Malta Today." [Online]. Available: https://lovinmalta.com/news/news-politics/heres-everything-you-need-to-know-about-voting-in-malta-today/. [Accessed: 12-Feb-2020].

[23] "Blindness and vision impairment," 2019. [Online]. Available: https://www.who.int/news-room/fact-sheets/detail/blindness-and-visual-impairment. [Accessed: 12-Feb-2020].

[24] CRPD, "Round table discussion on voting and active participation in politics," Valletta, 2018.

[25] C. Frauenberger and M. Noisternig, "3D AUDIO INTERFACES FOR THE BLIND," in *Proceedings of the 2003 International Conference on Auditory Display*, 2003, pp. 280–284.

[26] B. Leporini, P. Andronico, and M. Buzzi, "Designing Search Engine User Interfaces for the visually impaired," *Comput. Phys. Handicap.*, pp. 17–18, 2003, doi: 10.1145/1036401.1036409.

[27] K.-P. Yee, "Extending prerendered-interface voting software to support accessibility and

other ballot features," 2007.

[28] R. Kuber, W. Yu, and G. Mcallister, "Towards developing assistive haptic feedback for visually impaired internet users," in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2007, doi: 10.1145/1240624.1240854.

[29] G. E. Piner and M. D. Byrne, "The Experience of Accessible Voting: Results of a Survey among Legally-Blind Users," in *Proceedings of the Human Factors and Ergonomics Society*, 2011, doi: 10.1177/1071181311551351.

[30] "Motor Impairment - NeuRA." [Online]. Available: https://www.neura.edu.au/research-centre/motor-impairment/. [Accessed: 12-Feb-2020].

[31] "Motor Impairment." [Online]. Available: https://www.neuromodulation.com/motor-impairment. [Accessed: 12-Feb-2020].

[32] S. Trewin and H. Pain, "Keyboard and Mouse Errors Due to Motor Disabilities," 1996.

[33] "FAQs on Intellectual Disability." [Online]. Available: https://www.aaidd.org/intellectual-disability/definition/faqs-on-intellectual-disability. [Accessed: 12-Feb-2020].

[34] K. Hutcherson, J. Langone, K. Ayres, and T. Clees, "Computer Assisted Instruction to Teach Item Selection in Grocery Stores: An Assessment of Acquisition and Generalization," *J. Spec. Educ. Technol.*, vol. 19, no. 4, pp. 33–42, 2004.

[35] C. W. Holsapple, R. Pakath, and S. Sasidharan, "A website interface design framework for the cognitively impaired: A study in the context of Alzheimer's disease," *Artic. J. Electron. Commer. Res.*, vol. 6, no. 4, 2005.

[36] O. Shabalina, M. Siplivaya, J. Borblik, M. Kultsova, A. Pidoprigora, and R. Romanenko, "Assistive technology software for people with intellectual or development disabilities: Design of user interfaces for mobile applications," in *6th International Conference on Information, Intelligence, Systems and Applications (IISA)*, 2015, doi: 10.1109/IISA.2015.7387976.

[37] J. Dekelver *et al.*, "Design of Mobile Applications for People with Intellectual Disabilities," *Commun. Comput. Inf. Sci.*, pp. 823–836, 2015, doi: 10.1007/978-3-319-23766-4.

[38] C. S. Lanyi, D. J. Brown, P. Standen, J. Lewis, and V. Butkute, "User interface evaluation of serious games for students with intellectual disability," 2010.

[39] D. K. Davies, S. E. Stock, and M. L. Wehmeyer, "Application of Computer simulation to Teach ATM Access to Individuals with Intellectual Disabilities," *Educ. Train. Dev. Disabil.*,

vol. 38, no. 4, pp. 451–456, 2003.

[40] H. Störrle, “Model driven development of user interface prototypes: An integrated approach,” 2010, doi: 10.1145/1842752.1842802.

[41] B. Myers, S. Y. Park, Y. Nakano, G. Mueller, and A. Ko, “How Designers Design and Program Interactive Behaviors,” in *IEEE Symposium on Visual Languages and Human-Centric Computing*, 2008, pp. 177–184.

[42] R. F. Zant, “Hands-on Prototyping in system Analysis and Design,” *Issues Inf. Syst.*, vol. VI, no. 1, pp. 10–14, 2005.

[43] J. M. Rivero, G. Rossi, E. R. Luna, J. Grigera, E. Robles Luna, and A. Navarro, “From Interface Mockups to Web Application Models,” *Lect. Notes Comput. Sci.*, pp. 257–264, 2011, doi: 10.1007/978-3-642-24434-6_20.

[44] J. M. Rivero, G. Rossi, J. Grigera, J. Burella, E. R. Luna, and S. Gordillo, “From Mockups to User Interface Models: An Extensible Model Driven Approach,” 2010.

[45] N. Tractinsky, “The Usability Construct: A Dead End?,” *Human–Computer Interact.*, vol. 33, no. 2, pp. 131–177, Mar. 2018, doi: 10.1080/07370024.2017.1298038.

[46] M. Hertzum, N. Ebbe Jacobsen, and R. Molich, “Usability Inspections by Groups of Specialists: Perceived Agreement in Spite of Disparate Observations,” *Ext. Abstr. ACM CHI 2002 Conf.* , pp. 662–663, 2002.

[47] “ISO 9241-210,” 2010. [Online]. Available: https://www.iso.org/obp/ui/#iso:std:iso:9241:-210:ed-1:v1:en. [Accessed: 03-Apr-2020].

[48] M. Hertzum and T. Clemmensen, “How Do Usability Professionals Construe Usability?,” 2012.

[49] H. Petrie and N. Bevan, “The Evaluation of Accessibility, Usability, and User Experience,” *Univers. Access Handb.*, 2009, doi: 10.1201/9781420064995-c20.

[50] A. B. Naumann, I. Wechsung, and R. Schleicher, “Measurements and Concepts of Usability and User Experience: Differences between Industry and Academia,” 2009.

[51] “Introduction to Web Accessibility | Web Accessibility Initiative (WAI) | W3C.” [Online]. Available: https://www.w3.org/WAI/fundamentals/accessibility-intro/. [Accessed: 03-Apr-2020].

[52] S. J. Laskowski, M. Autry, J. Cugini, W. Killam, and J. Yen, “Improving the usability and accessibility of voting systems and products,” *NIST Spec. Publ. 500-256*, no. 202, pp. 1–

92, 2004.

[53] S. T. Lee, Y. E. Liu, X. Xiong, and J. Sanford, “Development of a more universal voting interface,” *Proc. Hum. Factors Ergon. Soc.*, pp. 1624–1628, 2013, doi: 10.1177/1541931213571361.

[54] B. B. Bederson and P. S. Hernson, “Usability Review of the Diebold DRE system for Four Counties in the State of Maryland,” pp. 1–11, 2002.

[55] F. Conrad, “Usability and voting technology,” *Hum. Asp. Comput. Des. Use …*, no. March, 2008.

[56] F. Adebesin, P. Kotzé, and H. Gelderblom, “The Complementary Role of Two Evaluation Methods in the Usability and Accessibility Evaluation of a Non-Standard System,” in *Proceedings of the 2010 Annual Research Conference of the South African Institute of Computer Scientists and Information Technologists*, 2010.

[57] G. Brajnik, “Beyond Conformance: The Role of Accessibility Evaluation Methods,” *Web Inf. Syst. Eng. - WISE*, pp. 63–80, 2008.

[58] “Useful Links – FITA Malta.” [Online]. Available: https://fitamalta.eu/resources/useful-links/. [Accessed: 13-Feb-2020].

[59] G. Brajnik, Y. Yesilada, and S. Harper, “The expertise effect on web accessibility evaluation methods,” *Human-Computer Interact.*, vol. 26, no. 3, pp. 246–283, 2011, doi: 10.1080/07370024.2011.601670.

[60] J. Mankoff, H. Fait, and T. Tran, “Is Your Web Page Accessible? A Comparitive Study of Methods for Assessing Web Page Accessibility for the Blind Is Your Web Page Accessible? A Comparative Study of Methods for Assessing Web Page Accessibility for the Blind,” in *Proceedings of the SIGCHI conference on Human factors in computing systems*, 2005.

[61] G. Brajnik, “A comparative test of web accessibility evaluation methods,” in *ASSETS’08: The 10th International ACM SIGACCESS Conference on Computers and Accessibility*, 2008, pp. 113–120, doi: 10.1145/1414471.1414494.

[62] Disability Rights Commision, “The Web Access and Inclusion for Disabled People A Formal Investigation conducted by the Disability Rights Commission,” 2004.

[63] J. Brooke, “SUS-A quick and dirty usability scale.”

[64] H. Petrie, F. Hamilton, N. King, and P. Pavan, “Remote usability evaluations with disabled people,” in *Conference on Human Factors in Computing Systems - Proceedings*, 2006, vol. 2, pp. 1133–1141, doi: 10.1145/1124772.1124942.

[65] M. S. Andreasen, H. V. Nielsen, S. O. Schrøder, and J. Stage, “What happened to remote usability testing?: An empirical study of three methods,” in *Conference on Human Factors in Computing Systems - Proceedings*, 2007, pp. 1405–1414, doi: 10.1145/1240624.1240838.

[66] S. Batra and R. R. Bishu, “Web Usability and Evaluation: Issues and Concerns,” 2007.

[67] K. E. Thompson, E. P. Rozanski, and A. R. Haake, “Here, there, anywhere,” 2004, p. 132, doi: 10.1145/1029533.1029567.

[68] T. Tullis, T. Tullis, S. Fleischman, M. Mcnulty, C. Cianchette, and M. Bergel, “An empirical comparison of lab and remote usability testing of Web sites Measuring UX View project An Empirical Comparison of Lab and Remote Usability Testing of Web Sites,” 2002.

[69] C. Sjöström, “DESIGNING HAPTIC COMPUTER INTERFACES FOR BLIND PEOPLE,” 2001.

[70] “(No Title).” [Online]. Available: https://www.cambridgema.gov/~/media/Files/electioncommission/2017municipalelection/cityspecimenforweb.pdf?la=en. [Accessed: 03-Mar-2020].

[71] M. Depares, “Designing a User Interface for a Maltese Electoral System Voting Machine,” 2015.

Appendices

Appendix A - Prototypes

To access the prototypes created during this study, please follow the links bellow. The first three websites are intended for tablet devices. If you do not want to access them with tablet device, use Google Chrome's developer tools to view them in tablet mode. These web applications were not developed to be responsive because they are meant for one device only: the voting machine at a polling station.

- https://prototype-a.netlify.app/ for the mid fidelity prototypes which is regarded as Prototype A in the study
- https://prototype-b.netlify.app/ for the mid fidelity prototype which is regarded as Prototype B in the study
- https://accessible-voting.netlify.app/ for the high-fidelity prototype used for testing on tablets
- https://accessible-voting-2.netlify.app/ for the high-fidelity prototype used for remote desktop user testing

Appendix B – Consent Form

Voting Machine for People with Disabilities

Participation Consent Form

- The research has been satisfactorily explained to me and I understand what its aim is.
- I understand that the research will involve testing prototypes, being observed while doing so, giving feedback and responding to questionnaires.
- My participation is voluntary, and I understand that I can withdraw from this study at any time without giving an explanation.
- I understand how my input will affect this research.
- I understand that the progress and results obtained from this research might be discussed with others.

Full Name of Participant: ____

Signature: _______________________ Date: __________________________

Full Name of Researcher: ____

Signature: _______________________ Date: ___________________________

Appendix C – Information letter

For the participating experts

Title of study: Voting Machine for People with Disabilities

Student Researcher: Martina Gauci (3rd year B.Sc. Software Development student at the University of Malta - email: martina.gauci.17@um.edu.mt)

Supervisor: Dr Colin Layfield (Senior Lecturer at the Faculty of ICT at the University of Malta - email: colin.layfield@um.edu.mt)

Co-Supervisor: Dr Conrad Attard (Deputy Dean at the Faculty of ICT at the University of Malta - email: conrad.attard@um.edu.mt)

This document will explain the study and your participation within it. General questions regarding the purpose, risks and benefits are included, however, should you have any other questions or feel the need to inquire further about the details of the study, please contact the researcher or the supervisors mentioned above. A hardcopy of this document will be provided upon request.

The research's scope

You are invited to participate in a research study about accessible voting machines. The objective of this project is to design an interface for a voting machine which can be easily used by people with different disabilities. At present, paper ballots are the only means of casting a vote in Malta. This causes people with disabilities to require the help of an assistant electoral commissioner. This, in turn, compromises the secrecy of the vote which is a fundamental right asserted by the United Nations in The Universal Declaration of Human Rights.

The participant's role

Your participation in the study will consist of attending one meeting to discuss three low fidelity prototypes. This meeting will last around one hour and a half and it will take place at your desired location. Meeting will be held one-on-one or in small groups. I would like these meetings to take place in late November or early December.

I will present to you one prototype at a time and I will explain the thought behind the layout and the behaviour of that prototype. These prototypes consist of wireframes which point to one another depending on what action is taken. You can ask me questions about each prototype and we will discuss any possible improvements that can be made.

The purpose of this meeting is to identify which elements of the prototypes perform better than others in terms of accessibility. After the meeting I should be able to adjust these prototypes into two more accessible prototypes. I will refine the prototypes and make them resemble the real interface more in preparation for user testing.

Eligibility

In order to participate in this study, you must be knowledgeable about accessible interfaces. You must be able to guide me in developing my prototypes such that they can be easily used by people with disabilities.

Voluntary participation

Your participation in this study is voluntary. You may decide to withdraw your participation at any time by communicating this to the investigator or the supervisors. Any previous information you provide will not be used. You can request your withdrawal up to May 2020 which is when my thesis is due. After that point I will not be able to remove the information you have provided as it would have been submitted.

Possible benefits

This research will possibly benefit people with disabilities because if this project was to be implemented in real life, they would be able to vote independently.

Risks

There are no known or anticipated risks associated with participation in this study.

Identity

No record of your identity will be kept and your name will not be revealed within my thesis.

Confidentiality

No identifiable information will be recorded for this study. Nonetheless, when discussing the expert evaluation and the results I may mention how particular experts highlighted certain elements of the prototype but I will not identify the participant.

For the participating testers

Title of study: Voting Machines for People with Disabilities

Student Researcher: Martina Gauci (3rd year B.Sc. Software Development student at the University of Malta - email: martina.gauci.17@um.edu.mt)

Supervisor: Dr. Colin Layfield (Senior Lecturer at the Faculty of ICT at the University of Malta - email: colin.layfield@um.edu.mt)

Co-Supervisor: Dr. Conrad Attard (Deputy Dean at the Faculty of ICT at the University of Malta - email: conrad.attard@um.edu.mt)

This document will explain the study and your participation within it. General questions regarding the purpose, risks and benefits are included, however, should you have any other questions or feel the need to inquire further about the details of the study, please contact the researcher or the supervisors mentioned above. A hardcopy of this document will be provided upon request.

The research's scope

You are invited to participate in a research study about accessible voting machines. The objective of this project is to design an interface for a voting machine which can be easily used by people with different disabilities. At present, paper ballots are the only means of casting a vote in Malta. This causes people with disabilities to require the help of an assistant electoral commissioner. This, in turn, compromises the secrecy of the vote which is a fundamental right asserted by the United Nations in The Universal Declaration of Human Rights.

The participant's role

Participation in the study will consist of attending two testing sessions in which you will have to cast a vote through an application on a tablet. Each session should not take more than an hour. First, you will be briefed about how to use the interface. Then I will provide you with a tablet where you will attempt to cast your intended vote. I will observe you to detect any pain points in the interface. When you have completed this process, you can give me some feedback on how to improve the interface. Furthermore, you will fill out a usability questionnaire. This questionnaire consists of ten statements with a five-point likert scale. This means you will have to rank each of the ten statements from ‘strongly agree’ to ‘strongly disagree’. No personal information will be asked for in this questionnaire.

The date, time and location for the testing will be suited to each participant in an effort to minimise the disruption.

Eligibility

In order to participate in this study, you must be of voting age and unable to independently cast your vote using the current system.

Voluntary participation

Your participation in this study is voluntary. You may decide to withdraw your participation at any time by communicating this to the investigator or the supervisors. Any previous information you provide will not be used. You can request your withdrawal up to May 2020 which is when my thesis is due. After that point I will not be able to remove the information you have provided as it would have been submitted.

Possible benefits

This research aims to show that it is possible for people with disabilities to exercise their right to vote independently. I hope that this study will help push towards making accessible voting methods a reality.

Risks

There are no known or anticipated risks associated with participation in this study.

Identity

No record of your identity will be kept. I will observe how you interact will the voting system and will discuss this in my research but I will not reveal how you, specifically, performed or responded to the questionnaire.

Confidentiality

No identifiable information will be recorded for this study. Nonetheless, when discussing the testing phases and the results I may mention how particular testers performed but I will not identify the participant.

Appendix D – Evaluation forms

The following forms were used to extract user satisfaction of each prototypes. The first questionnaire is based on the System Usability Scale but has optional questions in case the tester would like to give a reason for their answer. This questionnaire was available on Google Forms in order to be accessible to all testers including the ones who did the user tests remotely.

Questionnaire

This questionnaire aims to extract the testers' subjective satisfaction with regards to the prototype that has been tested.

* Required

1. I think that I would like to use this system frequently. *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

2. Do you have any particular reason for the previous answer?

   ____

3. I found the system unnecessarily complex. *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

4. Do you have any particular reason for the previous answer?

   ____

5. I thought the system was easy to use. *

   Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

6. Do you have any particular reason for the previous answer?

   ____

7. I think that I would need the support of a technical person to be able to use this system. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

8. Do you have any particular reason for the previous answer?

____

9. I found the various functions in this system were well integrated. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

10. Do you have any particular reason for the previous answer?

____

11. I thought there was too much inconsistency in this system *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

12. Do you have any particular reason for the previous answer?

____

13. I would imagine that most people would learn to use this system very quickly. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

14. Do you have any particular reason for the previous answer?

____

15. I found the system very cumbersome to use. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

16. Do you have any particular reason for the previous answer?

____

17. I felt very confident using the system. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

18. Do you have any particular reason for the previous answer?

____

19. I needed to learn a lot of things before I could get going with this system. *

Mark only one oval.

	1	2	3	4	5	
Strongly disagree	◯	◯	◯	◯	◯	Strongly agree

20. Do you have any particular reason for the previous answer?

____

21. What would you change to make the website more accessible? *

____

A slightly different questionnaire was used for the remote desktop testing. All the questions above were included so that the user satisfaction score could be obtained. The questions shown below were added to get a better idea of what the testers tried to accomplish while discovering the system at home and whether or not they came across any issues.

Are there any elements you found helpful when casting your vote?

Are there any elements you found annoying to use?

What would you improve?

Which of these objectives did you attempt and complete successfully?

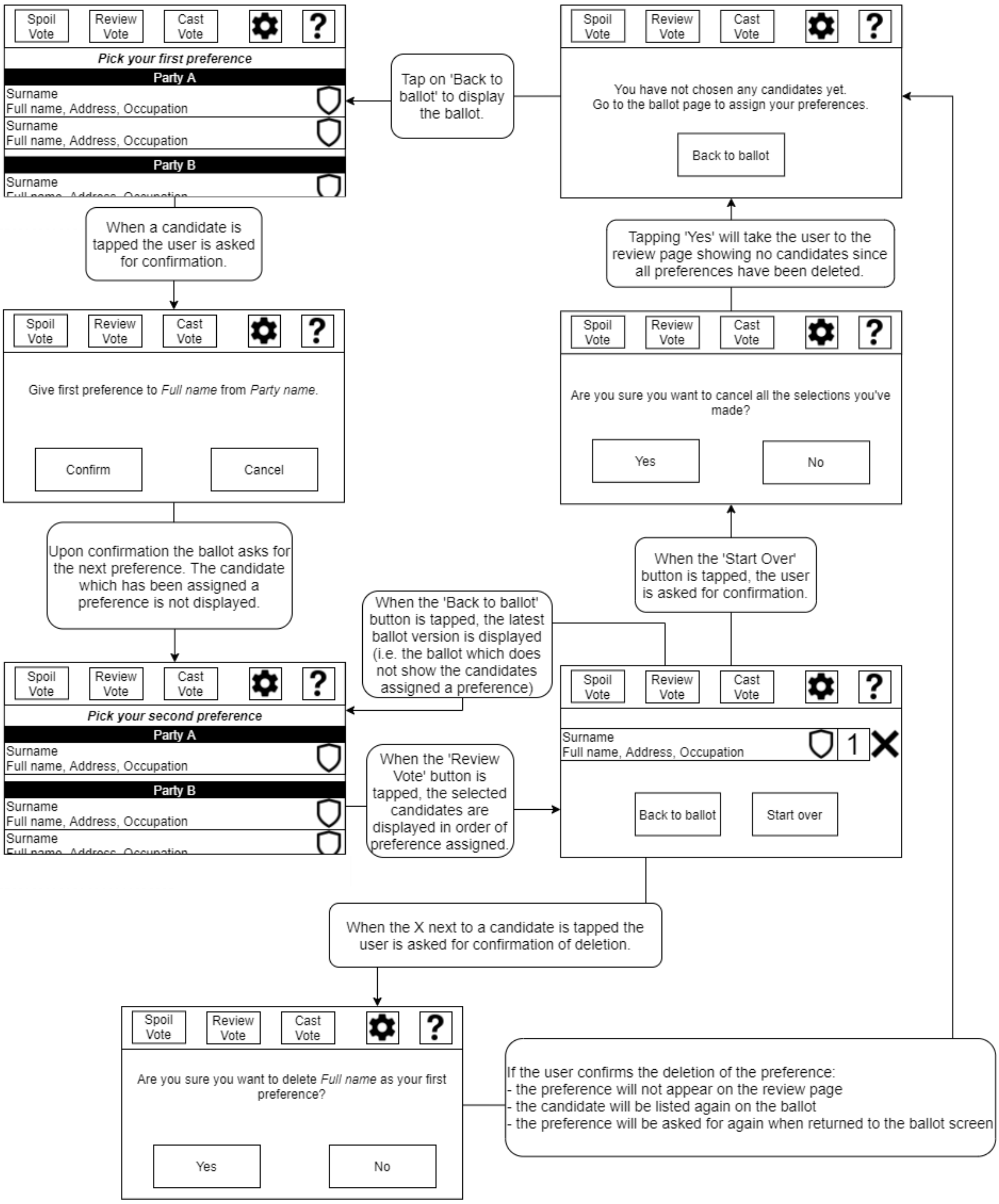
Mark only one oval.

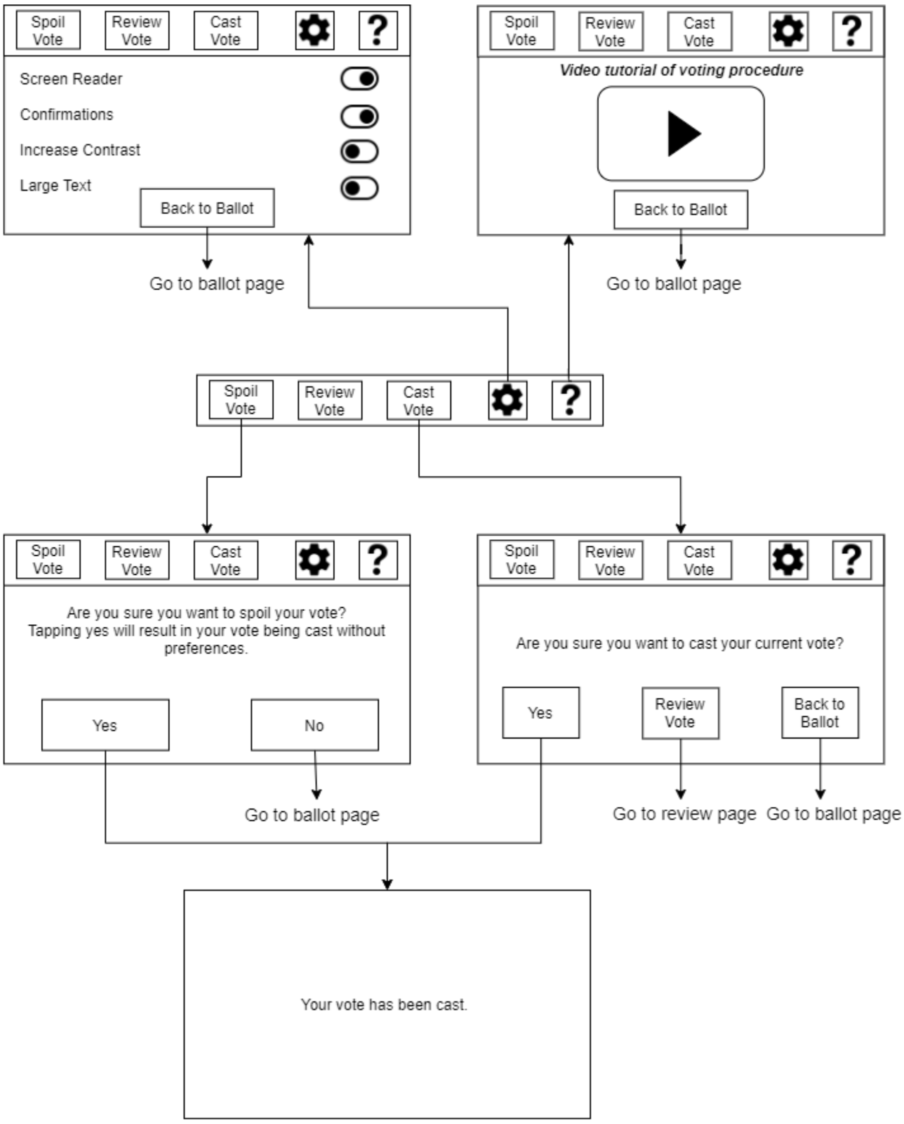
- Cast my intended vote
- Make changes to the vote
- Cast a protest vote
- Other:

Did you attempt any task which you could not complete? If yes, what could you not accomplish?

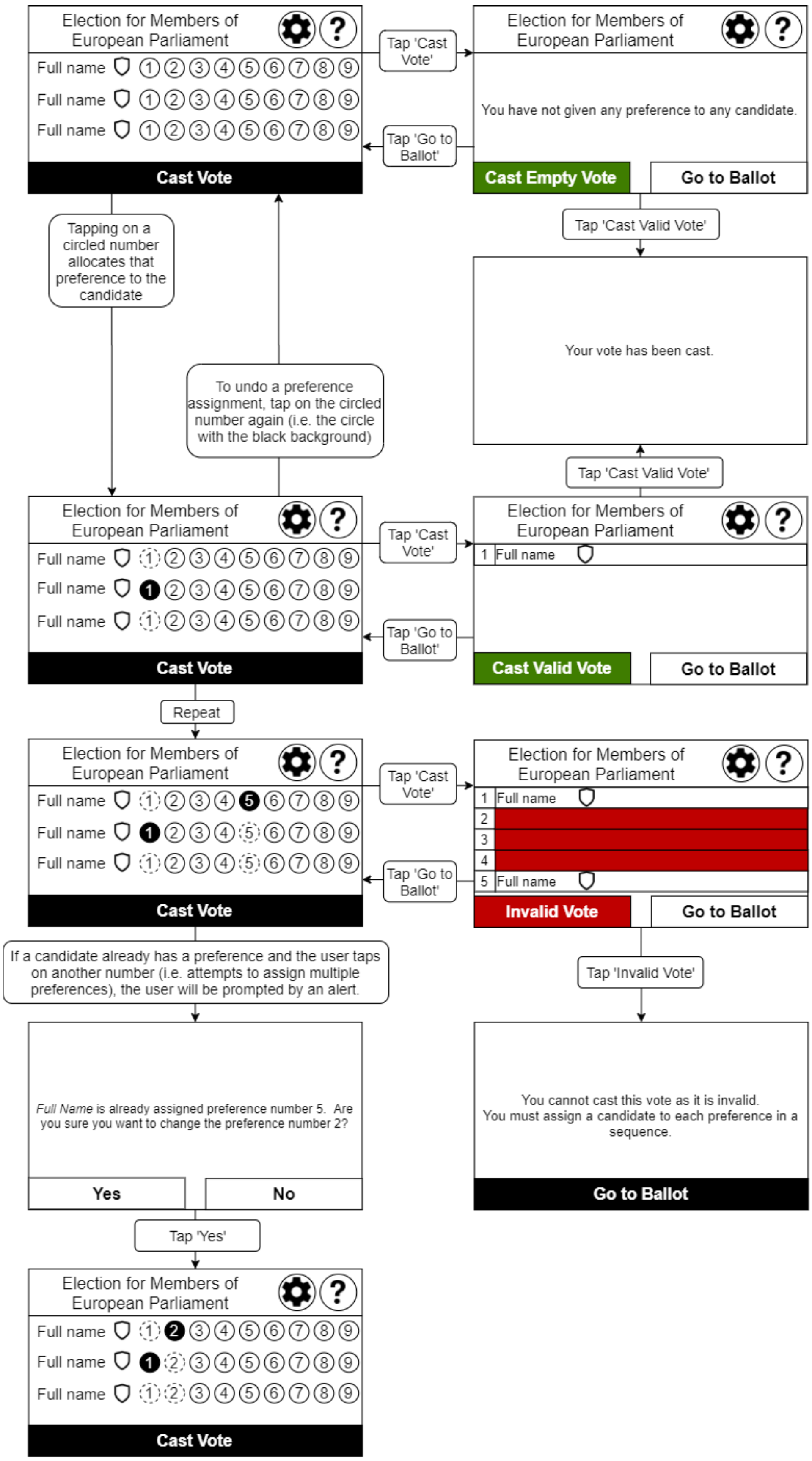
Appendix E – Low Fidelity Designs

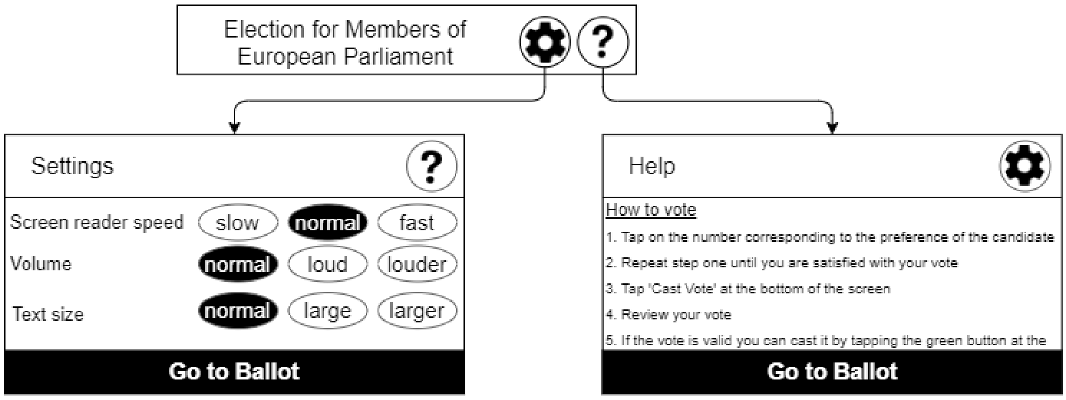
Wireframe for Design 1



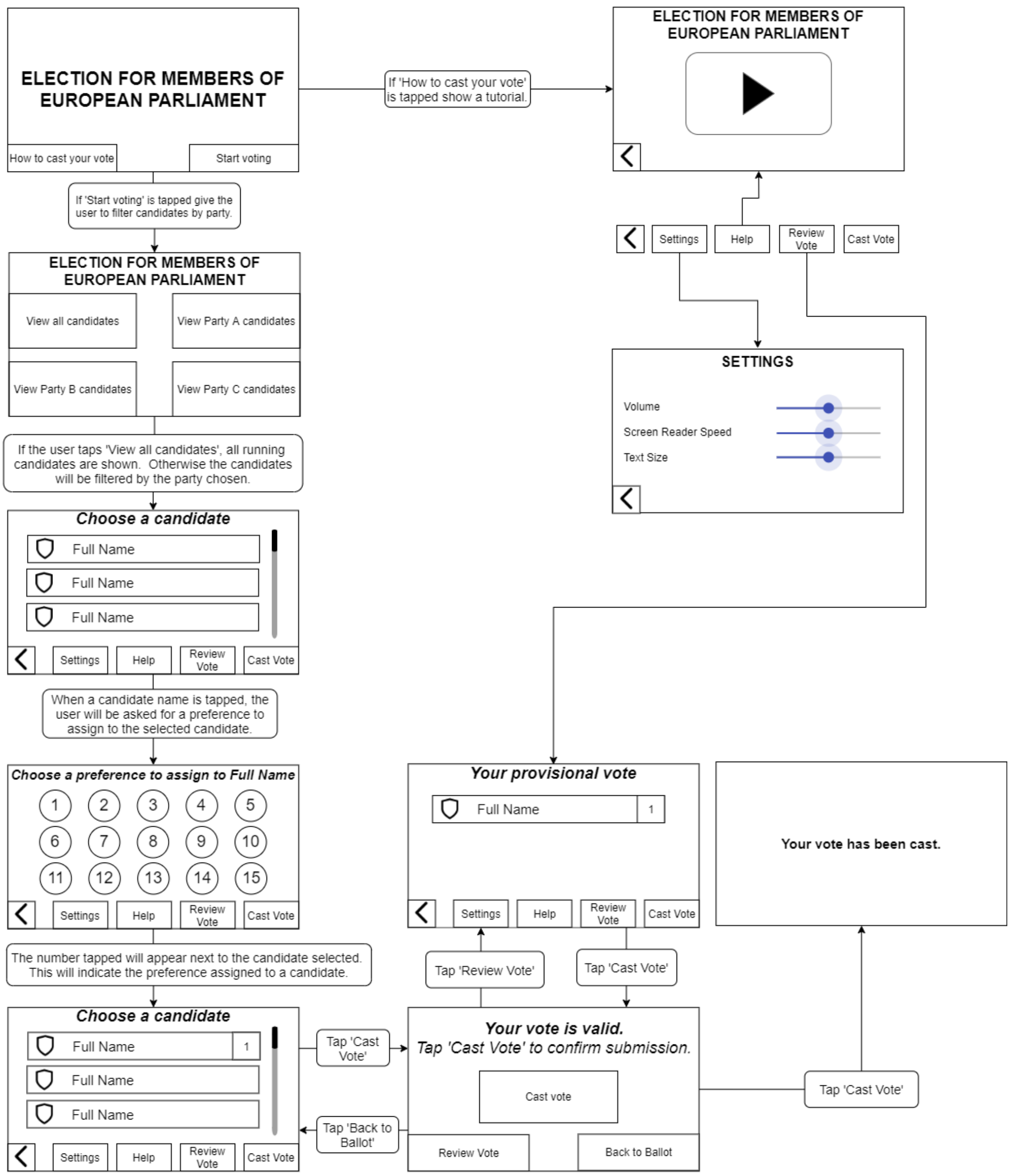

Spoil Vote
Review Vote
Cast Vote
Screen Reader
Confirmations
Increase Contrast
Large Text
Back to Ballot
Go to ballot page
Video tutorial of voting procedure
Back to Ballot
Go to ballot page
Are you sure you want to spoil your vote? Tapping yes will result in your vote being cast without preferences.
Yes
No
Go to ballot page
Are you sure you want to cast your current vote?
Yes
Review Vote
Back to Ballot
Go to review page
Go to ballot page
Your vote has been cast.

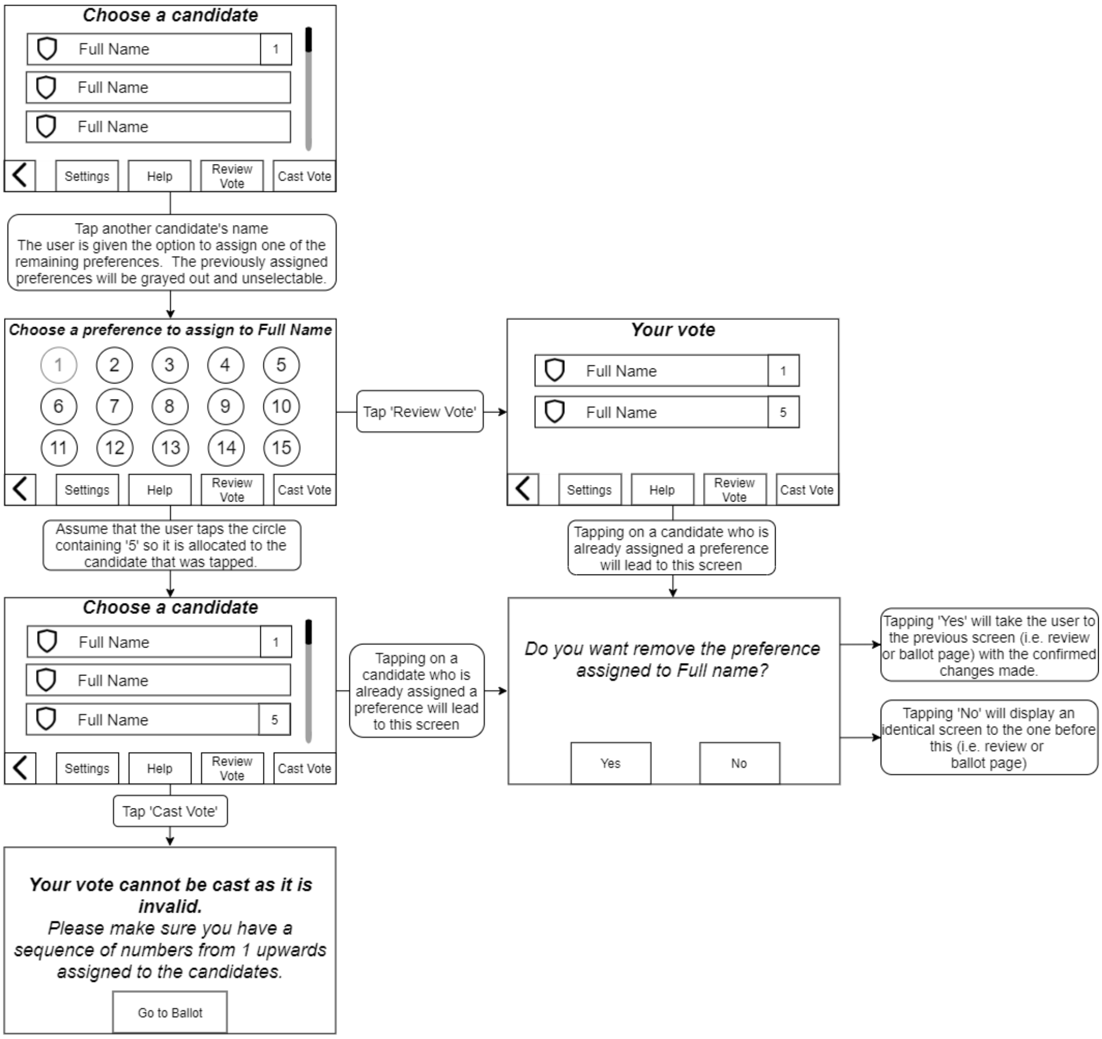
Wireframe for Design 2




Election for Members of European Parliament
Settings
Screen reader speed
slow
normal
fast
Volume
normal
loud
louder
Text size
normal
large
larger
Go to Ballot
Help
How to vote
1. Tap on the number corresponding to the preference of the candidate
2. Repeat step one until you are satisfied with your vote
3. Tap 'Cast Vote' at the bottom of the screen
4. Review your vote
5. If the vote is valid you can cast it by tapping the green button at the
Go to Ballot

Wireframe for Design 3




Choose a candidate
Full Name 1
Full Name
Full Name
Settings
Help
Review Vote
Cast Vote
Tap another candidate's name
The user is given the option to assign one of the remaining preferences. The previously assigned preferences will be grayed out and unselectable.
Choose a preference to assign to Full Name
1 2 3 4 5
6 7 8 9 10
11 12 13 14 15
Tap 'Review Vote'
Your vote
Full Name 1
Full Name 5
Assume that the user taps the circle containing '5' so it is allocated to the candidate that was tapped.
Tapping on a candidate who is already assigned a preference will lead to this screen
Choose a candidate
Full Name 1
Full Name
Full Name 5
Tapping on a candidate who is already assigned a preference will lead to this screen
Do you want remove the preference assigned to Full name?
Yes
No
Tapping 'Yes' will take the user to the previous screen (i.e. review or ballot page) with the confirmed changes made.
Tapping 'No' will display an identical screen to the one before this (i.e. review or ballot page)
Tap 'Cast Vote'
Your vote cannot be cast as it is invalid.
Please make sure you have a sequence of numbers from 1 upwards assigned to the candidates.
Go to Ballot