

Using Personal Data to Configure Navigation Support for Blind and Partially Sighted People

A thesis submitted to the University of Nottingham for the degree of Doctor of Philosophy

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DEDICATION

This thesis is dedicated to the memory of my beloved mother, whose impact on my life will never fade. You taught me the value of hard work, determination, and resilience, and you never stopped believing in me. You were my rock and my inspiration, and I will always cherish the memories of our time together. Though you are no longer with us, your legacy lives on through me.

ABSTRACT

Being able to navigate is an important part of everyday life and difficulties in being able to do so are likely to affect people's opportunities for work and social inclusion and participation in general. However, blind and partially sighted people (BPSP) face difficulties when they navigate as they are not able to observe the surrounding effectively. Traditional navigation aids such as white canes and guide dogs are commonly used by BPSP. However, they can be limiting and fail to provide adequate information to facilitate independent travel. With the advent of new navigation technologies, there is an opportunity to develop affordable and user-centric navigation systems that cater to the specific preferences and needs of BPSP by incorporating personal data into navigation systems.

Researchers have focused on developing navigation solutions for BPSP to allow them to navigate independently whether by developing special tools or apps on the smartphone and wearables. As a result, there are numerous navigation solutions for BPSP varying in efficiency and price. These navigation solutions have been developed and updated over time considering the latest technologies and user interaction with the systems. However, user preferences, needs and strategy have not been effectively considered which are among the key factors of providing user-centric systems and tailoring solutions to individual users.

The work described in this thesis represents an attempt at understating of how personal data might enhance the outdoor navigation of BPSP including user preferences and needs. In addition, drawing from BPSP and mobility trainers' inputs, describing a conceptual framework of a state-of-the-art navigation system that is user-centric, affordable and efficient. This research presents a series of studies starting from interviews with blind, partially sighted and sighted people to understand the nature of their navigation and identify navigation strategies in familiar and unfamiliar journeys. In addition, comparing the navigation

experience of BPSP with sighted people. The findings of this study revealed the route selection factors that affect the navigation of BPSP. Extensive data analysis resulted in classification and presentation of the factors whether they are useful or potential risk for the individuals. The navigation experience and route selection strategy tend towards safety and assurance issues in unfamiliar journeys. Unique definition of good and bad routes has been elicited from the participants revealing individual preferences and concerns.

Interviews with mobility trainers who provide training and navigation support to a considerable number of BPSP were carried out to elicit their navigation requirements, challenges and preferences. Useful insights have been received from the participants about their challenges, strategies and concerns of navigation. Highlighting the potential of creating navigation-related user profiles. One of the key findings was the necessity of orientation and mobility as well as technology training to BPSP to enhance their navigation support and increase their confidence level. This will encourage them to navigate independently and improve their livelihood.

Focus groups were carried out with BPSP to highlight the current navigation systems' strengths and weaknesses as well as describing a state-of-the-art low-cost navigation system which meets the needs of BPSP. The study identified the navigation systems used by BPSP and the issues with the current systems. Moreover, the findings identified the potential navigation systems that are not used by the BPSP and the associated reasons. A key finding of the study was describing an ideal navigation system that can be tailored to individual preferences and needs to help them navigate independently. The data from the interview and focus group studies were used to highlight the navigation-related personal data of BPSP. Developing a user profile structure that can be incorporated into the existing and future navigation systems. The user profile structure contains novel components that accommodate user, technology and environment-related navigation data. This allows the

navigation systems and relevant authorities to provide personalised navigation support to BPSP.

A conceptual framework of the navigation system for BPSP was developed benefiting from the findings of previous studies in this thesis. The necessary components have been presented with their associated details accounting for the planning and other navigation stages. The navigation system conceptual framework was evaluated using comparative evaluation with the main navigation system used by BPSP. In addition, user evaluation was carried out using scenario-based decision-making approach. The findings of the comparative evaluation study revealed the issues with the main navigation systems such as lack of obstacle and landmark details on the map that are of concern to the blind or partially sighted individual. This confirmed the necessity of incorporating the user profile into the navigation system's route-finding component to account for those details. The findings of the user evaluation study revealed the need for customisation in the navigation system conceptual framework for both planning and navigation stages. Another key finding confirmed the necessity for prioritising the safety over preferences of the individuals. This includes the route generation stage and during the journey.

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TABLE OF CONTENTS

Contents

Dedication i

Abstract ii

Acknowledgements v

Table of Contents vii

List of Figures xiii

List of Tables xv

PhD Nature and Sponsors xvii

1 Introduction 1

1.1 Overview 1

1.2 Background 1

1.3 Thesis Research Questions and Approach 4

1.3.1 Research Questions 4

1.3.2 Thesis Aims 5

1.3.3 Objectives 5

1.4 Thesis Structure 6

1.5 Chapter Overview 7

1.6 Original Contribution to Knowledge 9

1.7 Chapter Summary 10

2 Literature Review 12

2.1 Chapter Overview 12

2.2 The Community 12

2.3 Navigation of BPSP 14

2.3.1 Nature of Navigation 15

2.3.2 Challenges of Navigation 15

2.4 Cognitive Navigation 17
2.4.1 Wayfinding 19
2.4.2 Orientation and Mobility 28
2.4.3 Allocentric and Egocentric Spatial Representation of Objects 30
2.5 Technology-Based Navigation 30
2.5.1 Positioning 32
2.5.2 Guidance 34
2.5.3 Maps 35
2.5.4 Route-Finding 39
2.5.5 Interface Design 45
2.6 Environment-Based 46
2.6.1 Indoor Navigation 46
2.6.2 Outdoor Navigation 48
2.6.3 Landmarks 50
2.7 Current Navigation Systems for BPSP 50
2.7.1 Navigation Tools 52
2.7.2 Navigation Aids 54
2.7.3 Personalisation in Navigation Systems 55
2.8 Research Paradigms 57
2.9 Discussions 59
2.10 Chapter Summary 61
3 Understanding BPSP's Route Selection Strategy in Familiar and Unfamiliar Journeys 63
3.1 Chapter Overview 63
3.2 Methodology 63
3.2.1 Study Design 63
3.2.2 Ethics Approval 65

3.2.3 Recruiting Participants 66
3.2.4 Accessibility of Study Materials 67
3.2.5 Study Process 68
3.2.6 Thematic Analysis 69
3.2.7 Presentation of the Themes 70
3.3 Study Findings 76
3.3.1 General Themes 76
3.3.2 Familiar and Unfamiliar Journeys 76
3.3.3 Navigational Preparations and Strategies 78
3.3.4 Route Selection Factors 85
3.3.5 Uncertainties 96
3.3.6 Definition of Good and Bad Routes 98
3.3.7 Route Selection Strategy 103
3.4 Discussions 106
3.5 Chapter Summary 110
4 Navigation Requirements of BPSP 112
4.1 Chapter Overview 112
4.2 Methodology 112
4.2.1 Study Design 112
4.2.2 Recruiting Participants 115
4.2.3 Accessibility of the Study 115
4.2.4 Study Process 116
4.2.5 Data Analysis 116
4.3 Study Findings 119
4.3.1 Nature of Navigation 119
4.3.2 Navigation Requirements, Challenges, and Preferences 121
4.3.3 Navigation Support 130

4.4 Discussions 133
4.5 Chapter Summary 136
5 Describing a Personlised Navigation System for BPSP 137
5.1 Overview 137
5.2 Methodology 137
5.2.1 Study Design 137
5.2.2 Accessibility of the Study 139
5.2.3 Study Process 140
5.2.4 Data Analysis 145
5.3 Study Findings 148
5.3.1 Navigation System Support in Routine and non-Routine Journeys 148
5.3.2 Navigation Systems Used or not Used 149
5.3.3 Navigation System Support in Specific Scenarios 151
5.3.4 Describing an Ideal User-Centric Navigation System 155
5.3.5 Navigation System Architecture and Model 163
5.4 Discussions 166
5.5 Chapter Summary 168
6 Personal Data and User Profile 170
6.1 Chapter Overview 170
6.2 User Profiles for Navigation 170
6.3 User Profile Content and Structure 171
6.4 Ontology-Based User Profiles 174
6.5 Data Management 175
6.5.1 Data Sharing and Collaboration 176
6.5.2 Data Classification 176
6.5.3 Data Storage and Communication 176

6.5.4 Data Protection 177
6.6 Mobility Trainers' View of User Profiles 177
6.7 Discussions 183
6.8 Chapter Summary 186
7 Development and Evaluation of a Navigation System Framework for BPSP 187
7.1 Chapter Overview 187
7.2 Navigation System Conceptual Framework Development 187
7.2.1 Route-Finding 187
7.2.2 Route Selection's Scoring Criteria 189
7.2.3 Navigation System Physical Components 191
7.2.4 Navigation System Conceptual Framework 194
7.3 Comparative Evaluation of the Developed Navigation System Framework 198
7.4 User Evaluation of the Developed Navigation System Framework 201
7.4.1 Accessibility of Study Materials 202
7.4.2 Study Process and Data Analysis 202
7.4.3 Study Findings 209
7.5 Discussions 220
7.6 Chapter Summary 222
8 Conclusions and Recommendations for Future Work 223
8.1 Review of Aims 223
8.2 Main Contributions 226
8.3 Limitations 229
8.4 Recommendations for the Future Works 230
References 233
Appendices 256

Appendix A: Information Sheet of the First Study 256

Appendix B: Consent Form of the First Study 258

Appendix C: Table of the Rest of the Statements from the Participants of Section 3.4 259

LIST OF FIGURES

Figure 1 Thesis structure 6
Figure 2 Photographs of different visual impairments 13
Figure 3: The four types of social wayfinding: synchronous and strong (upper left); asynchronous and strong (lower left); synchronous and weak (upper right); asynchronous and weak (lower right) from (Dalton et al., 2019) 20
Figure 4 Popular terms in Assistive Technology for BPSP in the constructed publication database (Palumbo et al., 2015) 32
Figure 5 Guidance concept (Wieser et al., 2007) 34
Figure 6 Tactile map showing a plan with braille (RNIB, 2019) 36
Figure 7 Map showing a plan with large print (RNIB, 2019) 36
Figure 8 Tactile map of Nottingham Station showing the details and places in an accessible way for BPSP 38
Figure 9 Route selection between two points using GraphHopper algorithm (GraphHopper GmbH, n.d.) 41
Figure 10 Route selection between the same two points using OSRM algorithm (Luxen & Mapbox, n.d.) 42
Figure 11 Openrouteservice route selection choices (HeiGIT, n.d.) ... 43
Figure 12 Openroute service route details (HeiGIT, n.d.) 44
Figure 13 Openroute service route-finding system (HeiGIT, n.d.) 45
Figure 14 Mobility devices historical trends (Hersh et al., 2008) 52
Figure 15 Relationship between codes (yellow boxes) and specific themes (orange boxes) and its categories (blue boxes) under the general theme of location-based 73
Figure 16 Relationship between codes (yellow boxes) and specific themes (blue boxes) and the general themes (orange boxes) 75
Figure 17 The key challenges BPSP face when navigating 122
Figure 18 The key navigation requirements and needs of BPSP 125
Figure 19 Age and employment status of participants 142
Figure 20 Age distribution of the participants 143
Figure 21 Causes of blindness of the participants 143

Figure 22 Wayfinding specific themes (Green boxes) and codes (yellow boxes) 146
Figure 23 Navigation system design specific themes (green boxes) and codes (yellow boxes) 147
Figure 24 Navigation system components from (Wieser et al., 2007) 155
Figure 25 Hand-free position of GPS system with guide dog from (May & LaPierre, 2008) 162
Figure 26 Navigation system architecture. The blue boxes represent the inputs, the orange boxes represent the navigation system process and the green boxes represent the navigation stages 164
Figure 27 User Profile Components (Kikiras et al., 2006) 172
Figure 28 Components of a navigation-oriented User Profile from (Kikiras et al., 2009) 174
Figure 29 Illustration of pathfinding between two nodes in a 4x4 grid 189
Figure 30 Physical components of the navigation system 192
Figure 31 Navigation system interface choices 194
Figure 32 Navigation system conceptual framework (yellow boxes are the inputs, the pink boxes are the data processing parts and the green boxes are the outputs) 195
Figure 33 Types of the user's feedback after completing the journey 197
Figure 34 Navigation system scenarios 203

LIST OF TABLES

Table 1 Typical characteristics of the main types of social wayfinding: strong and weak type (Bae & Montello, 2019) 21
Table 2 Available wayfinding technologies for BPSP 22
Table 3 Navigation system personalisation from relevant literature 56
Table 4 Methods used by other researchers to identify the navigation requirements of BPSP 58
Table 5 Probing Questions 64
Table 6 Participant demographic details and interview method 66
Table 7 Details about the BPSP participants in numbers..... 68
Table 8 Stages of thematic analysis by Braun and Clarke (2006) 69
Table 9 Demonstration of general and specific themes 70
Table 10 Journey example selection during the interviews by BPSP . 77
Table 11 Participant (P) responses to the question: How long does the person walk before using other modes of transport? 78
Table 12 The different types of navigation aids with number of sighted participants (N) using them 79
Table 13 The different types of navigation aids with number of BPSP using them (N) 79
Table 14 Detailed route selection factors with their Themes, number of participants (N) mentioned them and whether Useful (U) or Risk (R) . 86
Table 15 The strategy of participants (P) in dealing with navigational uncertainties 97
Table 16 definition of "good" and "bad" routes by participants (P) 99
Table 17 Route selection strategy of the participants (P)..... 104
Table 18 Statements from participants (P) about their navigation experience 107
Table 19 Interview questions 114
Table 20 Navigation challenges with supporting quotes 123
Table 21 Focus group questions..... 138
Table 22 Participant details..... 141

Table 23 The mobility training that might have been received by the participants (P)..... 144
Table 24 Typical user profile content 172
Table 25 Revised and extended version of the user profile 181
Table 26 Map elements 188
Table 27 Route score calculation illustration (WS is weighted score)190
Table 28 Comparative evaluation of the conceptual framework with Google Maps 199
Table 29 Demographic details of the participants 203
Table 30 User profile for participant Pa7 (the colour coding was used to enhance the presentation of each row)..... 204

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The multidisciplinary nature of the PhD brought together the following themes: “Innovation and Society”,” Enabling Technology” and” Global Impact”. The general topics of the project prior of starting was personal data and navigation of BPSP. Furthermore, the prior requirements of each of the 3 sponsors have been considered in this PhD.

CHAPTER

ONE

1 INTRODUCTION

1.1 Overview

This chapter demonstrates the real-world need for research within the area of navigation of BPSP, highlighting the importance of considering personal data associated with navigation. Of particular importance to this thesis will be an investigation of incorporating personal data by navigation technologies and relevant authorities for the purposes of developing a series of recommendations which may assist technology developers and relevant authorities in creating effective and inclusive solutions based on human needs and state of the art affordable navigation systems. This chapter will describe the approach to addressing the problem and declare the aims and objectives of the research, which will serve as a framework for the thesis.

1.2 Background

In the United Kingdom, the number of people suffering visual impairment exceeds two million, with approximately 320,000 people classified as either blind or partially sighted. A large number of those impacted belong to the aged group (RNIB, n.d.-b). According to Douglas et al. (2006), approximately 50% of individuals with visual impairment make an attempt to take part in daily activities outdoors. Nevertheless, the decision of people to take part in future social activities can be affected by previous negative experiences and the obstacles they have experienced. Furthermore, the process of traveling freely is an important challenge for those with Borderline Personality Disorder which often results in a sense of limitation within their own homes (Slade & Edwards, 2015). Vision impairment costs the economy of the UK each year more than £8 billion (RNIB, 2013).

The BPSP have different levels of visual impairment, each of which has specific consequences for overall navigational skills. The National Health Service (NHS) offers comprehensive data related to different degrees of impairment and explains the differences between them. Researchers used different techniques to classify BPSP into various categories according to their level of vision. In a research carried out by Alwi and Ahmad (2013) and Hersh and Johnson (2010) a classification of blind users based on two key variables: the age when sight loss happened and the real cause of the sight loss. Furthermore, Alwi and Ahmad (2013) added into their analysis of the particular kind of visual issues that was experienced by the participants. Sighted people use their sight for navigation complement by other senses such as hearing. BPSP might only be able to use the sese of sight for a limited extent if they have useful remained vision (Hersh et al., 2008).

People depend on their vision to find directions, move around, perform activities and locate themselves. Blind and partially sighted people can struggle with these tasks and how to find their ways without finding obstacles. The surrounding environment might restrict their mobility, they might bump into people and hit objects if not accompanied by another person. “More broadly, the needs of blind and partially sighted people are often not taken into account by designers or planners. For example, the design of transport systems, signage, labelling, public buildings and shared space environments often fail to take into account the needs of people with sight loss” (Kaye & Marriott, 2010) cited in (RNIB, 2013).

There are numerous techniques of navigation currently available in day-to-day practice for blind and partially sighted individuals. New systems of indoor and outdoor navigation have been presented in recent years and are clear indicators of the importance of implementing more advanced technology into this field of knowledge. The use of readily available applications, sensors and software in mobile phones such as beacons can be used to allow the individual to recognise different

obstacles (Sangale et al., 2023). Outdoor supports used by visually impaired people include guide dogs that are especially trained to help them in their daily life. Dogs can take an important role in guiding Blind and partially sighted people to find places and protect them from potential risks. They also help with their social life and mental health but their services only last for a few years (Glenk et al., 2019).

White cane is another solution used to guide and protect blind and partially sighted people to find their paths. They have to move it from side to side to inform them of any obstacles that might restrict their movement such as crosswalks or steps. Tanabe et al. (2022) find the white cane an important technique to bring the visually impaired people back to society, but requires training them to learn how to use it. Global Positioning System (GPS) is commonly used in outdoor assistive navigation systems such as BlindSquare and Blindhelper (Velázquez et al., 2018). Meliones and Filios (2016) state that Blindhelper efficiently simplifies localisation so blind pedestrians can reach desired destinations in their surrounding area. Users of Blindhelper are able to move without the aid of guides. They can also make calls and contact local services to identify their current locations in the case of an emergency.

A reference can be made to a study, by Manduchi and Kurniawan (2011) on the range of accidents undergone within a group of 300 blind individuals who use the white cane. 40% of these individuals experienced head-based incidents at least once a year and 23% of these resulted in medical consequences. However, it is difficult to improve the white cane in order to give it more functions in day-to-day practice. The use of technology has been proposed in order to improve these canes. Digital enhancements, however, have been proven to be limited as seen in a comparison undertaken by (dos Santos et al., 2021).

In a survey conducted by the RNIB in 2015 called My Voice, they used telephone interviews with more than 1200 blind or partially sighted

people across the UK (Slade & Edwards, 2015). In this project, the RNIB collected information about the experiences and circumstances of registered blind and partially sighted people. They found huge differences in their views because of different factors such as age and other disabilities. Additionally, most people lost their sight gradually and needed to adapt to it. However, they did not receive the required practical support, especially the older ones, nor received financial support. Most of them were left to suffer emotionally and only 17% of them were offered emotional help. The RNIB found that the blind and partially sighted individuals have barriers to travel and use public transport. One of the major problems they were facing outdoors is the obstacles left on the pavement. 40% of them claimed that they were unable to continue their journeys, and half of them needed support to leave their homes.

Example of researches that suggest the need to fill gaps in the limitations of the available navigation products for BPSP as all their needs are not addressed include (Padmanaban & Krukar, 2017) who considered the needs of navigation in the BPSP community as they referred to the area of research as ‘neglected’ and realised that the creators of these aids were restricted to their knowledge and did not fully understand the wishes and needs of those who use them. In addition, Gori et al. (2016) also addressed the failure of the navigation systems in meeting the daily requirements of the BPSP people.

1.3 Thesis Research Questions and Approach

1.3.1 Research Questions

* To what extent can personal data enhance the navigation of BPSP?

* What are the user requirements and preferences of BPSP for navigation system design?

* What are the specifications of a user-centric navigation system for BPSP?

* How can personal data be structured in ontology-based user profiles?

To answer the above questions in this thesis, the following aims and objectives have been developed. the structure of the thesis and the details of the chapters are described in the subsequent sub-chapters below. The first aim corresponds to the first two research questions. The second and third aims correspond to the third and fourth research questions.

1.3.2 Thesis Aims

- To investigate the factors that influence the route selection strategy of blind and partially sighted people (BPSP) and their natures.

- To establish whether the combination of existing mapping and positioning technology, can be used to build a navigation system which meets the needs of BPSP.

- To develop and evaluate a navigation system conceptual framework for BPSP which incorporates crowdsourced route choices, identified route selection factors and relevant individual user preferences.

1.3.3 Objectives

- Investigate the factors that influence the route selection of blind, partially sighted and sighted people based on the literature and interviews.

- Describe those factors and how their measurability and communicability might allow them to be incorporated into a navigation system.

- Based upon the literature and interviews describe the navigation requirements of BPSP.
- Survey current navigation systems and techniques to describe the state of the art for practical, low-cost navigation system.
- Assess the strengths and weaknesses of current navigation systems against the identified requirements.
- Develop a navigation system framework which incorporates location history, user preferences and previously identified route selection factors to address weaknesses in the state of the art.
- Evaluate the developed framework against the current state of the art navigation system.

1.4 Thesis Structure

Figure 1 illustrates the objectives which are required to be accomplished in order to achieve the overall aims of the thesis, and in turn which chapters accomplish the specified objectives. It should be noted that whilst the chapters and studies described in this thesis broadly align with

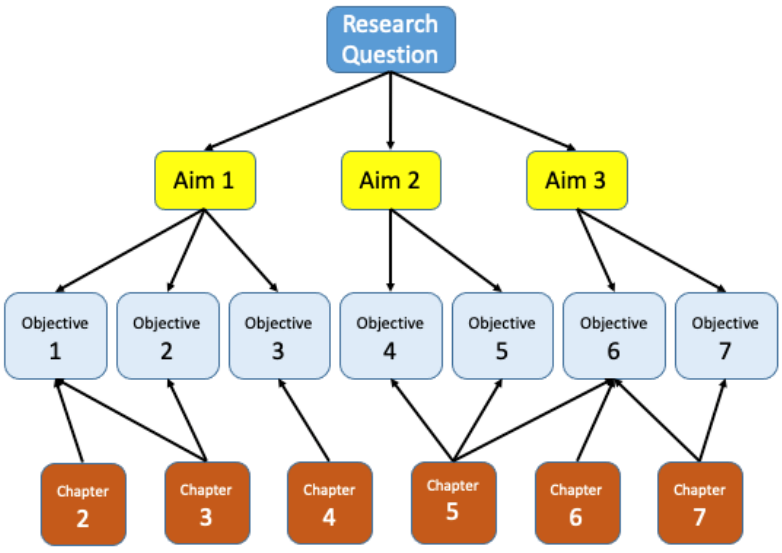


Figure 1 Thesis structure

the objectives specified in the diagram above, in practice, there is far more overlap between the chapters and objectives than is represented.

1.5 Chapter Overview

*Chapter **2** Literature Review*

The literature review chapter of this thesis provides an overview of previous research related to the navigation of BPSP. It begins by examining the nature of navigation and challenges that BPSP face when navigating unfamiliar environments, including the physical, social, and emotional barriers that affects their mobility. The chapter then explores the various technologies and tools that have been developed to support BPSP in navigation as well as research methods used in the past for similar research. The literature review concludes with a discussion of the gaps and limitations in previous research, including the need for more user-cantered approaches to navigation system design. The chapter sets the stage for the researches that follow, providing a foundation of knowledge and insights that inform the development and evaluation of a new navigation system for BPSP.

*Chapter **3** Understanding BPSP's Route Selection Strategy in Familiar and Unfamiliar Journeys*

This chapter presents the findings of the first study with BPSP as well as sighted people. Providing a detailed investigation into the factors that influence route selection and decision-making among BPSP. It will explore how they navigate both familiar and unfamiliar environments, and the strategies they use to make navigational decisions. The study identifies several factors that influence route selection, including the perceived safety and familiarity of a route, the presence of environmental cues and landmarks, and the availability of social support and assistance.

*Chapter **4** Navigation Requirements of BPSP*

This chapter Provides detailed information about the navigation requirements of BPSP including needs, preferences and requirements based on the literature and interview data. It highlights detailed classification and presentation of the requirements and which part/stage of navigation they can be used for. Requirement's elicitations will be utilised in the form of expert interviews with mobility trainers who work closely with this population.

*Chapter **5** Describing a Personalised Navigation System for BPSP*

This chapter presents details of describing a user-centric navigation system design considering the existing navigation resources that can accommodate the user requirements from the previous chapter and help BPSP navigate independently. The study involves conducting focus groups with BPSP to understand their experience with navigation systems and describe a user-centric navigation system. Similarly, the chapter discusses the structure and components of such the potential navigation system.

*Chapter **6** Personal Data and User Profiles*

This chapter provides an overview of personal data relevant to navigation of BPSP and its importance and how the data can be incorporated in user profiles. Accordingly, how the user profiles can be structured in a computer-recognised format and the extent to which personal data as well as other relevant data can be used in the existing navigation solutions to personalise the navigation experience. This chapter benefits from the data gathered from previous chapters of the thesis. Finally, the study involves conducting interviews with BPSP to identify their navigational preferences, requirements, and challenges, and analysing data from previous chapters related to factors that influence route selection and the design of low-cost and personalised navigation systems.

*Chapter **7** Development and Evaluation of a Navigation System Framework for BPSP*

This chapter presents the details of developing a navigation system conceptual framework for BPSP based on the study findings. The developed system will be evaluated by comparative evaluation with the existing navigation systems and user evaluation to identify gaps in the state-of-the-art.

*Chapter **8** Conclusions and Recommendations for Future Work*

The conclusion chapter will summarise the key findings of the PhD and address how the findings achieved the aims of the PhD. Finally, it will present the recommendations for future work.

1.6 Original Contribution to Knowledge

This interdisciplinary PhD contributed to enhancing navigation of BPSP in a new way by extensive investigation of personal data and describing a user-centric and practical navigation system to provide a safe and pleasant navigation for BPSP with direct inputs from BPSP and mobility trainers. It contributed to knowledge concerning the user requirements, navigational preferences, and factors in navigational safety of the BPSP who represent a relatively understudied group in society. It also contributed to knowledge in the area of navigational systems by exploring how crowdsourced route information could be used to design/feed algorithms that emphasise factors other than speed and efficiency (i.e., those that match the profiled needs of blind users and which emphasise ease and safety). Finally, it explored methods for evaluating navigational experiences themselves (both aided and unaided) using criteria relating to safety and ease.

The study with the mobility trainer experts revealed unique preferences and requirements of BPSP. Majority of mobility trainers interviewed in

this research were experienced people who provided navigation support to hundreds of BPSP. The nature of the results made the study findings a useful database of user requirements for user profile creation and future studies. The focus groups with BPSP presented valuable navigation system design experiences and requirements which showed specific details of each navigation system component. The findings of the study contributed to highlighting the functionality and interface requirements of an ideal navigation system design.

The user profile structure and content were developed using an original approach accommodating all the necessary information about the navigation of the user. The user profiles also contain non-user navigation data such as relevant information from third party providers. The user profiles are not only limited to navigation systems. The way they are structured, and the nature of the content makes them a great resource for relevance third-party such as government to understand the navigation experience of the users and offer tailored services whilst maintaining privacy and security of the data.

The final chapter contains the developed navigation system conceptual framework that shows the key components required to enhance the navigation of BPSP. The unique structure of the framework contains the necessary components and sensors required to provide a personalised navigation experience enhancing the safety and confidence of the individual. Evaluation of the existing navigation systems and user evaluation provided original contribution to the design of user-centric navigation system conceptual framework. This included identifying the gaps in the current systems and confirmation of the developed structure components that accommodates human and technical needs.

1.7 Chapter Summary

In this chapter, a broad overview of personal data and navigation of BPSP was covered along with the study methodology. The PhD's aims and objectives have been discussed, and it has been explained how

each of the suggested research would achieve the aims. The chapters' contents have been briefly explained, and the research's original contributions have been underlined. The literature review on personal data, navigation technologies and navigation of BPSP in general will be covered in the next chapter.

CHAPTER

TWO

2 LITERATURE REVIEW

2.1 Chapter Overview

This chapter describes and critically assesses relevant research which may shed light on navigation of BPSP. It will provide an overview of the nature and challenges of navigation of BPSP. In addition, the cognitive navigation and technology-based navigation will be highlighted. The chapter will also describe the existing navigation aids and systems for BPSP and highlight their capabilities and limitations. Furthermore, the role of personal data and its impact on navigation of BPSP will be presented looking at the most relevant literature. The chapter will conclude with a summary of research paradigms; providing a deeper insight into navigation and providing a theoretical underpinning for the work described in this thesis.

2.2 The Community

There are two groups of BPSP. The first group are the officially registered BPSP and the second group includes the BPSP who are not officially registered. Although people with sight loss are encouraged to register to get help and access certain benefits, the official certification and registration do not indicate the total number of BPSP (RNIB, 2018).

The terms “blind” and “partially sighted” are commonly used to identify a person with visual impairment or no vision at all. If we look at literature, it can be seen that various other terms have been used such as “visually impaired”, “vision impairment” and “sight loss”. In fact, there is an ongoing debate on which terms are most appropriate/more precise to describe people with different sight conditions. RNIB uses the term “sight loss” as a single term for BPSP (RNIB, n.d.-c). It is important to consider

the fact that sight loss could be congenital or acquired later in life and this fact have been taken into account by a number of researchers such as Secchi et al. (2017), Lahav and Mioduser (2005) and X.M.Almeida et al. (2015). Generally, the congenital BPSP have better adapted their life compared to BPSP who acquired sight loss at a later stage in their life.

The criteria for certification in the UK is either certified as severely sight impaired (blind) or sight impaired (partially sighted) (RNIB, n.d.-a). However, as stated above, the terms “blind” and “partially sighted” are the most common used terms. Certification is given through NHS by referral from eye specialist looking at both visual acuity and visual field. The RNIB resource “the criteria of certification” (RNIB, n.d.-a) provides the details and criteria of certification. In addition, “eye health and sight loss stats and facts” report by RNIB (2018) highlights the leading causes of sight loss among BPSP. The leading cause is age-related macular degeneration which is about half of the cases. The other main causes are glaucoma, cataract, retinitis pigmentosa and diabetic eye disease. Figure 2 shows the representations of different sight conditions compared to normal vision.

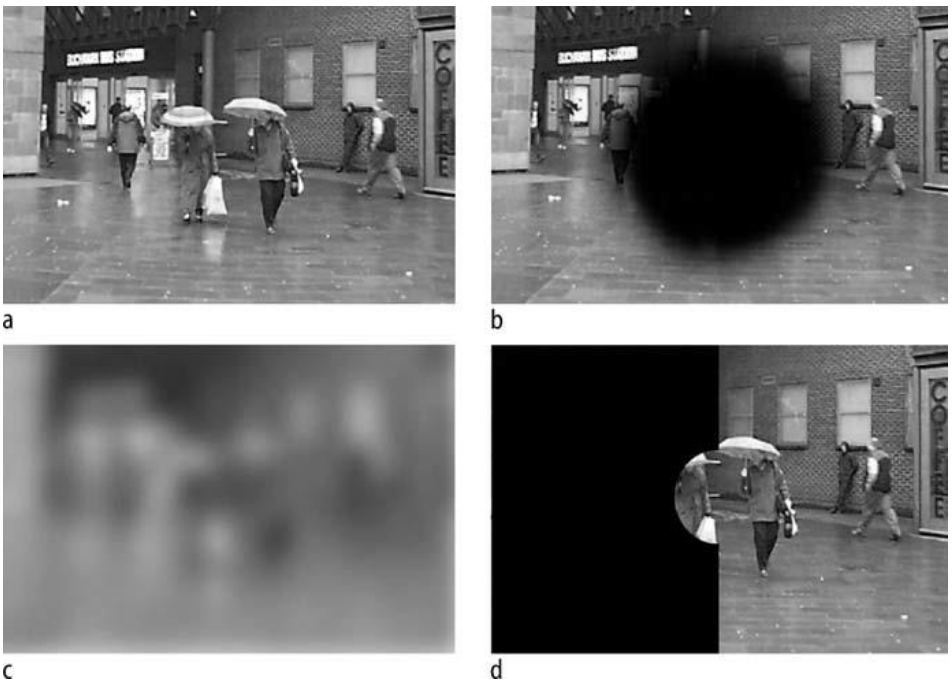


Figure 2 Photographs of different visual impairments

a good vision; **b** central vision loss **c** advanced cataract side effects; **d** half-field of vision lost (could be from stroke) (Bradley & Dunlop, 2008)

It is important to note that having only two categories of certification and registration is not enough to accommodate the various sight conditions and different combinations of vision elements. Different level of support needed for each sight condition. Subsequently, a more detailed classification is necessary with sub-categories to accommodate the needs of BPSP.

Researchers have used various descriptions for BPSP in their research. Vincenzi et al. (2021) used the terms “no vision”, “blurry vision” and “light and dark” and Hicks et al. (2013) used “blind with useful residual vision” and “blind without useful residual vision”. Similarly, level of experience of BPSP have been considered to classify BPSP. For instance, Kim et al. (2016) and Low et al. (2020).

2.3 Navigation of BPSP

Navigation is a term used to cover multiple features of discovering the surrounding space. Aspects of navigation have different requirements and challenges. Researchers developed various navigation approaches to assist BPSP move freely. Despite the development in modern technology to help with independent navigation and mobility (Rodriguez-Sanchez et al., 2014), there is no navigation system which can be personal and meets all needs of BPSP and all environments (Renaudin et al., 2017). Current navigation systems could not be customised for all personalised purposes. In recent years, many devices have been designed to help BPSP travel to their desired destinations independently. These devices are either handheld, connected to a cane or worn (Smith & Penrod, 2010).

Navigation is a complex task that could involves different modes of transport. In this research, the focus will be on the navigation of pedestrian walking standalone or using an assistance. The assistance

could either be from another person or navigation aids directly or indirectly, and separately or together. This study focuses on the importance of outdoor navigation in all environments. Navigation of BPSP includes positioning and guidance (from the system perspective) and orientation and mobility from the user perspective. These will be discussed in detail in sections 2.4 and 2.5. These will be addressed separately as:

- Orientation and mobility navigation (user perspective) in 2.4
- Positioning and guidance navigation (system perspective) in 2.5

2.3.1 Nature of Navigation

Navigation is the movement that is purposeful and coordinated within the environment. It includes preparation and implementation of movements. It includes both mobility and wayfinding. Mobility is body movement in coordination with the surrounding and wayfinding is planning and decision making integrated to the far and near surrounding (Montello, 2005). BPSP navigate in outdoor environments for similar purposes as sighted people including going to the local shop, exercise, attending an interview, etc. However, the whole process of navigation can be completely different to sighted people depending on the sight condition factors like functional vision, nature of sight loss, level of confidence, navigation skills and when did severe sight loss started. Navigation strategy helps BPSP to travel in unfamiliar environments freely and safely. However, in order for this navigation to be effective and safe, BPSP have to obtain the necessary travel skills. They should be able to use the non-visual information about the environment to avoid obstacles such as tree branches (Guiudice & Legge, 2008).

2.3.2 Challenges of Navigation

The challenges and limitations of navigation of BPSP need to be carefully considered. The challenges are arising from the technology, environment and users. Basiri et al. (2016) addressed the challenges

and issues related to reliability and privacy protection issues in the field of Location based Services (LBS). In addition, Renaudin et al. (2017) showed that there are different challenges of pedestrian navigation systems involving engineering, human and legal challenges. This is important for BPSP to protect them, their data, privacy and security. According to RNIB, more than 40% of BPSP feel “moderately” or “completely” disconnected from the society and 55% feel that their roads are “unsafe” (Slade & Edwards, 2015). Additionally, a statement was given by a BPSP in ‘Travellers Tales’ in response to the safety aspect of travelling with guide dogs.

Douglas et al. (2006) stated that 45% of BPSP get out of the house daily, 20% one day in a week. McManus and Lord (2012) conducted two national surveys on circumstances of BPSP and performed a secondary analysis into their part in the society considering different aspects of life. In their study they found that half of BPSP are experiencing difficulties when getting into and moving around buildings. Their results show that sight loss among older people is higher than the rest and they are less able to afford simple daily requirements such as maintaining the heating of their house. As memory, mobility and visual functionality of elderly people decreases every year, BPSP will face more challenges in navigation (Bourne et al., 2017; Olshansky & Carnes, 2010).

A study by Gori et al. (2022) has shown that Covid-19 affected the life of BPSP mentally and physically. Consequently, they are staying indoors more often than before. They emphasised that new interventions needed to support individuals. In fact, the government regulations to follow social distancing and changes made to the walkway surrounding made the navigation experience of BPSP worse. On the other hand, social media has been used as a network to connect BPSP with other people by sharing their stories. Hashtags are used to highlight challenges; however, they need to be starting with a capital letter to make it easier for screen readers (Perkins Access, n.d.).

2.4 Cognitive Navigation

There are two distinct ways to approach the acquisition of spatial information. The first one is navigation-based learning, which involves directly interacting with the environment to gather and process spatial information. While the second approach is resource-based learning. In this approach the spatial information is extracted and processed using environmental experience. Examples of resource-based learning include using TV, newspapers, education, seeking guidance from others, and following written or verbal directions (Bradley & Dunlop, 2008).

The main aim of navigation for BPSP is to support their guidance during the journeys they take to their desired destinations. Blind and partially sighted individuals rely heavily on cognitive skills in navigation unlike sighted people who mainly rely on visual skills to observe the environment (Giudice, 2018). According to Montello (2001), the term cognition regards to knowledge which is about manipulating, storing, acquiring, retrieving and using knowledge by humans. Vision helps detect distant obstacles and see the path in a good time. However, this is not the case for BPSP as they can only detect obstacles when they are close enough. Montello (2001) argued that losing vision is not the main challenge for spatial cognition of blind people, it is the lack of information available for them to access.

The majority of theories on human spatial cognition treat vision as the only or the main input and describe memory representations by means of their visual-spatial arrangements. Contrary to this view, an increasing number of research has shown that learning from combinations of various spatial inputs results in behavioural performance that is strikingly comparable across a variety of spatial tasks, a phenomenon known as functional equivalence (Giudice, 2018). The ability of a blind person to see, hear or to be aware of an obstruction in the way requires a more cautious and harder cognitive process (Bigelow, 1991). In addition,

BPSP uses adaptive skills for practising independence in all aspects of life (DSB, n.d.).

An important aspect of navigation is the sense of direction. It refers to individuals' ability to orient and navigate through the environment, relying on spatial cues and cognitive maps to reach a destination. For sighted individuals, this often involves visual landmarks, memory of spatial layouts, and an understanding of cardinal directions. For blind and visually impaired individuals, however, the sense of direction is primarily developed through auditory, tactile, and proprioceptive inputs, which can vary greatly depending on the individual's experience, training, and familiarity with their surroundings. The Santa Barbara Sense of Direction Scale (SBSOD) which was developed by (Hegarty et al., 2002), assesses the self-reported navigational abilities. This scale can be a valuable tool for understanding the diverse navigational strategies and capabilities among BPSP. By measuring an individual's sense of direction in specific questions, the SBSOD can help with personalising navigation systems to better suit BPSP's specific needs, ensuring that the systems cater to their strengths and compensate for any weaknesses in their spatial orientation. This personalised approach can enhance the usability and effectiveness of navigation aids for BPSP, making them more reliable and intuitive.

The SBSOD scale consists of 15 questions about spatial and navigational characteristics where each question can be scored by a number between 1 and 7 based on the user's opinion. However, there are certain questions that will be very likely for BPSP to have common scores. For instance, question 5 asks about thinking of the environment in terms of cardinal directions which is not a suitable directional format for BPSP. Other examples include the questions 7 and 9 asking about the map reading skills and experience. The majority of BPSP are not able to read the maps and need to use alternative ways of accessing map details. Evidently, the SBSOD scale is a useful tool for

understanding the sense of direction of BPSP, but consideration should be given to the above questions.

2.4.1 Wayfinding

The concept of navigation includes a cognitive element called wayfinding. This element depends on spatial cognition in tasks such as travel planning and route selection (Montello, 2001). More information on the wayfinding will be provided in subsection 2.4.1. Locomotion is another component of navigation that is conceptually different from wayfinding (Montello, 2005). It refers to directional movement of humans and objects through space within the environment that surrounds the navigator (Wiener et al., 2009). Golledge (1999) argued that the cognitive map is built in the navigator's mind only if they engage their thoughts and senses effectively to understand the acquired spatial knowledge. He also stated that spatial knowledge is gained through activities involving sensory and motor functions within the surrounding environment. On the other hand, “Space Perception” refers to the process of gaining awareness of bodily positions in accordance with surrounding objects and involves the recognition of cues that aid motion and orientation (Korkala et al., 2017).

A study supported by the National Institute on Aging (NIA) outlined that visual impairment in the older generation is related to the gradual deterioration of cognitive function (Zheng et al., 2018). This study also relayed the idea that visual impairment has a substantial effect on the physical and psychological health. Wayfinding as an everyday life task involves planning journeys and making decisions using cognitive functions including sensing, feeling and thinking (Dalton et al., 2019). It requires recognising landmarks placed on the way to the desired destination as well as remembering the route which depends on spatial representations (Bae, 2020). Different people hold different spatial knowledge, therefore they can contribute differently to the navigation.

Kikiras et al. (2006) states that there are four key steps of wayfinding which are:

1. Orientation
2. Route Selection
3. Routing Control
4. Recognition of Destination

When talking about wayfinding, the interaction of the user within the environment with the surrounding should be considered. This includes the interaction with other people.

Social wayfinding refers to the process when other individuals are involved in the process of decision making. This can be either directly or indirectly which will have an influence on the social context of navigation (Bae, 2020). In the broadest sense, any situation where the presence and/or activities of others, now or in the past, has an observable impact on wayfinding behaviour and cognition can be called “social wayfinding” (Dalton et al., 2019). In addition, there are four types of social wayfinding: Synchronous Strong Type, Synchronous Weak Type, Asynchronous Strong Type, and Asynchronous Weak Type, as shown Figure 3.

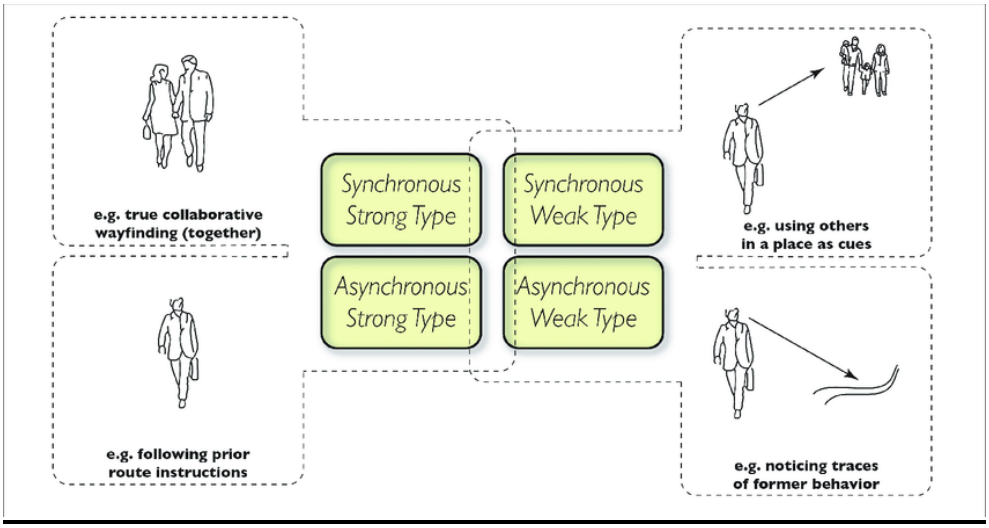


Figure 3: The four types of social wayfinding: synchronous and strong (upper left); asynchronous and strong (lower left); synchronous and weak (upper right); asynchronous and weak (lower right) from (Dalton et al., 2019)

Dalton et al. (2019) divided social wayfinding into two types using the terms “weak” and “strong”. The main difference between these two types is the ability of exchanging information. Dalton also used “people-as-cues” to refer to the weak social wayfinding and “collaborative wayfinding” to represent the strong type. The main characteristics and differences between these two types are listed in Table 1. This table shows that the Strong social wayfinding is characterised as “Direct”, “Proximal” and “Verbal”, whereas the corresponding characteristics of the Weak social wayfinding are “Indirect”, “Distal” and “Non-verbal”. The communication about wayfinding in Strong social wayfinding is between two or more individuals close to each other, which is intentional and involves communicators awareness. In contrast, the Weak type involves unplanned communication, senders and receivers of wayfinding cues have no previous awareness of this information and are strangers.

Table 1 Typical characteristics of the main types of social wayfinding: strong and weak type (Bae & Montello, 2019)

Strong Type (Collaborative)	**Weak Type (People-as-Cues)**
Direct	Indirect
Reciprocal	Unidirectional
Proximal	Distal
Verbal/gestural	Non-verbal
Acquaintance/s	Stranger/s
Rarely many	Often many

The two types of social wayfinding are also classified by Dalton et al. (2019) as “asynchronous” and “synchronous” using time modes. Asynchronous communication happens between the contributors in different places and times, whereas synchronous happens in real-time and the same time and place (Bae, 2020). Dalton et al. (2019) argued that in the Synchronous Strong type, the communication is interactional, and participation occurs at different times, which is contrasting the weak type in that it does not involve interactions.

Wayfinding technologies for BPSP have evolved significantly. This includes advancements in radar, AI, and mobile applications to enhance spatial awareness and independent navigation. Smart canes can integrate GPS and ultrasonic sensors to identify obstacles and provide navigation support. They act as an extension of the traditional white canes but with enhanced capabilities. Radar-based approaches, employ echolocation principles to help users perceive their environment through haptic feedback. Recent AI-based tools, such as image-recognition applications, have further expanded the possibilities for BPSP. A comprehensive review of these technologies, including their capabilities and limitations is shown in Table 2 below.

Table 2 Available wayfinding technologies for BPSP

Radar-based technologies
Innomake Smart Shoes  InnoMake is a water-resistant smart shoe that helps BPSP with wayfinding. It was developed by Tech Innovation company in Austria. It lets the user to identify the position and navigate around obstacles. It can tell the distance to obstacles ahead of the user and has vibration and audio sensors onboard. The distance measurement is performed using ultrasound sensors in the front of the shoes. The limitation of the product is the cost and the fact that it cannot detect the higher obstacles (Sakharkar, 2021)
Sunu Mobility Smart Band  A smart band designed to help BPSP to find their way around obstacles and travel confidently. It emits a sound wave when detecting objects up to 5.5 meters using advanced haptic feedback, sonar, radar, smartphone applications, sensors and augmented reality. Its navigation and directional features help with reducing accidents among BPSP.

This band can be used in addition to the white cane and guide dog to navigate unfamiliar places. The limitation of this band is that it cannot be used to detect stairways, whether the surfaces are slippery and while crossing in intersections with heavy traffic (Sight Research UK, n.d.)

AI-based tools (image recognition)

StellarTrek



This GPS-enabled device helps BPSP navigate places according to their needs using a tactile interface and GPS. It is AI powered with a camera to find landmarks and pedestrian crossings and it can read specific information. It also has an audio guidance for any destination requested by the user. The limitations of this product include the cost and the way of carrying the device with other navigation aids (Humanware, n.d.)

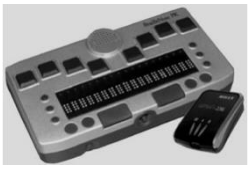
Navigation. Obstacles. AI. (NOA)



NOA is a device used to help BPSP with navigation. It has to be worn over the shoulders and it is hands-free. This device has an integrated GPS system and uses an AI enabled camera that analyses images in real time using an AI button. It also has 3D sound capability. These features help with identifying obstacles including low obstacles. However, there are limitations such as the cost and the weight of the product. Additionally, it is an easy target for the thieves because it is worn on the shoulders (biped, n.d.)

Braille technology

BrailleNote



This is a portable device that helps BPSP to use touch for reading and writing. This navigation system has an integrating keyboard and has the route calculation capability. It uses GPS and street maps and has

improved software features. It requires internet access and is compatible with specific devices. Another limitation of this device is that it has to be carried with other tools and devices (May & LaPierre, 2008)

Trekker



This is a stand-alone GPS navigation device that helps BPSP identify locations. It assists in finding the path, intersections, destination and POI in real-time using digital maps. This device is portable and light weight that allows users record locations verbally. It informs users by voice if there are any landmarks and allows the users to enter their route details. Its functionality is approximately half the BrailleNote. In addition, routes are only calculated for one map section. Trekker depends on user's input about the path (May & LaPierre, 2008).

Braille Sense U2 Model H432B



This is a braille notetaker used by BPSP. It is a portable word processor that has a 9 keys keyboard and an LCD display. It works as a laptop including features such as Wi-Fi chat, GPS, Excel, YouTube, and DropBox. This device can do seven tasks in any chosen language out of the five available languages using the bilingual dictionaries. Connectivity of this device could be through Wi-Fi, 3G or USB (ABLEDATA, n.d.-b)

Other navigation technologies

Assisted Vision Smart Glasses



A pair of prototype glasses that can help BPSP to find their way independently in unfamiliar places. The glasses use transparent OLED displays and equipped with two cameras. They also have a GPS unit, a compass and a headphone as well as 3D printed frames. Different data are processed then communicated through the piece that is built in the ear's part to help with navigation, such as using brightness for

depth. This device uses gyroscope to measure changes and the GPS helps with the direction. The camera could help reading signs and buses approaching if used with the correct software (ABLEDATA, n.d.-a)

G-Navi



G-Navi is a device that helps BPSP navigate by steering a guide dog to the chosen destination. It uses a voice system, GPS and a vibrating harness that helps steer the guide dog. There is also a headset that when the user speaks, the voice control starts vibrating and sending information to the sensor. This allows the user to check whether the guide dog is following the correct path. G-Navi is Bluetooth-enabled to connect to smartphones and other devices (ABLEDATA, n.d.-c)

Envision glasses



This is an AI-powered smart glasses with a speaker and camera to aid BPSP in their journeys.

It can read information and understand the surroundings. The product is also capable of connecting with relevant apps for BPSP to improve the navigation experience. However, the product is expensive which makes it difficult for BPSP to buy **(Sight and Sound Technology, n.d.)**

Smartphone apps

Lazarillo GPS for Blind

This is a smartphone app designed for the navigation of BPSP. It allows navigating routes that are introduced in advance and helps identify surrounding POI and routes. This app could be used indoors as well. Lazarillo helps with reaching the destinations easily if there is a special infrastructure that can be recognised by this app. The limitation of Lazarillo is that it does not provide 3D sound experience (Lazarillo, 2016)

Eye-D Pro

This app is designed for navigation of BPSP. It provides information about the user location and POI around you. This app uses the cameras to understand the surroundings. With image capturing, the user can get audio information about the printed texts and the landmarks around the user. In addition, the app provides live chat support for any concern. The issue with this navigation solution is the necessary experience required for using the camera to observe the surrounding (GingerMind Technologies, 2017)

Be My Eyes

The Be My Eyes app connects BPSP with volunteers around the world to help with everyday needs. Whenever a blind or partially sighted person needs help, he/she can request assistance through the app and the first person to respond to the request will be connected to the blind or partially sighted individual. The camera allows the user to show the surrounding to let the volunteer fulfil the request. The limitation of this app is the occasions of being connected with unexperienced volunteers (Be My Eyes, n.d.)

Aira Explorer

Aira is a similar navigation app to Be My Eyes in the way that it connects the blind or partially sighted individual with a person to help them with the navigation or another task. However, Aira is better, because it connects BPSP with trained professionals rather than random people. The limitation of this app is the cost of subscription to use the service (Aira Tech Corp, 2023)

BlindSquare

BlindSquare is an app designed to help BPSP with mobility and orientation. Using the GPS and OSM, BlindSquare searches for environmental information on Foursquare which is a database of information about nearby locations. It then communicates the command in the voice format in different languages. BlindSquare

requires internet connection and voiceover as well as connection with third party applications. It also supports Braille displays, so individuals who are deaf blind can use it as well (BlindSquare, n.d.)
Microsoft Soundscape This is an app designed for navigation of BPSP where it creates 3D audio map to help the user understand the surrounding environment. It has the capability of reading out the POI and the location of the user. The app can be used in conjunction with other apps on the phone. The navigation solution requires a stereo headphone to be operated which might limit the audio cues perception for the user. Another issue is that it is only available on iPhone. The app design is available as open-source code for people to use or develop. However, Microsoft is no longer supporting the app (Microsoft Corporation, 2018)
Intersection Explorer Intersection explorer is an audible program used by BPSP to find locations. It uses the mobile or computer as a guiding tool for BPSP to learn about their environment and the surrounding. This app is working with Google Maps' apps allowing users to drag their fingers along the map to obtain information about streets and locations (Yatani et al., 2012)
Smart canes
WeWALK WeWALK is a smart cane that has been designed to help BPSP with their navigation. It has a number of sensors on board to allow the user to determine the location and identify obstacles. The AI-enabled functionality helps with understanding voice commands from the user and provide navigation commands. The advantage of the WeWALK smart cane is that it can be used to communicate with the navigation system. Moreover, it can detect overhang items. However, the cost of the device is the limitation and the skills required to operate it (WeWalk, 2020)

The table above highlighted the current landscape of the navigation systems available for BPSP. The advantages and limitations of the systems have been presented. One of the main issues with the existing systems is the cost. BPSP find it difficult to buy expensive devices as their income is limited. Another issue is the location of the navigation system components. Having a phone in hand, a device on shoulder or heavy eye glasses will make the navigation experience unpleasant. Demand for the required skill to operate the navigation devices is another limitation. Operating the devices, interacting with the interface and understanding the navigation commands requires training and practice. There is need for further innovations and accountancy for user requirements in navigation system design to step towards inclusiveness and independency.

2.4.2 Orientation and Mobility

2.4.2.1 Orientation

"'Orientation' refers to a person's awareness of his/her position in space" (Bradley & Dunlop, 2008). Orientation is an important skill for BPSP that depends on senses to determine their position. It depends on the navigator's cognitive skills in mapping the space (Montello, 2005). Ran et al. (2004) argues that one of the challenges for BPSP is knowing their position and where they are going to, which makes it almost impossible for them to leave their homes. Lewis et al. (2015) reviewed several studies to investigate the technology requirements for navigation support for BPSP. One of them showed the effect of different level of guidance on supporting BPSP to find their way. Petrie et al. (1996) argues that some information is fundamental, such as personal location, while secondary information include orientation-related cues and travel time. They interviewed both BPSP and mobility trainers.

Ohn-Bar et al. (2018) investigated the BPSP walking patterns in terms of personal memory and technology aid. According to their field trials, they concluded that BPSP who rely on memory have better performance in walking than the rest. This is because BPSP rely mainly on their mental abilities for navigation. They can recall information about routes and tasks such as crossings and turnings (Ohn-Bar et al., 2018).

2.4.2.2 Mobility

"'Mobility' refers to the ability of a person to move safely and efficiently from one point to another within the physical environment" (Bradley & Dunlop, 2008). Visually impaired people are unable to quickly adapt to the situation. Therefore, when considering the navigation aids, it is important to know their age (Bozeman et al., 2015). Previous studies have suggested that both mental and physical adaptation as two most challenging and negative experiences which significantly affect the future decision. Therefore, training BPSP and encourage them to use navigation technology will help them navigating independently. Human factors including awareness of situation, environmental ergonomics and mental workload are affecting the journey of BPSP positively or negatively (Chandler & Worsfold, 2013). In addition, fall incidences among BPSP are higher (Bozeman et al., 2015). Renaudin et al. (2017) studied the effect of physical and any changes in the other characteristics such as ageing of the navigation systems. According to Montello and Sas (2006), a successful journey requires the awareness and use the specified route to get to the destination without accidents and delays. Moreover, circumventing obstacle and knowing locations of crossings are critical for safe navigation journey (Worsfold & Chandler, 2010).

Lewis (2010) explained the ways that the travel could be supported by technology. Giving information about the surrounding is one of them. Getting real-time journey information, notification, and warning is another way. Other ways include user preferences information input,

presentation and conducting a reliable journey until reaching the destination. Visually impaired people, consider the safety and independency of orientation and mobility as more important than distance and time of journey (Bozeman et al., 2015).

2.4.3 Allocentric and Egocentric Spatial Representation of Objects

Due to the limitation in light perception, the spatial representation for BPSP differs from sighted people. Different researchers studied the allocentric (identifying object locations with respect to each other) and egocentric (identifying the objects with respect to the user location) navigation separately in particular with user preference of one of the systems (Tournier et al., 2016). The BPSP, uses egocentric navigation because they have difficulties in depth perception, therefore it is of particular importance for them. As a result, they cannot accurately locate objects with respect to each other. In some cases the BPSP are able to apply allocentric navigation, but the objects need to have sound feedback or be at a close distance to the user (Schinazi et al., 2016).

2.5 Technology-Based Navigation

There are iOS and Android apps used by blind and partially sighted individuals including Braille Tutor and Be My Eyes in which they are useful for the guidance and aid of the BPSP and their sighted peers. Be My Eyes uses video connections to contact a sighted volunteer who explains the view in front of them from different parts of the world. Whilst Braille Tutor teaches blind, partially sighted and seeing individuals how to read and write in this special language created for those who cannot see letters and numbers due to visual impairment. Lookout by Google and Seeing AI can also be used to scan texts and images to help users recognise and identify products and materials (Walsh, 2022). The issue with some of these applications are that they are limited to only Android or iOS systems. This makes relying on certain navigation systems, such as BlindSquare on iOS, difficult when an alternative device is used.

Tactile-Foot Feedback is also used in support of GPS reliant apps as it ensures accurate locations and directions are provided. There are a few drawbacks to relying on these applications. Primarily, there is no single technology that can offer a solution for both indoor and outdoor systems of navigation making it difficult for the visually impaired when switching between two locations. There is also the issue of satellite signals being restricted indoors as infrastructure limits the line of sight between satellites and receivers (Velázquez et al., 2018).

The common traditional navigation tools which are used by the BPSP are cane and guide dog (Hersh et al., 2008). On the other hand, the smartphone-based navigation system is a common technology used by BPSP. According to Bozeman et al. (2015), support canes help stabilising and prevents falling. Additionally, BPSP may refuse replacing white canes and guide dog with navigation tools that are technology-based if they offered smartphones. Therefore, using various tools at the same time should be taking into account factors such as deficiency and usability.

Technology-Based Navigation is another solution used by BPSP to help them travel confidently and independently indoors and outdoors. However, some of these technologies are still not efficient enough and much research has been done to support this area. The performance of navigation depends on the accuracy, availability, integrity and continuity (Kuriakose et al., 2022). There are advantages and limitations for each technology used by the BPSP such as limitations to indoor use.

Smartphones are one of the wayfinding solutions used by BPSP as they provide many platforms that help them to navigate easily. Other solutions include Galileo, Wi-Fi fingerprinting, NFC/RFID, Bluetooth and LED lighting (Kuriakose et al., 2022). Technology-based navigation offers BPSP freedom and independency in travelling. Although there are many smartphone applications offering solutions for BPSP to navigation freely, many of these existing applications are costly and require subscription.

This is one of the limitations of the technology-based navigation as many BPSP have difficulty in being employed and face financial issues (SSMR, 2009). (Slade & Edwards, 2015) claims that one-third of visually impaired people are unable to go out when they want and 71% of the BPSP face extra cost due to the use of navigation aids. Consequently, reducing the cost of navigation technology is necessary to support BPSP.

To identify the requirements of aspect of navigation systems, this section is divided into two positioning and guidance requirements. Figure 4 shows the popular terms used in researches around assistive technology for BPSP in an extensive research database over the last two decades. It can be seen that there is lack of strong representation of phrases like user-centric, preferences and user requirements which are indicators of inclusive design.



Figure 4 Popular terms in Assistive Technology for BPSP in the constructed publication database (Palumbo et al., 2015)

2.5.1 Positioning

Positioning refers to identifying the location of the user within the area. To locate the position of the user, two ways can be used based on technology or personal senses to inform users about cues within the

environment. BPSP use what is remained from their vision as well as touch, sound or the combination of senses to identify their position. They require a multi-sensor navigation system in the case of deficiency or stopping as these sensors cover each other. Palumbo et al. (2015) argues that Global Positioning System (GPS) is a reliable outdoor navigation system as it provides coordinates of locations with respect to a standard coordinate system. Chen et al. (2016) asserts that Inertial Measurement Units (IMU) informs about long-term navigation independently. On top of that, Wi-Fi is used for both positioning and communication using devices and camera (Zelek, 2005). Grejner-Brzezinska et al. (2016) discussed the use of multi-sensors navigation system for GPS that has limitations in areas where GPS performance is poor.

The mentioned positioning systems have some limitations in accuracy, reliability, efficiency and working environment. Therefore, consideration of these limitations for the navigation of BPSP are of great importance. For instance, the smart phone GPS accuracy is suitable for a blind person who requires a positioning accuracy of 5 meters. This accuracy is useful when it operates in an ideal GPS environment. According to Bai et al. (2014), it is important to localise positions for BPSP to help them move freely. They argued that indoor positioning is harder than outdoor because of the structure of the building and the signal of GPS might not be available indoors. Therefore, they concluded that position localisation is important for BPSP and they used an indoor landmark positioning system for BPSP.

Triangulation technique is also used for positioning and localising to help BPSP navigate easily to their desired destination. Wu et al. (2012) used an optical triangulation system to guide BPSP that consisted of a camera to capture the image of the light beam and a netbook computer to analyse the information. They used an algorithm that deals with signal-processing to find the distance between the item and the BPSP. Their experimental results helped them design a simple and low-cost guidance

system for BPSP to use to measure how far they are from an object in front of them.

2.5.2 Guidance

The second component of navigation technology is guidance, which primarily includes the utilisation of maps and routing systems. In order to ensure the accessibility and clarity of BPSP maps, it is important to design them in a manner that facilitates ease of use and understanding. Furthermore, it is necessary that the maps shown in the BPSP's navigation system have accurate and relevant information, both in terms of quantity and quality. The following sections are categorised into two main components: map representation and routing system, see Figure 5. An additional significant concern is to the efficacy of warnings in relation to both permanent and temporary impediments. In the scenario of a permanent case, the data should be accessible in the database, even if the obstacle can be spotted by a blind individual using a stick (Wieser et al., 2007)

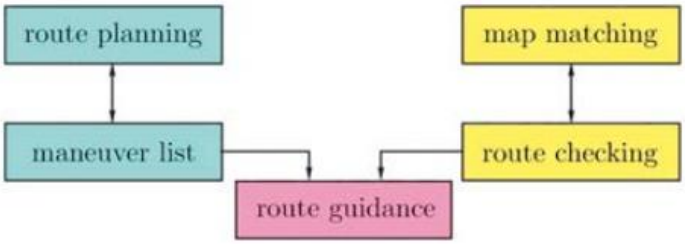


Figure 5 Guidance concept (Wieser et al., 2007)

Kitchin and Blades (2002) present an overview of three key ideas that define the process by how people gain knowledge about their environment through spatial contact. One significant theoretical structure includes the idea of:

1. landmark concepts, as the initial setting of environmental cues act as bases for the next inclusion further information, such as the layout of landmarks along an existing pathway.

2. In contrast to landmark theories, route theories are defined by dependence on path-based information as their primary foundation, with the later incorporation of spatial assignments of landmarks along this route.

3. Theories concerning to ordered views/scenes and way-finding suggest that the reliance on memorising ordered views or scenes may take precedence over the acquisition of knowledge regarding landmarks and pathways (Kitchin & Blades, 2002).

2.5.3 Maps

Maps are used to help BPSP move independently in unfamiliar environments. There are a variety of maps available for BPSP including tactile maps, maps with braille information and digital maps. RNIB developed “Map for All” for all people to access, whether sighted or blind and for all ages. It could be used indoors and outdoors and includes visual and tactile parts (RNIB, 2011). RNIB accessible hand-held maps either large print or tactile by (RNIB, 2019) are shown in Figure 6 and Figure 7.

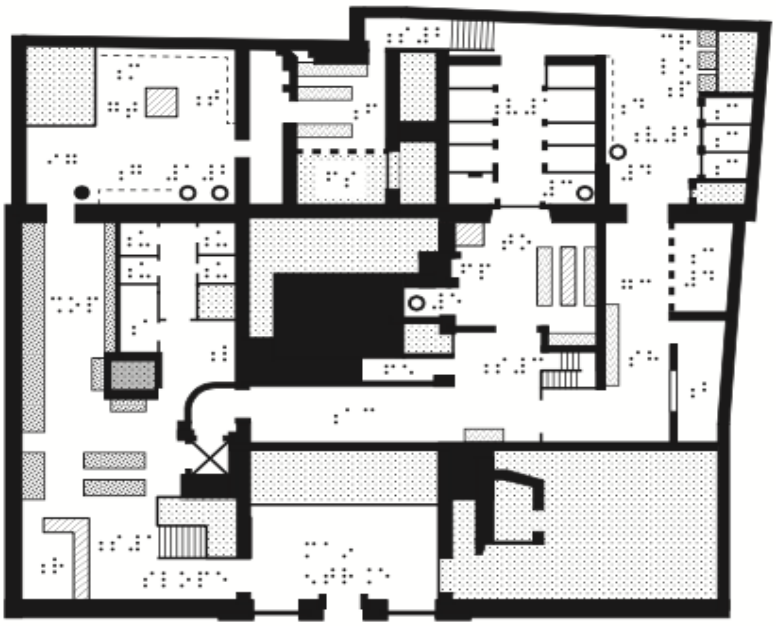


Figure 6 Tactile map showing a plan with braille (RNIB, 2019)

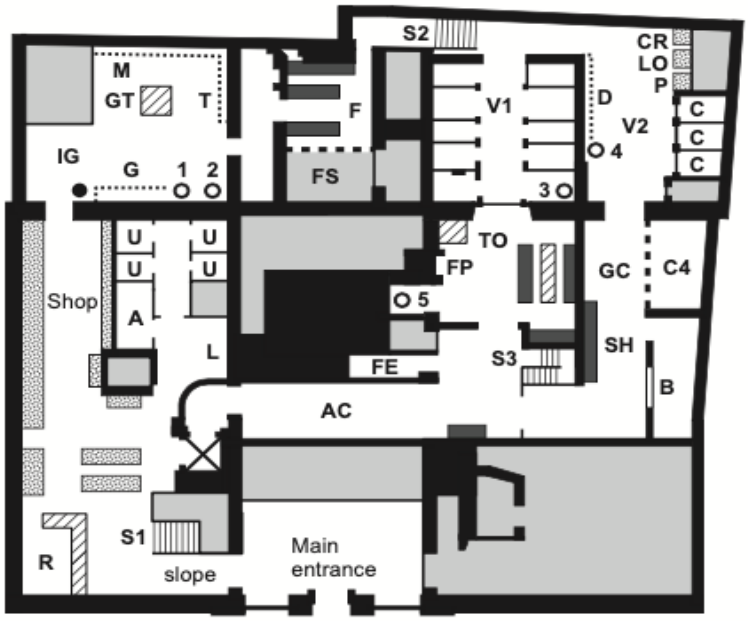


Figure 7 Map showing a plan with large print (RNIB, 2019)

Google Maps is used by BPSP to navigate outdoor places. It has recently added advanced voice guidance and verbal cues to make navigation easier and safer in unfamiliar environments. Google maps requires Wi-Fi or mobile data connection to operate pedestrian

navigation route-finding and provide voice guidance. However, the car navigation mode works offline if the map was downloaded in advance. On the other hand, Google Maps requires open sky visibility for GNSS satellite connection to find the real-time location. The estimated arrival time to the destination is measured according to the distance and speed.

OpenStreetMap (OSM) is another map used by BPSP for outdoor navigation and to get to the desired destination in a short time independently and safely. OSM is a free and open-data map suited to blind and partially sighted pedestrians. The map relies on Volunteered Geographic Information and the participation of any individual from anywhere in the world to update its features (Cohen & Dalyot, 2020). The data is taken from a variety of sources and allows the services to be updated, flexible and powerful. There are many route-finding systems that rely on OSM such as GraphHopper and OpenRouteService.

RNIB provides great help in installing tactile maps at specific locations like train stations to help BPSP know about their location and find their next destination. Figure 8 shows a picture of the tactile map that was taken at Nottingham Train Station. The map shows the station layout including the details of the surrounding roads, entrances and the location of the platforms. The information and the map legends are provided in text and braille format for enhanced accessibility. The “you are here” icon is shown as a circle surrounding a raised dot.



Figure 8 Tactile map of Nottingham Station showing the details and places in an accessible way for BPSP

The study by Chandler and Worsfold (2013) provides the necessary data requirements for those with visual impairments to navigate via maps. The requirements cover multiple variables such as direction and orientation, location and the distances, environmental data, and significant landmarks. The presence of this information is essential for inclusion into the navigation system, as it enables users to acquire knowledge about multiple aspects of their travel while making informed choices appropriately. Additionally, the research adds additional data requirements related to the positioning of building entrances, the positioning of accessible services, and the identification of possible hazards such as lamp posts and waste bins. According to Alwi and Ahmad (2013) , it is necessary for users to have the ability to view crucial information on maps, such as the path of traffic flow at crossings. This information helps users to predict the direction from which traffic will arrive. The previous need has been identified through a survey research performed with the BPSP. Petrie et al. (1996) supply an equivalent discovery on the necessary amount of detail and interface design that must be expressed to the user. This study is based on interviews performed with BPSP and mobility trainers. One of the main needs that evolved from these interviews is the need for users to possess the ability

to adjust their path plans depending to their personal tastes. These modifications may take the form of comments or notes.

Interactive and multimodal maps are necessary for BPSP to access the information and add their inputs. Brock et al. (2010) investigates the use of multi-touch displays for BPSP and outlines the requirements concerning the multi-modal maps such as technology, accuracy, number of inputs, size, orientation and programmable interface. In the experiment conducted part of the study, it was identified that some multi-modal issues need to be addressed such as sensitivity of touch screen during figure movement on the screen and adding unique features to interact with the map such as ‘double click’ and using multiple fingers tapping.

Majority of maps are designed for sighted people. Such maps lack the necessary information and design details to be accessible for BPSP such as tactile representation of the information and level of details. A work conducted by Götzelmann (2014) demonstrates an approach of generating tactile maps for blind people and using smartphone camera to explore the details. The idea of integrating the map with a free map database enables presenting rich information about the location and features on the map. Multi-modal interface and external map database enable BPSP to interact with the map in an accessible way. In addition, they enable access to various information sources about specific locations and features on the map which are not available on the original map. By leveraging multimodality and external data sources, navigation solutions can provide richer and detailed contextual information, thereby improving the usability and effectiveness of navigation systems for BPSP.

2.5.4 Route-Finding

The development of routes is an essential part in assisting navigation of people with visual impairments, as it enables the recognition and choice of the safest and most appropriate path accessible. When selecting the

best route, it is essential to take into account several factors at the same time, each given a certain weight according to the user's choices. The factors covered in this analysis include safety as a whole, user data, shape data regarding the route, and time. Chakraborty and Hashimoto (2011) offers an algorithmic structure that concentrates on the selection of routes in walking navigation, taking into account individual preferences. The study presents an extensive data set containing route information derived from road attributes and surrounding characteristics, including duration, slope, curvature, and the number of trees. The data set forms the basis for a user-centric route generation approach, enabling individuals to make knowledgeable choices about the best navigation route. The suggested computer framework shows effectiveness in the selection of paths, as it can be modified to match different navigation approaches.

According to Renaudin et al. (2017), walkers exhibit a diverse array of motivations during the navigation process. In contrast to car navigation, individuals may not prioritise the shortest route between two locations, rather they select a route that meets their particular needs. There is agreement with the authors' point of view, as it is likely that BPSP have a preference for choosing the safest or most comfortable option for approach. likewise, it is essential to take into account the routes that should be avoided, as this part has not been addressed in the prior research.

According to Lewis (2010), there are different ways in which technology could offer support for travel. One such strategy is the supply of historical data. An additional approach is the offer of real-time travel data, notifications, and warnings. Additional strategies involve incorporating consumer options relating to information consumption, show, and output, as well as providing an accurate user interface along the journey until the target destination occurs. Figure 9 and Figure 10 show the different features of two different route-finding algorithms used to identify similar starting and ending stages, such as full data related to the actual

route-finding system. Both of the route-finding algorithms work on OSM. However, they are provided by different developers.

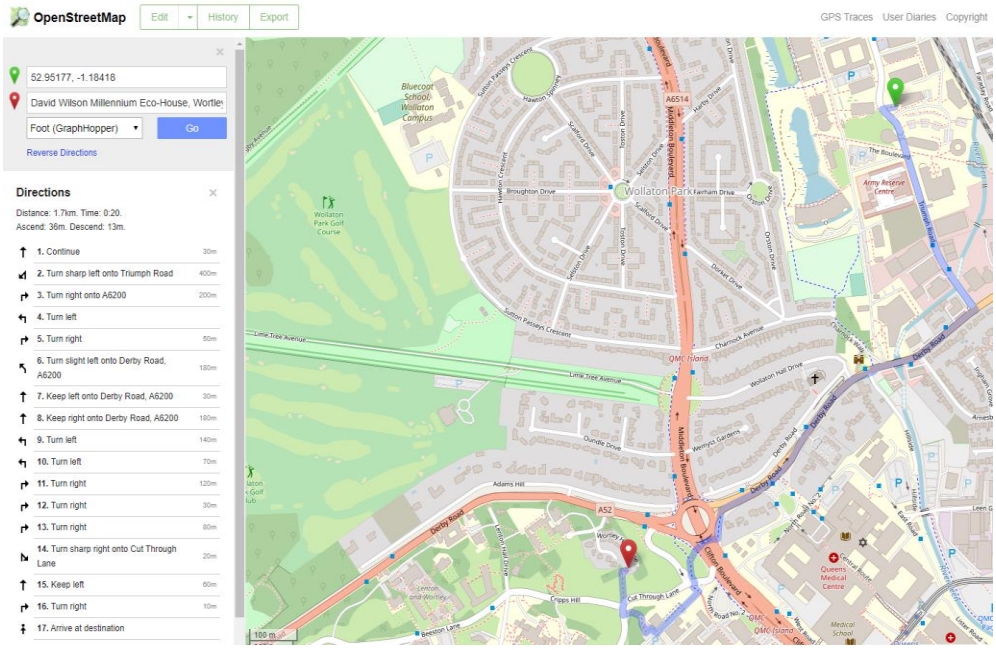


Figure 9 Route selection between two points using GraphHopper algorithm (GraphHopper GmbH, n.d.)

The route-finding system shown in Figure 9, is provided by GraphHopper GmbH that can work in online and offline modes. The system is designed in Java program and the routing library is open source. On the other hand, the route-finding system shown in Figure 10, is provided by Dennis Luxen and Mapbox. The route-finding system's name is OSRM which stands for Open-Source Routing Machine. The system is designed by C++ language and optimised for fast results.

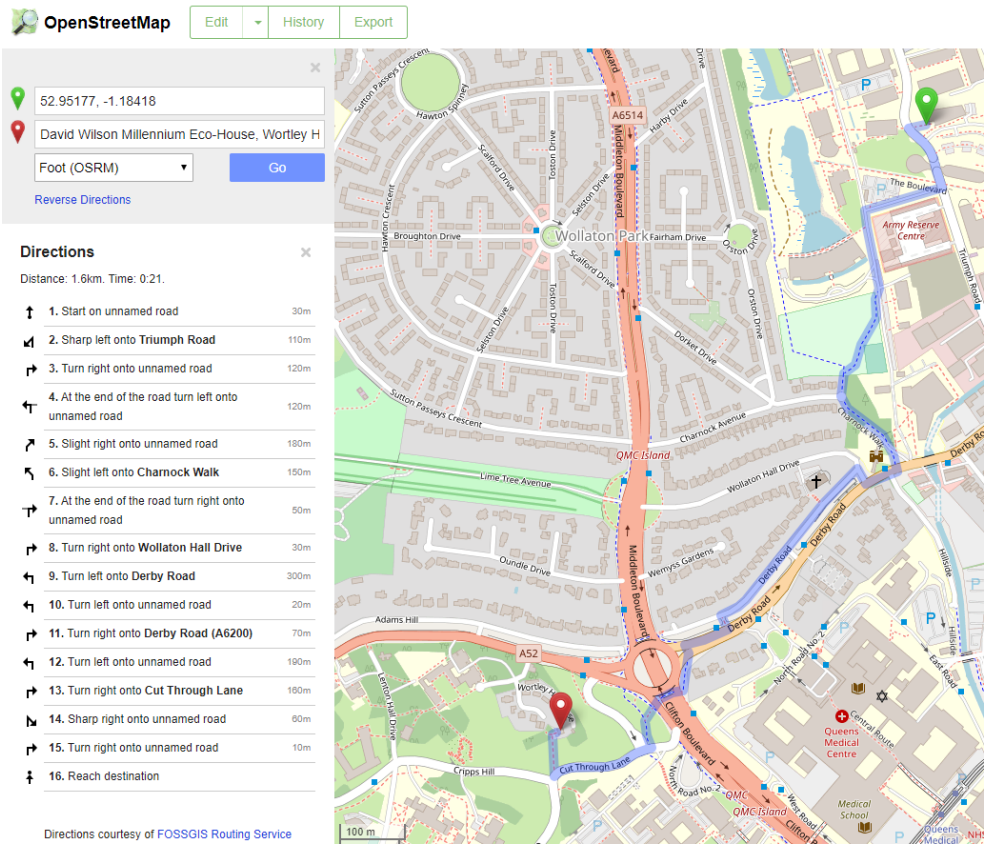


Figure 10 Route selection between the same two points using OSRM algorithm (Luxen & Mapbox, n.d.)

OpenRouteService by HeiGIT, provides a route-finding system that has specific route choices for pedestrian and wheelchair users. Furthermore, it provides the opportunity of selecting routes based on safety and providing detailed information about the route such as type of road and type of surface. In addition, there is an option of editing the route such that it includes landmarks in the instructions. Figure 11, Figure 12 and Figure 13 show the interface and details of the route-finding system by OpenRouteService.

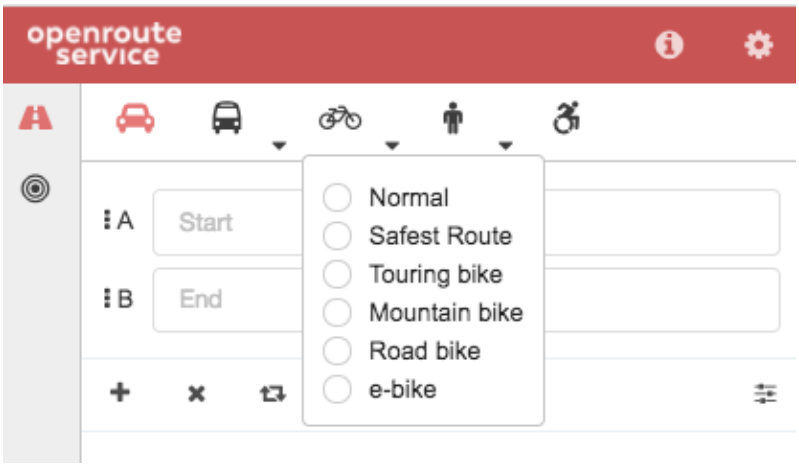


Figure 11 Openrouteservice route selection choices (HeiGIT, n.d.)

From the above figure, it can be seen that there is an option of selecting the safest route. This shows the importance of having this option as a standard so that the user can select the safest route over the quickest or shortest. Figure 12 demonstrates the route-finding system scenario showing the distance from the origin to the destination. More importantly, it shows the total vertical distance encountered along the route in terms of upward and downward components separately.

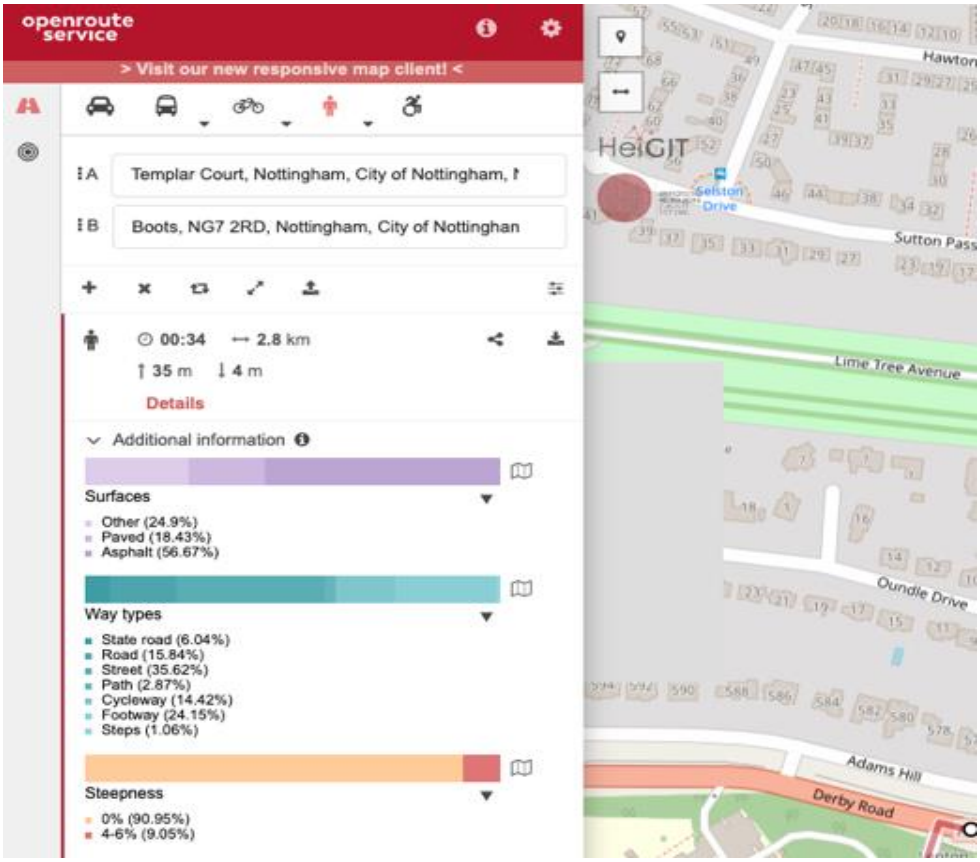


Figure 12 Openroute service route details (HeiGIT, n.d.)

Figure 12 shows another important element which is the type of the surface of the walkway and the percentage of each type. It presents the amount of the paved and unpaved sections along the route.

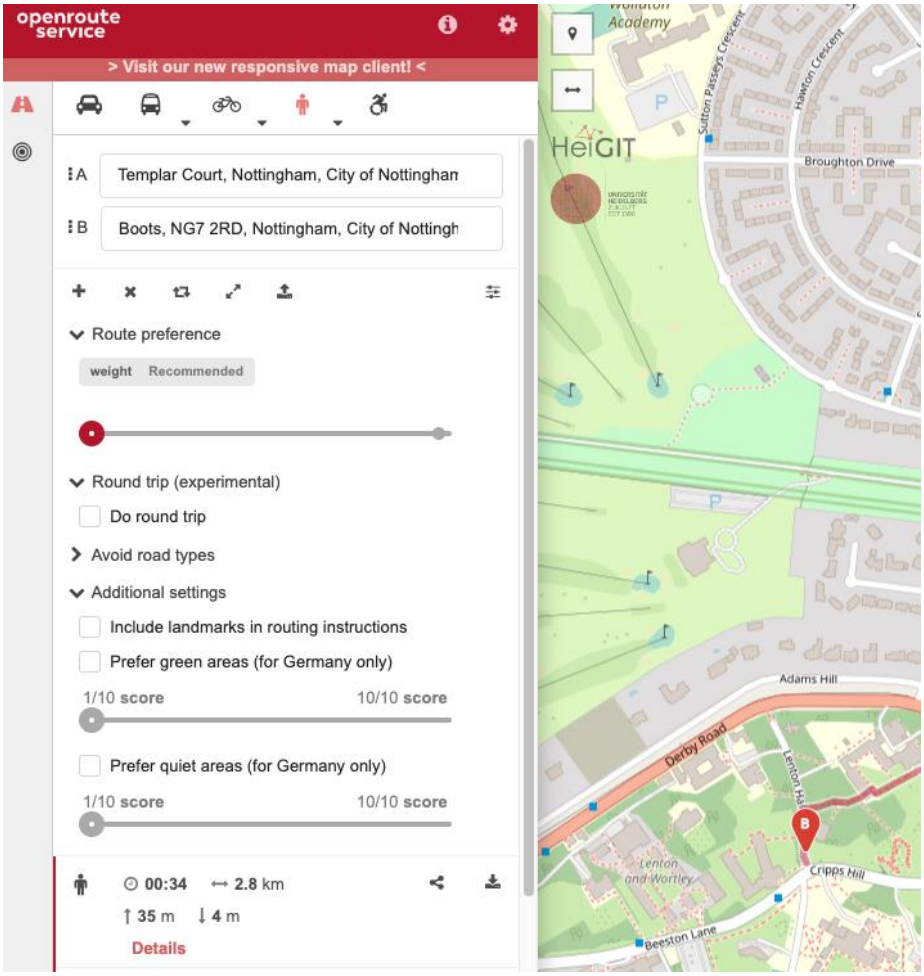


Figure 13 Openroute service route-finding system (HeiGIT, n.d.)

Figure 13 presents extra route selection parameters of the type of the walkway. The user will have the ability to select the preferred type of the walkway where applicable such as selecting green and quiet area.

2.5.5 Interface Design

Multimodal interaction provides individuals with a combination of modes that are designed to make interaction with systems easy. Technologies that use multimodality, enable BPSP to use the navigation technology in a practical and effective way (Kuriakose et al., 2020). The advantages of using a multimodal interaction system include allowing the use of several modes to ease navigation as well as being able to choose a better modality (Oviatt et al., 2000). Brock et al. (2015) argued that

interaction with a single mode for visually impaired people is not as effective as multimodal interaction that offers alternative modes to the failed ones. Bie et al. (2019) used the “EyeBeacons system” as a framework for wayfinding. It is based on three models for communication using different devices. This system requires a smartphone, a headphone and a smartwatch to pass tactile, visual and aural instructions (Bie et al., 2019). They used bone-conduction headphones to allow sound to be transmitted and the smartwatch for sensing the vibrations. However, individuals involved in testing this system found it difficult to distinguish between the sounds and vibrations (Bie et al., 2019).

2.6 Environment-Based

BPSP navigate both indoor and outdoor environments and most of the time the task of navigation involves both. There are similarities and differences between both environments. Similarly, there are researches focusing on navigation in indoor environment while others are focusing on navigation in outdoor environment. In addition, there are literatures which focus on both environments at the same time such as Ran et al. (2004). It is obvious that each environment is completely different in terms of the navigation challenges for BPSP and can expand to different spaces. Hence, addressing each environment on its own is essential particularly in terms of the common spaces. For example, considering a shopping mall for indoor navigation and urban walkways for outdoor navigation. On the other hand, there are navigation aspects common between both environments such as journey planning and using assistive aids.

2.6.1 Indoor Navigation

Indoor navigation within public transport hubs and buildings is critical for ensuring accessibility, safety, and efficiency for BPSP. Public transportation hubs and buildings include airports, train stations, bus terminals, and large commercial buildings. Effective indoor navigation

helps reduce travel time, improve accessibility, and increase safety, ensuring that BPSP can efficiently find key locations like platforms, ticket counters, sanitation facilities, and exits. Given that public transport hubs are critical nodes in urban mobility, the integration of seamless indoor navigation solutions is essential for enhancing the navigation support of BPSP. Wayfinding in indoor spaces involves navigating partially or fully enclosed areas with high foot traffic and diverse user behaviour. In addition, the architectural and structural design of indoor spaces can significantly affect both the users' and the navigation technologies' performance. Navigation within these spaces can be overwhelming for BPSP, particularly when the users identify them as unfamiliar places.

Many navigation tools have been designed for indoor environments however, they are not very accurate and do not provide explanations about the surroundings. Therefore, many indoor navigation systems have been proposed such as NavCog3 that was designed by Sato et al. (2017). This system provides users with instructions for orientation, direct audio feedback if there was a mistake and landmarks details in the surrounding.

Virtually learning environments using different modalities are useful for BPSP to navigate unfamiliar places. Lecuyer et al. (2003) used a virtual reality (VR) audio and haptic multimodal system to give visual feedback to navigators who are sighted or partially sighted inside virtual environments. Force feedback, thermal feedback and auditory feedback are also given using this system. Learning about using VR and interactions within the VR environment can be challenging for BPSP despite its benefits. Khoo et al. (2012) used sensors to aid navigation and orientation in the virtual environment. Rivière et al. (2019) designed "NAV-VIR" to navigate unfamiliar areas. This multimodal system was designed to give force feedback about the virtual environment using a tactile interface. It also provided an audio feedback to the navigators which was believed to be a powerful tactile stimulation. Zhao et al. (2018) designed "Canetroller" using three multimodal feedback to stimulate the

interactions of the white cane into the real world. This was done by producing a resistance when touching an object, simulating vibrotactile feedback and then the 3D sound is generated which could be used for indoor virtual environments as well as outdoor.

The multimodal feedback system designed by Lahav et al. (2012), called “The BlindAid system”, was based on the users’ prior knowledge about orientation. Their system used auditory and haptic cues to allow navigation through the virtual environment using spatial landmarks. To control the virtual environment and be able to map the real world, Kunz et al. (2018) used the idea of cognitive navigation map. This was based on sending haptic feedback to the navigator when finding an obstacle in the environment.

2.6.2 Outdoor Navigation

Outdoor navigation is equally crucial for BPSP. It is a totally different experience compared to indoor navigation. Factors such as environmental obstacles, traffic noise, dynamic crowds and changes in terrain can make it difficult to navigate outdoor places safely and efficiently. Outdoor navigation for BPSP often requires specialised tools and techniques to help with orientation and mobility. A questionnaire was conducted by El-Taher et al. (2023) which involved 49 participants who are blind or visually impaired in the outdoor navigation. They investigated hazards, tools used, how they are crossing roads, how they plan a journey and their knowledge about the surrounding environment and found that there are gaps. These gaps include lack of information provided by the current applications and they are not equipped with enough knowledge about how to plan and perform a journey.

Many technologies such as GPS, smartphone applications and ultrasonic detectors are used to help BPSP navigate outdoors. Other technologies designed to increase accessibility to the built environment includes accessible pedestrian signals, smart paint, talking signs, autonomous vehicles, integrated travel systems, and devices that

communicate between the pedestrian and the built environment (Wall Emerson, 2017).

2.6.2.1 Open Space

Navigation in open spaces can create challenges for BPSP even though many technologies have been designed to help them perform their activities outdoors and indoors. Navigating in an unfamiliar environment is not an easy task even for sighted people. For BPSP this challenge can discourage them from interacting with people and travelling independently. Jeamwatthanachai et al. (2019) recruited 15 experts who interviewed 30 visually impaired people and asked them questions related to indoor navigation challenges in public places. They found that indoor navigation in an unfamiliar place or building for the first time is not an easy task and could affect their determination in navigating alone. The use of dogs is limited in some places and when permitted, they have to be trained to access the environment (Kulyukin et al., 2004). Accessible maps used by BPSP, such as tactile maps, can help with navigation, however it does not provide information about safety and wayfinding.

2.6.2.2 Walkways

Using different surfaces can help BPSP detect information about the environment. For example, tactile paving has a surface that provides an indicative feeling when stepped on to let BPSP know that there is a road crossing. It is also used to indicate that there is a cycle lane and in some cases is used to inform about steps (NIDIRECT, n.d.). Colours, such as red, are also used to distinguish the crossing type and are an indicator for partially and fully sighted individuals that pedestrians can cross (NIDIRECT, n.d.).

A modelling approach is suggested by Chen et al. (2015) using the idea of orientation to aid BPSP navigate pathways and make decisions. Their object-oriented module represented the spatial formation at different

levels to allow spatial learning and cognitive behaviour. However, these data models and other suggested modules can create unnecessary object-oriented classes. They suggested that there is still a need for a data model that can order spatial information.

All the technologies that have been designed to help BPSP are not fulfilling their needs and there is still a gap between these designs and the needs of the blind and partially sighted people. “There is a need for the design and layout of accessible urban environments, accessible public spaces and buildings and accessible signage to make independent mobility much easier for blind and visually impaired people” (Hersh et al., 2008).

2.6.3 Landmarks

The term "landmark" is used to describe a distinct object in an environment that facilitates navigation and spatial understanding (Elias & Brenner, 2005). Landmarks typically have unique visual features, specific roles or meanings, or are situated in key or noticeable locations. Broadly, landmarks can be grouped into three types: visual, cognitive, and structural landmarks.

Visually impaired individuals navigate various environments independently, much like sighted individuals. Traditionally, they've used the sound of traffic flow to gather critical navigational information, such as the layout and direction of streets (Wall Emerson, 2017). However, changes in urban infrastructure over the past two decades, including larger intersections, rounded corners, adaptive traffic signals, and complex intersection geometries, have significantly altered the environments they navigate. These changes necessitate adaptations in the navigation techniques used by visually impaired individuals.

2.7 Current Navigation Systems for BPSP

It can be difficult for a blind individual to navigate the world. Without vision, individuals must rely on other modalities, such as hearing and

sensation, for orientation and mobility. The white cane is a common tool used by blind persons for navigation. White canes and guide dogs (a specially trained canine) assist a BPSP in navigating their environment.

GPS navigation, audio-based mapping, and smart eyewear are additional technologies that can aid blind people in navigating their environment. For example, GPS-based navigation systems are capable of offering users with spoken directions and navigational-information to their destination, whereas audio-based mapping can supply users with information about surrounding buildings, landmarks, and other points of interest. Moreover, smart eyewear equipped with a camera and a speech synthesiser can provide the wearer with real-time information about the obstacles and objects. even with these tools and technologies, BPSP still encounter many obstacles when navigating their surroundings, among them uneven pavements, construction barriers, and a lack of accessible facilities. It is essential for society to continue to seek for higher accessibility and inclusion in order to make it more straightforward for BPSP to independently navigate their surroundings.

There are numerous navigation solutions for BPSP to help them navigate independently. However, only few of them are affordable and efficient for use by BPSP. Smartphone-based navigation solutions are better than the dedicated navigation systems in terms of cost and usability. Travel aids can be categorised into different parts such as primary and secondary navigation aids according to Hersh et al. (2008). Further, it is possible to use the primary travel aid on its own or as a complement to another system. Primary aids can be used independently and able to provide a safe walking experience such as walking cane. On the other hand, secondary aids cannot be used independently to provide a safe journey such as a handheld ultrasonic device. Figure 14 shows the historical trends in mobility devices.

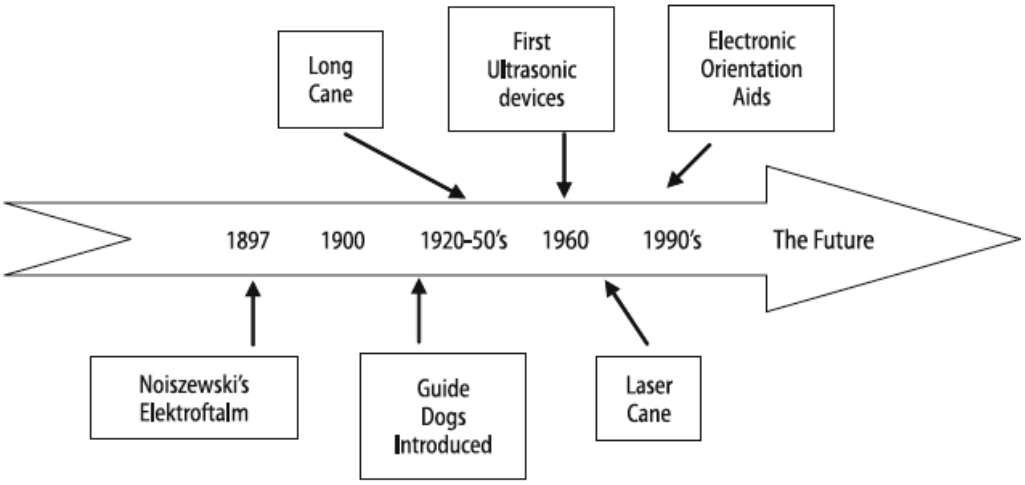


Figure 14 Mobility devices historical trends (Hersh et al., 2008)

2.7.1 Navigation Tools

BPSP need a multi-sensor navigation system such that each sensor has a specific role in the navigation process. According to Palumbo et al. (2015), GPS is a reliable system for outdoor navigation. In addition, according to Chen et al. (2016), Inertial Measurement Units (IMU) provides navigation information independently for a long-term. Wi-Fi can be used for communication with remote server or devices and camera can be used for extracting information of the surrounding to be used for navigation (Zelek, 2005) as well as for AR navigation guidance (Amirian & Basiri, 2016). Grejner-Brzezinska et al. (2016) in their paper discuss the use of multi-sensors navigation system which aid the environments where GNSS has vulnerabilities such us urban canyons and how the positioning and navigation task can be improved specially when GNSS is used with image-based and terrain-based navigation collaboration. In this PhD, it is essential that multi-sensor navigation works in a way that when a certain sensor fails or is not capable of providing necessary positioning and navigation accuracy then through collaboration among the rest of sensors the vulnerability will be minimised. In addition, using a remote server for computations and date storage is vital to reduce workload, save battery power and reduce storage use on the

smartphone. Sharker and Karimi (2012) presents an approach to overcome the previously mentioned challenges by using a cloud platform.

According to Kuriakose et al. (2022), there are three categories for navigation systems based on travel, orientation and positioning. These categories are: electronic travel aids (ETAs), electronic orientation aids (EOAs) and position locator devices (PLDs). Additionally, Real and Araujo (2019) investigated the development of ETAs and the sensory systems used for positioning indoors and outdoors. They also considered recent systems that depend on artificial vision. They argued that although many devices have been developed, the needs of the BPSP still have not been met and there is a gap between the needs of the users and the technical requirements.

ETAs are travel aids that can help blind and visually impaired people recognise and avoid obstacles (Kuriakose et al., 2022). Sensing inputs used in ETAs include sensors such as infrared, beacons using Bluetooth, camera, and Radio Frequency Identification (RFID) (Kuriakose et al., 2022). There are drawbacks of using ETAs such as not detecting obstacles' location and recognising their type (Fallah et al., 2013). EOAs also help orient blind or visually impaired people to find their path and recognise obstacles. However, there is a limitation of this aid because of the involvement of computers in the operations (Kuriakose et al., 2022). PLDs uses GPS to guide individuals from their position to their desired destination. It also uses the Geographic Information System (GIS). Lin et al. (2017) finds this combination not beneficial for blind and visually impaired people because it does not guide them about obstacles. Additionally, PLDs can only work outdoors because they need to receive satellite signals from the GPS (Kuriakose et al., 2022).

Bartie and Mackaness (2006) developed the Edinburgh Augmented Reality System (EARS), a speech-based navigation tool designed to

assist users in exploring urban environments. The system utilises spatial datasets and a digital surface model derived from LIDAR data to calculate the visibility of landmarks and points of interest. As users move through the city, the system announces these points of interest as they come to the user's field of view, providing real-time, location-specific information by a hands-free, audio interface. The audio-based human-computer interface facilitates the interaction by allowing users to request additional information or record notes verbally. This will enhance the user's navigational experience without requiring visual engagement. This approach supports natural and conversational communication, ensuring that users remain focused on their surroundings while receiving contextual information, making the system beneficial for BPSP.

The EARS offers potential for aiding BPSP by providing audio-based navigation and real-time spatial information including recent obstructions warning and navigation locations. However, its reliance on accurate speech recognition could be problematic in noisy urban environments, potentially leading to communication errors. Additionally, it may not adequately convey essential information about immediate obstacles or hazards, which are crucial for safe navigation for BPSP. The system's effectiveness would also depend on the clarity and relevance of the audio descriptions, which may require further refinement to ensure accessibility and usability for BPSP.

2.7.2 Navigation Aids

BPSP use both the traditional and state of the art navigation support to move around. The common non-technology-based navigation supports are cane and guide dog. The common technology-based navigation support is using smartphone navigation apps. White canes have a metal or plastic tip that can detect curbs and steps and alert the user of their presence. On the other hand, a guide dog is a specially trained canine that can assist a blind person in navigating their environment. The guide dog assistant is mainly about obstacle avoidance, help with orientation

and safely following the route. However, guide dogs could not be able to help with some route-following details (i.e., current location within the route, number of turns or crossings before the next landmark). According to Bozeman et al. (2015), support canes are used for avoiding fails and maintaining balance. In addition, visually impaired people may not leave the white cane and guide dog if they have been provided with smartphone-based navigation solution. Consequently, the use of different navigation support at the same time needs to be considered to avoid problems and efficiency degradation. Traditional mobility aids only provide limited details of the environment. As a result, more focus should be given to spatial orientation for distant environment to allow BPSP be more encouraged and travel to unknown destinations along unfamiliar routes (Bradley & Dunlop, 2008).

2.7.3 Personalisation in Navigation Systems

Personalisation in the navigation systems can significantly enhance user experience by adapting to individual needs and preferences. For BPSP, personalisation should involve selecting preferred input and output methods of the navigation system as a single or combination of haptic, audio and visual options. It should also involve some control over the amount and nature of information presented by the system. Furthermore, there has to be the ability of personalising the real-time guidance system in terms of decision-making time and criteria of the route-finding system.

Zhang et al. (2017) emphasises the importance of personalisation in mobile web adaptation for BPSP. It highlights that traditional web content often does not accommodate individual user preferences. The Personalised assisted web system in the research addresses this by dynamically generating a hierarchical outline view of a website's content, tailored to the inferred interests of users based on their previous browsing activities. This allows the system to adapt the content presentation to enhance the accessibility and usability. The study found

that personalised adaptations significantly improved users' experience, demonstrating the potential benefits of customising web experiences to meet the diverse needs of individual users. This study shows that personalisation is an important aspect that should be considered in the design of the systems. Table 3 below shows the details of the navigation system personalisation from relevant literature.

Table 3 Navigation system personalisation from relevant literature

Navigation system components	**Relevant literature**
Input (Miao et al., 2011a)	Most blind users prefer speech input provided that speech recognition system works well
Output (Miao et al., 2011a)	Feedback of warning of obstacles in advance in audio format
Route finding (Miao et al., 2011a)	Announcing specific details based on the user input such as nearest landmark.
Map (Hersh et al., 2008)	Integrating detailed digital information with tactile elements can greatly enhance the navigation experience for visually impaired users by providing both an overview and detailed context of their environment
Memory (Miao et al., 2011a)	Ability to save the input data for future use Ability to annotate and classify input data for future use
GPS receivers: (Hersh et al., 2008)	These are essential for determining the user's location. They need to be wireless, small, and accurate.
Personal navigation modules (Hersh et al., 2008)	These modules include motion detectors and a compass to keep track of the user's movements.

Menu navigation (Miao et al., 2011a)	Navigation system menu need to be easy for learning and use. interaction buttons need to be in a way that they are easy to be memorised

The provided requirements for a navigation system for blind users highlight critical aspects that ensure personalisation of the navigation systems. Speech input is a preferred method among blind users, depending on the effectiveness of speech recognition systems. However, the practicality depends on the microphone location whether integrated in the smartphone or used as a dedicated device and connected to the smartphone wirelessly. Audio feedback for obstacle warnings and announcing nearby landmarks enhance real-time navigation safety and orientation. The type and location of the audio feedback system device greatly depends on the user preferences and design of the navigation system.

Integrating tactile elements with digital information can significantly improve spatial awareness, offering both an overview and detailed context of the environment for some users. The ability to save, annotate, and classify input data for future use is vital for personalised navigation experiences and efficiency of the system. Additionally, the menu of the navigation system and the interaction buttons need to be designed for simplicity of learning and memorisation, ensuring that the system remains user-friendly and accessible for BPSP. These requirements highlight the importance of a multi-modal approach that combines audio, tactile, and digital technologies to provide a personalised and effective navigation solution.

2.8 Research Paradigms

Multiple techniques were used by researchers to determine the navigation needs of the BPSP. According to the underlying features of sight loss and the relatively small percentage of BPSP in contrast with the sighted people, the task of adapting particular techniques offers

major obstacles, especially in terms of recruiting an adequate number of participants for studies. A possible reason to use restricted numbers of participants in many study designs is the necessity to employ diverse techniques and methods for generating demands. Table 4 displays the prevailing techniques employed by multiple investigators that have been incorporated in this thorough review of the literature.

Table 4 Methods used by other researchers to identify the navigation requirements of BPSP

Method	Obtained Requirements	References	Details
Field Trials	• Making choices • Performance tracking • Role of assistive knowledge on navigation	Richer et al. (2014), Lewis et al. (2015), Ohn-Bar et al. (2018)	• Walking trials to test navigations system
Usability studies	• Interaction needs • Graphs in the design • Interface design of interactive maps	Brock (2013), Kim et al. (2016)	• Smartphone interaction • Map interface interaction
Interviews sessions	• Interface design of smartphone • Orientation system	A. A. Alkhanifer and S. Ludi (2014), Richer et al. (2014)	• Requirement elicitation from BPSP and experts
Literature review	• Services inclusiveness	Jeamwatthanachai et al. (2016), Bhowmick and Hazarika (2017)	• Exploration of previous work

The study carried out by Armeni and Chorianopoulos (2013) explores the connection between preference and distance in pedestrian navigation, with an emphasis on the shortest path. The research relies on the application of GPS technology to track individuals as they journey between various places, employing their own preferences and criteria to figure out the fastest path. According to the findings of the research, it has been noted that users sometimes view their chosen path as the

quickest a single one, when actually it is not. In addition, users often view the shortest route advised by the system for the direction to be longer in duration because of their personal experiences along the way, while it is officially the shortest option. It can be concluded from the statement above that users' decision-making in light of navigation, a task of significant and frequent relevance in their lives, is not always reliable. It has to notify the user of this fact and develop their understanding and appreciation of the navigation suggestions given by the system, which favours safety over user preferences. The stress on safety remains critical even if the user shows disgust with the instructions.

2.9 Discussions

Considering studying the navigation solutions addressed in this chapter, it will be feasible to recognise both connections and differences. The concept of multimodality can be easily noticed in the input and output of navigational systems, since people with visual disabilities rely on various kinds of input and output to deal with and reduce their vision problems. The main types of input in this setting include recognition of speech and touch screen communication, while the main kinds of output are hearing, haptic, and sensory feedback.

Current systems show an inability in taking into account user preferences and needs when it comes to route selection and navigation guidance. As a result, the user's path may be marked by challenges and obstacles, resulting to a less pleasant and effortless navigating experience. Eventually, there is a need for further improvement of the current technology in order to better match the mapping system with the particular goals and specifications of the BPSP. The addition of BPSP's info into the mapping system has a chance to develop a navigation system that is additionally more accessible and more advanced.

The BPSP have specific needs for each aspect of navigation, as discussed in this chapter. Particularly, these requirements often differ from those of people who have eyesight that is normal. BPSP often have

financial constraints that limit their capacity to gain suitable navigation solutions, that tend to be expensive. This is primarily because of their poor access to meaningful employment opportunities. Phones play a significant role in providing navigation support for BPSP because to their capabilities, cost-effectiveness, and availability of relevant applications. Nevertheless, there is need for improvement in terms of system compatibility, technical proficiency, and usability in order to improve the overall efficiency.

The task of meeting the demands and improving access of services will not just rest upon the BPSP and navigation system designers. Rather, multiple outside parties, charity groups, government councils, and related groups, may also contribute greatly to satisfying these requirements. The linked entities of BPSP have the capacity to offer training assistance in using modern navigation technologies, as well as awareness programs on the most recent advancements in navigation technology for BPSP. Councils have a chance to work together with navigation system providers in a manner that enables them to address user-reported issues on the map. This partnership could involve the council's team going to the specific location in which an issue has been highlighted, with the aim of solving addresses concerning walkway accessibility or the safety of other walkway users. The government holds a chance to create a uniform framework for the requirements of BPSP in order to make sure that any new created navigation system conforms to this standard. This could successfully guarantee the availability of services people with BPSP. Individuals with visual impairments have a duty to contribute to the fulfilment of the navigation experience by conveying essential concerns regarding walkway arrangements to suitable authorities.

There have been various methodologies implemented by researchers to elicit the user requirements and improve the design of the navigation systems for BPSP. However, there are still aspects of inclusive design, user preferences and needs that has not yet been fully addressed. The

navigation experience needs to be carefully classified into different components so that the required information is collected for each aspect of navigation separately. In addition, the user requirements and system design need to be covered in more detail. This will be addressed in this research. Many study designs didn't breakdown the navigation experience effectively into its components as needed.

There is the need to collect and structure the information in a format that can be effectively stored, shared and incorporated into the navigation systems. For this purpose, user profiles need to be created as part of the research to store individual's navigation-related information. There has been research around creating user profiles. However, the amount of information and particularity required has not been addressed yet. It should be noted that as the technology develops and the lifestyle changes, new needs and preferences emerge. Hence, there is a need to update the methodology and capture the new set of requirements and preferences of the design of the navigation system.

It can be concluded that there are a considerable number of navigation solutions and researches on navigation of visually impaired people. Researchers used different approaches to provide better navigation for visually impaired people. BPSP face different challenges while navigating from one place to another. Smartphones play an important role in providing navigation guidance through the existing apps but have limited hardware and software capabilities. BPSP can independently travel using navigation technologies provided that their preferences and needs are considered. There are different approaches for multi-criteria route selection. Multimodality is the key to provide an efficient navigation system.

2.10 Chapter Summary

This chapter has reviewed the literature concerning the navigation of BPSP including human factors and navigation technologies focusing on BPSP challenges, preferences and needs as well as the state of existing

navigation technologies. There is a significant number of studies focused on the navigation of BPSP, with the aim of achieving a user-centred approach and providing independent navigation help. However, the absence of a universally useful and cost-effective navigation system continues. Finally, the overview of relevant research around the appropriate elicitation methods for BPSP was outlined and discussed. The next chapter will present and discuss the study of understanding the route selection strategy of BPSP in familiar and unfamiliar journeys. This chapter contributes towards achieving objective 1 of the thesis.

CHAPTER

THREE

3 UNDERSTANDING BPSP'S ROUTE SELECTION STRATEGY IN FAMILIAR AND UNFAMILIAR JOURNEYS

3.1 Chapter Overview

This chapter describes an interview study with people with different sight conditions to understand their route selection strategies in outdoor environments by using Cognitive Task Analysis method in semi-structured interviews. As part of the study, sighted people, blind people, and partially sighted people were interviewed. Participants were asked to talk about a familiar journey and an unfamiliar journey that they have taken in the past. As they talked through each of these journeys, they were asked about the reasons for the decisions they have made during the journey that was related to the route selection whether it was preference-based, environment-based, terrain-based, etc. For that purpose, Critical Decision Method was used.

3.2 Methodology

3.2.1 Study Design

The choice of the study method and design was made based on some factors. The first factor was getting rich user data and trying not to shape their data into predefined categories. For that purpose, semi-structured interview was selected so that the interviewee has the chance of adding as many information and in the way they like. The concern about such method is that it is qualitative approach and the researcher need to spend more time on the analysis of the data. Semi-structured interviews similar to this research has been used by Low et al. (2020). In addition,

Andre et al. (2007) used interviews with participants to identify the journey planning factors. Additionally, Williams et al. (2014) used interviews with BPSP to understand their challenges and strategies. Consequently engaging with users is crucial for understanding the navigational needs of BPSP for an inclusive design.

The second factor was selecting a study approach that is appropriate for BPSP as well as sighted people to help them provide sufficient and rich information about their navigation experiences. For that purpose, the Cognitive Task Analysis (CTA) method was used which allows the users to talk through their navigation experiences in a story-like method and it allows the researcher to explore the reasons behind the decisions the users made at each point of the journey by breaking the task into parts, understanding each part on its own and the relationship between the parts all together. The study design and interview process benefited from the Working Minds Guide book (Crandall et al., 2006). Table 5 shows the probing questions asked during the interviews. Information sheet of the first study is shown in appendix A.

Table 5 Probing Questions

Probing questions	
Questions related to sight condition	Sight condition Light perception
Tell me questions	Tell me about a familiar journey that you have taken in the past and describe its stages? Tell me about a familiar journey that you have taken in the past and describe its stages? Thinking of the familiar journey, what were the key concerns that you had about the route? Thinking of the unfamiliar journey, what were the key concerns that you had about the route?

Navigation aids used for planning and while navigating	What apps are you using? What navigation aids you are using?
Walking distance?	How far you walk before using other modes of transport?
Planning routes	What is your route selection strategy? Quickest, safest, shortest, simplest
Personal definitions	What does a good route look like for you? What does a bad route look like for you?
Orientation, positioning and wayfinding	What cues and clues used and for what purpose? Orientation and positioning, following path, observing surrounding, Open spaces, path following, Senses you use
Decisions during uncertainty time?	First action? Alternative action? Getting lost, not sure, problems while navigating, uncertainty, fall
Route selection factors?	Walkway elements environment others sharing the same space, etc. work sign, scaffold, stairs, slope, crossing, traffic, parked car, bicycle, gaps busy full of people, Landmarks, pot hole, work, tree leaves, rain, wind, snow, day, night, ice, crime spot, busy, hot, cold
Chance to let the participant add extra information	Anything else you would like to add

3.2.2 Ethics Approval

The study received ethics approval from the School of Engineering's Ethics Committee at the University of Nottingham, and all participants supplied informed consent to participate in the study. The consent form of the first study is shown in appendix B. The privacy and confidentiality guidelines were followed in this study and all subsequent studies. To ensure data confidentiality and anonymity, the study was complied with

the Data Protection Act of 2018, EU General Data Protection Regulation (GDPR) and University data protection regulations this included storage and handling of the data, use of the data and what will happen to the data after the study. The data anonymisation was in a way that no individual is identifiable.

3.2.3 Recruiting Participants

The process of recruiting participants was made through the Horizon CDT, University of Nottingham Disabled Staff Network and RNIB communication channels. Recruiting sighted participants was straightforward and a total of 10 people were interviewed. However, recruiting participants within the BPSP community was challenging and without the help of RNIB, it would have been difficult and time consuming to recruit the targeted number of participants because of no previous experience in recruiting BPSP. A total of 20 BPSP were interviewed. The demographic details and method of the interviews are shown in Table 6.

The criteria for deciding on the number of participants was previous similar research and the variety of the data collected. No restriction was placed on the type of the visual impairment. However, only adults were interviewed in this study and the subsequent studies. The age of sighted participants ranged from 27-49 years while the age of BPSP ranged from 21-62 years.

Table 6 Participant demographic details and interview method

participants	gender	sight condition	Method of interview	Useful sight for navigation? Yes or No
P1	Male	Blind	In person	Y
P2	Male	Blind	Telephone	N
P3	Female	Partially sighted	Telephone	Y
P4	Male	Blind	Telephone	Y
P5	Male	Blind	Telephone	Y

P6	Male	Blind	In person	Y
P7	Male	Blind	In person	N
P8	Male	Blind	In person	N
P9	Female	Blind	Telephone	N
P10	Female	Blind	In person	N
P11	Male	Blind	Telephone	Y
P12	Other	Blind	In person	Y
P13	Male	Blind	Telephone	Y
P14	Female	Partially sighted	In person	Y
P15	Male	Blind	In person	Y
P16	Male	Blind	In person	Y
P17	Female	Blind	Telephone	N
P18	Female	Blind	In person	Y
P19	Female	Blind	In person	N
P20	Female	Partially sighted	In person	Y
SP1	Male	Sighted	In person	Y
SP2	Male	Sighted	In person	Y
SP3	Male	Sighted	In person	Y
SP4	Male	Sighted	In person	Y
SP5	Female	Sighted	In person	Y
SP6	Female	Sighted	In person	Y
SP7	Male	Sighted	In person	Y
SP8	Male	Sighted	In person	Y
SP9	Female	Sighted	In person	Y
SP10	Female	Sighted	In person	Y

3.2.4 Accessibility of Study Materials

The study materials were written as text in Microsoft Word documents. The accessibility feature of Microsoft word has been used to check the whole content for any accessibility issues. In addition, to make the study details accessible particularly for BPSP, alternative formats of the documents were made available on request. That included high contrast text with bold and big fonts and audio version of the documents recorded by my voice. Written or verbal consents were taken before the interviews

start. Participants were provided with both audio and text versions of the study materials and one participant requested the text documents in big and bold font which I provided. Communicating the documents was through email and phone (call and text). To review the accessibility of the study materials, previous research study designs and relevant organisation guidelines have been considered. A copy of the study documents can be found in the appendix.

3.2.5 Study Process

Participants were asked to talk through a familiar journey and an unfamiliar journey (each at a time) that they have taken in the past and how they have undertaken the journey from the planning stage until getting to the destination and thinking of the personal experience in that specific journey. Finally, allowing the participant to talk about any concerns or relevant information they have regarding their experience in general. As the participants were talking through their journeys, they were asked about reasons, decisions, strategies and concerns about particular aspects of that journey. This approach empowered us to elicit the necessary information about the user and navigation which could be used to achieve the goals of this study and provide entry to future studies.

20 adult blind and partially sighted individuals were interviewed as well as 10 sighted participants for comparison. Each interview lasted around 20 minutes depending on the participant response. The data collection involved note taking and voice recording. Participants were recruited through snowball sampling and accessing the list of volunteer participants for research. Table 7 shows information about the participants in numbers.

Table 7 Details about the BPSP participants in numbers

Number of blind people	17
Number of partially sighted people	3

Number of people with useful sight	13
Number of people with no useful sight	7
Average age of participants, minimum and maximum ages respectively	41 years, 21 years and 62 years

After the data collection, transcription options and their suitability in terms of time, cost and data protection were considered. Online transcription services transcribe the audio file automatically using machine learning techniques, then revising the transcriptions for improvements and corrections. This service saved time as it does part of the transcription correctly depending on the accent of the speaker and it has an easy-to-use interface which speeds up the play back and editing process. The editing of the transcription helped becoming familiar with what the participants said during the interviews and help with the data extraction.

3.2.6 Thematic Analysis

It was decided to use thematic analysis as an appropriate approach to interpret the data. In addition, quantitative representation of some of the interview findings were also presented as complement to visualise the findings giving broader view of the data. Thematic analysis is a method for identifying, analysing, and reporting patterns (themes) within data. It organises and describes the data set in detail. However, it also interprets various aspects of the subject (Braun & Clarke, 2006). This approach was used to analyse the study data using thematic analysis. Thematic analysis is an approach that is accessible and flexible which involves the following stages show in Table 8.

Table 8 Stages of thematic analysis by Braun and Clarke (2006)

Stages of thematic analysis	
1. Familiarise yourself with the data	Read and re-read the data, to become immersed and intimately familiar with its content.

2. Generate initial codes	Systematically code interesting features of the data across the entire dataset, while considering the research question.
3. Search for themes	Collate codes into potential themes and gather all data relevant to each potential theme.
4. Review themes	Check the themes against the dataset, to determine if they tell a convincing story of the data and refine the themes as necessary.
5. Define and name themes	Develop a detailed analysis of each theme, determining the 'story' the theme tells about the data, and decide on an informative name for each theme.
6. Write-up	Present a concise, coherent, logical, non-repetitive, and interesting account of the story the data tell, within and across themes.

The first stage of the thematic analysis started with familiarising with the interview data by going through the interview responses individually. The process included listening to the interview data again and going through the transcribed text. Then the code generation process started as the interview transcripts were analysed. Important and interesting data were coded and recorded using Microsoft Excel. The interview data coding was an iterative process that included merging and editing codes. The next stage involved creating the broad and specific themes and the coded data were grouped under the emerged themes.

3.2.7 Presentation of the Themes

In the thematic analysis of interview data concerning the route selection factors of BPSP regarding navigation systems, several general and specific themes have emerged. Table 9 shows a comprehensive framework for analysing the navigation challenges and preferences of BPSP, emphasising both location-based and environmental factors.

Table 9 Demonstration of general and specific themes

General themes	Specific themes
Location-based	1- Walkway Item (objects)

	Surrounding Surface texture Restricted area Location (bus stop) Shared path (no walkway) Walkway element Building design (entrance/exit) 2- Other users/modes of transport 3- Crossing
Environment	Weather
Navigation aids	Smartphone-based Dedicated device Traditional tool
Decision making	Skills Strategy Dealing with uncertainty Route selection Familiar journey Unfamiliar journey

Within the location-based domain, key themes included the design and characteristics of walkways. Wall Emerson (2017) argues that the changes in the built environment such as changing the design of the walkway sometimes pose danger on the navigation of BPSP. Hence, it is important to consider the location-based challenges in the study. The interaction with other users and modes of transport emerged as a significant factor. Other users include the sighted guide person that acts as a company to the person as well as other walkway users at the time of the navigation. Vincenzi et al. (2021) argues that independent navigation can be achieved with sighted guide collaboration. The collaboration includes sharing information and providing timely commands to the visually impaired person to deal with the navigation tasks while walking. The other modes of transport become part of the navigation of the BPSP at crossings and shared spaces. For instance, the user needs to cross a road to the other side of a walkway and this happens by walking on the road at a crossing.

The environment is also critical, particularly in relation to weather conditions that may impact navigation. Darko et al. (2022) discuss the effect of various weather conditions on the navigation experience of vulnerable walkway users. They highlight the fact that the change in environment condition might make a walkway inaccessible during the course of the walking. For instance, an inclined terrain becomes very slippery when it is snowing and raining.

Navigation aids are categorised into smartphone-based tools, dedicated devices, and traditional instruments, each influencing the navigational experience. The type of journey, whether familiar or unfamiliar, impacts decision-making strategies, including the skills required, the strategies employed, and the approaches to dealing with uncertainty. There is limited user of state-of-the-art navigation system algorithm. In addition, there is need for evaluation of the existing navigation systems when considering the design of a new one (Budrionis et al., 2022).

Location-based themes as shown in Figure 15, encompasses how blind and partially sighted individuals perceive and utilise spatial information. The specific themes under this category include walkway. This involves elements such as surface texture, restricted areas, and shared paths. Understanding these elements is crucial because they directly impact the safety and comfort of navigation for BPSP. For instance, restricted areas and shared paths can influence route planning and safety.

The Other users/modes of transport theme highlights the interaction between blind pedestrians and other users of the space, such as cyclists and vehicles. It is significant because the presence of other users and modes of transport can create potential hazards or require adjustments in navigation strategies. The crossings theme includes accessibility of crossings and the environmental factors affecting them, such as weather conditions. Accessible crossings are vital for ensuring safe and efficient navigation, and the impact of weather on these crossings can further complicate travel.

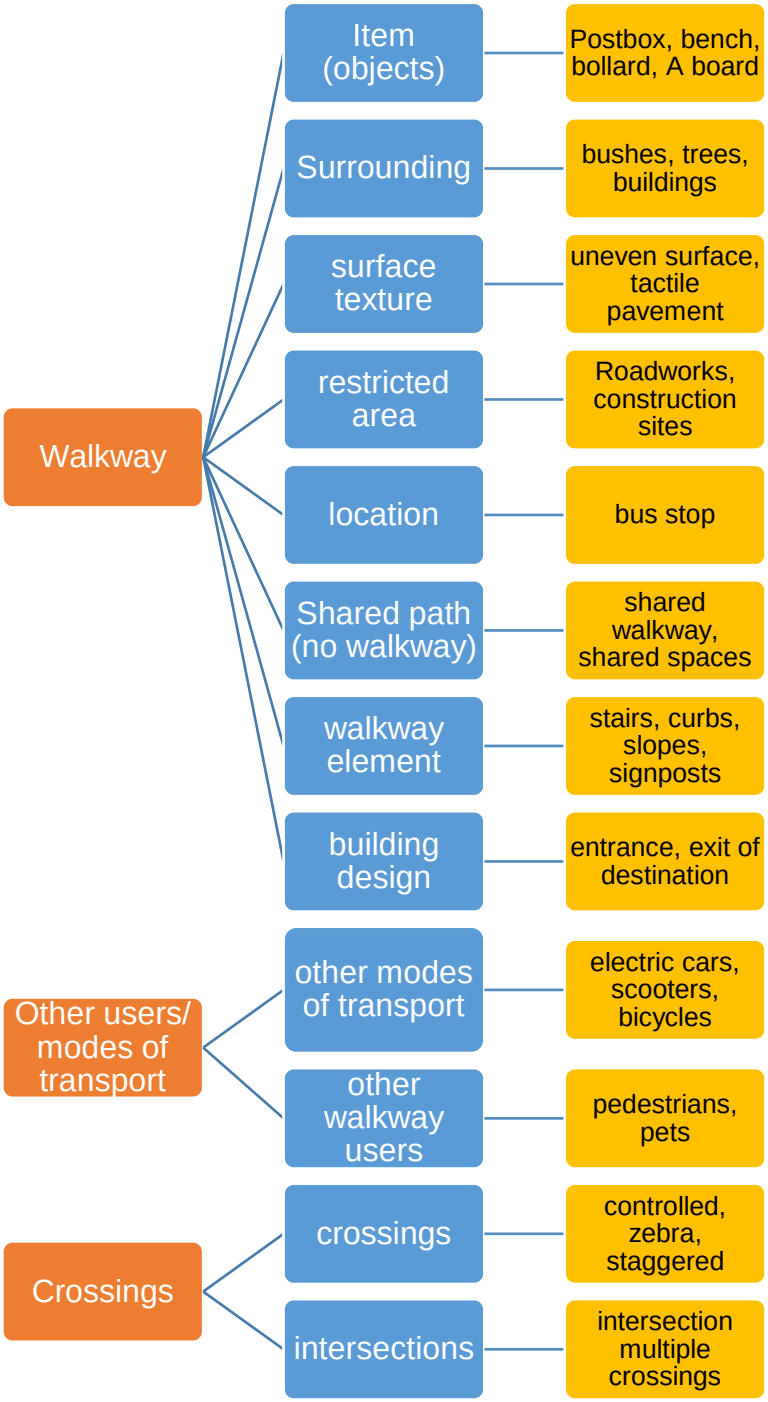


Figure 15 Relationship between codes (yellow boxes) and specific themes (orange boxes) and its categories (blue boxes) under the general theme of location-based

The rest of the themes are shown in Figure 16 starting from the decision-making theme which explores the cognitive processes involved in navigating and route selection. Specific themes include skills, which include the competencies and techniques employed by BPSP to

navigate the environment. This theme is important as it helps in understanding the practical abilities required for effective navigation. The other specific theme is strategy, which refers to the planned approaches used by BPSP to manage their travel and adaptive techniques. Strategies are important for improving travel efficiency and safety.

Dealing with uncertainty theme covers how BPSP handle unexpected situations or changes in their environment, which is vital for assessing the robustness of navigation systems and supports. Route selection theme involves the process of choosing a travel route based on various factors such as safety, time, and distance. Understanding route selection processes helps in designing navigation systems that align with user preferences and needs. Familiar and Unfamiliar journey theme helps in Differentiating between navigation strategies used for well-known routes versus new or unfamiliar routes. This distinction is important for developing tools and aids that cater to different levels of navigational experience.

The navigation aids' theme refers to the tools and technologies that blind and partially sighted individuals use to assist in navigation. The specific themes include Smartphone-based navigation aids which offer various applications and features tailored for BPSP. Dedicated device's theme Includes specialised devices designed specifically for navigation BPSP; These devices often provide features tailored to the unique needs of blind users. Traditional tool's theme encompasses tools, such as white canes and braille maps, which are used in navigation.

The environment theme reflects the broader context within which navigation occurs, particularly environmental factors that affect navigation. The specific theme here is weather. The weather conditions can significantly alter the navigational experience by impacting visibility, surface conditions, and the overall safety of travel. Understanding how different weather conditions affect navigation is essential for developing adaptive strategies and tools.

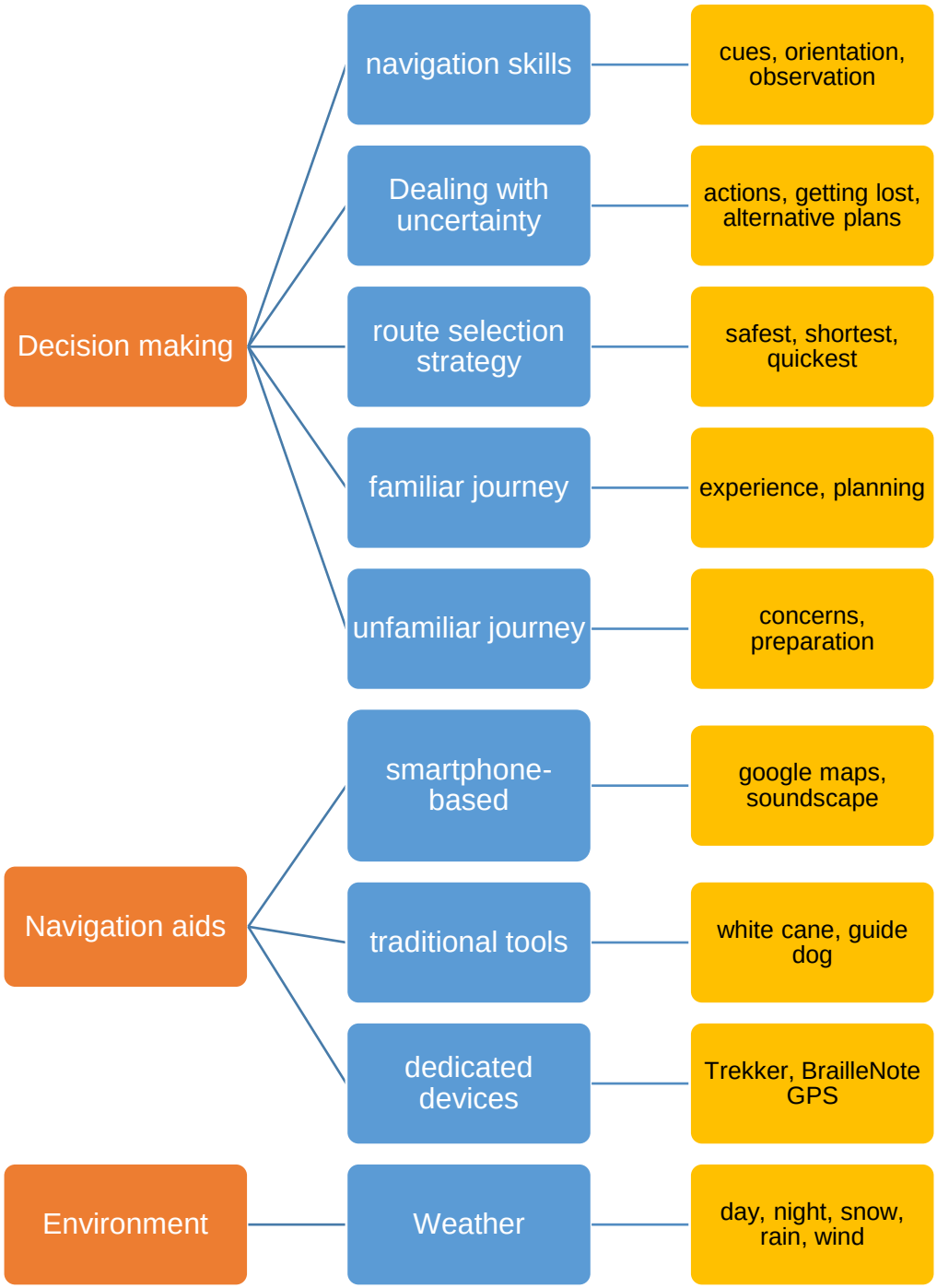


Figure 16 Relationship between codes (yellow boxes) and specific themes (blue boxes) and the general themes (orange boxes)

These themes collectively provide a comprehensive view of the factors influencing the navigation for blind and partially sighted individuals. They are critical for identifying areas where current navigation systems may fall short and for guiding the development of more effective, user-centered navigation aids and strategies. By focusing on these themes, the diverse needs of BPSP and their overall navigational experience can be better addressed.

3.3 Study Findings

3.3.1 General Themes

Following the analysis of the data, the results were tabulated according to the theme classifications. The amount of the results and the nature of the data were enormous. Some of the key findings are presented in the following sections which are structured according to the study design approach.

3.3.2 Familiar and Unfamiliar Journeys

Participants have provided different examples of familiar and unfamiliar journeys they have taken in the past. The type of the journey was up to the participant to select allowing the participant to pick the main journeys from their navigation experience.

> "With a familiar journey, there is not so much planning to be done. It is either I take my cane, or I don't take my cane, because it's like it is dark outside. With unfamiliar it is knowing you have to be comfortable within your comfort zone to be able to make that journey safely in a timely fashion" P1,

> "I think the most familiar ones from my home to work. Yep. Yep. So, the directories, I cannot remember all the names of the streets" SP4.

Table 10 shows the familiar and unfamiliar journey examples mentioned by the participants. The type and nature of the journeys taken by BPSP will be considered in the aspects of navigation whether related to route selection factor, personal strategy or challenges of navigation.

Table 10 Journey example selection during the interviews by BPSP

P	Familiar journey	Unfamiliar journey
1	Home to local shop	Explanation without origin-destination
2	Local walks	Bus stop to train station walk on return
3	Home to train station (visit)	Train station to organisation building (work-related visit)
4	Home to train station (work)	Bus stop to a bar
5	Train station to workplace	Walk to train station (work-related visit)
6	Train station to workplace	Train station to organisation building (work-related visit)
7	Bus stop to workplace	Train station to the correct exit for a street
8	Home to bus stop (work)	Explanation without origin-destination
9	Home to train station (work)	Office to work-related place
10	Train station to workplace	Home to hairdresser
11	Train station to workplace	Office to work-related place
12	Home to train station (work)	Walk out of train station
13	Train station to workplace	Train station to work-related place
14	Train station to workplace	Workplace to restaurant
15	Home to train station (work)	Train station to park
16	Train station to workplace	Home to the local council
17	Home to public place	Train station to workplace
18	Workplace to train station	Train station to health centre
19	Home to coffee shop	Train station to theatre
20	Home to workplace	Home to supermarket

3.3.3 Navigational Preparations and Strategies

Participants have used various preparation techniques, tools and strategies in preparation for the journeys and also during the journeys. When participants were asked about walking distance as shown in the Table 11, interestingly, some responses were time-related rather than distance related. This shows that some participants are better remembering journey details in duration rather than distance.

Table 11 Participant (P) responses to the question: How long does the person walk before using other modes of transport?

P	Walking distance	details
1	NA	NA
2	10-15 minutes journey	Local journeys
3	10 minutes	NA
4	5 miles	If not complex
5	2 miles	With guide dog
6	NA	NA
7	3-4 minutes	Familiar journey
8	10-15 minutes	On their own without help
9	100 minutes	A regular know journey
10	2-3 miles	If directions are known
11	NA	NA
12	20 minutes	It takes a normal person 5 minutes for unfamiliar journey
13	1 mile	Familiar journey
14	NA	NA
15	8-10 minutes	Familiar journey
16	50 metres	About two bus stops
17	About 1 mile	NA
18	15-20 minutes	15 minutes UF
19	Over a mile	NA
20	2 miles	NA

Sighted and BPSP use various navigation systems to aid them in the journeys they take. Table 12 presents the details of the navigation aids used by sighted participants and blind and partially sighted participants respectively.

Table 12 The different types of navigation aids with number of sighted participants (N) using them

Navigation aids	N	Type	purpose	details
Google maps	10	Mobile apps	Planning and navigation	for familiar and unfamiliar journeys
Asking people	7	Human help	navigation	When lost or uncertain, to know direction and destination, follow people going to the same destination
Phone compass	1	Mobile app	Navigation	For direction sometimes
Maps	11	Digital resources	Navigation	To check direction while walking
GPS	1	Mobile app	Navigation	For walking in rural areas
Paper maps	1	Paper maps	Planning	For planning
Waze	1	Mobile app	Planning and navigation	

A detailed analysis has been conducted to the navigation technologies and strategies used by BPSP as shown in Table 13. A detailed section shows the scenarios of using navigation tools/aids/strategy and whether the use is for planning or while navigating. Unlike sighted participants, BPSP rely on additional navigation aids such as white cane and guide dog for obstacle detection and orientation.

Table 13 The different types of navigation aids with number of BPSP using them (N)

Navigation aids N	Type/ Purpose	Details
Ask people 6	Human help/ Planning	Direction, planning the route, route information, street names, look for them on maps for planning

Ask people 8	Human help/ While navigating	Help with navigation, finding the final destination location, number of buildings, in unfamiliar journey, help with crossing. Issues: Sometimes they mislead you
Cane 15	Assistive tool/ While navigating	Used in unfamiliar and evening journeys, used to know where everything is, used only when need help, sometimes used with guide dog, use it and need to be more careful, can be used in narrow paths, use it always, carry it always, use it when not bright, use it for mobility and let people know person is visually impaired, use it for obstacle detection, use it when not using the guide dog Issues: Not as good as guide dog for obstacle detection
Guide dog 7	Assistive animal/ Navigation	Used for obstacle detection, crossing side roads, find entrances, get to destination safely, used for destination identification, rely more on it in the winter, with guide dog walks in the middle of the walkway. Issues: Can't do much in unfamiliar journeys, dog retired and now need to wait for another one.
Google Maps 15	Mobile app/ Planning	Help with how to get there, learn about landmarks and time needed for each segment of the journey with help of others, use it for planning unfamiliar journeys and short walks of about 10 minutes, check for known points of interest, help with remembering the directions, help to know which exit is used to know the direction, turn by turn details of journey with help of someone. Issues: It is not accurate, not successful in identifying pedestrian route, not easy to tell the direction you want to walk, don't use it personally because it doesn't tell the direction, 40-50% confident to use it for positioning, use a map printed out for navigation.

Google Maps 4	Mobile app/ While navigating	Use it in unfamiliar journey to find direction, description of the route is basic, use it while walking, to select easier route while navigating Issues: Needs trial and error to get to the destination,
Memory 6	Own memory/ Planning	To know where things are, in unfamiliar journey to remember direction of travel in case help needed to tell location, use knowledge and experience of route, remember journey details in order, remember landmarks on the route
Remained vision 3	Own senses/ navigation	Can see lit objects in the day, identify buildings vs spaces using dark and light perception, used to avoid obstacles
Smell 6	Own senses/ navigation	Smell of coffee to identify coffee shop, smell of hotel pool bleach to identify location, smell of shops to distinguish between them.
Sound 12	Own senses/ navigation	To look up roads, to help with crossing by listening to cars and moving objects, night is better for hearing sound cues, listening to blow of air between buildings as cue, prefer crossings with sound to know when to cross, use it to know the location of escalators. Issues: Can't hear electric cars, can't hear bikes, rain and wind affect hearing, listen to people when they cross and follow them which is dangerous.
Touch 1	Own senses/ navigation	Touch walls to identify home.
Type of shoes 2	Assistive tools/ navigation	Wearing boots for wet and winter weather to identify tactile information, using mountain shoes to read tactile information
Vibrating glasses 1	Assistive tools/ navigation	Used for navigation previously Issues: Not good for urban areas

Wrist vibration kit 1	Assistive tools/ navigation	Used for obstacle avoidance, can be connected with phone.
Notes on the phone 1	Assistive tool/ Planning and navigation	To make note of route details and recall it later while navigating
Audible note on the phone 1	mobile app/ Planning and navigation	Make note of the route and recall it later while walking
Apple watch 1	Assistive tools/ Navigation	Used occasionally, when taking it will tap on wrist if incorrect direction is taken.
Notes 2	Assistive tool Planning and navigation	To make note of route details and recall it later while navigating
Dictation machine 1	Assistive tool Planning and navigation	To make note of route landmarks and information in the past.
Weather forecast 1	Source of Information/ Planning	Overnight check of weather for planning the journey
Street maps 1	Digital maps/ Planning	Gives idea about useful landmarks on the route
Map printouts 1	Paper maps/ Planning and navigation	Use printed map with the planned route shown.
Monocular 1	Assistive tools/ Navigation	Use it to look up road signs.
Moovit 2	Mobile app/ Planning	Planning unfamiliar journey, to know how to get to the destination, to get the known points of interest and used while walking

	and navigation	It does help but not accurate
Navigation apps in general 2	Mobile app/ Planning and navigation	Used for identification of location of bus stops. It doesn't work for the person.
Navigation technology 2	Mobile apps and tools/ Planning and navigation	Used for planning routes Might use them if they provide high accurate position and provide pinpoint street number
SoundScape 4	Mobile app/ Planning and navigation	Only use it if I want to go around, ok to use, use it for unfamiliar journey direction, use it more, provide 3D audio mapping and connect to hearing aids. Issues: Not a very useful app
Compass 2	Mobile app/ Navigation	Use it for orientation, use it for orientation if get lost.
Citymapper 1	Mobile app/ Planning	To plan the journey including walking part of it
Waze 1	Mobile app/ Navigation	Occasionally used for unfamiliar journey Issues: Used although not suitable for walking.
RNIB Navigator 2	Mobile app/ Navigation	Good to use if you want to be independent Issues: Didn't find it useful, very expensive
NotNav 1	Mobile application/ Navigation	Reads street names, location and orientation. Announces nearest intersection. Good app even if not accurate
Aira 1	Mobile application/ Navigation	Good for long unfamiliar journey, someone guide through camera remotely, camera to be on the chest while walking.
Loadstone GPS 1	Mobile application/ Navigation	Mobile app used for navigation with ability to share POIs.
UK Train Times 1	Mobile application/ Planning	To know train times before departure from home.

London Bus 1	Mobile application/ Planning	Likes using the app because it uses clock directions
Buscountdown 1	Mobile application/ Planning	Bus information and time, good for planning
Tube Maps 2	Mobile application/ Planning	To know about tube station, need to be taken.
BeMyEyes 1	Mobile application/ navigation	Used for orientation
Blindsquare 2	Mobile application/ Planning and navigation	For planning unfamiliar journeys, use it while walking to check for known points of interest, use it when meeting other BPSP who use the same app to share location with each other.
Apple maps 2	Mobile application/ Planning and navigation	Unfamiliar journey planning, check for known points of interest, use it while walking, use it for GPS.
TFL Planner 3	Mobile application/ Planning	Which station to start from and how to get to the station
Not using digital apps and maps 1	Mobile apps/ and assistive tools/ Planning and navigation	Issues: Can't see the details and the screen reader can't pick up directions on the map
Not using the phone 2	Mobile apps/ navigation	Issues: Makes the user be vulnerable, makes the user be likely to be mugged

It can be noted that Google Maps is the most common used navigation app by BPSP. In addition, seeking help from people is the common approach to aid their navigation.

> "Yes. As soon as I get to where I need to be, I use Google Maps, turn the navigation thing on, have my head sense it and I can hear it whilst I walk. It will say where you need to go first" P14.

In contrast sighted participants might not necessarily be using navigation aids.

> "So, without using any navigation, it can't be anything that's fine with navigation without notice. It's just about the journey, but it's walking. So, it doesn't matter what's a systems technology you can use". SP3.

3.3.4 Route Selection Factors

In this section, the key route selection factors and personal strategies used by BPSP are presented. It can be noted that the analysis of the data includes identifying the nature of each factor whether it is useful as a landmark or risk for personal safety. Interestingly there are route selection factors that are identified as useful and risk at the same time. Route selection factors are widely covered in literature such as the works by A. Alkhanifer and S. Ludi (2014); (Helal et al., 2001; Miao et al., 2011a; Ruffa et al., 2015) . However, the findings of Table 14 contains novel information about the route selection of BPSP that has not been covered in literature. There are elements of walkway which poses risk for a person while it can be used as a landmark by another such as bollard and bus stops. In addition, one environmental situation might stop an individual from getting out while most environmental conditions are fine for another.

> "Snow can be a challenge" P11,

> "The rain doesn't bother me too much but it can make it hard to hear where you going" P19,

> "All the environmental situations are fine for me" SP10.

There are a serious of common risks on the walkway that are creating safety concerns for both sighted and BPSP such as bicycles.

> "Yeah, bikes are big concerns to me both when crossing and on the pavement" P18,

> "For me things that might affect me could be cyclists because when you're walking sometimes cyclists can become a bit fast" SP8.

Table 14 Detailed route selection factors with their Themes, number of participants (N) mentioned them and whether Useful (U) or Risk (R)

Route selection factor Codes, Themes N, U and/or R	Details
Walkway	
Trees Surrounding 7 5R 2U	Obstacle, uneven surface caused by tree, overhang parts, not cut parts, things falling from trees, tree roots create uneven surface and dog carry on as normal, trees with fence easier to go around. Count number of trees before turning, going to the side of the road with less trees
Bushes Surrounding 4 R	overhang parts, not cut parts, need to be familiar where it is, don't like it, go into the eyes. Cannot pick it up, unavoidable particularly in the dark
Bins, Item 1, R	When people take their bins outside, element of bad route
Dumped items Unexpected item 2, R	Unexpected, can be picked up by cane
Porch light Surrounding 1, U	Used to identify home entrance, without it might not find home.
Buildings Surrounding 13 9U 2R 2U-R	Corner building easy to identify, shops, unique buildings (big, shape, colour, etc.), building lines for orientation, locating the same building on the map, use of building coffee shops, pubs, restaurants, pharmacy.

	Used as landmark for position. Finding same building on map and in reality, for positioning. Difficult to identify the correct building, when design is similar and difficult to identify the correct shop, shop furniture layout, franchise buildings create confusion.
Location with multiple entrances/exits Surrounding 6 2Up 4R	Concern of selecting the correct entrance as destination or the correct exit as origin for building with multiple entrance and exit. Locating the entrance of a building is difficult. Need to be within 0.5m from entrance to find it and pick it by cane. Ask people to know which exit. Look on Google Maps to know at which exit they are. Always select the wrong exit when they are close to each other.
Parked cars Unexpected item 6 R	Unexpected, should not be there by low, hardest thing to deal with, guide dog cannot make way in the narrow path remained need to go on the road which is dangerous.
Slippery walkway Texture 1 R	Can't do anything about it, because it is not spotted
Roadwork Restricted area 11 10R Up	Unexpected, nature of the work and area, Gap under the fence not picked by cane, avoid it, how to go around it, slow walking, may end up on the street, construction sites, difficult to deal with, need to go to the other side, poor directions sometimes, the ones not safe like wobbly bridge over gap with no rail, tapes instead of barriers cane cannot pick it up.
Phone box Item 4, 3R 1U-R	Used for positioning as landmark, it can be a danger (like an obstacle)
Bus stop location 4, 3U R	Used as landmark, its position might make it dangerous
Post box Item 5, 4U 1R-U	Used as landmark to find position, element of bad route particularly the ones next to wall. It is obstacle, but also used as landmark
Bench	Used to find position. Element of bad route.

Item 2, R U	
Moved/unexpected items Unexpected items 3 R	If it is unfamiliar journey, don't know where things are. There are unexpected permanent or movable items like coffee shop furniture.
Change in flooring texture/tactile Surface texture 8 7U 1U-R	Good route should have good tactile reference, don't like route with no tactile cue, or tactile confusion from lots of different type of surfaces. Pavement type should be good. Tactile reference can be picked up by shoes particularly mountain shoes. Tactile cues are picked up by cane to know which side of the walkway. Used to know the position and wayfinding.
House gates open onto the walkway Unexpected item 2 R	Obstacle when they are open onto the pavement. People leave them open onto the pavement and they obstruct the pavement.
Shared driveways (no walkway) or spaces or paths Shared path (no pavement) 8, R	Difficult to keep on track, doesn't like it, nothing to use to keep on track. Dangerous with cars and bicycles. Element of bad route.
Road names Surrounding 6 1R 4U 1R-U	Difficult to read the ones without contrast and frame, can be used as a reference for navigation, used for direction and location, difficult to see the ones not marked clearly, used in case of uncertainty to ask people. Taxi drivers identify destination by street names. Use mobile app to announce the street name.
Place names Surrounding 4, 2R 2U	Used to know position, used as landmark, signs need to be lower at horizon level and with contrast, they are not clear,
Parked bikes Unexpected item 2, R	Unexpected it is an obstacle
Cycling racks	Difficult to identify in the night

item 2, R	
Stairs Walkway element 4, 3R 1U	Not easy to use, underpass with stairs is difficult. Element of bad route. It is useful to have wall or rail to make it identifiable and safe
Steps Walkway element 6 R	Need to be clearly marked, unmarked ones are of concern for the user, try to avoid them, difficult without guide dog, steep steps, cannot be seen in the dark in distance, sometimes bump into them. Difficult to know about their nature. Difficult to deal with because this relies on sight, down step start points difficult to identify
Obstacles Items 10 9R R-U	Mostly street furniture, if lots of them it is a bad route, difficult to deal with them if not knowing about them in advance, difficult to deal with without guide dog, unfamiliar ones are difficult, obstacle location in relation to the return journey (i.e., walking along nearside rather than offside), guide dog help with that.
Bright lights/ streetlights Surrounding 11 9U 2R	Useful for navigation high contrast, brighter is better, used to locate streets, help the guide dog to see in dark, useful in dark, used as direction cue, element of good route. Too bright affect going out and user needs cane. Not good for vision. Able to see bright level dependent
Bollard Item 4 R	Put light on them to be visible, caused injury in the past, difficult when they are lower than waist level, make the pavement narrow. Element of bad route
hole Walkway element 1, R	When it is windy can't identify it neither seeing nor cane detection.
Revolving door entrance/exit Building design 1, R	Not ideal for the person.
Curb Walkway element 7	Edge of curb useful for guide dog to identify, up and down curbs useful for planning journeys and counting, tactile curbs are used

4U 2R 1U-R	as reference for direction, follow curb for orientation, curbs with contrast are useful, dropping curbs No curbs or flat curbs might lead you on the road, dog cannot identify them, don't like curbs with no colour contrast, user prefers no raised curbs
Overhang item Walkway element 5 R	Unexpected for the user, need to be higher, guide dog might help identify it, sometimes like when it is raining guide dog is busy with other aspects and might not pick it up, sometimes guide dog misjudge the height of the item and might think it is high enough but it is not, guide dog doesn't help with locating it. User had lots of near misses with overhang items
Narrow walkway Walkway design 8 R	Difficult to navigate, more difficult with parked cars, difficult to overtake people, try to avoid them because there is no room, considered as a bad route element. Might be caused by concrete barriers and people bump into each other busy on the phone, caused by parked cars.
Lamp post Walkway element 6 4R 2U	Difficult to see the dark or shiny ones, try to avoid it on the walkway, if covered by leaves might not pick it up hence bump into it. Used as a cue for navigation, walk close to it without cane.
Street map stands Walkway element 1, R	Difficult to know the orientation.
Cycle barriers on pedestrian path Walkway element 1, U	Used as landmark
Building lines Surrounding 2, U	Used to go in straight line or follow path as well as like a landmark
Automatic doors Building design 1, U	Easy to enter and find

Pavement condition/Uneven surface Surface texture 7 7R	Stepping higher to avoid trip over, pavement should be in good condition, pavement should be smooth then element of good route. Might bump into it. Crack in the pavement is concerning, broken and worn pavement, element of bad route, need to be picked up by cane
No Colour contrast of pavement Surface texture 1, R	If no contrast, can't see the change in pavement which will result in trip over, good route needs to have good contrast pavements.
Unique colours Surrounding 1, U	Anything with unique colours and high contrast colour used as cue.
No high colour contrast on parts of walkway like stairs Surface texture 1, R	Can't see them, might walk/bump into
New items Unexpected item 2, 2R	Don't know about it and might walk into it.
Signposts Walkway element 1, U	Used as landmark
Parks Surrounding 1, U	Used as landmark for positioning
Side roads Walkway element 1, R	Avoid where possible particularly for UF journeys
Main roads Walkway element 2, U R	Stick to it where possible particularly for UF journeys. Don't like it because of fast cars.
Traffic light Walkway element 1, U	Used as landmark
Wheelie bags Unexpected item 1, U	Very good to know rich information about the walkway and following the path

Slope Walkway element 4, 1U 3R	Known slopes indicate position, not easy for walking, when they feel like steps but they are not
Door number Surrounding 1, U	Used to identify position in relation to the destination
Baby pram Unexpected item 1, R	Concern about hitting the pram with cane and the concern from family as a result of that
Note board Unexpected item 1, R	Movable obstacle
A board Unexpected item 1, R	Difficult to identify without guide dog
Street furniture Walkway element 1, U-R	Used as landmark, might be obstacle as well
Clear landmarks Walkway element 1, U	Useful to know the position
Roundabout Walkway element 1, R	Try to avoid routes with roundabouts, difficult to cross at roundabouts as cars sometimes don't stop and that makes the user hesitant to cross.
Bicycle barriers on pedestrian path Walkway element 1, U	Used as landmark.
Concrete barriers Walkway element 1, R	The ones on the pavement to stop the cars, but they narrow the path of walking and people on the phone might bump into others.
Newspaper stands Items 1, R	Difficult to identify without guide dog
Tables and chairs Items 1, R	Difficult to identify without guide dog
Other walkway users/ other modes of transport	
Electric cars Other modes of transport	Can't hear them approaching

2, R	
cars moving in opposite direction Other modes of transport 1, R	Cars not following the direction of travel particularly in the residential courts.
Car's light Other modes of transport 2, R	Glare from car light in the dark when navigating.
Busy walkways Other users 6, R	Cannot see ground, concern over going downstairs when people rush and is busy
People's help (asking for information, following direction) Other users 3, 2U R	People can help with directions. Sometimes people give incorrect information
People unaware of the surrounding (i.e., on the phone)/ not aware of rules Other users 2, R	Bumping into people
Bicycles Other modes of transport 6, R	Dangerous in shared walkways, can't hear them when they pass at crossings, not obeying the traffic rules, appear suddenly, not stopping for you.
Direction of travel of traffic Other users/modes of transport 5, U	Traffic includes all modes of transport, useful to know to help with crossing, know whether traffic is one-way, to know direction of travel of cars and pedestrians, to know own position.
Cars blocking the crossing area Other modes of transport 1, R	Crossing area is expected to be clear and not ending up bumping into cars parked there.
Non-stopping vehicles	Vehicles not stopping at crossings make it unsafe to cross.

Other modes of transport 1, R	
School pupil Other users 1, R	After finishing school, they run around with scooters, might bump into.
Crossings	
Crossings (intersections) Intersections 11 8U-R U R Up	Location of crossing, waiting time at crossing, frequency of crossing on the route, busy crossings, avoid crossings, if possible, use crossing to line up (orientation).
Location of crossing Crossing 1, U	Used to identify location while walking
Many crossings on route Crossing 1, R	Difficult to deal with
Tactile pavement at crossing Crossing 5, U	Used to identify points of crossing or whether there is crossing, used for positioning, used for orientation, very useful. Picked up by cane and help crossing.
Staggered crossing Crossing 2, R	Difficult to use, need to know the design (left and right), need to wait more than once to cross all the road, tricky to cross
Levelled crossing Crossing 1, U	Easy to cross, concern for give way by traffic
Zebra crossing Crossing 3, 2U R	Safe to cross, cars might not stop
Multi-stage crossings Crossing 2, R U	Whether it can be completed in one go or more,
Crossing in night Crossing 1, R	Challenging
Good (safe) crossing, Crossing 1, U	To be safe to cross

Controlled crossing Crossing 2, U	Preferred, with audio or rotating cone control
Crossing with sound Crossing 5, U	preferred over rotating cone, very good, quick and safe crossing
Crossing with rotating cone Crossing 4, 3U R	Rely on it, even though colour and sound available. Second preferred after crossing with sound, not good, might not be able to reach it, might be dirty.
Uncontrolled crossing Crossing 3, R	Not safe, need extra care, better if there is safety zone in the middle, don't like it, most difficult task to cross, need to listen to traffic and judge for crossing
Underpass crossing Crossing 2, R U	Safer, difficult to use when there are multiple exits.
Controlled crossing without sound Crossing 1, R	Considered as an element of a bad route
Controlled crossing without cone Crossing 1, R	Considered as an element of a bad route
Side road crossing crossing 1, R	Guide dog helps with the crossings
Environment	
Rain environment 11 U-R Up 9R	Amount of rain, puddles, slippery walkways, cane movement, cane/guide dog with umbrella Makes the phone wet, need umbrella in one hand, need to cover the head blocking sound.
Leaves on the ground, environment 10, R	Slippery, cover tactile information on the ground, number of leaves accumulated, cover holes and curbs, walking pattern
Snow and ice environment 15, R	Covers reference landmarks and edges (curbs), difficult for guide dog/cane, wet and slippery surface, difficulty with walking, causes sun glare, hate it.

	It might be useful creating high contrast walkway in relation to the surrounding
wind environment 7 6R Up	Sound distraction, dust in the air, unexpected movement of loose objects, difficulty with visibility, discomfort experience. Difficult for cane/guide dog movement, difficult for crossing the road, causes disorientation, very windy is difficult
Night environment 12 9R 3U	Difficult for crossings, visibility nature, safety (drunk people around), night blindness, slower walking, use cane more carefully, feel lonely, need extra preparation/tools, better than day for navigation because of eye condition, like it because it is quite and hear sound better. Prefers darkness to see better
Extra cold environment 1, R	Need to wear gloves so less feeling of feedback from cane
Sun light environment 4, 3R U	Causes sun glare, need hat to improve visibility and colour recognition, can see better. Sensitive to day light.
Puddle environment 4, R	Can't see them, biggest problem, need to make way around
Autumn season environment 1, U	Good time for walking, because the sky is bright but it is not sunny.
Quiet surrounding environment 1, U	Minimum noise preferred while walking

3.3.5 Uncertainties

Pedestrians face many uncertainties while walking in outdoor environments. BPSP are subject to more uncertainties due to the lack of effective visual observation and inaccessibility of the environment and infrastructure. When something goes wrong, participants mentioned their strategies in dealing with the uncertain situation that includes seeking sighted assistance and technology use.

> "Well actions number one two or three probably are all the same. Ask a question, find a pedestrian. Do they look friendly. Hopefully they do. "Excuse me can you help me". "I think I might be lost". "I'm trying to get from here to here". I'm going the right way and then they turn around and say "I don't know where I am" P6,

> "If I realise that I'm not where I think I am. I would consider myself lost and. I guess I would just open up my phone app to reorient myself. And even without using the sun or anything like that, the phone, Google Maps think or maybe it's the I think it is Google Maps. It has a very coarse heading yet shown on your little icon where you're walking" SP2.

Table 15 shows the strategies used in uncertainty times when the person is unsure where they are or when they realise that they are heading in the wrong direction.

Table 15 The strategy of participants (P) in dealing with navigational uncertainties

P	What to do in uncertainty, off route and getting lost
1	Phone a person I know (instruction or come and collect me) or ask someone around if I am confident enough (to know location then share it with someone I know)
2	Ask for help from people around
3	Ask people around, calling someone is not ideal they might be busy or be worried and give up their work
4	Use phone to check where he is
5	Going on Google Maps then Cityplanner app
6	Ask people around
7	Stop and put yourself in the correct orientation using the available cues, go to a place where easy to orientate

8	Ask someone for help around
9	Stand still and ask public for help to take the user back to somewhere identifiable
10	Stop and check surrounding information with the phone apps, then walk a bit in different directions to work out the position
11	Use phone to check the location, explore the surrounding
12	Retrace steps and go back which 90% doesn't work, get stressed about it
13	First, ask a member of public
14	Check Google Maps to check for position and potential alternative routes
15	Ask people
16	Ask people
17	Ask people
18	Google Maps to check where I am and where to go
19	Stop and wait a minute to see if someone helps
20	IF there are shops, then asking them

3.3.6 Definition of Good and Bad Routes

The reason of asking this question was to understand how a good and bad route looks like to each individual participant. The importance of this data is that it can be used to improve the design of current and future walkways when shared with the relevant authority. Participants had different views of good and bad routes. A good route is easy to navigate and know the location of the obstacles. A good route will have accessible design for the pedestrians.

> "A good route is a route that it is easy to follow. You are aware of the obstacles in advance. Good route where whether there is

> daylight or night the lighting is good on the route, because I still use a bit of sight to get around. The route that has got road pavements because this is like a dream route basically and if there are any obstacles, they are clearly visible so they don't disappear come and flash with the environment like the phone boots are all black and stuff they get lost and like you can't see them" P15.

From the perspective of a sighted participant, a good route is a very familiar route.

> "A good route would be as familiar as possible. It will have a large percentage of it being familiar" SP1.

On the other hand, a bad route is opposite to a good route where there are obstacles and roadworks taking place.

> "A bad route is all the things I've said you know in Contrast to good route. If there is any Works taking place that doesn't has enough directions. You know if they created a little path on the site then is not marked properly so end up fiddling around and getting yourself stuck in those little mazes" P15,

> "So, a bad route yeah mainly It will be Some places that contain a lot of obstacles" SP7.

Table 16 shows the definition of "good" and "bad" routes by each participant. The response of each participant is presented in one row of the table to compare and contrast the individual definitions easily.

Table 16 definition of "good" and "bad" routes by participants (P)

P	Good route	Bad route
1	very straight forward and without obstacles. Without unexpected	not 100% sure, done something wrong like lost track of counting the number of crossings,

	obstacles like buses and bins. IT is something which is simple	remembered something wrong like number of lefts and rights, you are lost
2	straight crossings or underpass for crossing	multi stage crossings like the staggered one which involves going halfway and then left or right then crossing the other half in another go
3	lots of street lights, there is people, not quiet, a little busy but not much, not peak hour.	peak time, congestion, too busy
4	good tactile references for crossing and other purposes audible references labelled for Soundscape app for example straight lines. Quite route is good and a little busy main road is good	shared places unfamiliar roadworks and trip hazards that don't know how to make your way around
5	direct, main roads and has bus route option	goes through lots of narrow lanes and walking through areas that have obstructions on the pavement
6	having pavements in good condition not having too much furniture in the middle well marked furniture elements any number of useful landmarks tactile pavement of crossing picked up by cane	sudden road works or pedestrian way works, traffic lights with no audio signal or revolving cone not being able to find the entrance of the office or the building

7	predictable good design, easy to remember, grid pattern, makes you not require looking at map, reach tactile and auditory information is present, crossings with audio signals, proper curbs with good contrast with the road, tactile information is present or the road is following a logical patter	broken up paths, lots of different type of surfaces, tactile confusion, presence of tree roots, road feels like footpath, lack of directional cues, no auditory cues, sudden zigzags, unpredictable routes, staggered crossings where you are limited and don't know it is a road or island and where to turn also cane might go under cars., too much noise affect hearing where people are walking flat and shared spaces are terrible
8	easy crossings, straightforward, marked crossings, corners, dropping curbs, smooth paving, friendly people, few obstacles, traffic with audio signal	narrow pavements, unmarked crossings, lots of obstacles, cars parked on the pavement, shared spaces, where destination is with narrow entrance or inaccessible entrance or multiple
9	minimise left and rights, minimise crossings main roads, maximise using safe crossing places, busy with pedestrians so people around if needed help	complicated in terms of crossing open or shared spaces, lots of left and right turns, lots of crossings on uncontrolled undefined areas, quite quiet
10	a route you know where you are going, good instructions for a UF route, things go smoothly	constructions happening on the route, road blocked, same route but things changed and ned to re-route

11	Wide pathway, don't bump into people, it wouldn't include multiple junctions, because Apple Maps get confused sometimes, so it would be a very direct route,	Not very well lit, really busy, narrow walkways, walkways leading to area with multiple exit which are close to each other, no clear landmarks
12	routes with controlled crossings if no crossings at all that is great People on route understand they need to give you more space and time useful tips available	People don't give space and time pavement cracks when it is crowded can't use cane at all like rush hour which is stressful and irritable
13	no obstacles, no barriers, no benches, no bollards, no post boxes particularly the ones next to the wall, no uneven pavement or curbs	stairs, roadworks, barriers, bollards, uneven pavement
14	does not include huge road, no high crossings, not busy, easy to walk on, no gaps, no uneven surface, light in dark	has no traffic light crossings (controlled crossings), main road cars not stopping, no enough lighting
15	easy to follow, aware of obstacle in advance, daylight, lighting in dark, broad pavement, clear and visible obstacles, high contrast lamp posts	No contrast on items, work place with poor directions, temporary left items on pavement like bikes,
16	safe to cross like traffic lights (not zebra crossing), clear pavements, no sudden work area	no traffic lights with cone or audio, unexpected work area, shop signs are high not visible on horizon, name of roads with contrast and frame around them

17	Quiet, familiar and can change route if needed	design of shops is similar and can't distinguish them
18	destination is clear which has multi entrance, directions are correct on systems, traffic information available like how and where to cross a specific dual carriageway road	when technology takes you to unwanted routes like fly-over and underpass which include stairs as well so a route which is un known and can tell at the beginning on Google Maps. Also takes you off pavement area
19	No shared surfaces, no a-boards, no bikes parked on pavement, tactile crossing that go all the way across the pavement, crossing with sound, vehicles have noise, staff is there if applicable	shared surface, no tactile pavement, crossing boxes not beeping, rubbish is everywhere, a-boards are everywhere, bikes and cars parked on the pavement
20	no too many changes of direction, easy to follow instructions, not crossing too many roads if don't have to	lots of directions, lefts and rights are not clear to take when it is very busy and can't check things on the go so need to stop and double check on the right path, no enough signage, place names are not marked clearly

3.3.7 Route Selection Strategy

Participants adopt diverse route selection strategies when navigating outdoor environments, based on factors such as speed, distance, and safety. Some might prioritise the easiest route when it is familiar journey, which would involve choosing paths that allow for a more straightforward progression, such as wider sidewalks or less crowded areas.

> "I will say my priority will be the easiest way to reach my destination, regardless of how difficult maybe the road or maybe how safe it is" SP7.

Others might opt for combination of route choices such as the shortest and simplest route which involves less physical exertion and potentially less navigation complexity.

> "If places I don't know, I go for the shortest and simplest route, because I can't take complicated buildings all very similar to me" P20.

> "Obviously, safety… I go for the safest route for unfamiliar places" P20.

Safety is also a critical consideration; therefore, routes with fewer obstacles, less traffic, or better tactile paving are often preferred. Each individual's choice ultimately depends on personal comfort, familiarity with the environment, and their proficiency with navigation aids and skills. These strategies highlight the adaptive capabilities of blind and partially sighted individuals in navigating the complexities of outdoor environments. Table 17 shows the route selection strategy of BPSP. Interestingly, one of the findings was about saying something that implies a completely different or opposite meaning. For example, several times participants mentioned "shortest" meaning "fastest".

Table 17 Route selection strategy of the participants (P)

P	**Route selection strategy**	**Details of the route selection**
P1	Safest	Safest even if it is longer Then quickest but not at risk of safety
P2	Best	Go through routes and pick the best not necessarily the quickest picking the route to tube station rather than

		bus station because tube staff provide good assistance and available
P3	Safest	Depends on the area going to, used shortest routes when younger, now takes longer one if it is safer
P4	Safest	Routes with controlled crossings and straight lines After safest, simplest then fastest
P5	Quickest or shortest	Unless it is an area not easy to walk around
P6	Safest first and shortest	Try to be safe and not waste time
P7	Will consider safe if it is an option	Whatever route is worked out, it doesn't matter how it is. A route that is predictable and user and systems are in control considering a route where taxi and bus are available to use in case of getting lost
P8	Shortest but safest	
P9	Simple route even if it is longer,	To minimise risk of getting lost and is easier for user and dog to learn the route and easier to remember by the user less left and rights and more straight particularly for unfamiliar journeys
P10	Fastest but less crossings involved	If less crossings and not fastest user will consider that route
P11	Fastest	Still have useful sight, so no concern about safety. It might not be reflected in the used navigation apps
P12	Safe and easy	Safety is the primary thing even if it is longer and not easy
P13	Familiar route	Knowing about obstacles

P14	Fastest	If it includes roundabout or busy roads, then prefer a route without those
P15	Familiar route	Try to find shortcuts, safety is not a matter
P16	Safe even longer	Quick and alternative routes if they are safer
P17	Quiet route	Back streets and more peaceful routes
P18	Fastest route,	On Google Maps always select the fastest route. Selecting the shortest time of walking
P19	Safest route and least-complicated	Less likely to make a mistake, even if it is longer
P20	Safest or shortest and simplest UF	Safest if there are distinguished landmarks, if no identified landmark suitable for the user, then shortest and simplest route

3.4 Discussions

This study highlights the route selection strategy of people with different sight conditions in familiar and unfamiliar journeys. The approach taken enabled obtaining detailed information about the navigation experience of BPSP. Moreover, the data was compared with the sighted participants experience to understand the similarities and differences. The study findings revealed a variety of preferences and needs of sighted and BPSP. Individuals prioritise routes based on safety, time, distance, familiarity and hedonic reasons. Regardless of sight condition, unfamiliar journeys are the difficult ones and require more navigation support for planning and during the journey. Table 18 lists some statements from the participants. each row represents the statements from each participant whether quoted or extracted. This way, the navigation experience and strategy of each participant can be presented individually to better understand individual experiences and concerns.

Table 18 Statements from participants (P) about their navigation experience

P	Statements from the participant about their experience
P1	"I think the hazards would all still be the same, but with unfamiliar surroundings it's a little bit more difficult because you just don't know where anything is" "I don't see road signs even if they are big enough, I don't see them"
P2	"You don't always go for the quickest you go for the best route"
P3	"When I use taxis and cabs, they know by street names, they don't know by letter box "
P4	"So, for a five-minute journey, it took me about half an hour to find this bar, because I couldn't find the front door"
P5	"It did take me a few months to work out what was the best exit for me. It wasn't something that was very easy when I first came"
P6	"The problem of the first junction is that there are traffic lights but no audio signal and no cone that I can feel revolving underneath" "I do everything in my power not to do unfamiliar journeys on my own, because I find that much more difficult"
P7	"Now I cannot see anything at all and my registration is still the same" "I then have to walk further to get more navigational cues to find out where I am" "I've done it years ago but they've changed the route so I had to use different cues to find my way up to the exit"
P8	"If Google Maps says it will take you 45 minutes to walk to this destination, I guarantee you it will not take 45 minutes it will take much longer."
P9	"In London lots of people are tourists themselves so they don't know either"

P10	"I would walk if it is something like 2-3 miles, I wouldn't mind walking that if I have good directions"
P11	"I only use Apple Maps, because I am familiar with it and because I don't really believe there is anything else out there right now that would be as good as what I've got" "I will always tend to one way or the other to make sure that my location is actually picked up through GPS"
P12	"It will probably take me about 20 minutes, when it takes the average person five"
P13	"Leaves are terrible terrible terrible, cane always get stuck in it"
P14	"I use the taxi service to go home specially in dark time"
P15	"There is a lot of anxiety a lot of stress till I get to my end point" "The technology is there, but the hardware is not suitable"
P16	"If I was on my own, I will be asking all the time, because I don't know where the safe places are to cross" "I can't read the name of the roads"
P17	"I have got an iPhone, but I haven't actually progressed to access the GPS" "I think I am very aware of my environment" "with the guide dog, she takes care of all of that" "I do feel safe when I am out and about"
P18	"I struggled to find out which direction on Google Maps, it can be a bit confusing sometimes" "I think it is cyclists that bother me on the pavement" "because I am quite sensitive to light anyway, I look down more than up"
P19	"Navigation is about check points" "Pretty busy road which is not pleasant on walking experiences, but it helps with navigation" "Does that route take me somewhere that I don't want to be on my own" "It is really hard to know you are going straight"

P20	"Because I have some useful sight for navigation, I have not thought about using technology for navigation" "franchised chains like McDonalds confuse me while walking"

The most common navigation systems used by sighted and BPSP included Google Maps, because of being freely available and having some accessibility features. Interestingly, all sighted participants stated that they use Google Maps. When it comes to route following strategies, there were similarities and differences between participants. It is obvious from some of the responses that route choices and strategies are down to the individual preferences first then considering other factors such as safety. Learning from the individual experiences will help in addressing the issues and improving the design of the existing navigation systems. Both sighted and BPSP mentioned about using compass for orientation. However, the uncertainty in the compass measurements makes it an unsuitable tool for BPSP. This is because of the difficulty in confirming the precise direction of travel without visual cues. The lack of suitable tools for verifying directions and the uncertainty in compass measurements further complicates navigation for BPSP, stressing the need for more reliable, inclusive technologies that account for non-visual navigation.

The built environment needs to be accessible for BPSP to accommodate their needs. Improving the accessibility of the built environment for BPSP will contribute towards its accessibility for sighted people. The built environment contains a variety of landmarks and obstacles that individuals might come across and interact with. It is important to address the requirements and needs of the individuals with various sight conditions separately. This is because the amount of the available and useful vision for navigation is directly related to the definition of landmarks and obstacles for each individual. For instance, sighted participants mentioned about using high-rise buildings and buildings with

distinguished designs and colours as landmarks. However, these buildings are not useful landmarks for blind people, because the buildings cannot be seen by them to be considered as landmarks while navigating. Likewise, sun's position in the sky was mentioned as a useful navigation cue for orientation by sighted participants only. On the other hand, building wall texture and smell has been used by BPSP as navigation cues to identify location and orientation.

To enhance the navigation experience for BPSP, both the built environment and technological solutions must be redesigned to better accommodate a range of sight conditions, ensuring that environmental cues and navigation systems are accessible, reliable, and easy to interpret for those with limited or no vision. There were a number of limitations associated with this study including difficulty of getting participants within the BPSP community. Without the help of RNIB, it would have been difficult to get participants. Another limitation was not getting older participants during the course of the study campaign. whilst the interviews were in-depth and elicited a rich dataset, the sample size for each group was relatively low and as such the findings may not necessarily be generalisable to the respective target populations. Another limitation is that some responses were irrelevant or incomplete to certain interview questions. This has been taken into consideration. However, the inputs provided valuable insights into the navigation experience of both sighted and BPSP.

3.5 Chapter Summary

This chapter outlined a major study of the PhD which investigated the factors that influence route selection and navigation decision making of BPSP. Using thematic analysis, the data were analysed and presented in detailed tables and written text format. In addition, the findings of the study revealed that BPSP have unique navigational requirements that are not adequately addressed by current navigation systems. This chapter achieved objectives 1 and 2 of this thesis. The next chapter

utilises the navigation requirements elicitation of BPSP in the form of expert interviews with mobility trainers.

CHAPTER

FOUR

4 NAVIGATION REQUIREMENTS OF BPSP

4.1 Chapter Overview

This chapter presents the study of interviews with mobility specialists who provide training and support for blind and partially sighted people about orientation, mobility and independent navigation. The study focused on highlighting the navigation requirements, challenges and preferences of blind and partially sighted people. Navigation requirements have been divided into specific components to focus on each component at a time. In addition, specific navigation scenarios have been discussed to highlight the relevant requirements and challenges of each scenario.

4.2 Methodology

4.2.1 Study Design

The navigation requirements of the BPSP include important factors that require effective consideration, including safety, simplicity, and efficiency. According to Bozeman et al. (2015), in the context of BPSP, the importance of safety and the ability to navigate independently take priority over factors such as distance and duration of travel. Indeed, it is evident people have varying needs and demands. It is important to consider the individual-level navigation requirements of BPSP in order to facilitate inclusive design. Moreover, there is a need to identify new requirements, because requirements change over time due to environmental, technological and personal changes over time.

The choice of the study method was based on getting rich data from experts in the navigation field of BPSP. For that purpose, semi-structured

interview was selected so that the experts have the chance of adding as many information and in the way they like. Expert interviews have been used by researchers to identify design needs. Andre et al. (2007) used expert interviews with domain experts to highlight the journey planning needs. Zimmermann-Janschitz et al. (2017) used expert interviews with mobility trainers to develop user profiles for clustering the mobility needs of BPSP. Therefore, it is crucial to consider expert inputs to understand the needs and preferences of BPSP from a different perspective.

The mobility trainers are not the only experts in the field of navigation of BPSP. Policymakers, urban planners and technology developers are also experts that can provide invaluable expertise on the legal, technological and financial aspects of navigation. Monahan (2023) interviewed various technology developers to discover new design aspects not covered in literature. On the other hand, Cushley et al. (2022) interviewed town planners and architectures as stakeholders to understand their views about the built environment's design for the navigation of BPSP. This study provides valuable insights from stakeholders with diverse expertise that have not been addressed by experts such as mobility trainers. For instance, Planners and architectures claim that the shared spaces' problem is not about the concept itself, but the people's behaviour and the design make it challenging for the navigation of BPSP. It should be noted that in general, there is lack of research involving policymakers and urban planners in the design of navigation systems for BPSP.

Cognitive Task Analysis (CTA) method was used which allows the users to talk about the navigation requirements of BPSP. This allows the exploration of the user requirements elicitation by breaking the task into different parts. This also involves understanding each part on its own and the relationship between the parts all together. This approach has been done differently accounting for the user requirements for each aspect of the navigation. The study design and interview process benefited from the Working Minds Guide book (Crandall et al., 2006). The study design

has been reviewed and approved by the Ethics Committee. Table 19 shows the probing questions asked during the interviews.

Table 19 Interview questions

Nature of support	What is the nature of support you provide for blind and partially sighted people (BPSP)?
Number of BPSP trained by you	How many BPSP have been supported by you (approximately)?
Willingness to get support	Are BPSP willing to get support?
Identifying BPSP who need to get support	How do you identify individuals who need navigation support?
Nature of navigation in specific scenarios	**Easy** journeys (like going to the local shop) **Hard** journeys (like taking a route that involves complex crossings) **Uncertainty** within the journey (like being unsure about the current position)
Challenges of navigation	What are the main challenges BPSP face while navigating?
Navigation requirements	What are the main requirements of navigation for BPSP that need to be accommodated (for designers, councils and relevant organisations)?
Preferences	What are the main navigation preferences BPSP have?
Needs	What do BPSP say about their needs for navigation?
What should be done	What is needed to be done to enable BPSP navigate independently?
Nature of navigation support	**What** type of navigation systems are used by BPSP (apps, devices, tools, etc.)? **What** is good about the current navigation systems? **What** are the weaknesses of the current navigation systems?

	How would an ideal navigation system look like to enable BPSP navigate independently (positioning, maps, interface, routing, guidance)? **How** likely is it BPSP might use a smartphone-based navigation system to help them navigate independently?
User profile content	Part of the PhD, I have created user profiles that contain data about navigation of BPSP (personal data and other relevant data). The user profiles can be incorporated into navigation system and can be used to inform the design when shared with relevant organisations: ▪ What do think is important to be included in the user profiles (personal data and other relevant data)? ▪ If the user profiles to be used for mobility training, what structure would you prefer and the nature of content?
Extra question for any extra input from the participant	Is there anything else you would like to ask/add

4.2.2 Recruiting Participants

Similar to BPSP recruitment. It was difficult to get participants who are mobility trainers. With the help of RNIB, the first participant was found. Consequently, the rest of the participants were recruited through snowball sampling.

4.2.3 Accessibility of the Study

A standard format document of the study materials was prepared for the mobility trainers who don't have accessibility requirements. In addition, there was a mobility trainer participant who was registered blind. The study materials were made accessible to that participant.

4.2.4 Study Process

Ten mobility specialists were interviewed. The interviews were performed using phone call or Microsoft Teams. The interviews lasted around one hour. The data collection involved audio recording and note taking. Mobility Specialists were asked about their expertise concerning the challenges, preferences and requirements of navigation of blind and partially sighted people. The nature of navigation of BPSP was explored and it was looked at the current state of their navigation and what support was provided/need to be provided to them.

4.2.5 Data Analysis

The audio recordings from interview discussions were transcribed. Thematic analysis was then conducted to identify recurring themes and patterns in the data. The thematic analysis approach by Braun and Clarke (2006) was used to analyse the study data. To better understand the data and get familiar with the responses, interview data was transcribed and coded looking at the key inputs from the users. The transcripts were coded and categorised into the general themes of challenges, requirements and needs and preferences of navigation.

The analysis process involved iterative coding and constant comparison to ensure the reliability and validity of the findings. The initial coding of the transcripts involved identifying key phrases and statements related to navigation challenges and preferences. These codes were then grouped into broader themes, allowing for a comprehensive understanding of the data. Once the themes were identified, deeper analysis was conducted to explore the relationships between the themes and to identify any sub-themes or patterns within each theme. This process involved examining the data for similarities and differences, as well as considering the context in which the statements were made. Attention was given to any contradictory or conflicting viewpoints expressed by the participants. Below are the codes, prevalence and themes emerged from the analysis of the study data:

1- Challenges of navigation

a- Unsafe crossings 6

b- Understanding route details 2

c- Shared spaces

i. Tactile cues 4

ii. Unfamiliarity 2

d- Finding turning points 1

e- Inconsistent environment

i. Unpredictable outdoor environment 4

ii. Weather conditions 5

iii. Inconsistent city designs: 6

iv. Difficulty using public transport: 4

v. Obstructions on walkways: 8

f- Lack of confidence

i. Fear of falling or getting injured: 3

ii. Confidence to go out independently: 5

g- Technology related

i. GPS accuracy issues 3

ii. Battery drainage 1

iii. Physical challenge of using technology 3

2- Requirements and needs of navigation

a- Navigation tools

i. Need for navigation tools 3

ii. Detecting obstacles 5

b- Orientation and mobility training

i. Technology awareness training 3

ii. Training on using specific technology: 4

c- Responsibility towards BPSP

i. Other pedestrians be mindful 8

ii. Drivers stop for pedestrians 3

iii. Cyclists' responsibility 3

iv. Non-compliant scooter riders 2

v. Buildings' staff mindfulness 2

vi. Council's responsibility 3

d- Clear signage 3

e- Addressing obstacles 4

f- Safer crossings

i. Controlled crossing 4

ii. Location of crossing 2

iii. Tactile paving at crossings 5

3- Preferences of navigation

a- Urban design

i. Wide walkways 1

ii. Clear pathways e

iii. Avoid open spaces 1

iv. Proper tactile paving 7

b- Affordable technology assistance

i. Preferring cane 6

ii. Audio announcements 5

iii. Route briefing 2

iv. Small device 2

v. Hands free 3

The themes included various aspects of navigation of BPSP, including the challenges of navigation, which highlight physical, environmental, and technological barriers that participants encounter. The study identified preferences and requirements regarding technology assistance to enhance the efficiency of the current navigation systems. Consideration was given to location specific codes such as crossing to highlight the safety issues. In addition, both the built and natural environment have been accounted for to identify the design and weather issues. Furthermore, the physical and emotional preferences and needs have been taken into account for a safer and personalised navigation experience.

4.3 Study Findings

4.3.1 Nature of Navigation

4.3.1.1 Easy and hard journeys

The interviews with BPSP revealed insights into both easy and hard journeys they undertake. For a routine trip to a familiar place like the local shop, many said BPSP can navigate easily highlighting the crucial role of familiar environments and routine routes, where they had memorised spatial layouts and could rely on a consistent mix of sensory cues. However, unfamiliar, unpredictable and poorly designed environments posed significant challenges to BPSP. Crowded walkways, heavy traffic at crossings and frequently changing layouts of sidewalk furniture made independent travel stressful. Several people recounted getting lost when landmarks or turn cues were missing, especially in new neighbourhoods.

An easy journey from the perspective of majority of the participants for BPSP is a journey that is straightforward and have least obstacles. This is the journey they hope for. Being mentally prepared and knowledgeable about the route will also make it an easy journey.

> "An easy journey is a journey that will be easier to learn would be from, for example, the users' home to the end of the street, where you go around all the way back to the home because of the presence of the mental map" MT1.

However, a hard journey is a journey that is challenging, complicated and have a lot of uncertainties. In fact, the person’s capability of dealing with the route is a key factor to distinguish easy from hard journey.

> "Obviously, things like being able to identify and negotiate obstacles, such as street furniture, curb steps, knowing when it's safe to crossroads, especially if they're uncontrolled crossings, these are the things that are particularly challenging" MT7.

Sometimes it is the change in the surrounding and in the environment that make a journey or part of it difficult.

> “The weather conditions will have an impact, as well. So, for example, if it's darker, and their vision means they don't see well when it's darker, that will make it more difficult. Crossing roads, uncontrolled crossing. So, crossing, whether or not there's stoplights at the crossing, that would make it difficult. And when the environment is quite busy, and there's a lot of pedestrians around because a lot of cars, like I said, it's a busy time of day, that would make it difficult” MT1.

4.3.1.2 Uncertainty within the journey

Routes can pose potential dangers due to sudden changes such as construction work or changes in the terrain. Even with the use of aids like white canes or guide dogs, detecting overhead obstacles or nature of a surface (for example, wet, slippery, or uneven) can be difficult. Additionally, crossing busy intersections can be a challenge due to the inability to visually confirm the safety of crossing.

> “If there was something unexpected on a route that they were doing. And if for example, they were crossing a road, and there was roadworks set up, which was something new, we would encourage them to wait and ask for sighted assistance, if they were unsure, for any reason” MT5.

Mobility trainers teach BPSP some strategies to handle uncertainties while walking. In addition, many individuals rely on other senses, such as hearing and touch, to gather information about their surroundings. They listen to the sounds of traffic, people, and the environment to build a mental map and determine their location. Lastly, asking for assistance from others when needed can also be a valuable strategy to address uncertainties.

> “So, what they would do after any point they feel something is not right, they will stop, you know, like, rather than keep going, if in doubt you stop, and you, you give yourself time to not panic, because if you keep walking, you're going to get further and further disoriented yeah. So, you would stop and you will immediately track back on your, where you have just come from, and then just like, assess your situation” MT8.

The importance of mobility trainers’ input arises from training numerous amounts of participants. Learning from the BPSP experience of dealing with difficulties within a journey, mobility trainers are able to highlight the necessary skills and navigation support required to navigate safely.

4.3.2 Navigation Requirements, Challenges, and Preferences

4.3.2.1 Challenges of Navigation

Visual impairment presents unique challenges for individuals when they navigate outdoor environments. BPSP face a multitude of obstacles and difficulties that can make outdoor navigation dangerous and isolating. Outdoor navigation for BPSP is a daily challenge that is consistently mentioned in both research literature and the experiences of visually impaired individuals themselves. Figure 17 shows the key challenges BPSP face when navigating outdoor environments.



Figure 17 The key challenges BPSP face when navigating

Navigating as a blind or visually impaired person presents a multitude of challenges. Skills are required to understand the origin and destination of a route, and these difficulties can be affected by the unpredictable nature of outdoor travel. The challenges that BPSP face when navigating outdoor environments, can be related to the environment design, personal abilities/skills, interaction with other walkway users and modes of transport. The physical environment often does not support independent navigation, and it can be hard to find assistance when needed. Health issues and the use of navigation aids such as the cane can present further difficulty, as it can lead to hand fatigue and other complications. Confidence level can significantly affect a blind person's ability to navigate.

The quality of infrastructure plays a major role in the experience of blind pedestrians. Poorly maintained pavements, a lack of controlled crossings, and issues related to social distancing can make navigation difficult and hazardous. Additionally, overgrown hedges can lead to injuries. Shared spaces and inconsistent or poorly maintained tactile pavements can also be problematic. Furthermore, the lack of consistency

in city and pavement designs across different areas can make it difficult for blind individuals to familiarise themselves with new environments.

The ability to trust in own abilities, the system, and mobility aids is crucial for navigation safety. Trust and confidence can be undermined if the person feels rushed or pressured. Fear of falling, getting lost, or sustaining injuries can further affect this confidence and deter individuals from getting out. Changes in the environment, such as the sudden appearance of wheelie bins, can also be disorienting. Obstacles like poles, chairs, and other street furniture scattered on walkways pose physical barriers. In addition, social attitudes, including those that discourage BPSP from going out, can also have a great impact on the level of confidence. Understanding tactile paving and identifying turning points on walkways often presents another layer of difficulty. Table 20 shows some of the challenges BPSP face with supporting quotes.

Table 20 Navigation challenges with supporting quotes

Challenges	Supporting quote
Keeping safe, not bumping into people, obstacles, or tripping up and down curbs and steps	“If you’re visually impaired, what challenges the most is, you know, keeping safe. So that you're not bumping into people. and not bumping into obstacles that's tripping up and down curbs and steps” MT7
Fear and Unpredictability: BPSP might have fears about the unpredictable nature of outdoor travel.	"Fear of the unpredictable nature of outdoor travel is probably the biggest one. Particularly if you've had sight" MT2
Health and Confidence: Other health issues can complicate navigation. Using a cane can lead to fatigue and hand issues. Confidence also plays	“And don't grip the cane tightly and move it from side to side, your wrist gets sore as arthritis, it can be sort of carpal tunnel syndrome, it can be quite tiring” MT4

a significant role in navigation ability.	
Poor Infrastructure: Poorly maintained pavements and crossings, as well, can pose challenges. Overgrown hedges can cause injuries.	“And they're just having issues maybe with a road crossing, an uncontrolled road crossing, they're not sure if the cars are seeing them” MT3
Trust and Confidence: Using mobility aids and crossing roads requires confidence and trust in the system. Walking at a comfortable pace is crucial to avoid stress.	“Being able to cross the road safely is probably the biggest challenge anyone would face with a visual impairment” MT7
Changing Environment: Fear of falling or getting lost can inhibit outdoor travel. Inconsistent environments, such as wheelie bins appearing overnight, can be disorientating.	“So, one day walk into the convenience store. There are no hazards. The next day there are wheelie bins everywhere” MT7

The challenges mentioned in Table 20 encompass safety concerns, including the risk of collisions with people or obstructions. The nature and type of each challenge has its own impact on the individuals depending on personal abilities. It is important to consider the challenges of navigation for each person separately to address the issues at individual level. This is true for requirements and preferences of navigation as a key step towards personalisation of navigation systems.

4.3.2.2 Navigation Requirements and Needs

In this section, the navigation requirements and needs of individuals with visual impairments will be highlighted, as informed by the in-depth

interviews with mobility trainers. Figure 18 shows the main navigation requirements and needs of BPSP.



Figure 18 The key navigation requirements and needs of BPSP

The concepts of requirements and needs in the context of navigation for BPSP are closely interrelated. While the two terms are similar in identifying areas that need to be improved for the navigation of BPSP, they differ in perspective. Requirements usually come from an analysis of the environment and systems in place, with the aim of making them more accessible for BPSP. Needs, however, tend to be more personal and subjective, often arising from the lived experiences of BPSP. It's important to note that both concepts are important in creating an inclusive and navigable world for BPSP.

It is important to highlight the accessibility issues of the physical environment. There are clearly a number of issues with the design of the walkways and the intersection of the walkways with the roads. It is the authority's responsibility to make the walkways accessible for BPSP and enforce accessibility rules on everyone to make sure that walkways are obstacle free.

> “Often it is the environment that truly disabled somebody” MT7,
>
> “It's the built environment around them that doesn't take into planning the use of people who have visual impairment. So, like the city planners, not really thinking about where they're putting crossings and the use of tactile paving” MT3,
>
> “And the other thing that can make it very difficult to make a journey very difficult is things like road work. So, I can teach a route to someone, and if all of a sudden there's a road work, and they're unable to do that journey that can make it very difficult for them” MT1.

Another issue spotted from the interviews was navigation in shared spaces. These spaces can be used by pedestrians, cars and other road users such as e-scooters and bicycles with a flat surface and no dropping curb. The issue of shared spaces is that, BPSP find it difficult to navigate safely along the designated walkways, because of the difficulty of identifying and maintain orientation within the walkway and the risk of crossover of other road users over the walkway area.

> “Shared pathways are becoming more popular. So, you're walking down a pathway and something you're sharing with e-bikes and push bikes and town centres are becoming shared spaces. So, they're getting rid of roads in some city centres. But there's no definition between where the pavement ends, and the road starts. It sometimes it's just a continuous flat level. Yeah. So, these are the hazards that people face every day. I admire people that are visually impaired that that still get out and about” MT9.

Everyone has the responsibility of making the walkways accessible for BPSP. The nature of responsibility and actions needed to be taken depends on the relation of the person to the navigation in general. For instance, shops are responsible to keep the walkways clear of furniture and wheely bins.

> “Deal with all those hazards by street furniture” MT9.

The residents need to take care of the walkways and keep them clear for example choosing appropriate location for wheely bins and maintaining garden trees and bushes out of the walking space.

> “Obstacles that are above ground level. So, the overhanging trees and bushes that I mentioned before” MT5.

The public need more understanding and awareness of how to support or avoid negative impact on safe navigation of BPSP.

> “Sometimes I think the general public can find it really intimidating. If you've got a cane, they're thinking like, oh, like, where do I hold you? Do I take your arm? Do I guide you to that? Do you hold on to this, and they don't really know what to do when someone's got a cane” MT6,

> “But you've got this busy main road and you don't know if someone's going to come and help you across that road at any point and you're pretty unsure but there's nothing to help you to tell you it's like safe to cross” MT3.

One discovered requirement in the interview sessions with mobility specialists was lack of training about navigation technologies available for BPSP. In fact, many mobility trainers only teach navigation skills based on the basic navigation aids of cane and guide dog. This results in many BPSP not being aware/able to use the cutting-edge navigation technologies available to them. So, it is important to add technology training to the qualification program of mobility trainers.

> “But for rehab worker we need to be taught all of these things. [Interviewer: Yeah] It is supposed to be part of our skill set. So, it should be built into standard training” MT8.

MT4 mentioned about the importance of providing training and support for BPSP to increase their confidence and encourage them to travel and enable them navigate independently.

> “Well, one gentleman said to me, after we've done, he was talking to going to had dramatic gone from partial sight to no sight at all very dramatic, and was getting lost in his living room. He just felt that, you know, his choice of what to do had been taken away from him. And at the end of the training, he was able to go from getting lost in his living room. He was able to go out to the park and sit or to the pub or to the beach on a bus” MT4.

The majority of participants highlighted the importance of the presence of safe crossings for BPSP. The best type of crossing in terms of safety is controlled crossing. However, there are many uncontrolled crossings between the roads and the walkways which poses high risk to BPSP to make a safe cross.

> “Control crossings are expensive, and they only tend to put them in where people die” MT2.

The term “control crossings” or “controlled crossing” refers to the crossing that is controlled by traffic light and the pedestrian has the legal right and control of crossing over other modes of transport. Controlled crossings can be classified into different types according to the design and the infrastructure used. In the UK, the Department for Transport has a publication available online for the design of the crossings including the controlled crossings.

4.3.2.3 Navigation Preferences

Individuals have their own preferences when it comes to navigating outdoor environments. Similarly, BPSP have specific navigational preferences whether it is personal-related, environment-related or safety-related. According to the mobility trainers, the preferences centre around the need for unobstructed and clear pathways. The preference of clear

pathways is not only related to safety but is also related to mental workload and the ability of remembering how to negotiate hazards and maintain orientation and position to continue the journey.

> “And not have to keep negotiating hazards” MT1.

To expand on the design of the walkways, navigation preferences include the presence of deep curbs and distinct delineations between walking and cycling paths.

> “Guide Dogs aren’t trained to walk without curbs. Yeah. It confuses them. If you don't have anything that signifies the curb, you can quite easily drift into the road” MT2.

Another preference is about the width of the walkways. BPSP tend to prefer walkways that are wide enough to accommodate all the walkway users.

> “I think what they prefer is for walkways and pathways to be wide enough, especially when they're navigating. It Needs to be wide enough so that they can actually walk. Yeah, that's- that's one of their preferences” MT1.

They also prefer to travel in straight lines to maintain their orientation and have more focus on the navigation task.

> “What people say to me quite consistently is, when they walk down the street, they want the ability to walk in a straight line” MT9.

The preferences of BPSP could be related to the environment. The preference of dark or bright mainly depends on the nature of sight loss. For example, if the person has remained vision, then he/she prefers travelling along walkways that have enough lighting in the night.

> “As far as street lighting at night you want that to be clear and even brighten enough that you can see where you going” MT3.

When it comes to crossings, BPSP prefer the crossings that are safer, easier to negotiate and easy to identify.

> “you'd be much, much safer. Because when you're crossing the road, there’s controlled crossing and the zebra crossings, you know” MT8.

MT4 highlights some of the issues of the design of the cane and its relation to the navigation experience of BPSP. She states that graphite cane is preferred due to its lighter weight compared to an aluminium one. However, they express dissatisfaction with a design change in the aluminium cane that resulted in shorter joints, causing the cane to wobble. The speaker suggests that longer joints are preferable as they provide a more stable feel.

> “I prefer the graphite, and somebody changed the joints of the aluminium cane and it made it wobbly, because the joints are shorter, so it just wobbles and I didn't like it. They might have changed that now and made them slightly longer but I preferred the longer joints“ MT4.

4.3.3 Navigation Support

This section highlights the navigation support used by BPSP including technology support. This part of chapter 4 is also useful for the next chapter, because the findings can be used with the focus group inputs to describe an ideal navigation system for BPSP.

BPSP rely on various navigation aids to help them navigate independently, each with its own advantages and disadvantages. One commonly used system is the long cane, which is a physical tool that helps individuals detect obstacles and navigate their surroundings. As one mobility trainer mentioned.

> "For as long as I can remember, the best piece of equipment is a long cane. That generally tends to be the best for most people,

> certainly those that are willing and happy to use one because, you know, it doesn't require batteries, it's not expensive" MT7

The long cane provides tactile feedback and allows for immediate detection of obstacles, making it a reliable and cost-effective option. However, it does not provide information about specific locations or directions. The choice of a navigation system depends on individual preferences and needs. The majority of interviewed mobility trainers only focus on navigational training of BPSP with the use of cane.

BPSP need to ask the mobility trainer to teach them about using a specific navigation technology when demanded. However, there is lack of teaching for the mobility trainers themselves about the available technology support for BPSP. As a result, mobility trainers are not adding technology support as part of the navigation training for BPSP.

According to the mobility trainers, the ideal navigation system for blind or partially sighted individuals would vary depending on the level of vision someone has. For those who are partially sighted and able to negotiate curbs and steps, a navigation device that exists already, such as satellite navigation or walking groups on Google Maps, would be accurate in providing location information. As one trainer mentioned,

> “An ideal navigation system would tell a person where they are in real time. That's one thing. Not only that, what you can also do is actually tell them what's around them… and enable them to actually read is also this ideal navigation system would have some sort of camera, that wherever they look, if there is a name on shop or the other side, would actually... outcome. So, they know where they are. So, that's enabled them to do that. I think the other idea, I mean, there hasn't been anything yet. They tried with a sonar cane. I don’t know if you heard of it. It is a cane that gives you vibratory feedback as to lower and higher obstacles. It's not, I don't think it's been great, because it doesn't give you that much feedback. And it's not always accurate. Some sort of probably-

> some sort of device that would enable people to identify all the obstacles that are in front of them. So, like I said, it enables them to identify with elevation changes on the terrain changes, to enable them to identify the surface areas or what kind of surface they are walking on, and even whether it's not all the obstacles in front of them. So perfect navigation device will do all those things, that give them an idea of where they're going. And it also enabled them to read their environment and everything that's going on it" MT1.

Having the ability to hear the surrounding and also hear the navigation device

> "I guess bone conduction or something" MT2.

> "I suppose it kind of exists already in, you know, satellite navigation. So, as we mentioned before, you can walk in groups on Google Maps and things like that is something that would be accurate in terms of saying to the person, you know, you're here" MT7.

However, for individuals with more severe vision impairments, physical cues are still necessary to detect obstacles. As another trainer pointed out,

> "I mean, you know, if we're talking it all depends on how far down the line you're talking. I mean, in an ideal scenario, what you would want equipment that actually mimics vision... I don't think anything like that will ever be possible" MT7.

Therefore, technology can provide valuable assistance, but the trainers acknowledged that medical intervention to improve vision would be the most significant advancement for navigation support. When BPSP navigate, they are walking on a certain route either planned or unplanned. Mobility trainers teach BPSP to navigate familiar routes to their destinations first. If they were successful, they move onto other routes they might need to take such as going to work or visiting the local hospital.

It is important to consider the route requirements of BPSP for a safe journey. Safety must override preferences of the BPSP to avoid any potential risk.

> “I will probably walk the route with the blind person at their side, just possibly just walking, guiding them over the whole route. So, they get a sense of the number of road crossings, there are the basic orientation that is straight over what hazards there might be on the way. Prior to all this, I would have looked at the route almost always looked at the route and worked out a few basic things. But try to keep in mind that they may already have had some preferences” MT2.

4.4 Discussions

The interviews with mobility trainers provided valuable insights into the needs and preferences of BPSP for navigating outdoor spaces. A key theme that emerged from the study was the importance of public awareness and infrastructure supports to enable safe, confident mobility. Many blind and partially sighted individuals rely on clear, predictable walkways with tactile guides like curbs and delineated cycling paths. Obstacles like bins and benches in walkways can be problematic. Another key need discussed is access to mobility aids and training, which build critical navigation skills and confidence. This is especially important for those experiencing gradual vision loss over time.

The trainers emphasised that personalised orientation and mobility skills need to be taken into account alongside the navigation technology. On the other hand, building public knowledge on assisting BPSP, improving infrastructure and access to support services are important steps toward facilitating the mobility and independence of BPSP. The needs that are highlighted by the participants signaled the urgent need for navigation technology training. This has to be included as part of the navigation support provided for BPSP.

In this study, it has been discovered that the mobility trainers have not received training to teach BPSP to use the navigation technologies. This is because it is not part of their qualification and training. This emphasises the need for technology training for mobility trainers to learn about the new technologies and navigation aids that enable the BPSP navigate independently. As a result, this should be added as part of the mobility training provided for BPSP.

In exploring the navigation requirements and preferences of BPSP, the discussions revealed a complex set of needs and preferences. A consistent theme was the desire for clear and unobstructed pathways, which includes deep curbs, distinct delineations between walking and cycling paths, and easily recognisable crossings. Moreover, the role of technology emerged as a significant factor, with BPSP expressing a preference for verbal announcements of location information. However, the use of technology did not overshadow the importance of personal skills, especially given potential issues such as signal disruptions.

The interviews also underscored the importance of timely support, highlighting the need for motivation and assistance as sight conditions deteriorate. The insights from these interviews further emphasised the desire for independence, confidence, and safety among BPSP, which strongly shapes their navigation preferences. These findings provide critical insights for developing more effective support systems and tools for BPSP.

Another important aspect discussed in the interviews is the role of technology, particularly GPS and smartphone applications, in supporting independent navigation. Participants mentioned the potential of GPS technology to provide accurate and real-time information for blind and partially sighted individuals, but also highlighted the limitations of older phones in accessing raw GPS data. The use of navigation applications like Google Maps and specialised route-finding apps were also mentioned as helpful tools for BPSP.

The interview data emphasises the need for a comprehensive approach to enable blind and partially sighted individuals to navigate independently. This includes both environmental considerations, such as consistent placement of objects and tactile indicators. By addressing these factors, it is possible to enhance the independence and mobility of BPSP, allowing them to navigate their surroundings with greater ease and confidence.

The interviews highlighted the importance of accessibility of the infrastructure and training along with public awareness to facilitate safe independent journeys for the blind. One key theme that emerged from the interviews is the importance of consistent environmental cues, such as the placement of wheelie bins and the use of tactile ground surface indicator tiles. Participants highlighted the need for local councils to have policies in place to ensure consistent placement of objects and adherence to standards for tactile indicators, which would greatly facilitate navigation for blind individuals.

Changes in the environment, such as roadworks, should be clearly marked and communicated to prevent potential accidents. High contrast and large print information can effectively assist those with residual vision. There is a pressing need for greater public and institutional awareness about the unique challenges faced by BPSP, underlining the importance of designing environments that accommodate their navigational needs.

The findings from the interviews have been analysed with consideration that the mobility trainer participants are describing the experiences of BPSP. Although it was decided that for this scoping research activity, mobility trainers were the most appropriate sources to provide a holistic view of the research problem. Their insights will be influenced by their experiences as mobility experts. Subsequently, BPSP views have also been collected part of the PhD project. It is important to consider the challenges mentioned in chapter 4 and 5 to get a holistic figure of the navigation challenges that BPSP face.

4.5 Chapter Summary

This chapter explored the user requirements of BPSP from interviews with mobility trainers. Additionally, it provided valuable insights into the outlining of BPSP needs and preferences. the findings from this chapter were used for the next subsequent chapters. This chapter achieves objective 3. The next chapter describes an ideal navigation system for BPSP using focus groups with blind and partially sighted individuals.

CHAPTER

FIVE

5 DESCRIBING A PERSONLISED NAVIGATION SYSTEM FOR BPSP

5.1 Overview

This chapter covers the details of a user-centric navigation system design considering the existing navigation resources, an affordable navigation system that can accommodate user's information. In addition, gaining insights into the experience of BPSP with the navigation systems they highlight in the study. Focus groups with BPSP explored the experience of using the existing navigation systems. This chapter will present a comprehensive description of the proposed navigation system, taking into account the specific needs and preferences expressed by the participants.

5.2 Methodology

5.2.1 Study Design

To gather the necessary data, a qualitative research approach was employed. The study method and design were selected based on getting rich user data. For that purpose, focus group was selected so that the participants have the chance of adding more insightful information, exchange useful ideas and building vital information on what other individuals said. Focus groups with BPSP have widely been used as an efficient approach for system design and user requirements by many researchers such as Lewis et al. (2015) and Zimmermann-Janschitz et al. (2017). In addition, Ntakolia et al. (2022) used focus groups with BPSP to identify smart assistive navigation systems' requirements. In this

research, specific questions will be asked to understand the requirements of each component of the navigation system for BPSP. This will help to get more accurate responses that precisely identify the design requirements. The focus group discussions consisted of open-ended questions that allowed participants to freely express their thoughts and experiences related to navigation. The study design has been reviewed and approved by the Ethics Committee. Table 21 shows the questions asked during the focus group sessions.

Table 21 Focus group questions

Focus group questions
• In the first part of the study, I would like you to talk about the way navigation technology can provide support in the following scenarios: ○ Routine journeys (specify your won routine journey like going to the local shop) ○ Non-routine journeys (specify your won journey like taking a route that involves complex crossings) ○ Uncertainty within the journey (specify your own situation, like being unsure about the current position)
• In the second part of the study, I would like you to talk about the navigation systems you use/have used/will be using: ○ What do you use and for what purpose? ○ What is good about what you are using? ○ What are the weaknesses of what you are using? ○ What have you used that didn't work and you stopped using it? ○ Are you aware of a good navigation system that you don't use? What stops you from using it (unfamiliarity with the interface, cost, not being practical)? ○ How would an ideal navigation system look like? How would you define it? ○ How likely is it that you will be using a user-centric smartphone-based navigation system to navigate independently?

○ How would you prefer to hold the navigation tool (in your hand, in your pocket, only occasionally in your hand)?
• In the third part of the study, I would like you to talk about the way navigation systems can support you for the following specific situations: ○ Negotiating crossings ○ Presenting route choices ○ Negotiating obstacles ○ Identifying the destination
• In the fourth part of the study, I would like you to describe an ideal user-centric navigation system in terms of: ○ Positioning and orientation (identifying user location and orientation) ○ Map (layout of information, level of details available, nature of details) ○ Generating route choices ○ Interface design (interacting with the system for information input) ○ Means of providing guidance for mobility support (auditory, visual, vibration, etc) • Anything else would you like to add?

5.2.2 Accessibility of the Study

The focus groups were performed on the Microsoft Teams which is an accessible platform for BPSP. Support was available before, during and after the focus group sessions to ensure that all participants have proper support.

The study materials were written using Microsoft Word. The accessibility feature of Microsoft word has been used to check the whole content for any accessibility issues. In addition, to make the study details accessible

particularly for BPSP, alternative formats of the documents were made available on request. That included high contrast text with bold and big fonts and audio version of the documents recorded by my voice. Written or verbal consents were taken before the interviews start. Participants were provided with both audio and text versions of the study materials and one participant requested the text documents in big and bold font which I provided. Communicating the documents was through email and phone (call and text). To review the accessibility of the study materials, previous research study designs and relevant organisation guidelines have been considered.

5.2.3 Study Process

The focus group discussions were conducted in multiple sessions to allow for in-depth exploration of the topic. Each session lasted approximately two hours including breaks, providing ample time for participants to share their experiences and insights. The discussions were guided by probing questions which allowed for flexibility in diving further into specific areas of interest that emerged during the discussions. BPSP were asked questions concerning the navigation systems used as well as describing a user-centric navigation system for BPSP. The discussions were conducted in a comfortable and inclusive environment to encourage participants to share their perspectives openly. The researcher ensured that all participants had equal opportunity to contribute and that their voices were heard. The data collection involved audio recording and note taking.

Participants were recruited mainly with the help of RNIB, advertising for the study by email and using social media platforms. Participants were paid an inconvenience allowance for their participation. A total of 20 BPSP were interviewed. The participants details are shown in Table 22 below.

Table 22 Participant details

Participant	Age	Gender/ Registration	eye condition	At what stage developed visual impairment	Employment
FG1 P1	40-49	Male Blind	Cone Dystrophy, Photophobia	From birth	NA
FG1 P2	40-49	Female Partially sighted	Visual impairment	29	yes
FG1 P3	20-29	Female Blind	Relating to Cornea	From birth	Currently no
FG2 P1	30-39	Female Blind	Lebers Amaurosis	From birth	No, previously was employed
FG2 P2	30-39	Female Blind	Retinitis Pigmentosa (RP)	from birth, rest of vision at 15	Yes, 16 years
FG3 P1	50-59	Male Blind	Glaucoma	From birth	yes
FG3 P2	40-49	Male Blind	LCA	PS from birth, B since 30	yes, full time
FG3 P3	30-39	Female Blind	Congenital Glaucoma and Cataracts	From birth	yes
FG4 P1	40-49	Male Blind	Ushers	from birth, but diagnosed at 15	yes
FG4 P2	30-39	Male Blind	Retinitis Pigmentosa	Late teen age	no
FG4 P3	20-29	Female Blind	anophthalmia L microphthalmia R	From birth	FT student, PT work
FG5 P1	30-39	Male Blind	Diabetic Retinopathy	mid 20s	Yes
FG5 P2	30-39	Female Blind	Stroke and CBS	in 2007	yes
FG5 P3	60-69	Male Blind	Retinitis Pigmentosa	early 20s	yes
FG6 P1	50-59	Male Blind	Bilateral Retinoblastoma	born with cancer, both eyes removed when infant	Self-employed
FG6 P2	30-39	Male Blind	Genetic eye condition	From birth	no

FG6 P3	20-29	Male Blind	Optic neuritis	From birth	no
FG7 P1	60-69	Male Blind	Diabetic Retinopathy	from 58 years, in 2011 lost all vision	Retired
FG7 P2	40-49	Female Blind	ROP, Glaucoma, Detached Retina's No functional vision	about 5 years old, and lost all vision in 2000	yes
FG7 P3	20-29	Female Blind	Aniridia, Nystagmus	from birth	yes

In the given data set of BPSP, there is a slightly higher number of males (11) compared to females (9). The participants span various age groups, with the average age being 41.2 years. A variety of eye conditions are represented in the data, with Retinitis Pigmentosa emerging as the most common cause of blindness. With regard to employment status, the majority of the participants (13) are currently employed, while 7 are not employed. These findings illustrate a diverse group of participants in terms of age, gender, cause of visual impairment, and employment status. Figure 19, Figure 20 and Figure 21 show the details of the participant's data.

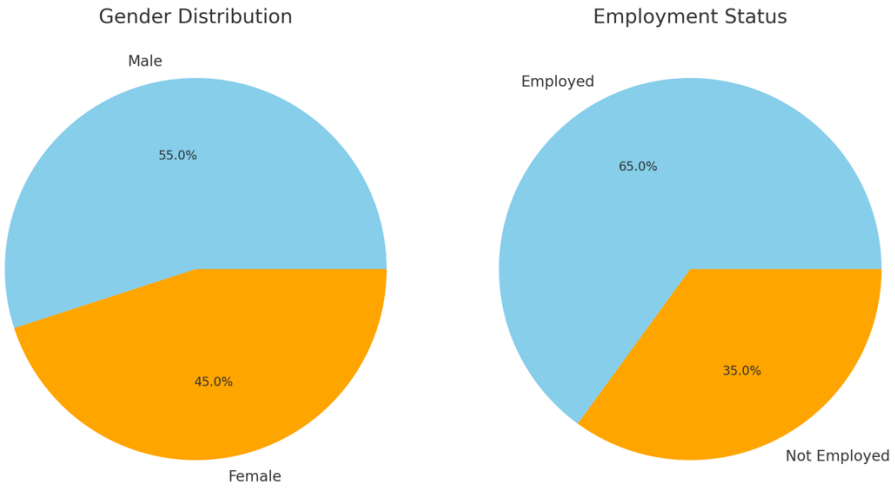


Figure 19 Age and employment status of participants

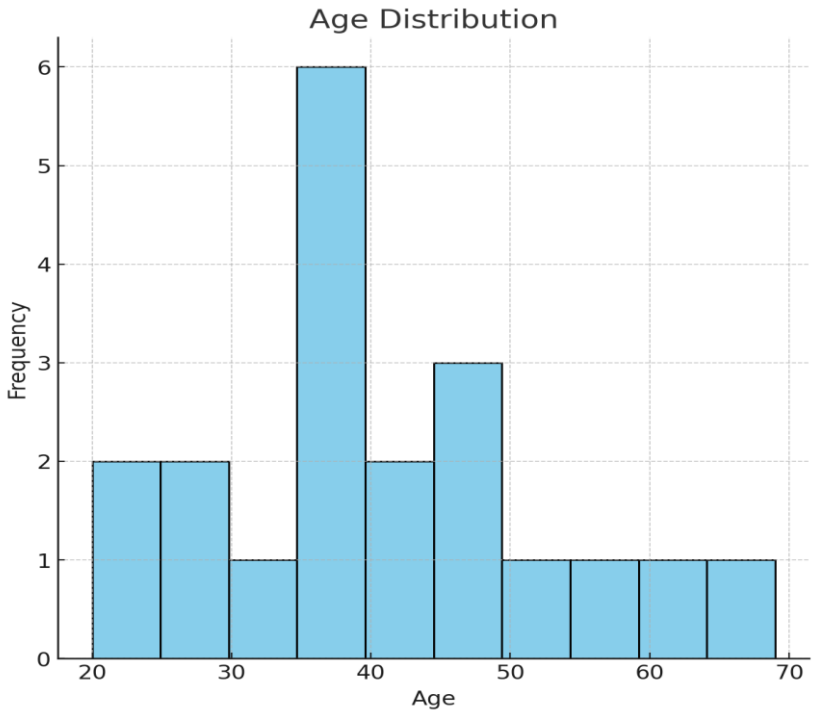


Figure 20 Age distribution of the participants

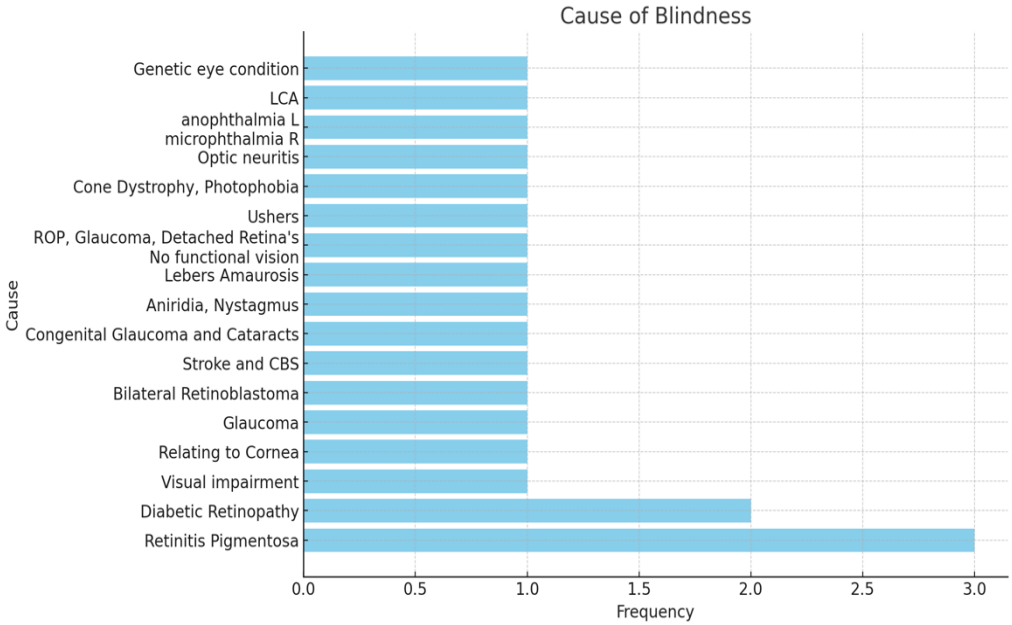


Figure 21 Causes of blindness of the participants

Table 23 highlights the responses of the participants with regard to the mobility training and support they might have received.

Table 23 The mobility training that might have been received by the participants (P)

P	Have you received any mobility training?
FG1P1	Yes, lots over many years. I was taught to use a long mobility cane from the age of 10 when attending a boarding school for blind and visually impaired children.
FG1P2	Yes, Adult Sensory Rehabilitation Service - Staff watched me Walk Around the Streets, then Provided Suggestions of how make it Safer e.g., Cross Roads Away from the Junction, so the Driver has Time to See you Crossing the Road
FG1P3	yes
FG2P1	Yes, long cane training at school, then how to get around each new place I've lived in. It got paused for the pandemic where I am now so I can't actually go out on my own currently.
FG2P2	yes
FG3P1	yes
FG3P2	long cane and guide dog training
FG3P3	yes, a long time ago as a child
FG4P1	yes
FG4P2	yes
FG4P3	yes

FG5P1	long Cane, Suno Band, Guide Dog
FG5P2	yes
FG5P3	some
FG6P1	Yes. I went through the special school system and had mobility training to teach me to use a white cane. I also had access to excellent tactile maps which I believe helped with my spatial awareness.
FG6P2	yes
FG6P3	yes, guide dog as well
FG7P1	yes
FG7P2	yes
FG7P3	no

5.2.4 Data Analysis

The analysis process of this study was similar to the previous in terms of transcription process, data preparation and initiating the analysis stages. The themes have been developed based on the navigation experiences of BPSP and the technology required to support their navigation. Figure 22 presents the specific themes and codes under the wayfinding general theme.

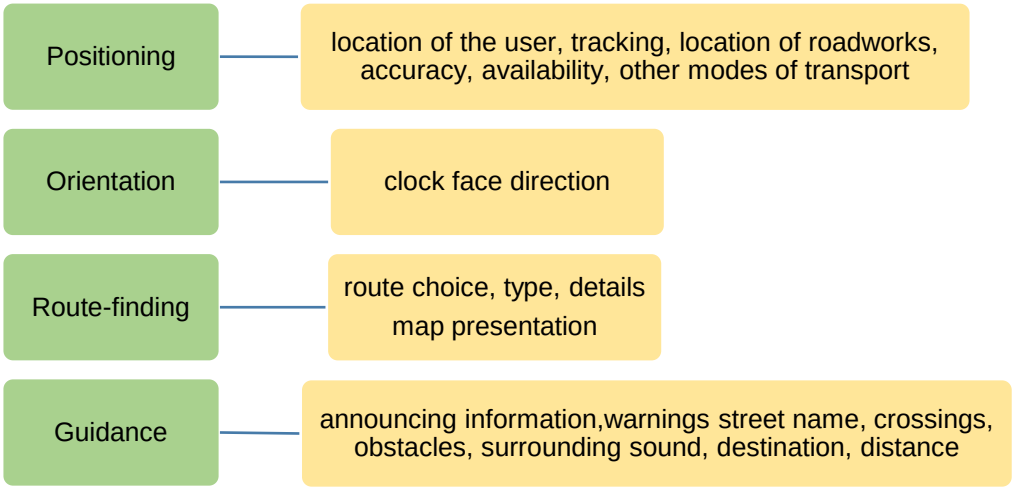


Figure 22 Wayfinding specific themes (Green boxes) and codes (yellow boxes)

The wayfinding specific themes included positioning, orientation, route-finding and guidance. The codes were identified based on the user's navigational experience to elicit the navigation support requirements. The focus group discussions helped with eliciting more data and highlighting both the navigation experience and the navigation design needs. Figure 23 presents the specific themes and codes under navigation system design general theme. The navigation system design general themes include specific themes around the components required for the system design. The sensors and interface themes cover the device components required to accommodate the orientation and wayfinding requirements of BPSP. The input, output and personalisation themes cover the interface design to learn the specific needs and preferences of interaction choices on the navigation device.

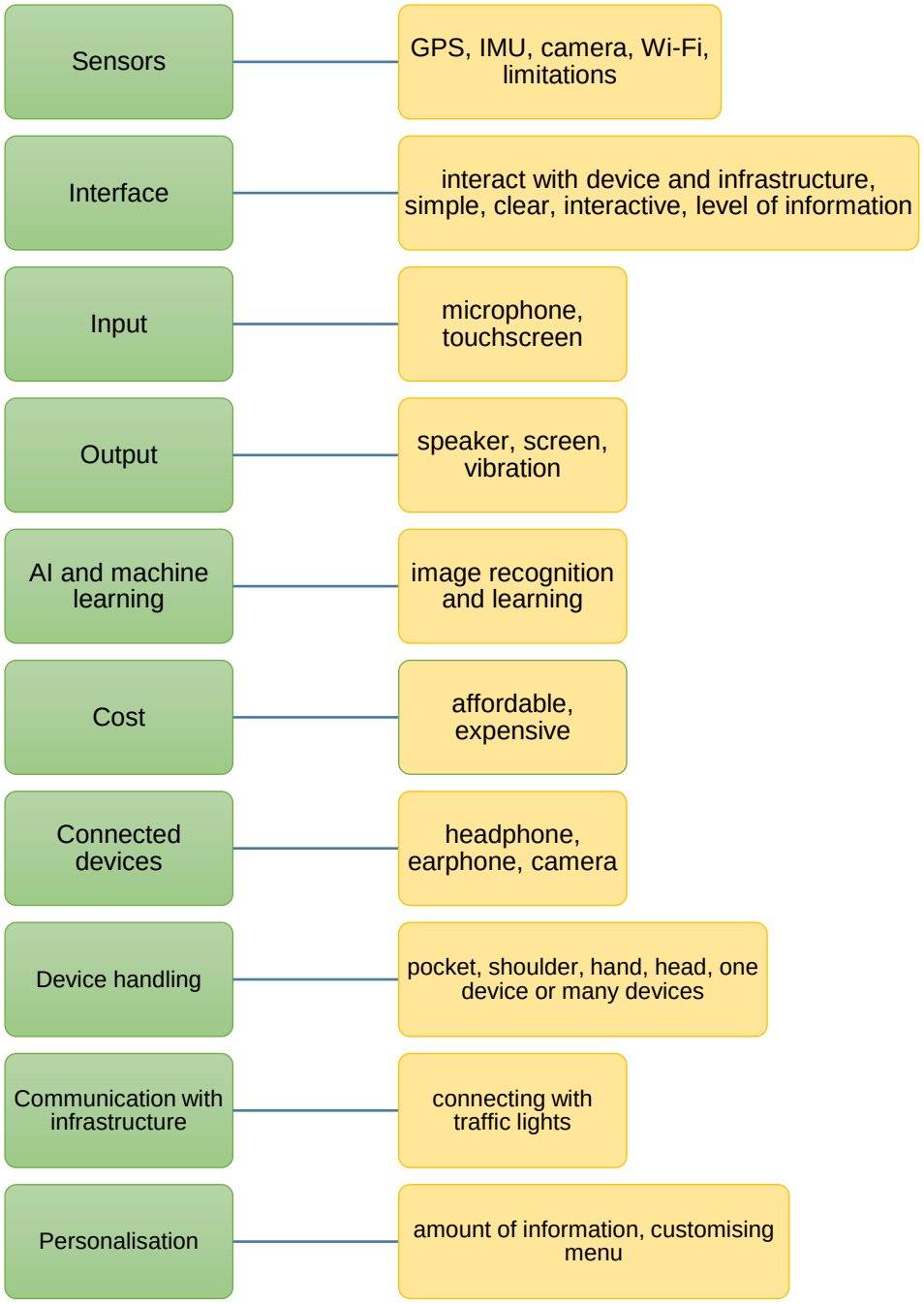


Figure 23 Navigation system design specific themes (green boxes) and codes (yellow boxes)

The AI and machine learning theme includes the navigation system capabilities required to learn and interpret the sensors' input data such as camera input for image recognition. The cost theme has been selected to learn about the affordability of the navigation systems and whether the cost is a barrier in front of the user to buy a navigation device. There are

other themes about the device communication needs with the infrastructure and other devices to complement the navigation experience. The device handling is an important theme that includes specific codes to identify user preferences regarding the handling of the device whether keeping it in the pocket, having it in the hand or placing it on the shoulder.

5.3 Study Findings

The focus group discussions provided valuable insights into the challenges faced by blind and partially sighted individuals in navigating their surroundings and the desired features of an ideal navigation system described based on the focus group discussions. Several key findings emerged from the data analysis that are shown below.

5.3.1 Navigation System Support in Routine and non-Routine Journeys

Navigation system support is vital for safe and independent navigation of BPSP. Many focus group participants mentioned about using navigation support for their routine and non-routine journeys. The nature of support depends on the individual needs and preferences as well as the capability of the navigation system for that particular journey. For familiar journeys navigation systems can help with positioning and adding extra and related information to the user that is useful and unknown otherwise.

> “Even if I know our journey, or like at the comfort of using a map. So, in my case, I actually like Apple Maps, when I'm doing a familiar journey, because I'm allowed, I'm able to use the tracking with reading feature, which then reads out any kind of intersections streets that I'm coming to, but it also tells me what the shops I'm going past as well. So, there's that element of security of knowing Yep, I'm on the right route. And if I go off track, I will know because it you know, it will announce something that I'm not expecting to be there generally” FG3P3,

> “So, I use technology quite a lot. Because I'm a white cane user. So, for me this means. So, I use like Soundscape. Google Maps, things like that, because it just even if I already know the journey, I think when you've got say audio announcements and stuff, it kind of takes the strain off of remembering exactly where you're going” FG4P3.

However, the navigation system support is mostly necessary in unfamiliar journeys to avoid uncertainties and maximise safety. Because it is not only for extra information and real-time position, but also to maintain orientation and learn about critical navigation-related information in the unknown surrounding.

> “I would like to be able to use technology for gaining more local information about particularity out here, when we have the movement of livestock, they will quite often block of a section while wildlife stocks be moved from one building to the other things like that” FG5P2,

> “I've got a number of apps on my phone; I generally use a smartphone. Okay. So, when I am navigating, I will generally almost always have a smartphone on hand loaded with apps to help me. So, I'll use apps like Soundscape” FG6P2.

5.3.2 Navigation Systems Used or not Used

In this part, the responses of the participants to the questions related to the navigation systems they highlight are presented including the advantages and limitations of the navigation support.

Smartphones play an important role in enhancing the navigation of BPSP. They act as an affordable central hub for integrating various navigation aids like GPS, and sensors’ data. With features such as voice assistance, haptic feedback, and real-time access to data, smartphones empower blind and partially sighted individuals with increased

independence and confidence in both familiar and unfamiliar environments.

> “I used to use the Braille note with an external GPS device some time ago, I stopped using that, because it was quite expensive. It was very good at that time, and smartphones weren't. But now smartphones are very good” FG6P1,

> “I already always have my phone with me anyway. So, if that technology works, then it wouldn't be like you have to carry around extra thing. And also, obviously, again, it's just, it's more intuitive, because you're more used to kind of how your phone works. So, you don't have to relearn technology and you don't have to carry an extra thing” FG4P3.

Bone conducting headphones are used to hear what is played on a device like listening to music, but more importantly the person can hear the surrounding noise as well. Although it was created for sports, they are useful for BPSP to listen to navigation instructions and also hear the surrounding sounds.

> “Yeah. So, I walk with the guide dog. So, if I were to use some assistive tech, again, probably bone conducting headset, or earbuds that allow me to hear all sorts going on around me” FG3P2.

Interestingly there are participants who doesn’t use any navigation technology and a participant who doesn’t want to use any, because the participant only relies on people when help is needed. The main reason for that was trust in technology and getting anxious if something goes wrong.

> “I don't tend to use technology. I just don't see the point in technology when people can help you” FG6P3,

> “I'm an independent world traveller who travels the world alone and uses a long white cane. I don't use smart phones or apps” FG1P1.

The level of usefulness of the navigation systems are related to many factors. It could be the performance of the system that makes it a useful or non-useful piece of technology. Another factor is the personal skills and capabilities of the user.

> “I tried Google Maps, which is slightly better. But I honestly thought what really made a difference was Blind Square” FG1P3.

> “So, starting off I got a guide dog. So obviously, he helps with my hearing navigation. I use Google Maps. Personally, I think something like that, always are very, very helpful. Because I've got dual sensory loss, I can't use audio navigation while I'm walking, whereas obviously a lot of people can. So, I often have to do stops and start and just sort of try and work out where I am” FG4P1,

> “Particularly when you're in busy areas like London, you can lose what direction you're going in. So, I haven't found the sort of solution that helps out if again” FG4P1.

The findings of this part of the study confirms what have been presented and discussed in chapter 3 and both findings will contribute to describing a user-centric navigation system components that meet the needs and preferences of BPSP. The next part will highlight the way navigation technology might help in certain navigation scenarios.

5.3.3 Navigation System Support in Specific Scenarios

5.3.3.1 Negotiating Crossings

The focus group discussions highlighted several design needs by BPSP in negotiating crossings. For instance, the inability to know when it is safe to cross was identified as a significant source of frustration and distress.

> “When it comes to negotiating crossings, the one thing that finds is difficult as knowing when it's safe to cross” FG5P1.

Navigation technology can assist BPSP at crossing by the creation of communication between the traffic light device and the individual’s smartphone. In this case the individual will be able to know when it is safe to cross by learning about the time of green and red lights of the traffic signal without looking at them.

> “So maybe we have to connect a technology with the lights changing to your handheld device. And then that would tell you all the- the lights have changed” FG1P1.

5.3.3.2 Presenting Route Choices

Navigation technology can significantly assist in presenting route choices to blind and partially sighted individuals. Using real-time data and advanced algorithms, these systems can offer multiple route options based on factors like distance, safety, traffic conditions, and user preferences, articulated through voice guidance.

> “When I plugged my destination into, into Moovit or Apple Maps or whichever app I'm using, it always kind of tries to work out the best route for me. You know, it was a go via here because it's quicker or go via here because you'll spend less time walking in more time, you know” FG6P2.

5.3.3.3 Negotiating Obstacles

Navigation technology plays a crucial role in assisting individuals in negotiating obstacles during their journeys. By providing real-time information and guidance, these technologies enable users to navigate their surroundings more effectively and safely. Participants in the study also emphasised the importance of navigation technology in overcoming obstacles.

> "You obviously need the cameras and those sensors to see what's around you and how far you are from different objects, whether it's a building or a person" FG1P2.

> “First to tell you what, what obstacles there are, because there's different kinds of and then there's this kind of fixed obstacles. And then there's kind of moving obstacles. So, I mean, there's obstacles that are there that are fixed, but there might not be there for- for a long time. So, to give you as much information about that as possible with this roadworks going on if there's likely to be workers on that route” FG7P2.

The navigation technology can be useful in describing and helping the individual learn about an obstacle and move around it safely. However, it is down to the person to define what is an obstacle and what is not. More importantly, which obstacles the person might need to be aware of using the navigation technology and which obstacles are less hazardous and the user does not want the system to issue warnings and/or further instructions about.

> “I have used something called a Smart Cane, and up to- I've only used it to try it, I don't like it very much. But it vibrates when you come close to obstacles. So, that's I guess, could help. But then the vibrations were too many for me to understand what sort of obstacle this is” FG2P2.

5.3.3.4 Identifying the Destination

Navigation technology has evolved greatly and now offers various features to assist BPSP in identifying their destinations. Using GPS and mapping data, these systems can provide real-time updates on the user's location and proximity to the destination.

> “Suppose if you're approaching the destination, you know, you get the alert signal the doors 10 meters at two o'clock, something like that” FG3P2.

However, in urban areas the positioning accuracy might get worsen to a level that it cannot provide accurate position of the user and for BPSP this will be a big challenge as not only it cannot tell the arrival to the destination, but might not even be able to tell which road the person is on.

> “You know, that the satellite sort of GPS sort of goes advertise you have arrived at your destination but it might still be 10 meters away” FG2P2.

As the users approaches their destination, auditory guidance systems can provide more detailed information about the surroundings, like the orientation of the entrance and notable landmarks nearby. Some technologies also integrate image recognition capabilities, which, when pointed at a location, can provide a verbal description of the place or read out any visible signage. Navigation technology greatly empowers blind individuals, allowing them to travel to their destinations confidently and independently.

> “Now you're trying to navigate yourself around independently, okay, yes, you can get staff members to help you. But these are the places where you don't want to talk to strangers, you want to just get on technology and move quite swiftly to your destination” FG3P1.

The navigation system should assist in identifying destinations accurately. Participants suggested using technologies like RFID tags or QR codes to guide users to the correct entrance of a building.

> “You're looking for having something that can gauge you like the RFID, because sat nav will get you to a building, but maybe the back of the building may not be the front end” FG3P2,

The previous parts of the study findings presented the way navigation system can support BPSP where participants highlighted the advantages and limitations of the current navigation technology to help in familiar and

unfamiliar journeys as well as specific navigation scenarios that blind and partially sighted individuals frequently come across in their journeys. In the next part, the details and structure of an ideal navigation system will be presented that emerged from the focus group discussions dedicated for this part.

5.3.4 Describing an Ideal User-Centric Navigation System

Participants provided insights into their ideal user-centric navigation system. It is important to describe the components of the navigation system separately based on the requirements and preferences of BPSP. Each navigation system has its own design and components. For instance, Wieser et al. (2007) considered the components shown in Figure 24 for the design. The interface, route guidance and positioning are among the key components of the navigation system. In order to show the details of each navigation component, it is important to highlight it separately. The final design details will be presented in a diagram in chapter 7.

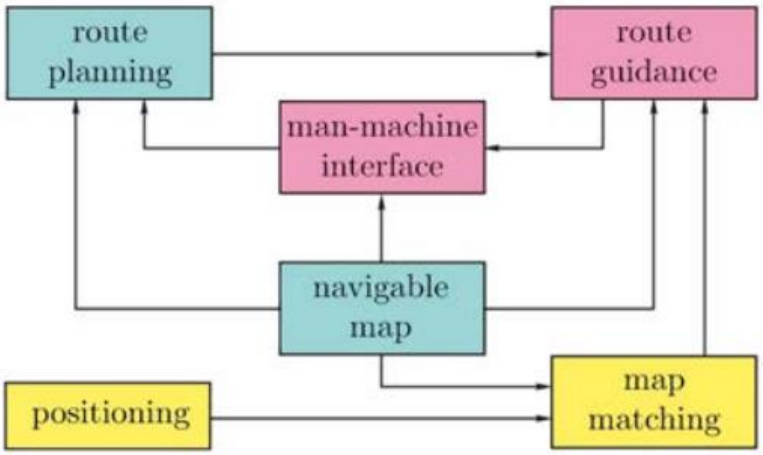


Figure 24 Navigation system components from (Wieser et al., 2007)

Based on the focus group data, an ideal navigation system for BPSP can be described in terms of its components: positioning and orientation, map, route choices, interface design, and the interaction between the device and the person. It is important to highlight the necessity for

pedestrian navigation standards that help navigation system designers and authorities to improve the design and provide the highest level of accessibility. An example of an available standard which provides valuable information about navigation system design and it is open access is Wayfindr Open Standard by (Wayfindr, 2018).

According to the responses of the participants, the proposed navigation system for blind and partially sighted individuals should incorporate various features to enhance safety and independence. The system should be a handheld device and potential headset, both equipped with advanced technologies to provide real-time information about the environment. In addition, participants showed willingness to use a smartphone-based navigation system if it works perfectly.

> “Assuming that the design is perfect” FG6P3.

Having a “perfect” navigation system design is not realistic, because every system is subject to certain limitations. Moreover, the rapid advancement in technology lead to existing system be left behind. There need to be a balance between expectations and reality when deciding to use a navigation device. Otherwise, there might never be a “perfect” solution. The subsequent parts describe the navigation system components starting from positioning and orientation.

5.3.4.1 Positioning and Orientation (identifying user location and orientation)

The ideal navigation system should provide accurate and precise positioning information to blind and partially sighted individuals. This can be achieved by improving the GPS accuracy. Participants expressed the need for a smaller margin of error in determining their location, especially when reaching a specific destination.

> "For the GPS distance, you know, and location, accuracy needs to be minimised... So that when we are reached on a certain entrance, it will say you have reached your destination" FG2P2.

Precise orientation and location information would help BPSP understand their location and navigate their surroundings effectively.

> “I can reorient myself to towards that point of interest. So that's a feature really made a huge, huge difference for me” FG3P1.

This implies the importance of a navigation system that can provide real-time and reliable location updates, ensuring blind and partially sighted individuals can confidently navigate their surroundings.

> “Soundscape will give me the information about my real-time information about my environment, whereas Google Maps will give me directions” FG6P2.

Participants expressed the desire for the system to use familiar references, such as a clock face analogy, to indicate direction and landmarks.

> "And be notified through 12 o'clock there is a man digging a hole at 12. So, three o'clock you've got Costa Coffee, etc." FG5P1.

5.3.4.2 Map

The navigable map should possess geometric accuracy, topological consistency, thematic correctness, up-to-date information, and comprehensive coverage at the highest level. In addition, it is necessary for both the map and the related database to adhere to the efficient data storage and modelling principles outlined by national standards, or ideally, those established by the Comité Européen de Normalisation (CEN) and the International Organisation for Standardisation (ISO), respectively. (Wieser et al., 2007).

In an ideal navigation system for BPSP, the map component should be designed with a focus on accessibility and user-friendly interaction. It should include tactile maps (subject to the availability of the feature on the navigation device). This can help BPSP understand their surroundings through touch. These maps could incorporate various types

of textures to represent different types of features or landmarks, such as buildings, streets, parks, etc. Furthermore, integrating Braille information into these tactile maps can provide additional context and information about specific locations and routes.

> “I think most people want a map just to be quite straightforward” FG4P1.

The digital maps in the navigation system should be designed to work seamlessly with screen reader technology, and should support text-to-speech functionality. They should describe the environment and provide turn-by-turn directions in a clear, detailed, and easy to understand manner. The descriptions should also include non-visual information about the environment, such as sounds or changes in temperature, which can provide additional navigational cues.

> "The best technology would be where you put your locations where you're going from and to, and it has an interactive map that you can see if you're able, and also audio, where it tells you where to go, when to turn right or left" FG1P2.

Advanced features could include real-time updates on the map for dynamic elements like moving vehicles, crowds, or other temporary obstacles. The map component should be customisable to meet individual user needs, preferences, and skills. For instance, some users might prefer more detailed descriptions, while others might prefer a more straightforward, minimalist approach. By creating a highly adaptable map component, the navigation system would be more likely to effectively serve the diverse needs of BPSP.

> "I think you need a macro and a micro level of mapping... The macro level should be on the database with a Sat Nav and everything using the GPS. And I think micro level is something that your phone should be doing in sync with the camera. And that is

> very much more immediate and much more to do with the area that you're in" FG2P1,
>
> “So, other feedback I would like from maps- I mean, things like you know all of you know where I want the names of roads and house where I want you know, whether I want businesses announced those sorts of things again level customisable level, tones, audio positioning, that sort of thing” FG6P2.

5.3.4.3 Generating Route Choices

Navigation in general can be divided into positioning and guidance. A key part of the guidance side of navigation is routing. The generation and selection of routes depends on many factors related to the user, terrain, environment and the technology system. The navigation system should offer clear route choices, including distance and directions, and provide the ability to view the route in advance. Participants mentioned the importance of having options and being able to choose between different routes.

> "If you have a route choice, if you have more than one route that can bring you there, then it will be nice if it says something like how long it takes me walking there, but at least you have a bit of an estimate. Also, what roads do I cross get to my route end? Because that will help me say, okay, I know those roads, I choose that route because I know the road names and I have actually walked there before" FG2P2.

The ideal navigation system should offer BPSP the ability to make informed route choices. This can be achieved by providing audio feedback about nearby landmarks, streets, and buildings.

The process of devising the most suitable trajectory from an origin to a destination is the quest for the most direct path between two nodes within a route network. In the context of navigation for blind and partially sighted

pedestrians, the "optimal" or "shortest" path implies the safest path (Wieser et al., 2007).

> "The quickest route might not be the safest route. So, having options and being able to choose based on factors like accessibility, distance, terrain, and safety would be important in route choices" FG1P1.

Additionally, the system should alert blind and partially sighted individuals about upcoming obstacles, such as traffic lights or pedestrians, to ensure safe navigation.

> “So, if I know my route, I might only want the head obstacle warnings. But if I don't know my route, and I want to do a slightly newer route, or I've been learning a route using it, I want it to talk me through it, or I might, you know, the levels of detail, it'd be nice to be able to maybe adjust those levels as well” FG2P1.

Furthermore, as the technology learns from the user's patterns and preferences, it can increasingly personalise route suggestions, thus ensuring an optimised navigation experience for blind and partially sighted individuals.

> “But what would be really good if it's an artificial intelligence, which learns based on your particular habits, your mobility habits, where you'd like to go, and then adapt routes accordingly” FG6P2.

5.3.4.4 Interface Design (input and output)

The interface design of the navigation system should be user-centric and easy to use. Participants expressed the desire for a system that allows for customisation of individual preferences The system should provide clear and concise multimodal instructions, guiding the user through the navigation process.

> " Talking systems and smart interface, you know, swiping and clear- clear menus, clear options, no graphics” FG7P2.

Participants expressed the need for a straightforward interface that allows for easy input of destination information, such as typing a postcode or using voice commands.

> " I think having the option to control it with voice with typing will be good, because personally, I don't really use voice control dictation things in public. I'd much rather type. So, I think having the option for either would be good" FG4P3.

The ideal navigation system should have accessibility features to cater to the specific needs of BPSP. This could include options for voice commands, audio information, and tactile keyboard commands.

> "I really don't mind whether it's tactile or touchscreen. Maybe there should be two choices. One is for an app on the smartphone. And one is a sort of very old version that will be with tactile buttons." FG2P2,
>
> "I think voice and vibration is fine. That's enough" FG2P2.

In terms of output, participants emphasised the importance of clear and concise information, including route choices, distance, and directions, presented in a way that is easy to understand and navigate. The interface should be intuitive and not require excessive navigation through multiple menus.

> "Given the output that is directional and calm enough for me to get used to the sound and recognise the meaning but without being alarmed by it" FG2P1,
>
> "And I will add that it needs to be voice interactive. So, I don't want to take my phone out, I can interact with voice commands saying, repeat, take me there again, or recalculate my route? Or, where am I? You know, simple things as if it's telling me exactly what's happening. Or I could say, well, how long to my destination and it says 15 minutes. Keep on walking" FG3P1,

> “Something that would give me vibration, vibrational feedback, good vibrations, vibrations in the right places” FG6P2.

BPSP often prefer to hold a navigation system, such as a smartphone, in a way that allows them to use their assistive mobility devices, like a white cane or a guide dog, without hindrance. Therefore, some may choose to carry their device in a pocket, with headphones providing auditory directions. Others may prefer to hold the device in their non-dominant hand, leaving their dominant hand free for their mobility aid, enabling them to adjust their path according to the haptic or auditory feedback from the device. Figure 25 shows a blind person with guide dog walking on a walkway carrying a dedicated braille GPS device.

> “I wouldn't want to be holding in my hand, I would definitely want it to be in my pocket. And I think that's just for safety reason, more than anything else, to be honest” FG5P2,

> “If you're walking around and visibly holding your phone, obviously, if someone can already tell that you're blind or visually impaired, you're then also an easier target to have that” FG4P3,

> “I would probably need my camera integrated to make it really useful, but then I’d have to be wearing headphones” FG2P1.



Figure 25 Hand-free position of GPS system with guide dog from (May & LaPierre, 2008)

The potential location of a navigation system can be in different places around the body of the user. Whether it is the design or the preference of the user, a navigation system can be made visible or invisible. In addition, a navigation system device can be handheld or put around the shoulders. Another possible way of handling the devices or their components and accessories is wearing them as glasses, hand band and belt. There is no one ideal location for locating the navigation system device. The design of the device and the preference of the user as well as the environment condition are deciding how to handle a navigation system device.

5.3.5 Navigation System Architecture and Model

Developing a navigation system architecture for BPSP involves a user-centred approach that takes into account the unique needs and experiences of this population. The architecture of such a system should be grounded in both empirical research and actual user data to ensure its effectiveness and usability. Figure 26 shows the navigation system architecture. The primary components include a map representation of the environment, user inputs for setting the starting point and destination, a route-finding algorithm, obstacle detection and information systems, real-time updates, and a user-friendly interface. Each of these components plays a critical role in facilitating navigation for visually impaired and blind individuals.

In terms of literature support, research has shown the importance of each of these components. For example, Ahmetovic et al. (2016) highlighted the effectiveness of utilising algorithms like Dijkstra's and A* in navigation systems for visually impaired individuals. They also underscore the value of real-time updates and obstacle detection in improving the user's navigation experience.

Users’ data also play a critical role in the development of the architecture. By incorporating feedback and data from actual users, the system can be tailored to meet their specific needs. This data can provide insights into the requirements of visually impaired and blind users, such as the need

for detailed audio instructions, haptic feedback, and integration with assistive devices like white canes or guide dogs.

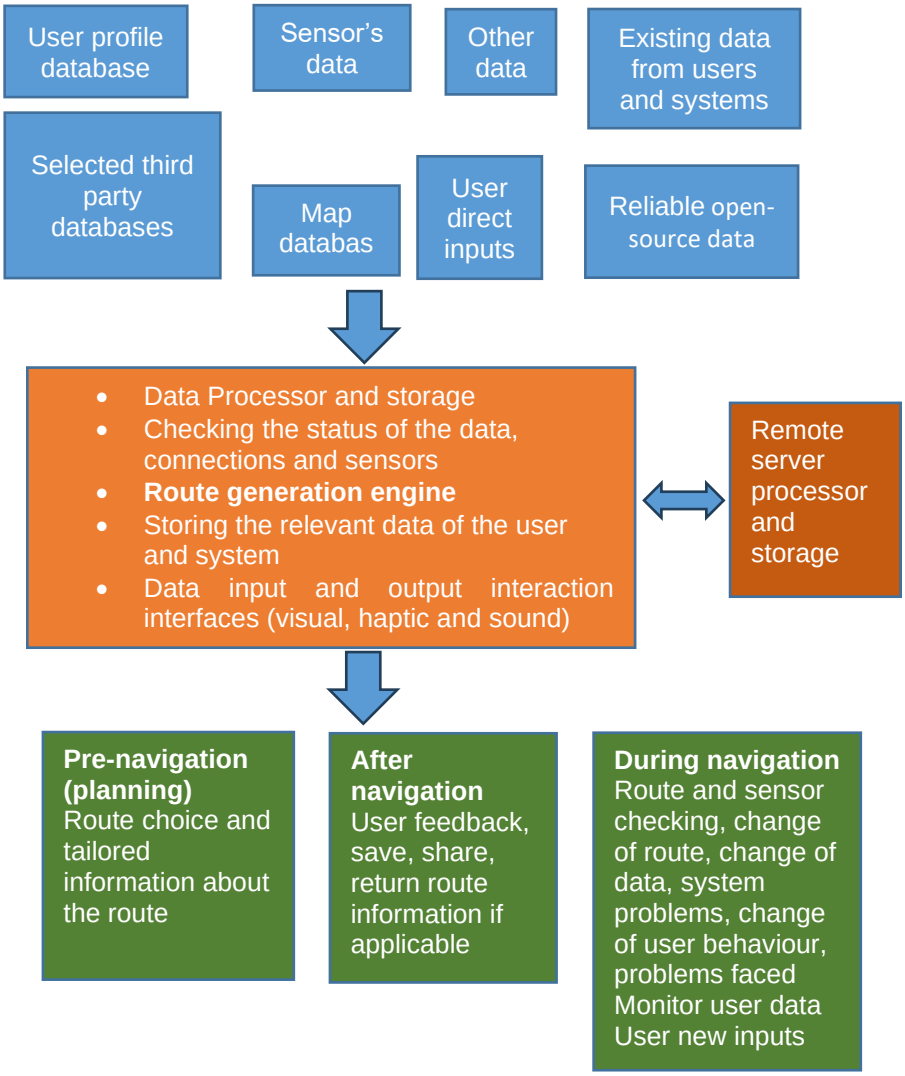


Figure 26 Navigation system architecture. The blue boxes represent the inputs, the orange boxes represent the navigation system process and the green boxes represent the navigation stages

The information flow within the system should be designed to be seamless and efficient, with real-time data updates feeding into the route-finding algorithm and user interface. The incorporation of data from multiple sources, including GPS, sensors, and user inputs, can enhance the system's ability to provide accurate and timely navigation guidance.

The architecture of a navigation system for BPSP should be designed with a focus on user needs, informed by relevant research and user data, and aimed at providing a seamless and user-friendly navigation experience. This approach will help ensure that the system is not only technically sound but also truly beneficial for its intended users.

A description of the components of the navigation system diagram:

- **User profile database:** This database stores information about the user, such as their location history, requirements and preferences. This information can be used by the navigation system to provide personalised navigation instructions.
- **Sensor's data:** This data comes from the navigation systems sensors such as GPS, camera, compass, Wi-Fi and Bluetooth. The data is used by the navigation system to generate navigation instructions.
- **Selected third party databases:** These databases contain navigation-related information, such as maps, traffic data, and weather information. This information is used by the navigation system to generate accurate and up-to-date navigation instructions based on the relevance of the data to the user.
- **Map database:** This database contains the digital map information. The map is used by the navigation system to generate navigation instructions and to track the user's progress as well as presenting the details to the user.
- **Remote server processor and storage:** This component is responsible for processing and sharing all the input data from various sources to the navigation system device. It also stores the processed data for future use in standard formats.
- **Route generation engine:** This component generates navigation instructions based on the processed data. The instructions are given in a clear and concise way, using multimodal outputs.
- **Pre-navigation (planning):** This phase of the navigation system involves planning the route to the user's destination. This includes

taking into account the user's current location, the destination, the obstacles, and the available data.

- **During navigation:** This phase of the navigation system involves providing real-time navigation instructions to the user. The instructions are updated as the user moves, and they take into account the user's progress and any changes in the environment.
- **After navigation:** This phase of the navigation system involves providing feedback to the user about their journey. This feedback can include information about the time it took to reach the destination, the distance travelled, and any obstacles that were encountered. The user will also have the opportunity to provide feedback and save relevant information.

The increasing reliance on digital technology suggests that many individuals, including BPSP, are likely to use smartphone-based navigation systems for independent navigation. These systems offer a host of benefits. First, they provide accessibility features such as screen readers and voice assistants. Second, they deliver real-time updates and directions, aiding navigation in unfamiliar environments and allowing route adjustments. Third, they adopt a user-centric approach, focusing on the user's needs, preferences, and limitations, thus leading to more intuitive and efficient systems for BPSP. These systems often include customisable verbal descriptions, vibrational feedback, and integration with other accessible apps. Fourth, the portability of smartphones makes them a convenient tool for navigation.

5.4 Discussions

The findings from the focus group discussions provided valuable insights for describing a navigation system model for BPSP. Participants emphasised the importance of a standalone device that uses GPS signals for accurate location updates. Participants also highlighted the need for using camera that can provide real-time object recognition and description. These suggestions aim to enhance the safety and

independence of blind and partially sighted individuals in their navigation journeys.

The ideal navigation system described by the participants would provide clear position and orientation guidance, incorporate familiar references and landmarks, and offer customisable settings to meet individual needs. The potential of navigation systems to support routine journeys for BPSP is immense. By incorporating real-time data, AI assistance, and a variety of sensors, the system could provide detailed and accurate guidance, ensuring safer and more efficient travel. The system could be programmed to recognise and remember frequent routes, such as the journey from home to work or the local grocery store, thus reducing the cognitive load on the user and increasing the predictability of their travels. Over time, the AI components of the system could learn from the user's habits and preferences, further enhancing its ability to assist in routine journeys.

Features such as obstacle detection, and haptic feedback could significantly reduce the challenges encountered by BPSP in their daily commutes. Moreover, the system's remote server integration feature could provide real-time updates about changes in the environment that could affect regular routes, such as construction or road closures. By providing comprehensive, reliable, and personalised support for routine journeys, the described navigation system could greatly enhance the independence and mobility of blind and partially sighted individuals.

One of the challenges identified by the participants was the potential danger posed by silent hybrid and electric cars in shared spaces. This complements the finding of the first study about electric vehicles being a danger at crossings. Blind and partially sighted individuals heavily rely on auditory cues to detect and avoid vehicles, but the absence of engine noise in these vehicles makes it difficult for them to perceive their presence. This finding highlights the need for a navigation system that incorporates advanced technologies, such as vehicle detection and alert systems, to enhance safety for blind individuals in urban environments.

Another significant challenge identified was the lack of spatial awareness, which leads to frustration and dependence on others for navigation. Blind and partially sighted individuals expressed the need for a navigation system that provides real-time information about their surroundings to create a mental map of their environment. Additionally, participants emphasised the importance of the system alerting them about upcoming obstacles, such as traffic lights or pedestrians. These features would empower blind individuals to navigate independently and with confidence.

The focus group discussions also revealed the preference for a hands-free navigation system that does not require BPSP to hold additional devices in their hand. The responses about BPSP preferences and needs of handling the navigation device provided new and insightful findings that need to be considered in the navigation system design. As BPSP often rely on a cane for mobility, having a navigation system that can be seamlessly integrated into their existing routines and equipment is crucial. This preference reflects the need for a navigation system that allows for a natural and intuitive navigation experience. The study findings and discussions highlighted the challenges faced by blind and partially sighted individuals while navigating and provided valuable insights into the desired features of an ideal navigation system.

5.5 Chapter Summary

This chapter investigated the navigation experience of BPSP with the existing navigation solutions. Additionally, this chapter provided valuable insights into the outlining of a low-cost and personalised navigation system for BPSP that takes into account their unique needs and preferences. The importance of personalisation and customisation in improving the effectiveness and usability of navigation systems for this population have been discussed, as well as the potential for such systems to enhance the overall quality of life for BPSP by improving their independence and mobility. This chapter contributed to the objectives 4,

5 and 6 of this thesis. The next chapter is about personal data and user profile content and creation.

CHAPTER

SIX

6 PERSONAL DATA AND USER PROFILE

6.1 Chapter Overview

This chapter covers presentation and classification of BPSP's personal data including preferences, needs and additional data about them. The focus of this chapter is on creating a user profile structure which accommodates all the navigation-related personal data. In addition, the way of incorporating user profiles into navigation systems has been presented. The user profiles can be shared with the relevant third-party including navigation system designers and government for inclusive design, independent and safe navigation. This chapter benefits from findings of literature review as well as the findings of the previous studies particularly the interview with the mobility trainers.

6.2 User Profiles for Navigation

User profiles for navigation of blind and partially sighted individuals constitute an innovative structure designed to enhance their mobility and overall quality of life. These profiles are personalised data sets that encompass significant navigation-related information for each individual, such as typical routes, preferred mobility aids, sensory capabilities, obstacles encountered, pace, and specific areas of difficulty. The utilisation of predefined user profiles is essential in order to get personalised information and facilitate customised routing that caters to individual preferences, encompassing factors such as barriers, orientation cues, and preferred route options (Zimmermann-Janschitz et al., 2017).

The information gathered in the user profiles can be incorporated into the navigation systems, providing real-time, individualised guidance to aid BPSP in moving around both familiar and unfamiliar environments. Moreover, these user profiles can be shared with authorities or urban planners, allowing them to gain insights into the specific navigation challenges that BPSP face. Consequently, this information can guide enhancements in public infrastructure and services, making cities and towns more accessible and navigable for BPSP. The relationship between personal data, technology, and urban development presents a promising pathway to a more inclusive society.

User profiles were created as an important database for both the user and the navigation system. Each user is capable of creating a personalised profile through the navigation system and add personal information to the profile which can be later used for all future navigations. User profiles can be updated if there is the necessity of changing the user information, whether that is a change of user behaviour based on growing up in age or a personal choice.

6.3 User Profile Content and Structure

The main components of user profiles were created based on existing literature and the first study data. Kikiras et al. (2006) presented the user profile components for navigation in a diagram which includes cognitive and sensory abilities. Moreover, the components include the navigation preferences of the user as well as the interface design preferences. Figure 27 shows the user profile components of their research. The amount of information in each part of the user profiles depends on the provision of the information by the user as well as information by third parties whether personal data or navigation-related data.

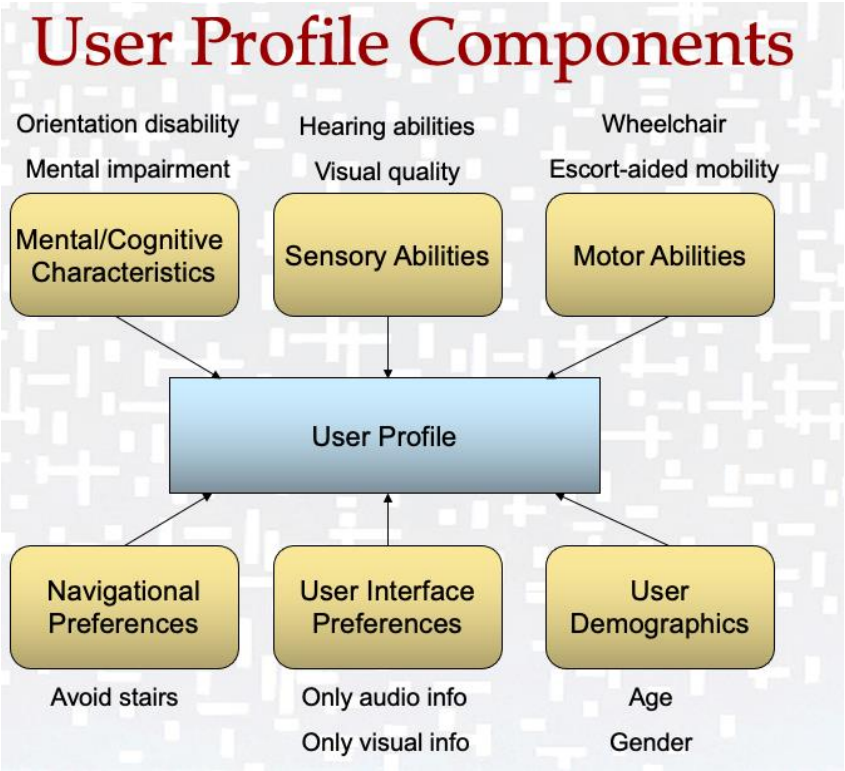


Figure 27 User Profile Components (Kikiras et al., 2006)

The importance of the user profiles is that it can be incorporated into the navigation systems to personalise the navigation experience of BPSP. Moreover, the information can be shared with relevant third-party authorities to understand the navigation state of BPSP and to improve the navigation experience based on actual user's data. Table 24 shows a typical user profile content.

Table 24 Typical user profile content

User's unique ID
Personal details
Registration Blind or Partially Sighted Nature of sight-loss and its effect on navigation
Any other disabilities/ conditions apart from sight-related? Navigation requirements based on the conditions
Set of requirements based on the journey type Familiar or Unfamiliar journey

Set of Preferences, needs and challenges needs
Sensory Abilities Senses used for navigation Interface interaction capabilities
Navigation aids available to use Smartphone applications, dedicated devices, mobility tools, guide dogs etc. In what capacity/condition they might be used Challenges/limitations
Personal Skills Cognitive Physical
Route selection factors Type and nature of the factors Relation to familiar and unfamiliar journeys
Route selection Strategy Elements of good and bad routes Factors affecting the route selection decision
Actions taken during uncertainty Prioritisation of actions
Relevant information provided by third party

The user profile includes key areas such as the personal details of users, including their specific nature of sight loss and their impact on mobility. Navigation requirements, preferences, needs, and challenges of the individuals have been accounted for. There is an emphasis on the significance of sensory abilities and the use of various senses in navigation, alongside the interaction capabilities with different interfaces. A section has been added in the user profile for the existing navigation aids including smartphone applications and dedicated devices. Physical and cognitive skills, are also considered, as they play a crucial role in the route selection.

Factors influencing route selection strategies relevant to familiar and unfamiliar journeys have been taken onboard. Furthermore, the user profile structure accounts for actions taken during the periods of

uncertainty, prioritising necessary steps and the role of real-time third-party information in the decision-making process. Overall, this structured approach demonstrates the user profile structure of a navigation system that adequately address the diverse needs of BPSP. The user profile structure will be revised based on the mobility trainers' inputs to be more inclusive. It is important to consider a user profile format that is well-structured and identifiable by different systems and platforms. Using a pre-defined format that is well structured and easy to incorporate is the key to successfully feed the data into navigation systems as well as an efficient use of the data.

6.4 Ontology-Based User Profiles

In this research, Kikiras et al. (2009) introduce an Ontology-based method for user modelling in the setting of pedestrian navigation systems. This study presents a comprehensive analysis of the difficulties involved in the navigation process and the basic concepts of wayfinding. Furthermore, this paper presents detailed insights into the different parts of the user profiles shown in Figure 28, which mostly focus on navigation-oriented aspects and clarify the relationships among these components. The user modelling is implemented through the use of a web-based form known as Web Ontology Language (OWL), which facilitates its integration with navigational applications and systems.

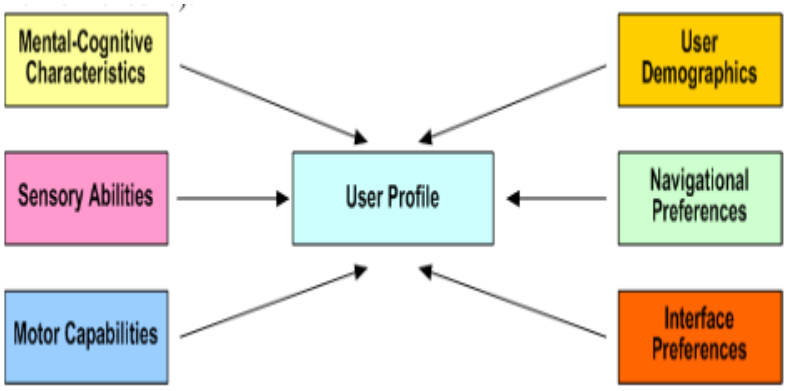


Figure 28 Components of a navigation-oriented User Profile from (Kikiras et al., 2009)

This user modelling can be used for creating a standard data structure that can be used by the navigation system. There are other works considering user profiles for navigation such as Völkel and Weber (2008) which considers user profile data for multi-criteria route personalisation for people with mobility impairment. In addition, Miao et al. (2011b) considers the creation of user profiles as a step towards user requirements analysis.

6.5 Data Management

The use of user profiles in navigation systems goes beyond just enhancing the experience for BPSP. By sharing user profile data with local councils, it can help them gain insights into the challenges faced by BPSP due to walkway designs and identify hotspot areas where frequent incidents occur. This crowdsourced data allows for classifying users into groups based on navigation-related categories, enabling better understanding and tailored support. Organising the data within user profiles through classification, such as differentiating between user, navigation aids, and environmental data, ensures a structured and computer-recognisable format.

Additionally, users can be classified based on their visual impairment level, allowing for more targeted assistance. Data storage is facilitated through databases and remote servers with flexible capacity, while two-way communication in recognised formats ensures seamless data exchange. However, data protection remains a top priority, addressing security, trust, ethics, and privacy in compliance with data protection regulations. Access to the data need to be restricted based on the user types to ensure appropriate usage and safeguarding sensitive information. Collaborative efforts in data sharing and utilisation can lead to significant improvements in the navigation support and overall well-being of BPSP.

6.5.1 Data Sharing and Collaboration

The sharing of individual's navigation-related personal data in the form user profiles holds significant importance in addressing critical issues and providing enhanced navigation support for BPSP. By collaborating with authorities and technology designers, the data from these user profiles can shed light on the challenges faced by BPSP in navigating outdoor environments, thus advocating for more accessible and inclusive walkway designs. App designers can utilise this valuable information to tailor navigation tools and features specifically catering to the needs of blind and partially sighted users, empowering them with the ability to navigate independently and confidently. Through responsible data sharing, we can enable a collaborative environment that not only promotes understanding and awareness of BPSP's unique navigation requirements.

6.5.2 Data Classification

Classification of the data within the user profiles is an important step towards creating an organised and computer-recognised format. One form of classification is assigning the data to its origin. For example, whether the data is related to the user, the navigation aids or the environment. Then creating sub-classifications within the main categories to assign individual data into more detailed classes.

6.5.3 Data Storage and Communication

To ensure the effective storage and communication of user profiles for BPSP's navigation, a robust system need to be employed, encompassing database management and remote servers. The data need to be securely stored, allowing for scalability to accommodate increasing profiles and evolving needs. Communication of this valuable data relies on recognised formats, facilitating seamless exchange between different platforms and navigation applications. Two-way communication enables real-time updates and feedback, ensuring that users' profiles remain

current and tailored to their preferences and requirements. Multiple communication sources can be utilised, enabling compatibility with a wide range of devices and ensuring accessibility for all users. By implementing these data storage and communication measures, BPSP can access personalised navigation support, enhancing their overall navigation experience.

6.5.4 Data Protection

Data protection is of great importance when it comes to user profiles containing personal information about BPSP. These profiles often include sensitive data related to individual's vision impairment, health conditions, mobility aids, and navigation preferences. It is essential to uphold the highest standards of security, trust, and privacy. Safeguarding this data is not only a legal and ethical obligation but also crucial to earning the confidence and trust of BPSP who rely on navigation systems for their independence and safety. Robust data protection measures, adherence to data protection regulations, and controlled access ensure that personal information remains confidential and is used solely for the intended purpose of providing personalised and effective navigation support.

6.6 Mobility Trainers' View of User Profiles

Mobility trainers provided very insightful information about the content of user profiles for navigation support of BPSP. The interview sessions allowed the participants to present, discuss and expand on the information provided about the user profile contents. The choice of interview method was based on the similar research approaches of creating user profiles such as Zimmermann-Janschitz et al. (2017) who created user profiles based on a number of studies including expert interviews. According to the interviewed mobility trainers, the content of a user profile should include personal data such as age and sight condition.

> "I need to know what level of sight they've got and how - so if they've got some residual vision how they use it, is it peripheral vision or is it central vision" MT2.

The trainers also emphasised the importance of using a mobility assessment form to identify aspects of the user's mobility, such as their capabilities, training, and skills.

> "It'll be useful to know if there are any physical limitations. Do they use a walking stick? Or do they have difficulty walking beyond a certain distance?" MT2.

Additionally, the trainers mentioned that physical and sensory impairments should be included in the user profile.

> “They’ve got additional impairments, like a hearing impairment or cognitive impairment is there a physical impairment. When they got other health conditions that make it harder for them to mobilise” MT7.

Overall, the trainers stressed the need for a comprehensive user profile that includes a range of information to better support and personalise the mobility training and navigation support provided to BPSP.

The mobility trainers’ version of user profiles

The user profiles aim to gather information about the person's vision condition, mobility aids, cognitive abilities, health issues, and navigation experiences. The ultimate goal is to tailor navigation assistance and support to cater to each individual's specific requirements. Below is a summary of the key points to include in the user profiles according to the mobility specialists:

1. Vision and Nature:

- Level of sight and residual vision.

- Ability to use peripheral vision.

- Impact of weather conditions on navigation.

2. Mobility Aids and Physical Limitations:

- Use of walking sticks or other mobility aids.

- Physical limitations affecting navigation.

3. Cognitive Impairments:

- Any cognitive impairments that affect decision-making during navigation.

4. Desire for Navigation and Objectives of Travel:

- The person's willingness and motivation to navigate independently.

- Specific objectives or goals of travel.

5. Positive Aspects Related to Navigation:

- Skills, abilities, and strengths that can aid navigation.

6. Preferences for Voice Feedback and Speed of Walking:

- Choice of voice level and male/female voice.

- Speed of walking and any associated anxiety.

7. Sensory Difficulties and Health Issues:

- Other sensory difficulties beyond vision impairment.

- Health issues like diabetes, blood pressure, etc.

8. Familiarity with the Local Environment:

- Knowledge of local places and landmarks.

9. Training and Familiarity with Tools:

- Past mobility training experiences.

- Proficiency in using canes, reading apps, and navigation tools.

10. Night Navigation and Time Preferences:

- Ability and willingness to navigate at night.

- Preferred time of day for navigation.

11. Social Support and Family Information:

- Availability of support from family or friends.

12. Preferences for App Features:

- Customisation options for landmarks and information.

- Accessible reporting or complaint system.

13. Additional Cognitive Abilities:

- Level of concentration and multitasking during navigation.

- Understanding of navigation concepts like clock face system.

14. Contact Information:

- Contact details and address for communication.

15. Goals and Expectations:

- What the person wants to achieve through navigation.

Revising and extending the user profile content based on the interview findings from mobility trainers will help ensure that the profiles are more comprehensive and accurately reflect the needs and challenges of blind and partially sighted individuals. This is done by incorporating insights from mobility trainers' perspectives. The revised user profiles will be

better equipped to cater to the diverse requirements of blind and partially sighted individuals, resulting in more effective and tailored navigation support. Table 25 shows the revised and extended version of the user profile content that can be used to enhance the navigation of BPSP either by incorporating it to navigation systems or sharing it with relevant third-party.

Table 25 Revised and extended version of the user profile

Unique ID
Personal details Age, gender, contact details
Registration Blind or Partially Sighted
Nature of sight-loss, effect on navigation Eye condition, remained vision and how they use it. Whether they can use their peripheral vision. Central vision. Distance that can be seen. History of sight loss. What their vision is like. Near functional vision if any Cause of visual impairment
Any other disabilities/ conditions apart from sight-related Any sensory difficulty, health issues Medication that makes them drowsy If there are other impairments like cognitive, physical or hearing. If they have diabetics (check level and take something to eat if needed) Blood pressure or diabetics if any Hearing level How much the person can travel independently, age. Physical limitation. Dominant hand Speed of walking
Familiar and unfamiliar journey experience Reason of travel Are they familiar with what is around them where they want to go? How different navigation experience is for unfamiliar journeys
User preferences Whether go out in night. Weather condition of concern. People desire for navigation Positive things about the person for navigation. What they like to do. Motivation helping them go out. Wellbeing related reasons to get out Preferred time to go out (might need training or support needed for the time given).

Expectations of the person (what they want to do and what goals they have) What they want to achieve and what they think can achieve
Navigation requirements and needs Brief stories about the person's life to get a good picture of the navigation needs. What is related to the safety of the person? Access of information available and its nature. What they need to access the information.
Challenges of navigation Challenges they have Description of incidents happened to them in the past and when. What prevents them from doing something. Barriers. What they struggle with
Sensory Abilities Touch, smell
Interface interaction capabilities Choice of voice level and gender What accessibility feature and level of interaction needed to access the information.
Personal Skills Any mobility trainings in the past Any cane training Mental problems if any. How much they rely on others. Education level, correlation between education and navigation independently. Employment and socialise (effect on navigation). cane training. Tactile information skills. Nature of support needed. level of confidence. Level of concentration (dealing with everything at the same time). Their understanding of concept of navigation (like clock face system)
Route selection factors More information about landmarks and customising landmarks as needed Environmental conditions Map information (nature and amount of information) Class and nature of the factors What they can pick up in the environment How they interpret the environment
Route selection Strategy What routes they want to take? Factors affecting the route selection decision Safest, quickest, shortest, most pleasant or combination
Actions taken when something goes wrong Human help

Technology assistant
Navigation aids Smartphone apps, devices, mobility tools, guide dogs etc. Do they use walking sticks? Beacons if any and whether can be connected/used for navigation. whether they use phone or reading apps.
Cognitive abilities Willingness to get training and learn Cognitive impairment affecting navigation (with regard to route decision making) Anxiety nature if any Confidence impact on navigation. Cognitive ability and leaning style
Good and bad routes What is a good route and what is a bad route in the perspective of the person
Relevant information provided by third party attached to the user profile Information from the smartphone applications, medical information, information from the council
Location history Visited places and interpretation of the data to update/learn about the capabilities and preferences of the person
Prioritisation of actions need to be executed What is the first action need to be taken in safety-related issues
Statements/ set of instructions provided by the user As much information as possible for the best navigation support Complaints or reporting by the user about any potential issues.

6.7 Discussions

The chapter provided valuable insights into the importance of user profiles for navigation systems designed for BPSP. The contents of these profiles should include information about the individual's level of sight, physical limitations, cognitive impairments, interests, desires, positive and negative factors, and environmental factors. These details are crucial for creating personalised and tailored navigation experiences that meet the unique needs and preferences of each user.

Physical limitations are another important factor to consider in user profiles. Knowing if a user requires a walking stick or has difficulty walking beyond a certain distance can help in planning routes that accommodate their mobility needs. Cognitive impairments should also be taken into account, as they may impact decision-making abilities and require routes with fewer complex choices.

Understanding the interests, desires, and objectives of blind or partially sighted individuals is crucial for creating a user profile that caters to their specific needs. For example, if someone is autistic, their interactions with people may cause difficulties, and routes can be planned to avoid crowded or overwhelming areas. Including positive and negative factors in the user profile can help identify what motivates or hinders the individual's mobility, allowing for more effective navigation support.

Environmental factors play a significant role in navigation of BPSP. This includes information about roadworks, construction, or other obstacles mentioned in the user profile. This can help the navigation system in providing real-time updates and alternative routes to avoid such barriers. This feature is particularly important as BPSP may face challenges in navigating unfamiliar or changing environments.

The importance of personalisation in user profiles should also be considered. Personal landmarks, such as preferred crossing points or friendly cafes, can be included in the profile to enhance the user's familiarity and comfort during the navigation. This level of personalisation allows the navigation system to provide tailored instructions and suggestions that align with the user's preferences and needs.

The unique structure and detailed content for the user profile was developed based on the findings of this research. This is a new approach that can be used to tailor the navigation experience to individual needs. Moreover, there is room to accommodate any changes and new data to be stored in the user profile and incorporated into the navigation system. Several challenges were identified associated with creating navigational

user profiles, including the need to balance the collection of detailed information with user privacy concerns, the need to incorporate dynamic and real-time data into the profiles, and the need to develop algorithms and models to process and analyse the data.

The use of personal data in navigation systems presents significant privacy and security challenges that must be carefully addressed. Location information and travel activities are sensitive data that can lead to exposure of user's position and behaviour. Additionally, BPSP's personal data need extra safeguarding based on their unique needs. This is particularly important to protect them from harm including online threats and the risk of being targeted by criminals. User profiles, which contain sensitive information such as health conditions, mobility aids, and navigation preferences, must be handled with the utmost care. While data sharing and collaboration with authorities and technology designers can enhance navigation of BPSP, the associated risks of data misuse or breaches cannot be overlooked.

Personal data must be protected through encryption, controlled access, and anonymisation techniques to prevent unauthorised access and minimise the risk of misuse. Implementing secure data storage and communication protocols is also vital to maintaining the confidentiality and integrity of user information. The anonymisation process should include the fine details of personal data. This is because the artificial intelligence and smart algorithms are capable of interpretation and extraction of enough details that might lead to the exposure of the user's identification, location or any other personal data. Adherence to data privacy regulations like GDPR is crucial to ensure that personal data is securely managed, anonymised where possible, and shared responsibly. GDPR compliance requires explicit consent from users, data minimisation, and secure storage, along with transparent communication about how their data might be used. The users must have control over the data management and sharing. In addition, there should be straightforward steps that allow the users to add, amend and remove their

data at any time. By taking these necessary precautions, stakeholders can foster a collaborative environment where data is used to improve navigation systems for BPSP while safeguarding user privacy and trust.

6.8 Chapter Summary

This chapter highlighted the importance of creating navigational user profiles to facilitate the personalisation and customisation of navigation systems for BPSP. The profiles included information about the user's mobility skills, navigational preferences, preferred landmarks and routes, and environmental factors that affect their navigation, such as weather and noise levels. Overall, this chapter provided important insights into the design of navigational user profiles for BPSP, highlighting the role of personal data in improving the effectiveness and usability of navigation systems for blind and partially sighted individuals. This chapter contributed towards achieving objectives 6 of this thesis. The next chapter covers the details of development and evaluation of a navigation system conceptual framework for BPSP drawing from the findings of the previous chapters and the final studies.

CHAPTER

SEVEN

7 DEVELOPMENT AND EVALUATION OF A NAVIGATION SYSTEM FRAMEWORK FOR BPSP

7.1 Chapter Overview

This chapter covers the details of developing and evaluating a navigation system's conceptual framework for BPSP based on the findings of the previous chapters. In addition, interview sessions were conducted with BPSP to inform the design of the framework based on the individual user profiles and navigation scenarios.

7.2 Navigation System Conceptual Framework Development

A navigation system architecture has been developed in chapter 5 based on the findings of chapters 2-4. The navigation system described in chapter 5 was used as the base for developing a detailed conceptual framework in section 7.2. The framework was compared with the existing systems to evaluate the design components. In addition, further evaluation was conducted based on a research study with the blind and partially sighted individuals using navigation scenarios. The following two sub-sections present the criteria of working of the route-finding component of the navigation system framework.

7.2.1 Route-Finding

Route-finding system is an essential part of the navigation system that can provide tailored navigation experience to BPSP. In chapter 5, the route-finding preferences and needs of BPSP have been covered.

However, the technical side of route-finding is presented in this section. Route finding can be dealt with node by node and edge by edge. In this approach, a node is a unit of the map that represents a point of interest or concern in reality. A node is typically encircled by other nodes connected by edges. In addition, there are areas of interest on the map and areas and spots of concern that needs to be taken into account by the route-finding system. Table 26 illustrates the basic map elements. Each element of the map is assigned a score based on specific optimisation criteria. This score informs the decision regarding the most suitable direction to proceed in. It is important to consider the directionality of travel between nodes, whether unidirectional or bidirectional, because this directionality may be influenced by factors such as traffic conditions, specific scenarios, or user requirements and preferences.

The creation of sub-nodes may become necessary. This could be due to the specificities of the terrain, user preferences, needs, or environmental conditions. The introduction of these sub-nodes adds another layer of complexity to the route optimisation process. Lastly, it is important to note that each potential route is scored based on a combination of these components. This integrated score helps to determine the most optimal path from a range of possible routes.

Table 26 Map elements

Node	
Edge	
Area	
Uncertainty spots	
Area of concern	

Map personalisation is the key for an effective route-finding system. The maps should maintain the information in a customisable way. In fact, the map details for one person could be completely irrelevancy to another person in terms of the weights of the nodes and edges. For instance, if a blind or partially sighted individual rely on GPS for positioning, then the areas of concern would be places were GPS signal are low. However, the same spot where GPS signal is low might not be an issue for someone who doesn't rely on GPS to find the real-time position. Figure 29 illustrates a path-finding scenario on a 4x4 grid of nodes and edges.

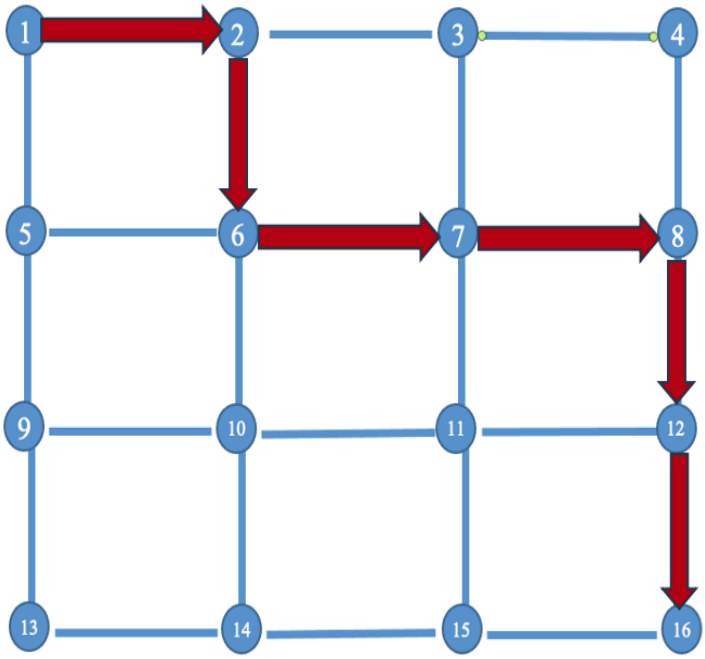


Figure 29 Illustration of pathfinding between two nodes in a 4x4 grid

7.2.2 Route Selection's Scoring Criteria

Route selection process can be considered as the equation of summing up the score of the route selection factors. Table 27 is an example of how to calculate the score for each route based on the scores given to the map elements and to the routes. The scores given to each map element must be weighted to account for the nature and type of the element. The weighted score criteria should account for the user profile data to provide

a tailored route selection experience. There is another important element of consideration in the calculation process which is consideration of combinations of factors together that trigger safety issues. Sometimes two or more factors cannot work together which highlights red signal for the process. One example might be raining with stairs in which case the user might face significant safety issues. If the consideration is in place for this in the route calculation, this segment of the route will be considered as a bad route and will be excluded in the route choices where applicable.

Table 27 Route score calculation illustration (WS is weighted score)

Map elements	User needs	User Preferences	Journey distance	Journey time	Overall safety
Node Edges Segments	WS1	WS2	WS3	WS4	WS5
Score calculation for the potential routes					
Route 1					Total score*
Route 2					Total score*
* Total score = sum of all weighted scores for each route					

Route-finding algorithms play a crucial role in the navigation of BPSP. These algorithms are capable of finding the shortest path between the user's current location and their destination. In addition to finding the shortest path, route-finding algorithms can also be used to take into account other factors that are important to BPSP, such as the number of turns in the path, the presence of obstacles, and the user's desired speed. This allows BPSP to find paths that are both efficient and safe.

Some of the most common route-finding algorithms used for navigation of BPSP include Dijkstra's algorithm and A* algorithm. These algorithms can be used to find the optimal path between any two points on the map,

regardless of the complexity of the environment. Shortest-path algorithms operate on the premise of creating a search tree that expands in a radial way from an initial node until the targeted end node is encompassed. This method effectively maps the shortest paths from the initial node to all other nodes included in the tree (Wieser et al., 2007).

Depending on the cost function, a route-finding algorithm can be faster or slower, more or less nodes might be covered. Each node carries information to characterise it. This includes node number, coordinates, cost of travel from the start node to the current node, cost of travel from the current to the final node and sum of the previous costs. Moreover, the path finding algorithms are able to account for the characteristics of the user in relation to the potential route such as speed of walking on flat and slope terrains as well as turns and steps.

7.2.3 Navigation System Physical Components

The physical components of the navigation system are classified into input units, processing unit and output units. The input sensors such as the microphone and touchscreen receive the responses directly from the user either to enter information or interact with the navigation system. On the other hand, the output units such as the vibration unit and audio transmitters transfer the necessary data to the user. Visual output includes presentation of information on the navigation system's screen. Although this option might not be applicable for the blind users with no light perception, it will help the partially sighted people with enough vision to read screes to explore the output information in visual feedback. The nature of visual presentation of information can include big fonts and high contrast to enhance the accessibility of the presented information. Figure 30 shows the physical sensors and units of the navigation system.

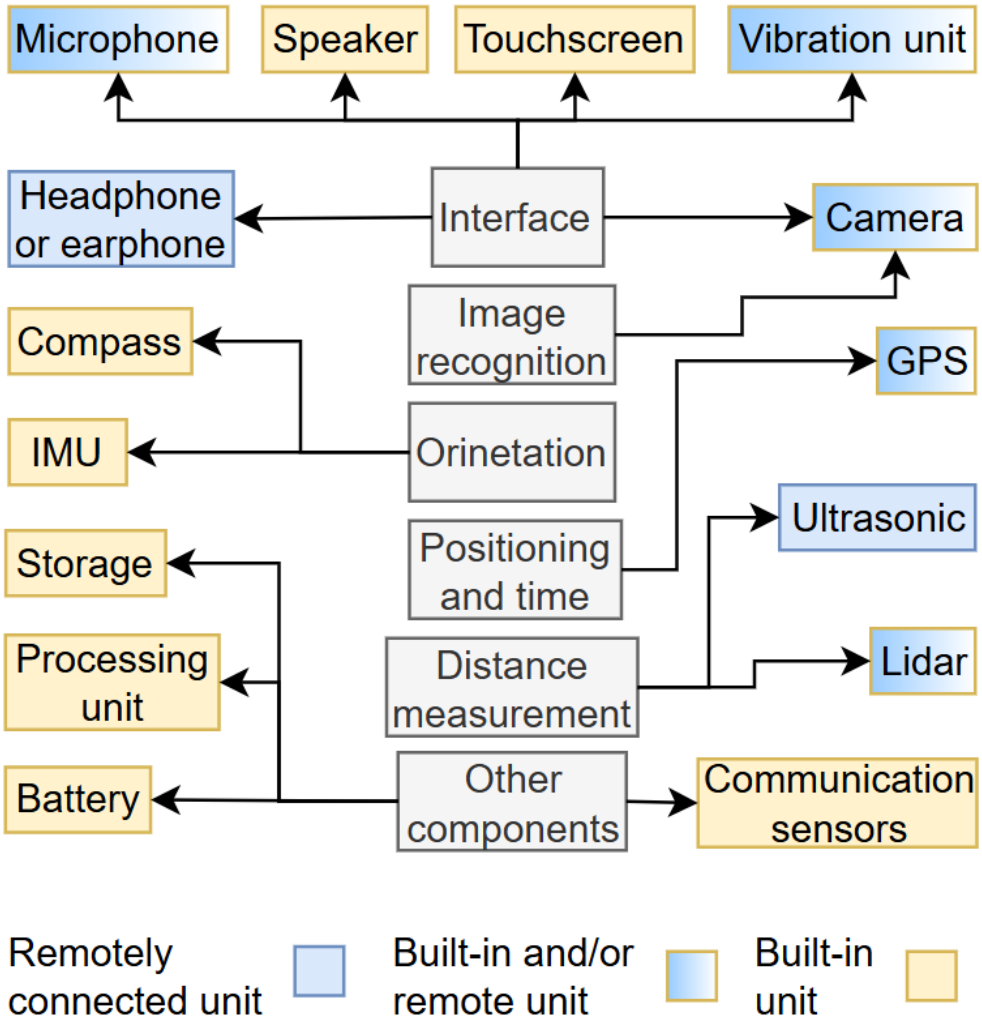


Figure 30 Physical components of the navigation system

There are other sensors which convey the technical information to the navigation system. For instance, the GPS is providing location and time information. The combination of location and time can be used to predict the speed, acceleration, deceleration, time of the journey, stopping time, moving time and other parameters which are critical for the navigation support. The Lidar and ultrasonic sensors provide valuable navigation support. They are capable of observing the 3D space around the user which can be integrated with the camera inputs for 3D space recognition. This combination will help in locating and identifying the obstacles and landmarks that might not be presentable on the map. There are sensors

that help with orientation such IMU and compass to monitor the user's real-time orientation and if there is a potential risk of fall or hit.
Communication sensors are used to exchange the data between the navigation unit with the other connected components. Another function of the communication sensors is to exchange the data between the navigation system unit and other information providers and databases. This process involves sending commands to receive or share the information. Communication sensors such as Bluetooth and Wi-Fi could also be used for positioning triangulation and distance determination. However, the results could not be suitable for navigation of BPSP unless for rough position and distance estimation. This is because of the nature and quality of the signals as well as the amount and type of the connected devices.

There are dedicated sensors that can be connected to the navigation system either to enhance the interaction or to improve the efficiency. For instance, if a smart cane is used with ultrasonic distance measurement onboard. It can be connected with the navigation system to add a valuable input which is the distance to the observed objects on the walkway. Another scenario is using a dedicated camera unit attached to a sunglass or reading glasses. The camera in this case needs to be connected to the navigation system to provide image recognition capability when used.

The operation of the navigation system needs other components such as the battery to power the system. In addition, storage and data processing units are crucial to make the system fully functional. Depending on the navigation system design and user requirements, various combination of components need to work together. The system can have a combination of onboard sensors and dedicated units connected in real-time. Busatto and Harvey (2022) highlights the sensors and components used by the navigation system providers. They highlight the common sensors for a navigation system with their functions. For instance, the camera use for

image recognition, GNSS for positioning, dead reckoning sensors for orientation and movement tracking, sonar for range finding and compass for orientation. This aligns with the findings achieved in this research.

User Interface for both input and output components must contain variety of interaction choices to allow the user to interact in an accessible way with the navigation system. Depending on the nature of visual impairment and skills of the person, the choice of interaction method can vary depending on the navigation stage. For instance, the user might want to get the warning feedback about an obstacle in vibration while receiving the navigation instructions in audio format. Figure 31 shows the possible input and output methods of the interface design.

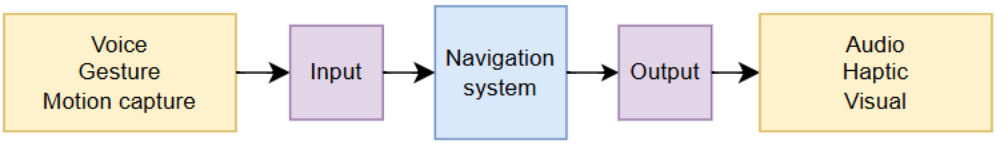


Figure 31 Navigation system interface choices

The choice of the interface method could also be a preference rather than a personal need. At the planning stage, the user is able to customise the settings to select the best interaction methods.

7.2.4 Navigation System Conceptual Framework

A conceptual framework for the navigation system based on the findings of the previous chapters is shown in Figure 32. This framework consists of a detailed presentation of the system in terms of the data inputs, processing and output.

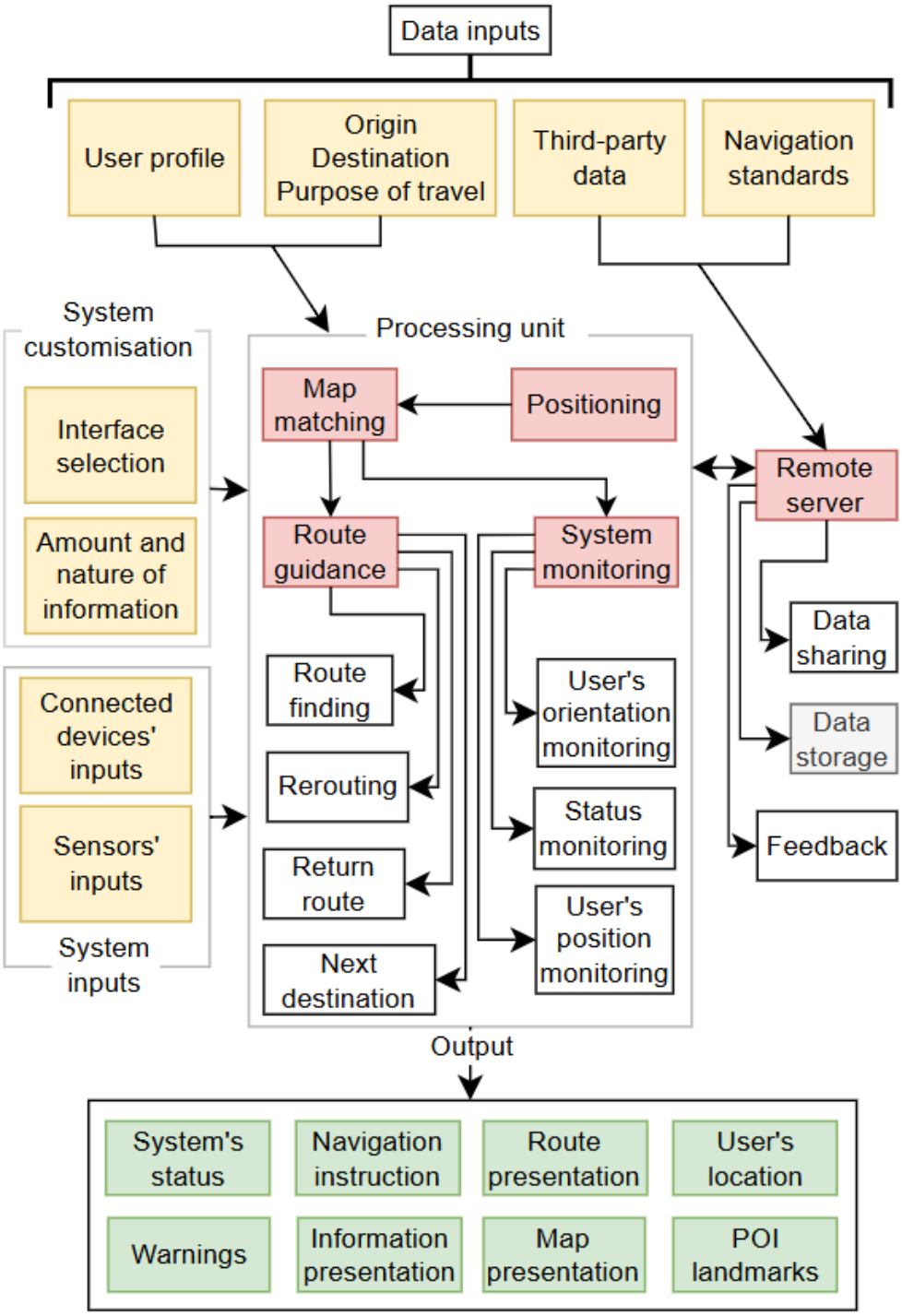


Figure 32 Navigation system conceptual framework (yellow boxes are the inputs, the pink boxes are the data processing parts and the green boxes are the outputs)

The input sources of information have been classified into three categories. The first category includes data sources other than the

system-related inputs. This category accounts for user's data and related third-party data. The amount and nature of information will be managed by the availability and the source of the data. The user profile structure and content has been described in chapter 6 which is a database of the pre-defined and real-time data about the user preferences and needs. The navigation system standards which are crucial sources of information, are accounted for in this conceptual framework. This is because they are reliable and rich sources of information to enhance the user's safety and personal needs. The issue with the navigation standards is that they are not ubiquitously available and location-dependent. However, they are an important provenance of information when available. There are two categories for system-related data whether they are customisation inputs from the user or sensor and component inputs to the processing unit.

It is important to mention the necessity for a default system configuration regardless of inputs from the user or relevant sources of information. The default parameters must be defined such that safety and common navigation requirements control the navigation from the beginning to the end of the journey. For instance, the route selection criteria must account for selecting routes with controlled-crossings by default to avoid the risk of accidents with other modes of transport.

The processing unit includes the necessary components to process the input information and provide the output in the required format. To cater for the navigation needs of BPSP and the functional requirements, there need to be a processor that can deal with complex computations with a high frequency. The sensors' positioning and acquired surrounding information will help with the route guidance in real-time. There need to be consideration for the user's change of the navigation plan and changes in the environment to provide necessary prompts for a safe and pleasant navigation experience. The system monitoring component has the responsibility to ensure an efficient operation. It can deliver the

system status to the user for assurance about the functionality of the navigation system and in case necessary actions need to be taken. For example, if the battery is running low, the user needs to consider recharging it to avoid the complete shutdown of the system.

Each navigation journey can contribute towards improving the consequent journeys. This can happen when the necessary details are provided, saved and crowdsourced by the navigation system. Consequently, sharing the data will enable the relevant parties to understand the navigation performance of a person and assess the infrastructure accessibility and system functionality. The user can provide feedback about any aspect of the journey. Figure 33 shows the types of feedback the user might provide.

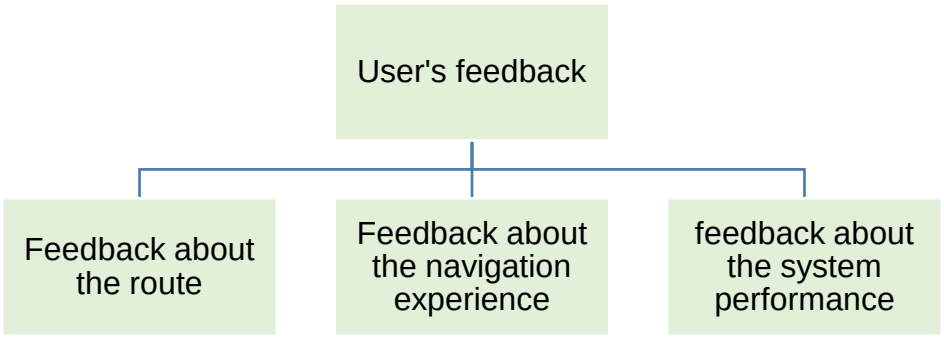


Figure 33 Types of the user's feedback after completing the journey

When the feedback is provided, it will be a crucial source of information to highlight technical issues and problem spots reported directly by the user. This can be related to the route itself, the walking experience or the efficiency of the navigation system in delivering tailored navigation support. The user feedback might contain information that is not necessarily captured and reported by the navigation system itself. The role of the remote server will be to capture and share these vital data about the journey and the user experience with relevant authorities, accounting for the privacy of personal data.

The output of the navigation system is classified into various categories to accommodate the required information for the user to monitor the journey and take actions. System status information allows the user to check the functionality of the system in real-time when needed. On the other hand, the warning prompts alert the user about an issue with the system or the journey. Overcrowding the amount of information in the output section might confuse the user. Hence, there need to be prioritisation of which information need to be presented first and in which format. This is particularly true for people with no useful vision who cannot access visual information.

The navigation instructions section accounts for the necessary navigational commands that need to be delivered to the user such as turning points. The route and map presentation section provide room for the route details to be presented with the map data to allow the user to check information like distance remained to the destination. The user's location information is one of the key information that need to be provided to the user. This has been highlighted in the findings of the previous studies as an expectation from the navigation system. On the other hand, announcing the relevant landmarks and POIs during the journey is also important. Hence, this part has been added to the output section of the navigation system. The developed conceptual framework demonstrated a unique and practical guidance for the design of a user-centric navigation system for BPSP.

7.3 Comparative Evaluation of the Developed Navigation System Framework

The developed navigation system framework in the previous part of the study was evaluated using two different methods. The first method was the comparative evaluation with the existing navigation solutions. The navigation systems that were identified and used by BPSP based on the previous studies has been considered. The second method was user evaluation of the navigation system framework in specific scenarios

where BPSP need navigation support to enhance the safety and navigation experience in general. This section includes the details of the first evaluation method.

The evaluation of the proposed navigation system framework was conducted through comparative evaluation with the most common navigation system framework identified in the previous studies which is Google Maps. Table 28 Comparative evaluation of the conceptual framework with Google Maps shows the comparison between the proposed system and the Google Maps in terms of the navigation system components. The criteria of evaluation was based on the system components and performance metrics to support the navigation of BPSP. By benchmarking the new framework against established systems, areas of improvement and innovation can be identified. This is particularly important in context-aware navigation and real-time adaptability to environmental changes.

Table 28 Comparative evaluation of the conceptual framework with Google Maps

Proposed system	Google Maps
User profile	
Development of a detailed user profile and accounting for it in the navigation system framework.	No accounting for a detailed user profile
Map	
There is room for selection of maps appropriate for BPSP (flexible map source)	Very little information relevant to BPSP available
Route-finding	
Route selection can be tailored to the blind or partially sighted user.	Calculated route is based on a cost function that is considering factors mostly irrelevant to BPSP

There is accountability for technical and user information in the route creation	
System customisation	
Customisation can be made to the map details and route selection parameters for BPSP	Customisation includes wheelchair accessible route selection option only
Unique preferences	
Tell the distance to the next station in number of side road crossings is possible	Distance is presented as the length of the segment in distance measurement unit format
Unique needs	
Clock face direction can be used to guide the user	Cardinal direction is used for guidance
Crossings	
Capable of presenting crossing details acquired from the third-party sources	Limited information about the crossing “you are crossing a large road” No account for type of crossing (controlled and uncontrolled)
Obstacles	
The map can show the location of fixed obstacles The surrounding observation sensors can detect potential moving and fixed obstacles	No information about obstacles relevant for BPSP on the map. Surrounding observation for obstacles not embedded in the design
Landmarks	
User-defined and default landmarks can be presented on the map	Limited landmarks are available on the map such as coffee shops There is a new function called “Live View” to detect landmarks using the camera, but only works

The surrounding observation sensors can identify potential landmarks	in limited locations and only buildings can be detected
Other modes of transport sharing the same path	
Shared spaces can be identified on the route where cars, pedestrians and bicycles share the same path	No information about the locations that the user might share the path with other modes of transport

Google Maps has been selected for the comparative evaluation, because it is the main navigation application used by BPSP that has some accessibility features. It is free and smartphone-based that works on both the Android and IOS devices. Google Maps allows for adding information to its map, but that is at a very limited context and mostly not beneficial for the navigation of BPSP.

7.4 User Evaluation of the Developed Navigation System Framework

The user evaluation study consisted of evaluating the navigation system framework with BPSP participants aiming to inform the design of the system in specific navigation scenarios. The selection and nature of scenarios were informed by the findings of the previous chapters. The study design has been reviewed and approved by the Ethics Committee. Interview method has been used by researchers to evaluate route-finding scenarios. Kan-Kilic and Dogan (2017) used interviews with users to evaluate blind people's route selection strategy and familiarity with the environment. Scenarios have been used by researchers to evaluate route-finding algorithm such as (Swobodzinski & Raubal, 2009).

Chakraborty and Hashimoto (2011) suggested that tailoring the system to individual preferences, could increase adherence and user proficiency in navigating the environment. They focused on the challenges of

designing a generalised system for pedestrians with different preferences, and needs. They emphasised the lack of data to support pedestrian navigation and the need for personalised route selection.

7.4.1 Accessibility of Study Materials

The study materials were made accessible for BPSP, alternative formats of the documents were made available on request. That included high contrast text with bold and big fonts and audio version of the documents. The study was in the form of semi-structured interviews using either telephone interview or Microsoft Teams.

7.4.2 Study Process and Data Analysis

The participants were first approached to collect the necessary information to create individual navigation-related user profiles. The user profile structure which was developed in chapter 6**,** has been used for that purpose. Consequently, the data was used to assess individual decision makings in specific navigation scenarios. After the initial data collection and user profile creations, semi-structured interview sessions were arranged with the participants. This was to evaluate the conceptual framework in the planning process as well as during the navigation scenarios related to crossings, obstacle circumvention, uncertainty situations and the environment. Figure 34 shows the route-finding scenario settings.

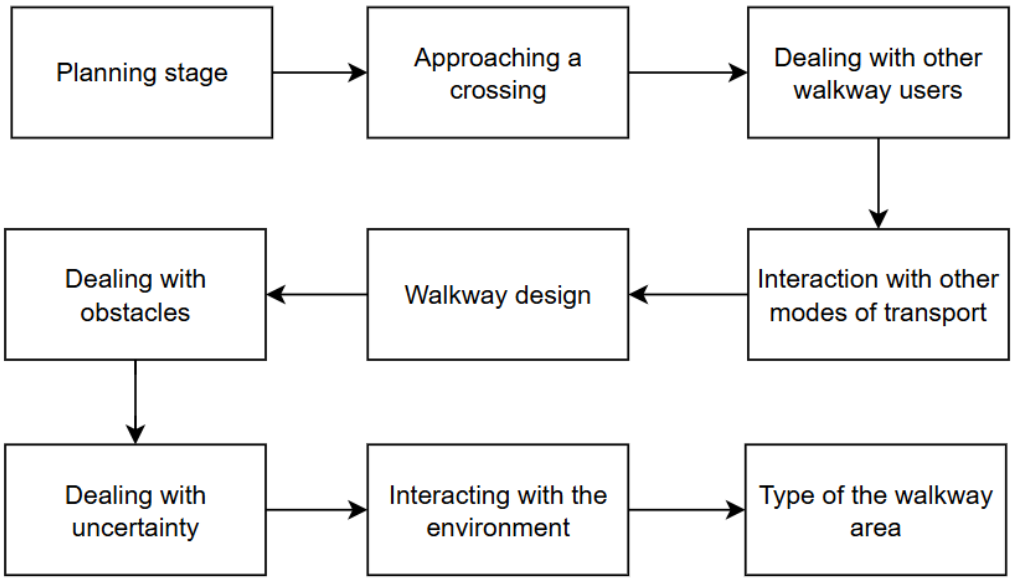


Figure 34 Navigation system scenarios

The scenarios were simplified and focused around specific decision-makings by the user. Consideration has been given to the route selection scenarios that enable the user to select between safety and preference. Other scenarios included route selection between safe and safer as well as preferred and most preferred. A total of 13 blind and partially sighted individuals were interviewed. The demographic details of the participants are shown in Table 29.

Table 29 Demographic details of the participants

Participant	Gender	Registration
Pa1	Female	Partially sighted
Pa2	Male	Blind
Pa3	Female	Blind
Pa4	Female	Blind
Pa5	Male	Blind
Pa6	Male	Blind
Pa7	Male	Blind
Pa8	Male	Blind
Pa9	Female	Blind
Pa10	Female	Blind
Pa11	Female	Blind

Pa12	Male	Blind
Pa13	Male	Blind

The user profiles were created for all participants and Table 30 presents the user profile created for participant Pa7 showing the necessary details in each component.

Table 30 User profile for participant Pa7 (the colour coding was used to enhance the presentation of each row)

User unique ID: Pa7
Personal details Age: 45-50 years **G**ender: Male Employed
Registration Blind
Nature of sight-loss, effect on navigation Usher syndrome (RP) tunnel vision, more rely on one eye Able to read a sign 6 feet away. Spatial ability is poor
Any other disabilities/ conditions apart from sight-related A lot of noise in ears health issue
Familiar and unfamiliar journey experience UF much harder and rely on Google maps and explore the route. It is a lot to do with planning “I do like to go somewhere where I kind of know how I have to walk somewhere, so in familiar areas and if I have to go somewhere that I have never been then I like to get a close description of the route as close as possible. So, I use things, apps, navigation apps to help me with that. Like Apple Maps, Google Maps, Lazarello, things like that. So that they can describe a little bit how I can get from A to B. “And I would probably look at all options. You know sometimes you are familiar with one route and that means you don't have to change the route. I would always do what's the easiest for me” “I'll probably take the Zebra one. But it always depends how familiar I am in an area, so if I'm not familiar I would go to the controlled crossing”
User preferences Try to avoid steps poor balance. Prefer quieter walkway even longer Knots are on the pavement. Bikes, people on bikes, not to be on the pavement. And the electric scooters, not to be left in the middle of the pavement.
Navigation requirements and needs

The route should be clear of steps because of personal safety concern. Avoid routes with reports of incidents of blind people with movable obstacles. Safe crossings should be selected on the road
Challenges of navigation Bench, stupid scooters, bikes bins in the middle Downhill and ramps the temporary movable obstacles. Walkway without steps
Sensory Abilities and skills Tactile pick up by touch, noise of cars, smell “Just a listen out. I mean, the remaining vision I've got, I try to make things out, but sometimes I miss judging exact the things I thought they were”
Interface interaction capabilities Okay so in terms of planning for journeys like before getting out so that's just the planning bit of it is this something that you do it on your own or you ask for help for planning for the journeys? I tend to do it on my laptop on Aviva. The journey plan on Aviva.
Personal Skills Received mobility training, familiar with using mobility aids
Route selection factors Times of the transport if we go on the bus or the train. Safe walkway Weather Rain
Route selection Strategy The safest and the shortest Fastest usually, safest if unfamiliar
Actions taken when something goes wrong I can ask someone
Navigation aids Guide dog Google maps, Apple maps, Lazarillo “Okay so in terms of planning for journeys like before getting out so that's just the planning bit of it is this something that you do it on your own or you ask for help for planning for the journeys, I tend to do it on my laptop on Aviva. The journey plan on Aviva.
Cognitive abilities Memorising the route details
Good and bad routes No obstacles. No people on bikes. No scooters.
Relevant information from third party Roadwork information, landmark locations
Location history Consider location history information for planning the route

Prioritisation of actions If something goes wrong, safest and fastest route
Other statements by the user Generally, no issue with weather conditions

Following the data collection and discussions with blind and partially sighted participants, the interview data were transcribed, and thematic analysis was used to analyse the data. The general and specific themes as well as codes with prevalence emerged from the thematic analysis of the study data are shown below:

1- Planning themes
   a- Third party information
      i. Weather 7
      ii. Local news 5
      iii. Roadworks 8
      iv. Location history 11
   b- Customisation of the route-finding system
      i. Time of travel 6
      ii. Journey milestones 9
      iii. Distance in meters 6
      iv. Distance in number of crossings 12
      v. Decision point selection 6
   c- Route selection
      i. Shortest 7 (in Uncertainty 3)
      ii. Fastest 7 (in Uncertainty 3)
      iii. Pleasant 6 (in Uncertainty 3)
      iv. Safest 7 (in Uncertainty 10)
      v. Easiest 1 (in Uncertainty 1)
      vi. Route avoidance 7
2- Location specific themes
   a- Crossings
      i. Zebra crossing 9

ii. Controlled crossing 7
iii. Tactile crossing 7
iv. Multi-level crossing 2

b- Type of area
i. Shopping area 4
ii. Residential area 8

c- Walkway design
i. Slope of walkway upward 2
ii. Slope of the walkway downward 9
iii. Steps on the walkway 6
iv. Walkway with curb 8
v. Narrow walkway 5
vi. Uneven surface 7

d- Obstacles
i. Fixed obstacles 8
ii. Moving obstacles 3

3- Other travellers' themes
a- Pedestrians 7
b- Other modes of Transport
i. Cyclers 5
ii. Scooter riders 3

4- Environment
i. Rain 9
ii. Snow 8
iii. Day 10
iv. Night 5
v. Bright light 9

The thematic analysis of the study data revealed several key themes related to the navigational decision making of BPSP. Participants emphasised the importance of third-party information, such as weather updates, local news, roadworks, and location history. The location history was the most frequently mentioned and useful third-party information

source. Customisation of route-finding systems was also proven to be crucial. Factors such as time of travel, journey milestones, and decision point's selection being the key elements. Route selection preferences were diverse, with participants indicating preferences for the shortest, fastest, safest, and most pleasant routes. However, safety was particularly prominent in uncertain conditions.

Location-specific themes included the types of safe crossings with and without tactile information. The zebra and controlled crossing with traffic lights were the two main safest crossing choices. The type of the neighborhood was also highlighted by participants during the route selection process. The residential areas are preferred for straightforward travel and avoiding crowds of people around the shopping areas. On the other hand, the shopping areas preferred by people who feel more comfortable having someone to talk to if needed. Walkway design issues, such as slopes, steps, curbs, and uneven surfaces, pose significant challenges for participants, particularly when navigating narrow or poorly maintained walkways. Participants made decisions of route choices based on individual preferences and needs.

Obstacles, both fixed and moving, posed frequent difficulties. Moving obstacles like scooters were the most commonly reported obstacles. Pedestrians, cyclists, and scooter riders might further complicate the navigation of BPSP for not obeying the traffic rules and because of lack of awareness. Environmental factors like rain, snow, light conditions, and time of day, were consistently mentioned as influencing the navigation experience and decision making. This helps with the choice of time of departure with the best environmental condition for the journey.

7.4.3 Study Findings

7.4.3.1 Route Planning

Participants in the study mentioned using various sources of information for planning a journey. These sources included asking about information regarding the route details or the destination.

> "I do ask people like a family member but I do try to check on the mobile even if there is map" Pa13.

Participants also mentioned using mobile apps, such as mapping applications, to gather information about the distance and estimated time of arrival.

> "So, it's an unfamiliar journey, what I would tend to do is use an app such as Google Maps or my new WeWalk Smart Cane. So, I would use a navigation app to review the steps I would need to take and then plan my route accordingly so I would use a combination of my existing route knowledge so if I'm passing through streets that I've been through before so like road crossings or streets that sort of thing and then of course I would then adapt I would try to navigate wherever possible the unfamiliar parts of the route using the satellite that the information I get from my navigation apps" Pa12.

These findings highlight the use of personal and third-party information to consider for journey planning. Although this is a vital source of information for planning the journey. However, the accuracy and reliability of the data remain a crucial consideration for the navigation system data input components shown in Figure 32. Communication's quality between the navigation system and the data sources is another factor that has a great impact on the availability of the requested data for planning. Furthermore, the availability of location specific information is required for a more precise journey planning. However, third-part data

only covers the locations they are available in. For instance, the local weather might not be available for the taken path. This will reflect in the navigation experience of the individual.

Planning for a route involves considering various factors to ensure an efficient and safe journey. Participants in the study highlighted the importance of selecting the type of route that best suits their preferences in terms of landmark and public transport availability.

> "I look out for all those kinds of simple clues or information before I kind of set off on my journey, like landmarks in order to locate my destination. I'm looking out for public services around that area, like local transportation, things like are there any buses around going to that particular place, not somewhere which is like remote where there is hardly a public transport available" Pa9.

Location history plays a critical role in supporting the navigation of BPSP. With the location history data, we can extract useful navigational information about the users' characteristics such as walking speed and distances of travel, but more importantly, we can learn from their routes and identify problematic spots. On the other hand, crowdsourcing other peoples' location history of the same route helps in assessing the routes and improve the navigation experience of BPSP. In addition, individuals can benefit from the other users' experiences of walking and use the best strategies applied by others.

> "I have found it beneficial to learn from the routes taken by other people. By observing their choices and experiences, I can gain insights into potential shortcuts, scenic routes, or areas to avoid. It helps me to discover new paths and consider alternative options that I may not have thought of on my own" Pa10.

The process of planning involves the routes that BPSP might take as well as the routes they want to avoid either because of safety issues or not satisfying their preference criteria. Participants mentioned avoiding

routes with major roads that are busy with lots of vehicles and routes with too many complicated crossings. On the other hand, participants mentioned preferring the safest and simplest routes.

> "I would be careful if there were a number of interchanges where I was unsure that I could get some assistance" Pa3.

> "I'd avoid an area that is badly not lit at night... going down the main road possibly... because you could stray into the main road" Pa3.

> "I'd probably try and avoid having to walk down a very busy, almost like a dual carriageway and try and find some public transport to get me past that part of the journey" Pa3.

Overall, the planning process involves consideration of various sources of information and necessary details to ensure the selection of a route that is safe, accessible, and tailored to individual preferences and needs.

7.4.3.2 Selection of Crossings

The selection of crossings is a crucial aspect of route planning, as it directly impacts the safety and efficiency of pedestrians. Participants in the study expressed preferences for different types of crossings based on their individual needs and circumstances. Some participants mentioned a preference for zebra crossings, particularly if they were feeling confident in their ability to cross safely. A personalised route-finding system should follow the preferences of blind and partially sighted individuals as long as safety is considered. Otherwise, the route-finding system should always prioritise the safety if there is a great risk in the route choice of the individual. Controlled crossing is another safe crossing choice for BPSP. However, the zebra crossing is better in prioritising the pedestrian crossing over the vehicles at all times. On the

other hand, the controlled crossing is arranging the crossing process by assigning limited time for the walkway users in an assigned traffic loop.

> "Depend on how busy the road is. Take the controlled crossing for safety. But might take the zebra crossing. Tactile crossing is the one I use it" Pa12.

Others mentioned considering the distance they have to cross and the presence of tactile markings when deciding between marked and unmarked crossings. The location of crossings and their type should be available on the map to generate the routes and provide navigation support as the user requests.

> "I find it helpful to know the distance of a crossing in meters rather than just relying on visual landmarks. Having the distance in meters gives me a better understanding of how far I need to walk before reaching the crossing, especially when there are no visual cues or landmarks to guide me. It helps me plan my route and anticipate when I need to start preparing for the crossing" Pa12.

Preferences for crossings included zebra crossings and controlled crossings with or without tactile surfaces. Some participants opted for crossings with tactile pavements as they provide useful navigation cues.

> "If given the choice between a zebra crossing and a controlled crossing, I would generally opt for the zebra crossing. This is because, on a zebra crossing, traffic is required to stop, providing a safer crossing experience. Additionally, zebra crossings are often spaced apart from controlled crossings, reducing the need to backtrack if the controlled crossing is not functioning properly. However, the decision may also depend on factors such as the time of day and the noise level of the environment" Pa12.

These findings emphasise the need for a diverse range of crossing options that cater to the specific requirements of pedestrians, ensuring

their safety and accessibility. The route-finding system can help with that benefiting from the data inputs to the system from the users and third parties in addition to the map data.

7.4.3.3 Walkway Choices

The choice of walkway type is an important consideration in the route planning, as it directly impacts the ease and safety of navigation. Participants in the study expressed preferences for various walkway characteristics including empty or busy walkways and shared spaces based on their individual needs and preferences. For instance, some participants mentioned a preference for walkways with slopes rather than steps, as slopes are easier to navigate.

> “I would probably choose the slope” pa8.

Other participants preferred wider and even surfaces, as narrow walkways can pose obstacles and hinder movement.

> "I find narrow walkways challenging because there's less room for manoeuvring and it can be difficult to navigate when there are other people around. It's like a game of 'human pinball' trying to avoid bumping into others" Pa2.

These findings underscore the need for walkways that are well-maintained, wide, even, and free from obstacles, ensuring a safe and comfortable pedestrian experience. In addition, Participants expressed a preference for clear walkways with fewer people, separate paths for pedestrians and cyclists, downhill walkways, and walkways with slopes instead of steps.

> “Yeah. That's perfect. Completely separate” Pa1.

Some may prefer a slightly busier walkway as it provides a sense of security and the opportunity to ask for assistance if needed.

> "I don't have a strong preference because the benefit of not having people around is that if you know the area, you can walk faster and feel more independent, but if it's an area you don't know, it means you can ask somebody if you're going the right way" Pa3.

However, shared spaces can pose challenges for blind and partially sighted individuals, especially when there are no distinguishable markings or clear lanes.

> "I would try to avoid one of those routes with shared spaces because they can be quite tricky. You have to hope that they can see your cane" Pa3.

The choice between walkway with bends or straight with multiple sideway crossings was considered in the scenarios to assess the balance between safety and preference. The route-finding system should opt for the safer choice which is less crossings involved. However, this might not be the case with the person.

> "I find bends in walkways quite challenging because it disrupts my sense of direction and spatial awareness. It's like navigating a maze where I have to rely on my other senses and cues to determine the correct path to take" Pa8.

When it comes to the choice between walkway with gradient or steps, there was different preferences for the route selection.

> "I would pick the steps but yeah I'd probably pick the steps they tend to be a bit faster the slope tends to the ramp tends to go around you know zigzags but you know that's because I'm fit yep when I get older and older and older, I might go for the ramp yep okay or if I'm carrying a suitcase with a wheelie if I've got a wheelie suitcase with me then I'll go for the ramp" Pa3.

Another criteria of route selection was the choice between two routes of concern one was a walkway with bicycles and the other was a walkway

with shared spaces. As a result, participants made choices based on their perspective of safety and past experiences with the two types of the walkway

> "I would probably go for the third choice which is staying well away from any of them because they both sound like a nightmare. I mean all I would say is the first one I would prefer not to share with bicycles ever. That would never be my choice, sharing pavement and bicycles, because I don't hear them, don't see them, they're generally very, very dangerous" Pa5,

> "I would never ever, I would always, always, if there's a shared, I mean obviously you can't always choose but given the option I would always go for something that's the safest option with the you know that is mainly for pedestrians or only for pedestrians" Pa5.

These quotes highlight the importance of considering the preferences and challenges blind and partially sighted individuals face when navigating different environments using a personalised route-finding system.

7.4.3.4 Obstacle Warning and Circumvention

Obstacle detection and avoidance play a crucial role in ensuring the safety and accessibility of BPSP pedestrians. Participants in the study highlighted the reliance on various sensory cues and assistive technologies to navigate and avoid obstacles. In situations where obstacles were unexpected or unfamiliar, participants mentioned the need to adjust their walking pace to navigate around them.

> "Obstacle warning is not just about safety, it is about empowering individuals to navigate their path with confidence and independence" Pa9,

Additionally, participants highlighted the importance of distinguishing between fixed and movable obstacles, with a preference for walkways with fixed obstacles that can be easily identified and avoided.

> "Fixed obstacles provide a sense of familiarity and consistency, allowing us to navigate with ease and confidence, while movable obstacles require constant vigilance and adaptability, challenging us to stay alert and flexible on our journey" Pa9.

These findings highlight the significance of incorporating obstacle detection and avoidance strategies, along with the use of assistive technologies, to enhance the safety and mobility of BPSP.

7.4.3.5 Dealing with Uncertainty

Dealing with uncertainty and unexpected situations during a journey is a common challenge for BPSP. Participants in the study mentioned various strategies that they employ when something goes wrong. One approach is to seek assistance from others, such as asking for directions from a passer-by or seeking help from a member of the public. Participants also mentioned the use of technology, such as GPS navigation apps, to navigate unfamiliar routes and find alternative paths.

> “So, let's say in the middle of a journey, something might go wrong, or you might want to check where you are or check your journey details” Pa7,

> “But if there are some indications of uncertainty there, then I will not take the shortcut. I will go for the safer route” Pa6,

> “So, my first thing, which I can continue to do while I'm walking, is just ask Siri where am I. And if I'm not satisfied with that as a response, most of the time I will stop and then check my phone or like kind of see what the map says you know” Pa11,

> “I first stop, and I try and listen. I try and ask somebody for help” Pa10.

In situations where technology or human assistance is not readily available, participants mentioned relying on their own problem-solving skills and adapting their route based on their surroundings.

> “I first stop and I try and listen” Pa10.

These findings highlight the importance of being flexible and resourceful when faced with unexpected challenges during a journey, utilising the route-finding system to seek assistance when needed. The route-finding system should always prioritise the safety and personal strategies of dealing with uncertainties to ensure the provision of a smooth navigation experience. The developed conceptual framework of the navigation system has accounted for the necessary components to deal with the various types of uncertainties.

7.4.3.6 Environment-Based Route Choice

When selecting routes, pedestrians often take into consideration the environmental factors such as weather conditions and the surrounding type. Participants in the study expressed preferences for routes based on these factors. For instance, when it comes to weather conditions, a participant mentioned a preference for walking in rain rather than snow, as snow can hide tactile markings and be slippery. A Participant also mentioned a preference for walking in bright light with car lights in darkness, as it provides better visibility.

> “Neither of them, quite frankly. I would, if I were, to be perfectly honest with you, if it was raining or if it was snowing, it would make it very difficult for me to navigate effectively with my cane, with my WeWalk. For one thing, my WeWalk isn't waterproof. It's not waterproof at all” Pa12,

> “Rain is okay we kind of used to it now” Pa13.

Additionally, preference was expressed for walking during the day rather than at night and vice versa as it tends to be safer and more comfortable due to the presence of more people and better lighting.

> “I prefer the evening because it is not too bright and not too dark” Pa13.

In terms of the surrounding type, a participant mentioned a preference for routes that pass-through shopping areas rather than residential roads.

> "I wouldn't have any difficulty navigating around a crowd of people on a busy high street. The busiest side of the high street is where most of the cafes and shops are located” P12.

These findings highlight the importance of considering the environment when selecting routes, as it can impact the safety, comfort, and overall experience of pedestrians. Hence, the route-finding system should always consider the preferences and needs of the person and safety must be considered when there are extreme environmental conditions.

7.4.3.7 Nature of Communicating the Details to the User

Presenting route details based on user preferences is crucial for ensuring a personalised and user-friendly experience. Participants in the study expressed a desire for accurate and detailed descriptions of the route, preferably in a human-like manner that provides step-by-step instructions, landmarks, and notable features along the way. This highlights the need for route planning software to incorporate up-to-date information and provide notifications and alerts when necessary. The developed conceptual framework interface shown in Figure 31 provides room for customisation of the system to personalise the navigation experience.

> "I prefer when the interface presents the route choices in a clear and concise manner, providing information such as the number of side road crossings or the distance in meters. Having this

> information helps me make informed decisions about which route to take and ensures a smoother and more efficient navigation experience" Pa7.

Establishing milestones is essential, not only for route marking process, but for breaking down the overwhelming journey into achievable segments.

> "I prefer to break down my journey into milestones, using familiar landmarks like shops or bus stops to guide me along the way" Pa6.

Whether presenting the path by its distance in meters, the number of steps taken, or the crossings encountered, each measure reflects a different commitment to the journey.

> "When planning a journey, I find it helpful to have the distance presented in meters rather than relying on the number of side road crossings. Knowing the distance gives me a better understanding of the overall route and helps me plan accordingly" Pa5,

> “Even as we approach our destination, unexpected turns at the end remind us that every journey requires adaptability and resilience" Pa3,

> "For me, the number of steps is more useful than distance in meters. Having information like 'after 100 steps, you will reach the crossing' helps me navigate and anticipate the next point on my journey" Pa13.

When communicating warnings to BPSP, it is important to use clear and concise language, as well as provide specific details about the potential hazards or obstacles they may encounter. Using descriptive words and phrases can greatly help with the navigation support. For instance, instead of simply saying "be careful," it would be more effective to say "watch out for the narrow walkway ahead with limited space for manoeuvring." Additionally, providing information about the location,

such as "there is a steep slope and steps on the path ahead," can help blind and partially sighted individuals better prepare for the terrain.

> “If there is a kind of uneven surface, you get a warning” Pa13.

The findings of the user study provided valuable information to assess the navigation system conceptual framework’s performance in specific navigation scenarios.

7.5 Discussions

The interviews with blind and partially sighted participants highlighted the preferences and needs of their navigational decision making. Key findings indicated a preference for direct routes with least road crossings and obstacles. In addition, accessible infrastructure like curb cuts, tactile paving, and controlled crossings were valued. However, these are not ubiquitously available on the map. As a result, the necessary information needs to be provided from third-party databases as in additional input to personalise the route selection process. Peer insights were seen as highly useful piece of information given shared preferences and needs among blind and partially sighted individuals.

Breaking long journeys into chunks using landmarks help with maintaining orientation. Crowded areas were often avoided with the preference for the availability of a certain number of pedestrians in case of need for support by the blind or partially sighted individual. Provision of such information is difficult, because there is no accurate information about the number of pedestrians on the walkways at all times. However, there is limited information about specific times where the walkway might be busy or empty. For instance, the morning and evening rush hour time as well as the mid-night.

Sharing route information among individuals can create a sense of community and collaboration, enhancing the overall navigation experience for everyone involved. The provision of location-specific

feedback by BPSP and sharing it with other walkway users will significantly help in the planning stage for any journey. This is a unique way of generating routes depending on the users' data with similar characteristics. This approach has not been effectively considered by the current navigation systems. Interestingly, participants have also mentioned about their unawareness about this useful source of information for journey planning and while navigating. In this PhD, consideration was given to this information in the navigation system's conceptual framework. 11 out of 13 participants showed their willingness to consider the location history as an important piece of information for the journey planning and route generation.

The route selection in the navigation-specific scenarios must be based on the criteria of safety first then the requirements of the participant for navigation and lastly the preferences of navigation. However, the participants showed a wide range of route selection strategies where they were asked about making route selections. 7 out of 13 participants mentioned about selecting the shortest and fastest route which was equal to the same amount of mentions of safest route selection. This variation shows the confidence level and decision-making skills of some participants when it comes to route choices. The route-finding system of the developed conceptual framework provides room for the route selection strategy, given the system inputs and safety prioritisation. However, safety must override other route choices despite personal preferences. An interesting finding of the user study was the response to the route selection strategy in the event of uncertainties. 10 out of 13 responses were towards the safest route selection by the navigation system in the event of uncertainty. This contradicts most of the participants' first route selection strategy. The variation in the decision makings by the same participant was not only in the route selection process. Other navigation aspects witnessed different responses when comparing the user profiles with the navigation scenario decision

makings. This shows the change in decision making over time which needs to be accounted for in the route-finding process.

The developed conceptual framework includes the necessary components to deal with various uncertainties that might happen during the journey. Technological uncertainties can be detected and dealt with by the system's monitoring component including the overall performance and individual sensors' resilience. The personal uncertainties can be detected and the necessary action be executed using the user's orientation and position monitoring component. Necessary data will be collected in real-time about the user using the GPS and inertial sensors to detect irregularities in the movements and fall incidents. Consequently, necessary actions can be taken such as re-routing and asking for help. The route-finding uncertainties can be dealt with using the route guidance components of the navigation system's conceptual framework. This can be unexpected route closures and safety concerns. The system can deal with the uncertainty by using the re-routing and next destination components and in certain cases using the return route component.

7.6 Chapter Summary

This chapter provided a comprehensive account of the process involved in developing and evaluating a navigation system conceptual framework for BPSP. It was mainly developed based on the findings from the chapter 5 and the previous chapters. Comparative evaluation was used with the main navigation systems. In addition, user evaluation was used to inform the navigation system conceptual framework design based on BPSP inputs and feedback. The study aimed to develop and evaluate the navigation system conceptual framework for an inclusive navigation system tailored to the unique preferences and needs of BPSP. This chapter achieved objective 6 and 7 of the thesis. The next chapter is conclusions and recommendations for future work.

CHAPTER

EIGHT

8 CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The conclusions chapter is the final chapter of this thesis aiming to review the way the aims were addressed and presenting the main contributions, limitations and recommendations for future work.

8.1 Review of Aims

The aims of the thesis were presented in section 1.3.2. this section will review the way the thesis chapters successfully achieved the aims and what has been learned from addressing them.

Aim 1 To investigate the factors that influence the route selection strategy of blind and partially sighted people (BPSP) and their natures.

In chapter 3 and 4 of the thesis, the first aim was addressed to confirm the route selection factors required to enhance the navigation of blind and partially sighted individuals based on literature review of chapter 2, interviews with participants with various sight conditions in chapter 3 and expert interviews in chapter4. Non-expert Participants reported their navigation experiences in familiar and unfamiliar journeys that they have taken in the past. Cane and Google Maps were the common navigation aids used by BPSP as key navigation supports. however, the limitations of the navigation systems restrict the expected performance that enable BPSP navigate safely and independently. Although many aspects of navigation were presented by the participants. however due to time restriction, only exploring specific navigation experiences was possible.

This included route selection factors, route selection strategies and definition of good and bad routes.

Expert participants provided vital information about the navigation requirements of BPSP. One of the key recommendations was making walkways more accessible and provide training support. The needs of BPSP included public awareness of how to provide support for BPSP as well as individual needs to enable safe and independent navigation. it was also pointed out that once individuals become blind or partially sighted, they are familiarised with the current navigation support in terms of orientation and mobility training. However, this is mainly possible where the blind or partially sighted individual come forward and ask for navigation support. Mobility trainers pointed out that Individual preferences are not addressed by the relevant designers whether navigation application designers or the walkway designers. Although safety is the priority for BPSP. However, addressing the blind and partially sighted individuals needs enable them to navigate more effectively and frequently. This includes a better mental health and wellbeing.

An interesting and critical fact discovered in this research was lack of technology training to the mobility trainers as well as a well-produced training support curriculum to enable them provide the best training and navigation support for BPSP. It was pointed out that unless the blind or partially sighted individual stresses the use of navigation technology. The mobility trainers only teach personal navigation skills related to guide dogs and canes. Moreover, planning routes for BPSP mainly include personal experience and use of Google Maps without consideration to the better map and routing support available publicly for free such as OpenStreetMap.

Aim 2 To establish whether the combination of existing mapping and positioning technology, can be used to build a navigation system which meets the needs of BPSP.

Chapter 5 achieved aim 2 of the thesis establishing building a navigation system that meets the needs of BPSP based on the available state-of-the-art navigation technology. The literature findings highlighted the importance of addressing the developing navigation systems that address the navigation preferences and needs pf BPSP. Focus groups with blind and partially sighted individuals provided critical information about the experience of BPSP with the current navigation technology and their expectations and descriptions of a navigation system design that meets the needs and preferences of blind people. it was pointed out that smartphone proves to be a successful navigation aid which contains multi-sensors and multimodal interaction and is affordable and widely available. However, the battery and accuracy limitations need to be addressed before considering them as a reliable navigation system.

The results of the study in chapter 5 highlighted new challenges faced by the BPSP as a result of the technology development. Electric cars are considered environmentally friendly in terms of noise pollution. However, for BPSP they are a big source of safety concern because they cannot be identified by BPSP at crossings and there is no current technology that can detect them and warn the person of upcoming electric cars.

Aim 3 To develop and evaluate a navigation system conceptual framework for BPSP which incorporates crowdsourced route choices, identified route selection factors and relevant individual user preferences.

Chapters 5, 6 and 7 are the main contributors of achieving aim 3 of the thesis. The navigation system described in chapter 5 by the focus group participants was used as the base to develop and evaluate a conceptual framework of navigation system for BPSP. This can be used as a base for current and future navigation systems to provide personalised route-finding guidance. In chapter 6 user profile structure of navigation of BPSP was created in a novel way accommodating the navigation-related information from the individuals and relevance third-party. The content, format and structure of the user profile not only empowers the navigation experience of the individuals, but also enables navigation system

designers and councils to highlight areas of concern and get feedback of users anonymously to tailor the design to individual needs and preferences and improve accessibility.

Chapter 7 presented the design and evaluation of the navigation system conceptual framework and covered the methods of evaluation based on comparative analysis with the existing navigation systems and actual user feedbacks. The user evaluation was based on navigation scenarios covering specific navigation experiences of concern for BPSP such as crossings. And the decision making was based on the user profiles of the participants as well as the criteria of route selection strategy related to prioritisation of safety, requirement and preferences respectively.

8.2 Main Contributions

This interdisciplinary research offers new insights into the design of the current and future navigation systems. This will contribute to better tailoring the navigation systems to the identified and unique needs and preferences of BPSP; improving their mobility, safety, and independence. The specific user requirements, preferences, and navigational safety factors critical to BPSP were explored. The first study investigated the factors that influence the route selection and navigational decision-making among BPSP. Table 14 presents unique route selection factors highlighted by BPSP; classifying the factors to tell whether a certain factor is useful or risk. In addition, it covers the explanation of the nature of the route selection factors and whether an object is considered as a landmark or obstacle in the individual's point of view. Table 16 presents unique definitions of "good" and "bad" routes based on individual's understanding of the nature of the route and what it might contain from landmarks and environmental cues.

The in-depth interviews with the mobility trainer experts revealed that BPSP have unique navigational requirements and preferences that are not adequately addressed by existing navigation systems. For instance, the study found that BPSP prioritise safety and ease of navigation over

speed and efficiency. Additionally, the study found that BPSP often rely on environmental cues and social support to navigate unfamiliar environments. The environmental cues include smell of restaurants and coffee shops that identify landmarks during the journey without the need for position information. On the other hand, the social support includes asking people on the walkway for navigation assistance or help.

The expert interviews also revealed the critical issue of lack of training for both the mobility trainers and the BPSP. It has been identified that mobility trainers are not receiving necessary training about the main technology support available for BPSP. On the other hand, it was revealed that BPSP are not aware of the technology support around them unless they come forward or learn from friends and family. These findings contribute to improving the technical skills of both mobility trainers and BPSP for best practice of using the current navigation systems.

Focus groups with BPSP resulted in eliciting essential data from the participants. The current navigation systems were evaluated by the participants to learn about the opportunities and limitations. The main issues with the current navigation systems were the cost of purchase and subscription. In addition, customisation of the current navigation systems for BPSP was another issue that pose difficulty in using them. The study contributed to describing a context-aware navigation system that meets the preferences and needs of BPSP as shown in Figure 26. The description of the components of the navigation system highlights the users' demand for a user-centric design of each navigation system component.

The development of a comprehensive user profile structure was another key contribution of this research. The user profile shown in Table 25, not only accommodates the individual's navigational preferences, but also includes data from third-party sources, such as environmental or infrastructural information, which can further enrich the system's personalisation and safety enhancement. These user profiles serve as a valuable resource for creating tailored navigation services, not only for

navigation systems but also for relevant third-party services, such as governmental and transportation organisations. The expert interviews with the mobility trainers included a dedicated session discussing the design and content of personalised user profiles for navigation. The revised and extended version of the user profile is a unique structure that accommodates the navigation-related information in its components. Moreover, the user profile has accounted for customisation and updating the content over time when needed.

The data from the focus groups and interviews were used to develop a novel navigation system conceptual framework that can be used as a base for future navigation systems. The holistic conceptual framework is shown in Figure 32 which outlines the key components required to enhance the navigation of BPSP. This includes the necessary sensors, crowdsourced data and necessary processing units required to operate. The design of the conceptual framework aims to provide a personalised and context-aware navigation experience. Through rigorous comparative evaluation, the gaps in the current navigation system have been identified. On the other hand, the design of the conceptual framework has been assessed. A user evaluation study in the form of scenario-based decision making further enriched the effectiveness of the conceptual framework in terms of route-finding decision making. The approach of the study was towards understanding user decisions and expectations from a navigation system in terms of safety and preference. This approach helped in understanding the user behaviour in specific navigation scenarios that may pose serious risk on the user's safety. For instance, whether a safer and further away crossing need to be chosen over a closer and less safe crossing. Overall, the key findings from this PhD research highlighted the importance of developing user-centred navigation systems that take into account the unique needs and preferences of BPSP.

8.3 Limitations

This research has some limitations that need to be acknowledged. One limitation of this study is the subjective nature of the collected data. The conducted studies heavily rely on blind and partially sighted individual perceptions, experiences, and self-reported information. Data from focus groups and interviews are crucial for understanding the lived experiences of BPSP. However, the data are influenced by the personal biases, memory recall, and emotional states of the participants. This subjectivity can limit the generalisability of the findings, as individual responses may not always represent the broader population of BPSP. The reliance on personal accounts and self-reports could result in variability that may not fully capture the complexities of navigation behaviour, especially in real-world settings where multiple factors interact in dynamic ways. On the other hand, experiment-based data can provide objective and measurable outcomes.

The subjective nature of the data may lead to the overlooking of key quantifiable insights that could have been uncovered through real-world navigation testing. For instance, specific metrics like journey duration or the accuracy of route choices might not be fully addressed through qualitative methods alone. These types of objective data are crucial for providing a comprehensive understanding of the navigational challenges faced by BPSP and may have revealed additional insights into system performance and areas for improvement.

Another limitation is related to the recruitment of the participants and further analysis of various sight conditions. Recruiting participants from the older generation proved to be challenging. This limitation may affect the diversity of the perspectives and experiences represented in the research, as the unique insights and experiences of older individuals might offer different, yet critical, viewpoints on the research questions. Despite these limitations, this research contributes valuable findings to the existing body of knowledge. The constraints identified also pave the

way for future research, highlighting the need for more diverse participant representation and the importance of field studies in fully understanding the context of the navigation of BPSP.

8.4 Recommendations for the Future Works

Future studies could aim to overcome the limitations, further strengthening the reliability and validity of the findings in this field. Based on the findings of this research and the identified limitations, the following recommendations are proposed for future work.

The main limitation of this research was not making use of field tests. Experimental field trials in specific navigation scenarios could serve as valuable tools to assess and refine the navigation system performance in real life settings. By observing and analysing system performance and user interactions in real-world settings, researchers can identify areas for improvement that may not be apparent in online settings. The navigation system performance can be evaluated with BPSP to assess the positioning accuracy, orientation performance and validating the route details presented by the system. This can include journey duration, walking speed, moving obstacles and landmark identification. A user profile structure has been created in chapter 6 which incorporated the users' and relevant data into the navigation system. The user profile structure needs to be evaluated with BPSP in real life experimental settings to inform its design. Future research should aim to embed the user profiles into the navigation systems to provide a more practical understanding of the user profile content and layout.

Route-finding is a crucial part of the navigation system. The concept of route generation is using path finding algorithms to generate route choices on the map and guide the user along the route up to the destination. Research is needed to develop and test route-finding algorithms that cater for the user preferences and needs. Unlike the current path-finding algorithms, the cost function of the algorithm needs to be adjusted to account for the landmarks and obstacles along the route

to generate routes that are tailored to BPSP. An implementation of the algorithm should be tested and evaluated in experimental settings to revise the weights assigned to the nodes and edges of the map.

There is need for research to create specialised maps and map layers for BPSP. The map must present the relevant information tailored to the user requirements. The current maps contain an overwhelming amount of information, making them unsuitable for the navigation of BPSP. Information such as landmarks, obstacles and type of crossings need to be added to the map to generate accessible routes for the users. Research needs to be conducted for intensive data collection about the selected research areas using satellite images and surveying instruments. The collected data has to be processed and added onto the map to create unique maps for the navigation of BPSP.

The navigation process from origin to destination typically involves movement through both indoor and outdoor spaces. Research into personalised indoor navigation support is essential to ensure equitable access and efficient movement within critical public spaces, such as transportation hubs. Research is needed to develop a navigation system conceptual framework for indoor navigation similar to the framework outlined in section 7.2.4. In addition, there is pressing need for research to develop wayfinding systems that integrate indoor and outdoor navigation with consideration to the transition between both environments. This is important because effective navigation in general encompasses indoor and outdoor spaces including the transformation between both environments.

In this research, a conceptual framework for navigation has been developed based on literature review and user studies. Various user requirements have been identified. However, there is need for further research to establish a holistic default configuration for the navigation system. This configuration must be defined such that all the system parameters are set to provide a safe and efficient navigation support for the users by default. This will be necessary when the user does not adjust

certain or all system parameters. The default configuration must support the navigation of the user regardless of the changes made. Card sorting research method can be used to define the default settings for the navigation system recruiting both BPSP and experts.

The study with mobility trainers identified an important issue that requires consideration which was the lack of technology training support for the about the navigation systems available for BPSP. Some mobility trainers highlighted their unfamiliarity with the latest navigation technologies used by BPSP for independent navigation. The main reason behind the issue was not receiving technology support training by mobility trainers About the navigation technology of BPSP. As a result, the only training support provided to BPSP is to navigate around using the cane and guide dog. Research should be carried out to develop a new curriculum for the certification of the mobility trainers to learn about the latest navigation technologies available for of BPSP. This will help mobility trainers to include the navigation technology support part of the training provided for BPSP.

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APPENDICES

Appendix A: Information Sheet of the First Study

University of Nottingham

Nottingham Geospatial Institute



Information Sheet

Title of the study: Understanding People's Route Selection Strategy in Familiar and Unfamiliar Journeys.

Name of the investigator: Ahmed Al-Talabany

Please review the following information carefully to decide whether to take part in this study.

The aim of the study is to understand people's route selection strategy in outdoor environments by using Cognitive Task Analysis method in semi-structured interviews. You will be asked to talk about a familiar journey and an unfamiliar journey that you have taken in the past.

As you talk through any of these journeys, you will be asked about the reasons for the decisions you have made during the journey that is related to route selection.

There are no risks associated with participation and there is no requirement to disclose any sensitive personal data about yourself.

Who will be involved in the study?

The study involves adults of different ages and sight conditions.

Your participation

Please ensure that you have reviewed and understood this information sheet, which you may keep for your records. Your participation in this study is entirely voluntary. Please review the consent form and give your informed consent if you agree to participate in the study.

Please feel free to ask the researcher any question before choosing to participate in this study also anytime during the study. Please note that you have the right to withdraw from the study at any time without giving a reason. If you withdraw after the study, your data will be excluded from subsequent use or analysis.

Who will have access to your data and how will it be stored?

The research team involved in the data collection and analysis from the University Of Nottingham will have authorised access to the full collected data. In addition, selected researchers may have access to the anonymised data in the future. Paper-based data will include the following: your consent form and your response to the interview. Paper-based data will be stored in locked cabinet. In addition, Audio recording will be taken. The audio record will be stored securely in password-protected storages. All data will be stored according to the Data Protection Act 2018 and EU General Data Protection Regulation (GDPR). All data will be stored for a minimum of seven years post-publication in line with the University of Nottingham's Data Retention Schedule. After this time, electronic files will be deleted and any hard copies of data will be destroyed.

How will your data be used?

Data from your participation will be used to understand the route selection strategy in familiar and unfamiliar journeys. This will include identification and classification of route selection factors and using them to feed navigation system algorithms to create personalised routes.

All reported findings will be made anonymous so that you will not be identifiable in any form of dissemination of this research (unless if you request this).

Findings will be released in the form of academic reports, in PhD thesis form and may also be disseminated in peer-reviewed academic publications.

Who has reviewed the study design?

This study design has been reviewed and approved by the Ethics Committee of the Faculty of Engineering, University of Nottingham.

Research Details:

This research is being conducted by Ahmed Al-Talabany, PhD Student at the Nottingham Geospatial Institute. Ahmed Al-Talabany is supported by the Horizon Centre for Doctoral Training at the University of Nottingham (UKRI Grant No. EP/L015463/1), the UKRI's Horizon Digital Economy Research Institute (UKRI Grant No. EP/M02315/1), the Satellite Applications Catapult (External Partner) and by the Royal National Institute of Blind People (RNIB) (External Partner).

Contact details:

For further information, please contact

Researcher: Ahmed Al-Talabany

Email: ahmed.al-talabany@nottingham.ac.uk

Thank you for your interest in my study.

Appendix B: Consent Form of the First Study

University of Nottingham

Nottingham Geospatial Institute

University of Nottingham
UK | CHINA | MALAYSIA

Participation Consent Form

Project Title: Understanding People's Route Selection Strategy in Familiar and Unfamiliar Journeys.

Researcher name: Ahmed Al-Talabany

You have been asked to participate in the study detailed in the in the attached information sheet. Please read through the list below and sign this form to confirm that you understand what the study involves and that you are happy to participate.

• I have read and understood the information sheet about this study, a copy of which I can keep.	☐
• I have been given the opportunity to ask questions about the study.	☐
• I understand that my personal information will remain confidential.	☐
• I understand that the study will be audio recorded, but that my voice will not be identifiable in any reports or publications.	☐
• I understand that my data may be published in reports, academic journals, conference papers, books or other publications, but that I will remain anonymous.	☐
• I understand that the data may be further analysed by selected Researchers.	☐
• I understand that I am volunteering for this study and that I do not have to answer any question if I do not want to.	☐
• I understand that I am free to withdraw from the study at any time without giving any reason.	☐

Please sign this form only if you are happy to take part in the study.

Participant's name:

Participant signature: **Date:**

Researcher's contact details: ahmed.al-talabany@nottingham.ac.uk

Appendix C: Table of the Rest of the Statements from the Participants of Section 3.4

Statements from the participant about their experience
P1: "On a good day it is a two-minute journey, on a bad day it can be a five-minute journey or even longer than that" “With unfamiliar, you have to be comfortable within your comfort zone to be able to make that journey safely in a timely fashion. So having preplanning is very very important and preplanning for anything” “I'd rather be 10 minutes early rather than one minute late” “One thing that I used to struggle with is coming into work. With the journey that takes you 45 to 50 minutes it will take me an hour and a half” user try to remind that in the return journey , location of the obstacles will be changed like the ones on the left are now on the right User says their biggest problem is planning for the journey in the way they feel comfortable about user might consider using Bluetooth earpiece for navigation but not the phone in hand with cane for example user says that sharing location through an app is really useful in case lost to be located or help provided
P2: when he got out of the bus in the return journey, he was lost and couldn't managed to make his way round without seeking help. That happened in the return part of un familiar journey while taking the same route on return With the eye condition, sometimes participant feels that he/she passed people but he/she actually haven't so it resulted to bumping into people.

P3: if she got a meeting, she puts the time at 2pm for example to avoid rush hour time of people picking pupil from schools in a particular area
P4: Google Maps doesn't give information about down curbs and up curbs for planning the route which he looks for
P5: extra time needed for unfamiliar routes to get to the destination on time
P6: "from my conversation with colleagues, I understand that navigational technology is not perfect either" "and then the real problem comes at the very end which is identifying the correct building" "I have yet to be convinced, but then maybe I should give it more chance" this is regarding phone
P7: "but to me what does just there mean" "so just there means it's near, but near is not good enough if you are using a white cane and you need to know within half a meter where your door is" "the bus driver defines the start of the journey" "I try to avoid unfamiliar journeys as much as possible, because they create problems" "I know almost everywhere, I do a lot of walking journeys" this user don't prefer routes with no cues either sound or tactile cues even route is familiar user is getting lost user use an app in open space to help orient towards a targeted street when the orientation is correct it beeps to help get to the street in open spaces where there are no streets nearby user might consider a route where it intersects with the bus route that takes him home USER SAY THAT advance information about the potential hazards on a route is useful

it is important an app gives real time information about the route rather than only information at planning stage, pieces of information that are relevant to blind pedestrians such as the road ahead has traffic lights on it, or the road coming ahead is one way so pieces of information that the user don't know in advance user says advanced information about weather is useful, such as yesterday was windy so expect objects on the path
P8: user says that it is needed to depart earlier to be there on time and account for unexpected things
P9: user might change the normal route slightly depending on the weather information of the overnight user needs extra time to cross the road if it is snowy the user walks for 1 h40m as the maximum of one of the walking journeys user says busy walkways will make the guide dog work harder hence become tired
P10: user attempts to go out independently even for unknown routes as user likes adventure user states that for unknown routes there is always worry about whether something go wrong, but for familiar routes, user feels more confident that things go right user considers walking longer if weather is summer, nice and warm user avoid going in a route where getting lost is more likely and it is raining user states that with guide dog it is easier to walk and not get lost as the dog will continue through the path until the sign come to tell about turning left or right user says that sometimes public misguide you in the sense that they

think you are heading to a certain place like RNIB while you might go for a coffee shop instead
P11: "Although I will know that it won't take me directly to the door, I may recognise where it is, but I will be heavily reliant on the Apple platform for navigation" "I never got a bus in London on my own" "I would tend to always go for the fastest route, but I know that the fastest route may not necessarily be reflected in whatever app or map that I am a user of" "an area which has multiple exit points which are close together, this is probably the worst thing, because I always go down the wrong one" "Day is easier, because the familiar things are clearer"
P12: for familiar journey, there is no much planning to do, but for UF there is much more planning user adds more time for journeys which regular person takes People perception of you as a person need help is important in UF routes
P13: participant says that journey from train station to work is the one they are confident about. However, they stated that it is one of the most difficult journeys because of the obstacles
P15: User states that street furniture should have contrast colour as they walked into some in the past "The technology is there, but the hardware is not suitable" "when it comes to navigation, I am very old fashioned, I use people and sometimes they mislead you. I use human beings and I think I need to move to technology, because they are more hands on basically" User occasionally use Soundscape but like to use technology more

P17: User uses memory to remember road names in case she was lost or use it as a reference User uses a card which is written help needed, so when they need, they show the card and people start offering help and not hesitate User states that the guide dog does most of the job for obstacle detection and when it died until getting next one it was hard to deal with all the obstacles which they were not aware of
P19: User says tactile crossing is a fantastic navigation tool but most of them are not installed appropriately and you might miss it User don't use tech very much because they find it hard to use User don't like to use headphone with a navigation system, because it is distracting