

Improving digital maps in academic settings using design principles and user-centred research methods

Dan Yang

Submitted in accordance with the requirements for the degree of PhD.

The University of Leeds: School of Design

March 2024

The candidate confirms that the work submitted is his/her own and that appropriate credit has been given where reference has been made to the work of others.

This copy has been supplied on the understanding that it is copyright material and that no quotation from the thesis may be published without proper acknowledgement.

Important note:

This thesis was completed between October 2019 – March 2024 during the COVID-19 pandemic. The pandemic coincided with the end of Chapter 3 and impacted work starting in Chapter 4. This is reflected in the user-participated experiments described later in the thesis.

Covid-19 Impact Statement

Due to the impact of Covid-19, the research plan and thesis submission for this research had to change from the original planning. This includes the scope and focus of the original research project, experimental design, and data collection plan. The impacts are listed below:

1. Scope of original research project:

In Chapter 3 of this thesis, a user questionnaire survey was conducted. In the research plan, the scope of the research should have been determined through the results of a user survey, combined with the research related to wayfinding in academic environments from the literature review. As a result, user surveys showed that users have similar probabilities of getting lost outdoors/indoors on campus (60.64% and 69.97%, respectively). At the same time, the literature review also showed that users tend to feel stressed when looking for a specific room (Chao, 2016). Therefore, the initial research hoped to focus on how the campus digital map presents the spatial layout of the building, including exterior and interior layouts. However, the widespread spread of Covid-19 caused the temporary closure of most facilities while the research was underway. This research therefore needed to consider the possibility that case studies in indoor situations would not be possible. From this, the research turned to consider the impact and solutions of factors such as map information design, navigation and positioning on outdoor wayfinding in academic environments.

2. Experimental design

In *Experiment II* of this thesis, when selecting the starting point and end point of each task for user testing, the researcher initially considered choosing the most efficient (shortest time-consuming) route between the two points that needs to pass through indoor locations: Go to the Worsley Building via the Irene Manton Building. Such location selection would satisfy the previously investigated problems of wayfinding in academic environments, including outdoor wayfinding, and indoor wayfinding to specific rooms. However, the temporary closure of campus facilities due to Covid-19 has made such experiments

impossible. In order to deal with this problem, this research focused the experiment on the three wayfinding tasks of users, abandoning focusing on "in-depth analysis of the discovered problems". Instead, user testing was conducted to observe and analyse the performance of participants in three wayfinding tasks to obtain the limitations of the use of digital maps in the campus environment.

3. Data collection plan

The Covid-19 pandemic affected data collection for *Experiment II* and *Experiment III* respectively. In *Experiment II*, the effects were more driven by the personal reasons of the recruited participants: many were unwilling to be in close physical contact with a researcher, even in an outdoor setting. To deal with this, the researcher made sure to adhere to safety measures before the experiment such as wearing masks and maintaining distance from participants while observing wayfinding behaviour. In the end, 13 participants agreed to join the test (one of them had final data invalidated because the participant was unable to complete the task). The biggest factor affecting the data collection in *Experiment III* was the researcher. After unfortunately being infected with Covid-19 three times in a row, the researcher's physical condition was affected, specifically reflected in a decrease in physical strength. Therefore, the wayfinding time of 40 minutes like in the quest task of *Experiment II* became a huge challenge for the researcher to follow and observe the participants. In order to deal with this problem, and based on the requirement that wayfinding in academic environments often needs to be completed within a limited time, a time limit was added to the task planning stage of *Experiment III*. At the same time, the test frequency was reduced, and the experimental period was increased, allowing the researcher to have enough rest time to meet the adequacy of observation and recording of each participant.

Acknowledgements

I would like to thank my supervisors, Professor Maria Lonsdale, Dr Francisco Queiroz and Professor Stephen Westland, for their professional and patient guidance, and for all the help during my PhD journey.

My sincere thanks to all participants for their time participating in my research. Their participation is what allowed this research to go from strength to strength, receiving many valuable suggestions, real life insight and advance its progress in a way that will be impactful to many people in the future.

I would like to express my sincere appreciation to my parents, Ping Yang and Rong Jiang, for their continued trust, support and encouragement.

I would like to thank all my friends, for their support and encouragement.

I would also like to acknowledge at my cat Lili, my companion during my PhD and during Covid. A period that was at times very difficult due to isolation and loneliness. She gave me the emotional strength and companionship I needed to keep going despite all challenges.

Abstract

Maps are an important tool for people to find help when finding their way. The development of the Internet, the use of Global Positioning System (GPS) and people's daily use of mobile devices have made digital maps almost a necessary aid for wayfinding activities. However, current interactive digital map design greatly rely on GPS for automatic positioning and navigation; when positioning is wrong or navigation is ineffective, people need map information to reposition themselves in their environments. Creating better design representations of map information that meet users' needs for self-orientation and navigation requires user-centred design approach.

Campus universities are in many cases a collection of multi-functional buildings in a city, and campus users work and live on campus on a daily basis. Studying the use of digital maps in academic settings can identify people's wayfinding issues in similar situations, and study the limitations and improvements of digital maps, thereby improving people's wayfinding experience in similar environments (universities, areas of complex buildings, cities).

However, the current design, usage and development prospects in this field are largely unexplored. To tackle this problem and contribute to knowledge in this area of research, first a literature review was conducted to define research-based design principles applicable to campus digital maps. Second, data on the use of campus maps was collected from a large number of British academic institutions, to conduct usability analysis based on design principles. Current campus wayfinding and navigation was found to mostly rely on digital maps with external links, with deficiencies in the information design of campus digital maps defined. Following this, a series of research activities were then initiated to identify campus user needs for the use of digital map wayfinding in academic settings. An online questionnaire collected user experiences of wayfinding on campus, their opinions on digital maps, and on campus digital maps. A user test of three types of wayfinding tasks based on different wayfinding purposes was held to explore the limitations of using digital maps and the deficiencies of information design in academic environments. The results show that three factors - environmental complexity, map navigation efficiency, and user wayfinding

purpose - are considered important for the information design of digital maps. Solutions that focus on these factors were designed and iterated based on user testing and feedback, and these resulted in convincing and applicable design results. Finally, through the literature review and the conclusions of this research, design principles of campus digital maps were established.

Overall, the research conducted shows that following a user-centred methodology to observe and record participants' wayfinding behaviour: a) can directly impact the research process and results; b) can generate research questions for in-depth study; c) can obtain participants' creative contributions to the research that meet user needs and expectations; d) and can generate more convincing design results. This methodology has high potential to improve the effectiveness and persuasiveness of design solutions. The practical results of this thesis include: a) organising and summarising the existing research on wayfinding systems and map design, so that future related research can obtain valuable references; b) studying the limitations of use of digital maps in complex building environment and obtain map information improvement plans; c) providing a complete and convincing user testing approach that incorporates both qualitative and quantitative data for how maps are designed and evaluated; d) user-centred research approaches demonstrate the importance of user participation in improving and testing campus digital maps using existing design theories and principles; e) The design principles established by this thesis also enrich knowledge in the field of map design and will provide valuable insights and references for researchers and map designers in future approaches and design practices.

Table of contents

<i>Covid-19 Impact Statement</i>	<i>i</i>
<i>Acknowledgements</i>	<i>iii</i>
<i>Abstract</i>	<i>I</i>
<i>Table of contents</i>	<i>III</i>
<i>List of Tables</i>	<i>VII</i>
<i>List of Figures</i>	<i>VIII</i>
<i>1. Introduction</i>	<i>1</i>
<i>1.1. Context</i>	<i>1</i>
<i>1.2. Aims and objectives</i>	<i>6</i>
1.2.1 Research aims	6
1.2.2 Research objectives	6
<i>1.3. Research questions</i>	<i>7</i>
<i>1.4. Research structure</i>	<i>8</i>
<i>2. Information design theories and principles in campus digital maps</i>	<i>12</i>
<i>2.1. Introduction</i>	<i>12</i>
<i>2.2. Wayfinding design theory</i>	<i>13</i>
2.2.1. Wayfinding and human behaviour	14
2.2.2. User-centred wayfinding design	15
2.2.2.1. User cognitive map	17
2.2.2.2. How familiarity affects wayfinding	18
2.2.3. The information structure of wayfinding systems	19
2.2.3.1. Signage	21
2.2.3.2. Image	22
2.2.3.3. Colour	24
2.2.3.4. Typography and layout	26
2.2.4. Summary	28
<i>2.3. Map design theory</i>	<i>29</i>
2.3.1. Map design principles	30
2.3.1.1. Map visuals	30
2.3.1.2. User experience in map design	34
2.3.2. Digital map design theory	35
2.3.2.1. Scale	36
2.3.2.2. Visualisation of map	37
2.3.2.3. Emotion and landmarks	38
<i>2.4. Research of campus digital map design</i>	<i>39</i>
2.4.1. Wayfinding behaviour in academic environments	40

2.4.1.1. Wayfinding problems in academic environments	40
2.4.1.2. Wayfinding task process in academic environments	42
2.4.2. The spatial relationship of the map	44
2.4.3. Text and layout	44
2.4.4. Summary	47
2.5. Discussion	48
3. Existing deficiencies of current campus digital maps	51
3.1. Introduction	51
3.2. Study I: Survey on the usage of digital maps in UK universities	52
3.2.1. Sample selection criteria	52
3.2.2. Analysis and conclusion	54
3.3. Study II: Visual survey of campus digital maps	56
3.3.1. Sample selection criteria	56
3.3.2. Procedure	57
3.3.3. Results of the visual survey	57
3.3.3.1. Map visual elements	57
3.3.3.2. Interaction and operation	65
3.3.4. Discussion of results	75
3.4. Experiment I: A questionnaire survey on the use of campus digital maps	76
3.4.1. Suitability of methodology and research	76
3.4.2. Research aims and questions	77
3.4.3. Data collection and analysis	78
3.4.3.1. Investigation and analysis of campus users	78
3.4.3.2. Analysis of campus wayfinding behaviour	79
3.4.3.3. Analysis of the use of campus digital maps	83
3.4.4. Summary	86
3.4.4.1. Wayfinding problems in the campus environment	87
3.4.4.2. Usage of campus digital map	87
3.5. Conclusion	88
4. Experiment II: The performance of digital maps for wayfinding in academic environments – University of Leeds as a case study	91
4.1. Introduction	91
4.2. Commute task	94
4.2.1. Content	94
4.2.2. Participants' completion of tasks	95
4.2.3. Analysis of the task	97
4.2.3.1. Commuting route	97
4.2.3.2. Environmental complexity influence	98
4.2.3.3. Building entrance selection	99
4.2.4. Summary	100

4.3. Quest task	101
4.3.1. Content	101
4.3.2. Participants' completion of tasks	103
4.3.3. Data analysis of task A	105
4.3.4. Data analysis of task B	109
4.3.4.1. High frequency stopping areas	115
4.3.4.2. Participants wandering areas	125
4.3.4.3. Effect of map appearance	128
4.3.4.4. Summary	129
4.3.5. Conclusion	130
4.4. Explore task	132
4.4.1. Content	132
4.4.2. Analysis of the task	134
4.4.2.1. The attractive factors of the campus environment	134
4.4.2.2. Digital map function	137
4.4.3. Summary	140
4.5. Conclusion	141
5. Experiment III: Examining the effectiveness of campus digital maps with different layouts	144
5.1. Introduction	145
5.2. Map prototype design and iterate	148
5.2.1. Design of additional information on the map	150
5.2.1.1. Icons	151
5.2.1.2. Passable routes	152
5.2.1.3. Map appearance	153
5.2.1.4. First generation prototype design	153
5.2.2. User testing of first generation map prototype	155
5.2.3. Second generation prototype design	164
5.2.4. Second generation prototype evaluation methods	174
5.2.4.1. A/B testing methodology	175
5.2.4.2. Participants recruitment	176
5.2.4.3. Test process	177
5.3. Analysis and results	181
5.3.1. Results of A/B testing	181
5.3.2. Results of observation	183
5.3.3. Results of interview	192
5.4. Conclusion	196
6. Design principles for campus digital maps	200
6.1. Information needs	200
6.1.1. Typography exists to convey information	200
6.1.2. Image for quick processed information	202

6.1.3. Colour to distinguish map visual information	202
6.1.4. Spatial information corresponds to geographic environment	204
6.2. Practical needs	205
6.2.1. Positioning and navigating	205
6.2.2. Personalisation of digital maps	206
7. Discussion	208
7.1. Overview of the research	208
7.1.1. Research stages and objectives	209
7.2. Major findings of the research and contributions to knowledge	212
7.2.1. Use design theories and principles to evaluate the legibility of digital campus maps	213
7.2.2. Find the limitations of digital maps in complex academic environments and explore additional information to enhance map visual information design	216
7.2.3. Use paper prototypes to control research focus	218
7.2.4. Make A/B testing results more detailed and objective through qualitative data analysis	220
7.2.5. Establish information design principles for campus digital maps	223
7.2.6. Use user-centred methods on information design research	226
7.3. Limitations and future work	228
References	231
Appendices	244
<i>Appendix I: Heat map of final chosen institutions – usage of campus digital map</i>	<i>244</i>
<i>Appendix II: Screenshots of campus digital maps' usage of UK institutions</i>	<i>248</i>
<i>Appendix III: Questionnaire of Experiment I</i>	<i>258</i>
<i>Appendix IV: Route record maps of commute task in Experiment II</i>	<i>268</i>
<i>Appendix V: Route record maps of Quest task in Experiment II: from Laidlaw Library to School of Mathematics</i>	<i>274</i>
<i>Appendix VI: Route record maps of Quest task in Experiment II: from School of Mathematics to Irene Manton Building</i>	<i>276</i>
<i>Appendix VII: Questionnaire of Explore task in Experiment II</i>	<i>278</i>
<i>Appendix VIII: Paper map prototypes provided to participants in Experiment III</i>	<i>280</i>

List of Tables

Table 1.1. Structure of the research.....	8
Table 2.1. Framework of wayfinding design principles	28
Table 2.2. Wayfinding tasks in academic environment.....	43
Table 2.3. Framework of digital map design principles.....	48
Table 3.1. British academic institutions' usage of campus digital maps	54
Table 3.2. Key visual elements performance of campus digital maps	58
Table 3.3. Visual survey findings: campus digital map design guidelines framework.....	76
Table 3.4. Participants' basic information for questionnaire	78
Table 3.5. Participants' opinions of necessity for help when conducting wayfinding tasks in the university.....	80
Table 3.6. Participants' opinions of reasons for having been lost on campus	82
Table 3.7. Participants' opinions of map types to seek help when lost on campus.....	83
Table 3.8. Participants' opinions for of campus digital maps' functions.....	86
Table 4.1. Participants' data in the commute task.....	96
Table 4.2. Reasons for participants' choices of building entrance	99
Table 4.3. Participants' data in the quest task	104
Table 4.4. Participants' reasons of route choices in Destination A Task	108
Table 4.5. Participants' reasons of route choices and decisions when getting lost in Destination B Task	113
Table 4.6. Participants stop positions and description of high-frequency stop areas in Destination B Task.....	116
Table 4.7. Participant's wandering area vision.....	127
Table 4.8. Participants' data in Destination B Task.....	128
Table 4.9. Places of the exploration	134
Table 4.10. Elements attracted participants during exploration.....	135
Table 4.11. Participants' opinions of the attractiveness of campus facilities	136
Table 4.12. Methods and times participants explored using Google Maps.....	138
Table 4.13. Problems that participants faced when using Google Maps.....	139
Table 5.1. Participants' basic information	156
Table 5.2. Route map collection and reasons for route decision	157
Table 5.3. Findings of each chapter.....	165
Table 5.4. Participants' basic information	177
Table 5.5. Participants' performance on the task	181
Table 5.6. Participants' time spent on the task	182
Table 5.7. Participants' behaviours and problems they faced during the test.....	185
Table 5.8. Collection of participants' answers of the interview.....	193

List of Figures

Figure 2.1. Screenshot of Google Maps London city area – simplified appearance in standard mode	32
Figure 2.2. London attractions map	32
Figure 2.3. London underground route map.....	32
Figure 2.4. University of Leeds area at different scales on Google Maps	37
Figure 2.5. Horizontal transportation (Left) and Vertical transportation (Right)	41
Figure 2.6. University printed and signage maps (Oxford, Leeds, Manchester and Shepherd).....	45
Figure 3.1. Main page of Kingston University’s mobile application (Left) and De Montfort University’s mobile application (Right).....	55
Figure 3.2. University of Leeds digital map starting page	61
Figure 3.3. University of Manchester digital map starting page	62
Figure 3.4. University of Oxford digital map starting page	62
Figure 3.5. University of Cambridge digital map starting page.....	63
Figure 3.6. University of Sheffield digital map starting page	63
Figure 3.7. University of Leeds digital map - art attractions and two routes.....	66
Figure 3.8. University of Leeds digital map - select “Libraries” on the menu.....	67
Figure 3.9. University of Manchester digital map – Campus facilities category	67
Figure 3.10. University of Manchester digital map – menu.....	68
Figure 3.11. University of Oxford digital map - menu.....	69
Figure 3.12. University facilities information example – Exeter College.....	70
Figure 3.13. University of Cambridge digital map - coordinate menu	71
Figure 3.14. University of Cambridge digital map – information chaos on the map	72
Figure 3.15. University of Sheffield digital map - information about Campus building.....	73
Figure 3.16. Heat map of whether campus digital maps follow map design principles	74
Figure 3.17. Participants’ opinions of necessity for help when conducting different wayfinding tasks in the university	80
Figure 3.18. Features of the map functions that can provide a better user experience.	84
Figure 3.19. Percentage of participants choosing campus map features that can provide a better user experience.....	85
Figure 4.1. Participants stop time in each task	98
Figure 4.2. Routes to Destination A provided by Google Maps (Laidlaw Library to School of Mathematics).....	102
Figure 4.3. Routes to Destination B provided by Google Maps (School of Mathematics to Irene Manton Building)	102
Figure 4.4. Participants’ routes to Destination A.	106
Figure 4.5. The shortest route to Destination A (road, path and lawn)	107
Figure 4.6. The position of Destination B on Google Maps	109

Figure 4.7. Main entrance of Destination B (Irene Manton Building, University of Leeds)	110
Figure 4.8. The shortest route to Destination B (stairs, square, garden and corridor)	111
Figure 4.9. Participants' routes to Destination B.	112
Figure 4.10. Area 1 – Square	117
Figure 4.11. Area 2 – Near destination	118
Figure 4.12. Area 3 – Ground floor of destination	119
Figure 4.13. Area 4 – First floor of destination	120
Figure 4.14. Area 5 – Corner	120
Figure 4.15. Area 6 – An entrance.....	121
Figure 4.16. Area 7 – End of the road	122
Figure 4.17. Area 8 – Stairs	122
Figure 4.18. Area 9 – End point 1.....	123
Figure 4.19. Area 10 – End point 2.....	124
Figure 4.20. Participants' repeated route sections in route record maps	126
Figure 4.21. The University of Leeds Sustainable Garden and surrounding environment	133
Figure 5.1. Stages of the map prototype design and evaluation.	147
Figure 5.2. Locations of Parkinson Building and Irene Manton Building on Google Maps.....	149
Figure 5.3. Extra information designed for the first-generation prototype – Icons.....	151
Figure 5.4. Extra information designed for the first-generation prototype – Landmarks.....	152
Figure 5.5. Extra information designed for the first-generation prototype – Passable route.....	152
Figure 5.6. Appearance of the first-generation map prototype.....	154
Figure 5.7. Areas of confusion when planning the route.....	162
Figure 5.8. Colour of map background and roads.....	163
Figure 5.9. An example of lack of information on map: only road lines	163
Figure 5.10. Second-generation prototype without additional information(left) and Google Maps of the same area(right)	170
Figure 5.11. Visualisation of stairs and slopes	171
Figure 5.12. Visualisation of passable entrances	172
Figure 5.13. Visualisation of roads through buildings.....	172
Figure 5.14. Second-generation map prototype with additional information.....	173
Figure 5.15. Appearance of the original prototype (Left) and the information-added prototype (Right)	175
Figure 5.16. Additional visual information shown to participants in group B	178
Figure 5.17. Recommended wayfinding time for Google Maps navigation after updating missing roads	180
Figure 5.18. Participants' stationary positions during testing	184
Figure 5.19. Locations where the three wayfinding problems occurred.	187
Figure 5.20. Locations where map cannot correspond to the real environment.	188
Figure 5.21. An example of passages in information-added map prototype.....	189

Figure 5.22. An example of unusual roads on information-added map prototype.	190
Figure 5.23. Participants' route tracking maps of two groups	191

1. Introduction

1.1. Context

When beginning the research of “wayfinding”, a clear definition is first needed. The *Oxford English Dictionary* (2015) defines this term as “The act of finding one's way to a particular place; navigation”. Wayfinding behaviour has been around since humans began exploring the world around them. People visualise their surrounding environment by constructing cognitive maps in their brains and use spatial cognitive memory to assist wayfinding when moving in an environment (Lynch, 1960; Tversky, 1993; Mcfarland, 2014). Today, humans carry out wayfinding tasks for different purposes in their daily lives. This may be commuting in a familiar environment, exploring an area, or heading to a specific destination. Allen (1999) divided these tasks into three categories: commute, explore and quest. When completing these tasks, a well-designed wayfinding system based on information design principles can help people judge the surrounding environment and destination faster and more accurately. Wayfinding is so important in our daily lives that it begins as soon as humans move through physical space. Wayfinding has also become more complex due to the complexity of the environments we now live in (cities) and work/explore (buildings and external environments). People either commute in familiar areas, travel to unfamiliar places for various reasons, or explore surrounding areas (Allen, 1999). These wayfinding behaviours require people to construct a map in their minds to perceive the environment (Mcfarland, 2014). However, the scope of human vision limits our understanding of the spatial layout of the entire area. At the same time, even in an environment where a cognitive map has been constructed, that is, a familiar environment, there may be errors in the cognitive map due to memory limitations, thus affecting the understanding of the entire space (Tversky, 1993). Well-designed maps which follow information design principles, meet user needs, can improve user wayfinding efficiency (reduce wayfinding time and errors), and can show spatial layout are a good tool to reduce the complexity of wayfinding.

As a significant type of information design to assist wayfinding, maps containing real-world environmental information can help people understand the overall layout and spatial

location of the entire environment (Pollett and Haskell, 1979). It is a symbolic image that selects the visual characteristics of geographical reality (The International Cartographic Association, 2003). Cartography, which represents geographical areas using maps, began to be recognised at the end of the 19th century and the beginning of the 20th century, and attempts were made to establish theoretical principles (Kent and Vujakovic, 2018). Its exploration and research covers multi-disciplinary content, such as information design, art, technology, humanities, etc.; for example, Burroughs (1995) explored the character positioning in Michelangelo's *Last Judgment* in the field of art and humanities and the correspondence with the Roman terrain; Conley (2011) explored the connection between the division of national space by maps and the development of early modern French literature from the perspective of literary development. Designers tend to explore innovations in map form and content by examining the purpose of using maps and user expectations. Geographers emphasise the representation of territory elements and terrain on maps; sociologists focus on maps and social consciousness in the context of nationalism relationship. The research of cartography is flourishing, and while studies of culture, society, and art are stimulating, maps should not be divorced from their form and function. When using maps for wayfinding in modern complex cities/buildings, we need to pay more attention to the map's expression of geographical reality and the user's receiving ability: for example, focusing on the user's visual perception, that is, the user's ability to receive map symbols and map information (Wood, 1968; Treisman, 1985; Fabrikant et al., 2010); the impact of user cognition (e.g. experience and knowledge) on map reading (MacEachren, 1995); discussions on map visualisation and representation (Buisseret, 1992; MacEachren, 1995; Papadias and Theodoridis, 1997; Tyner, 2014). The user's ability to understand map information is so important. Rather than its artistic expression, its functional definition needs to start from the user's perspective.

Therefore, this thesis focuses on relevant research theories on the design principles and functions of maps which consistent with wayfinding behaviour, and explores the research and development of map design applicable to cities (including building complex, block divisions, and terrain) where most people live in daily life, and discusses changes in map

form and dominant medium usage today.

Beginning in the 1960s, the emergence of geographic information systems (GIS) brought more possibilities to maps. Its development gives people the ability to use computer systems to store and process geographic data, and provides the functionality to create, develop, and update global map databases (Kent and Vujakovic, 2018). The real-time visual representation of the global geographical environment through satellites and the collection of data provided by a large number of volunteers make mapping no longer a technology solely controlled by cartographers. For example, Google Maps offers a route drawing feature that allows users to add missing roads to the map. The dominant medium of maps has gained more possibilities from traditional paper, and the research and design of digital maps have received attention (Fabrikant et al., 2010; Kent and Vujakovic, 2018). With decades of development, maps on the Internet have entered a mature stage: in contemporary people's lives, digital maps are as commonly used as paper maps and are everywhere (Kent and Vujakovic, 2018). The widespread use of the Global Positioning System (GPS) allows users to locate their position in the environment in real-time when using digital maps. Using screens (such as mobile phones, tablets, personal computers, large rolling screens in public places) as communication media, digital maps relying on Internet technology have more interactive functions than printed maps. Based on this property, recognition of the importance of map users has been one of the hallmarks of cartography (Montello, 2002).

Depending on needs and expectations, maps take on different visual presentation forms and purposes. Kent and Vujakovic (2018) classified Internet maps into location-based service maps, narrative maps, persuasive maps, etc., and admitted that Internet maps and printed maps have the same goals - to communicate. While digital maps have grown technologically and distanced themselves greatly from printed maps - such as the ability to switch information by clicking on a touch screen - the most fundamental thing remains the map itself. The visual information of a map still cannot be separated from its basic function: to extract features of geographical reality and design it into a symbolic image that reflects spatial relationships (The International Cartographic Association, 2003). Although "the aesthetic is extremely flat" (Kent and Vujakovic, 2018, p385), the interface design of digital

maps is still worthy of development: paper maps and digital maps also provide a purposeful summary of visual information in space. In complex urban environments, they have the same focus on visual elements, such as the arrangement of buildings, regional layout, road distribution in the city. As Kent and Vujakovic (2018) suggest, a map is characterised by its communication objectives rather than the medium. Before focusing on the interactivity of the digital map, the visual information content it displays is the map's visual representation of the real environment. Therefore, when discussing the design principles of digital maps, related research on printed maps can also be relevant, and is considered in the context of this thesis. Likewise, the characteristics of printed maps can also be taken into account when testing digital map performance and, in particular, the impact of research on information design on digital map performance.

This research explores the use of digital maps in academic environments. Wayfinding in universities is a simple reflection of urban wayfinding: universities are where students, faculty, and scholars work, study, and live. The research of campus maps contributes to the study of modern urban area maps with similar complex environments. Finding their way in the campus environment has become a daily behaviour for universities' users. Existing research on wayfinding in academic environments is very limited, mostly focusing on indoor wayfinding systems such as libraries (Barclay, 2012; Li and Klippel, 2012; Mandel, 2013), as well as on campus wayfinding behaviour: Scott-Webber et al. (2000) discussed the difficulties and challenges of wayfinding indoors for student groups; Bishop (2011) investigated how people perform when wayfinding systems are ineffective; Kanakri et al. (2016) focused on the emotional impact of wayfinding when time is limited in a campus environment. Although these studies are not related to digital map information design, their findings have given this thesis valuable theoretical support: an early understanding of people's wayfinding behaviour and the problems encountered in wayfinding in academic environments. The data on wayfinding behaviour and problems in academic environments provided the basis for designing the content of the questionnaire to understand digital map usage in academic settings. Current research on campus digital maps also includes application development. For example, Basri et al. (2020) used Open Street Map to build a

campus digital map, but focused more on the development process rather than map information design. Roth et al. (2009) shared two interactive digital maps of the same campus and pointed out that even if they describe the same geographical environment, the different purposes will cause the maps to present completely different visual effects. There are more studies on the development of campus digital map applications (Mantoro et al., 2009; Wu et al., 2016; Zhang et al., 2019). Currently, there is a lack of research on the information design based on design principles of the campus digital map itself. In this thesis, in order to understand the design and use of digital campus maps today, campus digital maps were found and analysed for academic institutions recognised by the British government (see Section 3.2 for details). The conclusions obtained provide a great opportunity for this thesis: to investigate the use of digital maps for wayfinding in academic environments, and to improve the information design of campus digital maps by combining the conclusions with information design principles.

Maps are tools for human use, and their necessity and level of demand need to be determined by the target users. This thesis therefore established a user-centred approach to the whole research, which involves four stages of the research process:

1. **Theoretical support:** Understand the principles and theories of campus digital map design, and relevant knowledge of human wayfinding behaviour;
2. **Existing deficiencies:** Find possible problems with existing campus digital maps and wayfinding problems in academic settings;
3. **User needs:** Discover the limitations of people using digital maps to find their way in academic environments;
4. **Design improvements:** Propose solutions to these problems and limitations.

Therefore, several experiments were conducted according to specific purposes during the stages of the research process involving user participation: "existing deficiencies" were obtained through questionnaires, and user tests were carried out to propose map design limitations through "user needs". While in the "design improvements" stage, user testing was used to evaluate the solution. The user-centred research approach adopted in this

research always maintains the importance of users to map design (Montello, 2002). Therefore, this thesis explores the potential of information design and map design based on user needs to improve the effectiveness of map information reading and the wayfinding function of maps - measured by user feedback on using the map (user opinions and wayfinding behaviour) and wayfinding tasks success rate/wayfinding time. The findings of the thesis and the literature review of related research are used to create design principles for campus digital maps, aiming to provide valuable advice to researchers and designers who focus on information design of campus digital maps, and maps with similar complex environments.

1.2. Aims and objectives

1.2.1 Research aims

The main aim of this thesis is to use user-centred design methods to improve campus digital map information design, and establish the design principles of campus digital maps. The first aim is to investigate the challenges people face using digital maps to find their way around campus, and to identify the research and theories that would be relevant to campus digital map design, and establish opportunities for improvement to campus wayfinding design. The second aim is to investigate how map information design affects legibility (factors that may influence route planning, reading accuracy, comfort, and efficiency) in wayfinding tasks. The third aim is to investigate the role of user-centred map information design methods in improving the effectiveness of map design in campus wayfinding systems.

1.2.2 Research objectives

In order to achieve the research aims, the main objectives of this thesis are divided into five stages:

STAGE 1 - Theoretical support

1. To find out the design factors that have an impactful effect on the design of campus digital map information.
2. To understand the relevant theories of wayfinding behaviour in academic environments, and to explore the characteristics of wayfinding on campus.

STAGE 2 - Existing deficiencies

3. To explore the usage of existing campus digital maps.
4. To identify design constraints (in terms of visual elements and interactive features) that affect the legibility of campus digital maps.

STAGE 3 - Participatory case studies

5. To investigate the opinions of campus environment users on the legibility of digital maps.
6. To observe the behaviour of users using digital maps to find their way in academic settings and the problems they encounter, and find the limitations and solutions of map information design.

STAGE 4 - Design solutions and evaluation

7. To conduct map information design on the solutions and conduct evaluation and iteration to obtain scientific and comprehensive solution content.

STAGE 5 - Discussion and conclusions

8. To summarise the contribution of research-based user-centred map information design practices in campus digital map design, and to establish design principles based on experimental results and related research summaries.

1.3. Research questions

In this thesis, four key questions are discussed and answered:

1. What design principles and theories are beneficial to the design of digital map information in an academic environment?
2. How is current campus digital map used? How do they reflect design principles?
3. How is the digital map used in academic settings? What are the restrictions?
4. How can maps in academic settings meet user needs (effective, usable, readable) through information design principles?

1.4. Research structure

In order to achieve the aims and objectives of this research, this thesis is divided into seven chapters including the introduction of this chapter. Table 1.1 shows the structure and research methods of the entire thesis.

Table 1.1. Structure of the research

Stage	Objective	Methods	Outcome
Theoretical support	To find out the design factors that have an impactful effect on the design of campus digital map information.	Literature review	Identification of design principles to guide the development of the prototype
	To understand the relevant theories of wayfinding behaviour in academic environments, and to explore the characteristics of wayfinding on campus.	Literature review	Understand of human wayfinding behaviour and wayfinding tasks in academic settings
Existing deficiencies	To explore the usage of existing campus digital maps.		Limitation of current usage of campus digital map in UK
	To identify design constraints (in terms of visual elements and interactive features) that affect the legibility of campus digital maps.	Visual survey	Refined design principles with current approaches and informs

Stage	Objective	Methods	Outcome
Participatory case studies	To investigate the opinions of campus environment users on the legibility of digital maps.	Online questionnaire investigation	Refined wayfinding problems in academic environments
	To observe the behaviour of users using digital maps to find their way in academic settings and the problems they encounter, and find the limitations and solutions of map information design.	User testing; Observation; Online questionnaire investigation.	Limitation of digital maps' usage in academic settings
Design solutions and evaluation	To conduct map information design on the solutions and conduct evaluation and iteration to obtain scientific and comprehensive solution content.	User testing; Observation; Interviews.	Design and improvement of solutions, discussion of impacts
Discussion and conclusions	To summarise the contribution of research-based user-centred map information design practices in campus digital map design, and to establish design principles based on experimental results and related research summaries.		Design principles applicable to campus digital maps/wayfinding maps in complex environments

CHAPTER 2 - Information design theories and principles in campus digital maps reviews the literature related to the research background. This chapter discusses the relevant principles of wayfinding system information design and wayfinding behaviour, map design theory and principles, and research of wayfinding behaviour in academic environments. Through literature review, frameworks of wayfinding system design principles and digital map design principles are established, which become the basis for evaluating the existing campus digital map information design in Chapter 3, and provide references for the campus digital map design principles established in Chapter 6. At the same time, a preliminary understanding of people's wayfinding behaviour and campus wayfinding problems is provided, which establishes good theoretical knowledge for the user-centred experimental design in

subsequent chapters.

CHAPTER 3 – Existing deficiencies of current campus digital maps discusses the necessity and the current usage of campus maps. It investigates the use of digital maps on campuses by academic institutions in the UK, and reviews people's experiences and limitations of using existing digital maps. Section 3.2 investigates the use of campus digital maps by government-recognised UK academic institutions and identifies that most campus digital maps lack design based on information design methods. Section 3.3 conducts a visual survey of five unique campus digital maps and evaluates them based on the design principles established in Chapter 2, which helps explore the visual presentation content and interactive functions of digital maps. Section 3.4 utilises an online questionnaire, which provides a more detailed understanding of personal experiences of using digital maps for wayfinding in academic environments, thereby identifying the most common problems and needs of users in campus wayfinding, which helps conduct experiments based on user needs in Chapters 4 and 5. This chapter provides references for campus digital maps design principles through visual survey, and investigates users' wayfinding experiences and common problems in campus environments. The results of this chapter provide user needs and a reference for establishing task content for subsequent experiments research.

CHAPTER 4 - Experiment II: Performance of digital maps for wayfinding in an academic environment - University of Leeds is used as a case study in which to conduct user testing. This chapter introduces three wayfinding tasks based on people's different wayfinding purposes: commute, quest and explore, and designs and tests tasks content based on problems people often encounter. By tracking user wayfinding routes, observing wayfinding behaviours, and conducting questionnaire surveys, this chapter collects and analyses the limitations of the use of digital maps in academic environments. In this chapter, the limitations and errors in the use of digital maps in campus settings are understood. It identifies the design elements necessary for the design of campus digital map information, as well as identifying current usability problems that should be addressed in wayfinding design practice. At the same time, the results of this chapter provide new research ideas, that is, the evaluation of map information legibility needs to focus on the map itself, rather

than letting the Global Positioning System (GPS) assist users in establishing the correspondence between map information and the geographical environment.

CHAPTER 5 - Experiment III: Examining the effectiveness of campus digital maps with different layouts analyses the conclusions obtained in the previous chapters (user needs, limitations of use of digital maps), draws possible solutions, and uses solutions to design a map prototype based on design principles. Next, the map prototype is tested, iteratively designed, and evaluated in order to obtain more convincing results. Section 5.2.1 describes the process of how to visualise the design elements necessary for campus digital map information design on the map prototype. Section 5.2.2 provides a user testing practice to evaluate the legibility of the map prototype, recording the participants' reading comprehension ability and information legibility of the map prototype. The end of this section reflects on the limitations and shortcomings of visual information for the map prototype. Sections 5.2.3 and 5.2.4 conduct an iterative design of the map prototype, and use the new map prototype after iterative design to perform actual wayfinding tasks. A discussion of the value of map prototypes and reflections on the visual presentation of information are discussed in Section 5.3.

CHAPTER 6 - Design principles for campus digital map summarises the research results and related empirical research results, and proposes information design principles applicable to campus digital maps. The results of this chapter provide valuable suggestions for researchers and designers who focus on campus digital map information design. Moreover, the results are not only applicable to campus digital maps, but can also provide support for the design of map information in similarly complex environments.

CHAPTER 7 - Discussion reviews the findings from the thesis and contributions to knowledge. The limitations of the research are also reflected on, and possible future research is discussed.

2. Information design theories and principles in campus digital maps

2.1. Introduction

The existence of "maps" predates the definition and design of visual maps by humans. "Cognitive maps" have emerged when humans began to develop wayfinding behaviours in unfamiliar or familiar environments (Mcfarland, 2014). As people's exploration of the physical environment expands, their requirements for the layout and visual information of the exploration area increase. Advances in designed maps aim to enhance wayfinding design to improve people's understanding of the physical environment. Nowadays, maps have appeared in our daily lives in various forms: digital maps, printed paper maps, map boards, etc. Other wayfinding system designs such as guide signages, signs, door labels, etc. also provide people with the convenience of wayfinding in the physical environment. However, as mentioned in Chapter 1, people still experience confusion when they fail to find their way, such as getting lost or unable to orient themselves (Stanney, 1999; Scott-Webber et al., 2000). Using wayfinding systems that conforms to information design principles in specific contexts to assist people in their daily lives may be effective in reducing the challenges encountered: this research focuses the study on the wayfinding experience in academic environments, and several studies have identified challenges encountered by campus users on a daily basis (mentioned in detail in Section 2.4.1.1 of this chapter). Therefore, in order to understand the basic needs of users in campus digital map design, it is first necessary to clarify people's wayfinding behaviour. At the same time, the research needs to be established based on the principles of information design, so it is necessary to review the existing literature for research on wayfinding system design and map design principles. To this end, relevant literature is reviewed and organised in this chapter to better understand people's wayfinding behaviour and experience, as well as the problems encountered in wayfinding in academic environments; how the design principles of wayfinding system and map design principles can improve people's wayfinding efficiency and their potential in campus digital map design.

This literature review first concentrates on wayfinding design theory to establish an understanding of wayfinding behaviour, wayfinding design, and the composition of information in wayfinding systems. The user's wayfinding experience and how user-centred wayfinding design works are discussed.

Then, this research focuses on map design theory. Map design principles and digital map principles are discussed in detail in this session in order to form unified guidelines of information design principles, and used as a base reference for design evaluation in each experiment of this research.

Finally, this review continues with a discussion of related research on campus digital maps, exploring people's wayfinding behaviours in academic environments. The reasons why the academic environment is selected as the research object are explained, and some existing research and research gaps in wayfinding in the academic environment are understood.

Although the focus of this research is on improving the legibility of campus digital map designs, this review draws on research in areas outside of digital map design. There are two reasons for this situation: a) There is currently very little information design research related to campus digital maps; b) Digital maps and printed paper maps have commonality in information design (Kent and Vujakovic, 2019). This chapter concludes with a summary of the significance of this research. In addition, through the discussion of literature in this chapter, a framework of wayfinding design principles and a framework of digital map design principles are summarised.

2.2. Wayfinding design theory

In this section, the relevant literature on human wayfinding behaviour and information on wayfinding systems is reviewed. Information design research based on user-centred concepts requires first understanding user needs. In this research, how people carry out wayfinding, their performance and experiences in wayfinding are first discussed. Then the reasons that may affect the efficiency of wayfinding, and the information elements of a

wayfinding system that are beneficial to map design are analysed. On this basis, wayfinding design principles are summarised and discussed.

2.2.1. Wayfinding and human behaviour

Architect Lynch (1960) discussed in detail the connection between wayfinding and urban legibility in cities in his book *The Image of the City*. This book's discussion of the urban environment examines how people position themselves in the city. Lynch (1960) believed that urban space is not only composed of physical characteristics, but also composed of people's psychological images. Lynch (1960) also defined people's wayfinding behaviour as positioning through mind maps, consisting of five elements: paths, edges, districts, nodes and landmarks. This wayfinding method understands the wayfinding behaviour as a self-learning behaviour of environmental characteristics. Chen and Stanney's (1999) research indicates this point, suggesting that wayfinders usually start wayfinding by directly sensing the environment. For the wayfinding process, Giuliani (2001) described it as the dynamic organisation and communication between people and the environment. The guidelines book published by NHS Estates (2005) also mentioned that people use mental maps to simplify the environment and route through information, thereby matching the mental model with the actual environment. It can be seen from this that people are constantly sensing the changing environment during their wayfinding journey. Therefore, in the design of the wayfinding system, real-time visual elements and wayfinding information should help people quickly perceive the surrounding environment information and locate themselves. The digital map design based on information design principles that this research focuses on should pay more attention to this point. Because maps have the function of showing the overall layout of the environment (Pollett and Haskell, 1979; The International Cartographic Association, 2003), how to unify the visual elements and information design of the map, and enable people to compare the map information with the physical environment at any time when viewing the map is a key point to consider when designing a map.

Prior to this, how people position themselves and explore the environment has long existed

in history, and has continued to innovate with the development of science and technology. Golledge (1999) described human wayfinding as a purposeful, targeted, and motivated behaviour. Due to different purposes and goals, humans find routes and locate themselves in complex environments, and therefore invent and use technology to assist them. Research shows that historically, humans have autonomous wayfinding behaviours, including travellers using technology (such as maps and compasses) to locate and find routes on land and ocean (Buisseret, 1992). Similarly, Harley and Woodward (1992) mentioned in the book *The history of cartography* that cartographic techniques, especially mapping techniques, have appeared in history of countries around the world, such as China, the Roman Empire, India, and medieval Europe. In this research, user needs are always considered at every step. This is because discussing the legibility of a campus digital map cannot avoid the target audience. It has been confirmed that people's wayfinding behaviour has a purpose, so the purposes of wayfinding in an academic environment will be discussed later and used in experiments.

Nowadays, the structure of cities is becoming more complex. Universities often exist in cities. The stronger the complexity of the layout, the stronger the negative impact on the user's satisfaction during wayfinding (Tao et al., 2018), which brings a new round of wayfinding challenges. At the same time, the trend of globalisation and increasingly convenient transportation makes people face unfamiliar scenes and environments more often. NHS Estates (2005) argues that getting lost is a common part of life. When there is no wayfinding system to assist, people can only perceive the surrounding physical environment through their eyes, and it is difficult to understand the overall structure and planning of the environment. How to use technology to assist people to obtain information in the environment and find their way correctly and effectively has become a challenge for designers and researchers.

2.2.2. User-centred wayfinding design

Wayfinding design needs to meet the user's wayfinding behaviour, so that it follows a user-

centric design approach. As Lynch (1960) proposed, if cities are to be designed for people to live in, designers must learn how people respond to these cities. Therefore, user-centred wayfinding design is particularly important in this research. This review stage of this research is dedicated to exploring wayfinding design and map design in relation to research on user needs and how users influence design development, in order to gain a more detailed understanding of users' wayfinding behaviour and the impact on design research.

Regarding people's wayfinding behaviour, NHS Estates (2005) summarises it as a series of decisions: a) decisions on specific destinations, b) decisions on how to get there, c) and decisions on routes. This is also consistent with Golledge's (1999) theory that human wayfinding is a purposeful behaviour. For the wayfinding process, Arthur and Passini (2002) identified it as decision making, decision execution, and information processing. It can be found that decisions influence and correlate with each other. Throughout the wayfinding process, people repeatedly make and execute decisions for a purpose. Based on this, how to facilitate users to quickly process information and make decisions during the process is a very important part of the wayfinding system design.

However, users' individual factors may affect their decision-making ability. In the research of user needs and user behaviour, the user's wayfinding performance changes with individual characteristics and purposes. Süzer (2018), Tao et al. (2018), and Wang et al. (2018) indicated that elderly people need more help with spatial orientation and positioning due to limited memory and difficulty in orientation. Güneş (2018) and Süzer (2018) also proposed the effects of gender, habits, familiarity, experience, education and other factors on spatial navigation. This may be a research direction for information design of wayfinding systems, because many user groups may use wayfinding systems to assist themselves in reaching their destinations successfully and quickly. An in-depth understanding of potential users is crucial to successful wayfinding design. In this research, considering that most users of campus digital maps are students, faculty, and visiting scholars, this research identified them as potential users and recruited participants within this group.

Targeting and understanding user groups formed the core of the strategies involved in map

development in this thesis. User-centred research also focuses on understanding how people make decisions, that is, the theory of cognitive maps; and the impact of "familiarity" on wayfinding, because people live and work on campus, it is necessary to build an understanding of whether their wayfinding will be different when they are familiar with the environment.

2.2.2.1. User cognitive map

According to Mcfarland's (2014) definition of **Cognitive map** in the *A Dictionary of Animal Behaviour*, the behaviour of many animals shows that they have a map. When people move in an environment, such as going to work or on the way from home to the station, they use cognitive memory of space, which is what Lynch (1960) called the cognitive map. When people are looking for a route in the environment, a clear environmental mind map is needed to deal with the confusion and fear of getting lost. The construction of the cognitive map can be obtained in different ways. For instance, moving around in an area to gradually build a cognitive map in the brain, or looking at the map to understand the spatial composition. Previous studies suggest that if people successfully solve the wayfinding problem and build a clear mind map when they first visit their destination, they will not be confused when they face the same problem later (NHS Estates, 2005). To help people find their way better, legibility (also called imageability and visibility) was proposed as a central concept of wayfinding system in Lynch's (1960) book, which requires that the information of the wayfinding system be readable and easy to understand. The association between wayfinding and legibility has been indicated by many studies (Baker, 1986; Liu, 1991; Yoo, 1992; Abu-Ghazze, 1996). Humans have basic self-awareness needs for information given by the environment (Kaplan and Kaplan, 1982). Based on this, the legibility of maps has become one of the core research focuses of this thesis. The information design of maps must be based on the requirement that people can quickly obtain and understand the information.

So when people understand the composition of space through self-construction or looking

at maps, do they obtain a complete and correct cognitive map? The answer is not necessarily. Sometimes the cognitive maps are not necessarily correct. If there are deviations or memory confusion in the construction process, they will cause errors. Tversky (1993) suggested that the cognitive map be called cognitive collage. Since the cognitive map belongs to the category of long-term memory, it may change over time. However, even if the cognitive map is correct, people may get lost. Kanakri et al. (2016) believe that on the university campus, even if wayfinders understand the route, they may feel stressed. When students are asked to go to the tutor's office, they may get lost due to room changes or desk changes. This is not because the cognitive map is wrong, but because it has 'expired'. Therefore, some tools that assist in positioning and wayfinding can help people cope with the wayfinding tasks of daily life. For example, common notices posted on the wall, door numbers, or digital wayfinding systems that are networked and can update information.

2.2.2.2. How familiarity affects wayfinding

It has been shown that familiarity with specific environments may affect wayfinding behaviour (Weisman, 1981; Yoo, 1992). Garling and Evans (1992) explained that the more familiar people are with the environment, the easier it is to complete detailed cognitive maps. Ruddle et al. (1998) suggested that different levels of familiarity with the environment provide spatial knowledge with different accuracy. O'Neill (1992) pointed out that the complexity of spatial layout becomes less important for those who have already established an environmental cognitive map, that is, those who are familiar with the environment. This is indicated by Hölscher et al. (2006), and it is believed that for people who are familiar with the environment, they rely more on knowledge and memory while wayfinding. In contrast, people who are new to the environment often use external information to aid wayfinding, such as maps, signages, and landmarks (Chebat et al., 2005). Previous research has demonstrated that information from wayfinding systems plays an important role in optimising the wayfinding experience for first-time users (Conroy, 2001; Holscher et al., 2007; Vilar et al., 2015). Based on this, during the participant recruitment phase of

Experiment II and *Experiment III* of this research, people's familiarity with the experimental location was taken into account to avoid the possibility that some participants were familiar with or had knowledge of the physical environment of the experimental location, which would then influence to the depth of their reading of map information.

Additionally, people may face wayfinding stress even in familiar surroundings. It may be the confusion caused by the mismatch between the cognitive map and the changing physical environment mentioned in the previous section, or it may be the tension caused by the need to complete the wayfinding task within a limited time. The latter is discussed in detail in Section 2.4.1.1 in conjunction with the research of wayfinding problems in academic environments.

2.2.3. The information structure of wayfinding systems

Environmental, design, and social factors influence wayfinding behaviour. Lynch (1960) 's research provides ideas and suggestions for architects and researchers in wayfinding design and user-centred design. He pointed out that while getting a clear mental map of the environment, people should be able to learn how to navigate in this environment through training. To enable people to operate and act on the environment, designing a wayfinding system based on user needs should be adopted.

The main purpose of the wayfinding system is to improve the user's wayfinding efficiency (Harding, 2011), which is related to the "least effort" proposed by Zipf (1949), i.e. allowing users to quickly and easily recognise the direction and reach the destination. To accomplish this, wayfinding systems need to provide the necessary information for intuitive navigation (Gibson, 2009). Lynch (1960) 's research emphasises the role of vision in wayfinding information, as suggested by NHS Estates (2005), and determines that people use vision, sound, touch and smell to varying degrees when searching for destinations. NHS Estates (2005) argues that an important factor in improving wayfinding efficiency is to consider how people use all their senses while finding their way. Now that wayfinding behaviour has

become a part of people's daily life, the research on information design of wayfinding systems has been fully discussed in many fields: Harding (2011) summarised the sign design principles of airport wayfinding systems; Miller and Lewis (1999)) have enumerated wayfinding guidelines for signage systems in healthcare institutions, Hashim et al. (2014) discussed how health navigation signage design adapts to different cultures in globalisation, and Mikhael and Yandi (2018) studied the visualisation of hospital wayfinding signage design; Kim et al. (2011) studied the use of digital signage design; Pollett (1979) defined library signage systems design principles, Barclay et al. (2012) focused on the help of direction and information signs in library wayfinding systems; Mandel's (2013) study increased the knowledge of how library wayfinding system design affects users; Weisman (1981) discussed and evaluated wayfinding through architectural legibility in the buildings environment, and Raubal and Winter (2002) suggested that landmarks can enrich wayfinding instructions.

Research on outdoor and indoor, urban and architectural, wayfinding system information design covers many aspects of people's daily lives, and there are already universal guides on wayfinding design. For example, Apelt et al.'s (2007) wayfinding design guidelines, Gibson's (2009) wayfinding handbook for information design in public places, and the wayfinding design section of Black et al. (2015) information design handbook. In order to have an in-depth understanding of the information composition of wayfinding systems, this review integrates research on wayfinding information design in other fields of design research and discusses information divided into four key components: a) signage; b) image; c) colour; d) typography and layout. First, a unified understanding of signage, an important component of wayfinding system design, is established, and secondly, the three main components of wayfinding information are discussed separately. This section selects and organises information from existing research to be more suitable for the needs of this research. The discussion results can analyse and organise a framework of wayfinding design principles, which forms the core of the information design principles involved in map development in this thesis.

2.2.3.1. Signage

Signages in the wayfinding system are essential for users to find directions and destinations, also agreed in the book of NHS Estates (2005). That is, the signage is a key part of the wayfinding system. In order to make it user-friendly, more effective signs should be designed to guide the search to the destination. Signages and floor plans have been identified as effective in increasing user satisfaction (Bosman and Rusinek, 1997). Signage is widely used in wayfinding systems. It is used for route guidance and information integration for daily use and emergency situations (Xie et al., 2007). If navigation signs are not recognised, it will be difficult for people to reach their destinations successfully and quickly. Ganesh (2016) identified the main factors affecting the effectiveness of navigation signs as the design of the signs, the placement of the signages, and the legibility of the signs. This was also indicated by McLaughlin et al. (2005) and Mikhael and Yandi (2018), and showed that the visibility of signage is a key factor in the effectiveness of spatial navigation. McLaughlin et al. (2005) also proposed that signages should not be obscured by physical obstacles such as walls, columns and corners. However, as the complexity of the environment increases, many elements create visual impairments in the environment, which makes environmental visibility more difficult. Therefore, visibility analysis needs to be incorporated into the signage design process. Signage needs to be effective, which requires it to meet certain characteristics, such as being clearly identifiable from a distance, and being placed where people need information or are easily confused (Montello and Sas, 2006).

The principles of signage information design focus on text and layout, icons, colours, and the spatial location of signs. In the previous theoretical review of signage design research, it can learn that signage often exists in the physical environment and follows people's movements to provide information in the environment (such as walls, floors, standing signs, etc.). As Apelt et al.'s (2007) summary of wayfinding design guidelines illustrates the principles of spacing between signage and placement of visual information, the signage system is a wayfinding system that is broken down into parts and composed of many information boards with a unified visual presentation style. In contrast, maps organise the information that needs to be given to users in the same medium (printed paper, screen, network

interface, etc.), and a unified information layout needs to be considered. Therefore, design principles for the spatial location of signage are not considered for this research. Design principles focusing on text and layout, icons, and colours can be used as the suggestions of information design for this research, as follows:

1. Visual information (background, letters, graphics) has colour contrast and brightness differences (Lomperski, 1997; Apelt et al., 2007; Gibson, 2009; Sandnes, 2017; Roefs and Mijksenar, 2017);
2. Appropriate font style and spacing, such that uppercase and lowercase letters are easier to read than all uppercase letters (Apelt et al., 2007; Roefs and Mijksenar, 2017);
3. Sans Serif typeface such as Arial, MS Sans Serif, Tahoma, Futura, Geneva and Helvetica Medium make it easier for people to read. (Apelt et al., 2007, p.10; Calori et al., 2015, p.131);
4. Font size, type, and layout should be legible and easy to understand. The size and spacing between letters and words should be proportional to the amount of information provided (Apelt et al., 2007; Gibson, 2009);
5. Clear definition of elements in the physical environment (buildings, roads, bridges, etc.) (Apelt et al., 2007; Gibson, 2009).

2.2.3.2. Image

In the design of the wayfinding system, people's access to information largely comes from words and images. However, when the language of the sign is unknown, people may lose their goals. In this case, images such as icons, arrows, and pictograms used by the wayfinding system are necessary elements for identifying destinations and directions (Miller and Lewis, 1999; Gibson, 2009; Süzer, 2018).

As a visual element, images are recognised by humans before text, and can be easier to process compared with reading text (Norman, 1990). Images can be useful in a variety of situations, such as users who are unfamiliar with text (non-native or low literacy), have

visual problems (myopia or the elderly), especially when information needs to be processed quickly (escape signs) (Lomperski, 1997; Apelt et al., 2007; Xie et al., 2012; Hashim et al., 2014; Süzer, 2018; Wang et al., 2018). Rather than being represented by words, arrows have been understood as directional symbols by most people, including users with lower literacy levels (Pollett and Haskell, 1979; NHS Estates, 2005; Rousek and Hallbeck, 2011; Roefs and Mijksenar, 2017); the importance and effectiveness of pictograms in wayfinding systems is discussed in the guidance on wayfinding design for public facilities published by NHS Estates (2005); Gibson (2009) gave an example of how the design of symbols in European train stations helps people from many language backgrounds travel successfully; research by Rousek and Hallbeck (2011) shows that excellent healthcare signage has a positive impact on reading efficiency and information acquisition for both visually impaired and non-visually impaired individuals.

But relying on images also has many disadvantages. Hashim et al. (2014) realised in the design of health navigation signs that different cultural backgrounds and educational backgrounds lead to different interpretations and understandings of wayfinding images. Therefore, the purpose of the images may not be properly understood by everyone. When confusion or opposite interpretation is caused, it may cause additional wayfinding burden. In this research, image legibility also needs to be considered. In today's globalised world, universities bring together users from various cultural and educational backgrounds. The design of the images and pictograms in the visual information of campus digital maps should ensure that people are easy to understand, or provide explanations so that people can quickly understand their functions. Based on the existing literature review, the design of images should follow:

1. Destination and direction can be identified using images such as icons, arrows, and pictograms rather than text descriptions (Miller and Lewis, 1999; Süzer, 2018);
2. For information that needs to be processed quickly, images are easier to recognise than text (Lomperski, 1997; Apelt et al., 2007; Xie et al., 2012; Hashim et al., 2014; Süzer, 2018; Wang et al., 2018);
3. Different cultural and educational backgrounds lead to different understandings of

images, and it is necessary to consider the legibility of images among different groups of people (Hashim et al., 2014), or to assist in explaining images' functions.

2.2.3.3. Colour

Colour is an indispensable element in design. When reviewing relevant research on information design for wayfinding systems, almost all design principles mention the role of colour in design. NHS Estates (2005) made a number of recommendations for the design of colour information for wayfinding systems in healthcare facilities, focusing on how to make information easier to read through colour contrast (background colour versus text, amount of colour, etc.): Low contrast colours will make information difficult to obtain, and when there are too much colour (more than five), it may be difficult to distinguish; Gibson (2009) also focused on the contrast of colour and discussed the role of three properties of colour in information design: hue selection is the first thing to consider in a wayfinding colour system, followed by ensuring colour contrast and legibility (through changes in intensity and value). Feisner (2006) similarly stated that too much colour should be avoided to make the wayfinding system difficult to use. For designers, how to interpret colour to convey meaning can use colour-coding when conducting colour information design research. This is a method of linking colour with messages, whereby colour conveys information (Calori et al., 2015). Colour coding can create different cues in the environment to provide distinction to facilitate wayfinding (Abu-Obeid, 1998). One of the most common situations is traffic lights. With the unified use of traffic signals, driving populations around the world have defaulted to red for stop and green for action.

When constructing environmental mind maps, the use of colour as an additional navigational tool is considered beneficial for information identification (Dalke et al., 2006). Read (2003), Holscher et al. (2006), Davis and Therrien (2012), and Farran et al. (2012) also show that colour can improve wayfinding efficiency and performance. However, not all colour settings are suitable for wayfinding. Süzer (2018) compared the effects of cool, warm and neutral colours on wayfinding and indicated that neutral colour settings have a negative

impact on visual-spatial navigation, because the grey and beige colours used in the research have less contrast with the background colour (white walls indoors), they minimise people's attention and concentration, which in turn affects navigation performance. This is also in line with the colour contrast requirements in the colour information design research of Gibson (2009) and NHS Estates (2005). In addition, colours not only affect people's attention and reading ability, but also bring different emotions. Park and Guerin (2002) studied the impact of colour on environmental perception and discussed differences in colour perception (pleasant, comfortable, complex, exciting, etc.) in different cultural contexts. The choice of colour needs to be considered as different cultures have different interpretations of the meaning of colours (Hashim et al, 2014). Traffic lights can still be used as an example. In many countries, exits are expressed in green because green is related to the concept of *go*; however, Calori et al. (2015) investigated the use of red in exit signs in some countries because it is related to emergencies.

In this research, the design of colour information should pay attention to:

1. It should be avoided when the colour settings do not provide enough contrast. The colours used for text and logo background should contrast with each other and with the dominant colours of the environment (NHS Estates, 2005; Gibson, 2009; Süzer, 2018);
2. The colours used in the colour settings should not be too many, otherwise there will appear reading difficulties (NHS Estates, 2005; Feisner, 2006);
3. Focus on the three properties of colour (hue, intensity and value) to enrich colour composition and create contrast (Gibson, 2009);
4. Use colour coding can convey information (Abu-Obeid, 1998; Calori et al., 2015);
5. Colour can bring about different environmental perceptions, and when choosing colours it is necessary to consider whether different cultures will bring different interpretations of the meaning of colours (Park and Guerin, 2002; Hashim et al, 2014; Calori et al., 2015).

2.2.3.4. Typography and layout

Even though image elements are often recognised before text, much of the information content of wayfinding systems is conveyed through text (Calori et al., 2015, p.127).

Typography design involves style, font style, appearance and structure (Bringhurst, 2002):

Typography style is related to the visual design of specific projects and is not helpful to the research of this thesis, so it is not discussed in this section. For font styles, thousands of fonts have been designed and used as people's tastes, cultures, and design requirements vary and develop, and as digital fonts are loaded on computers (Gibson, 2009). The style and appearance of a font needs to be carefully considered in terms of how it is used: Where is it used? What is the best size of the font? How to communicate with users? What is its function? For this research, the use case is text information on maps. The size should meet people's needs for clear reading and should not be too large to obscure the environmental image. The user needs are clear and easy-to-read text information. The function is to name the elements on the map. Rather than designing and using new fonts, using existing fonts is a standard practice in wayfinding system design (Calori et al., 2015). Under the usage requirements, artistic and decorative fonts are not a suitable choice. Apelt et al. (2007) briefly lists several fonts suitable for wayfinding systems, which are listed in Section 2.2.3.1 and will not be mentioned again here.

While providing convenient help to users, the information in the wayfinding system also needs to provide a hierarchical structure in the layout. This is to classify the information into levels of importance and give users a reading order to avoid confusion in reading (Gibson, 2009; Calori et al., 2015). Harding (2011) classified signage information into primary, secondary and tertiary levels, which indicated the necessity of information hierarchy. This review identified several characteristics that influence information layout. Researchers focus on the quality of the message itself, such as the design of signage, emphasis on colour, and decoration of the environment (Lomperski, 1997; Apelt et al., 2007; Rousek and Hallbeck, 2011); font style (upper and lower case, bold or italic, The first letter is capitalised and the remaining letters are lowercase, etc.) and the impact of font size on information hierarchy (Bringhurst, 2002): Bold, capital letters and larger font sizes tend to quickly attract readers'

attention and are considered to be the first-level information emphasised in typesetting; fonts with explanatory functions should be unified, otherwise it may increase reading difficulties (Gibson, 2009).

In addition, since the purpose of the wayfinding system is to improve people's wayfinding experience, the relationship between people and space and the individual behavioural habits of users should also be considered in the research of information layout. People's ability to generate and improve cognitive maps of the physical environment during wayfinding is closely related to spatial orientation (i.e., the person's ability to orient themselves in space) (Passini, 1992). Insufficient spatial orientation affects wayfinding abilities, leading to cognitive confusion and making it difficult for users to construct mental maps (Kitchin, 1997). In this case, improving the legibility (layout and complexity) and spatial recognisability (how helpful the environment is to the user) of the environment can give people a better sense of orientation (Canter, 1974; Güneş, 2018). These studies imply that to help people generate correct cognitive maps and successfully find their way around, it is necessary to consider how wayfinding systems help users orient themselves. In the wayfinding system, the map can show the overall layout of the environment. Accurately representing a user's location in the physical environment on a map can help users orient themselves and understand the areas of the map they should read to understand their surroundings. For navigation directions, linear circulation is more likely to have a positive impact on the sense of direction than other circulation types such as grids and crosses (Yanhua, 2011; Tap et al., 2018). However, Passini (1981) argued that signage, although providing linear wayfinding (from point A to point B to point C), cannot meet the spatial needs of users (providing users with spatial knowledge and information of overall meaning, e.g. as floor plan, or all accessible points in an area). Since this research focuses on map information design, route navigation between two points can often be provided during the wayfinding process and meet the user's spatial needs. Research on other navigation directions in the wayfinding system, such as linear circulation and grid circulation, is not paid attention to by this research again. In terms of typography and layout, the wayfinding system design should meet:

1. Information design involves the layout of information (Harding, 2011). For emphasised information, bold, capital letters, and larger font sizes can be adopted (Bringhurst, 2002);
2. Fonts with descriptive functions should be unified (Gibson, 2009);
3. Wayfinding systems need to help users orient themselves (Canter, 1974; Passini, 1992; Kitchin, 1997; Güneş, 2018).

2.2.4. Summary

This section reviews the concept of wayfinding design, including research on people's wayfinding behaviour, user-centred wayfinding design (including the impact of cognitive maps and environmental familiarity on the wayfinding process), and design principles for the information composition of wayfinding systems. A review of wayfinding behaviour and cognitive maps and environmental familiarity provides an in-depth understanding of how users find their way in the physical environment and the behaviours they produce when finding their way, which helps to conduct the content of the experiment and define the scope of participant recruitment during the experimental stages. The discussion of the relevant literature on the information composition of wayfinding systems subdivided the information into signage, image, colour, typography and layout, conducted an in-depth analysis of the design principles, and they are summarised as the framework provided in Table 2.1, which can guide the future research.

Table 2.1. Framework of wayfinding design principles

Wayfinding information	Design principles
Signage	Visual information (background, letters, graphics) has colour contrast and brightness differences (Lomperski, 1997; Apelt et al., 2007; Gibson, 2009; Sandnes, 2017; Roefs and Mijksenar, 2017); Appropriate font style and spacing, such that uppercase and lowercase letters are easier to read than all uppercase letters (Apelt et al., 2007; Roefs and Mijksenar, 2017); Sans Serif typeface such as Arial, MS Sans Serif, Tahoma, Futura, Geneva and Helvetica Medium make it easier for people, including those with visual impairments, to read. (Apelt et al., 2007, p.10; Calori et al., 2015, p.131);

Wayfinding information	Design principles
Signage	Font size, type, and layout should be legible and easy to understand. The size and spacing between letters and words should be proportional to the amount of information provided (Apelt et al., 2007; Gibson, 2009); Clear definition of elements in the physical environment (buildings, roads, bridges, etc.) (Apelt et al., 2007; Gibson, 2009).
Image	Destination and direction can be identified using images such as icons, arrows, and pictograms rather than text descriptions (Miller and Lewis, 1999; Süzer, 2018); For information that needs to be processed quickly, images are easier to recognise than text (Lomperski, 1997; Apelt et al., 2007; Xie et al., 2012; Hashim et al., 2014; Süzer, 2018; Wang et al., 2018); Different cultural and educational backgrounds lead to different understandings of images, and it is necessary to consider the legibility of images among different groups of people (Hashim et al., 2014), or to assist in explaining images' functions.
Colour	It should be avoided when the colour settings do not provide enough contrast. The colours used for text and logo background should contrast with each other and with the dominant colours of the environment (NHS Estates, 2005; Gibson, 2009; Süzer, 2018); The colours used in the colour settings should not be too many, otherwise there will appear reading difficulties (NHS Estates, 2005; Feisner, 2006); Focus on the three properties of colour (hue, intensity and value) to enrich colour composition and create contrast (Gibson, 2009); Use colour coding can convey information (Abu-Obeid, 1998; Calori et al., 2015); Colour can bring about different environmental perceptions, and when choosing colours it is necessary to consider whether different cultures will bring different interpretations of the meaning of colours (Park and Guerin, 2002; Hashim et al., 2014; Calori et al., 2015).
Typography and layout	Information design involves the layout of information (Harding, 2011). For emphasised information, bold, capital letters, and larger font sizes can be adopted (Bringhurst, 2002); Fonts with descriptive functions should be unified (Gibson, 2009); Wayfinding systems need to help users orient themselves (Canter, 1974; Passini, 1992; Kitchen, 1997; Güneş, 2018).

2.3. Map design theory

After an in-depth understanding of the literature related to wayfinding behaviour and wayfinding design principles, this research next focuses on the literature related to map design principles. This section analyses map design elements from the perspective of map visual elements and user experience, and studies digital map design principles.

2.3.1. Map design principles

In daily life, humans often walk around to carry out wayfinding activities. In a familiar environment, this is usually done unconsciously. However, in unknown or large complex environments, some wayfinding aids will often be used. The map is an important element in a wayfinding system, because maps can provide information to help people understand the overall layout and spatial location of entire buildings or environments (Pollett and Haskell, 1979). The International Cartographic Association (2003) defines the map as:

“A map is a symbolised image of geographical reality, representing selected features or characteristics, resulting from the creative effort of its author's execution of choices, and is designed for use when spatial relationships are of primary relevance”.

In the process of cartography, the choice of information needs to be considered first. The map presents the geographical reality in a visual expression. In this process, the map represents the geographical environment with visual effects which are far from the real environment, but can better describe and emphasise the information of the map. In the field of design, the visual effects and user experience of the map dominate the principles of map design.

2.3.1.1. Map visuals

Maps use visual effects to illustrate the relationship between geographic reality and space, thereby showing the location of certain reference objects in space (Papadias and Theodoridis, 1997). When dealing with spatial relationships, Cartwright (2014) argued that appropriate choice of information in the real environment and simplifying the geographical environment content can provide a more useful representation. This means that, although used to describe geographic reality, maps can represent real or fictional spaces, regardless of context or scale. Whether the map needs to represent the geographic environment may depend on the information it conveys, which has been suggested in many previous research studies. For example, Buisseret (1992) collected and discussed the evolution of maps across

early modern Europe and found that in some cases the aesthetic value of maps and numerical and verbal descriptions were more important than spatial representation (maps other than nautical charts); Cartwright (2014) provided an expert survey on whether the iconic London Underground image, which did not carry out geographical description, abandons the absolute position in the physical environment, and even the azimuth angle, could be regarded as a map - the conclusion was that people agreed that the image was an effective communication tool and that it was defined as a "map"; this kind of diagrammatic map that only focuses on necessary information was similarly reflected in Sadahiro et al. 's (2015) investigation of the design of bus route maps, focusing on the readability and aesthetics of the map rather than the "symbolised images of geographical reality"; Katarzyn's (2018) collection of maps enriched the map type database, and it was found that screen-based maps, non-interactive maps, and qualitative maps appeared most frequently. Even if the map depicts the same area, the map will present a completely different visual effect based on different purposes. This thesis uses multiple images to show different maps of the same area. They are Screenshot of Google Maps showing London city area (Figure 2.1), London Attractions Map (Figure 2.2) and London Underground Route Map (Figure 2.3). Maps of the same city present completely different visual effects due to the different information conveyed by the selected maps: a) Google Maps may focus more on navigation and positioning. Figure 2.1 selects its standard mode with simplified appearance: at the scale shown in the figure, the urban architectures are simplified as much as possible, highlighting the layout of the roads; b) the attractions map only arranges the landmark buildings in the city on the map with attractive illustrations (Figure 2.2), omitting most other elements of the city to help tourists understand the attractions' locations in the city; c) the London underground route map shown in Figure 2.3 completely abandons geographical reality (location in the physical environment, geographical description and actual line direction, etc.), and focuses more on the readability and aesthetics of complex underground route lines.

Figure 2.1. Screenshot of Google Maps London city area – simplified appearance in standard mode

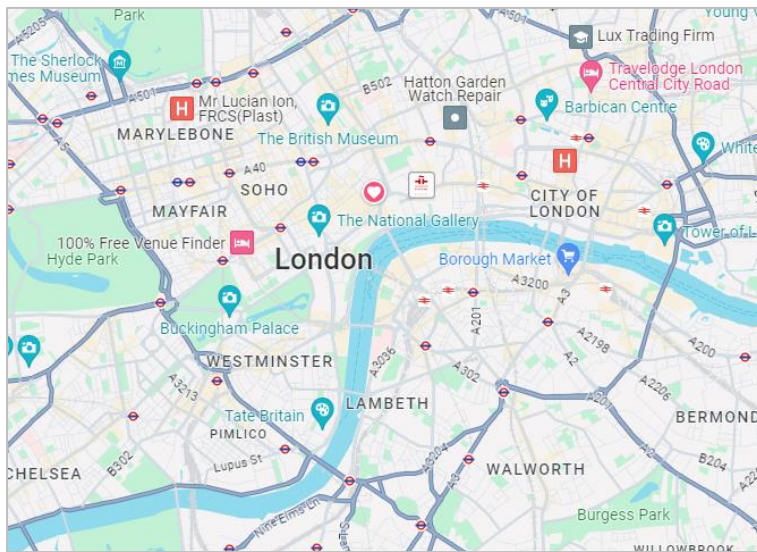
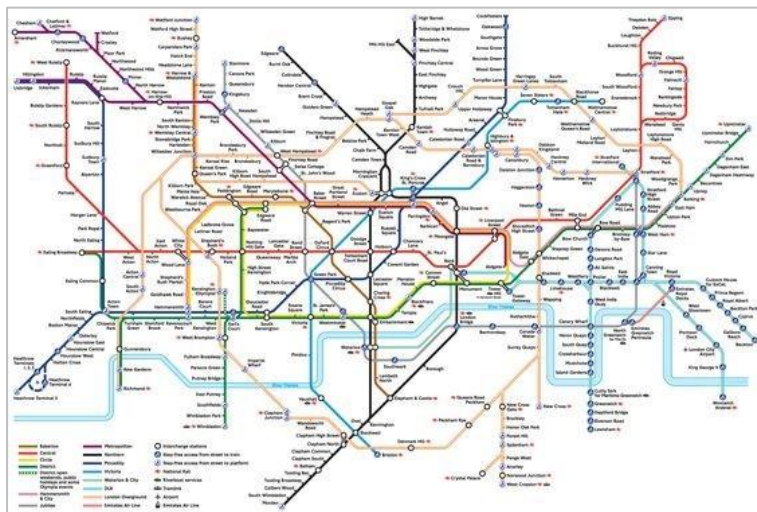


Figure 2.2. London attractions map



Figure 2.3. London underground route map



However, these three maps have the common feature that they successfully convey complex visual information, to a simplified version that prioritises the information required for the purpose of the map. The visual communication of a map requires the selection and simplification of visual elements according to purpose and communication method so that users can quickly and easily obtain the information they need. In addition, the aesthetics of the map need to be considered. Tyner (2014) summarises the key visual elements of the map as lines, shapes, colours, and textures. How to combine the purpose of a map with its visual elements is an important step in map design. The research object of this thesis is the campus digital map. Its purpose should be more to display the campus environment and assist users in finding their way and locating themselves. Take the three map forms of London urban area mentioned above as an example:

1. A map format similar to an underground route map displays a single piece of information (route arrangement), which is not suitable for the campus map;
2. The attractions map may be able to meet the purpose of the campus map by showing the main roads and also representing important buildings on the map. However, the campus environment is complex and there are many buildings. People's daily life and work are carried out in campus facilities, so it is difficult to choose which to represent on the map. If all campus buildings are represented on the map with attractive illustrations, the visual information may be complicated. This manifestation can be explored in the following chapters;
3. Maps similar to Google Maps Standard Mode reproduce and simplify the geographical environment, retaining passable roads while making the interface less difficult to read due to too much information. However, its simplification of architecture may make it difficult to contrast with the visual elements of the real environment.

After preliminary analysis, the design principles of map visual elements that are helpful for this research can be summarised as:

1. There is a need for appropriate selection of information in real-world settings and

simplification of geographical environment content (Cartwright, 2014);

2. The visual effect of a map is used to illustrate the relationship between geographical reality and space, requiring the use of visual elements to show the location of objects in space (Papadias and Theodoridis, 1997);
3. When simplifying complex visual information, prioritise information necessary for the purpose of the map;
4. Design by integrating the map's key visual elements (line, shape, colour, and texture) with the map's purpose (Tyner, 2014).

2.3.1.2. User experience in map design

When using a map, the user's geographic information is particularly important for the efficiency of the map. This means that users need to successfully locate themselves at any time when using the map. Raper (2007) described geographic information as information composed of location, space and time. It can be expressed using geocentric coordinates or positions and landmarks. In order to facilitate user positioning, map signages usually use familiar pictograms such as stars to emphasise visually concentrated information to inform people of "You Are Here" (Giuliani, 2001). The organisational elements of spatial information, including paths, landmarks and areas, should be displayed on the map (Apelt et al., 2007). The map collects these visual elements and displays them on a flat surface, and people can directly view these visual elements. This method needs to allow users to obtain environmental information in a flexible and direction-independent manner (Apelt et al., 2007). Even if interactive digital maps (such as Google Maps) can display the user's location in the geographical environment on digital maps at any time with the help of the Global Positioning System (GPS), we still need consider the situation when the map navigation fails (positioning errors, navigation offsets, etc.). Therefore, how the spatial information of maps helps people position themselves in space by reading visual elements is still a particularly important factor in map design.

2.3.2. Digital map design theory

Many maps are fixed on paper or other media such as wooden boards and silk cloth in a static form. With the development of technology, the emergence of digital maps allows maps to become dynamic and interactive (Kent and Vujakovic, 2018). What is the digital map? How is it different from traditional paper maps? Winter and Tomko (2004, p.7) defined mobile digital maps as “maps on mobile handheld devices”. Kent and Vujakovic (2018) believed that when talking about Internet maps, it is too broad to define it only as a digital map that relies on Internet technology and uses screens as communication media. Kent and Vujakovic (2018, p.376-380) explained and define Internet maps through their purposes and uses:

1. **Reference maps**, such as Google Maps. Their purpose is to provide directions and explore areas to users in conjunction with tracking technology;
2. **Location-based service maps**. They are used together with reference maps, focusing on target marketing: users can see the spatial location of the target group on the map (for example, when searching for "café" on Google Maps, there will be many storefronts that match the option marked in on the map);
3. **Thematic visualisations**. Users can convert information into different representations by clicking on the touch screen, in which case the map can use multiple theming styles;
4. **Exploratory geovisualisations**. This purpose is to analyse data and transform geography into useful visual information;
5. **Narrative maps**. Like naming, this format tells a story through a combination of maps, text, and images. With the addition of network technology, narrative maps are interactive and can tell stories in a hyper-textual, and graphic order;
6. **Wiki Maps**. This is certainly an often-overlooked category. But it assumes the capacity to add people's personalised data, histories, knowledge and visual artifacts to the landscape, which can be a repository of mental maps and shared histories;

7. **Persuasive and copy maps.** A simple example of a persuasive map is a map of U.S. presidential election approval ratings by state. The purpose of such maps is to disseminate information quickly and easily.

From the above discussion of the purpose-based definition of digital maps, it can be found that digital maps sometimes do not necessarily only serve one purpose (for example, Google Maps meets the purposes of both reference maps and location-based service maps). On the other hand, it can be found that digital maps and paper maps are sometimes similar. For example, paper maps are sometimes used to visualise geographical information, allowing users to determine directions and explore areas by region. Due to network technology and interactivity, digital maps often have more functions (such as touching the screen to zoom in and out of the map, quickly locating targets through the search function of the map, etc.). However, when its visual information design is discussed based on purpose and use, it should also refer to the design principles of paper maps for the same purpose.

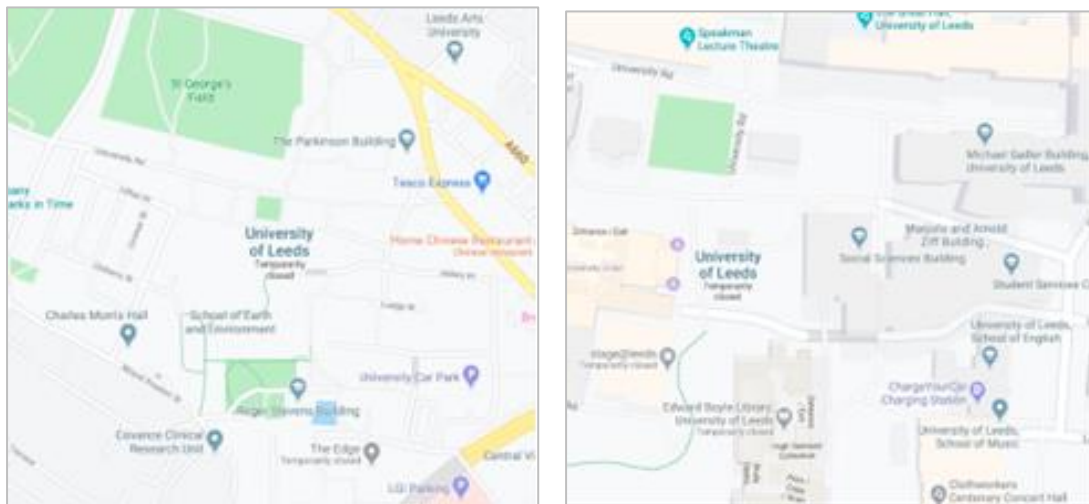
In Section 2.3.1.2, the importance of locating oneself when using maps has been mentioned. When locating, the self-centred view map has the best decision speed and navigation accuracy (Thomas, 2008). This is because people use the map from a self-centred perspective, which means that when using a map for navigation, we need to understand the space. For example, when we walk to a fork and need to turn, we need to align the map with the real environment (our direction). Interactive digital maps can do this automatically, displaying the live location of the user within the map which can make them easier to use. The navigator performs real-time navigation and reorientation during the wayfinding process. In this case, digital maps can be updated more easily to perform user-specific tasks than printed maps. However, the design of digital maps needs to consider some other factors such as scale, visualisation and generalisation, emotion and landmarks on the premise of satisfying the principles of map design.

2.3.2.1. Scale

When considering the medium of a mobile device, many limitations have been imposed on

the information design of digital maps. Nagi (2004), Dillemath (2005), Chittaro (2006), Van Tonder and Wesson (2009) all suggested that the screen size of smartphones or tablets constrains the design of mobile maps. However, digital maps can be ‘more personalised’ than paper maps due to screen size and interactive features (Davidson, 2014): the scale of digital maps is no longer fixed, and compared to paper maps, users can customise the information according to their own needs to operate digital maps. This can be reflected on the map scale. Users can freely choose the appropriate map scale (Figure 2.4) by zooming in/out, which can allow for greater personalisation of user needs. If the goal is to present the entire range of the environment to understand the entire wayfinding process, a smaller scale map can be displayed; if the goal is to present each node (intersection) in real time, a larger scale of the map can be displayed.

Figure 2.4. University of Leeds area at different scales on Google Maps



2.3.2.2. Visualisation of map

How to design the visual content of the map is essential, because the scale of the digital map is controllable, the visualisation of its geographic information needs to be considered. Reichenbacher (2004) listed the types of geographic information visualised on digital maps as: location and route, points of interest and regions, search results, events, and ranking of visual relevance or importance. Wang et al.'s (2018) research shows that maps should reduce the complexity of landmarks and views, and keep key nodes in key locations to

improve people's memory efficiency of the route. This is consistent with the principle of map design proposed by Apelt et al. (2007) where only important and memorable elements are used when choosing the displayed information. When the irrelevant details that would confuse the map are removed, the map information will be more clearly expressed. For example, underground route maps and railway traffic maps visually discard most of the geographic information and focus on the direction of the route, on the intersection and on the platform information. This is consistent with the fact that the visual effect in the design principles of maps is based on information transmission. As the scale of the map decreases, the level of detail of the information decreases (Töpfer and Pillewizer, 1966): a map of the national territory cannot depict the buildings and roads of the city on the map; while a map of the internal layout of the building can point out the role of each room and area in detail. For digital maps, building details can be omitted when viewing the context of an entire area, and the detail displayed on the map can be increased when the map scale is enlarged to view more detailed content.

2.3.2.3. Emotion and landmarks

Emotional changes occur when users read the map. When maps cannot effectively convey the information users need, causing reading difficulties, users can easily develop negative emotions such as anxiety and dissatisfaction (Wood, 1968; Winter and Tomko, 2004).

Conversely, map information may convey positive emotions. Rodriguez's (2019) study on tourist maps combined the visual presentation of maps with cultural content, improved the visual content of tourist maps from the aspects of emotional design theory, storytelling, and visual information design, and suggested that map content attracts user interaction. Norman (2005) suggested that users' emotional responses are affected by design and aesthetics, and that the attractiveness of a product can be evaluated and reflected through user emotions. When considering the function of a map, i.e. its purpose, aesthetics should also be considered, in order to convey a positive emotion while ensuring legibility of the map.

In the transmission of emotions by digital maps, some research shows that special

geographical information has a positive effect on the use of digital maps. Davidson (2014) indicated that having a recognisable landmark when using mobile maps has a positive impact on the successful use. As a special element in the environment, landmarks usually have certain visual characteristics. Their presence is usually unique and memorable and makes them easy to attract people's attention, contextualising a users position within the map space, and improving the clarity of the environment (Lynch, 1960). People's wayfinding behaviour is affected by the environment and there is evidence that people can obtain better spatial memory and performance in landmarked environments (Çubukçu and Nasar, 2005). Siegel and White (1975) studied how to describe important locations in the environment, and suggested that using landmarks in the description can lead to more efficient results. The research of Kim et al. (2011) also shows that people are not only concerned about the destination building itself, but also other landmark buildings when looking for a route. Osmann and Wiedenbauer (2004) used landmarks as reference points to connect the locations of other nodes in the environment in their research. Moreover, landmarks can be used as guidance of routes and directions (Raubal and Winter, 2002). In the research of campus digital maps, this gives us the possibility to consider displaying landmarks on campus on maps, or in the form of attraction maps discussed in Section 2.3.1.1. However, whether this form can meet the functional requirements of the map still needs to be verified in the following chapters.

2.4. Research of campus digital map design

In this section, the literature on campus wayfinding behaviour is reviewed. The problems and processes faced when finding the correct way on university campuses are discussed. In addition, the spatial relationship of the campus map is analysed, and the framework of the digital map design principles is preliminarily obtained.

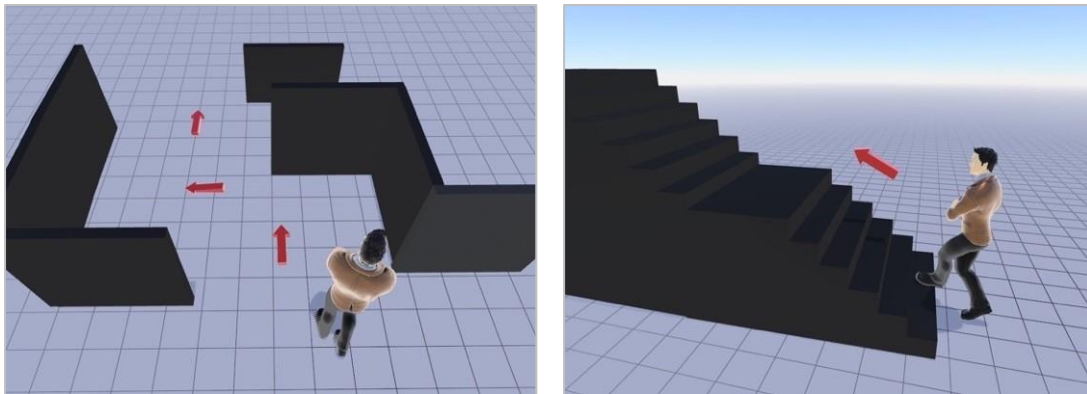
2.4.1. Wayfinding behaviour in academic environments

Existing literature and research on wayfinding in academic environments is very limited. Previous research on wayfinding systems includes research on indoor wayfinding in libraries, which uses unified signage to improve information resources and user experience (Barclay, 2012; Li and Klippel, 2012; Mandel, 2013). There are also some studies on wayfinding behaviour in academic settings. Research by Scott-Webber et al. (2000) explored the challenges encountered by student groups when finding their way around indoors; Bishop (2011) investigated the steps people might take when getting lost in an academic environment; Canakry et al. (2016)'s investigation showed the emotional changes produced by wayfinding in a campus environment when time is limited. Other research on applications of campus digital maps focuses more on usage and functions of maps, either than information design applications (Mantoro et al., 2009; Roth et al., 2009; Wu et al., 2016; Zhang et al., 2019; Basri et al., 2020). There is currently a lack of in-depth discussion on the information design and usage of campus digital maps. Before conducting the research of the usage of current campus digital maps, a review of research on wayfinding behaviour in the academic environment is the last necessary step, divided into the problems encountered in wayfinding and the wayfinding process in academic environments.

2.4.1.1. Wayfinding problems in academic environments

Finding the way in academic environments includes outdoor and indoor wayfinding. This makes it necessary to consider horizontal and vertical transportation in different areas (Figure 2.5). Horizontal transportation can be understood as moving in a flat environment, often on the same level, such as in a park; vertical transportation is moving between different levels, such as different floors of a complex building.

Figure 2.5. Horizontal transportation (Left) and Vertical transportation (Right)



Indoor and outdoor wayfinding technologies are different. Search engines such as Google and Microsoft Bing have developed wayfinding technologies to guide users to find their way outdoors, and use mobile phones to locate themselves. At the same time, Google Maps allows users to enlarge the map to display indoor maps of some buildings. However, indoor navigation seems to be restricted. Using a search engine as a framework to design a navigation system is a convenient method for outdoor wayfinding. The research by Arengi et al. (2018) uses Google Map as a basic framework to design a map navigation system for people with disabilities. However, they may not be used effectively indoors. In the user research of student groups, it can be found that they have encountered more difficulties and challenges in indoor navigation (Scott-Webber et al., 2000). This may be due to the function of the teaching building, where users are often required to go to different locations within the same complex building. When the wayfinding system is unusable, people typically go to the reception desk of the campus building to find a route to a specific building or classroom (Bishop, 2011). Usually, staff will provide verbal instructions to help them reach their destination. However, the widespread use of smartphones today provides opportunities to create dynamic, interactive digital campus maps. This is in agreement with Roth et al. (2009) that the campus map can become an interactive online tool to facilitate the acquisition of spatial information.

Disorientation during wayfinding can cause negative emotions such as anxiety and dissatisfaction (Passini, 1992; Yoo, 1992; Darken and Peterson, 2002). In addition, being

asked to complete a wayfinding task within a limited time may also cause stress and anxiety, which can affect perception and cognitive ability (Xie et al., 2012). Both first-year university students and experienced students feel stressed when they try to attend classes on time but cannot find the right location (Kanakri et al., 2016), which adds to the burden of performing a wayfinding task and getting lost. However, as explained in Section 2.2.2.2, the individual's familiarity with the destination clearly affects the wayfinding behaviour and efficiency and therefore this needs to be considered in this research. Moreover, the familiarity with the target location and environment is positively correlated with the frequency with which people use wayfinding assistance (Garling and Evans, 1992). Therefore, the relationship between wayfinding experience and personal wayfinding behaviour in a university environment is of importance in this research.

2.4.1.2. Wayfinding task process in academic environments

When discussing wayfinding behaviour in an academic environment, it is necessary to clarify what tasks people need to complete when finding the way in this setting. Based on the purpose of human wayfinding, Allen (1999) divided wayfinding tasks into three categories:

1. Travel between two known places along a familiar route;
2. Travel to explore the surrounding environment of a familiar area;
3. Travel from a familiar place of origin to an unfamiliar destination.

Traveling between known starting and ending points is very common. Commuting between residence and work locations is a common example of daily life in an academic environment. Exploratory wayfinding often happens inadvertently, with the purpose of learning the surrounding environment. In an academic environment, a complex space allows users to perform exploratory wayfinding, such as exploring the environment around a classroom. In addition, Kanakri et al. (2016) indicated that major users (students, teachers and staff) in universities are often required to go to unfamiliar places. This type of wayfinding makes them more dependent on the help of wayfinding systems. There are no clear boundaries between these three types of wayfinding tasks, as people in the academic environment are

likely to perform all these different wayfinding tasks according to their needs. Table 2.2 shows the different wayfinding tasks in an academic environment and the problems encountered.

Table 2.2. Wayfinding tasks in academic environment.

Wayfinding task	Purpose	Wayfinding purpose examples in academic environments	Problems when finding the way in academic environments
Commute	Travel from familiar place to familiar place.	• Go to regular classroom from home; • Go to the office from home; • Go to restaurant from classroom.	• Need reach the destination on time (Xie et al., 2012; Kanakri er al., 2016); • The destination address is updated or different from the address in memory (Agarwal and Lawrence, 2014);
Explore	Learn the environment around a known starting point.	• Walk around the teaching building; • View the layout of the library.	• Difficult to find the specific building and specific room number through the same wayfinding system (i.e. map, signage) (Chao, 2016);
Quest	Travel from a familiar place of origin to a strange destination.	• Go to a strange place for a meeting; • Change of class location; • Find a book in the library.	• Need to travel to different locations within the same complex building (Scott-Webber. 2000; Bishop, 2011).

As the wayfinding tasks in academic environments can be divided into three categories, what strategies to follow when completing these tasks need to be discussed. Passini (1981) referred to wayfinding as the sum of multiple tasks. The success of each wayfinding task depends on the success of the previous task. All paths from the beginning to the end of the wayfinding strategy can form a tree diagram. All nodes connected to the starting point through paths are combined into the first level, and subsequent nodes extending from the node are the second level. Similarly, third and fourth levels can be obtained. The wayfinding strategy at the same level can be called 'breadth search', and the wayfinding strategy at different levels until there are no extended nodes is called 'depth search'. Among them, depth search is suitable for commute and quest tasks. Breadth search applies to explore task. The farther the destination, the more effective the depth-first search strategy; on the contrary, the closer the destination, the more effective the breadth-first search strategy.

From the discussion of map scales in Section 2.3.2.1, it can be concluded that different scales should show different levels of detail. Considering the applicable conditions of the two searches, the information of the nodes on the map needs to be considered in order to avoid obstacles to information acquisition.

As part of the digital university, campus digital maps can be designed to help users complete daily wayfinding tasks. One of campus digital maps' important functions is to show the various locations in a university. At the same time, campus digital maps are different from general navigational digital maps (such as Google Maps). Because a campus digital map is specially designed for the campus, it can add more functions based on the needs of university users. In the visual survey, the function of the campus digital map will be analysed in detail.

2.4.2. The spatial relationship of the map

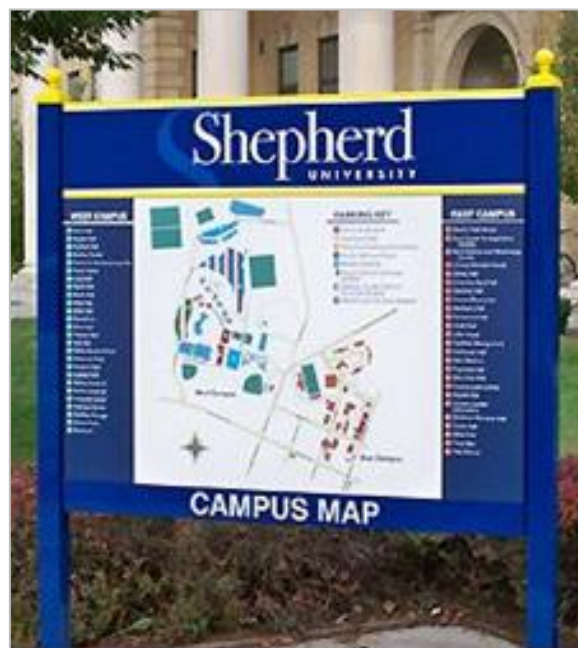
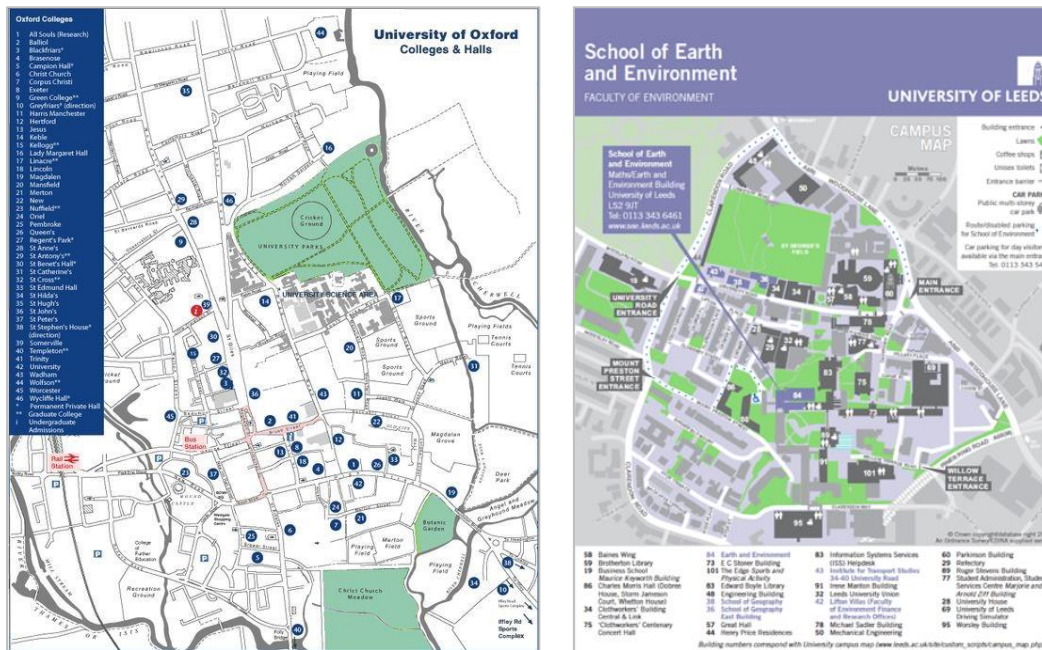
The spatial relationship and information structure of the map are important components of map information. Cao et al. (2008) believe that, in addition to paths and intersections, the spatial relationship of campus maps also needs to represent the relationship between the direction of spatial objects and the direction and order of buildings. This may be because people need to understand the real environment through virtual objects on the map. There are a large number of buildings on the campus and users' commuting needs require them to know the distribution and orientation of the buildings. This means that the spatial relationship of map information needs to be divided according to user needs to help them find relevant information more effectively when performing wayfinding tasks.

2.4.3. Text and layout

Apelt et al. (2007) mentioned in the design principles of the map that the text and layout of the map should be proportionate and neat, avoiding the use of letter and number codes.

However, due to complex and diverse buildings and different names, many universities often use digital codes to represent buildings on signage maps and printed maps (Figure 2.6). At the same time, buildings are distributed in the environment, which is difficult to guide to a certain extent, and cannot provide enough information for people to find the next sign or map (Apelt et al., 2007).

Figure 2.6. University printed and signage maps (Oxford, Leeds, Manchester and Shepherd)



Interactive digital maps have the potential to include more detail in visual expression and level of information than printed maps and signage maps. When testing interactive maps, Slocum et al. (2004) found that students and teachers can easily overcome technical obstacles because they use computers and smartphones every day. Kim (2011) studied how visitors interact with the university's existing campus signage and digital maps and acknowledged that digital maps can be more personalised and enhance the map's appeal by displaying and interacting with information of buildings and landmarks. Chao (2016) also completed research focusing on campus interactive maps. Unlike railway traffic maps, campus maps are characterised by their block characteristics (space occupancy of campus buildings) and user purposes (reaching different campus buildings and rooms). In an academic environment, the correlation between nodes and areas is stronger: student dormitories may be in the same area; teaching buildings and administrative units of different schools can be divided into different areas; connected building groups may have similar functions (teaching or laboratory? living residence or activity facility?) can also be integrated into unified areas. More consideration should be given to the relationship between shapes, paths, and spaces in the display of map information.

In addition, Chao's (2016) research indicates that when using an interactive campus map, people's search examples include many building names and room numbers, which is consistent with the findings of Scott-Webber et al. (2000) and Bishop (2011). Such searches may be the result of users copying and pasting from course catalogues, and users of university campus wayfinding systems are often required to enter unfamiliar rooms. However, building plans with room numbers are usually not displayed on the navigational digital map, and finding a specific room depends more on the guidance of the wayfinding system inside the building. In addition, frequently changed office numbers and names make the information on the network sometimes obsolete and cannot provide complete information about the location (Agarwal and Lawrence, 2014). The campus digital map provides an opportunity to present the internal layout of the building on the map to assist in wayfinding. At the same time, the campus digital map that belongs to the university has an advantage in updating network information. The map information can be changed according

to the changes of facilities and personnel for the convenience of users.

2.4.4. Summary

This chapter analyses the campus digital map design theory. The existing literature has been organised and divided into the following sections: wayfinding behaviour in academic settings, spatial relationships in maps, and text and layout. Due to the lack of research on wayfinding in academic environments, this summary is combined with the review on digital map theory in Section 2.3 to discuss the design principles of digital maps and their application to campus digital maps:

SECTION 2.3

The first part analyses the different visual effects of maps and draws on user experience the importance of successful orientation for users when using maps.

The second part analyses the advantages of digital maps from the aspects of scale, visualisation, emotion, landmarks, etc., and sorts out the design principles of digital maps.

SECTION 2.4

In **the third part**, the researcher discusses the problems people encounter when finding their way in the academic environment, analyses and evaluates the wayfinding in indoor and outdoor environments, and concludes the feasibility of campus digital map research.

The fourth part elaborates on the information needs of campus digital maps and analyses the advantages of using digital maps on campus.

As a conclusion, a framework of design principles applicable to campus digital maps (Table 2.3) is developed for reference in subsequent research.

Table 2.3. Framework of digital map design principles.

Map information	Design principles
Spatial information	The organisational elements of spatial information, including paths, landmarks and areas, should be displayed on the map (Apelt et al., 2007); The spatial relationship of the campus map needs to represent the relationship between the direction of space objects and the direction and order of buildings (Cao et al., 2008); When using digital maps for positioning, a self-centred view should be taken (Thomas, 2008); Digital maps can display information about buildings and landmarks and interact with them to enhance the attractiveness of the map (Kim, 2011); The complexity of landmarks and views should be reduced, and key nodes should be kept in key positions (Wang et al., 2018); Using recognisable landmarks on digital maps (Siegel and White, 1975; Çubukçu and Nasar, 2005; Davidson, 2014).
Text and layout	Use only important and memorable elements when choosing the information displayed (Apelt et al., 2007, p.4); The text and layout of the map should be proportional and neat, and avoid using letter codes and number codes. (Apelt et al., 2007); The display of map information should consider more the relationship between shapes, paths, and spaces; Campus digital maps have advantages in updating network information, and the information can be updated according to changes in facilities and personnel.
Scale	Users should be allowed to freely choose the appropriate map scale (Davidson, 2014); As the scale of the map shrinks, the level of detail of the information should decrease (Töpferand and Pilewizer, 1966).

2.5. Discussion

This chapter analyses human wayfinding behaviours and map design. The existing literature has been organised and divided into the following three parts:

1. **Wayfinding design theory.** Includes a discussion of human wayfinding behaviour, user-centred wayfinding design considerations, and research and design principles related to information structure in wayfinding system design.
2. **Map design theory.** Includes discussion of map design principles and related

theoretical research on digital map design.

3. **Campus digital map design theory.** Includes a review of research on wayfinding behaviour in academic settings, spatial relationships in maps, and text and layout.

In reviewing these three parts, this research follows an in-depth sequential approach.

First, the entire background related to the research needs to be understood: What research references and opportunities can related research on humans' use of wayfinding systems and their wayfinding behaviours bring to this research? As a conclusion, this thesis conducts an understanding of the user's wayfinding process and decision-making, the construction of cognitive maps, and how environmental familiarity affects user wayfinding, which all provide support for the three experimental contents and participant recruitment conditions of this research. The research of the information structure of the wayfinding system divided the information into signage, image, colour, typography and layout, and finally sorted out a framework of wayfinding design principles suitable for this research, providing a reference for the final design principles of campus digital maps.

Second, a more in-depth review: How does a map work as a wayfinding system? How can research into map design and digital map development support this thesis? In this session, map design principles are discussed, including the visual elements and user experience of maps, and then a detailed understanding of the development, functional and aesthetic requirements from the uses, scale changes, visualisation, emotions and landmarks of digital maps.

Finally, as the understanding of existing wayfinding design and map design knowledge deepens, this research focuses on relevant research and cases in the field to which the thesis belongs. Research on wayfinding behaviour in academic environments is reviewed and provides an initial understanding of the difficulties people tend to encounter when finding their way in academic settings (they are indicated and expanded on in subsequent experiments). Focusing on wayfinding behaviour in a specific environment requires understanding people's purpose of wayfinding. This research combines the concept of

wayfinding tasks to map people's wayfinding behaviour in an academic environment to tasks one-to-one, and thus guides the task content design of subsequent *Experiment II* and *Experiment III*. After then reviewing the relevant research on the spatial relationship, text and layout of campus maps, combined with the review of the design principles of digital maps, as a summary, a framework of digital map design principles is sorted out, which also provides theoretical support and reference for campus digital map design principles.

3. Existing deficiencies of current campus digital maps

After reviewing existing research on wayfinding behaviour and map design principles, this chapter examines the legibility of existing campus digital maps. The research in this chapter is carried out in three parts. First of all, academic institutions in the UK were considered, and their use of their campus digital maps explored, in order to have a preliminary understanding of the existence of independently designed campus digital maps. Next, five representative campus digital maps were selected, and their design styles and limitations were analysed according to the map design principles summarised in Chapter 2. The research results help to refine the design principles of campus digital maps in the early stage. On a deeper level, through questionnaire investigation, the limitations of digital map information (e.g. when people get lost on campus) and the user experience were explored, to provide effective suggestions for the next user test.

3.1. Introduction

In Chapter 2, the necessity of an independently designed digital map in the complex environment of the university has been found. University users live, study and work on campus, and a well-designed campus digital map plays a significant role in improving people's wayfinding efficiency.

The purpose of the research is to evaluate the design quality of existing UK campus digital maps based on wayfinding information design principles and digital map design theory, and to find out their design limitations in terms of visualisation and function. In addition, the aim of the research conducts user needs, explores the use of digital maps by university users and their evaluation of campus digital maps, and then proposes more effective design directions. The three main research objectives are as follows:

1. To find out how existing digital campus maps exist and how they are used;
2. To evaluate the legibility of existing maps in terms of visual design and functionality, and identify limitations that affect user efficiency;

3. To understand user's behaviour and performance when looking for information/ places on campus, and investigate people's understanding and use of campus digital maps.

Guided by the research objectives, the research proposes the following research questions:

1. Do UK academic institutions value independently designed digital maps of their campuses?
2. What design limitations can be identified from the visual design of the map based on the principles of wayfinding design and digital map design?
3. How are people using campus digital maps and where do people tend to get lost in university environment?

To achieve the objectives and answer the research questions, visual surveys and an online questionnaire investigation are carried out in this chapter. More details about why questionnaire is chosen as the research method of this research will be introduced in detail in this chapter.

3.2. Study I: Survey on the usage of digital maps in UK universities

In this research, the current usage of campus digital maps in universities is considered. In order to investigate how current universities in UK use digital map on campus, universities in the UK were listed through the UK government website (<https://www.gov.uk/check-university-award-degree>).

3.2.1. Sample selection criteria

265 universities and colleges were listed at the beginning. All the institutions on the list are recognised bodies with university status, but some of them were removed because they conflicted with the research analysis direction, or did not meet the analysis requirements.

The reasons for removing them from the lists are as follows:

1. Institutions do not have a complex outdoor environment (Abertay University, Blackburn College, British College of Osteopathic Medicine, and Cardiff Metropolitan University, etc.);
2. Institutions have mobile applications with maps, but do not allow visitors without a university account to use them, which makes it difficult to ascertain whether the map is an own designed campus digital map (Aberystwyth University, University College Birmingham, Bishop Grosseteste University, University of Bristol, University of Lincoln, etc.);
3. Institutions have more than one location in different cities (University of Central Lancashire, East Riding College, University of the Highlands and Islands, etc.).

After selection, the list finally included 75 institutions which have complex outdoor environment (schools, buildings, facilities, etc.) and allow visitors to use their mobile applications.

The list records the use of digital maps by the selected institutions from four aspects:

1. Whether the official website of the institution has an interactive campus digital map;
2. Whether the institution provides its own mobile application;
3. Whether the mobile application provides an interactive self-designed campus digital map;
4. Whether the mobile application has a digital map that is not self-designed, such as Google Maps.

Appendix I shows the list of final chosen institutions. Whether they meet the above aspects is presented in the form of a heat map in *Appendix I*. In addition, *Appendix II* lists the campus digital maps published online by these academic institutions as evidence.

3.2.2. Analysis and conclusion

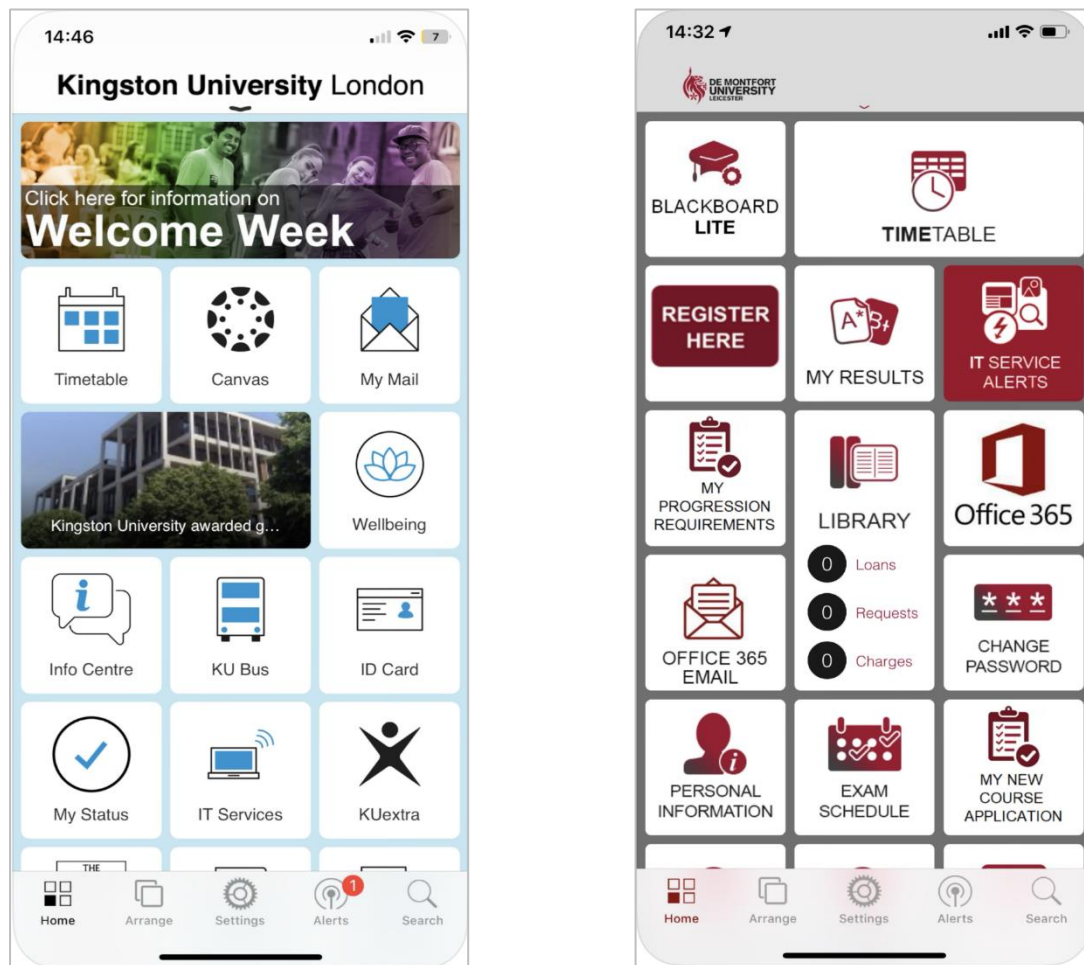
As shown in Table 3.1, the results show that among the 75 institutions, a total of 29 have interactive campus digital maps on their official websites; 57 have downloadable mobile applications. Among them, 20 have both, accounting for 26.7% of the total. Ten institutions only provide downloadable paper campus maps, or do not provide campus maps. Among those institutions with mobile applications, 86% provide digital maps, of which 24.5% are self-designed campus digital maps. However, in the choice of wayfinding system, 75.5% of institutions only provide links to external digital maps (such as Google Maps). Among these institutions, 12 institutions can find interactive campus digital maps on their mobile applications, accounting for 30% of the number of mobile applications linked to external digital maps. 26 institutions do not have their own interactive campus digital maps. Heat map of the choices can be viewed in *Appendix I*.

Table 3.1. British academic institutions' usage of campus digital maps

Institutions' provision	Interactive campus digital map	University's mobile application	Own mobile digital map	Not own mobile designed map
Provide	29	57	12	37
	20			0
Not provide	10			26

From the perspective of the convenience of digital maps, mobile phone users can access and use digital maps to find their way more conveniently than desktop computer users because they can use digital maps in real time outdoors. Among the 57 institutions that provided mobile applications, the applications often have functions that facilitate the daily work and life of campus users, such as class schedules, library rental systems, computer room usage, and campus notifications (Figure 3.1). Providing the wayfinding function in the mobile phone application will make it more convenient for users to understand and use the university environment.

Figure 3.1. Main page of Kingston University's mobile application (Left) and De Montfort University's mobile application (Right)



External digital maps are heavily used as a tool in academic institutions' wayfinding systems. However, its use efficiency in the campus environment cannot meet users' expectations; when institutions link wayfinding systems with external common maps, the usability of digital maps of their campuses is greatly reduced. In addition, when the institution only uses the web window of the official website as the primary medium to provide the campus digital map, its usability is reduced. However, using an external digital map on the wayfinding system of a mobile phone application cannot help users to find their way in a campus environment efficiently and conveniently. An interactive campus digital map that conforms to the campus environment is more suitable for a specific institution, and can give users a better experience in terms of information detail and update timeliness. Therefore, the next

step of the research will focus on the detailed study of the visual elements and information design of existing campus digital maps to explore the limitations in terms of legibility and efficiency.

3.3. Study II: Visual survey of campus digital maps

After collation and preliminary analysis of the use of existing digital maps of British universities and colleges, this research selects campus digital maps of several universities as case studies for visual survey. Evaluation of them help the researcher better understand the information distribution of the campus digital maps, and obtain examples of good practice, as well as less successful cases that have limitations, providing a research basis for subsequent research.

3.3.1. Sample selection criteria

For visual survey, 5 British universities with campus digital maps are selected for analysis with focus on the information and functions conveyed by digital maps. These universities are: University of Leeds, University of Manchester, University of Sheffield, University of Oxford, University of Cambridge. The reason for choosing these universities is because they are the most comparable: their geographical environment has certain similarities, they are all located in the city, and all have complex campus environments. Their campus area has a boundary with the urban area, and the campus buildings are concentrated in a special area.

Chapter 2 has studied that digital maps can be used on mobile phones, tablets, laptops and other devices. As the most portable and simple mobile interactive device, mobile phones are first considered as the display device for digital maps. However, the development of campus digital maps based on mobile applications is very limited. Only the University of Leeds and the University of Sheffield have mobile applications that visits are allowed to use. However, their functions are very limited, and the wayfinding function needs to be completed with the help of Google Maps. Therefore, the visual survey samples selected are the desktop format

of the maps. They can be accessed using a laptop or tablet.

3.3.2. Procedure

The following features of the digital map are analysed: the overview of the map, the operation mode of the interactive interface, and the available map functions. Digital maps of the universities are compared and analysed to identify good and bad practice. Finally, a list of guidelines is created on the basis of this campus digital map analysis.

3.3.3. Results of the visual survey

After entering the original interactive campus map, the entire area of the campus is displayed to the user and provides available map functions.

3.3.3.1. Map visual elements

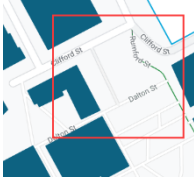
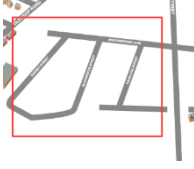
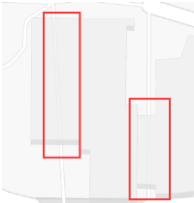
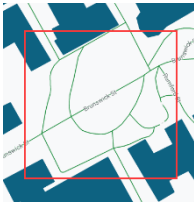
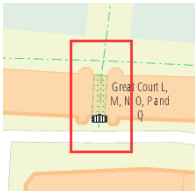
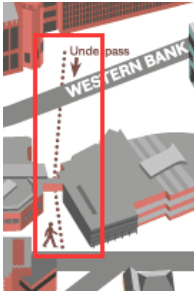
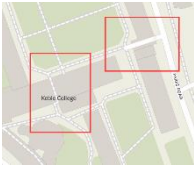
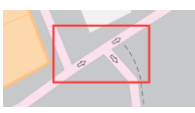
In the original interface, all five universities have information of the real environment but use distorted geography (Cartwright, 2014). They also have a certain similarity in the visual expression of information and show different effects in certain aspects. According to Tyner's (2014) requirements for key visual elements of the map, the same can be drawn in lines, shapes and colours. Tyner's (2014) principles were used to analyse the maps (as shown in Table 3.2), and these include:

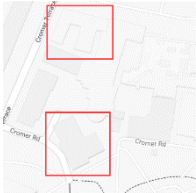
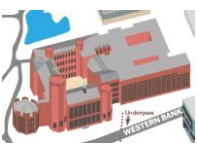
LINES: use lines to represent roads;

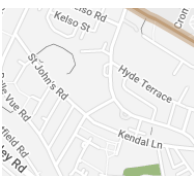
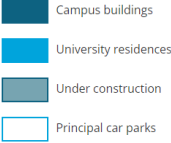
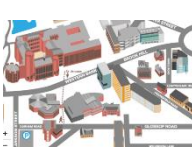
SHAPES: use different shapes to represent the landscape with volume in the real environment (such as buildings/lawns/rivers and lakes);

COLOURS: Use colours similar to the actual environment to represent lawns and rivers.

Table 3.2. Key visual elements performance of campus digital maps

	University of Leeds	University of Manchester	University of Oxford	University of Cambridge	University of Sheffield
Lines					
	Road thickness corresponds to the width of the road in the real environment;	Road thickness corresponds to the width of the road in the real environment;	Road thickness corresponds to the width of the road in the real environment;	Road thickness corresponds to the width of the road in the real environment;	Roads use the same width;
					
	Paths through the buildings are represented by transparency changes;	Use thinner lines to represent pedestrian areas;	Roads use different representations (colour, thickness, dotted & solid lines) depending on the functions;	Paths through the buildings are represented by dashed lines;	Use dotted lines to indicate underpass.
					
	Use thinner lines & dotted lines to represent pedestrian areas;	One-way street assists with narrow roads to guide the directions.	Paths through the buildings are represented directly.	One-way street assists with narrow roads to guide the directions;	
					
	The campus area is separated from the city.			Different blocks are circled;	

	University of Leeds	University of Manchester	University of Oxford	University of Cambridge	University of Sheffield
Lines				 Roads of different representations (colour, thickness, dotted & solid lines) depending on the functions.	
Shapes	 Use geometric images to represent building appearance;	 Use geometric images to represent building appearance;	 Use geometric images to represent building appearance;	 Use geometric images to represent building appearance;	 Architectural shapes are represented in three-dimensional drawings.
	 Connected building groups are represented individually.	 Connected building groups are represented by a single shape.	 Connected building groups are represented individually.	 Connected building groups are represented individually.	

	University of Leeds	University of Manchester	University of Oxford	University of Cambridge	University of Sheffield
Colours	 Buildings use low saturation colours like background so that the buildings are not prominent on the map;  Buildings use two colours to distinguish connected buildings;  Use low-saturated grey as the background colour;  Green (lawn), white (road) and orange (lines dividing the campus area).	 Buildings use different colours according to their functions;  Campus buildings use colours that contrast with the background to make them stand out from the environment, and only campus buildings appear on the map;  Use low-saturated grey as the background colour.	 Use low-saturated green as the background colour;  Most of the buildings are in light gray; a small number of buildings are represented in dark gray/low saturated blue.	 Use low-saturated grey as the background colour;  Use different colours to distinguish colleges areas;  Use many hues to enrich the map colours.	 Use white as the background colour;  Buildings use different colours to enrich the map colours.

In the campus area, the digital maps of these universities have taken measures to distinguish the campus environment from the urban area. When entering the original interface of the digital map, users can quickly find the campus area. At the same time, when entering the original interface, the map places the campus area in the centre of the interface. In terms of scale selection, the original interface of the digital maps of the University of Leeds (Figure 3.2), the University of Manchester (Figure 3.3) and the University of Sheffield (Figure 3.6) shows the entire campus, while University of Oxford (Figure 3.4) and University of Cambridge (Figure 3.5) show the local area of the campus. Displaying the entire campus area allows the user to quickly identify the campus coverage area in the city, while the local area prevents the user from confirming the location to a certain extent.

Figure 3.2. University of Leeds digital map starting page

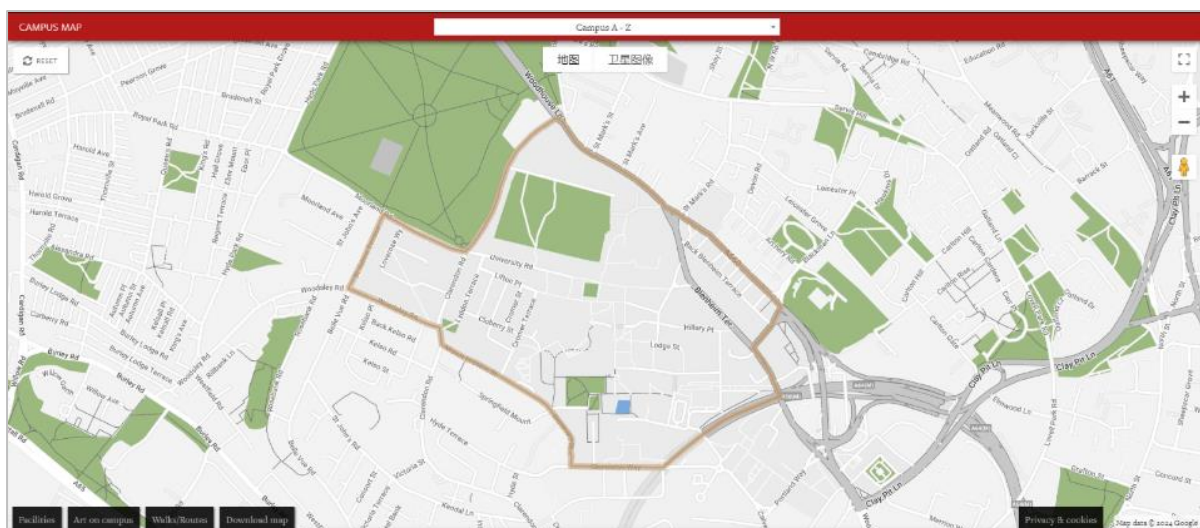


Figure 3.3. University of Manchester digital map starting page

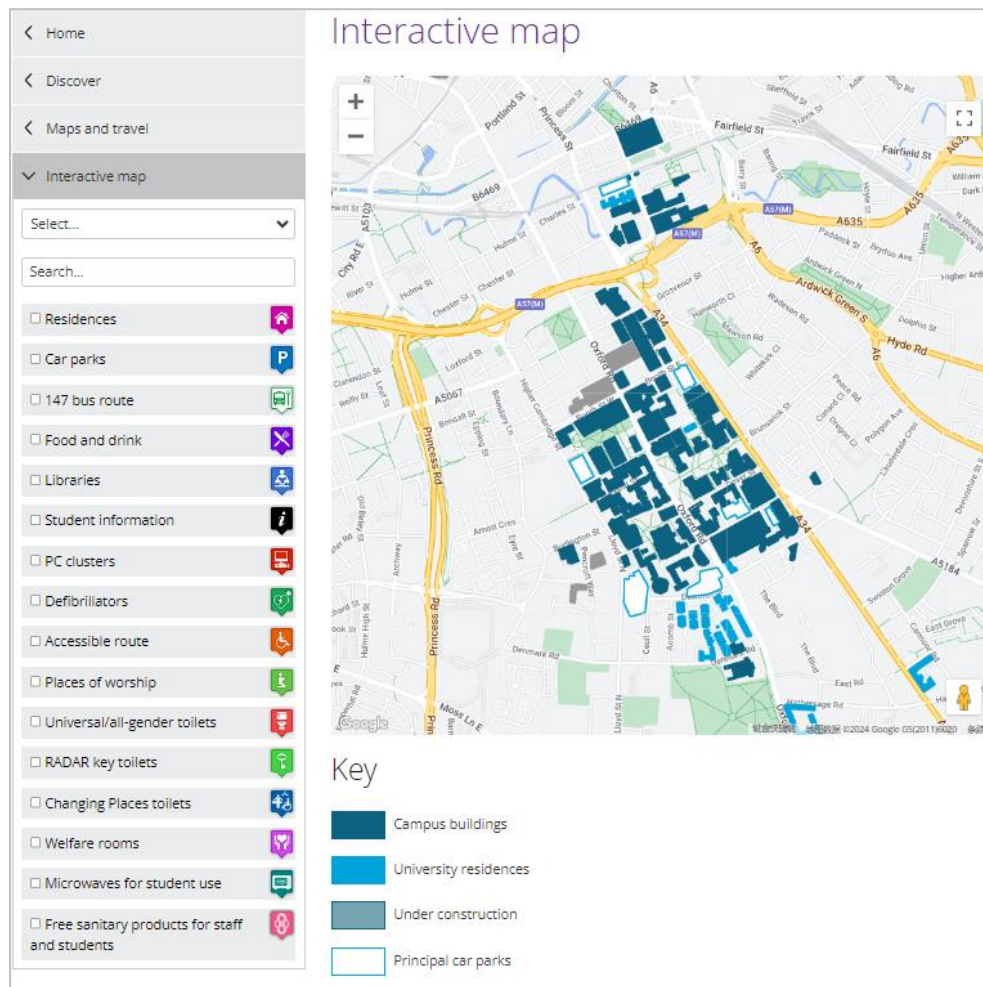


Figure 3.4. University of Oxford digital map starting page

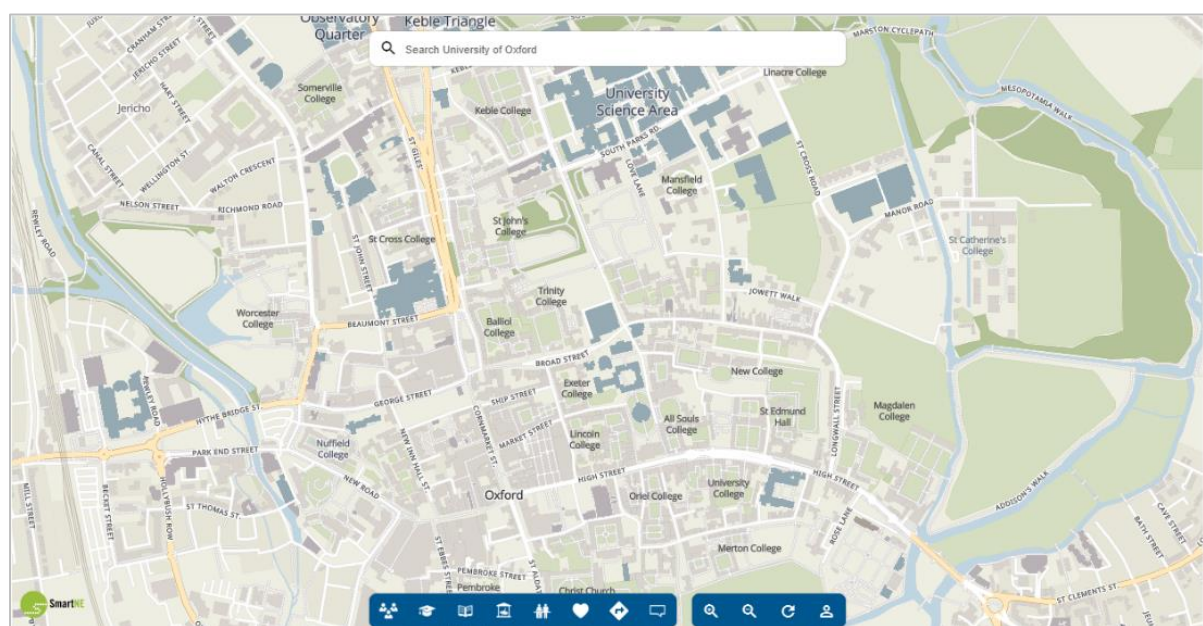


Figure 3.5. University of Cambridge digital map starting page

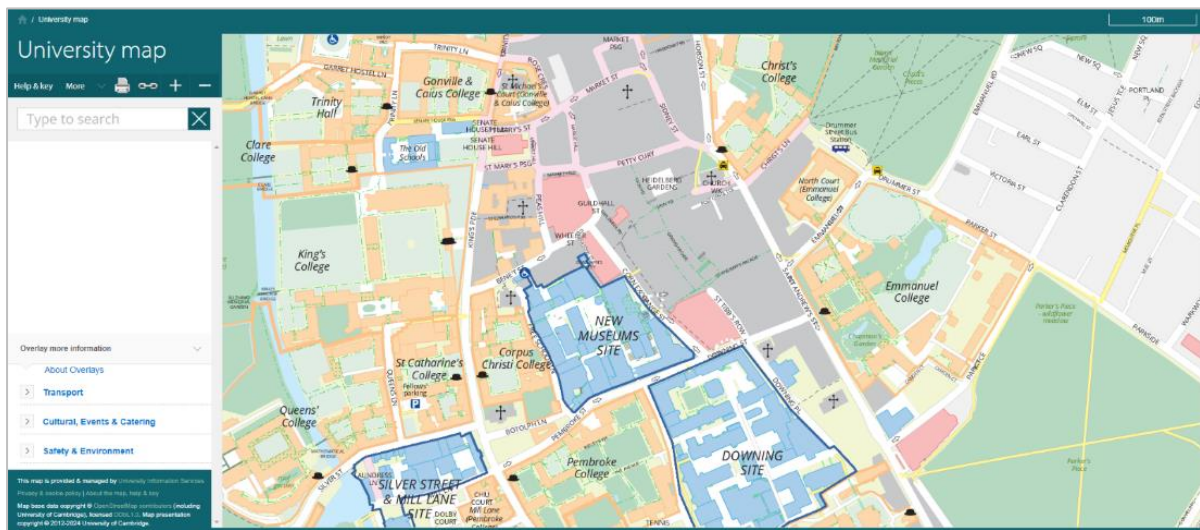


Figure 3.6. University of Sheffield digital map starting page



Regarding the choice of information, except for the University of Leeds, the remaining selected cases use shapes and colours to make the buildings in the university stand out in the environment. The digital map of the University of Leeds has the cleanest visual effect in the selected cases, with only roads included in the map information (Figure 3.2). However, this makes it difficult to identify the campus areas because building and facility information cannot be obtained from the map. The campus digital map of the University of Sheffield

separates the campus area and does not display any information outside the campus environment (Figure 3.6). While eliminating all the extra information, this map separates the campus area and ignores the surrounding environment. When a user interacts with this map to find a way, access to the campus environment from the external environment cannot be obtained. As for the University of Oxford, it uses text to indicate the campus area (Figure 3.4). Compared with other cases, the users cannot quickly identify the edge of the campus area using this map. On the original interface, the map of University of Cambridge shows the most amount of information where text is used to indicate the various areas of the campus (Figure 3.5). While allowing users to obtain more information, the original interface of this map is the most complex and has low legibility, which may impair recognition and cause negative emotions for users.

After the visual survey, the following representations of key visual elements of the map can be derived:

LINES:

1. Use lines to represent roads;
2. Change the thickness of lines to indicate the width of roads;
3. Change the form of lines (dotted/solid lines, transparency) to represent different functions (sidewalks, driveways, paths through buildings, underpass, etc.);
4. Arrows can be added to lines representing lanes to indicate the direction of a one-way street;
5. Use lines to frame campus areas to make the campus environment independent of the city.

SHAPES:

1. Use different shapes to represent the landscape with volume in the real environment (such as buildings/lawns/rivers and lakes);
2. Connected building groups should be represented separately.

COLOURS:

1. Use colours similar to the actual environment to represent lawns and rivers (green and blue);
2. When the background colour and the colour of the visual elements are similar, it may be difficult to read the information (*University of Leeds*);
3. Use different coloured lines can represent different road functions (*University of Cambridge*);
4. Buildings can use different colours to increase the colour diversity of the map and the distinction between building groups:
 - a. Two-hues differentiation (*University of Leeds*). Use minimal colours so that connected buildings are not difficult to distinguish;
 - b. Colour sequence changes (*University of Manchester, University of Oxford*). The visual elements in the map have more than one hue, and the brightness and saturation change in sequence, so that the colours of different information change without causing reading difficulties due to too many colours;
 - c. Hue changes (*University of Cambridge*). Use different hues to add colour richness and show differentiate areas in the environment.

3.3.3.2. Interaction and operation

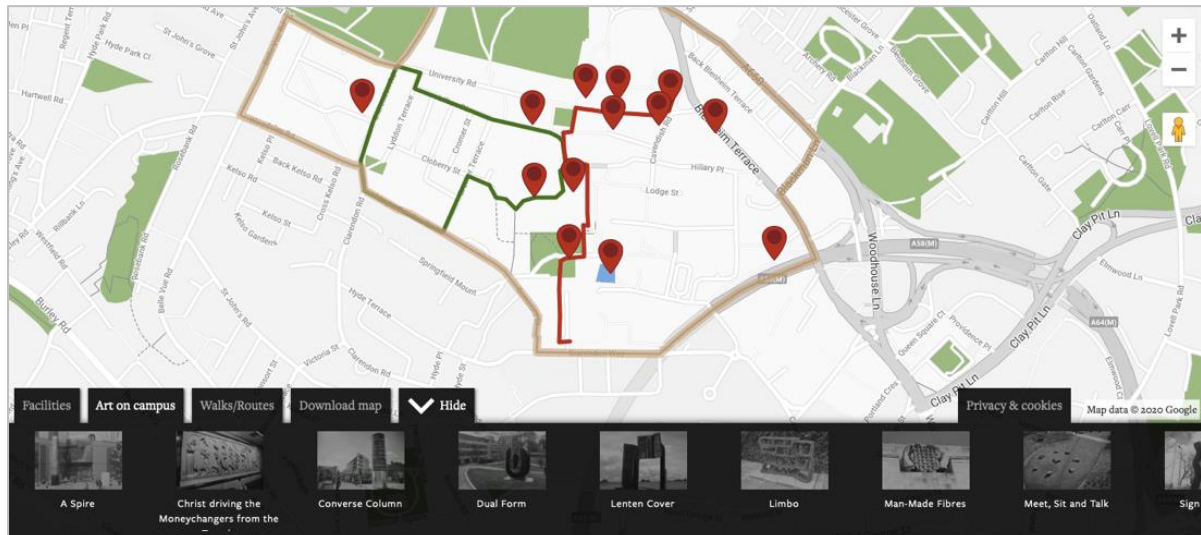
While displaying the entire campus, all selected cases provide access to other information on the map. Firstly, all 5 cases have a search field that allows users to search for building names, departments, and areas of interest. Secondly, all of them have expandable menus display popular sites such as facilities and buildings on campus. The visual survey of this part is based on the framework of map principles summarised in the previous content (as shown in Table 2.3, in Chapter 2). The five samples are analysed separately below.

UNIVERSITY OF LEEDS

l) Spatial information: Since the map at any scale only provides road information, when the user wants to know the information of a certain facility, for example, a building name, it

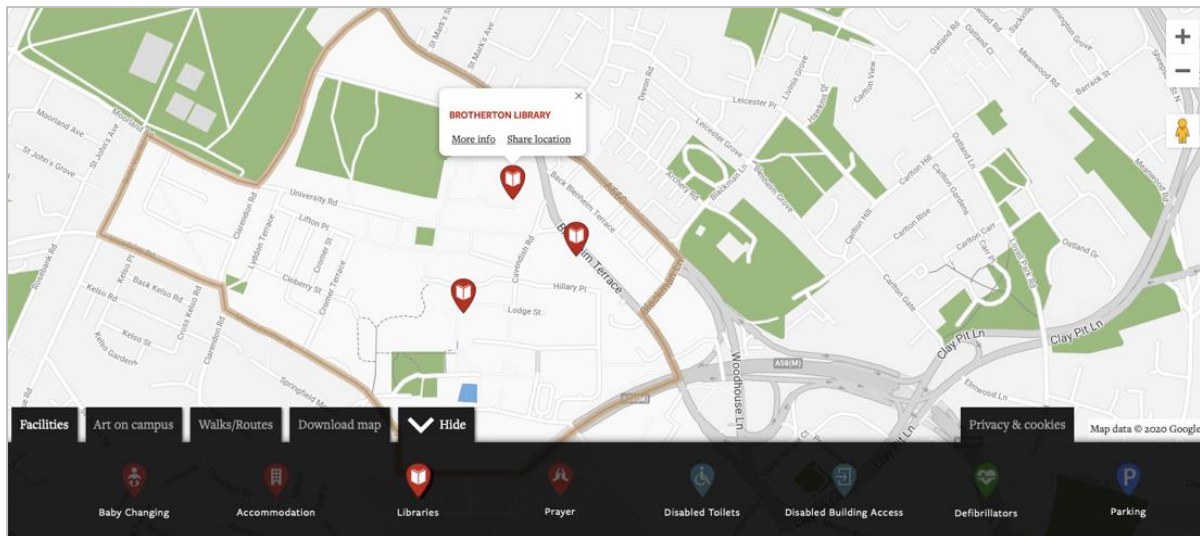
cannot be directly found on the map, and can only be displayed on the map through the search function. When the user's wayfinding purpose is to explore or quest (Allen, 1999), the map cannot meet their needs. In the “Walks/Routes” function, only two routes are provided, and this is not explained (Figure 3.7).

Figure 3.7. University of Leeds digital map - art attractions and two routes



II) Text and layout: The menu of the map is hidden at the bottom of the page, and the menu functions are divided into facilities, art on campus, walks/routes, download map. When the user clicks on facilities, 12 overlays including food and culture are displayed. When one facility is selected, all eligible areas on the map will be marked, and clicking the mark on the map will bring up a link to provide more information about the facility (Figure 3.8). However, the screen size limits the number of menus displayed, and facility options cannot all appear on the screen. This will increase confusion because they do not confirm the complete options.

Figure 3.8. University of Leeds digital map - select "Libraries" on the menu

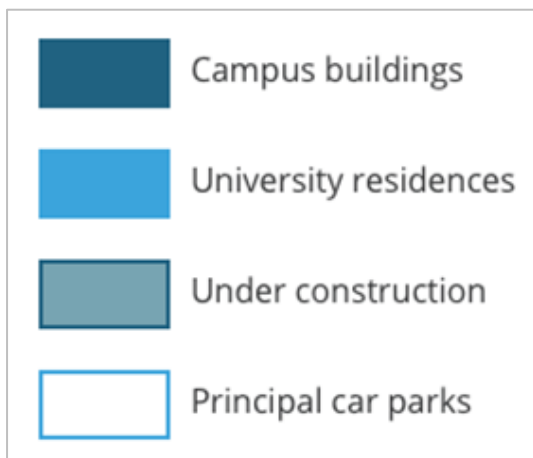


III) Scale: A pair of zoom buttons ("+" and "-") are provided in the upper right corner of the map to change the scale of the map. The text information on the map only shows the names of the roads, and the directions are consistent with the roads. As the map scale increases, more road names are displayed on the map.

UNIVERSITY OF MANCHESTER

I) Spatial information: Building categories are provided below the map, and they are divided into four categories using schematic diagrams (Figure 3.9). The user can directly operate the map and click on the shape on the map to obtain the name information of the facility.

Figure 3.9. University of Manchester digital map – Campus facilities category



II) Text and layout: The map's menu locates on the left side of the map, dividing the popular list on campus into 13 options (Figure 3.10). They are presented in a drop-down list, and users can see all the options on the screen at the same time. They will be marked on the map when people choose them.

III) Scale: The map also provides zoom button. The button is located in the upper left corner and lower right corner of the map. At the same time, a full-screen button is provided in the upper right corner of the map, allowing users to view the map in full-screen mode. Only roads' names are displayed on the map, and marked on the road lines. Road information increases as the map scale increases.

Figure 3.10. University of Manchester digital map – menu



UNIVERSITY OF OXFORD

I) Spatial information: There is a positioning button in the lower left corner of the map, which allows users to quickly get their position in the environment.

II) Text and layout: The menu divides the facilities and buildings on campus into “University” and “Lifestyle” (Figure 3.11). This separates the users’ work/learning needs from their daily needs, allowing them to quickly identify the list to which their target belongs. When selecting the “University” list, there is a drop-down menu that provides all the choices that match the keyword. For example, when the user needs to find “Exeter College”, the target can be found in alphabetical order in the “Colleges” menu bar. While displaying the target building, the map provides an additional information bar for users to understand the detailed information of the selected target (Figure 3.12).

Figure 3.11. University of Oxford digital map - menu

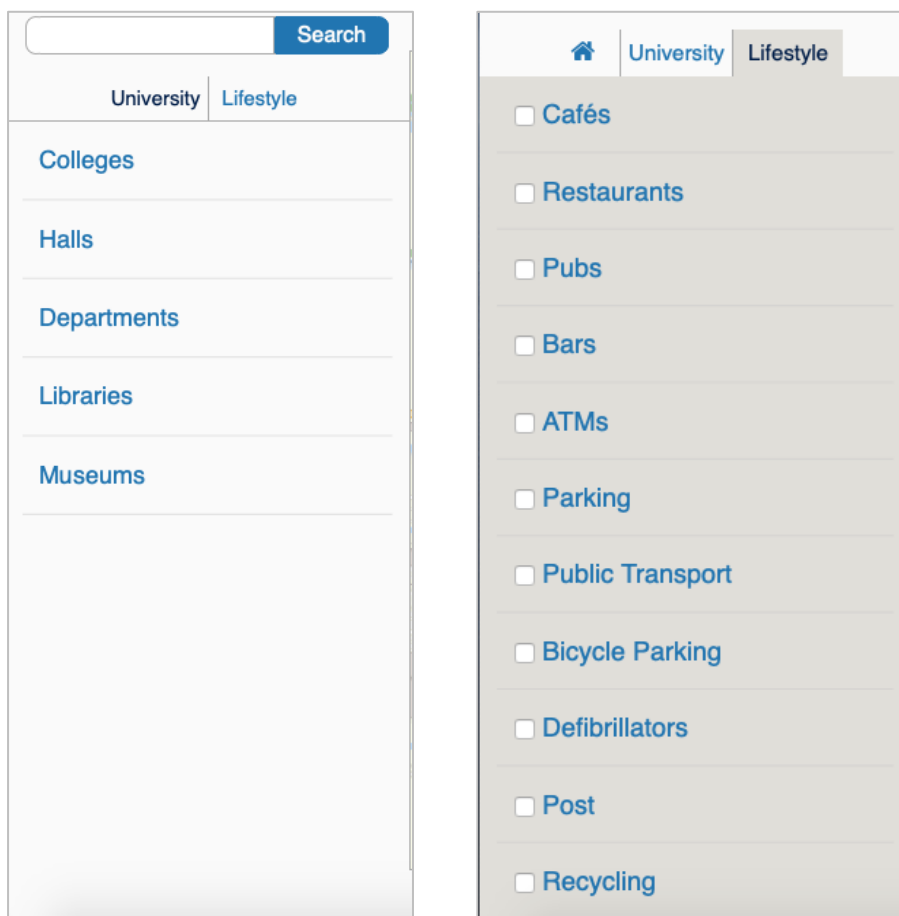
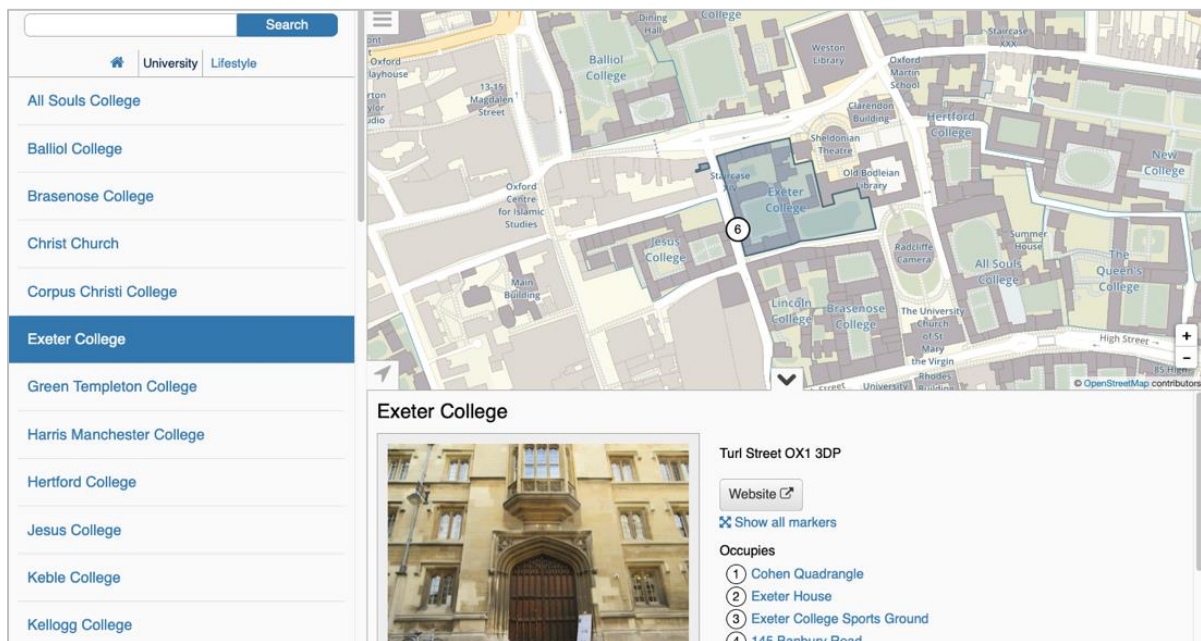


Figure 3.12. University facilities information example – Exeter College



III) Scale: The map has a zoom button, located in the lower right corner of the map. In addition, the map provides four levels of scale. The first level is the minimum scale, users can see the entire campus area on the screen, and the text information on the map only shows the area name. By enlarging the scale to the second level, the map shows the name of each college, and indicates the name of the main road. The names of other facilities and buildings are added to the scale of the third level, and arrows appear on the road to indicate the road direction. At the level with the largest scale, the building names in colleges appear on the map, and some complex buildings provide simple internal layouts, such as the location of staircase and gate.

UNIVERSITY OF CAMBRIDGE

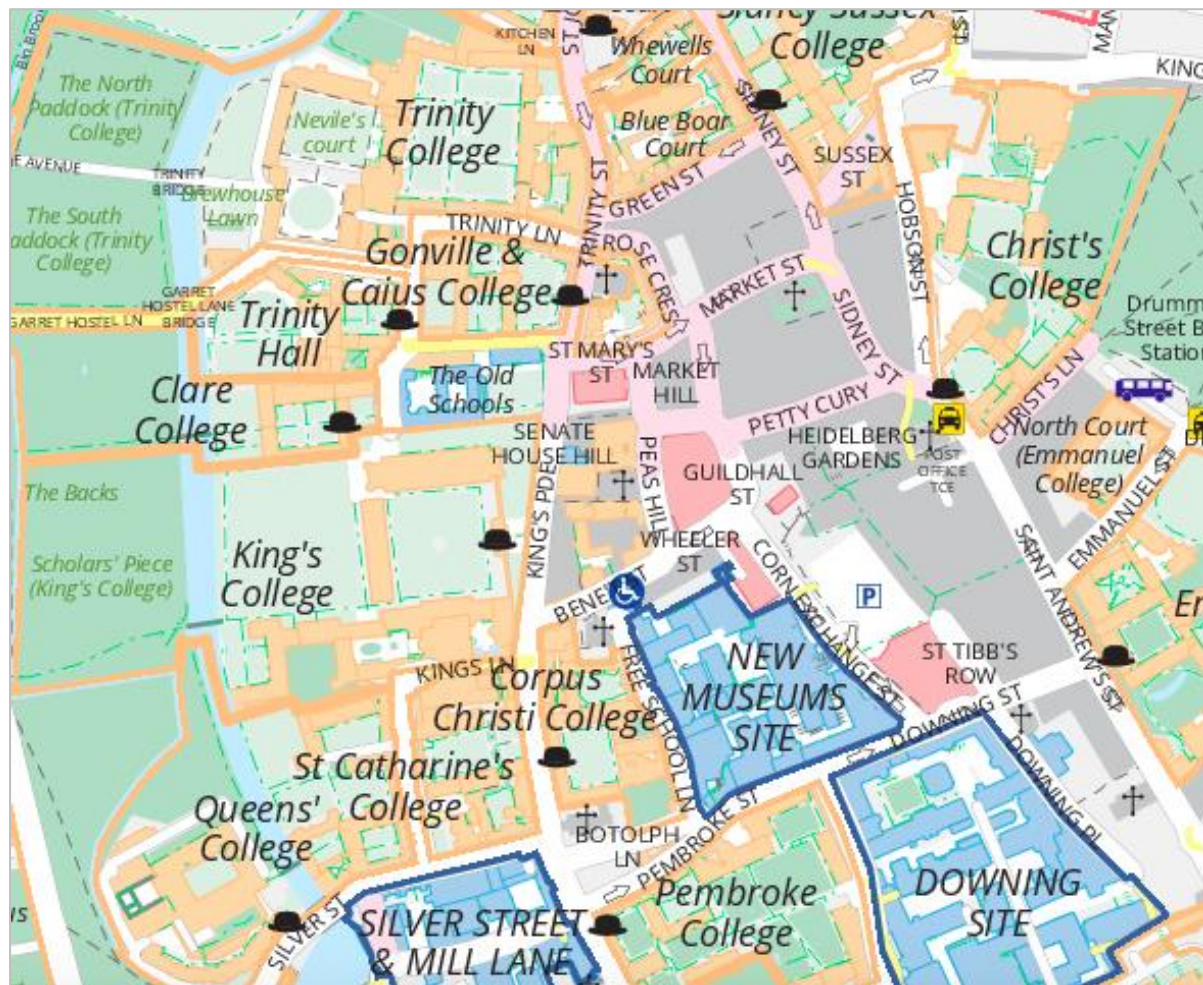
I) Spatial information: When the user clicks the left mouse button at any coordinate of the map, a menu will appear at that coordinate (Figure 3.13). In the menu, the user can choose to view the street view of the area. Unfortunately, this feature is a link that allows users to use Google Maps to visit Street View, but does not provide a way to return to the original campus digital map.

Figure 3.13. University of Cambridge digital map - coordinate menu



II) Text and layout: The user is allowed to mark the coordinates and use the whole screen to view the map. When the user wants to know the information of one coordinate, the “what’s here” function displays the institutions near the location in the menu on the left side of the map and provides detailed information. Text information on this map is complicated and difficult to read. The information is displayed in different sizes, some are in italics, and some are all capital letters, and there is no unified format (Figure 3.14). At the same scale, it displays too much information, which makes the map information unclear.

Figure 3.14. University of Cambridge digital map – information chaos on the map



III) Scale: The map provides 7 different scales. At the smallest scale, users can see an entire campus area on the screen. But in the original interface, the map uses the fourth scale. In this case, users cannot fully see the entire campus. In addition, in order from the largest to the smallest, the first and second scales, the third and fourth scales, and the sixth and seventh scales have similar levels of detail. It is difficult to hierarchise the information because the map is too crowded with text information.

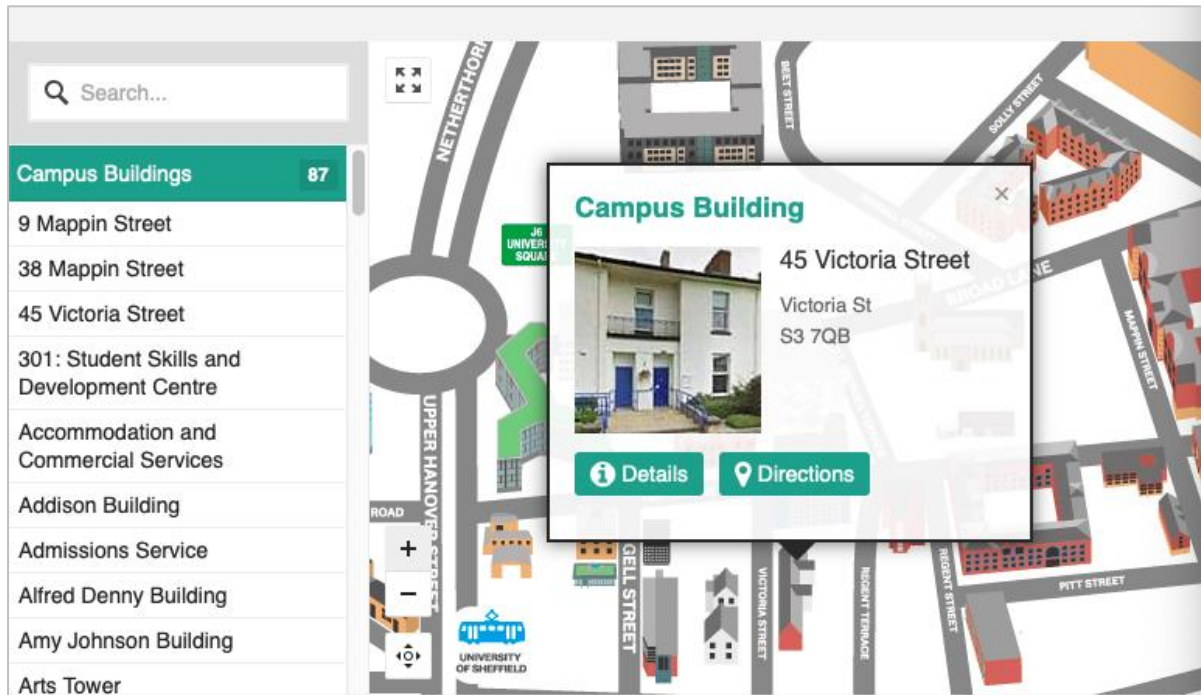
UNIVERSITY OF SHEFFIELD

I) Spatial information: The map has an initialisation button that when clicked can return the map to the original interface.

II) Text and layout: The menu is located on the left, and sites on the campus are divided into

three categories. Clicking on each category will bring up a drop-down menu, and alphabetise the corresponding options to form a list. Clicking on the selected facility or building, will locate the selection as the centre point and display related information (Figure 3.15). The text on the map shows only the road names and is in the same direction as the road lines.

Figure 3.15. University of Sheffield digital map - information about Campus building



III) Scale: The map has a zoom button, which is located in the lower left corner of the map. The map provides four scales, the original interface is the smallest scale. The information displayed on the map at any scale is the same.

Next, we can view the visual survey results in the form of a heat map (Figure 3.16). The framework of digital map design principles obtained in Section 2.4.4 is listed one by one. Whether the campus digital maps in the visual survey can comply with these principles is expressed in a visual form. Among them, light red is used to correspond to those features/symbols that do not exist in the campus digital map; when there are these features/sizes, it is bright green. Simple results show that, overall, the selected campus digital map cannot effectively convey the map information.

Figure 3.16. Heat map of whether campus digital maps follow map design principles

Map design principles	Campus digital maps				
	University of Leeds	University of Manchester	University of Oxford	University of Cambridge	University of Sheffield
Spatial information displayed on the map					
Show building direction and order					
Take self-centred view for positioning					
Display and interact with information					
Reduce landmark/landscape complexity					
Use recognisable landmarks					
Display important and memorable elements					
Proportional and neat text layout					
Consider information with shapes, paths, space					
Can update network information					
Allows selection of appropriate scale					
Information varies with map scale					
		Principle followed			
		Principle not followed			

3.3.4. Discussion of results

The selected samples have their own characteristics in the map appearance, and the interaction and functions also show different styles. Unfortunately, they cannot be used by mobile users to locate and guide routes. The campus digital maps of the University of Leeds and the University of Manchester do not have the function of locating users and wayfinding; University of Oxford and University of Cambridge allow users to locate where they are, but cannot provide corresponding wayfinding suggestions; University of Sheffield provides a way to link to Google Maps, but cannot provide wayfinding assistance through the map itself.

In terms of the relationship between information and scale, the map information of the University of Leeds, the University of Manchester and the University of Sheffield is inadequate, and the amount of information of the University of Cambridge is too much. Compared with them, Oxford University is a good example of the generalisation of information processing: at the same scale, there will not be too much text information, causing the text information to overlap; at the same time, too little information will not be displayed, and the text information will increase as the map is zoomed in.

For interaction and function, the maps of the University of Manchester and University of Cambridge allow users to directly operate the map to obtain information, which is more convenient and user-friendly than using the menu outside the map. For the introduction of sites such as university facilities/buildings, the University of Leeds, University of Oxford and University of Cambridge all provide labels in the interface to display the detailed information of the selected site, which allows users to have a deeper understanding while not making the map information too complicated. Overall, the Oxford University map performed best. This is also the same result as the heat map performance, which shows that Oxford University satisfies the most design principles. In addition, the results of the visual survey show that the digital map in the case cannot meet users' demand for wayfinding in the building.

The guidelines emerging from this visual survey and also taking into account the literature reviewed in Chapter 2, that will be used at later stages of this research, are as Table 3.3

shown.

Table 3.3. Visual survey findings: campus digital map design guidelines framework

Map elements	Guidelines
Map overview	Take measures to enable users to quickly identify campus areas on the map; The centre of the original map should be located in the campus area; Use shapes and colours to distinguish campus facilities and buildings, and can assist with schematic diagrams to remind facilities functions; The visual elements of the map should be balanced to avoid using too many formats.
Map information	The detailed level of information changes accordingly with the change of the map scale; The information on the map should be balanced and orderly (Tyner, 2014); Should avoid excessive information; Text information in the same format should be used.
Digital map interaction	Users should be allowed to locate themselves at any time; Combine the wayfinding function with the campus digital map to allow users to use the campus digital map for wayfinding; The menu should have hierarchy to avoid too much information at the same level; The user should be allowed to directly operate the map to view the facilities/buildings on the map.

3.4. Experiment I: A questionnaire survey on the use of campus digital maps

3.4.1. Suitability of methodology and research

The questionnaire is one of the most direct ways to collect information and obtain a higher number of responses, which is important to identify behaviour and needs. The questionnaire can collect and analyse users' attitudes, opinions and preferences (O'Grady and O'Grady, 2017). The questionnaire survey in this research was conducted online through Google Forms to collect information. Online questionnaires can avoid location and time interference (Blair and Conrad, 2011) and obtain information about participants in different geographic locations. At the same time, it is easier to obtain large amount of data, so that researchers can obtain more data without being affected by time and equipment (O'Grady and O'Grady,

2017). The purpose is to find users' difficulties in finding paths on campus and understanding of digital maps.

Participants were recruited among users of digital maps on universities. According to Muratovski (2016) and O'Grady and O'Grady (2017), the sample size in the online survey should be 30 or more. To further improve the reliability of the results, the sample size of this online survey should be at least 60. At the same time, it was discussed in the literature review that age, gender and educational background may affect people's wayfinding behaviour and efficiency (Abu- Ghazze, 1996; Lomperski, 1997; Allen, 1999; Chebat et al., 2005; Kanakri et al., 2016; Güneş, 2018; Süzer, 2018; Wang et al., 2018). Therefore, participants were grouped according to the following factors: age, gender, occupation.

3.4.2. Research aims and questions

The visual survey revealed that current campus digital map design could be improved. This further research is to understand how to truly meet the users' need. In order to better understand users' knowledge and opinions on campus digital maps, the research uses online questionnaire to obtain users' evaluations of campus digital maps, and provide relevant suggestions for creating campus digital maps that satisfy users, so as to improve the quality and readability of campus digital map design.

In order to achieve the aims, three research questions were conducted:

1. Where are people most likely to get lost on campus?
2. What behaviours and expressions do people engage in when looking for information/ places on campus?
3. How do people understand and use campus digital maps?

Based on the research questions, the questionnaire was divided into three parts: a) basic questions (including participant gender, age range, university position, etc.); b) wayfinding experience on campus; c) experience in using digital maps. All questions in the questionnaire are shown in *Appendix III*.

3.4.3. Data collection and analysis

The survey was based on the main users of campus digital maps. From October 9th to November 18th, 2020, 344 questionnaires were distributed to university students, staff (academic) and staff (others). There were 343 valid answers from people of different ages and different universities, making the survey results more authentic and reliable.

3.4.3.1. Investigation and analysis of campus users

The users of the campus digital map were composed of students, teachers and staff. The gender, age and occupation of the participants are shown in Table 3.4. Previous studies have suggested that gender, age, familiarity, experience, education and other factors can affect people's wayfinding behaviour (Güneş 2018; Süzer, 2018; Tao et al., 2018; Wang et al., 2018). The age of the participants in this research was between 18-60 years old; including this makes the research data include users of all genders and age groups, and the occupations of the participants include students and staff which makes the data more credible.

Table 3.4. Participants' basic information for questionnaire

N	Gender		Age		Occupation	
343	109	Male	214	18-20	249	Student
	225	Female	43	21-30	90	Staff (Academic)
	9	Prefer not to say	34	31-40	3	Staff (Other)
			28	41-50	1	Visitor
			24	51-60		

Since the participants who took part in the online questionnaire survey were only designated as campus users, their gender, age and position could not be controlled. Most of the participants were between 18 and 20 years old, accounting for 62.39% of the total number. The ratio of men to women was close to 1:2, and there were 9 other participants who did not want to reveal their gender. Among the 343 participants, 249 were students, 93

faculty members, and 1 visiting scholar. Participants were identified as frequent users of the campus environment. As mentioned in the previous paragraph, users' personal factors may affect their wayfinding behaviour (Güneş 2018; Süzer, 2018; Tao et al., 2018; Wang et al., 2018). However, the focus of this research is not on differences in wayfinding caused by factors such as user gender/age, but on exploring users' wayfinding behaviour and digital map usage experience in academic environments, so this research no longer focuses on this in the analysis stage. Future research may focus on the impact of individual differences.

3.4.3.2. Analysis of campus wayfinding behaviour

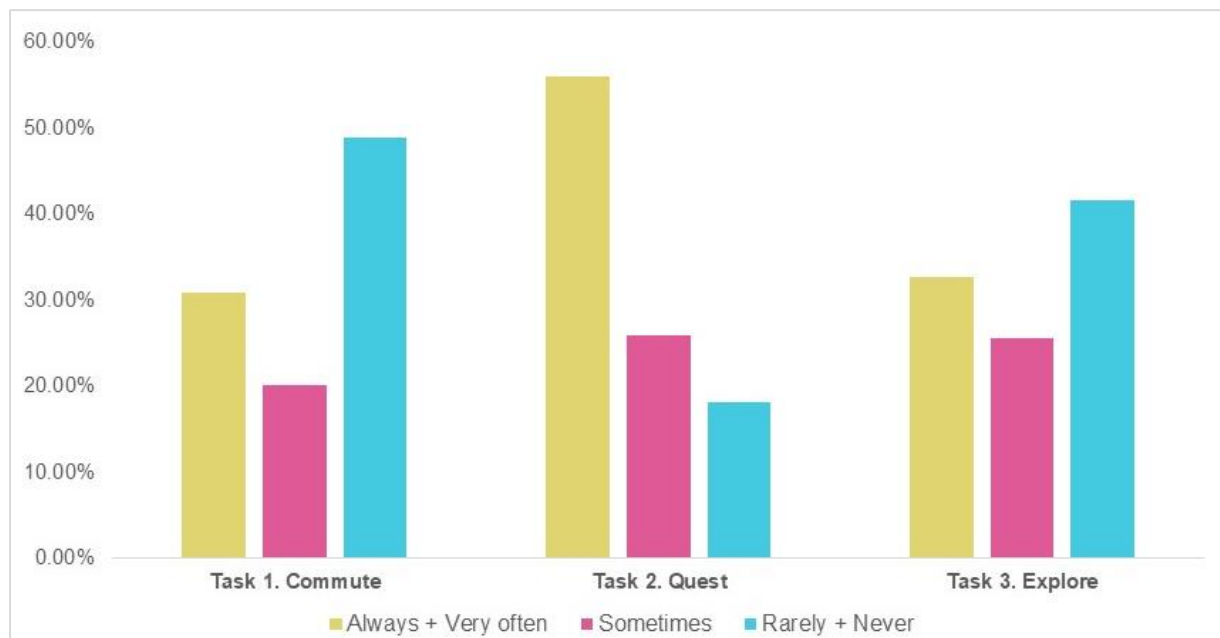
Analysis of campus wayfinding tasks

The first step of the analysis of campus wayfinding behaviour is to understand the tasks that users need to complete in campus wayfinding. The questionnaire divides the wayfinding tasks on the university campus into three categories according to Allen (1999) research. As shown in Table 3.5, more than half of people think it is necessary to get help when going to an unfamiliar place purposefully (55.98%). Some people think that help is sometimes needed in this situation (25.95%). Only 18.07% of the participants considered it unnecessary. In addition, in the case of the commute task, half of the people think that no help is needed (48.98%), and this type of view also accounts for half of the explore task (41.96%). In previous surveys, it has been found that users on university campuses are often asked to go to unfamiliar locations (Kanakri et al., 2016). Participants' need for help is shown in Figure 3.17. It can be found that people have obvious needs for quest tasks. The results indicated that it is necessary to conduct further research into this wayfinding task.

Table 3.5. Participants' opinions of necessity for help when conducting wayfinding tasks in the university

	Opinion					
	N	Always	Very often	Sometimes	Rarely	Never
Task 1. Commute	343	13.70%	17.20%	20.12%	18.95%	30.03%
		30.90%			48.98%	
Task 2. Quest	343	27.99%	27.99%	25.95%	13.70%	4.37%
		55.98%			18.07%	
Task 3. Explore	343	14.58%	18.08%	25.66%	22.74%	18.95%
		32.66%			41.69%	
	Task 1. Commuting between two places (e.g. from the residence to the commonly used office/classroom)					
	Task 2. Purposefully go to an unfamiliar place (e.g. go to a building that has not been to)					
	Task 3. Freely exploring the campus environment.					

Figure 3.17. Participants' opinions of necessity for help when conducting different wayfinding tasks in the university



Reasons for getting lost on campus and help

In the previous research in Chapter 2, it was noted that people can be lost both in the indoor

and outdoor environment of the campus. Therefore, the research asked why people were lost in the campus environment and evaluated the effectiveness of the ways to ask for help.

I) Indoor lost place

University campuses are often composed of buildings. The research is based on the functions of buildings. With reference to the existing digital map of campus in the visual survey, the researcher classifies the campus indoor environment according to the classification of campus buildings and asks the participants about the situation of getting lost. Participants are allowed to make multiple choices. As a result, 76.38% of people lost their way in the teaching building; 23.91% in the library; 20.99% thought it was difficult to find the way in the dormitory building; 20.41% of the people would get lost in the gym; 11.66% of people thought that they would get lost in the restaurant. In addition, 8.45% of the participants had different opinions. Analysing their answers, 4.57% of the participants did not think that they would get lost indoors, and 2.04% of the participants thought that the wayfinding in office buildings and laboratory buildings was confusing. It can be known that most people will get lost in the teaching building. The complex buildings and internal structure in the university environment cause people to risk getting lost in different buildings.

II) Reasons for getting lost on campus

According to the previous literature review and visual survey, the research selected 5 main reasons for getting lost on campus. As shown in Table 3.6, 39.06% of people believed that couldn't understand the school map will lead to getting lost, and 30.02% of people believed that wrong information makes it impossible to find a route. Most people thought that the inability to find the entrance to the building is likely to lead to getting lost (60.64%); 69.97% of the participants thought that the most important reason for getting lost is the inability to find a specific room; many people thought that being asked to arrive at a designated place at a prescribed time would easily lead to getting lost (65.89%). In addition, through the feedback analysis of the participants, it is known that the lack of landmark navigation and

the confusion of campus building names and internal room numbers/labels can lead to getting lost. Through the analysis of the reasons for getting lost on campus, it is concluded that how to help users find building entrances and accurate rooms in a relatively short time will be the direction to improve the problem of getting lost on campus.

Table 3.6. Participants' opinions of reasons for having been lost on campus

	Opinion					
	N	Very likely	Likely	Neutral	Unlikely	Very unlikely
Re 1. Map	343	10.20%	28.86%	27.11%	22.45%	11.37%
		39.06%			33.82%	
Re 2. Information	343	8.45%	21.57%	24.49%	34.40%	11.08%
		30.02%			45.48%	
Re 3. Entrance	343	21.28%	39.36%	21.87%	12.24%	5.25%
		60.64%			17.49%	
Re 4. Room	343	29.74%	40.23%	19.53%	7.87%	2.62%
		69.97%			10.49%	
Re 5. Time	343	26.82%	39.07%	22.45%	7.29%	4.37%
		65.89%			11.66%	
	Reason 1. Could not understand the university map					
	Reason 2. The map gave me the wrong information					
	Reason 3. Could not find the building entrance					
	Reason 4. Could not find the specific room					
	Reason 5. Was rushing to get a place on time					

III) Ways to help when getting lost on campus

In order to identify more suitable ways to assist campus wayfinding, the research selected different commonly used campus wayfinding maps and obtained user reviews (Table 3.7). As a result, only 25.07% of users think paper maps are effective. 62.39% of the participants believed that the map board could help to find the way; similarly, the users who believed that the digital map was effective accounted for the majority (66.76%). Therefore, the direction digital map of this research has advantages and user expectations in the

effectiveness of campus wayfinding.

Table 3.7. Participants' opinions of map types to seek help when lost on campus

	Opinion					
	N	Very effective	Effective	Neutral	Ineffective	Very ineffective
Map board	343	18.37%	44.02%	32.94%	4.37%	0.29%
		62.39%			4.66%	
Paper map	343	4.37%	20.70%	53.94%	14.87%	6.12%
		25.07%			20.99%	
Digital map	343	21.28%	45.48%	28.57%	3.79%	0.87%
		66.76%			4.66%	

3.4.3.3. Analysis of the use of campus digital maps

The investigation of the use of campus digital maps starts with the device. The research asked users about the usage habits and expectations of digital maps in order to obtain a more suitable medium for campus digital maps to interact with users. As a result, 96.5% of participants used digital maps (such as Google Maps) on mobile phones more often; for campus digital maps, 86.5% of participants chose mobile phones. This is in line with the previous literature research on digital maps, which believed that the mobile media enables digital maps to meet user experience requirements (Winter and Tomko, 2004).

Unfortunately, only 46.36% of the participants confirmed that their universities have campus digital maps, while some participants think that their universities do not have campus digital maps (13.7%). In addition, 39.94% of the participants do not know whether a campus digital map exists. However, the survey revealed that users have expectations for the use of campus digital maps. Most of the participants expressed that they hope to find their way to their destination through the campus digital map (83.97%); more than half of the participants expected to use the campus digital map to find campus facilities (53.06%); 46.94% of the participants thought that positioning their location is very important; 45.77% of participants wished to understand the overall campus layout through the campus digital map.

The research analysed the samples of visual survey, combined with the digital map design principles from literature review, and selected 6 options from the visual effects and functions of the digital map. Participants were allowed to select all the ways that can bring a better experience to the campus digital map (Figure 3.18). The results of the research are shown in Figure 3.19. Except summary campus facilities and provide detailed information of the building/facilities inquired, other options have an approval rate of more than 50%.

Figure 3.18. Features of the map functions that can provide a better user experience.

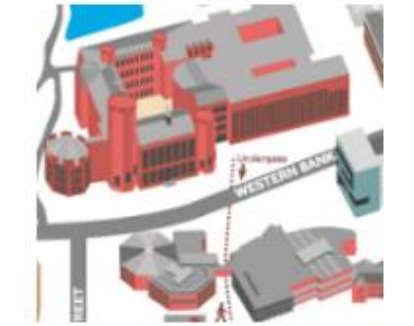
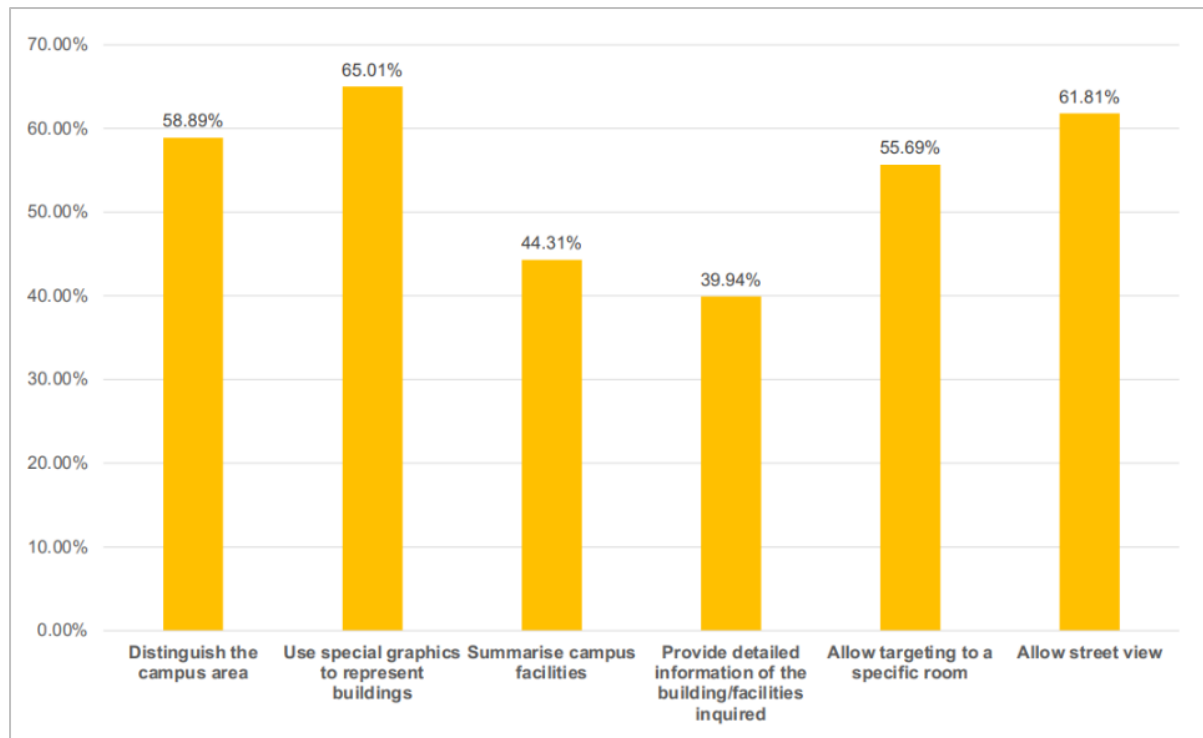
	
☐ Distinguish the campus area (i.e. use different colour blocks to indicate different areas)	☐ Use special graphics to represent buildings
	
☐ Summarise campus facilities	☐ Provide detailed information of the building/facilities inquired
	
☐ Allow targeting to a specific room	☐ Allow street view

Figure 3.19. Percentage of participants choosing campus map features that can provide a better user experience.



Therefore, the participants were asked about the assessment of these functions, as Table 3.8 shows:

1. In terms of the visual effects of the campus digital map, as a result, 69.97% of the participants thought that distinguish areas of the campus digital map was useful; most people believed that distinctive patterns should be used to represent campus buildings and facilities (70.55%); 70.84% participants hope that the campus digital map allows street view mode.
2. In the use of the menu, 73.47% of the participants agreed that summarising and categorising campus facilities is a useful direction.
3. In terms of wayfinding and location functions, 71.43% of participants hoped that campus digital maps provide detailed information about buildings and facilities; at the same time, 74.63% of the participants said that the campus digital map can have

the function of locating specific rooms, not just buildings.

From the results of the survey, users have certain expectations for the use of campus digital maps. According to the summarised data, the priority of each aspect is: locate to room> facility classification> facility information> visual effect.

Table 3.8. Participants' opinions for of campus digital maps' functions

	Opinion					
	N	Extremely useful	Somewhat useful	Neither useful nor useless	Somewhat useless	Extremely useless
Func 1	343	21.87%	48.10%	26.24%	2.92%	0.87%
		69.97%			3.79%	
Func 2	343	22.45%	48.10%	26.24%	2.62%	0.58%
		70.55%			3.20%	
Func 3	343	20.70%	52.77%	23.91%	2.04%	0.58%
		73.47%			2.62%	
Func 4	343	24.49%	46.94%	23.91%	4.08%	0.58%
		71.43%			4.66%	
Func 5	343	32.94%	41.69%	22.74%	1.75%	0.87%
		74.63%			2.62%	
Func 6	343	28.57%	42.27%	24.78%	3.50%	0.87%
		70.84%			4.37%	
	Function 1. Distinguish the campus area (i.e. use different colour blocks to indicate different areas) Function 2. Use special graphics to represent buildings Function 3. Summarise campus facilities Function 4. Provide detailed information of the building/facilities inquired Function 5. Allow targeting to a specific room Function 6. Allow street view					

3.4.4. Summary

A questionnaire was conducted to obtain users' cognition of campus environment

wayfinding, as well as experience and expectations of existing campus digital maps. Through the analysis of the data, the main problems encountered by users in the campus wayfinding and their expectations for the function of the map can be summarised.

3.4.4.1. Wayfinding problems in the campus environment

In a campus environment, users are more likely to get lost indoors. Due to the complex building structure, people may get lost in any building on the campus. Among them, the teaching building is the most likely place to get lost. People are often confused when asked to go to unfamiliar locations. As for the specific reasons for getting lost, confusion about the internal structure of the building has become one of the main reasons: users on a university campus are likely to get lost because they cannot find the entrance to the building or a specific room. At the same time, the need to rush to the designated place within the specified time is also an important reason for getting lost.

3.4.4.2. Usage of campus digital map

When facing a lost situation, people generally think that digital maps are more effective than paper maps. Mobile phones are considered the best devices for using digital maps. For the functions of campus digital maps, further research should be conducted in accordance with user expectations and experience. Positioning is considered one of the most significant functions. Because campus users are often required to complete wayfinding tasks within a limited time, the timely, accurate and updateable positioning function can effectively help users reach the designated location. If the campus digital map has the positioning and navigation functions inside and outside the building, it will more successfully help users find their way in the campus.

In the visual expression of the campus digital map, distinctive map visual elements can be used on the map, such as the distinction of campus areas and the special graphics of buildings and landmarks. How to effectively combine the information and visual elements of

the map so that the campus digital map can more effectively help find the way and meet the needs of users requires more research in the future.

3.5. Conclusion

Overall, the research collates the design and use of campus digital maps by UK academic institutions, assesses the visual and information design of the maps through a visual survey, and captures user needs using questionnaire investigation. Starting from the map design itself, the visual survey analyses the advantages and various design limitations of the existing campus digital map design based on the summarised design principles. The research also collects a large number of participant responses, providing evidence to explain the main problems users encountered in campus wayfinding and expectations for map functionality. This is the first step in this research 's user-centred information design to add users into the research process with the aim of finding design problems. Like Lynch' (1960) research, the study of digital maps first needs to know how users think about it. The research brings valuable insights for future directions of map design improvement.

In the research, it is found that the independently designed campus digital map has a huge development space. Of the UK universities that have digital maps, most use external links rather than specific well-designed maps. It has already been found in Chapter 2 that there is not enough existing research experience in the field of digital campus mapping and outdoor wayfinding. This chapter focuses on the existing digital campus map design in UK academic institutions and evaluates them based on information design principles. This research shows that the existing knowledge of digital campus map design based on information design principles in UK academic institutions is insufficient. This provides another layer of evidence for the necessity of this research.

Additionally, existing campus digital maps suffer from various design limitations in terms of visual design elements and information legibility. Based on the research of Tyner (2014), this thesis classified key visual elements from lines, shape and colour and discussed them

separately, so as to obtain a discussion of visual element design that can be used as a reference for campus digital map design. After analysing the elements individually, the main issues of the visual design of the entire map were discussed, focusing on how well the map elements correspond to the real world (Papadias and Theodoridis, 1997). A map that is too simple or has too many visual elements will create a poor reading experience, and the appearance of the map needs to be carefully considered. The main problem in information design is the hierarchical division of information and the lack of correlation between large amounts of information. Judging from the visual survey results, the large amount of text information on the map will make the reading experience difficult and prone to misunderstanding; the functions provided may not meet the needs of users. This is the same point as Apelt et al. (2007) put forward, the text and layout of the map should be proportional and neat. The research results show that it is necessary to form a complete set of information-based and visual design principles for the design of campus digital maps.

Research on user needs used a questionnaire investigation. The results show that users prefer using mobile phones as a medium for reading maps. Analysis of participant feedback revealed scenarios where users are more likely to get lost: unable to find a building entrance or a specific room. The latter has been indicated by many studies: Scott-Webber et al. (2000) conducted user research on student groups and found that they encountered more difficulties and challenges in indoor navigation; many studies focused on indoor wayfinding in libraries to improve user experience (Barclay, 2012; Li and Klippel, 2012; Mandel, 2013). No studies were found on building entrances. This can help the researcher gain insights into how users find specific locations, such as successfully entering a specific building. Users' expectations of finding their destination within a limited time have also become a focus. This was suggested by Kanakri et al. (2016), who believed that students would feel stressed when they need to attend class on time but could not find the target location quickly. Research also shows that positioning accuracy and visualisation of the campus environment are key points in map design. The importance of positioning oneself has been emphasised in many user experience studies on map design, such as Giuliani's (2001) study on positioning pictograms on map signs (such as pentagram represent the user's position in space); Apelt et

al.'s (2007) discussion of how the display of spatial information on maps affects user positioning; Tyner (2014) investigated how map design strategies help users locate, etc. Whether a map can help users successfully position themselves in a specific environment determines whether it can successfully assist in wayfinding. By analysing the questionnaire, users' confusion and expectations about positioning and wayfinding when using digital maps on campus can be better understood.

Overall, this research discovered many limitations of current campus digital maps in terms of information and visual design, clarified the development prospects of campus digital maps, and provided a preliminary understanding of wayfinding issues with the help of user suggestions. The next stage of research will focus on the performance and problems of mobile digital maps in campus wayfinding, as well as the direction of design improvements. Research in this chapter highlights the importance and design limitations of digital campus maps. More specific design issues will be studied and refined in future research of *Experiment II* and *Experiment III*.

4. Experiment II: The performance of digital maps for wayfinding in academic environments – University of Leeds as a case study

In Chapter 3, research on the usage and legibility of existing campus digital maps was conducted. Through the analysis of map limitations and user research, the limitations and expectations on the use of digital maps in the campus environment were obtained. Based on the wayfinding tasks (commute, quest and explore) in the academic environment summarised in Section 2.4.1.2, this chapter describes user tests conducted through these three tasks. In the **commute** task, participants were required to go to familiar buildings on campus without any help; in the **explore** task, participants conducted a time-limited inspection of the surrounding environment and completed questionnaires; in the **quest** task, participants used a digital map (this experiment uses Google Maps as a research tool) to go to unfamiliar areas. Through the feedback of the completion of the three tasks, the most common wayfinding problems in the campus environment and the limitations of the digital map are further obtained. The test results are helpful for the design of campus digital map to improve the user's wayfinding efficiency and provide design improvements for the next step of campus digital map evaluation.

4.1. Introduction

In this chapter, through the campus wayfinding tasks obtained from the literature research in Chapter 2 and the campus wayfinding problems in Chapter 3, three different tasks were designed to further investigate the behaviour and problems of users in the process of completing the wayfinding tasks in the campus environment. Since following user-centred design research always requires understanding the feedback of users using research subjects (Lynch, 1960; Montello, 2002), *Experiment I* (questionnaire survey) in Chapter 3 alone cannot observe the wayfinding behaviour of users in the campus environment to understand the wayfinding problems and performance they encounter when using (or not using) digital maps. This chapter serves as the final step of pre-research to design and evaluate a campus

digital map prototype designed based on information design principles, which requires a detailed understanding of how the digital map work in a campus environment and how efficiently it can be used.

The aims of the research is to observe and record the behaviour of participants based on the principles of wayfinding information design, evaluate the efficiency of the existing digital map in the complex environment of the campus, and find out its limitations in terms of legibility and positioning accuracy. The three main research objectives are as follows:

1. To observe the different performance and completion efficiency of the participants under the three wayfinding tasks;
2. To assess the visual design legibility of existing digital maps and identify limitations that affect user efficiency and mission success;
3. To understand people's perception of the campus environment, and investigate the environmental elements that people pay attention to when finding their way.

Under the guidance of the research objectives, this research proposes the following research questions:

1. How does familiarity with the destination environment and routes affect wayfinding efficiency?
2. What are the limitations of using digital maps in an academic environment?
3. Where do people tend to get lost in the university environment? How do they read map information and find their destination when lost?

In order to achieve the research objectives and answer the research questions, this chapter conducts user tests and questionnaires.

To solve **the first question**, this experiment has three stages, requiring participants to complete three types of wayfinding tasks: 1) commute; 2) quest; 3) explore. These three tasks respectively represent 1) familiar daily routes; 2) places that have never been before; 3) free exploration of the surrounding environment. By observing the user's performance in the three tasks, the impact of environment and route familiarity on wayfinding efficiency can be discussed.

Regarding **the second question**, during the quest task stage of this experiment, participants were required to use Google Maps navigation to perform several wayfinding tasks of different difficulties. In the explore task, participants were asked to explore functions of Google Maps beyond navigation and evaluate its ease of use in a campus environment. There are three reasons to use Google Maps for testing:

1. External digital maps are widely used as tools for wayfinding systems in academic institutions (see Section 3.2 for detailed discussion);
2. When "map" is used as the keyword in Google and Apple app stores, Google Maps shows strong competitiveness: it has the largest number of downloads (more than 10 billion) in the Google App Store, and in Apple App store navigation apps ranked first;
3. Google Maps can navigate and locate, and provides multiple visual appearances (standard mode and satellite mode). Users can interact with it to navigate or search for facilities, meeting the requirements for digital map personalisation derived from the literature review.

Using Google Maps as a tool, observing participants' behaviours and problems encountered using it for wayfinding, and post-task feedback can yield more detailed data on the limitations of digital maps for wayfinding in academic settings.

As for **the third question**, it can be learned from Chapter 2 that user research on student groups shows that they encounter more difficulties and challenges in indoor navigation (Scott-Webber et al., 2000). However, the questionnaire results of *Experiment I* showed that the three reasons of being unable to a) find the entrance to the building; b) cannot find a specific room; c) arrive at the designated place within the specified time are the main reasons for getting lost on campus, and the probability of being selected is 60-70%.

Unfortunately, at the time this experiment was conducted, the spread of the COVID-19 caused the University of Leeds, the case study, to close most of its facilities. Also considering that participants might have concerns about indoor contact during that period, this experiment targeted outdoor wayfinding during the planning stage. This would also maximise the functionality of Google Maps as a tool, as it does have almost no navigation

capabilities in indoor environments. To sum up, this experiment required participants to complete a wayfinding task outdoors. By tracking and recording their wayfinding performance, specific information about the physical environment in which they were easily disoriented were obtained. In this experiment, participants were not required to limit their time and could read map information as much as possible for wayfinding and orientation, so that more detailed feedback on their efficiency in using digital maps could be obtained. Time limits were required in *Experiment III* and are detailed in Chapter 5.

This chapter will introduce the contents and results of three user tests in detail.

4.2. Commute task

4.2.1. Content

University campus users usually have a common wayfinding task in their daily wayfinding activities which is commuting. The main users of the campus often travel to frequently visited places, such as their schools and libraries. In order to explore the influence of the user's choice of route and environment on the efficiency of wayfinding when traveling to a known location, several tasks were set up to analyse participants' wayfinding behaviour. Participants were asked not to refer to any navigation systems such as maps and signages, and to go to several locations that they knew and were familiar with. During the experiment, participants were asked to use think-aloud methodology to express their decisions, emotions, and thoughts. At the same time, participants' wayfinding behaviours were recorded through video recording and route tracking software (Strava¹).

Using the University of Leeds as a case study, the task's starting location were positioned to one of the University's well-known landmarks (Parkinson's Building). Participants were asked to follow a familiar route to their school and campus library. In this task, because participants came from different schools in the University, their familiarity with the campus

¹ Strava is a software that uses GPS to track movement status. Users can start Strava before starting an activity to track performance statistics, and then they can analyse activity data in depth.

buildings was separately confirmed before the experiment to ensure that each participant was provided with the location of the destination that they actually knew and were familiar with.

When choosing a destination, the selection criteria were used:

1. There are multiple routes to the destination;
2. The destination has more than two passable entrances;
3. Participants need to go to more than two destinations, and the complexity of the environment to the destination is different:
 - a. There is no altitude difference between the destination and the departure place, and there is no need to pass through obstacles on the way to the destination;
 - b. There is an altitude difference between the destination and the place of departure, and obstacles (teaching buildings, corridors, etc.) must be passed through to reach it.

4.2.2. Participants' completion of tasks

As shown in Table 4.1, a total of 12 participants took part and completed the task. The time they spent traveling to each location and the length of time they stopped were recorded using the route tracking software (Strava). Since each destination and initial position cannot be reached in a straight line, the shortest route is defined as the route with the least number of turns and the shortest distance. *Appendix IV* shows participant route maps recorded by the route tracking software.

Table 4.1. Participants' data in the commute task

No	Start location	End location	Distance	Time using	Stop time	Shortest route or not
1	Parkinson Building	School of Design	0.29km	3:04	0:00	Y
	School of Design	Edward Boyle Library	0.51km	8:20	3:05	N
	Edward Boyle Library	Laidlaw Library	0.19km	2:13	0:11	Y
2	Parkinson Building	School of Design	0.32km	2:42	0:00	Y
	School of Design	Edward Boyle Library	0.26km	3:01	0:25	Y
	Edward Boyle Library	Laidlaw Library	0.18km	1:36	0:03	Y
3	Parkinson Building	School of Design	0.33km	3:07	0:00	Y
	School of Design	Edward Boyle Library	0.22km	3:12	1:05	Y
	Edward Boyle Library	Laidlaw Library	0.29km	3:29	0:39	Y
4	Parkinson Building	School of Law	0.75km	8:31	0:00	N
	School of Law	Laidlaw Library	0.74km	8:31	0:17	Y
5	Parkinson Building	School of Business	0.51km	5:28	0:00	Y
	School of Business	Edward Boyle Library	0.36km	4:11	0:11	Y
	Edward Boyle Library	Laidlaw Library	0.15km	1:39	0:07	Y
6	Parkinson Building	School of Design	0.32km	3:24	0:00	Y
	School of Design	Laidlaw Library	0.27km	3:33	0:23	Y
7	Parkinson Building	School of Design	0.33km	3:10	0:00	Y
	School of Design	Edward Boyle Library	0.25km	2:51	0:36	Y
	Edward Boyle Library	Laidlaw Library	0.15km	1:49	0:12	Y
8	Parkinson Building	School of Philosophy	0.07km	0:46	0:00	Y
	School of Philosophy	Edward Boyle Library	0.17km	1:42	0:03	Y
	Edward Boyle Library	Laidlaw Library	0.24km	2:21	0:23	Y
9	Parkinson Building	School of Design	0.35km	4:02	0:00	Y
	School of Design	Edward Boyle Library	0.17km	2:19	0:19	Y
	Edward Boyle Library	Laidlaw Library	0.17km	2:09	0:20	Y
10	Parkinson Building	School of Design	0.28km	3:22	0:00	Y
	School of Design	Edward Boyle Library	0.22km	3:13	0:31	Y
	Edward Boyle Library	Laidlaw Library	0.16km	2:16	0:14	Y
11	Parkinson Building	School of Design	0.31km	2:46	0:00	Y
	School of Design	Edward Boyle Library	0.24km	2:42	0:38	Y
	Edward Boyle Library	Laidlaw Library	0.13km	1:50	0:33	Y
12	Parkinson Building	School of Design	0.28km	3:05	0:00	Y
	School of Design	Edward Boyle Library	0.23km	2:36	0:22	Y
	Edward Boyle Library	Laidlaw Library	0.12km	1:35	0:23	Y

4.2.3. Analysis of the task

The analysis of participant behaviour is divided into three aspects: commuting route, environmental complexity and building entrance selection.

4.2.3.1. Commuting route

In the judgment of commuting routes, the shortest accessible route between two points (the fewest turns, the shortest relative time spent, and the route closest to a straight line between two points) is regarded as the shortest route. As shown in Table 4.1, among the 12 participants, two participants did not follow the shortest route to their destination. The reasons why they deviated from the route were asked individually after the commute task was completed, and they were:

PARTICIPANT 1 - School of Design - Edward Boyle Library

This participant was familiar with the direction to the destination, but without using map navigation, they turned ahead and deviated from the route at intersections where they should go straight. The participant was well aware of the surroundings of the destination, but ignored whether the route was walkable and therefore walked to the back of the destination building.

PARTICIPANT 4 - Parkinson Building – School of Law

The participant did not use the shortest route, because they were used to a fixed commuting route - even if it did not seem to be the most efficient route, so chose the most familiar route to the destination.

When commuting, participants could complete tasks without the aid of any navigation system. Even if they deviated from the route, their familiarity with the environment still allowed them to discern the direction and reach their destination. Familiarity with the environment allowed participants to reach the destination through the shortest route in most cases, which enhances the efficiency of wayfinding to a certain extent and saves

people time when commuting.

4.2.3.2. Environmental complexity influence

In order to investigate the impact of environments with different levels of complexity on the efficiency of wayfinding, the selection criteria for destination selection were as follows:

1. There is no altitude gap from the starting point (Parkinson Building) to the participant's school, there are fewer turns.
2. There is a height difference between the participant's school and the Edward Boyle Library, and the environment is more complex, requiring more turning and crossing obstacles (buildings, grass fields, etc.).
3. The shortest route for participants to the Laidlaw Library is not to reach its main entrance, but to reach its passable side entrance.

In order to make the wayfinding behaviour of participants easier to observe, they were asked to stop and describe their decision when making a decision (such as choosing an intersection, whether to turn or not). The route tracking software recorded the time they spent in the wayfinding process and the time they stopped (Figure 4.1). Since participants 4 and 6 did not have familiarity with the environment to support their understanding of the route to Edwards Boyle Library, their data are removed from the figure.

Figure 4.1. Participants stop time in each task



In the task where the participant's school is the destination, which means there is fewer

turns, no altitude gap, and no obstacles to pass through, no participant needs to stop and think about the next direction. When there is a height difference between the destination and the starting position and need to cross obstacles to arrive, that is, the destination is Edward Boyle Library, the time required for the participant to stop and think about how to reach the destination is the highest of the three tasks. This is because there are multiple routes to reach the destination, and participants spend a certain amount of time judging the surrounding environment and choosing the direction.

In the case of Edward Boyle Library as the destination, participants spent more time stopping (average stay time: 64.4s). In the task that ends with Laidlaw Library, the average stay time of participants is 16s. With the participant's school as the end point, no participant needed to stop to choose a route.

This also indicates the impact of participants' familiarity on commuting tasks: people's familiarity with the environment is the highest in the most frequently visited workplaces, and the efficiency of wayfinding is the highest; for familiar but less frequent places, people's wayfinding efficiency is affected. This may be because the cognitive map belongs to the category of long-term memory, and it may change over time. In places that travel less frequently, people need to spend more time thinking about routes.

4.2.3.3. Building entrance selection

In the experiment, participants were asked to choose the shortest route to reach the destination and can reach any passable entrance to the destination. Participants' choices for the entrance are shown in Table 4.2.

Table 4.2. Reasons for participants' choices of building entrance

No.	Reason
1	I choose the entrance that can be reached with the fewest turns.
2	I am used to entering from this entrance, and the structure of entering the building from here is what I am familiar with.
3	I choose the nearest entrance.

No.	Reason
4	I choose the fastest entrance to the building. I am also very familiar with this entrance, if it is in this direction, I usually enter from here.
5	I choose the nearest entrance.
6	I choose the nearest entrance.
7	It is very convenient and quick to enter the building here.
8	This is the shortest route.
9	This is the nearest entrance.
10	This is relatively close, and the other entrance will detour.
11	My office can be reached quickly by entering from here. I am familiar with these entrances, and I usually enter through them.
12	I am used to going from here.

Among the reasons they chose, keywords such as nearest and familiar have a high frequency of appearance.

Convenient: 1 time;

Most familiar/ often used: 6 times;

Nearest: 10 times.

It can be seen that participants did not insist on going to the main entrance of the building under the premise of being familiar with the surrounding environment. Distance is the most important factor they consider. When commuting to work, people may choose the route and entrance that is the fastest to reach the destination. At the same time, habit is also an influential element of people's commuting routes. Without the use of navigation systems, people tend to choose the routes and entrances they use most often.

4.2.4. Summary

In the commute task, 12 participants participated and completed multiple wayfinding tasks. They are required to go to the buildings they are familiar with on campus, and choose the route they think is the closest without using any navigation system. Through the analysis of

commuting route, environmental complexity and building entrance selection, the following conclusions are drawn:

1. When commuting to work, people often choose to follow their customary route to decide the route to their destination, even if sometimes that route may not be the most efficient.
2. The more complicated the environment between the initial place and the destination, the more it affects the efficiency of commuting:
 - a. When there is a height difference between the two places, it will affect people's wayfinding efficiency to a certain extent;
 - b. People's environmental cognition is positively related to familiarity. When going to a place where there's a memory of the environment but visit less frequently, the cognitive map may be blurred and affect the efficiency of wayfinding;
 - c. When the destination has multiple passable entrances, people tend to choose the route according to the easiest and fastest entrance along the way.

4.3. Quest task

4.3.1. Content

University campus users are sometimes faced with occasions where they need to go to unfamiliar or unvisited locations to participate in work and study. Therefore, this part study how they use digital maps to go to teaching buildings that they have never visited. In this stage, participants were asked to use a digital map to go to two unfamiliar locations on campus and find the main entrance of each destination. During the whole task, participants were asked to judge and find routes only through Google Maps, and could not seek the help of other wayfinding systems such as signage and campus map boards. No time limit was set in this task, which provided enough time for participants to complete the task. At the same time, participants were allowed to abandon the task for any reason during the experiment. When participants used Google Maps to find their way, each location was presented with

multiple alternative routes to get to. When selected the two destinations, they met the following requirements:

1. Both destinations allow the map to show multiple roads leading to destinations (Figure 4.2, Figure 4.3).

Figure 4.2. Routes to Destination A provided by Google Maps (Laidlaw Library to School of Mathematics)

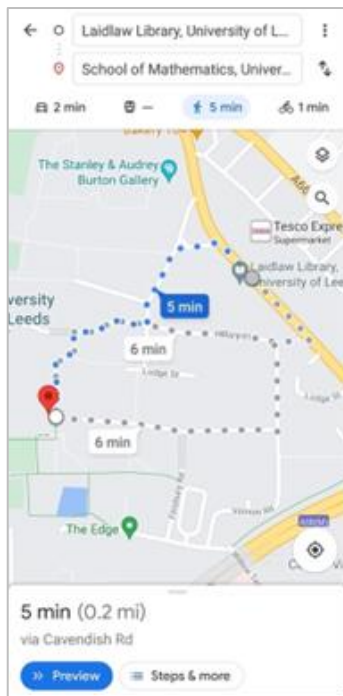


Figure 4.3. Routes to Destination B provided by Google Maps (School of Mathematics to Irene Manton Building)



2. Wayfinding to the two locations has different levels of difficulty:

a. Destination A (School of Mathematics, University of Leeds):

- i. The start point is Laidlaw Library, University of Leeds, which is also the end point of the commute task. This allows participants to directly start the quest task after completing the commute task;
- ii. Routes given by Google Maps are wide roads;
- iii. The entrance to the destination can be reached according to the navigation of the map.

b. Destination B (Irene Manton Building, University of Leeds):

- i. The start point is School of Mathematics, University of Leeds, which is the end point of the last task;
- ii. There is an altitude difference between the start position and the destination;
- iii. Arrival routes given by Google Maps are more complicated: need to pass through unusual paths (gardens, slopes, stairs);
- iv. The entrance of the destination cannot be found according to the navigation of the map.

4.3.2. Participants' completion of tasks

In this research, a total of 13 participants took part in the task, and valid data from 12 participants was harvested. One participant successfully completed the first task, which was to find the entrance to Destination A (School of Mathematics, University of Leeds). However, when looked for Destination B (Irene Manton Building, University of Leeds), after 41min 1s of wayfinding the participant still could not complete the task and finally gave up. Therefore, the participant's data is invalid.

Strava was used to track participants' time and route in the experiment. Additionally, the time it took for them to stop wayfinding and check the map during the experiment were

recorded through observation. The data for the 12 participants are shown in Table 4.3.

Table 4.3. Participants' data in the quest task

N o.	Map format	Start location	End location	Distance	Time using	Stop time	Shortest route or not
1	Satellite	Laidlaw Library	School of Math	0.17km	2:58	0:58	Y
		School of Math	Irene Manton	0.68km	13:22	6:05	N
2	Satellite	Laidlaw Library	School of Math	0.22km	2:52	0:36	Y
		School of Math	Irene Manton	0.74km	13:31	6:23	N
3	Standard	Laidlaw Library	School of Math	0.17km	2:05	0:09	Y
		School of Math	Irene Manton	1.59km	32:34	16:37	N
4	Standard	Laidlaw Library	School of Math	0.37km	6:23	2:12	N
		School of Math	Irene Manton	1.18km	24:26	12:02	N
5	Satellite	Laidlaw Library	School of Math	0.17km	1:52	0:35	Y
		School of Math	Irene Manton	0.88km	15:07	6:25	N
6	Standard	Laidlaw Library	School of Math	0.23km	3:20	0:38	Y
		School of Math	Irene Manton	1.16km	23:20	11:08	N
7	Standard	Laidlaw Library	School of Math	0.21km	3:02	0:49	Y
		School of Math	Irene Manton	1.08km	22:24	11:00	N
8	Satellite	Laidlaw Library	School of Math	0.21km	2:50	0:36	Y
		School of Math	Irene Manton	0.84km	14:49	6:02	N
9	Standard	Laidlaw Library	School of Math	0.20km	2:58	0:32	Y
		School of Math	Irene Manton	1.54km	30:42	15:32	N
10	Standard	Laidlaw Library	School of Math	0.18km	2:42	0:24	Y
		School of Math	Irene Manton	1.51km	31:56	16:07	N
11	Standard	Laidlaw Library	School of Math	0.32km	3:35	1:03	N
		School of Math	Irene Manton	1.11km	18:50	8:04	N
12	Satellite	Laidlaw Library	School of Math	0.17km	2:12	0:21	Y
		School of Math	Irene Manton	0.96km	16:31	7:26	N

Table 4.3 also shows whether the participant followed the shortest route to reach the destination. Since there is no straight-line route to reach the destinations, the judgment on the shortest route depends on whether the distance experienced by the user is close to the distance that can be reached through the straight-line to the destination. Similar to the judgment of the shortest distance in the previous task (commute task), the shortest route is

considered to be the route with the fewest turns and the most straight-line distance between two points. It can be seen that in the task of Destination A, 10 participants took the shortest route, and 2 participants took a longer route to reach the destination. In the task of Destination B, none of the participants used the shortest route to reach their destination.

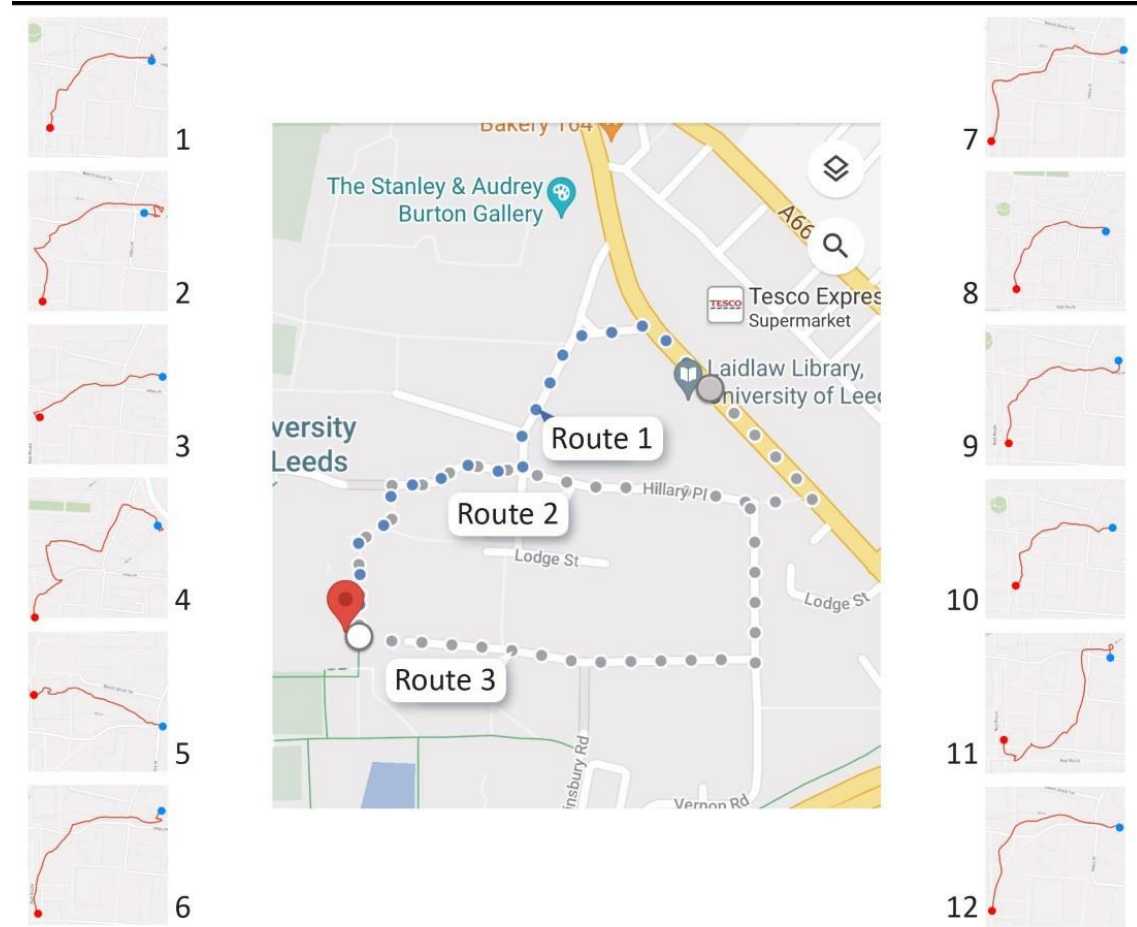
For the selection of the map appearance, 5 participants chose the satellite mode, and 7 participants chose to use the standard mode.

In the experiment the behaviour of participants was observed, the route taken by participants was video recorded, and participants were asked to speak out when making a decision or feeling confused through the Think-aloud method. Recordings were used to collect participants' thoughts and decisions on the way to complete the experiment. A detailed analysis of participants' problems in finding the way to the two destinations is conducted.

4.3.3. Data analysis of task A

Because this experiment tends to collect various problems that people have when they use digital maps to find ways on campus, there is no time limit for participants. This means that they can freely choose which way they want to follow to reach their destination. The route of participants can be seen in Figure 4.4. The route recording application displayed the route they took when wayfinding as a line on the map (image 1-12 in Figure 4.4). Here, the blue and red dots indicate the starting and end points respectively. The route record maps of participants are shown in *Appendix V*. Due to the different final destinations chosen by the participants in the commute task (different accessible entrances to Laidlaw Library), the starting points of their route maps were different in Figure 4.4.

Figure 4.4. Participants' routes to Destination A.



Participant No.	Route choice	Follow the route or not	Distance	Is it the shortest route
1	Route 1	Y	0.17km	Y
2	Route 1	Y	0.22km	Y
3	Route 1	Y	0.17km	Y
4	Route 1	N	0.37km	N
5	Route 1	Y	0.17km	Y
6	Route 1	Y	0.23km	Y
7	Route 1	Y	0.21km	Y
8	Route 1	Y	0.21km	Y
9	Route 1	Y	0.20km	Y
10	Route 1	Y	0.18km	Y
11	Route 2	N	0.32km	N
12	Route 1	Y	0.17km	Y

For Destination A, if the shortest route was taken, participants would pass through a road, a path, and a lawn with a pedestrian path (Figure 4.5). This route is provided by Google Maps and is indicated by Route 1 with blue dots in Figure 4.4.

Figure 4.5. The shortest route to Destination A (road, path and lawn)



Before the start of the experiment, participants chose the route to follow. Among them, 11 participants chose Route 1, and 1 participant chose Route 2. The reasons for their choice of route are shown in Table 4.4.

Table 4.4. Participants' reasons of route choices in Destination A Task

No.	Route choice	Reason
1	Route 1	I chose to follow the first route recommended to me by the map.
2	Route 1	Its time-consuming is relatively short, and it is the route recommended by the map.
3	Route 1	It is the route recommended by the map.
4	Route 1	It doesn't seem to need a detour.
5	Route 1	The map recommended it, and these three routes took about the same time, so I chose the route in blue recommended by the map.
6	Route 1	This route is marked blue, so I think it should be the most suitable route.
7	Route 1	It looks relatively short.
8	Route 1	The first recommendation on map is it.
9	Route 1	The first recommendation on map is it.
10	Route 1	The other two seem to be detours.
11	Route 2	The route in middle feels that it will pass more scenery.
12	Route 1	I didn't want to choose another route, the map gave me a choice, then I followed.

Among participants who chose Route 1, 8 of them chose because of map recommendations. Three participants compared three routes on the map and concluded that Route 1 was shorter. Participant 11 chose Route 2, and therefore did not reach Destination A through the shortest route. Participant 4 encountered the problem of positioning point offset during the wayfinding process. **The participant was unable to match their location with the map location, so they deviated from the route.** Digital maps, with their Global Positioning System (GPS), allow users to more concisely locate themselves on the map. The experience of participant 4 requires caution: when the user's position on the digital map is offset, or cannot be positioned, can they still successfully identify the correspondence between their position on the map and the physical environment? This gave this research a bold challenge:

Does the test of digital map legibility must rely on its navigation function? In *Experiment*

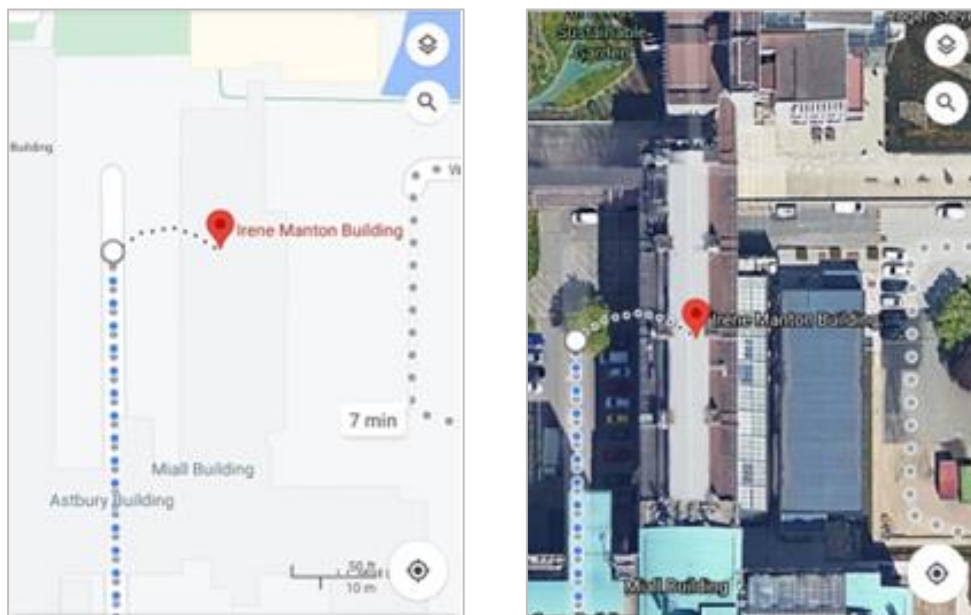
III, the navigation function of the digital map was disabled, and participants used the designed map prototype to plan routes and find ways to evaluate the information legibility of the prototype (see Chapter 5 for more details).

In this task, the roads they passed are all wide roads, with a wide view, and there is no altitude difference between the destination and the original place. In such a simple environment, the user's wayfinding efficiency is relatively high, and the digital map is more practical in this environment.

4.3.4. Data analysis of task B

For Destination B, participants faced more challenges: more sideroads, stairs, paths, gardens, and so on. In this task, the biggest difficulty for participants was to find the main entrance of Destination B. As shown in Figure 4.6, the marked location of Destination B on Google Maps lies in the centre of the target building, and following the route provided by the map cannot help participants reach the entrance.

Figure 4.6. The position of Destination B on Google Maps



The Irene Manton Building is part of the Faculty of Biological Science. However, in the search

interface of Google Maps, there is no correlation between them. To reach the main entrance of the destination, the user must pass through an outdoor corridor and enter from the second floor of the building instead of the ground floor (Figure 4.7).

Figure 4.7. Main entrance of Destination B (Irene Manton Building, University of Leeds)



For Destination B, if participants want to reach the destination through the shortest route, they need to reach a square through the stairs near Destination A, then pass through the square and a small garden and pass through a link corridor (Figure 4.8). However, none of the three routes given by Google Maps could reach and enter the destination building during the task. Instead, the user would be guided to the back of the target building complex, where there is only one emergency exit that is not open. If the user followed the map navigation, they would not be able to enter the building. This comes from the particularity of campus architecture, the complex buildings of universities often have more than one entrance. However, most of them are used as emergency exits, and users cannot enter or exit the building through them in daily life. When the route guided by the digital map is an inaccessible door, its wayfinding navigation fails. The user must find the right entrance through other means.

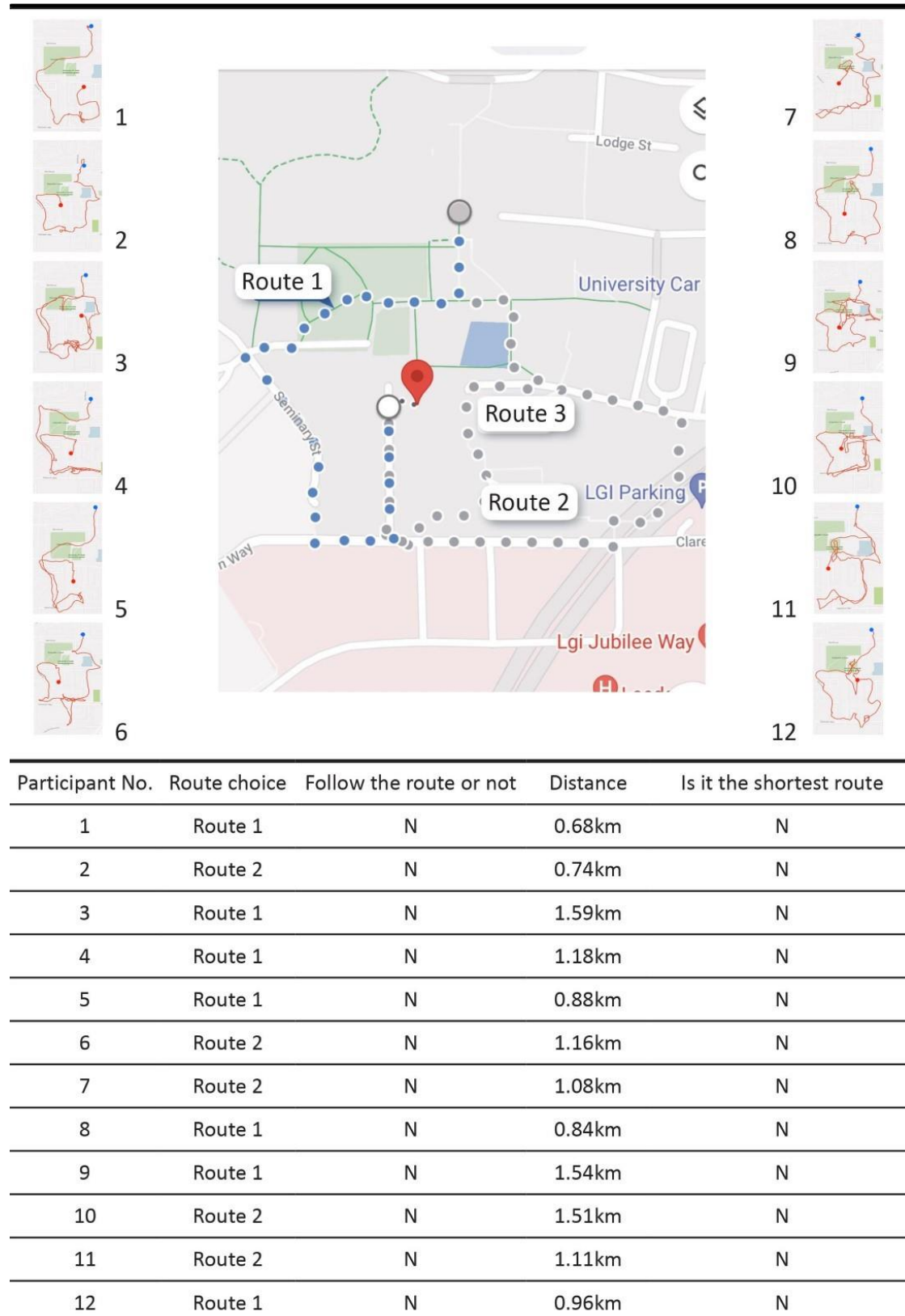
Figure 4.8. The shortest route to Destination B (stairs, square, garden and corridor)



The routes followed by the participants can be seen in Figure 4.9. The blue and red dots

indicate the starting and end points respectively. Clear route record maps can be viewed in *Appendix VI*.

Figure 4.9. Participants' routes to Destination B.



Since there was no single route that can take participants to the correct place, all participants chose to continue their wayfinding in their own way after discovering that they could not follow the route provided by the map. Participants were asked to find ways to seek help only including Google Maps and recorded their reasons when they started choosing the route and decisions they made when they got lost to help them find the right destination again (Table 4.5).

Table 4.5. Participants' reasons of route choices and decisions when getting lost in Destination B Task

No.	Route choice	Reason	Decisions when lost the way
1	Route 1	It takes shortest time.	This building is shown on the map, I can try to get closer to the marked point.
2	Route 2	I don't want to pass the road allows car to go through.	Using satellite mode I can see these buildings; I can try to find out where I can pass through the entire environment shown on the map.
3	Route 1	It is the route recommended by the map.	I can realise that where the building is, so I need to get my positioning point close to the target mark.
4	Route 1	It is the first route provided.	I don't know which entrance is the accessible entrance, so I check every door of the building to see if I can enter.
5	Route 1	It is the first choice by the map.	I look at photos provided by the map and try to close to the target mark.
6	Route 2	I don't want to pass garden.	I follow the map and circle the building to find the entrance.
7	Route 2	Time is shorter.	The different altitudes dazzle me, and I have to go back and forth up and down to find the way.
8	Route 1	The first recommendation on the map is it.	It tells me where the building is but not the way, I will use the map to see if I'm on the right way because there is a mark on it of this building.
9	Route 1	The first recommendation on the map is it.	I think the map is correct about the mark. So I will go close to the mark on the map.
10	Route 2	It looks shorter.	I look at photos provided by map.
11	Route 2	It looks shorter.	When I realise that where the building is, I try every path I can pass to go close to the building.
12	Route 1	The first recommendation on the map is it.	The mark is the centre of the building, so I can find the building through it.

For Destination B, 7 participants chose Route 1. The reason for 6 of them is that Route 1 is the route initially provided by the map. 1 participant chose it due to its short time.

The other 5 participants chose Route 2. Two of them came to the conclusion that Route 2 was shorter after comparing the three routes. One participant did not want to cross a road that allowed cars to pass (Route 1 and Route 3 both cross the road), one participant did not want to go through the garden, and one participant thought it was relatively short. None of participants chose Route 3. This may be because the map suggested that it took the longest time.

After following the route provided by the map and being unable to reach the destination, participants took different ways to complete the task. Six of them realised that they could use the **marked point** on the map as the destination. Two participants identified the **shape of the building** on the map to find a passable route. Two of them tried to identify whether the target building was correct through the **pictures** provided on the map. Four participants chose to **walk around** the building to find the main entrance.

It can be seen that when the navigation failed, 33.3% of the participants believed that they have reached the destination and no longer seek help from the map but find the entrance by themselves; 50% of the participants agreed that the marked point of the target building should be the end point, and took actions to position themselves as close to the marked point as possible; only a small number of participants realised that Google Maps could be interactive to view photos of the target building when navigation was ineffective. Two possible options to improve the legibility of digital maps can be drawn from this:

1. When a target mark is displayed on the map, if the target destination is a building on campus, it is easier to guide people to find the way if the mark is at the accessible entrance of the building than in the centre of the building shape;
2. Adding entrance markers to buildings may help users determine how to enter.

In the process of finding their way, participants spent a lot of time stopping to check the map, and wandering back and forth in the sections of the road that had been passed due to

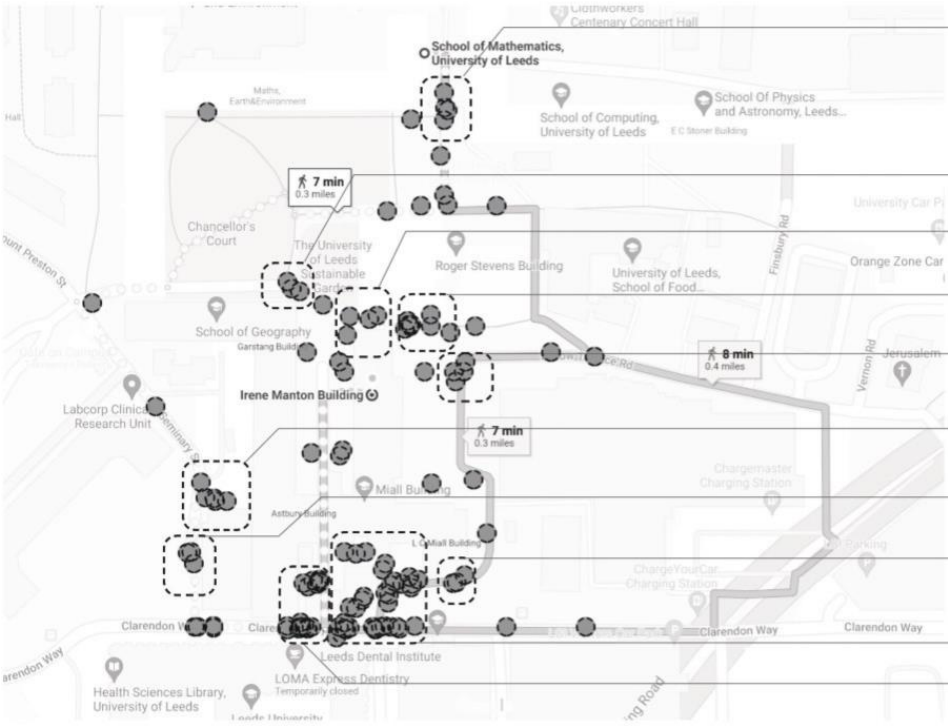
the wrong navigation of the map. In this task, participants used different map appearances that may have affected their wayfinding efficiency. Therefore, participants' wayfinding behaviour is analysed from three aspects: high-frequency stop areas, wandering areas and map appearance.

4.3.4.1. High frequency stopping areas

Strava was used to record participants' movement and time during the test, and compared them with videos, marking participants' stopping position on the map. After superimposing the stop position markers of the 12 participants, 10 high-frequency stop areas (Table 4.6) were obtained. The selection criteria are that the stay markers in these areas are more concentrated.

For the description of the areas, as shown in Table 4.6, the following points are considered: a) the total number of stops in each area; b) whether the view of the area is wide or narrow; c) whether there is a geographic height difference in the area (such as building floor gap, stairs up and down, slope, etc.); d) the number of optional walking directions in the area; e) whether the area is on the route provided by the map.

Table 4.6. Participants stop positions and description of high-frequency stop areas in Destination B Task

Stop positions		High-frequency stop areas			
		A1			
		A2			
		A3			
		A4			
		A5			
		A6			
		A7			
		A8			
		A9			
		A10			
Area No.	Description				
	Num of stops	Viewing angle	Height difference	Num of optional directions	Whether it is on the map route
A1	4	wide	N	3	Y
A2	3	wide	N	2	N
A3	4	narrow	Y	3	N
A4	8	wide	Y	2	N
A5	4	wide	N	2	Y
A6	5	wide	N	2	Y
A7	3	narrow	Y	1	Y
A8	3	narrow	Y	1	Y
A9	34	narrow	N	3	Y
A10	19	narrow	N	2	Y

The judgment of whether the field of view is wide or narrow is based on whether the walkable route in the area can be clearly distinguished. For example, when the optional

walking route in the area can be clearly identified in the real environment, and the participant's challenge is only to determine which road to choose, the area is defined as a wide field of view; when alternative routes are blocked (such as buildings, bicycle sheds, plants, etc.) or are difficult to distinguish, and the participant's challenge is to find a way out, the area is defined as a narrow field of view. The conditions of each high-frequency stop area are described in detail below.

AREA 1 – Square.

Area 1 is the first choice participants face in this task. Participants here have a wide field of vision (Figure 4.10). Four participants stopped here. The reason for their stay is that the routes provided by Google Maps are about to separate here (As shown in Figure 4.4). Among them, 3 participants stopped here to identify the route, and 1 participant was unable to judge their location due to the drift of the positioning point. The automatic positioning error or failure of digital maps is undoubtedly an important reason that affects the efficiency of wayfinding, because people's correct positioning of themselves in space is a very important factor in completing wayfinding tasks.

Figure 4.10. Area 1 – Square



AREA 2 – Near destination.

There were 3 stays in Area 2. Participants had already identified the destination location when passing through this area, and the three stops were to check whether the marked point on the map was near the area. Area 2 is close to a campus building, and the destination can be clearly identified by the signs on the building within the field of vision (Figure 4.11). However, since the route given by the map is opposite to the direction of the field of view, participants could not recognise the destination when following the map route to find the way. All stops in this area occurred after participants gave up following the map route navigation.

Figure 4.11. Area 2 – Near destination



AREA 3 – Ground floor of the destination.

Area 3 is located on the ground floor of the destination building (Figure 4.12). Participants can confirm the building as the destination through the signs on the building on the ground floor of the destination. However, the ground floor does not have an accessible entrance. There were 4 stops in this area. After finding the target building, participants could not find the accessible entrance on the ground floor, so they tried to find its entrance by reading

Google Maps. All stops in this area occurred after participants gave up following the map route navigation.

Figure 4.12. Area 3 – Ground floor of destination



AREA 4 – First floor of the destination.

A total of 8 stays occurred in area 4. This is the first floor of the destination building (Figure 4.13), and participants can reach it through the stairs on the ground floor. Participants can identify the destination through the signs on the building. However, they could not find the entrance in this area since the accessible entrance is not on this floor. Participants stopped in this area and not only looked at their location on the map. During two stops, participants looked at the photos on the map to determine the direction they should go. All participants during the stay carefully analysed the surrounding environment, hoping to find a path to the entrance. All stays in this area occurred after participants gave up following the map to find their way.

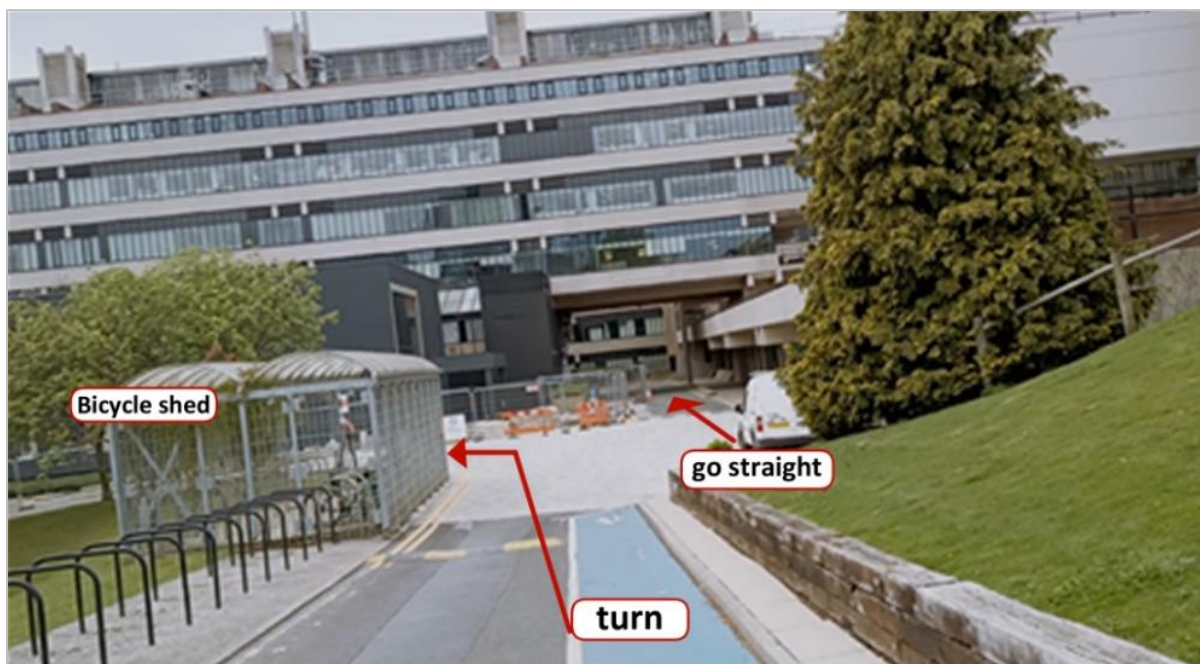
Figure 4.13. Area 4 – First floor of destination



AREA 5 – A corner of Route 2.

Area 5 is on Route 2, and there were 4 stops in this area. Participants can choose to follow the route to turn or go straight (Figure 4.14). Due to the visual obstruction (bicycle shed) at the turning intersection, participants had certain difficulties in accurately positioning themselves. This is the reason for all stays. Participants wanted to make sure that they turn in the right place.

Figure 4.14. Area 5 – Corner



AREA 6 – An entrance on Route 1.

Area 6 is on Route 1, and there were 5 stops in this area. However, all stops occurred after participants gave up following the route provided by the map. All stays in this area came from repeatedly passing through the area. The reason for staying is that there is a door that might enter the building near the area (Figure 4.15). Participants checked the marked point of the target building on the map to judge the distance between themselves and the destination, so as to determine whether it is the main entrance.

Figure 4.15. Area 6 – An entrance



AREA 7 – The end of a road.

The viewing angle of Area 7 is very narrow, and there were 3 stops here. It is located at the end of a road (Figure 4.16). Participants passed through this area when they chose Route 1. During the three stops, two of them expressed doubts, believing that there is no road to pass in the visual environment, even though the map indicated that this is the correct route. A participant realised that they were going to pass a flight of stairs. They had doubts about the navigation of the map, thought that the route has deviated too far from the marked point, so that needed to confirm whether they have deviated from the route.

Figure 4.16. Area 7 – End of the road



Figure 4.17. Area 8 – Stairs



AREA 8 – Stairs.

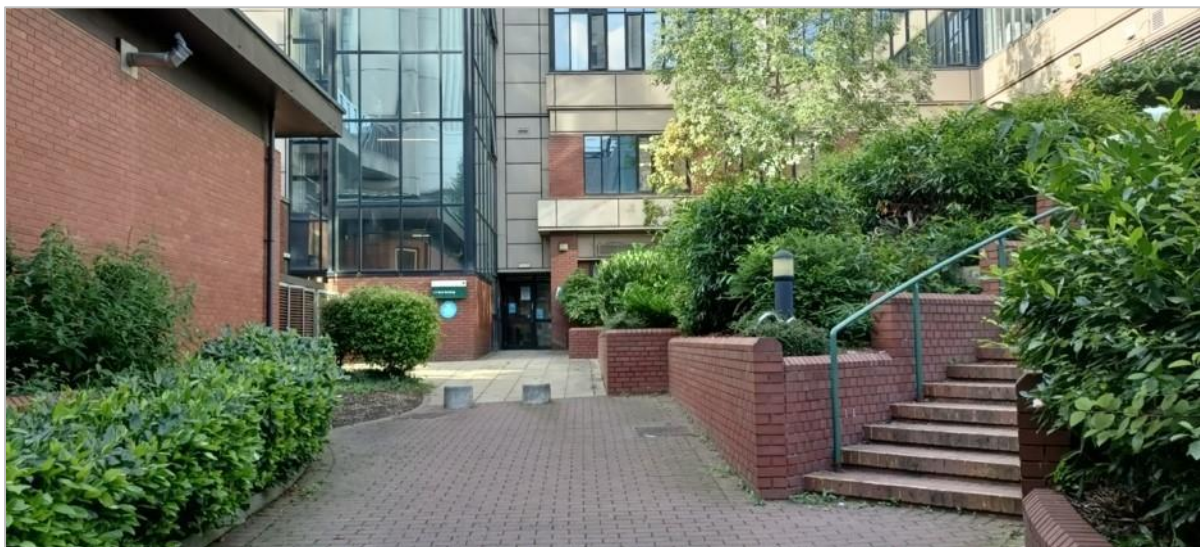
Area 8 is at the end of a flight of stairs (Figure 4.17), which is located on Route 2. However, there were 3 stops in this area, and they all appeared after participants gave up following the map route navigation. This area is accompanied by a height difference, and "this is not like a road" (feedback from a participant). During the 3 stops, participants were comparing

the distance between their location and the marked point. The narrow field of view and environment made participants wonder whether this road is passable.

AREA 9 – End point 1 of route guidance.

The number of stays in area 9 is 34. This is because the three routes provided by the map ultimately point to the vicinity of area 9 and area 10. Participants were very confused in this area because they are not sure where the accessible entrance is. The map near here provides a straight route, but participants can only see one building that cannot be passed through by following the map route. In addition, the environment of this area is very complicated. It has an emergency exit hidden in the corner of the building, a visible fire door, a road leading to Route 3, and a flight of stairs (Figure 4.18). Participants kept checking the map in this area to identify their location, and asked, "Is this here", "Is this the entrance", and "Is it here to go in" (all from participants' feedbacks during the test). Participants stayed in this area repeatedly and checked Google Maps carefully after moving a short distance. This is why there are so many stays in this area. Participants spent a lot of time wandering in this area.

Figure 4.18. Area 9 – End point 1



AREA 10 – End point 2 of route guidance.

The number of stays in this area is 19. The reason why it is less than that in area 9 is partly due to the complexity of the environment. Area 10 is also located near the intersection of the three routes provided by the map. The videos show that all participants regarded this area as the passing area of the last section of the road. However, this area is the courtyard of a building. Blocking participants' route included the impassable building and an emergency exit (Figure 4.19). Participants stayed and wandered in this area, carefully checking the map to find a passable path, which is the reason why there are so many stays in this area. When participants stayed in this area, they raised doubts such as "this direction pointed by the map", "only here can turn", and "this should be the entrance".

Figure 4.19. Area 10 – End point 2



SUMMARY

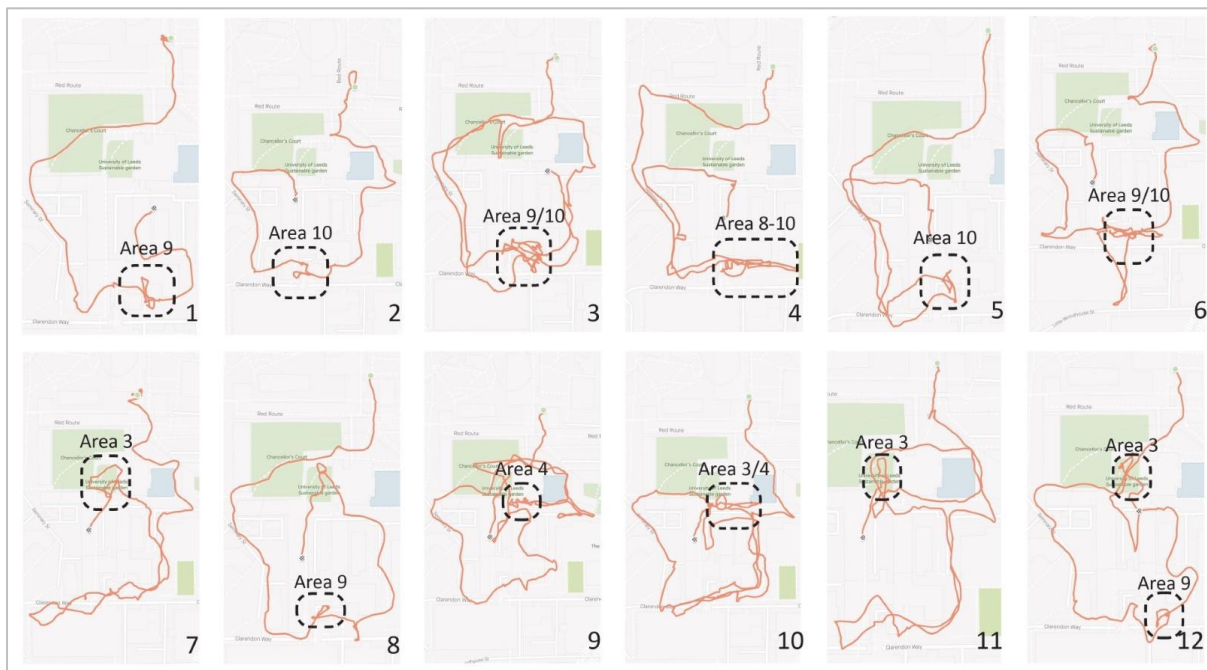
In the analysis of high frequency stopping areas, all stop positions of participants in the Destination B task were marked and summarised on the map, and 10 high-frequency areas were selected. After analysing the behaviours and difficulties encountered by participants while staying, the following conclusions can be drawn:

1. When people face multiple directions to choose from, they find it difficult to find their way (Area 1, Area 5, Area 6, Area 9).
2. Unusual terrain (small roads, visual blind spots) affects people's judgment when looking for a way (Area 7, Area 8).
3. When looking for the building entrance on campus, if the accessible entrance cannot be accurately located, the user will encounter difficulties in finding the way (Area 2, Area 3, Area 4, Area 6, Area 9, Area 10).
4. Visual obstruction makes it easy for people to miss their destinations when finding their way on campus (Area 2, Area 5).
5. Wayfinding difficulties caused by differences in elevation, make it difficult for users to accurately judge the route or building composition (Area 3, Area 4, Area 7, Area 8).

4.3.4.2. Participants wandering areas

For Destination B, since none of the three routes suggested by the map can guide the participant to the main entrance of Destination B, participants spent a lot of time repeatedly passing through some road sections. Strava recorded the routes that participants took during the task, and it can be found that they walked back and forth repeatedly in some areas (Figure 4.20). Repeated sections on the route tracking maps of the 12 participants are marked. The selection criterion is the area where participants wandered repeatedly, which was compared with the route tracking map by Strava.

Figure 4.20. Participants' repeated route sections in route record maps



In the high-frequency stop areas analysis, 10 high-frequency stay areas were selected. In the selection of repeated road sections, it can be seen that they are all included in these areas. This is because participants stayed in these areas and wandered back and forth. They were unable to confirm the correct direction in these areas, so they repeatedly identified. In the area where participants wandered repeatedly, Area 3 appeared 4 times, Area 4 appeared 2 times, Area 8 appeared once, Area 9 appeared 6 times, and Area 10 appeared 5 times.

Among them, Area 8, Area 9 and Area 10 occurred when participants followed the map navigation. The reason why they wandered in these three areas is that they couldn't find a passable route. In the case of Area 3, participants had successfully found Destination B, but couldn't reach its main entrance. This also further supports that the inability to navigate to the building entrance causes difficulty in finding the way on campus.

On the other hand, as shown in Table 4.7, during the experiment, participants wandered in the narrow field of view much more often than the wide field of view.

Table 4.7. Participant's wandering area vision.

Participant No.	Area No.				
	Area 3	Area 4	Area 8	Area 9	Area 10
1					
2					
3					
4					
5					
6					
7					
8					
9					
10					
11					
12					



In the above-mentioned narrow viewing angle areas, the obstacles that block the field of view are all buildings on the campus. The university environment often includes a complex group of buildings and has a certain degree of greening and landscape. This allows the university campus to have not only roads that allow vehicles to pass, but also trails that are only for pedestrians. The complicated environment may cause users to face obstruction of the field of vision in the campus wayfinding process. When accessible routes are not shown on the map, such as the ground floor platform of the target building in Area 3, and the stairs

in Area 8, even if the navigation indicates "go this way", there is no road within the field of view, and the map information is not enough for the user to identify the existence of the road. In this case, it will have an impact on the efficiency of wayfinding.

4.3.4.3. Effect of map appearance

Google Maps provides two map modes for users to use. In this experiment, according to the participant's preference for the map appearance, participants were allowed to choose any map mode to use. Five participants used the satellite mode, and the other seven chose the standard mode.

Since in the task of destination B, the navigation provided by the map failed to allow participants to complete the task and successfully reach the entrance of the target building, all participants gave up the navigation function of Google Maps after judging that the navigation was invalid. Instead, they relied on themselves to distinguish and compare real-world environment and map information to complete the task. Different modes of maps may affect their readability to a certain extent, making people's perception of the environment and ability to understand map information different. Table 4.8 shows data from participants completing the Destination B task.

Table 4.8. Participants' data in Destination B Task.

Participant No.	Map mode	Distance	Time consuming	Stop time
1	Satellite	0.68km	13:22	6:05
2	Satellite	0.74km	13:31	6:23
3	Standard	1.59km	32:34	16:37
4	Standard	1.18km	24:26	12:02
5	Satellite	0.88km	15:07	6:25
6	Standard	1.16km	23:20	11:08
7	Standard	1.08km	22:24	11:00
8	Satellite	0.84km	14:49	6:02
9	Standard	1.54km	30:42	15:32
10	Standard	1.51km	31:56	16:07

Participant No.	Map mode	Distance	Time consuming	Stop time
11	Standard	1.11km	18:50	8:04
12	Satellite	0.96km	16:31	7:26

In terms of distance, the average distance for participants used satellite-mode maps to complete tasks is 0.82km, while that for standard-mode maps is 1.31km. For the time it took to complete the task, the average time in the satellite mode is 14:40min/s, while the standard mode is 30:31min/s. Regarding the length of time participants stopped to check the map while completing the task, the average time in satellite mode is 6:28 min/s, and in standard mode it is 12:55 min/s.

Through comparison, it can be known that in campus wayfinding, when the map navigation cannot successfully bring the user to the destination, using the satellite mode requires a shorter distance and less time to reach the destination than the standard mode. This may be due to the complexity of the campus environment, and the satellite mode can make it easier to identify the distribution of buildings and the passable paths.

At the same time, in the process of tracking and observing participants in the experiment, participants who used the satellite mode gave some feedback such as "the building is shown on the map", "I can find out where I can pass through the entire environment shown on the map". Participants using satellite mode could perceive the environment more efficiently than using standard mode.

4.3.4.4. Summary

For Destination B, the Irene Manton Building of the University of Leeds was chosen as the destination and asked participants to find its main entrance. In a complex environment and with inaccurate navigation, participants encountered many difficulties in the process of completing this task. The analysis of the data was carried out from three aspects: the stop position, the repeated road section and the map appearance.

Ten high-frequency stop areas were selected and the reasons why participants stopped were analysed in detail. The stay area covers the repeated road sections, and it can be more intuitive to understand in what kind of environment on campus that users faced, they were more likely to get lost. At the same time, the selection of the map appearance has a certain degree of influence on the efficiency of completing this task. The following conclusions can be drawn:

1. Uncommon terrain affects the user's judgment when finding their way.
2. When finding a way on campus, if the destination is inside the building, whether the map navigation can guide the user to the accessible entrance is the key to the success of the way finding.
3. If the campus environment has altitude differences, users are prone to get lost when finding their way.
4. When the map navigation on campus fails, the satellite mode map has better readability and wayfinding efficiency.

4.3.5. Conclusion

The university environment is complex, and the main users often need to enter different teaching buildings to participate in academic work and study such as courses or conferences. In the analysis of existing navigation software (such as Google Maps), it is found that the navigation destination of digital maps is often located in the centre of the building. Based on the user's need to enter the building, in the quest task, University of Leeds was chosen as a case study and participants were asked to find the entrance of two campus buildings that they have never been to (Destination A, School of Mathematics and Destination B, Irene Manton Building). Due to the different surrounding environments, participants faced different levels of difficulty in finding the two destinations. The behaviours of participants were tracked and recorded in the task through observation methods, used a route tracking software (Strava) to record the route and performance of participants, and asked them to express their feelings, emotions and decisions during the task through think-aloud

methodology.

A total of 13 participants took part in this task, of which 12 valid data, with one participant choosing to abandon the task. After analysing the performance of the participants in the task of finding two destinations, the following conclusions were drawn:

1. The use efficiency of the existing digital maps decreases with the increase in the complexity of the campus environment.
2. When the altitude difference in the real environment cannot be displayed on the digital map, the user's wayfinding efficiency is affected.
3. When using digital maps to assist in wayfinding on campus, more consideration should be given to whether the route can lead the user to the accessible entrance of the destination.
4. The satellite mode map has higher environmental recognition than the standard mode map.

In this experiment, participants were given enough time to carry out the task, that is, to find the destination entrance without time limit. However, in the daily life of campus users, they are often required to go to lectures, classes, or meeting locations at specific times. This means that they need to complete the wayfinding activities within a limited time. When users are unfamiliar with the destination or have never been to the destination, digital maps that cannot successfully bring them to the destination will cause users to have negative emotions and make people doubt the correctness of map navigation.

In addition, two problems related to positioning and navigation emerged during the task: a) the automatic positioning offset of the digital map affects the user's ability to position themselves in the real environment; b) navigation routes cannot meet the wayfinding requirements of an academic environment and calculate a route to an accessible entrance of a destination building. We have to consider how people read map information to orient themselves and identify environmental information when digital map navigation is incorrect. A bold idea was born through those two problems: when designing a digital map and

evaluating its legibility and usage efficiency, its positioning capabilities and navigation functions need to start from the map itself, rather than relying on the Global Positioning System.

4.4. Explore task

4.4.1. Content

Among the three tasks of wayfinding, the explore task is a purposeless exploration of the surrounding environment. The campus environment of the university is functional and visually diverse, including teaching buildings, landscapes, laboratory buildings and other facilities with different functions. In the visual survey of existing campus digital maps, it can be found that campus facilities are often classified for search. It is worth researching how the main users of the university explore the campus during their daily non-working hours, and which facilities on the campus are more attractive.

In this part, participants need to spend 10 minutes exploring the surrounding campus environment. The starting location was selected as The University of Leeds Sustainable Garden. The reason for choosing this place as the initial location is that the surrounding environment centred on it contains many different elements, such as greenery, pond, library, square, teaching building, comprehensive building, gym and so on. Another reason is that the initial location is close to the last end location of the quest task, making it easier for participants to start this task quickly. Figure 4.21 shows the selected location and surrounding facilities.

Figure 4.21. The University of Leeds Sustainable Garden and surrounding environment



When participants explored, they were asked to describe the factors that attracted them in the environment, their biases towards the attractiveness of the campus environment were collected through interviews and a questionnaire. In addition, with regard to the auxiliary capabilities of digital maps in exploring campus, Google Maps was used as an example, requiring participants to spend 10 minutes using the functions of Google Maps, and collected their suggestions for campus digital maps through a questionnaire (the complete questionnaire content can be viewed in *Appendix VII*). The analysis of the exploration task is divided into two aspects: the attractive factors of the campus environment and the functions of the digital map.

4.4.2. Analysis of the task

4.4.2.1. The attractive factors of the campus environment

During the exploration process, participants were tracked and asked to explore and describe campus facilities they found that attracted their attention. Information was collected after the exploration by questionnaire (Table 4.9).

Table 4.9. Places of the exploration

Participant No.	Places that the participant explored
1	Garden, lake, church.
2	Parkinson Building, Laidlaw Library.
3	Red tree, small lake with ducks.
4	A beautiful red tree and a long stair has never been.
5	The park, the small cafe car, sitting area, pond.
6	1) A beautiful and eye-grabbing pool which could be a landmark. 2) A unique building which is well designed and high enough to notice. 3) A map board, it has the overall view of the campus, and it is a good place to correct the way and decide where to go next.
7	Garden; pool; stairs; buildings; outdoor tables.
8	The garden, the picnic tables, the big buildings.
9	Garden, pool, steps near Edward building, Biological department.
10	School of biology area.
11	Irene Manton Building, a beautiful building.
12	A beautiful architecture.

Due to the limited exploration time, participants try to find as many factors as possible that attract them. After analysis, their findings can be divided into green places (parks, lakes), learning places (teaching buildings, libraries), unique buildings (buildings with a sense of design), and leisure places (coffee carts, outdoor seats). Among them, green places are the most attractive to participants, and it has appeared 12 times. Both unique buildings and leisure places appeared 4 times, and the number of times that learning places were considered attractive was 2. This shows that in purposeless exploration, **vision is more attractive than function.**

This is also consistent with the conclusion drawn from the questionnaire. In order to identify the elements that attract people during exploration, participants were asked to write down the factors that attracted them in the environment during the exploration process (Table 4.10). This is a process that allows participants to analyse their behaviour when completing tasks and summarise them. Compared to specific descriptions, participants' responses tend to be summarised. The visual factors in the environment are more attractive.

Table 4.10. Elements attracted participants during exploration

Participant No.	Elements can attract participants when exploring on campus
1	Green areas, animals, well-designed architectures.
2	Architectures.
3	River, planet, landmark buildings.
4	The beautiful appearance.
5	Appearance.
6	Something special and unique which is not appear in other places.
7	Highly contrast colour.
8	Greenery, comfortable environment.
9	Unique stuff, beautiful stuff, with many people around, easy to find the entrance.
10	Plants; restaurants; stylish buildings; outdoor settings.
11	The architecture of the buildings and flowers on the gardens.
12	Plants, well-designed building.

However, this is not consistent with the survey of campus facilities' attractiveness. According to the visual survey, campus facilities were divided into libraries, teaching buildings, multi-functional buildings, restaurants, landmarks and entertainments. Participants were asked to rate their interest in the facilities. As shown in Table 4.11, most participants believed that the selected campus facilities were attractive to them to explore. Among them, 11 participants expressed interest in landmarks, accounting for 91.7% of all participants. The restaurant came next, with 10 participants expressing interest, accounting for 83.3% of the total. 75% of participants are interested in libraries and teaching buildings. At the same time, 66.7% of them expressed interest in multi-functional buildings. More than half (58.3%) of participants

thought that entertainment was attractive.

Table 4.11. Participants' opinions of the attractiveness of campus facilities

Campus facilities	Opinions				
	Not interested at all	Not very interested	Neutral	Interested	Strongly interested
Libraries	1	0	2	5	4
	1			9	
Teaching buildings	0	1	2	6	3
	1			9	
Multi-purpose buildings	0	2	2	6	2
	2			8	
Restaurants	0	1	1	5	5
	1			10	
Landmarks	0	0	1	4	7
	0			11	
Entertainments	0	1	4	1	6
	1			7	

Comparing the above analysis, it can be found that when exploring freely, visual attractiveness is the biggest factor affecting the attention of wayfinding users. When considering campus facilities as a wayfinding direction, users have shown a certain degree of interest in different types of campus facilities. In the design of campus digital map, how to classify campus facilities should be considered, so that users can conveniently explore according to their own preferences. At the same time, the scenery that the user sees during the wayfinding process should also be considered how to be reflected in the digital map, so that the user can easily know and timely understand the content of interest. This is also consistent with the results reviewed in Chapter 2 that landmarks can enhance wayfinding instructions (Raubal and Winter, 2002; Çubukçu and Nasar, 2005; Davidson, 2014). However, since participants can find attention-grabbing factors in the physical environment during free exploration, the purpose of wayfinding is different from the previous two tasks (commute, quest). Whether the conclusions drawn here can be useful for wayfinding in other tasks still

needs to be discussed, especially quest tasks. Since people tend to follow familiar routes or complete wayfinding tasks by judging the surrounding environment, the efficiency and legibility of digital maps are more prominent in quest tasks. In *Experiment III*, the quest task was mainly used to evaluate the legibility of map information.

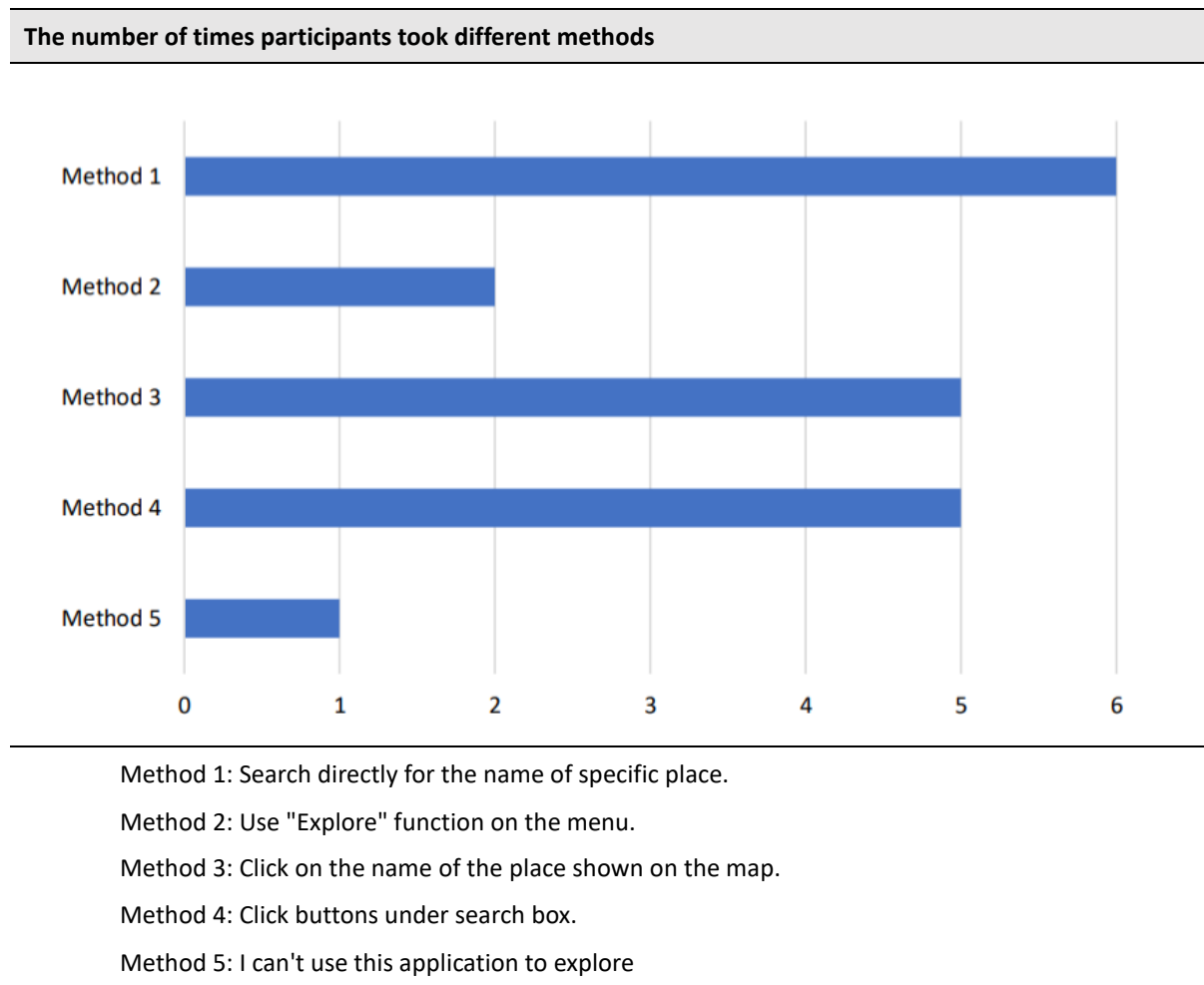
4.4.2.2. Digital map function

Based on the users' demand for the "exploration" function of the map shown in the previous questionnaire survey, Google Maps was used as the tool and participants were asked to spend 10 minutes browsing the functions of the digital map, and collect information on the facilities discovered during the free exploration session. Participants were asked to fill in their experience of using Google Maps in the questionnaire. This consists of two questions, namely:

1. How to find the place to be explored through Google Maps.
2. Problems encountered when using Google Maps to find the way.

When trying to explore through Google Maps, participants took several methods (Table 4.12).

Table 4.12. Methods and times participants explored using Google Maps



For a place with a known name, users often search for the place directly. This method appeared 6 times.

However, it is often difficult for participants to obtain information about unknown locations discovered during exploration. In the test, users took different methods to obtain information about unknown locations. Google Maps classified commonly used facilities by function (restaurants, grocery stores, cafes, etc.). Participants tried to click the classification buttons under the search box five times to identify the facilities contained in the surrounding environment by clicking on different categories. In addition, the user tried to click on the name of the place in the corresponding position on the map to obtain information. This way occurred 5 times. Participants found the "explore" function of the map twice. One participant could not use Google Maps to explore at all.

In these methods, when participants tried to find the places they explore through the classifications that come with the map, the classification of Google Maps could not meet the functions of campus facilities, and participants couldn't understand the information of the exploration locations in this way. When clicked on the corresponding location on the map, it was difficult for participants to distinguish whether the location they clicked corresponds to the location explored in the real environment. When acquired information through the "explore" function that came with the map, it was difficult for participants to get an introduction to campus facilities.

In addition, participants encountered some problems when using digital maps to explore the campus (Table 4.13).

Table 4.13. Problems that participants faced when using Google Maps

Participant	Problems participants faced when using Google Maps
1	No entrance instructions, and showing incorrect or inconvenience paths.
2	The real-time location is not accurate enough to help me making decisions at each conjunction points.
3	GPS inaccuracy, too many crossroads.
4	Not many ways that show on the map.
5	The route is not accurate.
6	It's so hard to find some place where their entrance is not very appealing, and some buildings are connected so you cannot find them in the map. Otherwise, some lane looks like not regular.
7	The direction of the arrow is wrong, especially at the beginning.
8	Lead me to the wrong location.
9	Sometimes, it guides you to a way which is obvious there is no way anymore. It can't tell you which floor it means to. The google maps can't work anymore when I go inside a building.
10	Sometimes it's confusing since it does not give the instructions precisely so I have to try to find the route on myself.
11	Sometimes google maps gives you unnecessary paths, or the pointer moves slower than you and then when you realise you are far away and have to return. Also the main problem that sometimes happens is that give you wrong directions and lead you to the wrong place, losing your time.
12	1. Sometimes there is a layback moment. 2. Cannot find the main entrance, just the central location of the place. 3. Incorrect leading sometimes, the algorithm might only focus the building itself, not that user-friendly to find the entrance for the building.

After analysis, it can be known that the problems faced by users when using digital maps to explore the campus may include:

1. The entrance to the building cannot be found through the digital map;
2. Digital maps lead users to incorrect/inconvenient roads;
3. Unable to locate oneself accurately and in real time when finding the way;
4. There are trails on the campus that do not appear on the map;
5. When the destination has an altitude difference, it cannot be displayed on the map;
6. It is not possible to conduct indoor navigation through digital maps.

Among them, Google Maps cannot navigate to the entrance of the building, provides wrong navigation, and cannot navigate to the destination with difference in altitude. These problems also caused participants to encounter many difficulties in completing the task in the quest task.

4.4.3. Summary

In the explore task, Google Maps was used as a tool to investigate the factors that participants paid more attention to when they explored purposelessly on campus and the help of digital maps for exploration.

When exploring the campus environment aimlessly, users pay more attention to the attractive visual elements in the environment. When the user cannot obtain the information of the exploration location from the environment, it is difficult to correspond to the information accurately and quickly on the map. How to reflect the scenery that the user is interested in in the process of wayfinding in the digital map, so that the user can more easily understand the relevant information is worthy of consideration.

At the same time, when categorising campus facilities, users should consider the needs of campus facility functions to ensure that the classification is comprehensive and correct, and help users quickly and conveniently find the places they want to explore according to their functions.

In addition, the navigation of the campus digital map needs to be combined with the campus environment. The university environment is complex, and users will have difficulty finding their way both outdoors and indoors. The map should help users find the destination correctly. When the destination is indoors, the navigation guide should not only be the location of the destination, but the entrance of the building. Due to the complexity of the environment, the correct path, and the altitude gap, accurate positioning should be taken seriously.

4.5. Conclusion

Wayfinding tasks can be divided into three types: quest, commute, and explore (Allen, 1999). This classification was subdivided in the literature review in conjunction with the purpose of wayfinding in academic settings and adopted as the types of tasks in this experiment. As users' hope that these three tasks can achieve good wayfinding efficiency when using campus digital maps in previous studies, University of Leeds was used as a case. Series of tasks were set up in order to investigate the performance of university users in completing these three tasks on campus. Google Maps was chosen as a tool to assist in wayfinding.

Among them, participants used Google Maps in the quest and explore tasks, and did not rely on any navigation system for wayfinding in the commute task. During the three tasks, participants' wayfinding behaviours and routes were observed, tracked, and recorded. Participants were asked to use think-aloud methodology to tell their decisions, emotions, and feelings during the three tasks. At the same time, the route tracking software Strava was used to record the route and walking speed of all participants. A questionnaire was used to collect participants' opinions and experience on the effectiveness of digital maps.

Due to the complexity of the University campus environment, each task was divided into several small tests according to the degree of difficulty to observe and analyse participants' wayfinding efficiency and problems in environments of varying degrees of complexity. After

analysis, the conclusions can be divided into three aspects: environmental complexity, map navigation efficiency, and user wayfinding purpose:

ENVIRONMENTAL COMPLEXITY

1. The user's wayfinding efficiency decreases with the increase of the complexity of the environment, and the demand for digital map navigation increases with the increase of the complexity of the environment;
2. When there is a change in the altitude of the destination, failure to indicate it on the map will make it difficult for users to find their way;
3. When the route to the destination is not a conventional outdoor route (carriage road, sidewalk, etc.), but a walking route belonging to the university campus (the walkable ground floor of the link building, trails, etc.), it will affect the efficiency of people's wayfinding.

MAP NAVIGATION EFFICIENCY

1. The appearance of the map affects the difficulty of corresponding to the map information and physical environment. Satellite mode shows better environmental recognition than standard mode;
2. Accurate positioning can help users identify routes more easily;
3. When the location on the map can quickly correspond to the real environment, the user's wayfinding efficiency is improved.

USER WAYFINDING PURPOSE

1. Users often need to reach a building on campus, and the navigation of the digital map should not only guide the user to the correct building, but guide the passable entrance of the building;
2. The categorisation of buildings of campus facilities needs to cater to user needs and help users find their destinations more conveniently based on functions of buildings.

At the same time, in this test, participants were given enough time in each task to complete it. This saved them from worrying about running out of time and causing anxiety. However, in the daily life of campus users, users often need to complete wayfinding activities within a limited time. Digital maps that fail to take them to their destinations will cause users to have negative emotions and make people doubt the correctness of map navigation.

In this experiment, an accidental situation brought new research ideas: a participant's positioning point drifted many times when using Google Maps, so that they had to spend a lot of time confirming whether their positioning was in the right location. A primary purpose of this research is to examine the role of user-centred map information design methods in improving the effectiveness of map design for campus wayfinding systems. The summarised information design principles are adopted in the map prototype design in the next chapter. There is a new idea on how to evaluate the map prototype: the object of evaluation is the legibility and usage efficiency of the information on the map, which should include the correspondence between the map's visual information and the physical environment. In this case, the normal operation of the Global Positioning System (GPS) will help the user locate on the digital map, reducing the difficulty of environmental recognition. The paper map can be used to evaluate the environmental recognition of the map prototype - this idea was adopted in *Experiment III*, and all current research contents were combined to design and evaluate a map prototype to obtain a more detailed and credible principles for campus digital map design.

5. Experiment III: Examining the effectiveness of campus digital maps with different layouts

In the previous chapters, the following research has been completed:

1. In **CHAPTER 2**: by analysing the existing literature, the basic concepts of wayfinding behaviour and the design principles of wayfinding systems were discussed, and the design principles of maps and digital maps were organised, as well as related research and challenges of campus wayfinding. The classification of campus wayfinding tasks derived from the literature review contributed to the task composition design of the three user experiments in this research. The framework of wayfinding system design principles constituted the research object of this research and the basic part of the campus digital map information design principles. On this basis, the existing literature on design map design theory and related cases was discussed in depth, and a framework of digital map design principles was constructed to form the evaluation reference for the visual survey in Chapter 3;
2. In **CHAPTER 3**: through user research and visual survey based on map design theories and information design principles derived from Chapter 2, the design limitations and development prospects of the existing campus digital map were clarified;
3. In **CHAPTER 4**: the University of Leeds campus environment was used as a case to test the wayfinding task in the academic environment, and the factors that affect users' wayfinding in the campus environment were summarised. Besides, it was proposed that testing the legibility of a digital map can exclude its automatic positioning and wayfinding functions and only focus on the map itself.

With the support of the above research, this chapter **first** integrated the conclusions obtained in Chapter 4, analysed additional visual information that may improve the efficiency of using digital maps in academic environments, and presented them in the research tool (Google Maps) of *Experiment II*. **Second**, a simple user test was developed to evaluate the legibility of the added visual information. After discussing the test results, the conclusions obtained in the previous chapters were compiled and more detailed digital map

design principles were listed, which were adopted in the **third** step of map prototype design. **Finally**, the A/B testing method was used to evaluate and compare the usage efficiency of map prototype under different layouts to explore the help of additional visual information on campus wayfinding behaviour and to make the design principles of campus digital maps more objective and credible. The content of the research will be explained in detail in this chapter. Through the analysis of the test results, practical design solutions to improve the efficiency of campus wayfinding will be derived.

5.1. Introduction

Based on the limitations of digital maps and current campus digital maps, as well as factors affecting wayfinding efficiency obtained in previous chapters, this chapter provides an in-depth analysis of the existing feasible improvements obtained in previous chapters:

1. Make complex environments easier to read through map information: indicate changes in altitude (indoor floors, outdoor height differences, etc.) through map information; display feasible routes through visual elements, whether they are regular outdoor routes or not (walkable ground floor through buildings, pathways, etc.).
2. Increase the correspondence and association between the map and the real environment, so that users can locate themselves more accurately and conveniently when using digital maps.
3. Meet the user's purpose when finding ways in an academic environment: enable the map to guide users to accessible entrances to the correct destination during navigation.

Based on the above improvement directions, taking the University of Leeds as a case study, this chapter uses A/B test methodology to evaluate whether the above improvement directions can effectively improve the efficiency of campus wayfinding.

The three main research objectives of this experiment are as follows:

1. To observe the performance and efficiency of different groups of participants in wayfinding tasks using different map prototypes.
2. To evaluate the readability of the map prototype and whether it improves the efficiency of completing tasks.
3. To understand people's perception of the correlation between maps and the real environment.

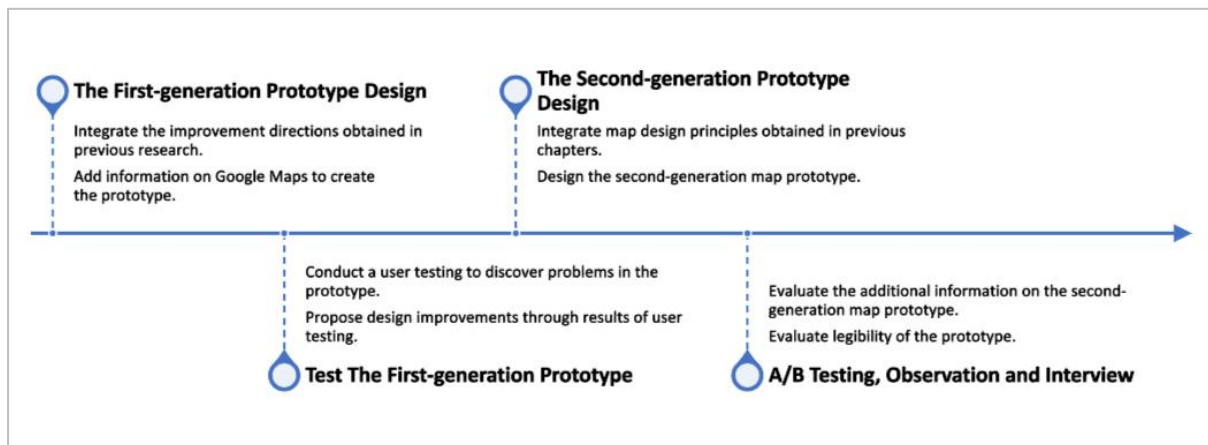
Under the requirements of the research objectives, this experiment raises the following research questions:

1. How is the readability and wayfinding efficiency of the redesigned digital campus map prototype?
2. Can people relate maps to real-world environments to locate themselves?

In order to achieve the research objectives and answer the research questions, the research designs and evaluates a campus map prototype. As shown in Figure 5.1, the experiment steps in four stages:

1. Based on improvement directions identified through the previous research, add information on Google Maps to design a prototype.
2. Conduct a user testing to investigate readability and identify areas of improvements to the prototype.
3. Based on map design principles obtained in previous research and improvements founded in stage 2, design the second-generation prototype for testing.
4. Conduct A/B testing to evaluate the impact of adding information on map usage efficiency, and evaluate map information legibility by observing participant behaviour during tasks and conducting interviews.

Figure 5.1. Stages of the map prototype design and evaluation.



In the experiment in Chapter 4, a situation occurred accidentally: the digital map positioning point drifted. This resulted in a significant impact on the wayfinding efficiency of the participant. At the same time, this incidental issue brings a challenge to this research: the evaluation of digital map legibility can abandon the support of the Global Positioning System (GPS). The views in the literature review support the progress of this challenge: Kent and Vujakovic (2019, p376) discussed that digital maps and paper maps have commonalities in information design, and their difference from traditional paper maps is reflected in their personalisation based on different purposes. For example, interactive map scale, search function, click on the screen to obtain target information, etc. (see Section 2.3.2 for a more detailed discussion). In addition, in the task of using map navigation for wayfinding in *Experiment II*, unclear positioning (the destination was marked in the centre of the building instead of the entrance) and wrong route navigation (the route to the destination following the navigation had inaccessible sections) all increased the difficulty of wayfinding. Consider the above questions and:

1. The information design of digital maps should not be discussed as a separate category of maps, they are the product of printed maps (Kent and Vujakovic, 2019);
2. Orienting oneself in space is particularly important in people's wayfinding behaviour (Lynch, 1960; Süzer, 2018; Tao et al., 2018; Wang et al., 2018). The automatic positioning of digital maps helps people quickly obtain their position in the

geographical environment, which makes it unreliable to test whether they can judge their position in space and reading efficiency through map information.

This chapter takes a bold step by using paper maps instead of digital maps to require participants to orient themselves, perceive the environment, and find their way entirely through map information to evaluate the readability and usage efficiency of the map prototype. This chapter details the design, content, and results of the test.

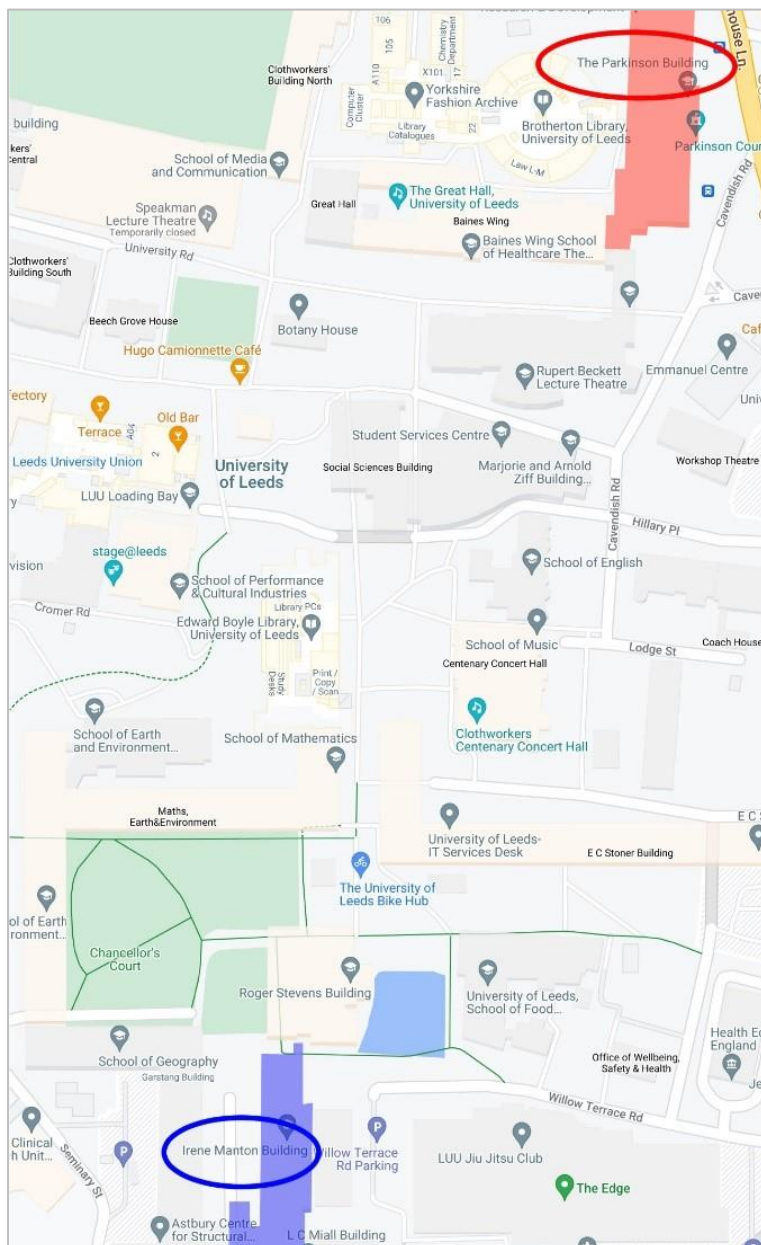
5.2. Map prototype design and iterate

In the quest task of Chapter 4, the deficiencies in Google Maps' wayfinding information after people's navigation failed have been analysed. Among the three wayfinding tasks proposed by Allen (1999) based on wayfinding purposes, the quest task showed the strongest demand for map visual information in *Experiment II*. Among the other two wayfinding tasks, the commute task showed that people prefer to rely on cognitive maps formed by their own memories for commuting; the explore task showed people's need for digital map functions when exploring their surrounding environment. It can be seen in the literature review and the analysis of *Experiment I* that the biggest challenge faced by users in finding their way in an academic environment is to reach a designated place within a limited time (Xie et al., 2012). It may be that students need to arrive in class in time (Kanakri et al., 2016). This question was expanded upon in *Experiment I*, which concluded that campus users face challenges in finding building entrances. These purposes are consistent with the quest task: travel from a familiar place of origin to a strange destination. Therefore, the experiment in this chapter is designed to require participants to reach the accessible entrance of the building at the designated location within a limited time. Since the legibility and usage efficiency of the designed map prototype information need to be evaluated, the experimental environment needs to meet the scenario where people encounter wayfinding problems in *Experiment II*. Taking the University of Leeds campus environment as an example, the starting point and end point of the test need to meet the following conditions:

1. There is a terrain height difference between the start and destination point;
2. The destination is an accessible building;
3. There are unconventional outdoor routes to the destination;
4. There are landmarks on the routes to the destination.

The starting point that meets the above conditions is designated as Parkinson Building, and the end point is designated as Irene Manton Building. Their locations on the map are shown in Figure 5.2: the building marked in red is Parkinson Building, and the building marked in blue is Irene Manton Building.

Figure 5.2. Locations of Parkinson Building and Irene Manton Building on Google Maps



After selecting the test departure point and destination, there needs to be consideration for the inclusion of additional information on the map to help users reach the destination.

Therefore, a prototype containing additional information need to be designed.

After the prototype was generated, it required a user test to investigate design problems and mistakes. The map was then redesigned based on map design principles proposed in the previous chapters and the results of the user tests obtained, and finally a redesigned map prototype was obtained for testing and evaluating.

5.2.1. Design of additional information on the map

This research used Google My Maps as a reference to design the map prototype. In order to evaluate the use of the improved digital map in the campus environment, additional information needs to be added to the digital map to test the improvements of the preliminary research:

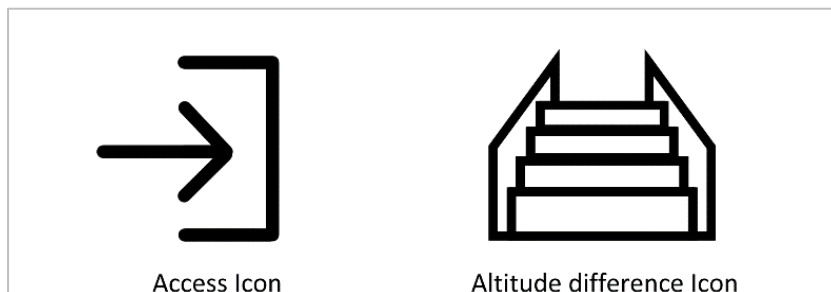
1. Add information on the map to indicate the existence of terrain height differences in the environment;
2. Identify the accessible entrances and exits of the building on the map;
3. The routes on the map should be complete, including unconventional outdoor routes, and can be identified by users;
4. There should be landmarks on the map, and they can correspond to the real environment.

During the designing process of the prototype, a map prototype which can satisfy the defined improvements should be first adopted. In the design of it, the visual effects of the added information are considered from three aspects: a) icons; b) passable routes; c) map appearance. At this stage, the focus is only on additional informative annotations of passing areas to help form a simple map visual.

5.2.1.1. Icons

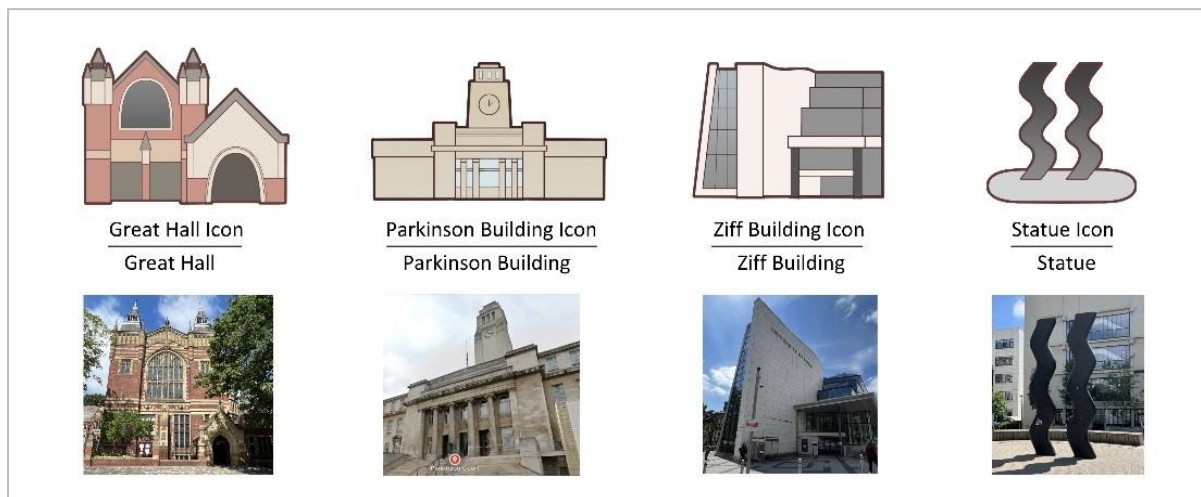
During the map design, icons are chosen as a way to add additional visual information. In the research of wayfinding systems in Chapter 2, it was established that visual elements are faster and more easily recognised by humans than text, and increases ease of understanding and accessibility of written information (Norman, 1990; Miller and Lewis, 1999; Süzer, 2018). At the same time, many feedbacks during *Experiment II* showed that participants identified the marked point of the building on the map as the end point, even though it was marked in the centre of the building, and the task required finding the entrance to the building. Markers take the visual form of icons, which is why icons were chosen to represent information here: they may serve the same function as markers. In order to avoid different cultural and educational backgrounds from impacting different interpretations of the icons of the wayfinding system (Hashim et al., 2014), the icons are designed to be as simple as possible. As shown in Figure 5.3, the icons are respectively designed in line mode to represent access and altitude differences.

Figure 5.3. Extra information designed for the first-generation prototype – Icons



In addition, the landmark icons corresponding to the real environment were carefully designed and included (Figure 5.4), which represent the main features of the landmarks on the icons, simplifying them to an easy to understand two-dimensional form.

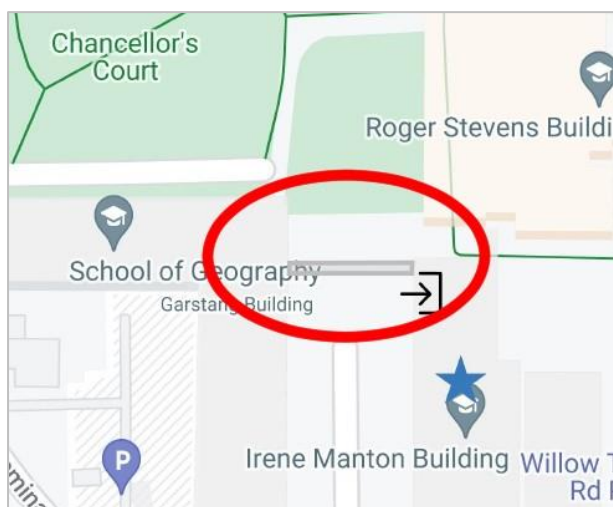
Figure 5.4. Extra information designed for the first-generation prototype – Landmarks



5.2.1.2. Passable routes

For the destination building of this experiment, reaching its entrance has to be done via an unconventional outdoor route: a connecting bridge between the buildings, which is not marked on Google Maps. In order to prevent the added route from being too conspicuous, and potentially affecting the experimental results, the same visual element representation of the route in standard mode (white lines) is added on the map to indicate the existence of accessible routes (Figure 5.5).

Figure 5.5. Extra information designed for the first-generation prototype – Passable route



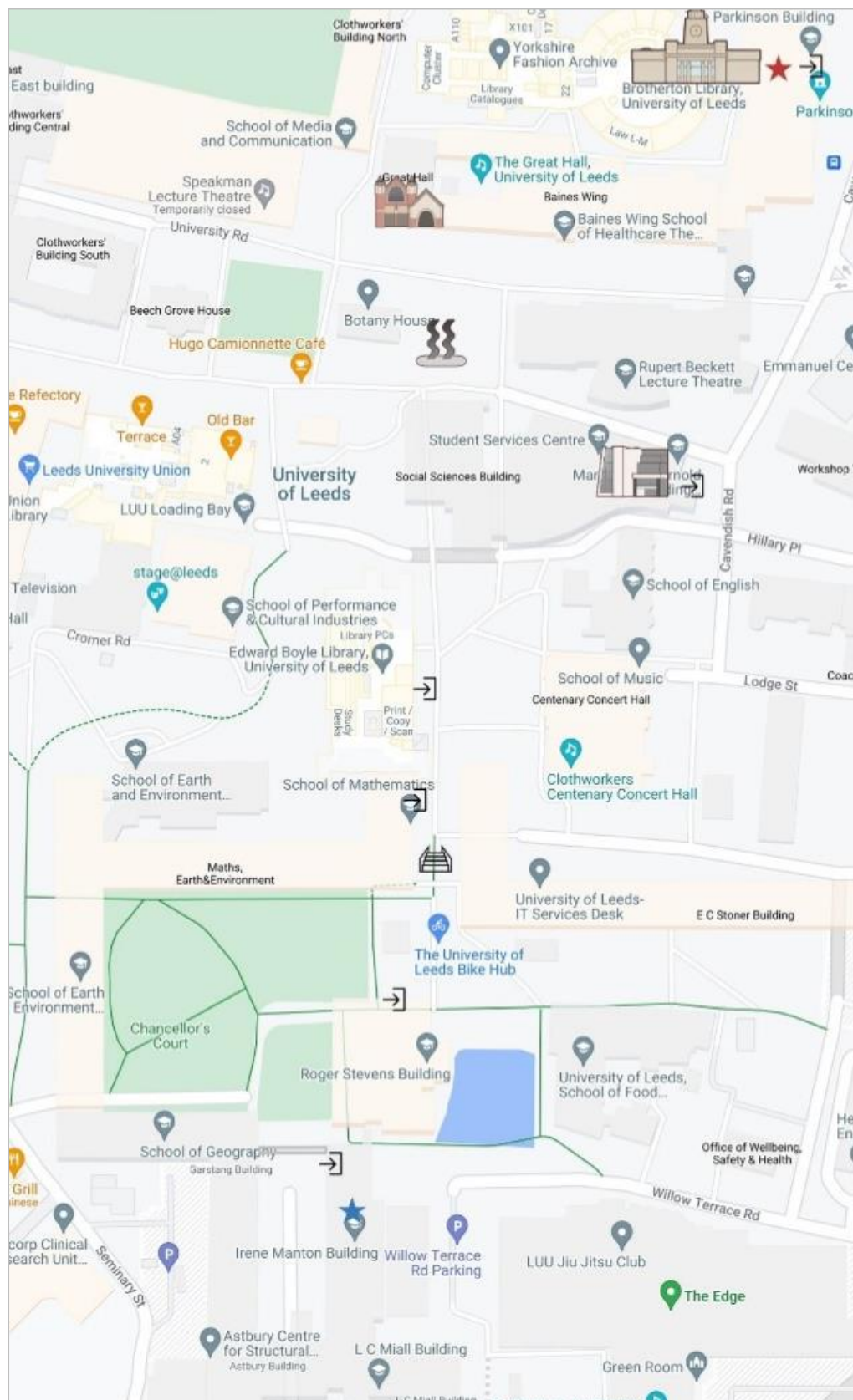
5.2.1.3. Map appearance

Regarding the choice of map mode, in order to control the amount of information on the digital map used for testing, the standard mode Google Maps which simplified the geomatical environment information is used during the prototype design. This is because the standard mode map uses simple graphics to show the orientation and distribution of buildings, and concisely marks most of the accessible roads in the form of lines. This allows readers to pay more attention to the information given by the map when finding their way, instead of looking for passable roads, which reduces the time for users to judge whether the route is feasible.

5.2.1.4. First generation prototype design

After adding the above design elements to Google Maps, an initial map prototype was completed. As shown in Figure 5.6, in the test area, the prototype marks the accessible entrances of the buildings and the locations with altitude differences, and adds accessible routes. The prototype was made using Google My Maps, which provided the users with the ability to create their own maps. Based on the feasible improvements proposed in Section 5.1, improvements were made to integrate design elements and added to the map information in the form of visual elements, so that the preliminary prototype could meet the requirements for improvement. At the same time, deficiencies in the design can be found through testing, and based on this, design improvement plans for adding visual information can be derived.

Figure 5.6. Appearance of the first-generation map prototype



5.2.2. User testing of first generation map prototype

In order to enable the map prototype to obtain legibility and specific reading feedback of the added visual information, the first generation map prototype was user tested and then the design solution was refined based on this. When conducting the test, the following issues should be paid attention:

1. How legible is the map prototype?
2. Does new information on the map help to find the destination?
3. Is there any trouble when reading the prototype? What is the improvement?

Since the purpose was to evaluate the legibility of the added visual information, the user testing did not test the wayfinding functionality in a real-world setting, but instead asked participants to use it to create routes on a map. To facilitate route planning during the test, the user test provided a paper Google map and a paper prototype containing the test area. In order to evaluate the legibility of the map information, the test presented two tasks that required participants to search and use information provided on the map. They were first required to create a route using the original map. In this step, participants were provided with a start and end point (both contained within the test area and could be identified) and asked to collect existing map information and create a route on the map to the destination building entrance. Next, how additional information changed and helped in route planning would be tested. The designed prototype would be provided, and participants would be able to recreate the route with the help of additional information. By analysing possible differences in the route and collecting participants' subjective opinions on the legibility of the original map compared to the map prototype, it is possible to learn what information on the original map caused misunderstandings or missing information. In addition, planning the route twice could more clearly show the comparison of information between the two versions of the map to participants. Through two rounds of user testing, participants could visually understand the usefulness of the additional information and provide feedback on the additional information during follow-up interviews, which could potentially improve its visual presentation to make the additional information more consistent with user

expectations.

Participants were required to complete the following tasks during the test:

1. Read the paper Google Map, confirm the starting point (Parkinson Building) and destination (Irene Marton Building), then plan and draw the route by a marker pen to reach the destination on the map;
2. Read the paper map prototype with additional information added, then re-plan and draw the route to reach the destination.

The test was divided into the above two steps to enable participants to first become familiar with the standard mode of Google Maps, understand the original information of the map, and plan routes through the original information and visual elements. On this basis, the prototype provided additional information consistent with the improvements proposed by the research. By comparing participants' changes in the two planned routes and participant usage feedback, it was possible to determine where the original map caused misunderstandings, as well as the extent to which the additional information helped complete the task and possible comprehension difficulties.

Participants were asked to consider the feasibility of the drawn route in a real-world environment, which means the route should be passable. This requires that the routes they draw must be consistent and fit the roads shown on the two paper maps.

During reading and annotation, participants were asked to identify and describe any problems that caused them difficulty reading. 10 participants were invited to conduct the test. Table 5.1 shows the basic information of them.

Table 5.1. Participants' basic information

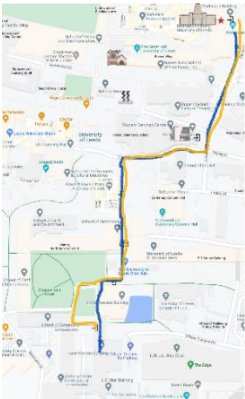
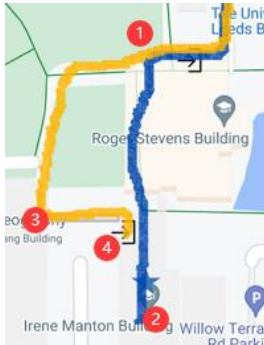
N	Gender		Age		Occupation	Native English speaker or not	
10	3	Male	8	21-30	10 Student	10	Non-native
	7	Female	2	31-40			

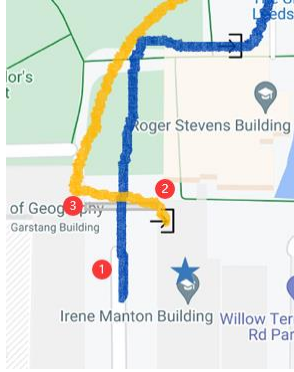
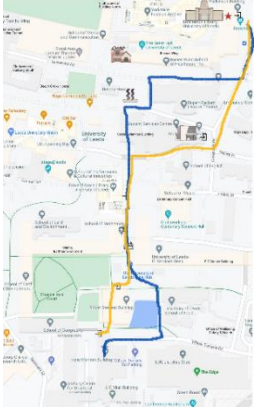
Routes they drew are shown in Table 5.2. The researcher added the routes drawn by the

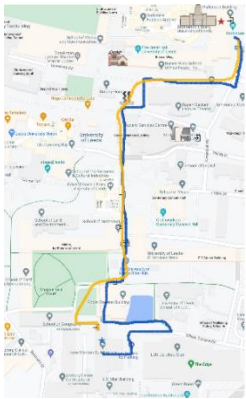
participants on the original Google Maps and the map prototype onto a single map, which provided a clear visual representation of the two route changes.

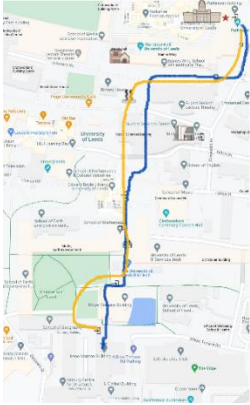
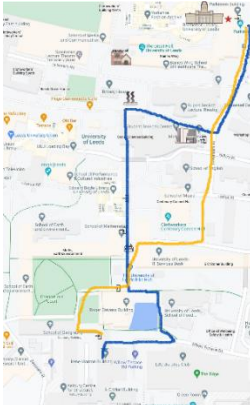
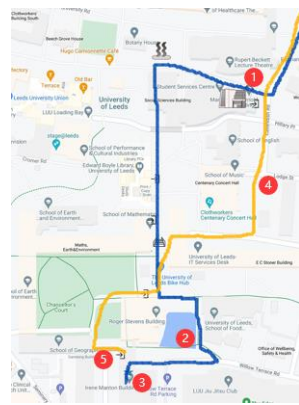
The two routes are represented by different colours: the first drawing (on the original map) is blue, the second drawing (on the designed prototype) is yellow. Whether the participant successfully plotted a route to the destination entrance is shown in Table 5.2. It can be seen that none of the participants successfully plotted a feasible route to the destination using the original Google Maps. After using the prototype, eight of them successfully plotted a route to their destination. At the same time, the reasons why participants decided on the route were collected, and the sections where the route changed were sorted out.

Table 5.2. Route map collection and reasons for route decision

Participant route map		Success or not		Reasons for route decision	
No.	Route map collection	Original	Designed	Decision points	Reasons
1		N	Y		Original: There's a green line going through that building so I think it is a road (1); besides, route through the building can reach marker (2) of destination. Designed: I realised the entrance icon (4) and there's a link (3) to reach the entrance, so I changed the route.
2		N	Y		Original: The way to the destination was blocked by a building (1), so I chose to take a detour from the pond and finally reached the destination marker (2). Designed: I recognised the sculpture (3), so I chose to pass there; the map showed the entrance (4), and I realised that the right way was on the lawn.

Participant route map		Success or not		Reasons for route decision	
No.	Route map collection	Original	Designed	Decision points	Reasons
3		N	Y		Original: There is a white road at the destination building's text information (1), which should be the end point. Designed: The map shows the entrance (2) and a new road (3) that can be reached.
4		N	N		Original: I am familiar with Parkinson's road into University (1) and can take fewer detours; reaching the destination requires a detour (2), and then I can reach the destination mark (3). Designed: I recognised the Ziff building (4) and the target entrance (5) through the icon, and I planned the shortest route with the fewest turns to get there.
5		N	N		Original: It is necessary to go around the building (1) to reach the destination (3), and there is a road (2) leading to the destination. Designed: There seems to be no way to get to the entrance (5), except for the green line (4) that goes through Roger Stevens Building so I drew the line through it.

Participant route map		Success or not		Reasons for route decision	
No.	Route map collection	Original	Designed	Decision points	Reasons
6		N	Y		Original: I made as few turns as possible, going straight to the left (1) and turning to get past the blocking building (2) to the destination. Designed: I recognised Ziff Building (3) and changed the route. After seeing the entrance (5), I connected the path from the garden (4) in the opposite direction.
7		N	Y		Original: I know there is a staircase going through Roger Stevens Building that can be passed through (1), but there seems to be no way; I may go around the destination (3) through the white road (2) on the map. Designed: I saw the end sign and an added road (4), obviously the route needed to be changed.
8		N	Y		Original: I minimised turns (1), and after going around the building and pond (2), I could reach my destination (3). Designed: I drew a route from the end (5) and a new path in the opposite direction to the starting point, with as few turns as possible (4).

Participant route map		Success or not		Reasons for route decision	
No	Route map collection	Original	Designed	Decision points	Reasons
9		N	Y		Original: I took the straightest possible route (1) to destination. I passed through the building blocking the road (2) to reach the end point (3) directly. Designed: I changed the route to the sculpture (4), again reducing the turns; a new path to the final entrance was added (5), so I changed my decision of route.
10		N	Y		Original: I remember that turning here (1) can lead to the library; bypassing the pond (2) can directly reach the destination (3). Designed: I reduced the turns (4) to access the newly added road and terminal entrance (5) through the garden.

The comparison of the drawn route presented together and the decision of route planning can analyse the following conclusions:

Reasons for route planning failure:

1. End point positioning error:
 - a. In the original Google Map situation, the mark icon of the target building is regarded as the end point: 9 times (Participant 1, 2, 4, 5, 6, 7, 8, 9, 10);
 - b. In the original Google Map situation, the text information of the target building is regarded as the end point: 1 time (Participant 3);

- c. Wrong understanding of the spatial relationship between the entrance and the target building in the prototype situation: 1 time (Participant 4).
- 2. The visual information about accessible roads on the map is confusing:
 - a. The added road cannot be identified: 2 times (Participant 4, 5);
 - b. The visual presentation of the roads on map is difficult to distinguish: 3 times (Participant 1, 3, 7).

Reasons for changing the route when drawing for the second time (using the prototype):

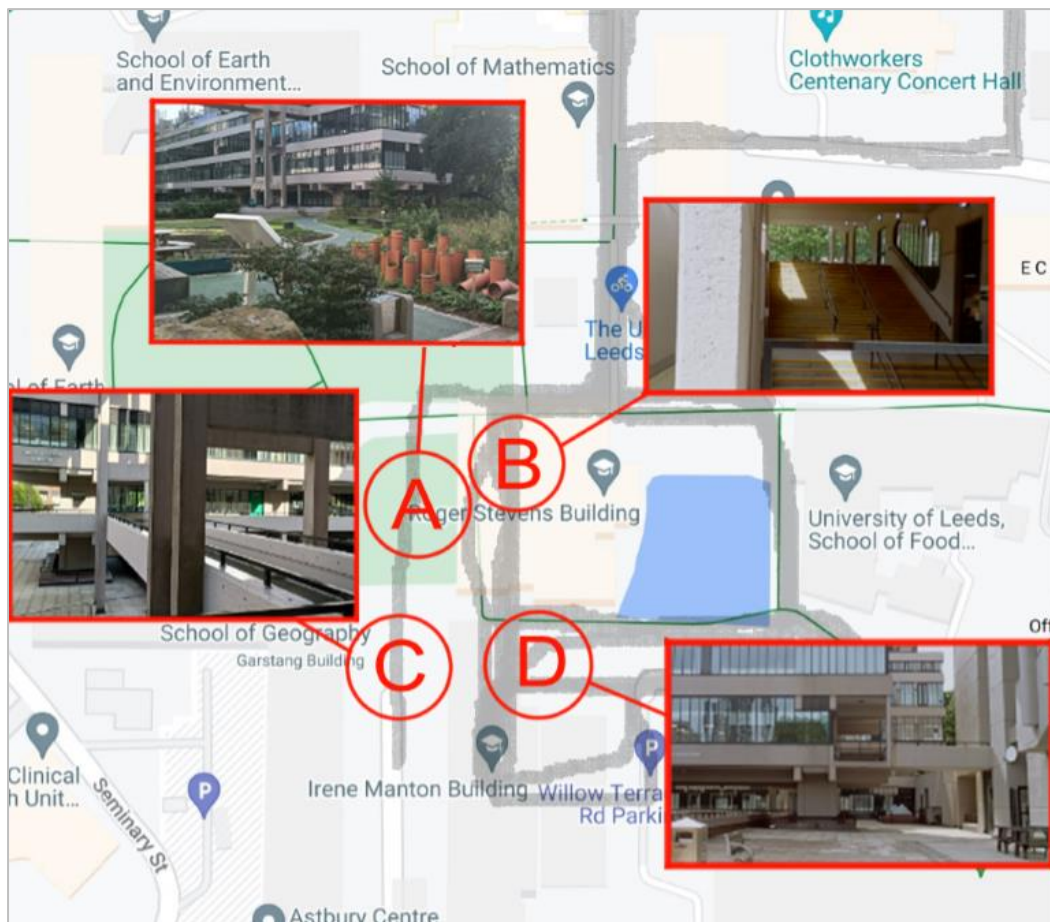
- 1. Clarify the target location (entrance icon) and the accessible road to the destination (newly added route): 8 times (Participant 1, 2, 3, 6, 7, 8, 9, 10);
- 2. Identify the landmark and reset the route to pass the landmark: 4 times (Participant 2, 4, 6, 9).

Preferences when planning routes:

- 1. Prefer fewer turns and reach the destination in a straight line as much as possible: 4 times (Participant 4, 6, 9, 10);
- 2. Relying on cognitive maps to correspond map information to the geographical environment, tending to allow routes to pass through familiar areas: 3 times (Participant 4, 7, 10).

In the case where the destination entrance was unknown, analysis of the route map showed that when the route reached the obstacle building, participants tended to a) bypass the pond (5 times); b) go directly through the building (4 times); c) bypass through the green belt (1 time). As shown in Figure 5.7, the real environment of the area is marked on the map: there are accessible roads not shown (A, C), there are roads passing through the floors (B), and there are height differences (B, D). This is consistent with the findings in *Experiment II*, which showed that map legibility is reduced when complex environments cannot be represented on the map.

Figure 5.7. Areas of confusion when planning the route



For cases where the route map to the destination cannot be successfully drawn after providing additional information, based on inquiries about the reasons for the failure during and after the experiment, the following reasons were given:

1. The added accessible route cannot be recognised;
2. The route on the map itself is confused and uncertain whether it is accessible;
3. The icons position of the accessible entrances is confusing, and it is impossible to determine the direction of the entrance.

In addition, after collecting the difficulties encountered by participants when read maps, it is concluded that the designed prototype has the following problems:

1. The background colour of the map is too similar to the road colour, making it impossible to quickly determine whether there is a route (Figure 5.8);

2. The height difference and entrances and exits are represented by icons, which cannot fit in with the original visual elements of the map, resulting in the need to distinguish the meaning of the icons (i.e. Which road does the height difference icon refer to? Which building does the entrance and exit belong to? Where exactly are the entrances and exits in the building?)
3. There is too little graphical information on the map in standard mode. Sometimes there is only the background and roads. In this case, it is impossible to tell whether anything other than the lines can be passed (Figure 5.9).

Figure 5.8. Colour of map background and roads

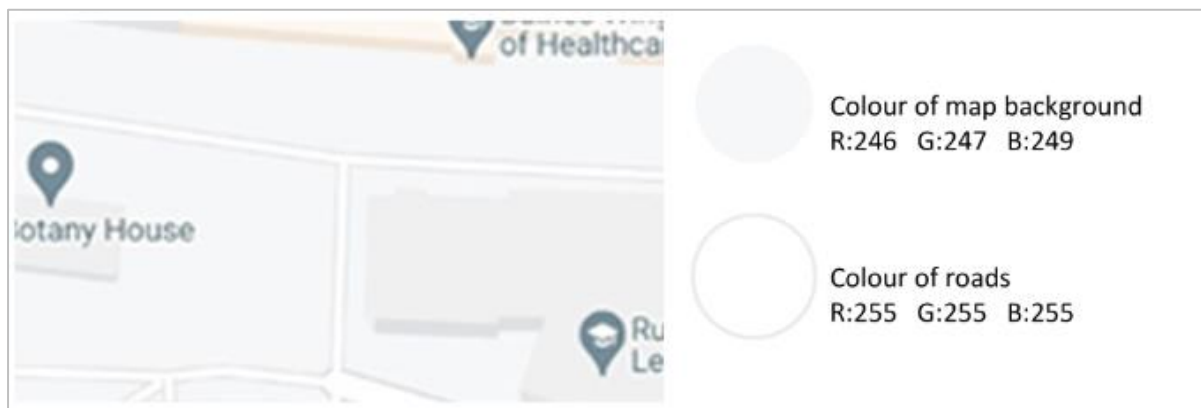
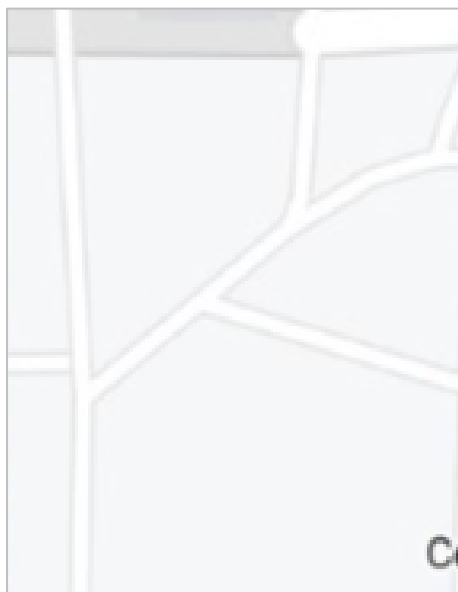


Figure 5.9. An example of lack of information on map: only road lines



At the same time, the 80% success rate shows that the additional information is indeed helpful to a certain extent in correct route planning. The design of the map prototype needs to meet the map design principles while avoiding the reading difficulties encountered by participants during the user test. Therefore, the information structure and visual elements of the prototype need to be improved to help users understand the information on the map more conveniently and correctly, so as to plan routes more efficiently.

5.2.3. Second generation prototype design

Before designing the second generation, a lot of preparatory work had to be completed:

1. Studied and analysed previous research to identify wayfinding and map design principles;
2. Collected existing digital maps of British universities for visual research to outline map design guidelines;
3. Through a questionnaire survey, investigated how users use digital maps and the limitations of using campus digital maps were understood;
4. Conducted user testing using Google Maps to sort out feasible directions to improve wayfinding efficiency in the campus environment;
5. Established and tested the map prototype designed based on Google Maps, thus obtained more specific design improvement directions for the visual and information presentation of the map.

As shown in Table 5.3, the main findings of each chapter are organised and listed to integrate existing findings.

Table 5.3. Findings of each chapter

Finding	Classification	Contents of finding
Wayfinding design principles (Chapter 2)	Image	• Destination and direction can be identified using images such as icons, arrows, and pictograms rather than text descriptions (Miller and Lewis, 1999; Süzer, 2018); • Images are easier to recognise than text for quick processed information (Lomperski, 1997; Apelt et al., 2007; Xie et al., 2012; Hashim et al., 2014; Süzer, 2018; Wang et al., 2018); • Different cultural and educational backgrounds lead to different understandings of images, and it is necessary to consider the legibility of images among different groups of people (Hashim et al., 2014), or to assist in explaining images' functions.
	Colour	• Visual information (background, letters, graphics) should have colour contrast and brightness differences (Lomperski, 1997; NHS Estates, 2005; Apelt et al., 2007; Gibson, 2009; Sandnes, 2017; Süzer, 2018; Roefs and Mijksenar, 2017); • The colours used in the colour settings should not be too many (NHS Estates, 2005; Feisner, 2006); • Focus on the three properties of colour (hue, intensity and value) to enrich colour composition and create contrast (Gibson, 2009); • When choosing colours, consider whether different cultures will bring different interpretations of the meaning of colours (Park and Guerin, 2002; Hashim et al, 2014; Calori et al., 2015). • Use colour coding can convey information (Abu-Obeid, 1998; Calori et al., 2015);
	Typography and layout	• Fonts such as Arial, MS Sans Serif, Tahoma, Futura, Geneva and Helvetica Medium make it easier for people, including those with visual impairments, to read. (Apelt et al., 2007; Gibson, 2009); • For emphasised information, bold, capital letters, and larger font sizes can be adopted (Bringinghurst, 2002); • Wayfinding systems need to help users orient themselves (Canter, 1974; Passini, 1992; Kitchin, 1997; Güneş, 2018); • Fonts with descriptive functions should be unified (Gibson, 2009); • Font size, type, and layout should be legible and easy to understand. The size and spacing between letters and words should be proportional to the amount of information provided, uppercase and lowercase letters are easier to read than all uppercase letters (Apelt et al., 2007; Gibson, 2009; Roefs and Mijksenar, 2017); • Clear definition of elements in the physical environment (buildings, roads, bridges, etc.) (Apelt et al., 2007; Gibson, 2009).

Finding	Classification	Contents of finding
Digital map design principles (Chapter 2)	Spatial information	• The organisational elements of spatial information, including paths, landmarks and areas, should be displayed on the map (Apelt et al., 2007); • The spatial relationship of the campus map needs to represent the relationship between the direction of space objects and the direction and order of buildings (Cao et al., 2008); • When using digital maps for positioning, a self-centred view should be taken (Thomas, 2008); • Digital maps can display information about buildings and landmarks and interact with them to enhance the attractiveness of the map (Kim, 2011); • The complexity of landmarks and views should be reduced, and key nodes should be kept in key positions (Wang et al., 2018); • Using recognisable landmarks on digital maps (Siegel and White, 1975; Çubukçu and Nasar, 2005; Davidson, 2014).
	Text and layout	• Use only important and memorable elements when choosing the information displayed (Apelt et al., 2007); • The text and layout of the map should be proportional and neat, and avoid using letter codes and number codes. (Apelt et al., 2007); • The display of map information should consider more the relationship between shapes, paths, and spaces; • Campus digital maps have advantages in updating network information, and the information can be updated according to changes in facilities and personnel.
	Scale	• Users should be allowed to freely choose the appropriate map scale (Davidson, 2014); • As the scale of the map shrinks, the level of detail of the information should decrease (Töpferand and Pilewizer, 1966).
Wayfinding behaviour in academic environments (Chapter 2, 3)	Wayfinding problems	• Need reach the destination on time (Xie et al., 2012; Kanakri er al., 2016); • The destination address is updated or different from the address in memory (Agarwal and Lawrence, 2014); • Difficult to find the specific building and specific room number through the same wayfinding system (i.e. map, signage) (Chao, 2016); • Need to travel to different locations within the same complex building (Scott-Webber. 2000; Bishop, 2011); • Can't find the entrance of building/specific room is the most common difficulty in campus wayfinding; • Time limitation will cause pressure (Xie et al., 2012; Canakry et al., 2016).
	Performance of campus digital map	• External digital map is heavily used, but it cannot meet users' expectations when finding way on campus; • Digital map is more effective/convenient than paper map;

Finding	Classification	Contents of finding
		• Mobile phone is the most suitable device for using digital maps; • Correct positioning is one of the most important functions; • Distinctive map visual elements can be used on map.
Map visual elements representations (Chapter 3)	Lines	• Use lines to represent roads; • Change the thickness of lines to indicate the width of roads; • Change the form of lines (dotted/solid lines, transparency) to represent different functions (sidewalks, driveways, paths through buildings, underpass, etc.); • Arrows can be added to lines representing lanes to indicate the direction of a one-way street; • Use lines to frame campus areas to make the campus environment independent of the city.
	Shapes	• Use different shapes to represent the landscape with volume in the real environment (such as buildings/lawns/rivers and lakes); • Connected building groups should be represented separately.
	Colours	• Use colours similar to the actual environment to represent lawns and rivers (green and blue); • When the background colour and the colour of the visual elements are similar, it may be difficult to read the information; • Use different coloured lines can represent different road functions; • Buildings can use different colours to increase the colour diversity of the map and the distinction between building groups; • Two-hues differentiation can use minimal colours to make connected buildings not difficult to distinguish; • Colour sequence changes (brightness and saturation change in sequence) makes colours of different information change without causing reading difficulties due to too many colours; • Hue changes adds colour richness and show differentiate areas in the environment.
Map design guidelines (Chapter 3)	Map overview	• Take measures to enable users to quickly identify campus areas on the map; • The centre of the original map should be located in the campus area; • Use shapes and colours to distinguish campus facilities and buildings, and can assist with schematic diagrams to remind facilities functions; • The visual elements of the map should be balanced to avoid using too many formats.
	Map information	• The detailed level of information changes accordingly with the change of the map scale; • Should avoid excessive information;

Finding	Classification	Contents of finding
		• The information on the map should be balanced and orderly (Tyner, 2014); • Text information in the same format should be used; • The user should be allowed to identify the entrance of the building on the map.
	Digital map interaction	• Users should be allowed to locate themselves at any time; • Combine the wayfinding function with the campus digital map to allow users to use the campus digital map for wayfinding; • The menu should have hierarchy to avoid too much information at the same level; • The user should be allowed to directly operate the map to view the facilities/buildings on the map.
Digital map improvements (Chapter 4, 5)	Complexity of environment	• The user's wayfinding efficiency decreases with the increase of the complexity of the environment, and the demand for digital map navigation increases with the increase of the complexity of the environment; • When there is a change in the altitude of the destination, failure to indicate it on the map will make it difficult for users to find their way; • When the route to the destination is not a conventional outdoor route (carriage road, sidewalk, etc.), but a walking route belonging to the university campus (the walkable ground floor of the link building, trails, etc.), it will affect the efficiency of people's wayfinding.
	Map navigation efficiency	• The mode of the map affects the difficulty of corresponding to the map information and physical environment. Satellite mode shows better environmental recognition than standard mode; • Accurate positioning can help users identify routes more easily; • When the location on the map can quickly correspond to the real environment, the user's wayfinding efficiency is improved.
	User wayfinding purpose	• Users often need to reach a building on campus, and the navigation of the digital map should not only guide the user to the correct building, but guide the passable entrance of the building; • The categorisation of buildings of campus facilities needs to cater to user needs and help users find their destinations more conveniently based on functions of buildings.
Digital map improvements (Chapter 4, 5)	Map information	• Colour of map background and the road need to have contrast; • Accessible roads need to be clearly and systematically represented on the map; • Icons are not suitable for use as visual elements on maps that represent height differences and entrances; • Visual elements need to be added to help users perceive the physical environment.

Based on the findings of research in the previous chapters summarised in Table 5.3 and combined with the purpose of this part, the design guidelines for the map prototype on spatial information, colour and added information are listed:

SPATIAL INFORMATION:

1. Map appearance:
 - a. It should make it easy for users to identify accessible roads and different entities in the environment (buildings, lawns, rivers, etc.);
 - b. While avoiding increasing the complexity of map information, it should ensure that users can easily and quickly correspond to the real environment through the map.
2. Block division:
 - a. There should be visual differences between different buildings to facilitate identification when reading;
 - b. Different areas of the map should be clear and easy to read.
3. Visual elements:
 - a. Unique visual elements should be used to help users connect the map to the real world, such as adding landmarks to the map;
 - b. Icons should be easy to understand to aid reading;
 - c. Unconventional paths (such as passages through buildings) should be marked on the map.

COLOUR:

1. Avoid using too many colours;
2. Avoid using similar colours that make it difficult to identify;
3. Colours that match the real environment (green for lawns, blue for rivers, etc.) should be used to base the visual information in reality.

ADDITIONAL INFORMATION:

1. The accessible entrance of the building needs to allow users to determine their

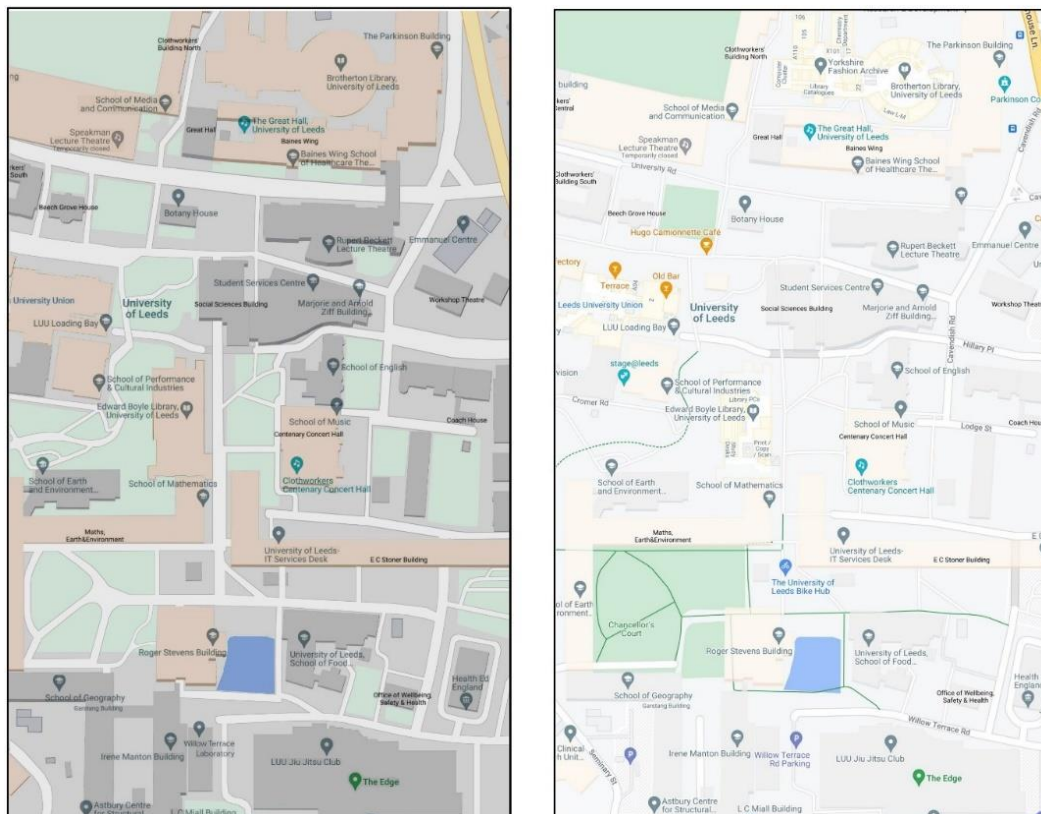
specific location when reading;

2. When representing altitude changes on the map, users need to understand the trend of changes so that they can correspond to the real environment.

Under the design guidelines, the second-generation map prototype was designed. Due to the need to evaluate the impact of added information on wayfinding efficiency, information on map prototype was divided into two categories: that without additional information and that with additional information. As shown during the introduction of this section, additional information should include a) height differences; b) accessible entrances and exits to buildings; c) unconventional outdoor routes; d) landmarks corresponding to the real-world environment.

During the design process, map information was selected as the focus of the research, meaning other factors remained the same to prevent influence from additional changes. The prototype map used for testing without additional information and the same area on Google Maps used as a reference are shown in Figure 5.10.

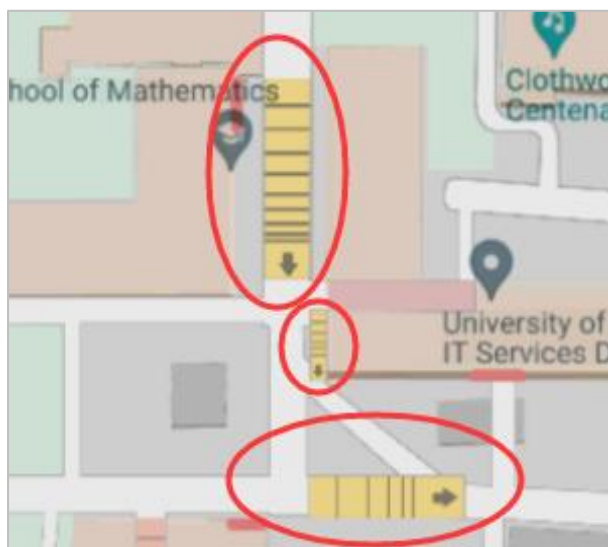
Figure 5.10. Second-generation prototype without additional information(left) and Google Maps of the same area(right)



In the map prototype, since user testing of first-generation prototype showed low colour contrast causing reading difficulties, the second generation adjusted the colour difference of visual elements. Considering that adding information will increase the colours used in the map, the original information did not adopt colour sequence changes or hue changes to enrich the map colours. Two-hue differentiation was used to represent buildings, which was in line with the two-hue differentiation of distinguishing connected buildings. The accessible roads on campus were represented by white lines, which contrasted with the gray background to allow users to distinguish them when reading the map. At the same time, the road width corresponded to the real environment. Green spaces (such as parks and areas of grass) were represented by a light green shape and bodies of water (e.g. ponds) were coloured blue. In the choice of text layout, only the name of the building was retained.

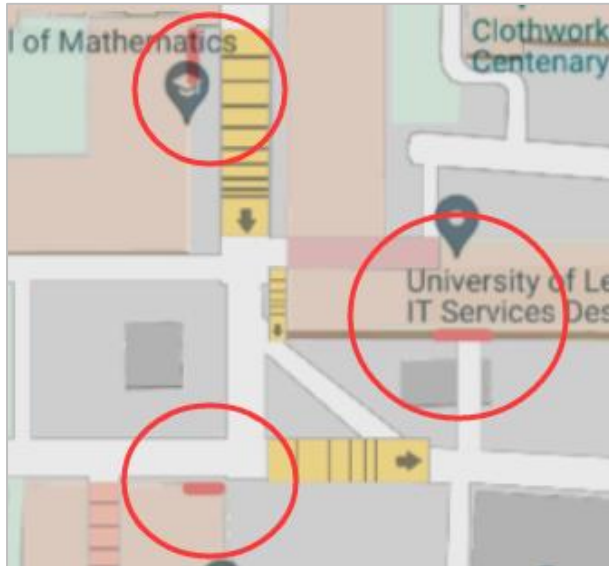
When adding visual information to the map prototype, icons indicating height differences and entrances were changed to colours and pictograms to address issues with icons causing reading difficulties discovered while testing the first generation prototype. As marked by the red circle in Figure 5.11, since there are slopes or stairs in the real environment that allow people to walk in different altitude, the yellow shape covering the road is used to represent the height difference, and lines and arrows are used to show from high to low.

Figure 5.11. Visualisation of stairs and slopes



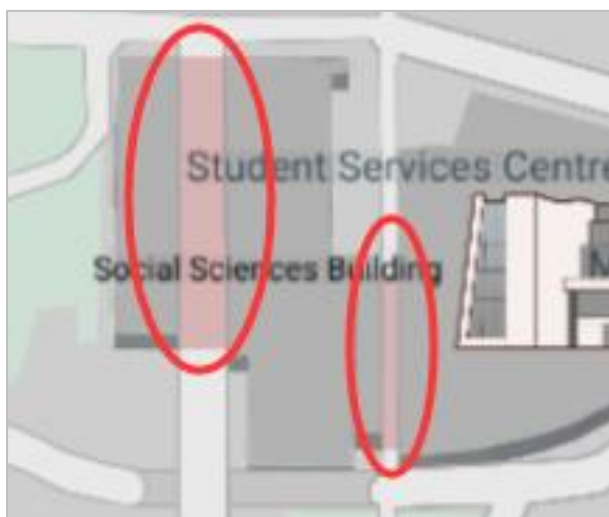
For accessible entrances and exits, since users need to be able to identify their specific locations when reading the map, the icons used in the first generation are replaced by lines that overlap the shape of the building (Figure 5.12).

Figure 5.12. Visualisation of passable entrances



In addition, the pathways and height changes through the building are uniformly coloured in light red (Figure 5.13) to create a visual distinction from the outdoor roads.

Figure 5.13. Visualisation of roads through buildings



Finally, after adding landmark patterns to the map, the second-generation map prototype is

shown in Figure 5.14.

Figure 5.14. Second-generation map prototype with additional information



After completing the design, two kinds of prototypes can be used in testing to evaluate how additional information helps wayfinding behaviour: a) map prototype without added information; b) map prototype with added information.

In previous studies (*Experiment II*, user testing of the first-generation map prototype in *Experiment III*), Google Maps has been used as a tool for testing and as a prototype for map appearance. Through user testing in *Experiment II*, the limitations of Google Maps in wayfinding in academic environments have been sorted out, and an information addition plan for campus digital map information design has been discussed. After user testing of the first generation prototype, a more detailed map appearance and visual information design improvement was obtained. The limitations of using Google Maps have been summarised by two rounds of user-involved experiments with user testing and route drawing. Therefore, Google Maps was no longer used as a tool in A/B testing. The focus of the test tends to be to evaluate the legibility of the added information through A/B test data; to observe wayfinding behaviour of participants to analyse the environmental perception of the second-generation prototype; to conduct post-experiment interviews to gain depth and persuasiveness feedback on using the map prototype.

5.2.4. Second generation prototype evaluation methods

To investigate the effect of the newly designed map prototype and evaluate the reading speed and wayfinding accuracy of the map with or without additional information (Figure 5.15), an A/B test was conducted among 16 participants. In this test, the layout of the two maps was identical, with and without additional information being the only variation.

Figure 5.15. Appearance of the original prototype (Left) and the information-added prototype (Right)



5.2.4.1. A/B testing methodology

Tomitsch and Wrigley (2018) suggested that to evaluate two different versions of the same product, A/B testing can be used to understand the impact of variables. This is consistent with the need for this research to evaluate the impact of additional information on the efficiency of map prototype use. In recent research, A/B testing is more commonly used to compare alternative versions of website user interface designs, as shown in Larsen et al. (2023) statistics of online controlled experiments. The statistics of Larsen et al. (2023) also pointed out the widespread use and help of A/B testing in online experiments. This is consistent with research by Koning, Hasan and Chatterji (2022), which found that companies that use A/B testing to evaluate products have significantly improved performance. This suggests that this methodology can help identify and expand promising ideas during product

evaluation, as well as detect and discard negative signals more quickly.

The use of A/B testing in the evaluation of tangible products or prototypes was used in the study of Madlenak et al. (2023) and helped to quickly obtain a comparison of the time spent by participants on completing tasks, thereby discussed whether the test variable helped the research purpose or not. Tomitsch and Wrigley (2018) also suggested that A/B testing can help to quickly determine whether A or B is more effective in a given scenario. In the evaluation phase of this research, it needs test whether the additional information helps wayfinding. After redesigned the improvements discovered during user testing of the first generation, users can more clearly identify accessible routes on the designed second generation prototype. In this case, by grouping the participants and conducting A/B testing, this research can determine whether the additional information is helpful to the efficiency of wayfinding through the time participants take to complete the wayfinding task.

For more directions in the research questions that need to be investigated, such as the legibility of additional information and in what ways the information affects the efficiency of wayfinding, these cannot be obtained by A/B testing since this methodology is used to offer a quick diagnosis between two products (Tomitsch and Wrigley, 2018). Therefore, observation was adopted in the test. Participants' performance during wayfinding was recorded and they were asked after the test to comment on the legibility of the map prototype during wayfinding. Their comments and suggestions were recorded in writing for qualitative analysis.

5.2.4.2. Participants recruitment

When planning an A/B testing, participants need to be divided into two groups. Therefore, in theory, two participants can constitute the necessary conditions for testing (Tomitsch and Wrigley, 2018). However, to obtain more data to avoid the possible influence of participants' personal factors on the results, a total of 16 participants took part in the test. Table 5.4 shows the basic information of them.

Table 5.4. Participants' basic information

N	Gender	Age	Occupation	Native English speaker or not
16	9 Female	16 21-30	16 Student	16 Non-native
	7 Male			

All the participants are Leeds University campus users and none of them had gone to or entered the destination building before participating in the test. This ensures that participants can not choose a route from memories, but instead find their way entirely through the map prototype. This prevents the wayfinding efficiency and success rate from changing due to the user's familiarity with the environment, thereby reducing the impact of additional variables on the experimental results.

Participants were randomly divided into two groups of eight people each and were introduced to the experiment in detail. At the same time, they were allowed to refuse or withdraw from the experiment for any reason.

In addition, during the wayfinding test process, regardless of whether the destination was reached or not, the experiment stopped when the time was up.

5.2.4.3. Test process

Before the test, participants were divided into control group and experimental group. The control group (group A) used the redesigned map prototype without added information; the experimental group (group B) used the extra-information-added redesigned map prototype. Based on the research purpose of evaluating the impact of additional information on wayfinding efficiency, a correct understanding of the information content is a necessary condition for testing. Due to differences in the comprehension abilities of different readers, the role of all additional visual information should be informed before the test to ensure participants' understanding (Figure 5.16). This avoids misunderstandings causing reading difficulties and producing variables that affect experimental results. During this stage, participants' confusion about the visual information was recorded according to information

type for subsequent design development. *Appendix VIII* shows the two prototypes provided.

Figure 5.16. Additional visual information shown to participants in group B



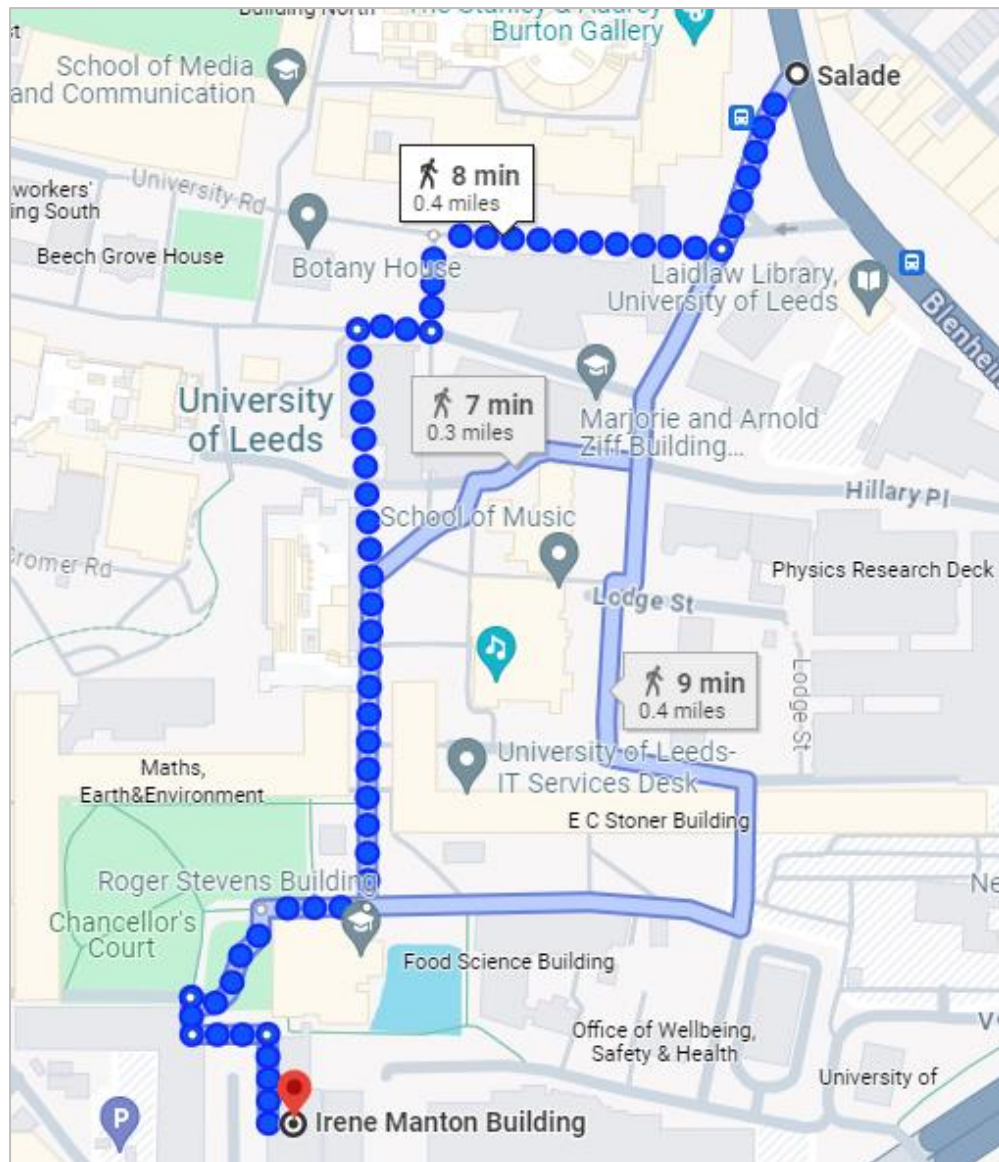
Only one person took part in each test, each participant had five minutes to familiarise themselves with the information on given map. It is known that during user testing of first generation prototype, some users had difficulty understanding map information. To prevent the possibility of test interference due to information comprehension issues during A/B testing, participants were allowed to question any uncertainty or confusion about the map information during reading so that they understood all the information given by the map before testing.

Next, after being informed of their destination, participants were asked to engage in route planning. Navigation was disabled due to the need for this research to evaluate the impact of additional information on the modified digital map prototype on wayfinding efficiency. Participants were provided with the paper map prototype covering the entire test area. They were allowed to mark routes to their destinations on the paper map to gain a clearer idea of how to get there before the test. Participants must keep their route on a passable road when marking it.

After planning their route, participants performed the wayfinding task. They started at the entrance of the Parkinson Building at the initial location, and the destination was Irene Marton Building. During the test, participants' wayfinding time is limited. A limitation in previous research was that the time constraints faced by users when finding their way in academic environments were not taken into account, and this is considered in this test. In *Experiment II*, when using Google Maps to automatically plan routes, incorrect navigation on the one hand reduced the participants' wayfinding efficiency, and made the participants have to rely on map information to find the correct destination. After *Experiment II*, the researcher used the "Edit the map" function of Google Maps to correct and add some missing roads to the map, thereby generating new navigation routes. As shown in Figure 5.17, after updating the missing roads on Google Maps, the digital map calculated the approximate wayfinding time from the starting point to the end point of this experiment to be 7-9 minutes based on the route length. Considering that this experiment using the map prototype for wayfinding requires participants to plan their own routes and cannot use the automatic positioning function of the digital map, this experiment extended the wayfinding

time limit to 15 minutes. Extending the limit time to twice gives participants ample time to think when finding their way, giving them a sense of time urgency and making them more active in the task.

Figure 5.17. Recommended wayfinding time for Google Maps navigation after updating missing roads



Participants could only judge and decide the route through the map prototype when finding their way, and their performance in the process was observed. In addition, Strava, which was used in *Experiment II*, was also used in this test to restore the participants' wayfinding routes.

5.3. Analysis and results

5.3.1. Results of A/B testing

A/B testing results can evaluate whether additional information has a positive impact on wayfinding efficiency and provide basic data for further development. Test data is shown by the time it took participants to complete the task. During the test, each participant was required to make decisions and complete specific wayfinding task based on the information given by the map. The routes they followed were drawn by themselves on paper map prototypes.

Therefore, their decision-making and wayfinding behaviours are completed by their independent judgment based on map information and are not affected by any external pressure.

In this test, there were eight people in each group, and a total of 16 participants took part in the experiment. Due to the limited wayfinding time, when participants were unable to reach the specified destination within 15 minutes, and the task would be determined to be incomplete. Participants' completion status is shown in Table 5.5. When the map prototype didn't include additional information, eight participants (Group A) were all unable to complete the task within the time limit. In contrast, all participants in Group B successfully found their destination within the time limit after using a modified map prototype that added extra information to find their way. The time spent by participants during the task was recorded. Table 5.6 shows the time each participant spent on the task.

Table 5.5. Participants' performance on the task

Participant Num	1	2	3	4	5	6	7	8
Group A (Original map)								
Group B (Information added map)								

 Task completed

 Task didn't complete

Table 5.6. Participants' time spent on the task

Group A	1	2	3	4	5	6	7	8	Average time
Total time spent	15:00	15:00	15:00	15:00	15:00	15:00	15:00	15:00	N/A
Moving time	14:57	14:32	14:55	15:00	14:40	15:00	14:19	14:58	14:47
Not moving time	00:03	00:28	00:05	00:00	00:20	00:00	00:41	00:02	0:12
Group B									
Total time spent	8:42	7:26	7:11	7:19	7:10	7:52	8:09	8:26	7:46
Moving time	8:42	7:26	7:11	7:19	7:10	7:52	7:53	8:26	7:44
Not moving time	00:00	00:00	00:00	00:00	00:00	00:00	00:16	00:00	0:02

In terms of total time spent, since all participants in group A failed to find their destination when the time limit arrived, their average time does not have reference significance. A/B testing in this experiment can only evaluate which of the two map prototypes used is better in wayfinding efficiency, and cannot determine the reason why participants in Group A were all unable to complete the task through data. Therefore, the observations and interviews with participants from both groups during the experiment will be analysed later to evaluate in more detail the help of additional information on the campus digital map in wayfinding.

On the other hand, participants in Group B all successfully reached their destination within the time limit, and the average time they took to complete the task is 7:46 min/s. When the map prototype included additional information, participants completed the task in much less time than the time limit, and the additional information clearly improved the map as a wayfinding aid.

During the task, Strava was used to record the movement of the participants, and then obtained their moving time and not moving time (as shown in Table 5.6). Here, moving time refers to the time participant spends walking in the environment; not moving time is the stationary time, which records the time the participant spends stopping somewhere during the task (including confirming routes, thinking about walking directions, identifying maps and other behaviours other than wayfinding actions). Due to time constraints, participants often continued walking rather than stopping to think about how to complete the task. This

is also shown in Table 5.6. The average not moving time of the participants of Group A is 12 seconds, while the average time of Group B is only 2 seconds.

For Group A members who were not given additional information on the map, during the task, the limit time made the participants become more anxious in their wayfinding behaviour and spend as much time as possible exploring the environment. Therefore, out of eight participants, five of them had a not moving time below 5 seconds. Another three participants had a static time of more than 20 seconds, and the highest static time among them was 41 seconds. Among the participants in Group B, only one member remained stationary for 16 seconds during the wayfinding process, and the rest of the participants maintained wayfinding behaviour throughout the process until they reached the correct destination. This means that they correctly corresponded to the real environment and the information given by the map. Following the map information enabled them to accurately identify feasible and correct roads in complex environments.

After the analysis of A/B testing, it can be concluded that under the same time limit, additional information on the map can help participants read and find the destination more effectively and quickly.

5.3.2. Results of observation

Participants were followed and observed throughout the task, and their wayfinding behaviour was recorded. During the wayfinding process, their stationary positions were observed and marked on the map corresponding to the real environment. Before the wayfinding task began, Participants knew that there was a time limit. They rarely stayed in one location for a long time, but walked around the campus as much as possible to find the destination. Figure 5.18 shows where participants paused whenever they encountered difficulties in wayfinding during the task.

As shown in Figure 5.18, colours are used to show the stationary positions of different participants. Participants with no colourful dots behind the numbers didn't stop their

walking once during the test. At the same time, the dots are numbered in Figure 5.18 so that the participants' behaviour at each dot can be listed more clearly in Table 5.7. The problems participants encountered are also listed based on their behaviour when they paused their wayfinding during the test.

Figure 5.18. Participants' stationary positions during testing

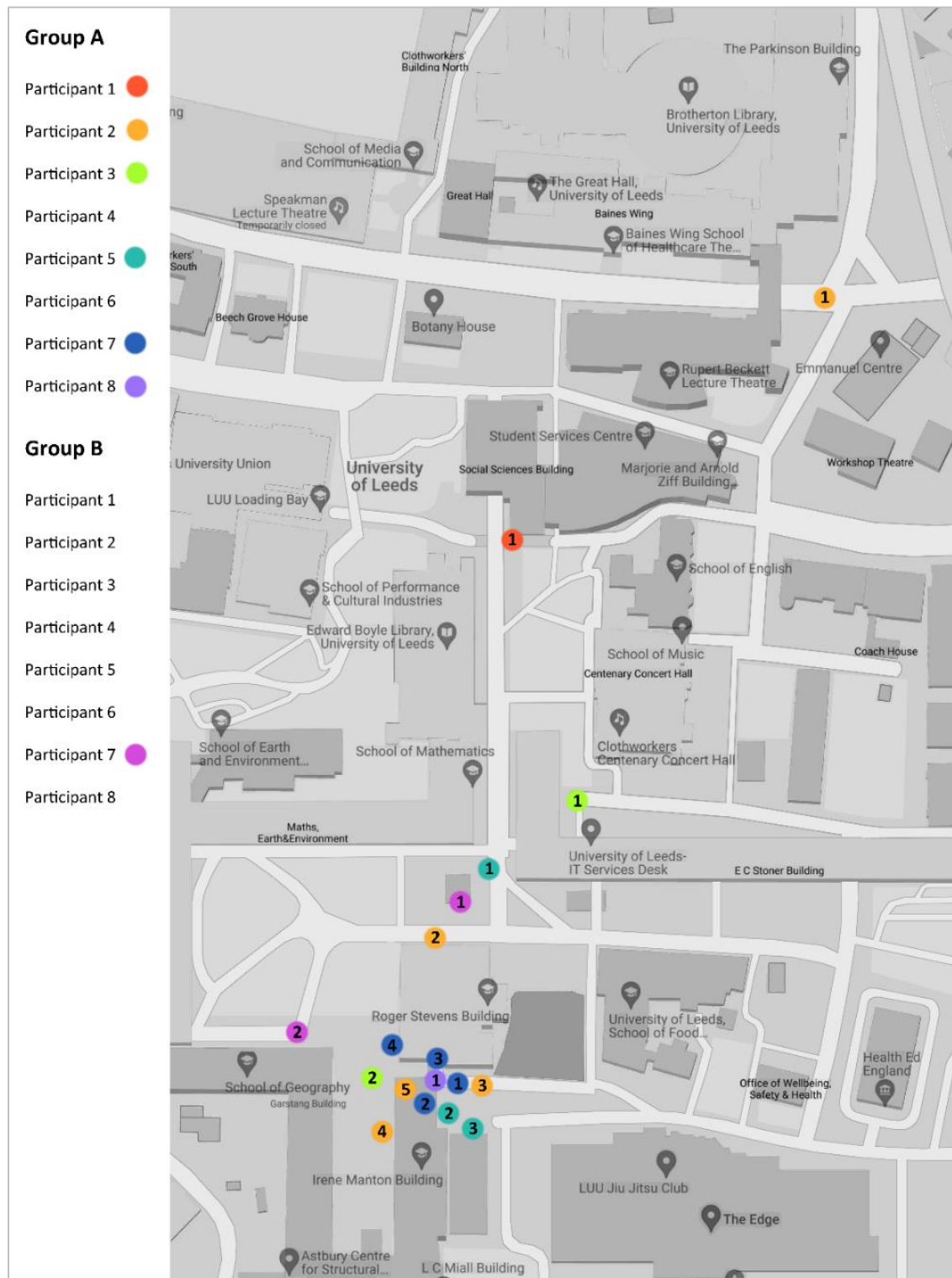


Table 5.7. Participants' behaviours and problems they faced during the test

Participant Number	Stop position number	Participant behaviour	Problems
Group A	1	1 Check if following the route drawn on the map.	Map cannot correspond to the real environment.
	2	1 Consider whether to change direction.	Map cannot correspond to the real environment (1).
		2 Consider whether to go downstairs.	
		3 Find the target building but cannot see an accessible entrance, look around to see how to enter.	Difficult to match the environment with height differences to the map (2).
		4 Wander around the ground floor of Irene Manton Building looking for a passable entrance.	Hard to find entrance (3-5).
		5 Wander around the first floor to find the entrance.	
	3	1 Try to correspond the route drawn on the map to the real environment.	Map cannot correspond to the real environment (1).
		2 Wander around the first floor to find the entrance.	Hard to find entrance (2).
	5	1 Look around the square to find accessible routes.	Map cannot correspond to the real environment (1, 3).
		2 Wander around the ground floor looking for a passable entrance.	
		3 Identify the shape on the map that represents the target building.	Hard to find entrance (2).
	7	1 Wander around the first floor to find the entrance.	Map cannot correspond to the real environment (3).
		2 Wander around the ground floor to find the entrance.	
		3 Look at the shape of the building on the map to find the entrance.	Hard to find entrance (1, 2, 4).
		4 Wander around the second floor to find the entrance.	
	8	1 Wander around the first floor to find the entrance.	Hard to find entrance.
Group B	7	1 Look around the square to find accessible routes.	Map cannot correspond to the real environment (1, 2).
		2 Check if following the route drawn on the map.	

Summarising the difficulties participants encountered during the task, the frequency of different problems they faced can be listed as follows:

Map cannot correspond to the real environment: eight times.

Hard to find entrance: nine times.

Difficult to match the environment with height differences to the map: one time.

Among them, the difficulty in finding the entrance/difficulty in matching the environment height difference with the map all occurred in Group A; regarding the perspective of the map's correspondence to the environment, Group B was obviously simpler than Group A: comparison of the number of times that the maps of Group A/B failed to correspond to the real environment is 6:2.

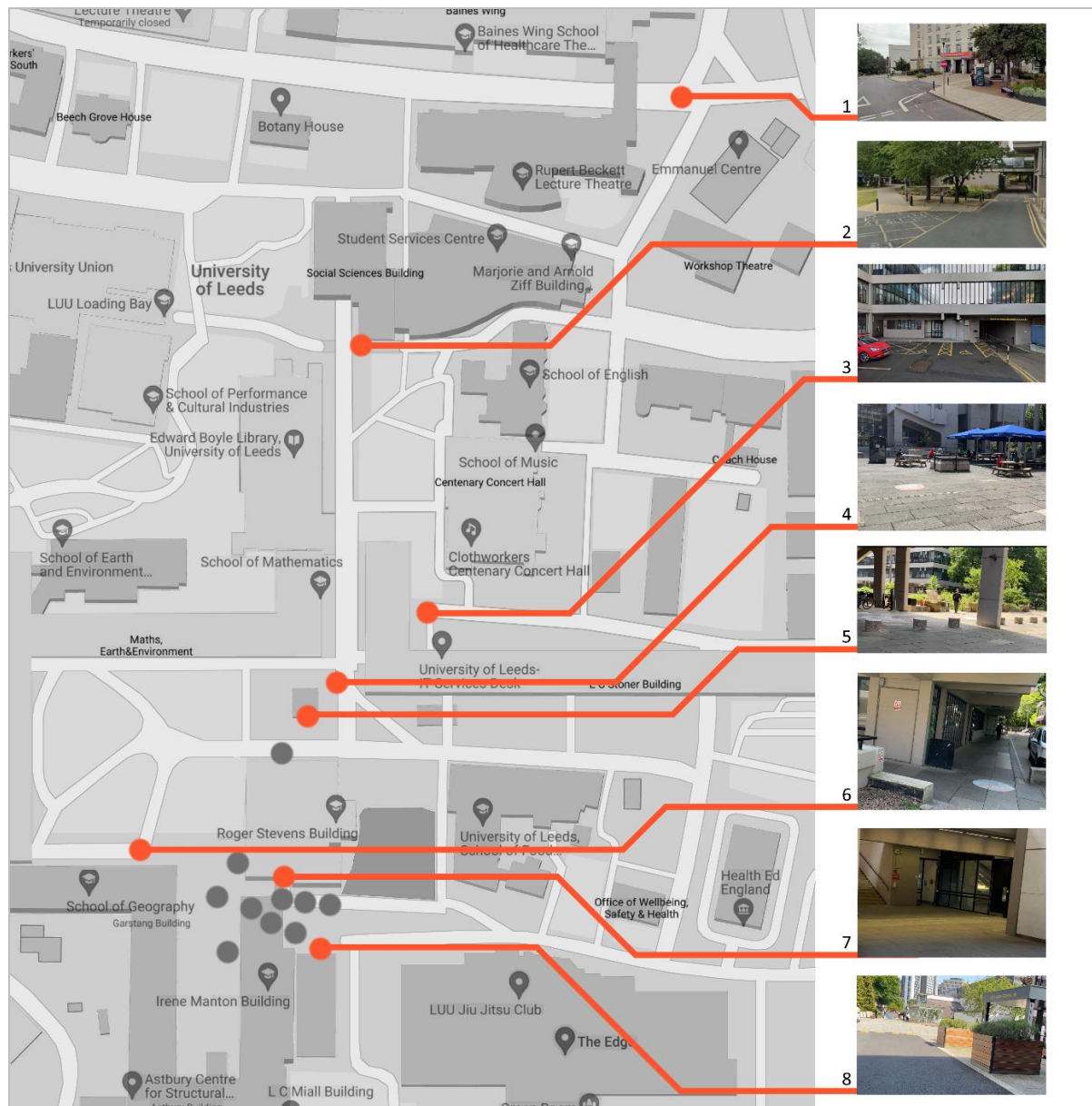
By reclassifying participants' stationary positions according to the above three types of problems encountered, the positions where they faced difficulties can be obtained (Figure 5.19).

Among these three types of problems, the inability to find the entrance occurred mostly near the destination building. The other two problems occurred at different locations in the wayfinding process. Figure 5.20 provides the surroundings of locations that do not correspond to the map when wayfinding in a real environment. Among them, 5 and 6 occurred in Group B (the additional information map group), and the rest occurred in Group A (the original map group).

Figure 5.19. Locations where the three wayfinding problems occurred.



Figure 5.20. Locations where map cannot correspond to the real environment.



By analysing the environment of the above eight locations, it can be concluded that the situations where it is difficult for participants to correspond the real environment with the visual information of the map occur in the following locations:

Open space (1, 4, 5, 8): When passing through a square or a large open space, it takes time to determine how to leave this space and where the accessible roads to other spaces are.

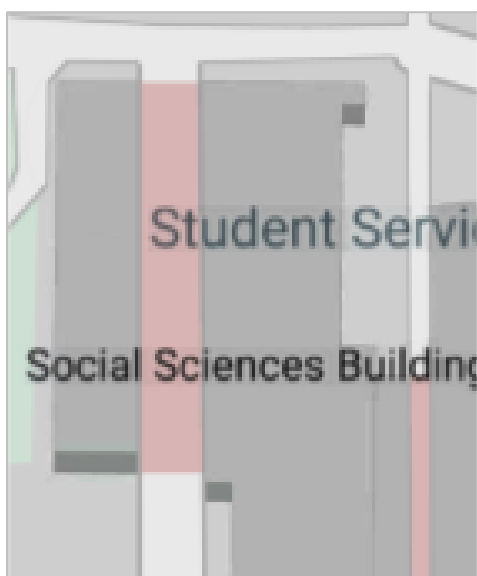
The accessible route is a passage (2, 3, 7): When the route needs to pass through the ground floor of a building or an underground passage, it takes time to consider the wayfinding direction.

The accessible route is difficult to identify (6): When the accessible route is not a common outdoor road, but a link between buildings or corridor, it takes time to confirm whether it is on the route.

In open spaces, because people's perspective cannot quickly capture the direction of the next walkable route (such as the intersection where point 1 is located, the square where 4 and 5 are located, and the large open space where 8 is located in Figure 5.20), they need to spend some time to confirm the walkable path. With the use of digital maps and route navigation, people can improve this problem by following the routes generated by the map.

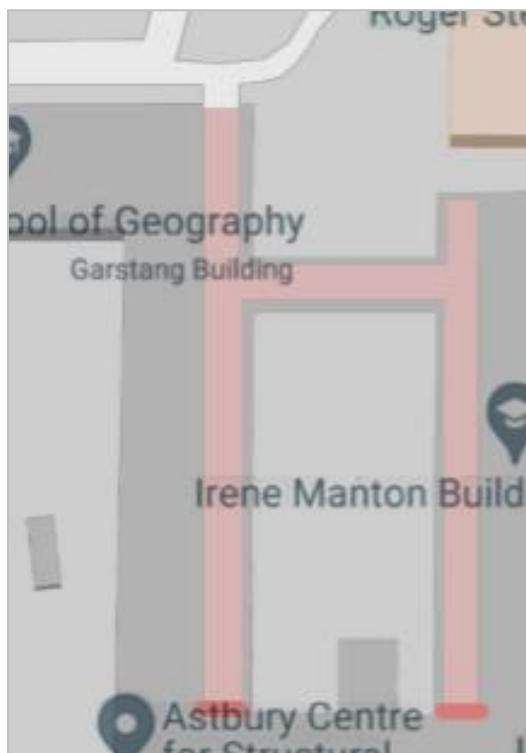
When the accessible route is a passage (such as passages on the ground floor of buildings in 2 and 3, and underground stairs in 7, Figure 5.20), accurately displaying such routes on a map can help users more easily realise that they are accessible and find the right route. This contrasts with the performance of the participants in Group B. When the pathways on the map were represented, shown on the map in a light red colour different from the outdoor road (Figure 5.21), none of the participants in Group B had to stop to look for the road during route finding.

Figure 5.21. An example of passages in information-added map prototype



When roads are difficult to identify, such as the unusual roads in 6 (Figure 5.20), clearly displaying the roads on the map to help users easily and quickly correspond to them in the real environment can improve this problem. In the experiment, all eight members of Group B were provided with maps with unusual roads added. Seven of them correctly understood the road information on the map and quickly identified the road in the real environment during wayfinding. One participant hesitated during wayfinding and identified the route after thinking. This may be because the additional information on the map prototype uses the same visual expression as a passage for unusual roads (Figure 5.22), which caused the participant to misunderstand that reaching the destination requires crossing from the ground floor of the building. This shows that the classification and design of visual expression of unusual roads is a direction worthy of research.

Figure 5.22. An example of unusual roads on information-added map prototype.



For situations where building entrances are difficult to find, the nine locations where this occurred all near the destination building. Those who encountered this difficulty were all Group A participants. Due to the complex environment and architectural shape of the

destination building, participants in Group A spent a lot of time finding ways to enter the building after arriving. When the building entrance was not given on the map prototype, participants had to find it through other ways, such as walking around the building to find doors, finding entrances through other wayfinding systems such as signs, map boards, etc. When time is limited, this forced them to spend a lot of time wandering around the destination. Figure 5.23 shows the movement trajectories of participants in two groups. The routes they took during the task were recorded by Strava, with red and blue dots indicating the start and end points respectively. Because participants in Group A did not complete the task within the specified time, their end positions were different. They all reached the destination building correctly through the map prototype information, but failed because they could not find the entrance required by the task.

Figure 5.23. Participants' route tracking maps of two groups



For the participants in Group B, all of them accurately determined the location of the entrance through added information on the prototype and successfully completed the task within the time limit. Accurately marking entrances on the map has a clear positive impact on the efficiency of wayfinding tasks. At the same time, as shown in Figure 5.22, the visual representation of the road leading to the entrance can assist participants in planning the correct route to the entrance.

As for the problem of not being able to correspond the height difference in the real environment with the map, a participant of Group A was confused when encountering a passage with stairs and was not sure whether it was a feasible route. This didn't happen in Group B, probably because the height difference was represented on the map prototype.

5.3.3. Results of interview

The map prototypes were evaluated using A/B testing methodology to more intuitively display the completion of the two map prototypes in the task. At the same time, observation was used in each test to obtain the different wayfinding performances of the participants, and the problems encountered by the participants in using prototypes can be summarised, thereby obtaining the shortcomings of the two prototypes. The participants' subjective opinions about the map prototype used were also helpful in the evaluation, so they were interviewed after the test was completed.

Interview questions were designed to focus the scope of information obtained. The purpose of the interview was to gain personal perspectives on the reasons for success or failure in completing the task, as well as the readability and wayfinding assistance of the map prototype information. Based on these purposes, the following questions were designed:

Q1. Are there any parts of the map information that are difficult to read or understand? If these parts exist, please elaborate.

Q2. Can you successfully correspond the information on the map to the real environment during the task? If there is a situation that cannot be corresponded,

where does it happen?

Afterwards, different questions would be asked depending on the participant's completion of the task:

A. Participants successfully completed the task:

Q3. Is the information on the map helpful in completing the task? What information improves the efficiency and accuracy of wayfinding?

B. Participants failed to complete the task:

Q4. What are the reasons for failure to complete the task?

Q5. Is there any information on the map that causes wayfinding to fail?

Q6. What necessary information is missing on the map to assist in wayfinding?

After collating the participants' answers, the answers were restated in Table 5.8 using keywords.

Table 5.8. Collection of participants' answers of the interview

Participant	Q1	Q2	Q3	Q4	Q5	Q6
Group A	1	No Passages	-	Entrance Height differences	No	Entrance
	2	No Height differences		Entrance	No	Entrance Stairs
	3	No Passages Height differences		Entrance Height differences	No	Entrance Different floors
	4	No Complex building		Entrance	No	Entrance Different floors
	5	No Open space Complex building		Entrance Height differences	No	Entrance
	6	No Hight differences		Entrance Hight differences	No	Entrance Stairs
	7	No Complex building		Entrance Complex	No	Entrance Different floors
	8	No Complex building		Entrance	No	Entrance

Participant		Q1	Q2	Q3	Q4	Q5	Q6
Group B	1	No	No	Entrance Unusual road	-		
	2	No	No	Entrance			
	3	No	No	Entrance			
	4	No	No	Entrance Unusual road			
	5	No	No	Entrance Unusual road			
	6	No	No	Entrance			
	7	No	Passages	Entrance Unusual road			
	8	No	No	Entrance			

The analysis of the interview is divided into two points: basic information and additional information of the map prototype.

BASIC INFORMATION

1. Legibility:

For Question 1, all participants had no problems reading the map. This shows that the map prototype clearly gives basic information to readers and is easy to understand.

2. Correspondence to reality:

When users of the map prototype encountered complex environments, the basic information couldn't enable them to successfully locate themselves and correspond the map information to the reality. This situation occurred when:

- a. When they met passages, three participants were unable to compare the map with the real environment;
- b. One participant believed that the map information did not match the real environment when met an open space;
- c. When there were altitude changes in wayfinding, three participants were unable to

get help from basic information on the map prototype;

- d. When there were complex buildings, four participants believed that basic information cannot satisfy the expression of environmental information.

3. Missing information:

When the participants used a prototype map that only provided basic information, all of them (eight people in total) were unable to complete the task because they could not find the entrance to the building. Four people also believed that the height difference in the environment hindered the completion of the task, and one person believed that the complex environment caused difficulty in finding the way. Regarding these issues, all of them agreed that the map information lacked the display of building entrances. Two people thought the stairs should be represented on the map, and three people thought the different floor layouts should be shown on the map.

ADDITIONAL INFORMATION

1. Legibility:

Group B participants were provided with a prototype map with additional information. They all found the information understandable.

2. Evaluation of the additional information:

After successfully completing the task, the eight participants who used the additional information map prototype believed that showing the building entrance on the map was a necessary condition for success. Four of them said that the unusual paths shown on the map - roads that pass through buildings - also helped in planning the route and completing the task successfully.

From the perspectives gained through interviews, the following results can be drawn:

1. The map prototype designed based on the standard map mode of Google Maps is easy to understand and allows users to understand the map information;
2. When the destination is within a specific building, displaying the building entrance on

the map can improve wayfinding efficiency and save time;

3. For complex buildings, users can be assisted in finding their way by displaying rarely used roads on the map, such as accessible passages, corridors, etc.;
4. When there is a height difference, showing the signs of stairs or the different layouts of different height planes on the map can help users locate themselves more easily.

5.4. Conclusion

This research added map information that is helpful for wayfinding (building entrances, height differences, unusual roads, and landmarks) obtained in the previous chapters into the map design and tested it. The research was divided into four steps:

1. Designed the map prototype;
2. Used the prototype for user testing and collected quantitative data (route planning and accuracy) and qualitative data (interviews) to obtain the design deficiencies and possible improvements of the prototype;
3. Designed the second-generation prototype based on the conclusions obtained from the user test of the original map prototype and map design principles obtained from previous chapters.
4. Conducted A/B testing and interviews on the performance of two sets of map prototypes (with and without additional information) and collected quantitative data (wayfinding time and accuracy) and qualitative data (observations and interviews) to evaluate the wayfinding efficiency and layout design of the two prototypes, and thus the test results were explained in more detail, and more valuable detailed improvements were provided for the design of the campus digital map.

Building entrances were shown as a decisive factor in successfully reaching the destination and were considered the most effective additional information to campus digital maps.

When the location of entering a building was not provided on the map, even if the target building was successfully found by relying on map information, the user must wander

around to find a way to enter. When users cannot identify the location of a destination entrance on a map, they tend to recognise the destination's marker as the wayfinding end point. This is consistent with the results observed in *Experiment II*. At the same time, in reviews of related research, icons, as a component of visual information in wayfinding systems, have been shown by many studies to be used to identify destinations and directions (Miller and Lewis, 1999; Gibson, 2009; Süzer, 2018). Giuliani's (2001) research mentioned the pentagram as a positioning icon to indicate "you are here." Icons and pictograms are a useful way to locate on maps. Based on the support of relevant theoretical research and the wayfinding behaviour of participants observed in *Experiment II*, the visual presentation of building entrances (and environmental height differences) was initially decided to be in icon mode. However, user feedback and experimental results reflected that icons cause difficulty in understanding, especially in the spatial positioning of icons.

Combining the entrance sign with the shape of the building (represented by a different coloured line outside the shape in this experiment design) takes full advantage of the shape of the building on the map without taking up more space. This method highlights the spatial orientation of the entrance on the map shape and helps users understand the spatial relationship between the entrance and the building.

The marking of unusual roads could significantly improve the efficiency of wayfinding. Research showed that sufficient and comprehensive roads reduced users' wayfinding time. Based on this, when designing a campus digital map, it is recommended to mark accessible roads (including ground floor passages, corridors connecting buildings, underground passages, etc.); when the environment is too complex and the roads overlap, the map can be based on different planes (floors) for layout design. Using visual information to represent height changes on the map can effectively assist users in locating themselves, but the experimental results showed that layering different heights (in units of floors) can reduce the information density of the entire map, which is very suitable for complex situations with different floors. Therefore, it is important to evaluate the design of digital campus maps based on user testing and feedback, otherwise it may lead to difficulties in using the map.

Additionally, research shows that displaying landmarks on maps has the potential to impact user route planning. Such visual information may be considered representative of campus character and culture, and there is much support for the discussion of displaying landmarks on maps in previous related research (see Section 2.3.2.3 for detailed discussion). The results of this research are consistent with some research: when participants plotted a route, there was a chance that they would change the route because they recognised landmarks. This is because the presence of landmarks is often unique and memorable, highlighting their characteristics and presenting them on the map, increasing the clarity of the environment (Lynch, 1960). Even if they are not destinations, participants will still pay attention to landmark icons when finding routes and even change their decisions because of their presence (Kim et al., 2011). However, there was no evidence in this research to support that it would help with wayfinding efficiency. This result highlights the importance of "functionality" in campus digital map design. Users pay more attention to the composition of the route and where the destination is positioned on the map; this is why entrances and unusual roads can improve wayfinding efficiency. This shows that when designing campus digital maps, the efficiency of the map should be considered first rather than aesthetics. Simplified building entrances, detailed and clear routes and layouts with varying heights always need to be considered first.

Overall, this research evaluated the addition of information to a campus digital map, used map design knowledge to design and refined a map prototype based on user needs, and tested it. As a result, the clean lines of the building entrance are highlighted as the most important and effective additional information. In the research, by observing user wayfinding behaviour and conducting interviews, a more in-depth discussion was conducted on the layout of map information, which provided new visual information improvements for the design of campus digital maps.

Regarding the contribution of the entire thesis, the case analysis of this research is a campus digital map, but as the research progresses, the results of this research are not only applicable to campus digital map design:

In the literature review in Chapter 2, the lack of research on wayfinding in academic settings was discussed: there is a lack of research on map information design for outdoor environments in academic settings. Whether it is worthwhile to conduct this research was verified in Chapter 3, which analysed the use of digital maps on campuses of existing academic institutions in the UK and conducted a questionnaire survey of campus users. While most academic institutions rely on externally linked maps to perform campus wayfinding, user research revealed campus users' needs for campus digital maps and campus wayfinding issues. Thus, in Chapter 4, Google Maps was used as a tool (the reason for using it is detailed in Section 4.1) for user testing. The test results reflected the limitations of using Google Maps in an academic environment, so a discussion on improving the visual information of digital maps was initiated, which was designed, evaluated, and iterated in this chapter. This research is always advanced from a user-centred perspective, allowing the research discussion to focus on addressing user needs. Taking an academic environment as the research object, user needs focus on the problems encountered in wayfinding in this complex environment - therefore, the results of this research are applicable to map design for complex environments similar to this type of environment.

In order to present the results of this research and unify the findings of the previous chapters, the next chapter develops design principles applicable to digital maps of campuses and maps focused on complex environments similar to academic settings. It incorporates the theories of other researchers and the results of this research and may bring convenience and reference to digital map designers and wayfinding system designers.

6. Design principles for campus digital maps

This chapter constructs design principles for campus digital maps based on the results of this thesis and other related research. In previous chapters of this thesis, existing relevant research was first reviewed, including related discussions of wayfinding behaviour and wayfinding system design principles, research on design principles of maps and digital maps and how users use maps, and focused on research on wayfinding behaviours and wayfinding systems in academic environments (see Chapter 2 for details). These theoretical and practical research provide theoretical support for the content of this thesis. Then, in Chapter 3, whether current design methods and information follow the design principles summarised in Chapter 2 was discussed, and users began to be included in the focus of this research. Considering the performance and feedback of user participation in Chapters 3 and 4, problems and possible map information design solutions were arranged, and feasible solutions to information design were designed and evaluated in Chapter 5 to obtain new improvements.

This thesis emphasises the importance of users in survey questions, practical testing, and design feedback. With this as the focus of the entire research, the campus digital map design principles summarised in this chapter are discussed and classified from a user-centred direction. Following the user needs, wayfinding issues and current design method limitations obtained in the previous chapters, the principles that need to be followed in the design of campus digital maps are proposed. Design principles are divided into two categories: information needs and practical needs. The subdivided design principles are derived from recognised relevant research and the conclusions of this thesis.

6.1. Information needs

6.1.1. Typography exists to convey information

Text conveys the majority of the information content used in wayfinding systems (Calori et

al., 2015, p.127). Even though image elements are often recognised before text, it requires text to explain information. The design principles of typography are listed from four aspects: text content, font style, appearance and structure:

1. **Text content:**

- a. In map design, textual information is used to clearly define elements of the physical environment (buildings, roads, bridges, etc.) (Apelt et al., 2007; Gibson, 2009).

2. **Font style:**

- a. Text information in the same format should be used;
- b. Typeface should be **Sans Serif** when a contemporary look is desired (Calori et al., 2015, p.131);
- c. Fonts such as Arial, MS Sans Serif, Tahoma, Futura, Geneva and Helvetica Medium make it easier for people to read. (Apelt et al., 2007, p.10; Gibson, 2009);
- d. Fonts with descriptive functions should be unified (Gibson, 2009).

3. **Appearance:**

- a. For emphasised information, bold, capital letters, and larger font sizes can be adopted (Bringhurst, 2002);
- b. Font size, type, and layout should be legible and easy to understand. The size and spacing between letters and words should be proportional to the amount of information provided, uppercase and lowercase letters are easier to read than all uppercase letters (Apelt et al., 2007; Gibson, 2009; Roefs and Mijksenar, 2017).

4. **Structure:**

- a. The text and layout of the map should be proportional and neat, and avoid using letter codes and number codes. (Apelt et al., 2007, p.5);

- b. The information on the map should be balanced and orderly (Tyner, 2014);
- c. Should avoid excessive text information;
- d. The display of map information should consider more the relationship between shapes, paths, and spaces.

6.1.2. Image for quick processed information

Images are easier to recognise than text for quick processed information (Lomperski, 1997; Apelt et al., 2007; Xie et al., 2012; Hashim et al., 2014; Süzer, 2018; Wang et al., 2018). Using images such as icons, arrows, and pictograms on maps can assist users in identifying destinations and directions rather than spending time reading text (Miller and Lewis, 1999; Süzer, 2018). The design principles for images suitable for campus digital maps are as follows:

1. Different cultural and educational backgrounds lead to different understandings of images, and it is necessary to consider the legibility of images among different groups of people (Hashim et al., 2014), or to assist in explaining the function of images to ensure that users fully understand the usefulness of images when reading maps;
2. Using recognisable landmarks on digital maps (Siegel and White, 1975; Çubukçu and Nasar, 2005; Davidson, 2014);
3. The position and form of the image need to consider its spatial position in the geographical environment to avoid positioning errors.

6.1.3. Colour to distinguish map visual information

Maps use visuals to illustrate the relationship between geographical reality and space (Papadias and Theodoridis, 1997). The use of colour as an additional navigation tool is considered beneficial for information recognition when users construct environmental mind

maps through maps (Dalke et al., 2006). The design principles about colour are divided into colour selection and colour contrast:

1. **Colour selection:**

- a. The colours used in the colour settings should not be too many (NHS Estates, 2005; Feisner, 2006);
- b. Use colour coding can convey information (Abu-Obeid, 1998; Calori et al., 2015): Colours that match the real environment (green for lawns, blue for rivers, etc.) should be used to base the visual information in reality;
- c. Focus on the three properties of colour (hue, intensity and value) to enrich colour composition and create contrast (Gibson, 2009);
- d. When choosing colours, consider whether different cultures will bring different interpretations of the meaning of colours (Park and Guerin, 2002; Hashim et al, 2014; Calori et al., 2015);

2. **Colour contrast:**

- a. Visual information (background, letters, graphics) should have colour contrast and brightness differences (Lomperski, 1997; NHS Estates, 2005; Apelt et al., 2007; Gibson, 2009; Sandnes, 2017; Süzer, 2018; Roefs and Mijksenar, 2017);
- b. Colour of map background and the road need to has contrast;
- c. Different colours should be used to increase the colour diversity of the map and the distinction between building groups:
 - i. Two-hues differentiation can use minimal colours to make connected buildings not difficult to distinguish;
 - ii. Colour sequence changes (brightness and saturation change in sequence) makes colours of different information change without causing reading difficulties due to too many colours;

- iii. Hue changes adds colour richness and show differentiate areas in the environment.

6.1.4. Spatial information corresponds to geographic environment

People's ability to generate and improve cognitive maps of the physical environment during wayfinding is closely related to people's ability to orient themselves in space (Passini, 1992). Insufficient spatial orientation affects wayfinding abilities, causing cognitive confusion and making it difficult for users to construct mental maps (Kitchin, 1997). In this case, improving the legibility (layout and complexity) and spatial recognisability (how helpful the environment is to the user) of the environment can give people a better sense of orientation (Canter, 1974; Güneş, 2018). The design principles of spatial information are also developed from these two aspects:

1. Environment legibility:

- a. Use only important and memorable elements when choosing the information displayed (Apelt et al., 2007, p.4);
- b. Users should be allowed to identify building entrances on a map;
- c. Maps should ensure that users can identify all accessible roads, including uncommon roads, such as passages, corridors, etc. to improve environmental recognition;
- d. Where there are height differences in complex environments, maps can show signs of stairs or different layouts of planes at different heights to enhance the legibility of the environment;
- e. Lines to represent roads:
 - i. Change the thickness of lines to indicate the width of roads;
 - ii. Change the form of lines (dotted/solid lines, transparency) or colour of lines to represent different functions (sidewalks, driveways, paths through buildings, underpass, etc.);

- iii. Arrows can be added to lines representing lanes to indicate the direction of a one-way street;
- iv. Lines can be used to divide areas within the city.
- f. Shapes to correspond to environmental visual elements:
 - i. Use different shapes to represent the landscape with volume in the real environment (such as buildings/lawns/rivers and lakes);
 - ii. Connected building groups should be represented separately.

2. Environment spatial recognisability:

- a. The organisational elements of spatial information, including paths, landmarks and areas, should be displayed on the map (Apelt et al., 2007, p.4);
- b. The complexity of landmarks and views should be reduced, and key nodes should be kept in key positions (Wang et al., 2018);
- c. Recognisable landmarks should be used on digital maps (Siegel and White, 1975; Çubukçu and Nasar, 2005; Davidson, 2014);
- d. While avoiding increasing the complexity of map information, it should ensure that users can easily and quickly correspond to the real environment through the map.

6.2. Practical needs

6.2.1. Positioning and navigating

Wayfinding is a process of orienting through mind mapping (Lynch, 1960). People become confused when they are lost or unable to orient themselves (Stanney, 1999; Scott-Webber et al., 2000). The positioning and navigation functions of maps are the most important factors in practical requirements. The positioning and navigation design principles are as follows:

1. Need to help users orient themselves (Canter, 1974; Passini, 1992; Kitchin, 1997; Güneş, 2018);
2. Self-centred view should be taken (Thomas, 2008);
3. Users should be allowed to locate themselves at any time;
4. Navigation destinations should meet user needs, not just reaching destination markers.
For example, if the destination is a building, navigate to the accessible entrance of the destination.

6.2.2. Personalisation of digital maps

Due to screen size and interactive features, digital maps can be "more personalised" than paper maps (Davidson, 2014): the scale of digital maps is no longer fixed; compared to paper maps, users can customise the information by interacting with the screen. Design principles for map personalisation are as followed:

1. **Screen size:**

- a. Users should be allowed to freely choose the appropriate map scale (Davidson, 2014);
- b. The detailed level of information changes accordingly with the change of the map scale; as the scale of the map shrinks, the level of detail of the information should decrease (Töpferand and Pilewizer, 1966).

2. **Interactive features:**

- a. Allows a variety of map modes (appearances) to be selected, making it easier for users to use multiple methods (simplified mode, satellite mode, etc.) to correspond to the environment when they are lost;
- b. Allow users to directly operate the map to view information on the map;
- c. Can display information about buildings and landmarks and interact with them to

enhance the attractiveness of the map (Kim, 2011);

- d. Menu should have hierarchy to avoid too much information at the same level.

7. Discussion

This chapter summarises the research's aims, its main findings and highlights the methodological and practical contribution to knowledge. Finally, potential limitations of the research and future research are discussed.

7.1. Overview of the research

This thesis aims to use user-centred design methods to improve the information design of campus digital maps and construct information design principles suitable for campus digital maps. Besides, it provides valuable suggestions to information design researchers and designers who focus on campus digital maps and similar complex environmental maps. The research focuses on the impact of the visual information of campus digital maps, including map appearance, colour, and map information communication on wayfinding efficiency. In addition, the research also investigates the information legibility of digital maps from the perspective of user needs, and proposes effective design suggestions to strengthen the connection between the information presented on campus digital maps and the real environment, so that they can help users more conveniently build a cognitive map when using a wayfinding design to navigate their environment.

As discussed in Chapters 1 and 2, since people need to construct correct cognitive maps to cope with confusion and fear of getting lost (Lynch, 1960), digital maps need to improve their legibility to help people navigate their environment (Baker, 1986; Liu, 1991; Yoo, 1992; Abu-Ghazze, 1996). The International Cartographic Association (2003) defines a map as a symbolic image of geographical reality. On this basis, digital maps become more dynamic and interactive than traditional paper maps (Winter and Tomko, 2004). In order to improve the legibility of campus digital map design, the research applied user-centred design principles, and conducted tests exploring existing map design and map symbol visual design. In Section 2.3.1, wayfinding behaviour in an academic environment was investigated. Currently, there is still a lack of existing research on campus digital map design focusing on

map legibility, and there is no current research on behavioural testing of users using campus digital maps to perform wayfinding tasks. Moreover, Section 3.2 investigated the use of campus digital maps by universities in the UK and found a lack of self-designed campus digital maps. To fill this gap, this research investigated, tested, improved, and evaluated campus digital maps following user-centred principles and explored how information design knowledge can help improve map design. Following the research, information design principles were created based on existing research (focusing on wayfinding design principles, map design principles, and visual design in digital maps) and research findings from this thesis.

7.1.1. Research stages and objectives

As proposed in Chapter 1, this thesis achieves the research objectives and completes the entire research through five stages.

The **first stage** in research is **theoretical support**. Two objectives were accomplished in this session, namely, to find out the design factors that influence the design of campus digital map information, and to understand the relevant theories of wayfinding behaviour in academic environments and the characteristics of campus wayfinding:

In Chapter 2, the relevant literature on wayfinding behaviour and map design was reviewed. At this stage, preliminary information design principles for wayfinding systems and digital maps were constructed, against which the legibility of digital maps could be assessed. This stage helps to build a preliminary knowledge framework for the entire thesis. By reviewing relevant research on human wayfinding behaviour (including cognitive maps, environmental familiarity, user experience of wayfinding systems, etc.), the researcher had a preliminary understanding of how humans find their way in the environment and the influencing factors; the discussion on the theories of wayfinding systems and map design constructed information design principles and confirmed the design factors that affect the information design of campus digital maps; in addition, the analysis of existing research related to

campus digital map design confirmed the shortcomings of existing research in information design, and explored other researchers' research on related issues such as wayfinding behaviour and getting lost in academic environments, thus laying a theoretical foundation for campus wayfinding behaviour and problems.

The conclusions obtained in Chapter 2 were applied to the visual survey of campus digital maps (*Study II*) to investigate the visual design limitations of existing digital maps that may affect user reading efficiency, and combined with the analysis of *Study I* (Section 3.2) to achieve the **second stage**: Research on **existing deficiencies**.

The research objectives of the second stage were achieved through two studies: investigating campus digital maps usage of existing academic institutions in the UK (Section 3.2) and identifying the design constraints that affect the readability of campus digital maps (Section 3.3).

Through the investigation and analysis of existing academic institutions, their shortcomings were found: the extensive use of external digital maps as route navigation tools greatly reduced the usability of campus digital maps. In order to confirm the design constraints of visual elements and interactive functions, representative campus digital map cases were selected in *Study II* (Section 3.3) and:

1. Investigated how key elements of selected maps “symbolise geographical reality” and observe the different expressions of key elements (lines, shape, and colour).
2. Evaluated the legibility of existing maps in terms of visual design and functionality, and identified limitations that affect user efficiency (crowded layout, confusing colour system, imperfect wayfinding, etc.).
3. Analysed the limitations of existing maps and combined the design framework obtained from literature research, and help improve the details and persuasiveness of the final design principles.

The results of the second stage identified the use of existing digital campus maps of UK academic institutions and identified the design constraints (in terms of visual elements and

interactive features) that affect the legibility of campus digital maps. After identifying the existing shortcomings, user opinions were taken into account in the research core.

In the **third stage** of this thesis, the research objectives were achieved through a series of **participatory case studies**: the opinions of users of the campus environment on the legibility of digital maps were investigated, and limitations and solutions of map information design were identified. *Experiment I* (Section 3.4) and *Experiment II* (Chapter 4) help complete this process:

1. Used online questionnaire survey to understand users' behaviour and performance when looking for information or locations on campus, and investigate their understanding and use of campus digital maps. Through the survey, users' basic needs for digital maps were established, and the environments and situations where it was easy to get lost on campus was collected.
2. Conducted user testing, observed the environmental elements and their performance observed when participants were looking for paths on campus, and identified environments where it is easy to get lost.
3. During user testing, also evaluated the effectiveness of existing digital maps in the complex campus environment and identified their accuracy and limitations in terms of legibility and geographic positioning.

Based on the wayfinding problems in academic environments obtained in *Experiment I*, *Experiment II* observed the limitations of users' wayfinding when using existing digital maps when completing wayfinding tasks (Section 2.3.1.2) and obtained possible feasible solutions, thus providing a reference for design methods aimed at improving map readability and usage efficiency.

The conclusions obtained were applied in the **fourth stage, designing solutions and evaluating** them. In *Experiment III* (Chapter 5), the researcher designed the map information for the solution built in the third stage, created, evaluated, and iterated the map prototype, aiming to obtain scientific and comprehensive solution content, enrich the design principles

of campus digital maps and make them more convincing. Through user testing of the map prototype to evaluate its readability and efficiency of use, the research results obtained are as follows:

1. When planning a route on the map, the building entrance is considered a decisive factor in successfully reaching the destination. Additionally, entrance signs show better reading efficiency when integrated with the shape of the building (without disrupting the shape).
2. Sufficient and complete roads can reduce users' wayfinding time, and unusual roads (ground floor passages, corridors connecting buildings, underground passages, etc.) should be indicated, through visualisation, on the map.
3. Using visual information to represent height changes on the map can effectively assist users in self-positioning.
4. Some visually enhanced and recognisable visual information (such as landmarks) will enhance the environmental recognition of campus users and help users position themselves in the environment, thereby changing the user's route planning.

However, they were not found to improve wayfinding efficiency in this experiment.

Finally, campus digital map information design principles including information needs and practical needs were established. This addressed the **fifth stage**, which was to establish campus digital map design principles based on literature research and experimental results.

7.2. Major findings of the research and contributions to knowledge

This research investigated legibility and developable design directions for campus digital map information design. This section discusses the main findings of the thesis, how to improve and enhance existing design principles, and related contributions to knowledge. The core research was conducted in five chapters, which addressed the research questions raised in Chapter 1 in the order of understanding knowledge, identifying problems, and

testing solutions, and gradually discussed the following:

CHAPTER 2: Theories and design principles that may contribute to the design of campus digital maps.

CHAPTER 3: The usage status of campus digital maps in universities in the UK; performance comparison of five different campus digital maps through visual survey; problems encountered by university users in campus wayfinding and usage of digital maps through questionnaire investigation.

CHAPTER 4: Testing of the actual use of digital maps in campus environments. The test results would help guide the improvement of campus digital map design.

CHAPTER 5: Practical design solutions and testing to improve the effectiveness of digital campus maps.

CHAPTER 6: Principles for campus digital map information design.

The following sections discuss in detail the main findings of the research and reflect on how these findings contribute to possible future research.

7.2.1. Use design theories and principles to evaluate the legibility of digital campus maps

This research analyses and evaluates campus digital maps within the framework of wayfinding behaviour and map design principles. Existing research on wayfinding in academic environments is currently limited, and the known studies include exploration of wayfinding behaviour and wayfinding systems. In terms of wayfinding behaviour, existing research discusses potential problems that may be encountered in campus wayfinding, such as user behaviour when the wayfinding system cannot be used (Bishop, 2011), and the negative emotions that users may have when they get lost (Passini, 1992; Yoo, 1992; Darken and Peterson, 2002), the pressure of wayfinding within a limited time in an academic environment (Xie et al., 2012), and the impact that users' familiarity with the environment

may have on wayfinding efficiency (Garling and Evans, 1992; Kanakri et al., 2016). In the two experiments (*Experiment II*, *Experiment III*) that included user testing in this research, participant recruitment as well as task content were regulated according to the theory of wayfinding behaviour:

1. For participant recruitment, in order to avoid factors that potentially affect the results: the participants recruited in the experiment were not familiar with the experimental area, so there was no possibility that the cognitive map formed in memory would affect the wayfinding efficiency (NHS Estates, 2005). They could only use the experimental map instead of seeking help from other wayfinding systems; based on the different purposes of the experiment, *Experiment II* did not limit the wayfinding time to observe more participants' wayfinding behaviours and problems encountered in the academic environment, while the user test in *Experiment III* put participants in a scenario where they needed to find the destination within a limited time (Xie et al., 2012), and focused more on the correspondence between map information and the environment.
2. Regarding the design of task content, the researcher applied the three wayfinding tasks summarised by Allen (1999), commute, explore and quest, into the experiment (Section 2.3.1.2). Dividing wayfinding behaviour into three categories according to purpose not only showed differences, but also clearly reflected the efficiency of users in finding paths and using maps for different purposes, and provided detailed and clearly differentiated contents for the analysis of observation data. More detailed discussions are provided in Section 7.2.2, Section 7.2.3 and Section 7.2.5.

Research on wayfinding systems focuses on indoor wayfinding, such as library wayfinding system research (Barclay, 2012; Li and Klippel, 2012; Mandel, 2013). Current research on outdoor wayfinding systems focusing on academic environments is limited. This research helps to address this gap. First, the use of campus digital maps by UK academic institutions was explored (Section 3.2) to understand whether there were independently designed campus digital maps and how they were used. The survey showed the lack of independently

designed campus digital maps, supplemented by the user needs for campus digital maps in the questionnaire investigation (Section 3.4, more details are further discussed in Section 7.2.5), to emphasise that this research has research prospects and serves as a reference for future related research. The research divides the campus digital map design into two main parts: map visual element design, interaction and operation. This classification expands the definition of maps as the extraction and visual presentation of geographical reality information (Papadias and Theodoridis, 1997; Buisseret, 1992; Cartwright, 2014; Sadahiro et al., 2015; Katarzyna, 2018), and adds the importance of user experience in design. This is consistent with Lynch's (1960) user-centred wayfinding design theory. This classification facilitates an objective and comprehensive assessment of the legibility of campus digital maps from the perspective of visual presentation and functional information design.

This research selected and evaluated existing campus digital maps in UK academic institutions as examples to supplement knowledge in the field of campus digital maps. The maps analysed are all campus digital maps with characteristics and different ways of visual presentation. Based on Tyner's (2014) requirements for key visual elements of maps, the design of map visual elements was discussed from three aspects: lines, shapes and colours (Section 3.3.3.1). After classifying map elements and discussing them, the research intuitively demonstrated their different visual presentation forms, especially highlighting the comparison and judgment of the design effectiveness of individual elements. At the same time, through the visual survey of lines, shapes and colours, the correlations between them were also clearly shown, providing references for the establishment of information design principles. For interaction and operation, the research divided the design quality of maps into three aspects: spatial information, text and layout, and scale according to the framework of digital map design principles (Section 2.4) and evaluated them (Section 3.3.3.2). The design principles that the maps "followed" and "not followed" were presented as a heat map to intuitively show their application of the design principles. Through the comparison of design theories and principles, the visual survey results classified and added map design guidelines in more detail, which helped to make comparisons during map design and avoided drawing conclusions that might affect legibility and efficiency of use.

In general, the review of relevant research in this thesis provides theoretical guidance for the entire research process, making the research process and results more convincing. When conducting the literature review, this thesis did not just focus on the relevant theories and research on campus digital maps, but went back to the source and started the discussion from the concept of "wayfinding": understood the relevant theories of wayfinding systems, then delved into the knowledge of map design, and finally focused on research related to wayfinding in academic environments. In each phase of the literature review, the application of relevant research in design and user aspects was discussed from the perspectives of information design and user experience. This provides this thesis with valuable theoretical support in the verification and refinement of design principles, as well as in the design of case studies with user participation. At the same time, the content of the review brings a unique contribution to knowledge: it integrated and analysed relevant research in detail, helping other researchers to benefit from it, providing them with theoretically supported references and advice when conducting research on wayfinding system design or map design - from both design theory and user experience perspectives. The application of the review conclusions in this thesis (as introduced in this section) can also provide researchers with valuable suggestions.

7.2.2. Find the limitations of digital maps in complex academic environments and explore additional information to enhance map visual information design

Research shows that successfully locating oneself can quickly find surrounding geographical information when using a map to find directions, which can improve map reading speed and efficiency (Passini, 1992; Kitchin, 1997). Compared with printed maps, interactive digital maps can automatically locate users and display their real-time location on the map. This also creates a problem. Compared with paper maps and map boards, which may be able to rely on landmarks on the map to locate or use symbols like pentagrams to mark the user's location (Apelt et al., 2007), when the positioning of digital maps is inaccurate or navigation fails, users need to match map information with the real environment to reorient

themselves.

This research conducted a user testing experiment (Chapter 4), focusing on participants' performance in completing three different wayfinding tasks outdoors: commute, explore and quest (Allen, 1999). The quest task contained two destinations, and the difficulty of reaching them increased. University users are often asked to visit unfamiliar places (Kanakri et al., 2016). Helping users find building entrances and accurate rooms in a shorter period of time would be a direction to improve the problem of getting lost on campus (see Section 3.4.3.2.2 for details). Combined with the positioning problem, the two destinations were set, which were a) enable map navigation to reach the building entrance, and b) the navigation end point is the central area of the building (unable to navigate to the entrance).

The results of this experiment highlighted that digital maps could not meet users' wayfinding requirements to a certain extent in outdoor campus environments, and found feasible solutions to enhance map information design. Through the experimental analysis of the quest task (Section 4.3), the research showed that the efficiency of using digital maps decreases as the complexity of the campus environment increases. This result points out the limitations of digital maps in complex environments. The information and navigation of digital maps cannot meet user wayfinding needs in such environments. In terms of map information, satellite mode maps have higher environmental recognition and readability than illustrated mode maps. Both modes lack the ability to find building entrances and determine height differences. In the explore task (Section 4.4), research showed that the map needs to reflect the scenery that the user is interested in during the wayfinding process, so that the user can more easily correspond to the visual element information in the environment and on the map. This requirement was strengthened in *Experiment III* (Chapter 5). In user test of first-generation map prototype (Section 5.2.2), the results showed that recognizable landmarks will enhance users' perception of the environment, thus affecting their route planning. In addition, this research also considered the map search function and put forward suggestions for classifying campus facilities. The needs of facility functions should be considered to ensure comprehensive and correct classification.

In summary, this research proposed issues that need to be paid attention to when designing digital maps in three aspects (environmental complexity, map navigation efficiency, and user wayfinding purpose) by researching the limitations of digital maps (see results in Section 4.5). These conclusions not only contribute to the concerns in the design of campus digital maps, but also add reference knowledge to other map design and testing methods other than campus digital maps (see Section 2.3.1, Section 4 Chapter, and Chapter 5 for more testing solutions). This research observed campus wayfinding with different purposes and difficulties in the experiments, expanded the knowledge about wayfinding behaviour in complex environments, refined the common problems when people find their way and the outdoor environments where wayfinding difficulties are prone to occur, and provided valuable suggestions for other relevant future studies investigating such issues. In addition, the experimental method adopted in this research can influence better wayfinding design practices, which will be explained in detail in Section 7.2.5.

7.2.3. Use paper prototypes to control research focus

Experiment III (Chapter 5) evaluated the information design that may improve the efficiency and readability of campus digital maps (derived from the experimental conclusions of the previous chapters), and designed a map prototype containing feasible visual information and conducted user testing (see Section 7.2.4 for a detailed summary). During the design step of the test materials, this thesis always focused on the research purpose: the information design of the map. This is based on the following two reasons:

1. Theoretical support:

The basic function of the visual information of maps used for wayfinding is to extract the characteristics of geographical reality and design them into symbolic images that reflect spatial relationships (The International Cartographic Association, 2003). Digital maps are very different from paper maps in terms of technology and are more interactive (such as operating a touch screen to switch information, automatically providing routes, etc.).

However, their functions are not reflected in the medium but in the purpose. Digital maps and printed paper maps have something in common in terms of information design (Kent and Vujakovic, 2019). When the purpose of the research is focused on "information design", the influence of other map functions on the experiment should be excluded, such as relying on the automatic positioning of the GPS function to enable people to quickly understand their position in space, thereby weakening the role of the map information itself in spatial positioning.

2. Experience reflection:

In *Experiment II* (Chapter 4), Google Maps was used as a tool to investigate the limitations of digital maps in academic environments. An occasional situation occurred during the experiment, that is, the GPS positioning was offset, which prevented one participant from determining "you are here" through the automatic positioning point of the digital map (Giuliani, 2001). On the contrary, the GPS positioning at the accurate position made other participants believe the distance between them and the destination (marked as a dot on the digital map). Even if the navigation function failed, the participants focused on making the "positioning point" as close as possible to the "marked dot" to complete the task, rather than focusing on the map information to determine how to reach the designated location.

When designing the map prototype, the possible impact of GPS positioning and navigation was considered. In *Experiment III*, the researcher wanted to obtain participants' feedback on the use of additional map information (described in detail in Section 7.2.4). With this clear purpose, participants were required to judge their own spatial position in the environment through map information. Therefore, the paper map prototype was selected as the design medium.

While this decision has the above advantages, it also has certain limitations: paper maps cannot meet the interactive advantages of digital maps (the scale of digital maps can be adjusted to read map information at different scales; similarly, due to the adjustable scale, digital maps can display different levels of detail at different scales) (Davidson, 2014).

Therefore, even if paper maps are similar to digital maps in information design, using them as a research tool still needs to be carefully considered. In this experiment, since the environmental area selected for the test is part of the University of Leeds, the map information (including key elements required by map design theory such as lines, shape and colour, as well as the additional information obtained from the experimental conclusions such as building entrances, height differences and accessible roads) can be fully displayed on a paper map (A4 size) and allow users to read it all. In this particular case study, the map size of the paper map prototype can meet the experimental requirements, so it was successfully designed and tested.

In the present and future of rapid technological development, we cannot define the future form of *map*: it may be that the street view mode develops more conveniently, it may be transformed from a two-dimensional plane to a three-dimensional space, or it may be a technology that has not yet been developed. This research used paper maps to test map information design, and reviewed the origin of maps - separated from technology and science, and started the research from the purpose of the map itself. This also gives other researchers the possibility to reflect on whether the research object can be separated from its most original purpose when technology develops rapidly, and what is the definition of the research object. In this research, due to the focus on user-centred information design, its conclusions are still applicable and can contribute to the design of maps whose target group is "human beings".

7.2.4. Make A/B testing results more detailed and objective through qualitative data analysis

Experiment III (Chapter 5) evaluated the impact of adding map information on wayfinding efficiency through A/B testing, with a campus digital map prototype. This is a successful demonstration of A/B testing possibilities in map design evaluation. A/B testing is more commonly used to compare versions of website user interface designs (Larsen et al., 2023),

or for the evaluation of tangible products (Madlenak et al., 2023). This research combined A/B testing with observing user wayfinding behaviour and interviews to evaluate additional information. This method is novel in map design: collected quantitative data (A/B testing) to intuitively judge the success rate of two groups of participants and wayfinding efficiency (through time to complete task); at the same time, qualitative data (observation and interviews) were used to more objectively collect participants' opinions and performance during the task, providing a more specific conclusion for map evaluation that combines user behaviour, the correspondence between the map and the environment, and user opinions. This approach expands the way map design is evaluated and may serve as a reference for future researchers/wayfinding designers to evaluate products.

The two experimental designed that were tested were map prototypes with and without added information that might help wayfinding efficiency. The additional map information was based on the results of *Experiment I* (Section 3.4.3.2.2) that established reasons that users get lost, the limitations of digital map design obtained in *Experiment II* (Section 4.5), and the discussion of wayfinding problems in academic environments in the campus digital map design theories (Section 2.3.1.1). The added information satisfied the requirements of making complex environments easier to read (showing elevation changes and unconventional accessible roads), increasing the relevance of the map to the real environment (highlighting some visually appealing landmarks), and satisfying the purpose of user wayfinding in an academic environment (enabling building entrances to be shown on the map). The map prototypes tested were iteratively designed and improved based on the design principles summarised in this thesis. The improvement process is described in detail in Sections 5.2.1-5.2.3.

The experimental results suggested that an A/B testing method is suitable to investigate the efficiency and success rate of participants using the campus map prototype to find paths under different conditions (with and without added information), helping to identify the effectiveness of additional information during the evaluation process. This also demonstrates a practical applicable of user-centred design in the context of wayfinding. When users tested with experimental objects, success rates and completion times of

different groups could be quickly compared to indicate whether the test variables (information added on the map prototype) were useful for research purposes (Madlenak et al., 2023). The experimental results were the same as the suggestions of Tomitsch and Wrigley (2018), which quickly determined that in the scenario of quest task, the map prototype with added information is more effective (see Section 5.2.4 and Section 5.3.1 for more details). This method can visually display the impact of map information on participants' wayfinding efficiency through the time and success rate of completing the task, providing a valuable reference for future design evaluation.

More importantly, this experiment found that assessments of information design performance should be analysed in conjunction with performance in user testing and user feedback, so that suggestions for the legibility of additional information could be obtained, and the ways in which additional information can impact wayfinding efficiency could be explored. This research adopted an observation method during the experiment and conducted interviews after the test to obtain qualitative data for more detailed analysis. Take the difficulties encountered by users during the task of A/B testing as an example, when participants need to decide about the route during the wayfinding process, they would stop moving and think about it. After analysing the wayfinding problems represented by user behaviours, their "stop position" points were marked on the map to indicate areas where different wayfinding problems were likely to arise. This helped the researcher more accurately understand the categories and frequencies of difficulties users encountered when map information was different, so that the importance ranking of added information could be derived from the analysis. This approach can serve as a suggestion for future wayfinding research, helping future researchers to visually locate the areas and frequencies where users have wayfinding problems, making it easier to analyse the usage limitations of the wayfinding system and make the design more convincing.

Moreover, although it is difficult for the test to fully simulate the wayfinding situations of real-life users based on different scenarios and purposes, the researcher assumed the time-critical situation that campus users often encounter when finding their way (Kanakri et al., 2016), and specified the task duration in this research. This method encouraged participants

to focus on the task and performed wayfinding behaviour as much as possible during the test, so that the occurrence of the “stop position” mentioned above means that participants had to “waste” limited time not searching but thinking. This made it more convincing to explore the wayfinding problems that arose in the "stop position" areas and the source of the problem (perhaps the lack of information on the map). This approach also enabled participants to perform the task as efficiently as possible and can be implemented in other product evaluation tests that involve users.

In addition, interviews were conducted to obtain participants' subjective opinions on the map prototypes used. The collection of this data helped the researcher obtain participants' evaluations of the legibility of the map prototype and suggestions for the visual presentation of additional information, which provided data support for the establishment of campus digital map information design principles. The interview questions were designed based on possible scenarios that might arise during the test session. Before starting the test, the possible results (test success, failure; reasons for success and failure) were anticipated, and the interview questions were designed starting from the prediction. This helps limit the scope of information obtained and focuses the interview on what the researcher are concerned about testing and evaluating (see Sections 5.3.2 and 5.3.3 for more details). The design and conduct of the interview in this thesis provide ideas for designing interview questions for future research to help researchers obtain interview data that is more closely related to the research content.

7.2.5. Establish information design principles for campus digital maps

Combining the discussion of design principles obtained from the relevant literature review and research results, information design principles for campus digital maps were constructed. Through existing relevant research and the design principles summarised in this research, the gaps in information design principles for campus digital maps were filled, providing principles for designers of map design and information design. Chapter 6 listed the campus digital map design principles in detail, bringing valuable reference to the map design

and information design disciplines, which also helps to evaluate the design quality and usage efficiency of campus digital maps.

This research highlighted that correct geographic positioning was one of the most important features of a map. When positioning, maps have the best navigation accuracy when people use the map from a self-centred perspective and display the user's real-time location on the map (Thomas, 2008). This advantage of an interactive digital map, however, could reduce the user's wayfinding efficiency when positioning errors or navigation errors occurred (see quest task in *Experiment II*, Section 4.3). In daily life, users of campus digital maps often find their way within a limited time. Students can feel stressed when they try to attend class on time but cannot find their destination (Kanakri et al., 2016), completing wayfinding tasks within limited time may further induce stress and anxiety, affecting perceptual and cognitive abilities (Xie et al., 2012).

In this case, the visual presentation and legibility of the map itself is an effective way to assist users in quickly matching map information with the real environment, positioning themselves and planning routes. Images are recognised faster by humans than text and are easier to process than reading text when users are unfamiliar with text (non-native speakers or have low literacy levels) or when information needs to be processed quickly (Norman, 1990). In *Experiment III* (Chapter 5), the researcher designed a series of added visual information to improve the correspondence between map information and the real environment, and evaluated whether they could help users successfully generate cognitive maps and improve wayfinding efficiency. This provides an idea for future research: when testing and evaluating the information content of a wayfinding system, self-positioning and planning routes are effective ways to verify its legibility. In this case it is necessary to exclude possible assistance, such as automatic positioning and route planning of digital maps.

At the same time, it is necessary to consider that different cultural and educational backgrounds may lead to different interpretations and understandings of images (Hashim et al., 2014). In order to avoid misunderstandings during the evaluation of the efficiency of map use, the role of visual information was explained in detail to the participants. This

provides ideas for research on the evaluation of map usability, that is, when evaluating the utility of a map rather than the understanding and interpretation of design elements, testers need to ensure they understand the information on the map before testing.

Besides, this research explored the design principles of visual information in campus digital map design through the legibility of iterative map prototypes. It mainly focuses on the visualisation and correlation of information, so that the map can reduce complexity while retaining key nodes at key locations (Apelt et al., 2007; Wang et al., 2018). For example, when displaying the entrance on the shape of a building, the entrance should be combined with the building shape so that the two become one and avoid too much visual information. Geographic information of the same category should be differentiated based on the real environment while maintaining consistent visual correlation: for example, routes should be compared with the width of roads in the environment by line thickness. As clear and beneficial findings from this thesis, these results are good recommendations for all future wayfinding designs in the built environment.

This research also discussed how visual information on a map differentiated the type of information visualised, such as location and route, area, visual relevance and importance (Reichenbacher, 2004). Colour contrast can provide distinction between information, which is useful to help users build environmental mind maps and improve wayfinding efficiency and performance (Read, 2003; Dalke et al., 2006; Holscher et al., 2006; Davis and Therrien, 2012; Farran et al., 2012). Through a literature review and case studies, the researcher noted the effectiveness of colour coding in map design. In *Study II* (Section 3.3), the researcher established a colour scheme for campus digital map design. Combining sequence scheme and hue scheme, the research proposed using hue division to distinguish information types, using sequential schemes (harmonic colours or lightness and saturation distinctions) to add colour variation to the same information type. The new colour system was used in tests on map prototypes to demonstrate legibility, using harmonious tones and rich colour variations to differentiate map information. This finding could help inform future research on the colour composition of wayfinding systems, helping researchers and designers build harmonious and rich colour schemes. This approach is also effective for designs related to

information classification, and may provide suggestions for distinguishing through background colour changes when visualising information.

In addition, this research emphasised the impact of the layout of text information and hierarchical division based on scale changes on reading efficiency. Due to its interactive capabilities, digital maps can be “more user-friendly” (Davidson, 2014), delineating the importance of textual information and classifying it at different scales. Text serves as an incongruous element on a map (Kent and Vujakovic, 2018), requiring discussion of text volume, font, placement and type to aid map reading. Based on the design principles compiled from relevant literature, and combined with the conclusions obtained from the visual survey in *Study II* (see details in Section 3.3), this research provided design suggestions for the density, fonts and hierarchical division of text on the map, which are summarised in the design principles of Chapter 6.

Due to differences in choices such as theme style and presentation when designing maps (Kent and Vujakovic, 2018), it is almost impossible to establish universal design principles that apply to all campus digital maps. However, the design principles summarised in Chapter 6 may be applicable in testing the effectiveness of map design, especially in environments with building complexes, not only in digital maps but also in the design evaluation of printed maps. This is because what digital maps and printed maps have in common is the map itself, with many similarities in information composition and map uses (Kent and Vujakovic, 2018). For the design of a map, it is always recommended to design and evaluate based on target user needs and user experience while discussing the fit with the design principles. The user-centred wayfinding system design approach is described in detail in the next section.

7.2.6. Use user-centred methods on information design research

The research explored user-centred design methods. In the process of finding problems, discovering problems, and testing solutions, information design decisions and the expansion of design principles were obtained through the participation of target users. Furthermore, it

demonstrated a successful case of using user-involved design methods to evaluate, design, and test digital maps and campus digital maps, and thereby added insights and user-centred design research methods that could be applied to future campus digital map design.

In the user participation processes of this research, the first step was to find and discover problems. Users' problems encountered when finding their way around campus and places where they are easily lost were collected. Their subjective evaluation of the use of digital maps and their expectations for map design were collected through a questionnaire investigation (Section 3.4). Lynch (1960) explained the important role of this step, that is, when the design object is used by people, the designer should first understand people's reactions to the design object. By discussing user feedback on campus wayfinding behaviour and the efficiency of using digital maps, the researcher summarised the situations where people often encounter problems of getting lost and their expectations for digital map functions. In *Experiment II* (Chapter 4), this thesis used information design knowledge to classify and design wayfinding tasks, and asked participants to complete commute, quest and explore tasks. Allen (1999) provided theoretical support for this, that is, the types of tasks that users need to complete when searching for different purposes. By observing users' performance during the task and post-task interviews, the researcher found the limitations of digital maps in wayfinding in the campus environment. In this process, potential missing design elements in the map help positioning and wayfinding were also identified. Since visual information is easier to recognise and understand than text (Norman, 1990; Kent and Vujakovic, 2018), these design elements were visualised and added to the digital map, as supported by established information design knowledge and principles.

In the test solution session, after improving the digital map through the visual design solution, the map showed better performance in solving potential problems (such as being unable to locate the building entrance) and in terms of route planning accuracy (Section 5.2.2). This shows that visual information plays an important role in digital map readability. However, the researcher observed that users had concerns about visually designed information. Research had considered that users' different backgrounds may lead to different understandings of visual images (Hashim et al., 2014). Even if it was ensured that

participants understood the role of visual information, the information added to the map still caused reading difficulties. This suggested that the visualisation used in the experiment became an incongruous element on the map. After analysing user feedback (see Section 3.4, Chapter 4 and Section 5.2.2 for detailed user participation testing and analysis), the researcher conducted an iterative design of the visual elements of the map prototype (Section 5.2.3). By testing the redesigned map prototype, the researcher observed that users encountered the same wayfinding problems in similar areas. For example, users mostly needed more time to compare map information with the real environment in open spaces (squares or empty road sections); when passages (the ground floor of a building or underground passages) appeared in the environment, users might need to spend time identifying roads on the map. Additionally, when analysing user feedback from the two map prototype tests, they demonstrated varying degrees of legibility. This provides a case for visualising information elements that adapts to user preferences and understanding capabilities and ensures that map information is delivered. When implementing a user-centred design approach, incorporating user insights into solution testing and refinement can be helpful in simplifying information transfer and making solutions feasible.

7.3. Limitations and future work

The first limitation of this research is that the research was conducted on digital maps of most UK campuses; focused on UK institutions when collecting usage of campus digital maps at academic institutions; then, universities in the UK were selected for both the visual survey and the selection of user testing locations. Ideally, the use of campus digital maps by academic institutions in different countries and regions will be explored, and map forms in different geographical and cultural environments will be statistically compared.

Unfortunately, this level of research collection was not possible within the timeframe of the research. Selecting academic institutions from different regions based solely on the opinions of the researcher may lead to inaccurate results. Instead, academic institutions in the same country were selected so that the findings are generalisable and potentially geographically

representative. Future research could investigate the implications of the results of this thesis for the effectiveness of campus digital map designs at academic institutions operating under other cultural practices. In addition, it is worth discussing how this research can be applied to wayfinding systems in other environments besides campus environments, such as cities and areas with a large number of buildings.

The second limitation of the research is the sample size. This thesis serves as a successful case of user-centred design, user participation is considered in every section. In the qualitative methods (*Experiment II*, *Experiment III*), a larger sample size would increase the detail of the data and the credibility of the research results. Future research could consider allowing more participants to evaluate the quality of digital map design through user testing.

The final limitation of the research was the presentation of the map prototype. Based on the purpose of evaluating the legibility of map information and whether it had a positive impact on wayfinding, the advantage of interactive digital maps that could automatically be located was excluded from consideration. The map prototype took the form of a paper map because in this research it had the same information composition and map purpose as a digital map (Kent and Vujakovic, 2018). In this case, the inability to obtain their position on the map in real time forced participants to always pay attention to whether the route deviated and to paid attention to the contrast between the map information and the real environment. This provided help for the researcher to observe the completeness of map information and its ability to guide participants. However, the interactive performance of digital maps cannot be tested and evaluated. In addition, live GPS coordinates can help users quickly locate themselves (when automatic positioning does not make mistakes), making it easier to match map information with the geographical environment. Considering the efficiency of user wayfinding, future campus digital wayfinding should include this. This thesis conducted a step-by-step in-depth discussion of the research object based on the order of searching for problems, discovering problems, and testing solutions, which means that it is necessary to make choices among the problems discovered. In this research, the in-depth direction of the research was determined by the importance of user needs, and ultimately focused on the visual information design of the map. Research on creating interactions between maps and

users, such as showing information or the internal layout of a building when clicking on a specific building, or categorising campus facilities on menus and search bars could be developed in the future. Based on the research results of this research, the visual information design principles of interactive campus digital maps will be expanded to help the readability of the map.

Finally, user involvement in information design can be further explored in future research to improve the potential research method limitations of this thesis. For example, adding users to the design process in future experiments and conducting collaborative design with users may help the researcher gain more visual design ideas. In addition, some technologies can be adopted into future research, such as eye-tracking technology, virtual reality technology, etc. These techniques may help expand empirical assessments of the legibility of map information designs. For example, eye-tracking technology can capture participants' gaze movements and information content they pay attention to when using maps. Virtual reality technology can simulate complex environmental facilities, including building groups, complex roads and passages, so that the map visual information design does not have to be limited by the real environment. Therefore, these experiments may build upon the findings from this thesis and could lead to the development of future wayfinding design practices.

References

- Abu-Ghazze, T. M. 1996. Movement and wayfinding in the King Saud University built environment: A look at freshman orientation and environmental information. *Journal of Environmental Psychology*. **16**, pp.303-318.
- Abu-Obeid, N. 1998. Abstract and scenographic imagery: The effect of environmental form on wayfinding. *Journal of Environmental Psychology*. **18**(2), pp.159-173.
- Agarwal, N. and Lawrence, H. 2014. Office Location Map of Individuals in the Library and Other College Campus Buildings: A Proof-of-Concept Wayfinding System. *Journal of Web Librarianship*. **8**(3), pp.305–323.
- Alex, G. 2007. *alex4D old blog* [Online]. [Accessed 25 December 2019]. Available from: <https://blog.alex4d.com/londons-tube-map/>
- Allen, G. L. 1999. Spatial abilities, cognitive maps, and wayfinding. *Wayfinding behavior: Cognitive mapping and other spatial processes*. **4680**.
- Apelt, R., Crawford, J. and Hogan, D. J. 2007. *Wayfinding Design Guidelines*. Brisban: CRC for Construction Innovation.
- Arengi, A., Belometti, S., Brignoli, F., Fogli, D., Gentilin, F. and Plebani, N. 2018. UniBS4All: A Mobile Application for Accessible Wayfinding and Navigation in an Urban University Campus. *Proceedings of the 4th EAI International Conference on Smart Objects and Technologies for Social Good*. pp.124–129.
- Arthur, P. and Passini, R. 2002. *Wayfinding : people, signs, and architecture*. Oakville, Ontario: Focus Strategic Communications.
- Axon, S., Speake, J. and Crawford, K. 2012. At the next junction, turn left. *Attitudes towards Sat Nav use, Area*. **44**(2), pp. 170–177.
- Azzam, T. and Evergreen, S. 2013. *Data Visualization Part 1, New Directions for Evaluation*,

Number 139. Hoboken: Wiley.

Baker, J. 1986. The role of the environment in marketing services: The consumer perspective.

The Services Challenge: Integrating for Competitive Advantage. **1**, pp.79–84.

Barclay, D., Scott, E. and Barclay, D. 2012. Directions to Library Wayfinding: Directional and Information Signs Guide Patrons into and around the Library. *American Libraries.* **43**(3-4), pp.36–38.

Basri, S.N.A., Ahmad, F., Abidin, N.I.A., Baba, I., Harun, H., Hamid, N.H.A., Awang, M., Rahman, M.A.A. and Kamaruzaman, M., 2020. Digital campus. *International Journal of Engineering & Technology*, **9**(2), pp.382-389.

Bishop, B.W. 2011. Location-based questions and local knowledge. *Journal of the American Society for Information Science and Technology.* **62**(8), pp. 1594-1603.

Black, A., Lund, Ole. and Walker, S. 2015. *Gower handbook of information design.* Farnham: Gower.

Blair, J. and Conrad, F. G. 2011. Sample size for cognitive interview pretesting. *The Public Opinion Quarterly.* **75**(4), pp.636-658.

Bojko A. 2006. Using Eye Tracking to Compare Web Page Designs: A Case Study. *Journal of Usability Studies*, **3**(1), pp.112-120.

Bosman, E. and Rusinek, C. 1997. Creating the user-friendly library by evaluating patron perception of signage. *Reference Services Review.* **25**(1), pp.71-82.

Brighurst, R. 2002. *The elements of typographic style* Version 2.5. Point Roberts, WA: Hartley & Marks.

Buisseret, D. 1992. *Monarchs, ministers, and maps: the emergence of cartography as a tool of government in early modern Europe.* Chicago: University of Chicago Press.

Burroughs, C. 1995. The “Last Judgment” of Michelangelo: Pictorial Space, Sacred

- Topography, and the Social World. *Artibus et historiae*. **16**(32), pp.55–89.
- Calori, Chris., Vanden-Eynden, D., Chermayeff, Ivan. and Geismar, T.H. 2015. *Signage and wayfinding design : a complete guide to creating environmental graphic design systems*. Hoboken, New Jersey: Wiley.
- Cao, H., Shi, J. and Lu, J. L. 2008. Modelling and Simulation Wayfinding in Unfamiliar Campus Environment. *2008 Fourth International Conference on Natural Computation*. **6**, pp.48–53.
- Canter, D. V. 1974. *Psychology for Architects*. London: Applied Science Publishers.
- Cartwright, W. 2014. Rethinking the definition of the word ‘map’: an evaluation of Beck's representation of the London Underground through a qualitative expert survey. *International Journal of Digital Earth*. **8**(7), pp.522-537.
- Chao, Z. 2016. From query analysis to user information needs: a study of campus map searches. *Library Hi Tech*. **34**(1), pp.104–129.
- Chebat, J.C., Chebat, C.G. and Therrien, K. 2005. Lost in a mall, the effects of gender, familiarity with the shopping mall and the shopping values on shoppers’ wayfinding processes. *Journal of Business Research*. **58**, pp.1590-1598.
- Chen, J. and Stanney, K. 1999. A theoretical model of wayfinding in virtual environments: Proposed strategies for navigational aiding. *Presence: Teleoperators and Virtual Environments*. **8**(6), pp.671-685.
- Chittaro, L. 2006. Visualizing Information on Mobile Devices. *Computer*. **39**(3), pp.40–45.
- Conley, T. 2011. *An errant eye: poetry and topography in early modern France*. Minneapolis: University of Minnesota Press.
- Cubukcu, E. and Nasar, J. L. 2005. Relation of physical form to spatial knowledge in large-scale virtual environments. *Environment and Behavior*. **37**(3), pp.397-417.

- Dalke, H., Little, J., Niemann, E., Camgöz, N., Steadman, G., Hill, S. and Stott, L. 2006. Colour and lighting in hospital design. *Optics and Laser Technology*. **38**(4-6), pp.343-365.
- Darken, R. P. and Peterson, B. 2002. Spatial orientation, wayfinding and representation. *Handbook of virtual environment technology*. pp.1-22.
- Davidson, B.D., 2014. *Cartographic design for mobile devices: A case study using the UW-Madison interactive campus map*. Doctoral dissertation.
- Davis, R. L. and Therrien, B. A. 2012. Cue color and familiarity in place learning for older adults. *Research in Gerontological Nursing*. **5**(2), pp.138-148.
- Dillemoth, J., 2005. Map design evaluation for mobile display. *Cartography and Geographic Information Science*. **32**(4), pp.285-301.
- Endsley, M. and Jones, D. 2012. *Designing for situation awareness*. Boca Raton, FL: CRC Press
- Fabrikant, S.I., Hespanha, S.R. and Hegarty, M. 2010. Cognitively Inspired and Perceptually Salient Graphic Displays for Efficient Spatial Inference Making. *Annals of the Association of American Geographers*. **100**(1), pp.13–29.
- Farran, E., Courbois, Y., Van Herwegen, J., Cruickshank, A. and Blades, M. 2012. Colour as an environmental cue when learning a route in a virtual environment: Typical and atypical development. *Research in Developmental Disabilities*. **33**(3), pp.900-908.
- Feisner, E. 2006. *Colour: how to use colour in art and design*. London: Laurence King.
- Ganesh, V. 2016. *Terminal signage*. Master thesis, Middle Tennessee State University.
- Garling, T. and Evans, G. W. 1992. *Environment, Cognition, and Action: an Integrated Approach*. Cary, Oxford University Press.
- Gibson, D. 2009. *The wayfinding handbook: information design for public places*. New York: Princeton Architectural Press.

- Giuliani, R. W. 2001. *Universal Design New York*. New York: Mayor Publication.
- Golledge, R. G. 1999. *Wayfinding Behavior: Cognitive Mapping and Other Spatial Processes*. London: The Johns Hopkins University Press.
- Google Maps. 2019. *University of Leeds (standard)*. [Online]. [Accessed 13 November 2019]. Available from: <https://www.google.com/maps/place/University+of+Leeds/>
- Google Maps. 2019. *London (standard)*. [Online]. [Accessed 25 December 2019]. Available from: <https://www.google.com/maps/place/London/>
- Güneş, E. 2018. Evaluating the Influence of Environmental Design Elements on the Legibility of a Shopping Mall. *Online Journal of Art and Design*. **6**(5), pp.71-93.
- Harding, J. R. 2011. *Wayfinding and signing guidelines for airport terminals and landside*. Washington, D.C: Transportation Research Board.
- Harley, J. and Woodward, D. 1992. *The history of cartography*. Chicago: University of Chicago Press.
- Hashim, M., Alkaabi, M. and Bharwani, S. 2014. Interpretation of way-finding healthcare symbols by a multicultural population: Navigation signage design for global health. *Applied Ergonomics*. **45**(3), pp.503–509.
- Hillier, B. 1996. *Space is the Machine: A Configurational Theory of Architecture*. Cambridge: Cambridge University Press.
- Holscher, C., Buchner, S.J., Brosamle, M., Meilinger, T. and Strube, G., 2007. Signs and maps—cognitive economy in the use of external aids for indoor navigation. *In Proceedings of the Annual Meeting of the Cognitive Science Society*. **29**(29).
- Holscher, C., Meilinger, T., Vrachliotis, G., Brosamle, M. and Knauff, M. 2006. Up the down staircase: Wayfinding strategies in multi-level buildings. *Journal of Environmental Psychology*. **26**(4), pp.284-299.

- ICA (International Cartographic Association). 2003. A Strategic Plan of the International Cartographic Association, 2003–2011 – Revised Version (16p). Durban: International Cartographic Association.
- Kanakri, S., Schott, M., Mitchell, A., Mohammad, H., Etters, M. and Palme, N. 2016. Wayfinding Systems in Educational Environments. *Environment and Ecology Research*. **4**(5), pp.251-256.
- Kaplan, S. and Kaplan, R. 1982. *Cognition and Environment: Functioning in an Uncertain World*. NewYork: Praeger.
- Katarzyna, S. 2018. Types of maps used as a stimuli in cartographical empirical research. *Miscellanea Geographica: Regional Studies on Development*. **22**(3), pp.157–171.
- Kent, A. and Vujakovic, P. (eds.). 2018. *The Routledge handbook of mapping and cartography*. Milton Park, Abingdon, Oxon ; Routledge.
- Kim, S., Park, E., Hong, S., Cho, Y. and Del Pobil, A. P. 2011. Designing digital signage for better wayfinding performance: New visitors' navigating campus of university. *The 4th International Conference on Interaction Sciences*. pp.35-40.
- Kitchin, R.M., Blades, M. and Golledge, R.G. 1997. Understanding spatial concepts at the geographic scale without the use of vision. *Progress in Human Geography*. **21**(2), pp.225–242.
- Koning, R., Hasan, S. and Chatterji, A. 2022. Experimentation and Start-up Performance: Evidence from A/B Testing. *Management science*. **68**(9), pp.6434–6453.
- Larsen, N., Stallrich, J., Sengupta, S., Deng, A., Kohavi, R. and Stevens, N.T. 2023. Statistical Challenges in Online Controlled Experiments: A Review of A/B Testing Methodology. *The American statistician*., pp.1–15.
- Li, R. and Klippel, A. 2012. Wayfinding in Libraries: Can Problems Be Predicted? *Journal of Map & Geography Libraries*. **8**(1), pp.21–38.

- Liu, L., Gauthier, L. and Gauthier, S. 1991. Spatial disorientation in persons with early senile dementia of the Alzheimer type. *American Journal of Occupational Therapy*. **45**, pp.67–74.
- Lomperski, T. J. 1997. Enhancing interior building sign readability for older adults: lighting color and sign color contrast. *Journal of Interior Design*. **23**(2), pp.17-27.
- Lynch, K. 1960. *The Image of the City*. Technology Press.
- MacEachren, A.M. 1995. *How maps work : representation, visualization, and design*. New York ; Guilford Press.
- Madlenak, R., Chinoracky, R., Stalmasekova, N. and Madlenakova, L. 2023. Investigating the Effect of Outdoor Advertising on Consumer Decisions: An Eye-Tracking and A/B Testing Study of Car Drivers' Perception. *Applied sciences*. **13**(11), pp.6808-.
- Mandel, L. 2013. Finding their way: How public library users wayfind. *Library and Information Science Research*. **35**(4), pp.264–271.
- Mantoro, T., Saharudin, S.A. and Selamat, S., 2009, December. 3D interactive mobile navigator structure and 2D map in campus environment using GPS. In *Proceedings of the 7th International Conference on Advances in Mobile Computing and Multimedia* (pp. 401-405).
- Mapaplan. 2019. *London printable map of top tourist attractions & city travel guide*. [Online]. [Accessed 2 December 2019]. Available from: <https://www.mapaplan.com/travel-map/london-top-tourist-attractions-map/london-top-tourist-attractions-map.htm>
- Mcfarland, David. 2014. "Cognitive Map." *A Dictionary of Animal Behaviour*. Oxford University Press.
- Mclaughlin, J. M., McNeil, B. and Sebald, S. 2005. *Addressing Wayfinding at Bumrungrad Hospital*. Undergraduate thesis, Worcester Polytechnic Institute.

- Mikhael, J. and Yandi, A. Y. 2018. Application of visibility analysis and visualisation in hospital wayfinding sign design. *Dimensi: Journal of Architecture and Built Environment*. **45**(1), pp.1–8.
- Miller, C. and Lewis, D. 1999. *Wayfinding: Effective Wayfinding and Signing Systems-Guidance for Healthcare Facilities*. London: The Stationery Office Books.
- Montello, D.R. 2002. Cognitive Map-Design Research in the Twentieth Century: Theoretical and Empirical Approaches. *Cartography and geographic information science*. **29**(3), pp.283–304.
- Montello, D. and Sas, C. 2006. *Human Factors of Wayfinding in Navigation*.
- Nagi, R. S. 2004. *Cartographic Visualization for Mobile Applications*. PhD dissertation, University of Twente. Enschede, Netherlands.
- Norman, D. A. 1990. *The design of everyday things*. New York: Doubleday
- Norman, D. A. 2005. *Emotional design: why we love (or hate) everyday things*. Oxford: Oxford Publicity Partnership distributor.
- NHS Estates. 2005. *Wayfinding: Effective wayfinding and signing systems: guidance for healthcare facilities*. London: TSO.
- O'Grady, J. V. and O'Grady, K. V. 2017. *A designer's research manual: succeed in design by knowing your clients + understanding what they really need*. 2nd ed. Beverly, MA: Rockport.
- Olsson, T., Lagerstam, E., Kärkkäinen, T. and Väänänen-Vainio-Mattila, K. 2013. Expected user experience of mobile augmented reality services: A user study in the context of shopping centres. *Personal and Ubiquitous Computing*. **17**(2), p.287-304.
- O'Neill, M. J. 1992. Effects of familiarity and plan complexity on wayfinding in simulated buildings. *Journal of Environmental Psychology*. **12**, pp.319-327.

- Osmann, P.J. and Wiedenbauer, G. 2004. The representation of landmarks and routes in children and adults: A case study in a virtual environment. *Journal of Environmental Psychology*. **24**, pp.347-357.
- Oxford English Dictionary*. [Online]. 2015. s.v. Wayfinding (n.). [Accessed 7 August 2023]. Available from: <https://doi.org/10.1093/OED/5328706609>.
- Papadias D., and Theodoridis Y. 1997. Spatial relations, minimum bounding rectangles and spatial data structures. *Intl. J. Geographical Information Systems*. **11**(2), pp.111-138.
- Park, Y. and Guerin, D. 2002. Meaning and preference of interior color palettes among four cultures. *Journal of Interior Design*. **28**(1), pp.27- 39.
- Passini, R. 1981. Wayfinding: A Conceptual Framework. *Urban Ecology*. **5**, pp.17–31.
- Passini, R. 1992. *Wayfinding in Architecture*. Hoboken, NJ: John Wiley & Sons Inc.
- Pollett, D. and Haskell, P. C. 1979. *Signs systems for libraries: solving the wayfinding problem*. New York, Bowker.
- Raper, J. 2007. Geographic relevance. *Journal of Documentation*. **63**(6), pp.836-852.
- Raubal, M. and Winter, S. 2002. Enriching wayfinding instructions with local landmarks. *GIScience*. **2478**, pp.243-259.
- Read, M. A. 2003. Use of color in childcare environments: Application of color for wayfinding and space definition in Alabama childcare environments. *Early Childhood Education Journal*. **30**(4), pp.233-239.
- Rodriguez, P. 2019. *Engaging map visualization through Emotional Design*.
- Roefs, F. and Mijksenar, P., 2017. Designing for wayfinding. Guidelines for designers and a case study of Amsterdam Airport Schiphol. *Information design: reserch and practice*, pp.527-540.

- Roth, R., Van Den Hoek, J., Woodruff, A., Erkenswick, A., McGlynn, E. and Przybylowski, J. 2009. The 21st Century Campus Map: Mapping the University of Wisconsin-Madison. *Journal of Maps*. **5**(1), pp.1–8.
- Rousek, J. and Hallbeck, M. 2011. Improving and analyzing signage within a healthcare setting. *Applied ergonomics*. **42**(6), pp.771-784.
- Ruddle, R., Payne, S. and Jones, D. 1998. Navigating large-scale "desk-top" virtual buildings: Effects of orientation aids and familiarity. *Presence: Teleoperators and Virtual Environments*. **7**(2), pp.179-192.
- Sadahiro Y., Tanabe T., Pierre M. and Fujii K. 2015. Computer-aided design of bus route maps. *Cartography and Geographic Information Science*. **43**(4), pp.361-376
- Sandnes, F.E., 2017. On-screen colour contrast for visually impaired readers. *W A. Black, P. Luna, O. Lund i S. Walker (red.), Information design. Research and practice*, pp.405-416.
- Scott-Webber, L., Marini, M. and Abraham, J. 2000. Higher education classrooms fail to meet needs of faculty and students. *Journal of Interior Design*. **26**(1), pp.16-34.
- Siegel, A. W. and White, S. H. 1975. The development of spatial representations of large-scale environments. *Advances in child development and behaviour*. **10**, pp.9-55.
- Slocum, T., Sluter, R., Kessler, F. and Yoder, S. 2004. A Qualitative Evaluation of MapTime, A Program for Exploring Spatiotemporal Point Data. *Cartographica: The International Journal for Geographic Information and Geovisualization*. **39**(3), pp. 43–68.
- Speake, J. 2016. I've got my Sat Nav, it's alright: Users' Attitudes towards, and Engagements with, Technologies of Navigation. *The Cartographic Journal*. **52**(4), pp. 345–355.
- Süzer, Ö. K. 2018. *Colour as an aid for elderly during visuospatial navigation in a virtual polyclinic environment*. Ph. D. thesis, İhsan Doğramacı Bilkent University.
- Tao, Y., Gou, Z., Lau, S., Lu, Y. and Fu, J. 2018. Legibility of floor plans and wayfinding

- satisfaction of residents in Care and Attention homes in Hong Kong. *Australasian Journal on Ageing*. **37**(4), pp.139–143.
- Thomas P. 2008. Measuring effective map design for route guidance: An experiment comparing electronic map display principles. *Information Design Journal*. **16**(3), pp.190-201
- Tomitsch, M. and Wrigley, C. 2018. *Design, think, make, break, repeat*. Amsterdam: BIS Publishers.
- Töpferand, F, and W Pillewizer. 1966. The Principles of Selection. *The Cartographic Journal*. **3**(1): 10-16.
- Treisman, A. 1985. Preattentive processing in vision. *Computer vision, graphics, and image processing*. **31**(2), pp.156–177.
- Tversky, B., 1993, September. Cognitive maps, cognitive collages, and spatial mental models. *In European conference on spatial information theory* (pp. 14-24). Springer, Berlin, Heidelberg.
- Tyner J.A. 2014. *Principles of map design*. New York: The Guilford Press
- University of Cambridge. 2020. *University Map*. [Online]. [Accessed 13 September 2020]. Available from: <https://map.cam.ac.uk/>
- University of Leeds. 2020. *University of Leeds Campus Map*. [Online]. [Accessed 8 September 2020]. Available from: <https://www.leeds.ac.uk/campusmap>
- University of Manchester. 2020. *University of Manchester Interactive Map*. [Online]. [Accessed 8 September 2020]. Available from: <https://www.manchester.ac.uk/discover/maps/interactive-map/>
- University of Oxford. 2020. *Searchable Map*. [Online]. [Accessed 13 September 2020]. Available from: <https://www.ox.ac.uk/visitors/map>

- University of Sheffield. 2020. *Campus Map of University of Sheffield*. [Online]. [Accessed 13 September 2020]. Available from: <https://ssid.sheffield.ac.uk/campus-map/>
- Van Tonder, B. and Wesson, J., 2009, August. Design and Evaluation of an Adaptive Mobile Map-Based Visualisation System. In *IFIP Conference on Human-Computer Interaction* (pp. 839-852). Springer, Berlin, Heidelberg.
- Vilar, E., Rebelo, F., Noriega, P., Teles, J. and Mayhorn, C. 2015. Signage Versus Environmental Affordances: Is the Explicit Information Strong Enough to Guide Human Behavior During a Wayfinding Task? *Human Factors and Ergonomics in Manufacturing & Service Industries*. **25**(4), pp.439-452.
- Wang, C., Chen, Y., Zheng, S, and Liao, H. 2018. Gender and Age Differences in Using Indoor Maps for Wayfinding in Real Environments. *ISPRS International Journal of Geo-Information*. **8**(1).
- Weisman, J. 1981. Evaluating architectural legibility wayfinding in the built environment. *Environment and Behavior*. **13**, pp.189–204.
- Winter, S. and Tomko, M., 2004. Shifting the focus in mobile maps. *Proc. UPIMap2004*. pp.7-9.
- Wood, M., 1968. Visual perception and map design. *The Cartographic Journal*, **5**(1), pp.54-64.
- Wu, F., Clarke, D., Jiang, J., Baba, A. and Buford, S., 2016. The digital age of campus maps on mobile devices. *Journal of Computer and Communications*, **4**(07), p.22.
- Xie, H., Filippidis, L., Galea, E. R., Blackshields, D. and Lawrence, P. J. 2012. Experimental analysis of the effectiveness of emergency signage and its implementation in evacuation simulation. *Fire and Materials*. **36**(5-6), pp. 367-382.
- Xie, H., Filippidis, L., Gwynne, S., Galea E. R., Blackshields, D. and Lawrence, P. J. 2007. Signage legibility distances as a function of observation angle. *Journal of Fire Protection*

Engineering. **17**(1), pp.41-64.

Yanhua, W., Zhilong, C., Bin, Z. and Kejia, W. 2011. Establishment of sense of direction and direction guiding in underground public architecture. *Chinese Journal of Underground Space and Engineering*. **4**, p.001.

Yoo, S. Y. 1992. *Architectural legibility of shopping centers: simulation and evaluation of floor plan configurations*. Ph.D. thesis, The University of Wisconsin.

Zhang, H., Tang, R., Qiu, J. and Qiu, X., 2019, October. Design and implementation of GIS+BIM-based digital campus system. In *2019 International Conference on Artificial Intelligence and Advanced Manufacturing (AIAM)* (pp. 329-335). IEEE.

Zipf, G. 1949. *Human behavior and the principle of least effort: an introduction to human ecology*. Cambridge (Mass.): Addison-Wesley P.

Appendices

Appendix I: Heat map of final chosen institutions – usage of campus digital map

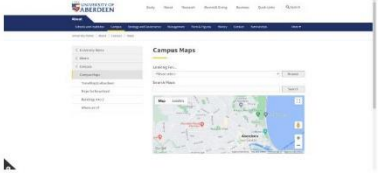
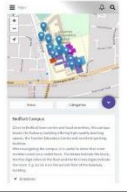
Colour of Heat Map	Have	Doesn't have		
University	Interactive Campus Digital Map	University's mobile application	Own mobile digital map	Not Own designed Map
Aberdeen, University of				
Askham Bryan College				
Aston University				
Bangor University				
Bath Spa University				
Bath, University of				
Bedfordshire, University of				
Birmingham City University				
Birmingham, University of				
Bishop Burton College				
Bolton, University of				
Bournemouth University				
Bradford, University of				
Brighton, University of				
Bristol, University West of England, (UWE)				
Cambridge, University of				
Cardiff University				
Chester, University of				
Chichester, University of				

University	Interactive Campus Digital Map	University's mobile application	Own mobile digital map	Not Own designed Map
City, University of London				
Coventry University				
De Montfort University				
Durham University				
East Anglia, University of				
Edinburgh Napier University				
Edinburgh, University of				
Falmouth University				
Glasgow Caledonian University				
Gloucestershire, University of				
Glyndwr University, Wrexham				
Greenwich, University of				
Heriot-Watt University				
Hertfordshire, University of				
Hull, University of				
Keele University				
Kent, University of				
Kingston University				
Lancaster University				
Leeds, University of				
Liverpool John Moores University				
Liverpool, University of				
London Metropolitan University				
Loughborough University				
Manchester, The University of				

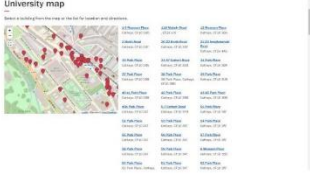
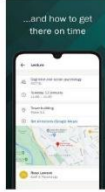
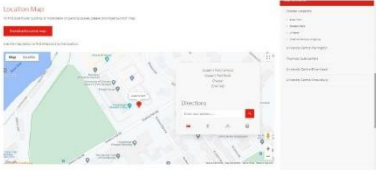
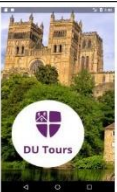
University	Interactive Campus Digital Map	University's mobile application	Own mobile digital map	Not Own designed Map
Middlesex University				
Newcastle University				
Newman University				
Northampton, University of				
Norwich University of the Arts				
Oxford Brookes University				
Oxford, University of				
Plymouth University				
Portsmouth, University of				
Queen Mary University of London				
Queen's University Belfast				
Robert Gordon University				
Roehampton, University of				
Royal Agricultural University				
Saint Andrews, University of				
Salford, University of				
Sheffield Hallam University				
Southampton Solent University				
Staffordshire University				
Stirling, University of				
Strathclyde, University of				
Suffolk, University of				
Surrey, University of				
Sussex, University of				
Swansea University				

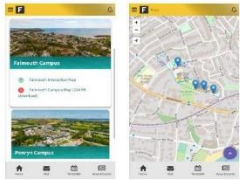
University	Interactive Campus Digital Map	University's mobile application	Own mobile digital map	Not Own designed Map
Teesside University				
Warwick, University of				
Winchester, University of				
Wolverhampton, University of				
York Saint John University				
York, University of				

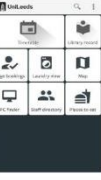
Appendix II: Screenshots of campus digital maps' usage of UK institutions

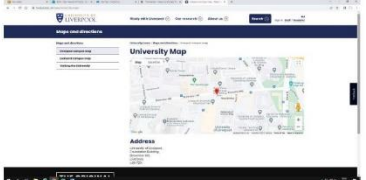
University	Website Campus Digital Map	University's mobile application	Own mobile digital map
Aberdeen, University of			
Askham Bryan College			
Aston University			
Bangor University			
Bath Spa University			
Bath, University of			
Bedfordshire, University of			

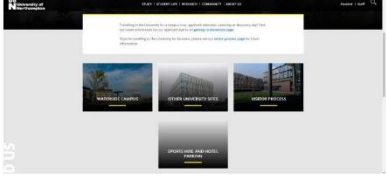
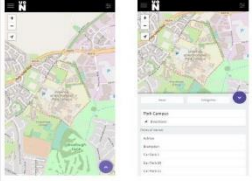
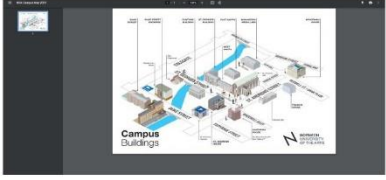
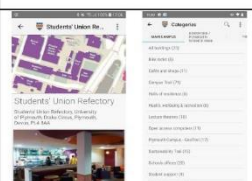
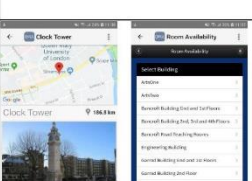
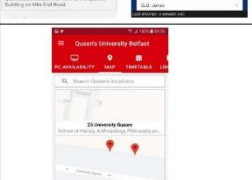
Birmingham City University			
Birmingham University of			
Bishop Burton College			
Bolton University of			
Bournemouth University			
Bradford University of			
Brighton University of			
Bristol University West of England (UWE)			

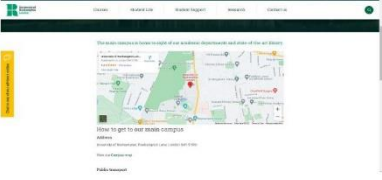
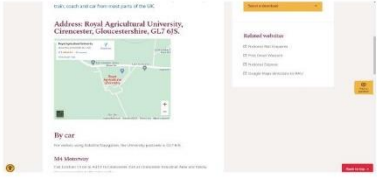
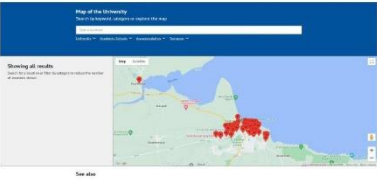
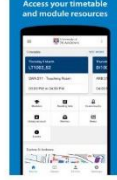
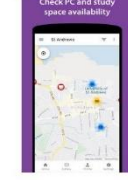
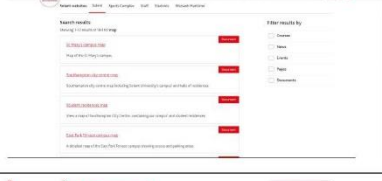
Cambridge University of			
Cardiff University			
Chester University of			
Chichester University of			
City University of London			
Coventry University			
De Montfort University			
Durham University			

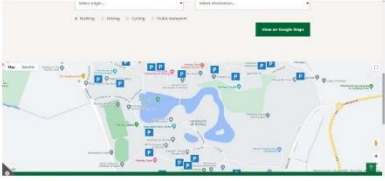
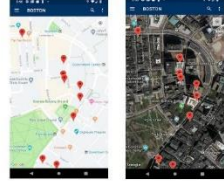
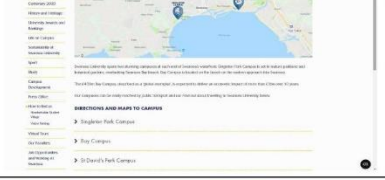
East Anglia, University of			
Edinburgh Napier University			
Edinburgh, University of			
Falmouth University			
Glasgow Caledonian University			
Gloucestershire, University of			
Glyndwr University, Wrexham			
Greenwich, University of			

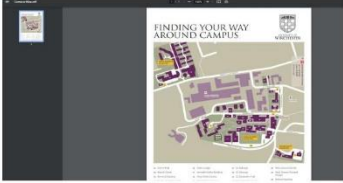
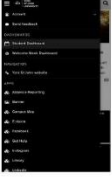
Heriot-Watt University			
Hertfordshire University of			
Hull University of			
Keele University			
Kent University of			
Kingston University			
Lancaster University			
Leeds University of			

Liverpool John Moores University			
Liverpool University of			
London Metropolitan University			
Loughborough University			
Manchester, The University of			
Middlesex University			
Newcastle University			
Newman University			

Northampton University of			
Norwich University of the Arts			
Oxford Brookes University			
Oxford University of			
Plymouth University			
Portsmouth University of			
Queen Mary University of London			
Queen's University Belfast			

Robert Gordon University			
Roehampton University of			
Royal Agricultural University			
Saint Andrews University of			
Salford University of			
Sheffield Hallam University			
Southampton Solent University			
Staffordshire University			

Stirling, University of			
Strathclyde University of			
Suffolk, University of			
Surrey, University of			
Sussex, University of			
Swansea University			
Teesside University			
Warwick, University of			

Winchester University of			
Wolverhampton University of			
York Saint John University			
York University of			

Appendix III: Questionnaire of Experiment I

1. If you agree that "the data I provide in the survey can be used for research purposes", please mark on the 'agree' button below and start completing the questionnaire. *

Mark only one oval.

☐ Agree

Part 1. Basic Information

2. What is your gender? *

Mark only one oval.

☐ Female

☐ Male

☐ Prefer not to say

3. What is your age group? *

Mark only one oval.

☐ 18-20

☐ 21-30

☐ 31-40

☐ 41-50

☐ 51-60

☐ 61-70

☐ over 70

4. Is English your first or second language? *

Mark only one oval.

☐ First language

☐ Second language

5. What is your connection to your University? *

Mark only one oval.

- ☐ Student
☐ Staff (academic)
☐ Staff (other)
☐ Visitor
☐ Other: _____

6. How many years have you been studying / working in the University? *

Part 2. Questions about wayfinding experience in the university

7. When searching for a way in the University, in the following wayfinding tasks, how do you rate the necessity for help (using map)? *

Mark only one oval per row.

	always	very often	sometimes	rarely	never
Commuting between two places. (i.e. from the residence to the commonly used office/classroom)	☐	☐	☐	☐	☐
Purposefully go to an unfamiliar place. (i.e. go to a building that has not been to)	☐	☐	☐	☐	☐
Freely exploring the campus environment.	☐	☐	☐	☐	☐

8. Inside which of these buildings/spaces (indoor environment) do you still get lost? *
(select all those that apply)

Tick all that apply.

- ☐ Teaching buildings
☐ Gym
☐ University residences
☐ Libraries
☐ Restaurants
☐ Other: _____

9. How likely would you rate the following reasons for having been lost on campus? *

Mark only one oval per row.

	very likely	likely	neutral	unlikely	very unlikely
Could not understand the university map	☐	☐	☐	☐	☐
The map gave me the wrong information	☐	☐	☐	☐	☐
Could not find the building entrance	☐	☐	☐	☐	☐
Could not find a specific the room	☐	☐	☐	☐	☐
Was rushing to get to a place on time	☐	☐	☐	☐	☐

10. Any other reasons why you got lost on campus? *

If not, fill in N / A.

11. How would you rate the effectiveness of the following ways to seek help when you are lost on campus? *

Mark only one oval per row.

	very effective	effective	neutral	ineffective	very ineffective
Use campus map board	☐	☐	☐	☐	☐
Use paper map	☐	☐	☐	☐	☐
Use digital map	☐	☐	☐	☐	☐
Ask others (e.g. receptionist)	☐	☐	☐	☐	☐

12. Any other ways can help when you are lost on campus?

If not, fill in N / A.

Part 3. Digital map

The campus digital map is the University's own online map using online media. Many universities have their own digital maps. One of the main functions of campus digital maps is to show university facilities to users.

3.1 Questions about digital map

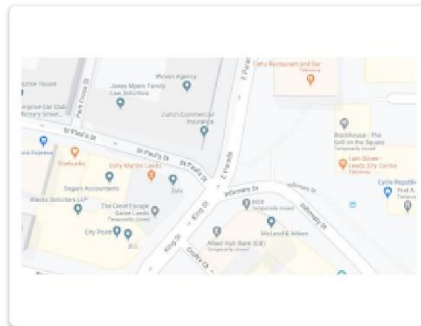
13. How often do you use a digital map to find your way in University? (e.g. Google * map)

Mark only one oval.

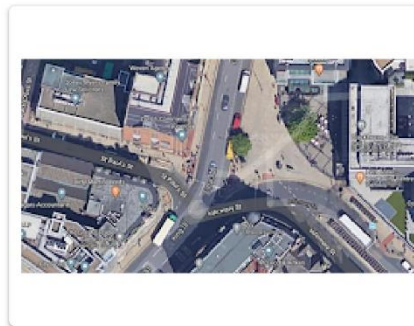
- ☐ Daily
☐ Weekly
☐ Monthly
☐ Less than once a month
☐ Less than once every six months
☐ Less than once a year
☐ Never

14. Which of these digital maps would you prefer to use? *

Mark only one oval.



☐ Map



☐ Satellite

15. On what device do you usually use digital maps? (select all those that apply) *

Tick all that apply.

- ☐ Computer & laptop
☐ Mobile phone
☐ Tablet
☐ Other: _____

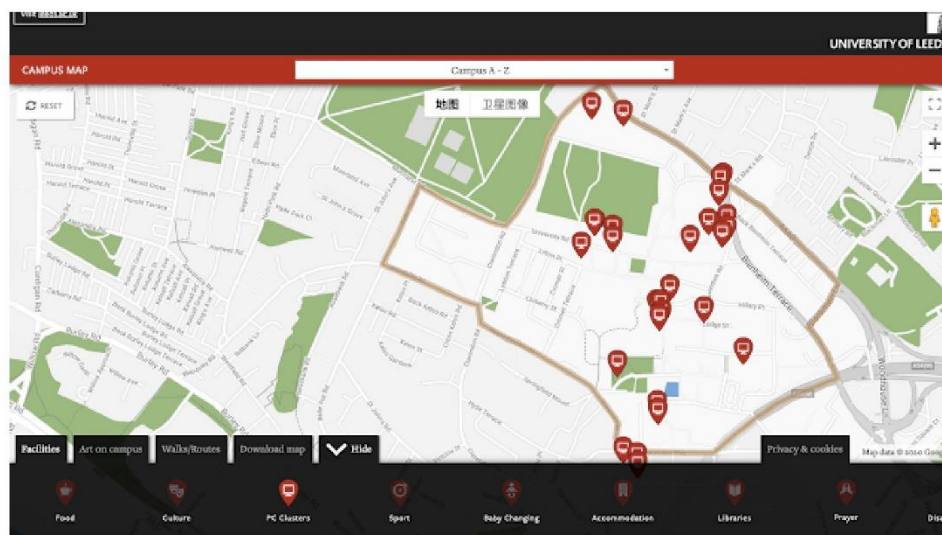
16. How often do you use digital maps on the following devices?

Mark only one oval per row.

	Always	Often	Sometimes	Rarely	Never
Computer & laptop	☐	☐	☐	☐	☐
Mobile phone	☐	☐	☐	☐	☐
Tablet	☐	☐	☐	☐	☐

3.2 Questions about campus digital map

University of Leeds Campus Digital Map



17. Does your university have a digital map? *

Mark only one oval.

- ☐ Yes
- ☐ No
- ☐ I don't know

18. On what device do you use the campus digital map? (select all those that apply) *

Tick all that apply.

- ☐ Computer & laptop
☐ Mobile phone
☐ Tablet
☐ I never use it
☐ Other: _____

19. How often do you use your campus digital map? *

Mark only one oval.

- ☐ Daily
☐ Weekly
☐ Monthly
☐ Less than once a month
☐ Less than once every six months
☐ Less than once a year
☐ Never

20. What do you use your campus digital map for? (select all those that apply) *

Tick all that apply.

- ☐ To find the way to a place
☐ To find university facilities
☐ To position yourself
☐ To understand the overall layout of the university
☐ Other: _____

22. How do you evaluate the usefulness of the following functions of the campus digital map? *

Mark only one oval per row.

	extremely useful	somewhat useful	neither useful nor useless	somewhat useless	extremely useless
Distinguish the campus area (i.e. use different colour blocks to indicate different areas)	☐	☐	☐	☐	☐
Use special graphics to represent buildings	☐	☐	☐	☐	☐
Summarise campus facilities	☐	☐	☐	☐	☐
Provide detailed information of the building/facilities inquired	☐	☐	☐	☐	☐
Allow targeting to a specific room	☐	☐	☐	☐	☐
Allow street view	☐	☐	☐	☐	☐

23. What other ways can a campus digital map be useful for? *

Please answer the functions you hope the digital map can have.

24. Through the above questions, which of the following devices do you think can more effectively reflect the functions of the campus digital map? (select all those that apply) *

Tick all that apply.

- ☐ Computer & laptop
☐ Mobile phone
☐ Tablet
☐ Other: _____

25. I certify that all the information I have provided on this form is true and correct *

Mark only one oval.

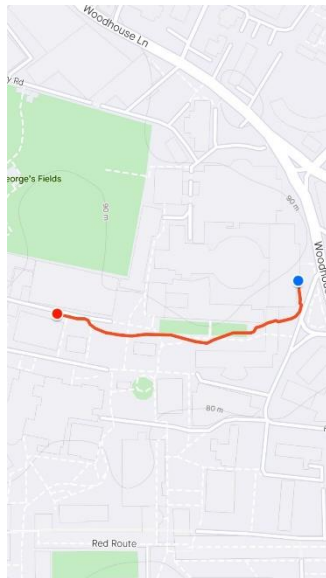
☐ Agree

Appendix IV: Route record maps of commute task in Experiment II

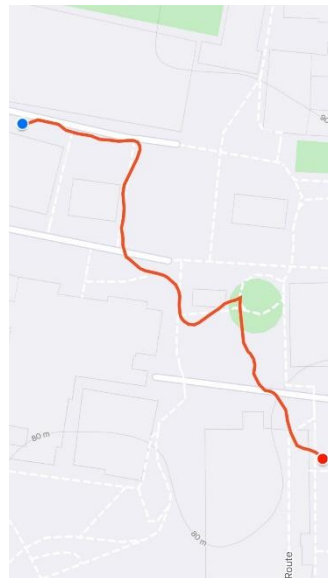
(Blue dot: Start point; Red dot: End point)

Participant 1

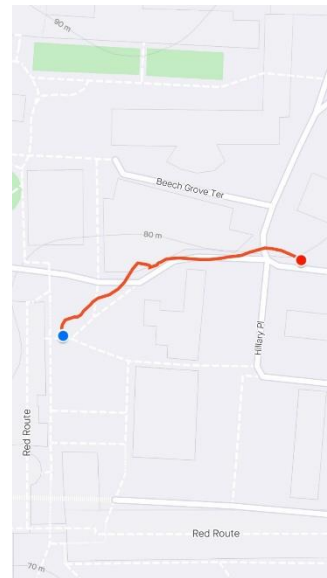
Parkinson to Design:



Design to Edward:

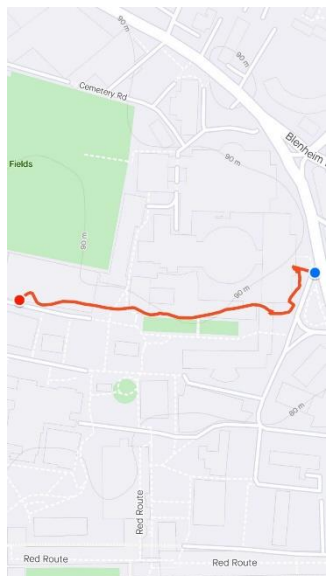


Edward to Laidlaw:

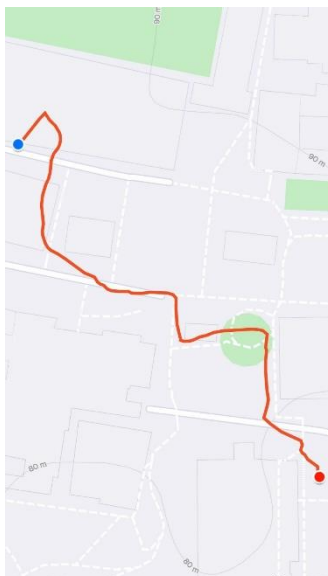


Participant 2

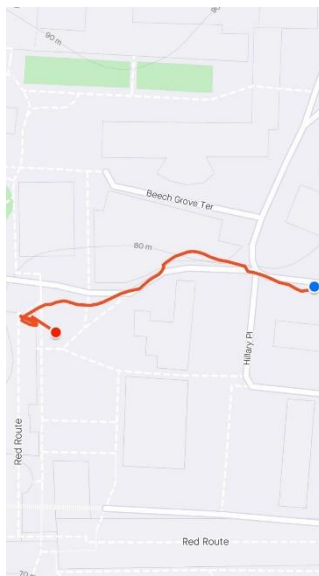
Parkinson to Design:



Design to Edward:

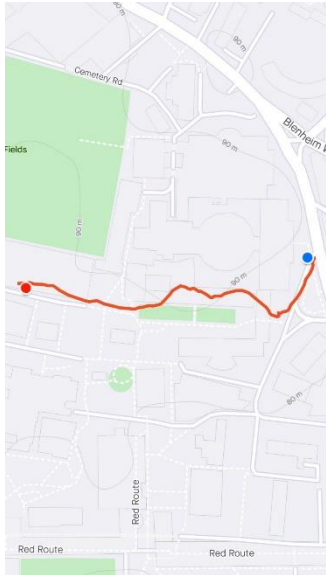


Edward to Laidlaw:

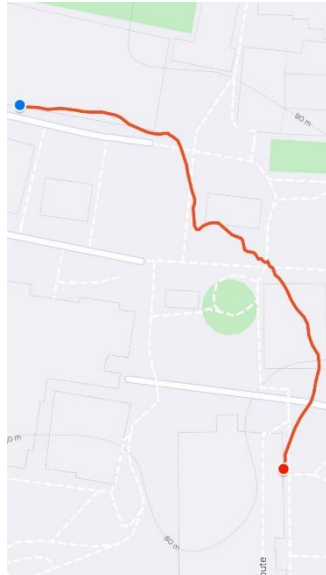


Participant 3

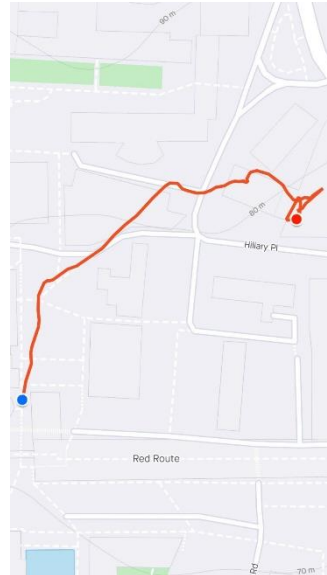
Parkinson to Design:



Design to Edward:

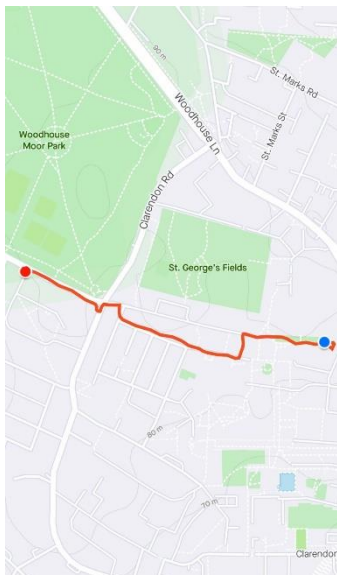


Edward to Laidlaw:

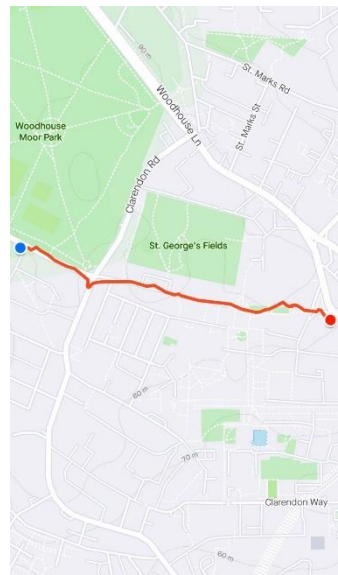


Participant 4

Parkinson to Law:

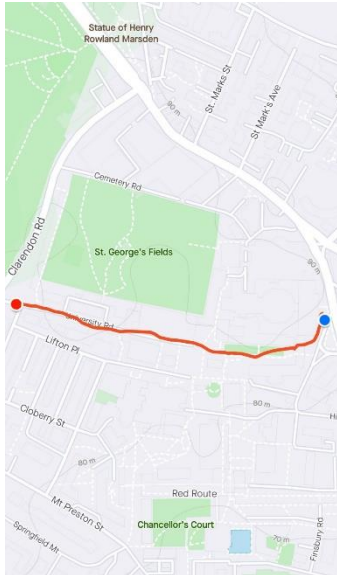


Law to Laidlaw:

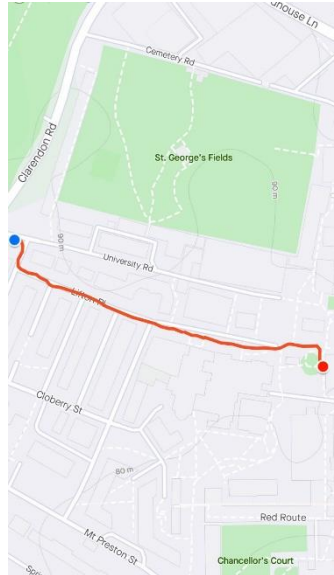


Participant 5

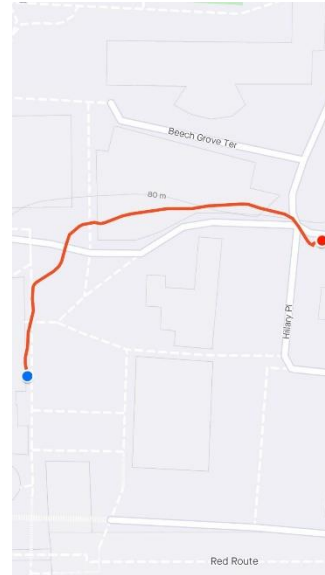
Parkinson to Business:



Business to Edward:

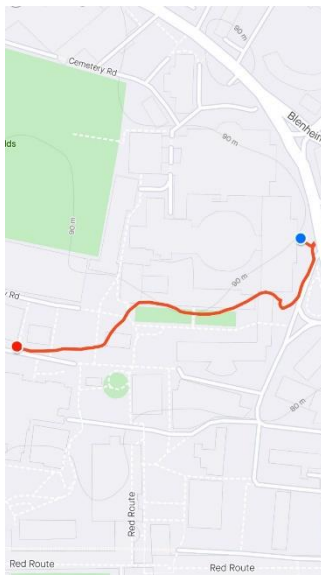


Edward to Laidlaw:

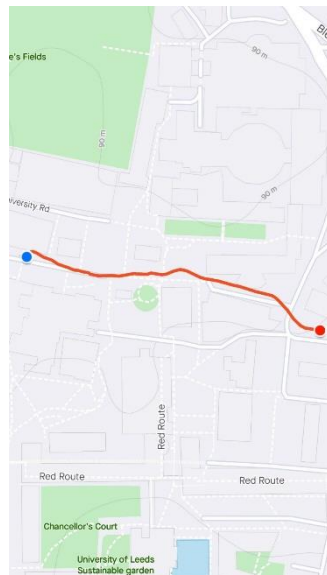


Participant 6

Parkinson to Design

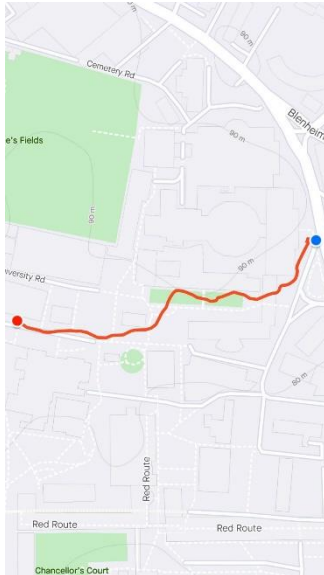


Design to Laidlaw:

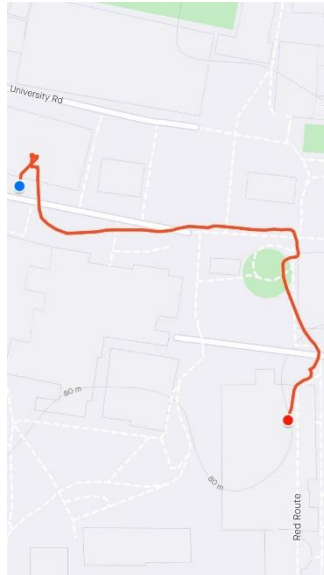


Participant 7

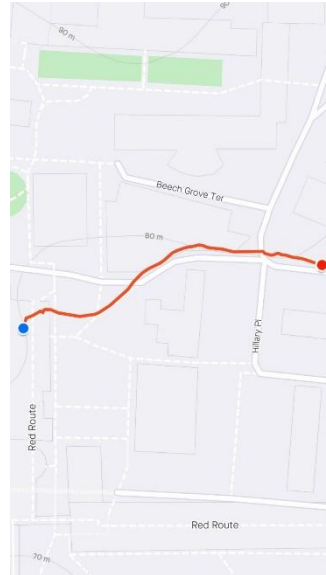
Parkinson to Design:



Design to Edward:

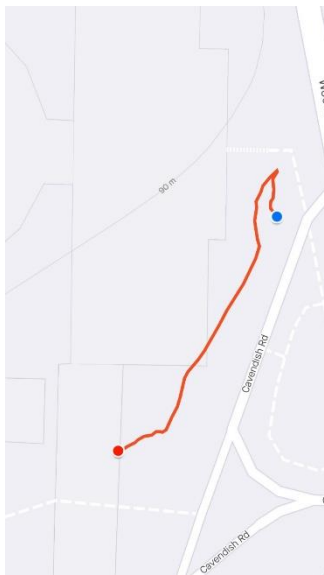


Edward to Laidlaw:

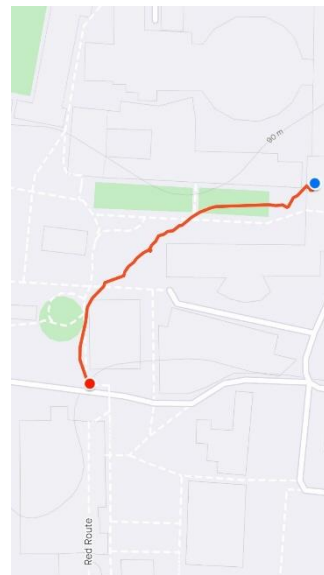


Participant 8

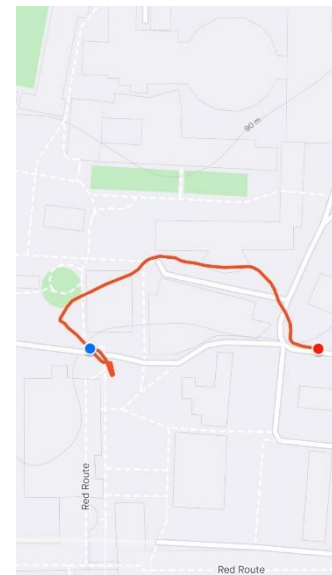
Parkinson to Philosophy:



Philosophy to Edward:

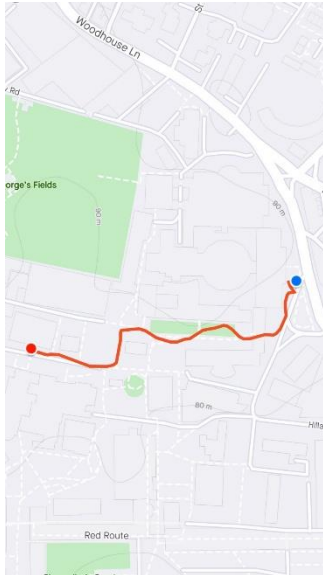


Edward to Laidlaw:

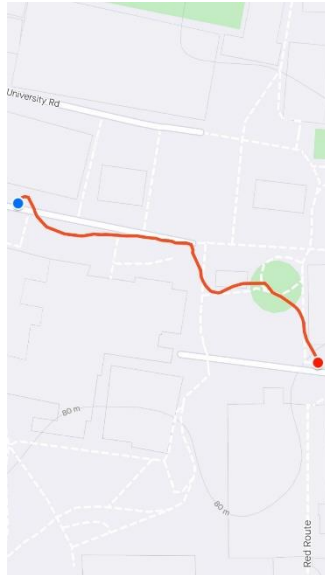


Participant 9

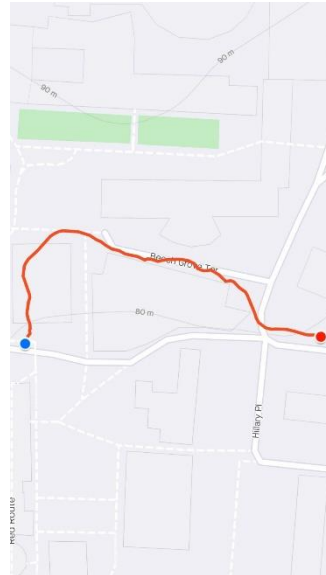
Parkinson to Design:



Design to Edward:

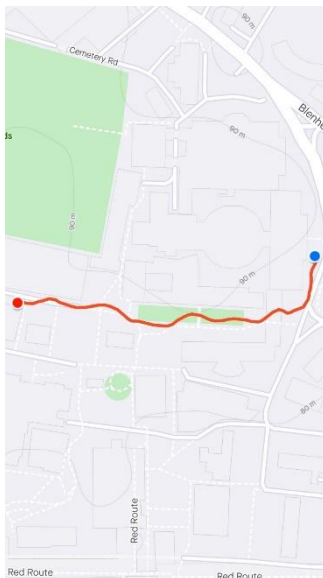


Edward to Laidlaw:

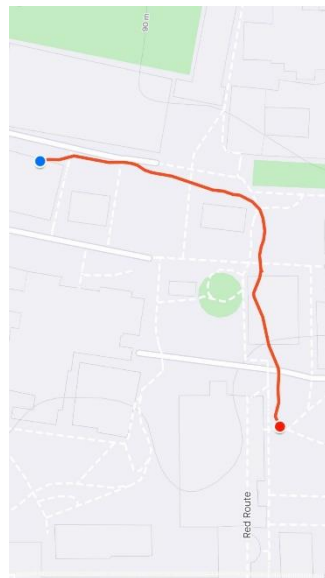


Participant 10

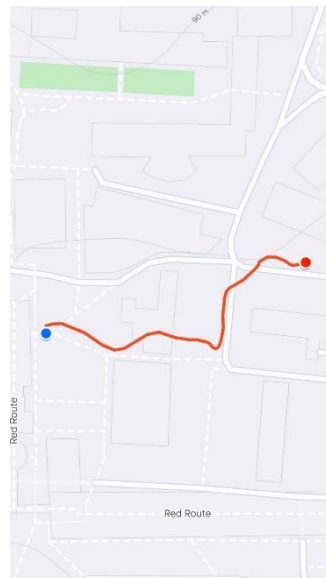
Parkinson to Design:



Design to Edward:

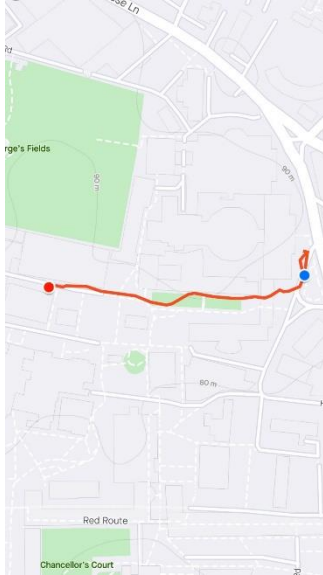


Edward to Laidlaw:

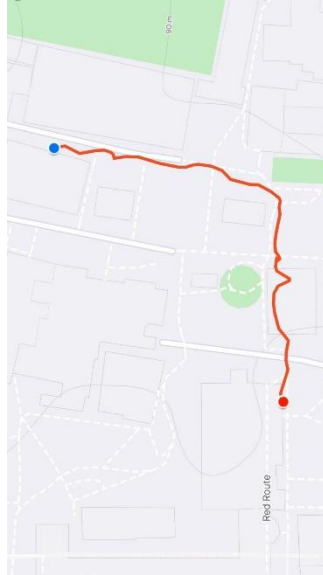


Participant 11

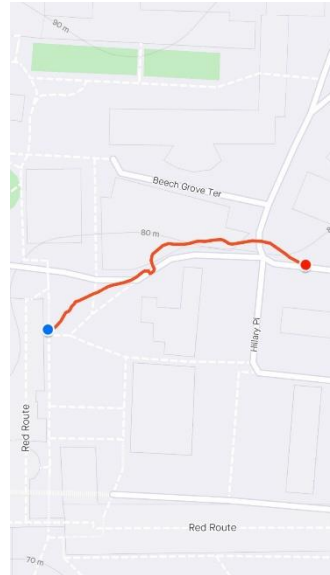
Parkinson to Design:



Design to Edward:

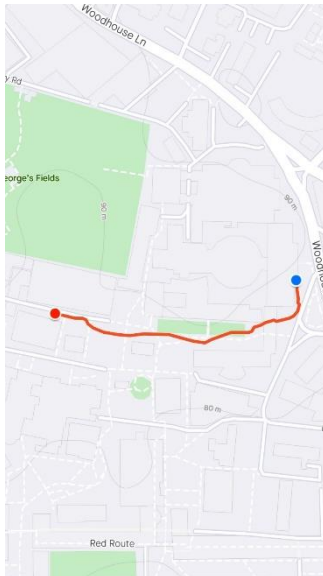


Edward to Laidlaw:

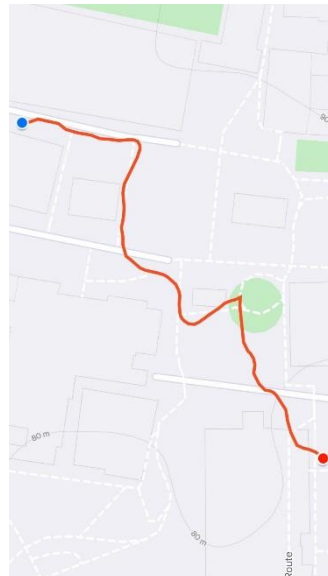


Participant 12

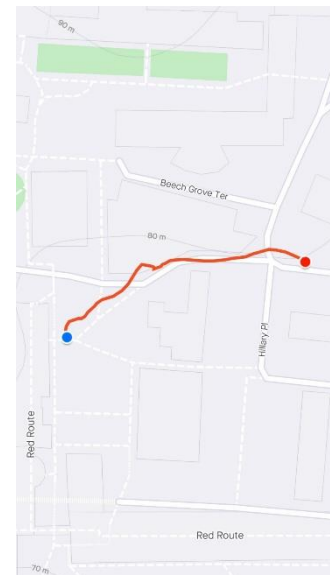
Parkinson to Design:



Design to Edward:



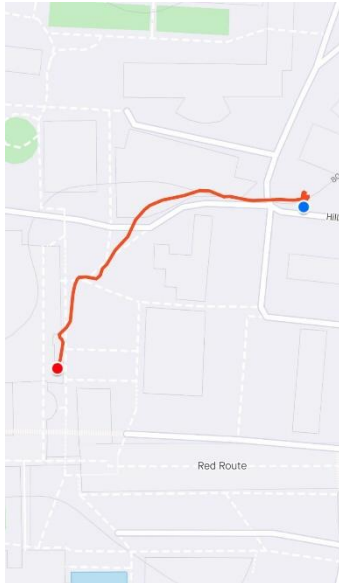
Edward to Laidlaw:



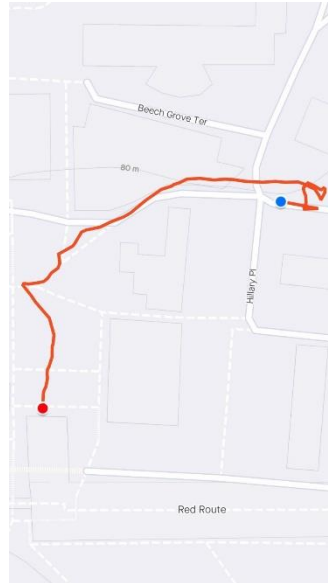
Appendix V: Route record maps of Quest task in Experiment II: from Laidlaw Library to School of Mathematics

(Blue dot: Start point; Red dot: End point)

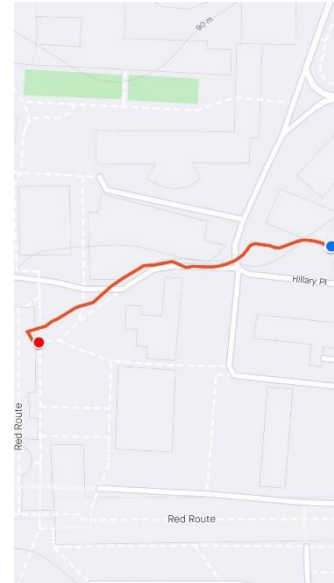
Participant 1



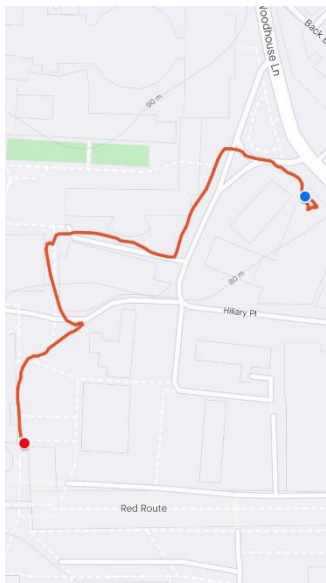
Participant 2



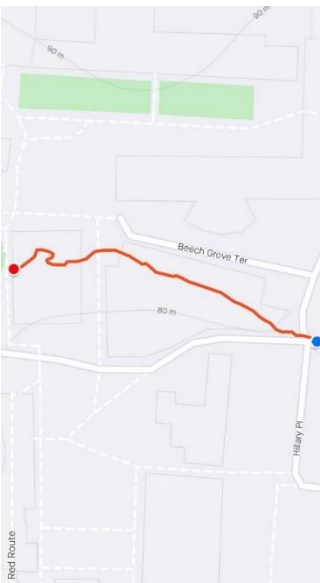
Participant 3



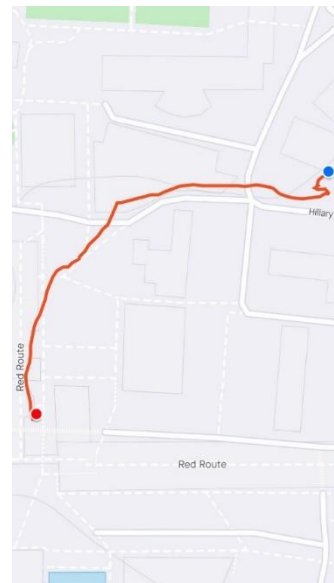
Participant 4

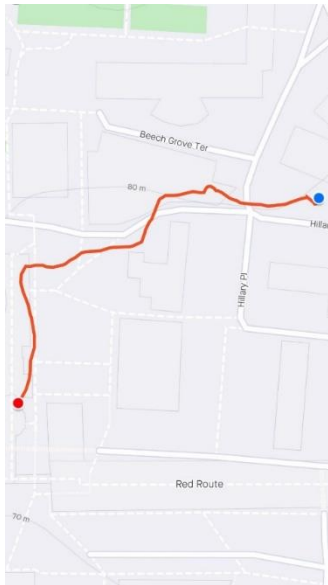
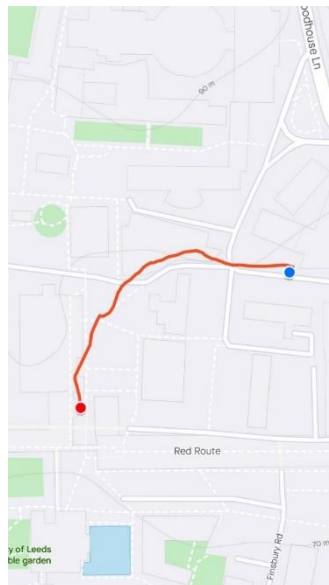
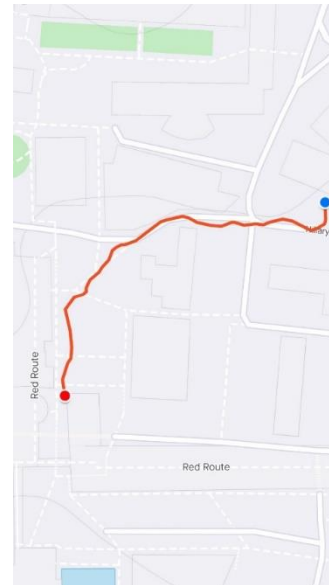
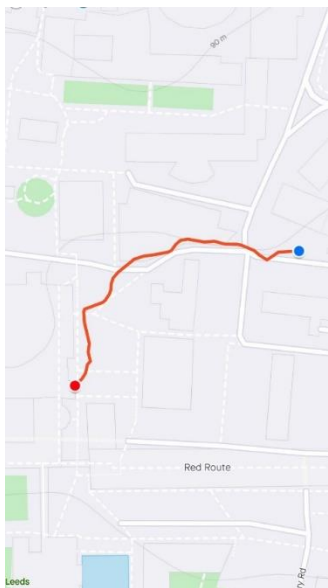
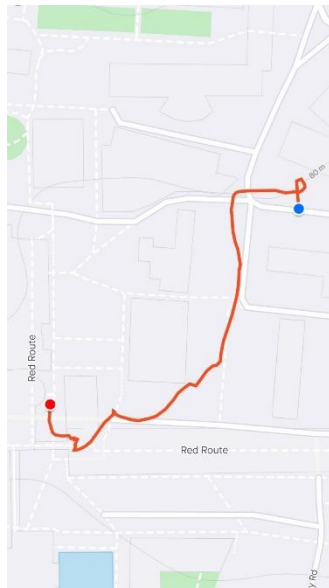
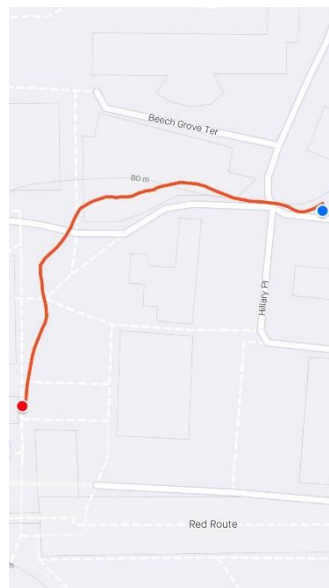


Participant 5



Participant 6

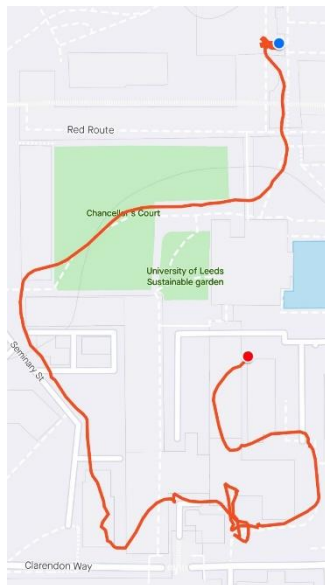


Participant 7**Participant 8****Participant 9****Participant 10****Participant 11****Participant 12**

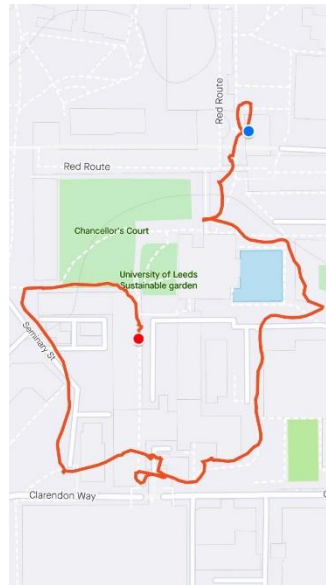
Appendix VI: Route record maps of Quest task in Experiment II: from School of Mathematics to Irene Manton Building

(Blue dot: Start point; Red dot: End point)

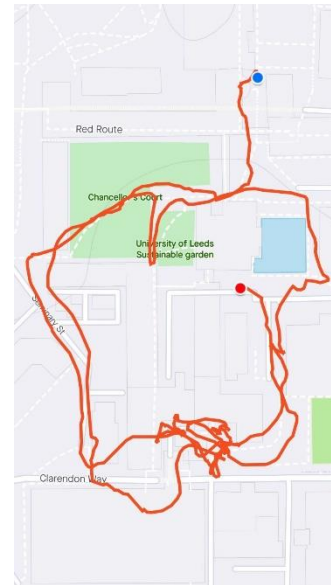
Participant 1



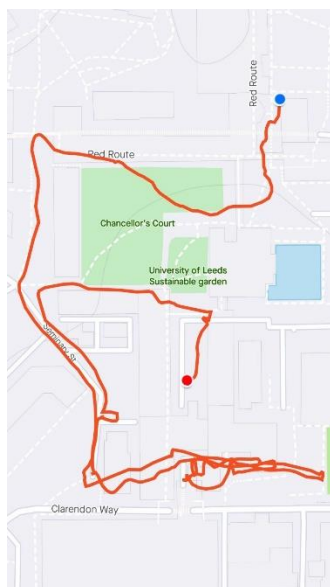
Participant 2



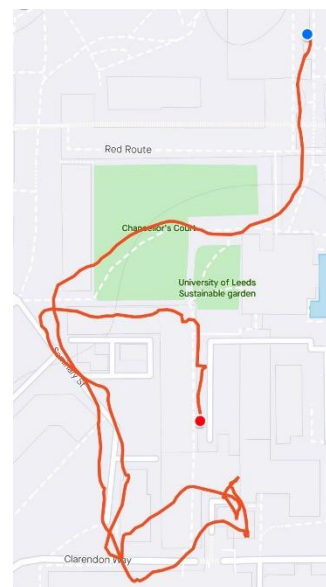
Participant 3



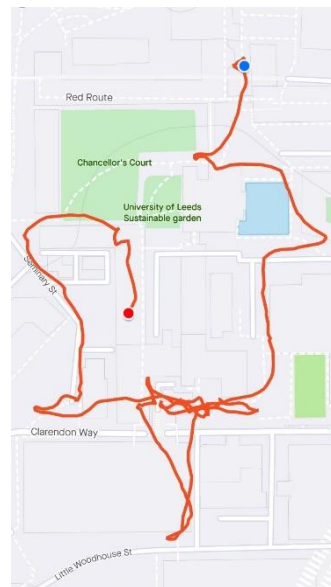
Participant 4

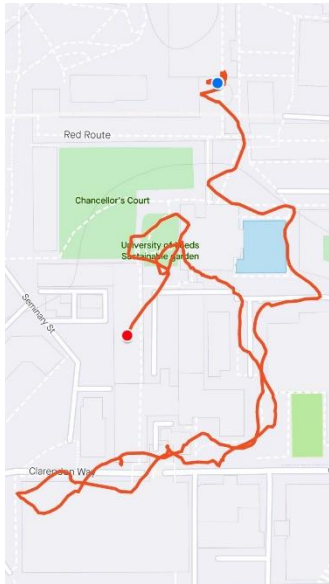
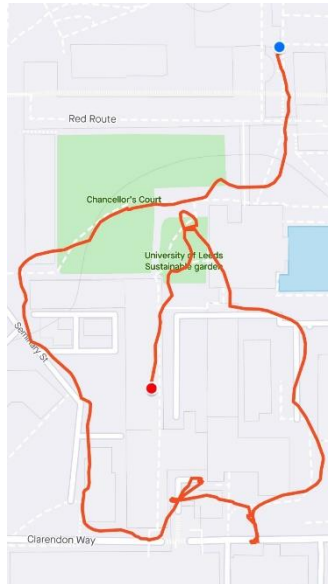
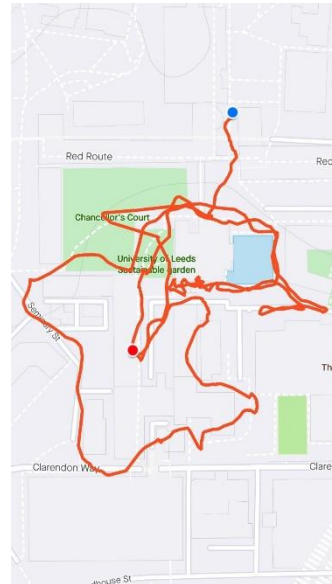
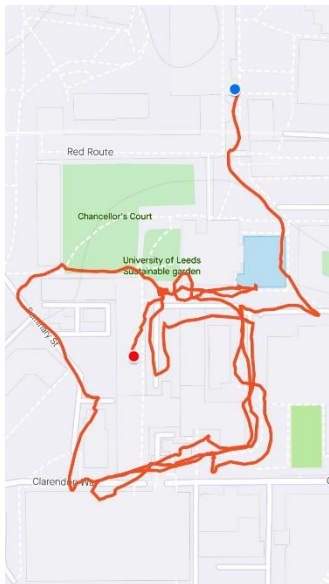
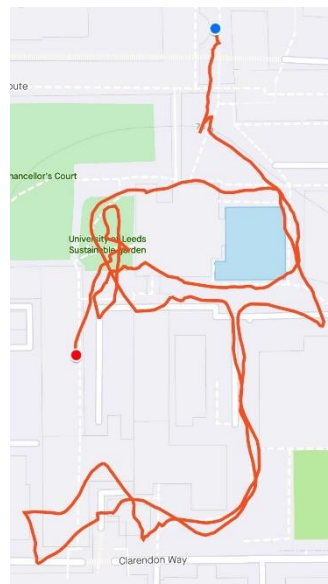
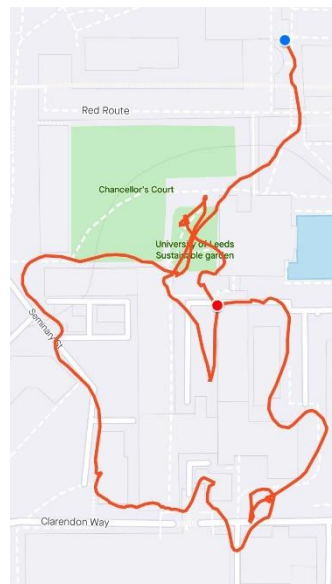


Participant 5



Participant 6



Participant 7**Participant 8****Participant 9****Participant 10****Participant 11****Participant 12**

Appendix VII: Questionnaire of Explore task in Experiment II

Research of exploring outdoor environment on campus

You are asked to answer a few questions about the environment you have explored in these 20 minutes. Please carefully recall your previous behaviour.

* Indicates required question

1. If you agree that "the data I provide in the survey can be used for research purposes", please mark on the 'agree' button below and start completing the questionnaire. *

Mark only one oval.

☐ Agree

2. Please rate your interest for the following options when "exploring" on campus *

Mark only one oval per row.

	Not interested at all	Not very interested	Neutral	Interested	Strongly interested
Libraries (i.e. Laidlaw Library, Brotherton Library)	☐	☐	☐	☐	☐
Teaching buildings (i.e. School of Design, School of Music)	☐	☐	☐	☐	☐
University facilities (i.e. Ziff Building, Union)	☐	☐	☐	☐	☐
Restaurants	☐	☐	☐	☐	☐
Landmarks (i.e. Parkinson Building)	☐	☐	☐	☐	☐
Entertainment	☐	☐	☐	☐	☐

3. How many interesting places do you find when freely exploring? *

Mark only one oval.

- ☐ 1
☐ 2
☐ 3
☐ 4
☐ Other: _____

4. Please write down the places you explored (If don't know the name, please slightly describe the places). *

5. What elements can attract you when you exploring in an outdoor environment on campus? *

6. When using Google Maps, how do you find interesting places? *

Tick all that apply.

- ☐ Search directly for the name of a specific place
☐ Using "Explore" function on the menu
☐ Click on the name of the place shown on the map
☐ Click the buttons under the search box
☐ Other: _____

7. Please describe any problems you might have had when following directions by Google Maps. *

Appendix VIII: Paper map prototypes provided to participants in Experiment III

Map Prototype

Group A



Map Prototype

Group B

