USE OF MAPS IN INDOOR WAYFINDING

QIUJUN LI
Febraury, 2017

SUPERVISORS:
Dr. C.P.J.M van Elzakker
Drs. B.J. Köbben

USE OF MAPS IN INDOOR WAYFINDING

QIUJUN LI
Enschede, The Netherlands, Febraury, 2017

Thesis submitted to the Faculty of Geo-Information Science and Earth Observation of the University of Twente in partial fulfilment of the requirements for the degree of Master of Science in Geo-information Science and Earth Observation.
Specialization: Geo-informatics

SUPERVISORS:
Dr. C.P.J.M. van Elzakker
Drs. B.J. Köbben

THESIS ASSESSMENT BOARD:
Chair: Prof.dr. M.J. Kraak
External Examiner: Dr. I. Delikostidis, University of Canterbury, Department of Geography

DISCLAIMER
This document describes work undertaken as part of a programme of study at the Faculty of Geo-Information Science and Earth Observation of the University of Twente. All views and opinions expressed therein remain the sole responsibility of the author, and do not necessarily represent those of the Faculty.

ABSTRACT

Wayfinding in complex and unfamiliar in buildings may be a frustrating and challenging task for visitors. In modern society, a growing number of applications that rely on indoor maps and other external navigation aids have become available to help people to find their way inside buildings. The goal of this research was to investigate the role of maps in indoor wayfinding in combination with other navigation aids, by figuring out whether, and, if so, when, where and how users want to use map displays. In this research, an indoor wayfinding experiment was conducted in the ITC building. In this experiment, 18 participants were selected after they had completed an online survey which was created to collect information about their background, previous experience with indoor wayfinding, sense of direction and spatial ability. Thereafter, they were split into 3 similar groups for a comparative task analysis. The first group did the test with textual instructions, photo navigation and signs, but without maps, while the other groups had access to maps in addition to the other navigation aids of group 1. Group 2 could use paper maps of the different floors of the building and group 3 could have a smart phone for displaying digital maps with a simulated positioning system. All participants were asked to perform wayfinding tasks while thinking aloud and wearing a TobiiPro Glasses 2 mobile eye-tracker for capturing their eye movement data and recording their verbalizations. The test results, which include the outcomes of the online survey, the recorded videos and interview materials, were analysed qualitatively and quantitatively. With respect to performance and aids usage, the analysis revealed that map displays were not the most popular choice for indoor navigation as only a minority of participants focused on maps. In particular the digital maps on the smartphone were not used a lot. Part of the reason for this could be that these maps with the simulated positioning system did not smoothly function as an indoor navigation application yet. Besides, test persons who used maps (printed or digital) did not a have better performance than others. On the other hand, most of the participants preferred the photo navigation, which indicated that photo images with direction arrows could be a helpful component of indoor wayfinding applications. In the end of this research, recommendations were proposed for the development of new indoor wayfinding applications.

Key words
Maps, Indoor wayfinding, Navigation aids, Experiment, Eye movement

ACKNOWLEDGEMENTS

The accomplishment of this thesis was impossible without the support and contribution from diverse people. I would like to appreciate everyone that helped me here.

First and foremost, I express my utmost gratitude to my first supervisor Dr. C.P.J.M. van Elzakker , who gave me very clear and intellectual guidance during my research period. He provided me much encouragement whenever I encountered problems and indeed detailed feedback on my every work. Besides, he played the role of researcher assistant during the implementation of indoor wayfinding experiment, which helped me to complete the user test.

My sincere thanks to my second supervisor Drs. B.J. Köbben for helping me solve the technical problem and giving much valuable advice.

I am also greatly indebted to W.J. Kock for providing me technical assistant during the experiment.

I am also deeply grateful for my GFM classmates especially my Chinese classmates, Yunmeng Zhu, Tianyuan Wang, Jiaxin Liu and Shengce Wang. They all brought a lot of happiness and concern to me and made my academic life more colourful.

My heartfelt thanks go to my girlfriends Ye Lyu and Runjun Wang for their love, accompany and encouragement whenever I was upset. Thanks to you girls spent many wonderful times with me. Love you all.

I am forever grateful to my beloved family – my father Wantao Li, my mother Sumei Jing and my little sister Jinjin Li – for trusting, supporting and inspiring me as always.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1. INTRODUCTION

1.1. Motivation and problem statement

In the modern society, wayfinding is an important issue for the convenient daily travel of people as the physical space we live in is becoming more complex with each day. Wayfinding is the process in which people orient themselves in real space and navigate from origin to destination. It involves both route planning and the actual navigation.

While outdoor wayfinding applications have a long tradition, the development of indoor wayfinding applications is still in its initial stages (Lorenz, Thierbach, Baur, & Kolbe, 2013). According to the U.S. EPA/Office of Air and Radiation (2012), people spend approximately 90% of the time inside buildings. Despite the sleeping and working time, individuals focus on public indoor spaces like campus buildings, airports, hospitals and shopping centres. Ellard (2009) asked the question "Why we can find our way to the moon, but get lost in the mall?" Indeed, humans are not good at locating themselves in unfamiliar and partially familiar environments (Klippel, Freksa, & Winter, 2006). For example, people tend to ask or be asked where the bathroom is in the shopping mall. The wayfinding is crucial for the traveller in the airport as well, to find the right desk and gate as soon as possible. The most serious aspect of indoor wayfinding is emergencies such as how to plan the escape routes if the building is on fire. If these questions can be answered, a lot of the annoyance in people's lives would be removed.

Technological developments have led to real-time location systems which can track the location of an object accurately, not only in outdoor environments but also in indoor environments. With the support of indoor positioning systems (such as WLAN, IR, and RFID), many indoor wayfinding applications became available in recent years (Li, Chan, Wong, & Skitmore, 2016). Most of these applications rely on maps and other visualizations of the indoor environments (such as Virtual Reality or indoor "Street View"), as displayed on the screens of smart devices like cell phones and tablets. However, the role of maps and other visualizations in helping users to orient themselves and recognize the right way is not clear because these indoor wayfinding users may also rely on spoken or written navigation instructions (e.g. "walk upstairs "), on landmarks (e.g. an escalator), on signs and on room number plates. For example, the Eyedog Company developed an application which allows users to get rid of digital indoor maps and provides users turn-by-turn navigation instructions conducted by landmarks. These landmarks, including physical outstanding objects and artificial landmarks inside buildings, are presented by pictures rather than by the map (Eyedog Indoor Navigation, 2016). This research aims at finding out whether navigation systems may indeed work without cartographic displays of indoor space.

1.2. Research objective and questions

1.2.1. Research objective

The overall objective of this research is to establish the role of map displays in indoor wayfinding in combination with other means of navigation support (e.g. signs, numbering systems, textual navigation instructions, Virtual Reality) by figuring out whether, and if so, when, how and where users want to make use of indoor map displays.

If these questions can be answered, the effectiveness of existing or to be developed applications for helping users to find the way inside buildings could be improved.

This research considers not only the indoor maps displayed on the screens of mobile services but also floor-plans which are stuck to the wall in a building or projected on large-scale display screens.

1.2.2. Research questions

Main questions:

1. How do people find their way in indoor environments?
2. What are the uses of maps in indoor wayfinding?
3. What are the suggestions for improving the design of indoor wayfinding applications (with emphasis on the incorporation of map displays)?

Sub-questions:
For question 1:

- Which user tasks are involved in indoor wayfinding?
- Which indoor wayfinding applications are currently available? What are the components of current wayfinding applications?
- Which components are meant to support which user tasks?
- What are the forms of visualization of indoor space among existing indoor wayfinding applications?
- How are the map displays in current wayfinding applications designed (e.g. how are multiple floors represented)?

For question 2:

- Do users want to use indoor map displays for wayfinding?
- When do the users want to employ a map (i.e. for executing which tasks)?
- Where do the users tend to make use of the map?
- How do the users use map displays during the wayfinding process?
- Does the indoor map help users to find the right way?
- Which visualization of indoor space do users prefer to execute which tasks?
- Which navigation aids do people prefer to find their way inside buildings?
- What difficulties do people have when they are using maps for indoor navigation?

For question 3:

- What recommendations can be made for the design of new indoor wayfinding applications?
- What recommendations can be made regarding the cartographic design of indoor map displays?

- How may indoor map displays be integrated with the other components of indoor navigation systems?

1.3. Organization of this thesis

The thesis consists of seven chapters. Chapter 1 includes the motivation, problem statement, research objectives and questions. Chapter 2 reviews previous researches about indoor wayfinding and external indoor navigation aids such as maps, signs and textual instructions. It also discusses several existing indoor navigation systems with emphasis on their components. A conceptual model of indoor wayfinding is presented in the form of an indoor wayfinding task analysis in the Chapter 3 and the research methodology is introduced in chapter 4. Eye-tracking and thinking aloud are the main methods applied in this user research. Chapter 5 is devoted to the set-up of the experiment and describes the test materials, participants and test scenarios. The experiment is implemented in the ITC building. Participants are divided into three groups for testing different test materials. The analysis of the test results is presented in Chapter 6. The conclusions of this research and recommendations for improving the design of indoor map and indoor wayfinding applications are summarized in Chapter 7. The future works that can extend this research are discussed in the final chapter as well.

2. INDOOR WAYFINDING RESEARCH

2.1. Introduction

This chapter covers the relevant literature for the research. First, section 2.2 illustrates the relevant researches focusing on wayfinding in general and indoor wayfinding in particular and contributes to summarize the factors that influence indoor wayfinding behavior and indoor navigation strategies of human beings. Then, an introduction of external wayfinding aids is given in Section 2.3. These aids, which are evidenced that can help people complete wayfinding tasks, include not only maps but also signage and landmarks etc. Some typical indoor wayfinding applications are discussed in Section 2.3.3. To test the use of tools in indoor wayfinding, user research is a technical and scientific way to examine the usability of these tools. Several researches about usability testing on indoor wayfinding are discussed in Section 2.4.

2.2. Indoor wayfinding

2.2.1. Wayfinding

The term wayfinding has emerged for many years in the literature on psychology, geography, environmental psychology and cartography. Researches mostly considered wayfinding as a spatial and cognitive problem. Passini (1981) came up with a conceptual framework of wayfinding which defined wayfinding in terms of spatial problem solving and divided it into three phases: (1) the environmental information processing from existing experiences, (2) the decision making and (3) the decision execution. And so, in order to make wayfinding easier for users, researchers should understand how people comprehend, interpret and deal with the spatial information to reach their goals. Car (1997)introduced a set of theories of human spatial knowledge in wayfinding and in navigation modeling. For instance, Lynch (1960) considered wayfinding is the way people understand urban landscapes as an interrelated set of images linked from one place to another. Gaisbauer & Frank (2008) followed the definition of wayfinding "goal-directed and planned movement of one's body around an environment in an efficient way" and created a pedestrian navigation model. As with variable definitions of wayfinding, Tenney (2013) summarized the term wayfinding, not only in perspective of behaviors, design practice, and processes of navigation, but also described the clear cognitive relationship between the human mind and the process of moving through space. Based on the previous studies, therefore, the wayfinding behavior is not only studied and analyzed as spatial problem from the geographical perspective but also considered as a cognitive issue from the aspect of psychology in this research. Outdoor and indoor wayfinding are different because of the different structure and scale of the environments. Due to the context of this research, which is indoor wayfinding, I mainly discuss the researches about indoor wayfinding.

2.2.2. Factors influencing indoor wayfinding performance

Finding one's way inside a building can be more challenging than outdoor wayfinding. Why do people often get lost in buildings? The complex spatial structure (Carlson, Hölscher, Shipley, & Dalton, 2010; Lorenz et al., 2013) and familiarity (Garling, Lindberg, & Mantyla, 1983; Hölscher, Büchner, & Meilinger, 2007; Lovelace, Hegarty, & Montello, 1999; Nossum, 2011) of environments are regarded as the main reasons making indoor wayfinding difficult. In reality, despite of the complex structure of and unfamiliarity with the indoor environment, there are still several other aspects that play a role in getting lost in buildings. For instance, some people can easily find the route back to the origin along the way they have walked the first time, while others may have difficulty with this and even get lost. What causes these difference between people is called "sense of direction". Kato & Takeuchi (2003) raised a study to examine the wayfinding difference between people with a good or poor sense-of-direction. The results revealed that people with a good sense-of-direction presented a better wayfinding performance and more flexible wayfinding strategies than people with a poor sense-of-direction. Based on a literature study, Karimi (2015) aggregated 7 factors contributing to wayfinding performance: 1)Visual access; 2) Individual spatial ability; 3)Navigation aids; 4)The mental maps user construct; 5)Spatial learning; 6)Reasoning strategies; 7)Physical environment and the structure of the building. As these factors can influence the wayfinding performance of participants, they will be taken into consideration in this research. To outstand the role of map in indoor wayfinding, the analysis of the test results should exclude the influences caused by these factors.

2.2.3. Indoor navigation strategies

With distinct individual spatial ability, purpose and preference, people will follow diverse indoor wayfinding strategies. Zlatanova, Liu, Sithole, Zhao, & Mortari (2014) gave an overview of possible indoor paths and indicated that the shortest distance and the shortest time are the most commonly-used strategies. The possible indoor paths are shown in Table 2.2.1. The summary of possible indoor paths is helpful for interpreting human indoor wayfinding behavior, which can examine the effects of maps as navigation aids in indoor wayfinding because different people have varying preferences and they may plan their ideal routes with the help of maps.

Table 2.2.1 Possible indoor paths (Zlatanova et al., 2014)

Path Type	Merit	Drawback
Shortest-distance	With minimum distance	If obstacles are considered may result in following a difficult to explain path
Shortest time	With estimated minimum travel time	Speed should be considered
Simplest path	Minimum turns	Could be longer distance/travel time
Least-space-visited	Least-number of passed rooms	May lead to more travelling time and distance
Least-obstruction	Least degree of blockage	Need accurate information about (dynamic) obstacles
Safest path	Avoid specific areas	May result in long detours
Possible path	Considers profile of agent	Requires clearance
Floor strategy (go through specific areas)	Better performance of homing users regarding time, similar with Least-Effort path	May not with the minimum distance

2.3. Approaches in indoor wayfinding

In outdoor wayfinding, people may keep track of their position during navigation through global landmarks, signage, reference directions, maps or coordinates (GPS). Especially with the development of GPS, outdoor wayfinding is not a difficult issue anymore. However, GPS positioning inside buildings is inaccurate and unreliable because the walls and building infrastructure interfere the signal propagation. On the other hand, people move more slowly in indoor areas than outdoor. Researches (Arthur & Passini,

1992) have shown that maps, signage and landmarks could be as tools for helping people locate themselves and plan the route inside the building.

2.3.1. Maps in indoor wayfinding

Maps are the common visualization method for space. Floor plans, the traditional architectural style indoor maps which present different floors of a different building in different maps, have been studied by many researchers. Garling et al. (1983) reported that floor plans can help decrease the impact of unfamiliarity with the environment and the improvement of the users' wayfinding performance was demonstrated through user testing. Radoczky (2007) also stated that floor plans have proven to be most effective to represent complex indoor structures. Except for floor plans, there are many other types of indoor maps, such as IndoorTube Maps (Alexander Salveson Nossum, 2011) Vertical Color Maps (Giudice, 2013) and 3D maps (Lorenz et al., 2013). IndoorTube Maps is an innovative approach to indoor maps, which is inspired by Beck's tube map (Garland, 1994). With IndoorTubes, one map can present multiple floors together with the connection between them at the same time in one map. Nossum & Nguyen (2011) compared this map with floor plans for patient navigation inside a hospital. The results showed that more participants preferred regular floor plans because of the familiarity with the floor plan concept. Giudice (2013) presented a data-independent alternative solution to floor plans that uses color to represent the vertical dimension on the map, named Vertical Color Map. It visualizes the multiple floors of indoor environments without the demand of geographic building data, and utilizes color to communicate the vertical location and building outlines to express the horizontal location. The results of this research proved that the vertical color map could be the valid alternative to floor-plan map, and also indicated that lack of map data does not hinder the implementation of indoor maps. For most of the existing indoor maps, the perspective is top view, called a 2D map, while the perspective of a 3D map is an oblique view. Lorenz et al. (2013) discussed that 2D maps are more appropriate for representing horizontal structures and 3D maps are more suitable for the representation of vertical structures as the top view segment floors wisely and cannot connect the adjacent floors, while the oblique view allows to link adjacent floors by tiny overlap.

In real life, a number of people have difficulties in reading maps, especially complex indoor maps. Butler, Acquino, Hissong, & Scott (1993) indicated that you-are-here maps did not have any positive effect on wayfinding performance as wayfinders spend more time reading maps without gaining more navigational knowledge. Hölscher et al. (2007) also investigated the map usage through user studies and gave the conclusion that floor maps had no effect on enhancing wayfinding performance for neither unfamiliar nor regular visitors. They explained that participants execute wayfinding tasks which require across-level navigation but they may have difficulties in integrating information from single floor maps into a coherent multi-level representation of a whole building because of the lack of floor plans alignment. In addition, they indicated that the reason that the floor plans failed to provide useful information for planning routes is that they only have detailed information about single floors. However, in my view, the results are not generally applicable because the researchers only provided their test participants with the fire plans on the wall. At first, the function of fire plans is to help people to quickly find their way in case of fire. The fire plans directly derived from architectural building data and are not well designed for routine indoor wayfinding. Indoor maps contain one or many designs but for the maps whose purpose is helping humans finding their way in the buildings, they should provide more navigational information. For example, the representation of resources, such as seatings and toilets, may be significant for identifying location to be included in an indoor map as a landmark (Ryder, 2015). But fire plans are too generalized to supply enough useful information to users for planning the route. Secondly, participants were not provided with handheld maps in their research, which means that participants may loose time on finding the maps on the wall when they wanted to use the maps. In this research, I hypothesize that an indoor map with a good design could have a positive effect on indoor wayfinding.

2.3.2. Other navigation tools in indoor wayfinding

A lot of studies have shown that other tools can improve indoor wayfinding performance as well, like signs (Arthur & Passini, 1992; Hölscher, Büchner, Brösamle, Meilinger, & Strube, 2007; O'Neill, 1991; van Schaik, Mayouf, & Aranyi, 2015), landmarks (Michon & Denis, 2001; Ohm, Müller, & Ludwig, 2015; Raubal & Winter, 2002; Sorrows & Hirtle, 1999), images, videos and textual and verbal instructions (Mulloni, Seichter, & Schmalstieg, 2011; Raubal & Winter, 2002). O'Neill (1991) examined the effect of floor plans and signage on wayfinding inside several buildings. The results claimed that the addition of signage decreased travel time costs and the times of wrong turns and backtracking. Another research (Hölscher, Büchner, & Meilinger, 2007) also presented evidence that map usage ceased 60% in the co-presence of signage, however, the usage of signs did not change whether or not making use of maps. The conclusion was that maps can help signs works well in indoor wayfinding but cannot replace them. Furthermore, landmarks are considered as having key characteristics in mental representation of space (Werner, Krieg-Brückner, Mallot, Schweizer, & Freksa, 1997) and studies (Deakin, 1996; Michon & Denis, 2001) have shown that landmarks are significant for giving route directions at specific points especially at reorientation points. Deakin (1996) raised another study which compared the wayfinding performance of participants in routes with landmarks at decision points and routes without landmarks. The results gave evidence that landmarks can lead to better guidance and less wayfinding errors. Some researches in indoor wayfinding focus on how the textual and verbal instructions help users find their way inside buildings. For example, Radoczky (2007) summarized that verbal guidance can be helpful for pedestrians in very quiet environments without disturbance of noise. Textual guidance is the simplest tool for navigation and can be used when users are situated in noisy environments, whereby good instructions are simple and clear, mention corridors and distances and include landmarks and upcoming decision points. A test by Mast, Jian, & Zhekova (2012) indicated that elaborate route instructions can improve the wayfinding performance. But in comparison to visualization tools for space, verbal or text instructions cannot give an overview of the environment. Mulloni et al. (2011) combined the instructions with Augmented Reality (AR) at info points (reorientation points) to support indoor wayfinding. With the help of AR, participants can get an overview of the upcoming situations; only arrows or instructions cannot. They observed that participants matched the visualization of situations with landmarks and their surroundings to recover from wayfinding errors. Therefore, reason that the image (overview of the situation) was useful for this matching.

Currently, there is a lot of research into the development of indoor positioning systems and this may revolutionize indoor wayfinding, like GPS revolutionized outdoor navigation (e.g. car navigation systems have brought a change to the use of traditional road maps). Real-time locating systems distinguish and track the position of an object / human being in indoor environments. Various real-time positioning systems have been investigated and developed in recent years. Li, Chan, Wong, & Skitmore (2016) reviewed nine existing indoor positioning systems; such as Bluetooth, Vision Analysis, wireless local area network (WLAN), infrared (IR) and radio frequency identification (RFID). With the support of real-time locating systems, dedicated indoor wayfinding applications can be used on mobile devices for navigating and planning routes in buildings like airports, shopping malls, libraries, etc. However, indoor positioning is not available everywhere like GPS was outdoors as it requires creating infrastructures in buildings.

2.3.3. Existing indoor wayfinding applications

Indoor wayfinding applications help people to orientate themselves and navigate from one place in a building to another quickly. Various types of interactive indoor navigation applications have been developed, based on the technological progress in indoor positioning and indoor visualization. Several already existing applications for indoor wayfinding are described in the next paragraphs.

M2mobi (2016) developed the Schiphol Airport App for guiding visitors at this airport (see Figure 2.3.1). The app provides an indoor wayfinding function and uses beacon technology based on Bluetooth 4.0 LE, which can reach a positional accuracy of 5-7 meters. Floor plan maps are utilized as the visualization of the space which has multiple layers. The map source data are managed in an Esri environment and the route planning is calculated using Esri's Network Analyst. In Network Analyst terminology, all the points of interest are junctions, the edges connect the junctions and represent the walking routes.

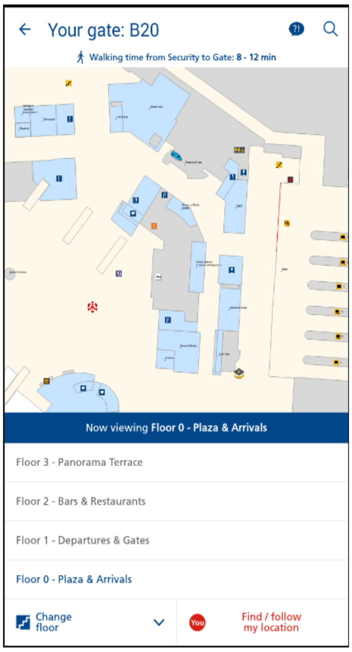


Figure 2.3.1 Schiphol Airport App

MazeMap (2015) is another indoor navigation system designed for large building complexes, such as universities, hospitals, conference venues and shopping malls (Figure 2.3.2). MazeMap also uses existing floor plans as a basis for the interface but the positioning technology is the existing WiFi network.

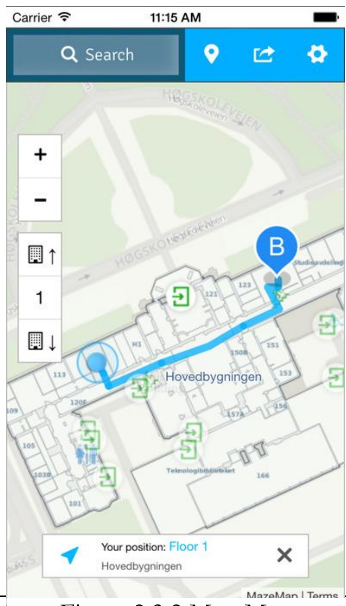


Figure 2.3.2 MazeMap

Google Maps (2011) provides an indoor navigation function which is called MapsIndoor. It takes floor-plan maps as the basis of maps as well (Figure 2.3.3). MapsIndoor can be interfaced with the most suitable indoor positioning system at specific buildings eg. WiFi positioning, Bluetooth or positioning based on magnetic fields.

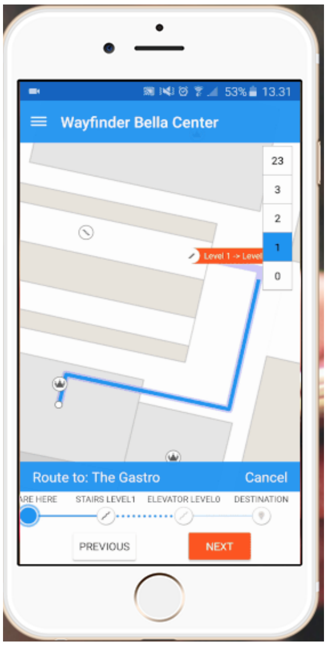


Figure 2.3.3 MapsIndoor: digital indoor wayfinding with Google maps

Guide3D (2013) is a three-dimensional platform-independent information and control system for indoor areas (Figure 2.3.4). It only can be used in Alice Hospital locates at Germany. The system uses a 3D model rather than floor plan maps and does not have a positioning system. It shows the paths to users by an animation in a web browser.

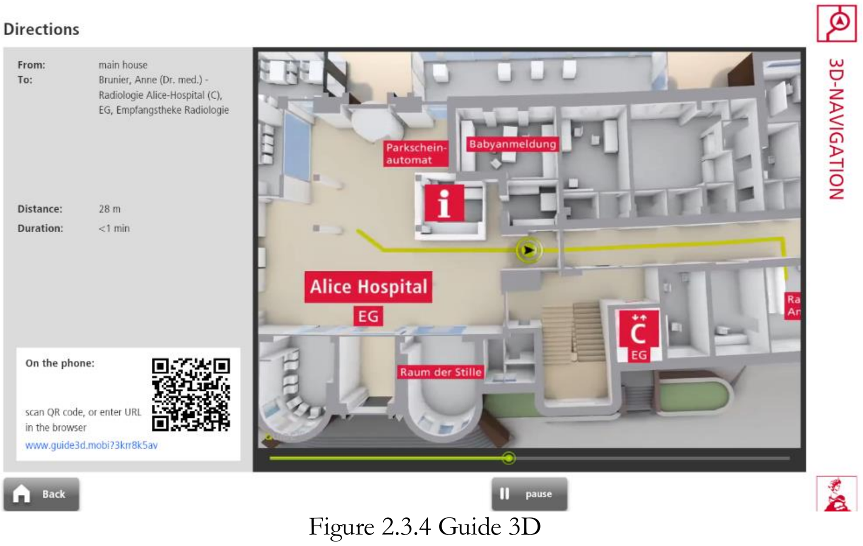


Figure 2.3.4 Guide 3D

The Eyedog Photo Landmark navigation system (2016) (Figure 2.3.5) is another case which does not utilize an indoor wayfinding positioning system nor floor plan maps. The app provides turn-by-turn wayfinding instructions in text, schematic direction and landmarks at every junction and complicated locations. The landmarks are presented by photos depicting the physical characteristic objects. Eyedog photo landmark identify the location through scanning the QR code in specified stations.

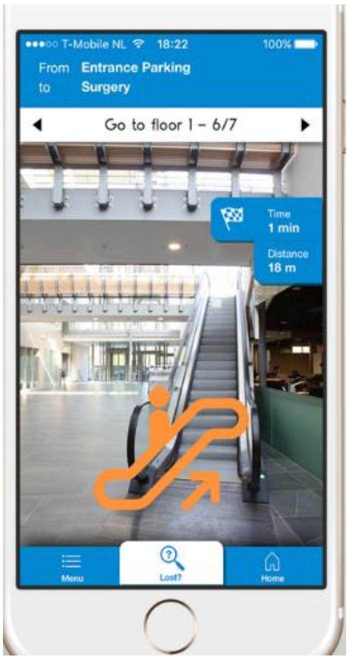


Figure 2.3.5 Eyedog Photo Landmark Navigation

From the above descriptions it can be seen that different applications work with various components. Floor plan maps are the most popular way to visualize the indoor environments but other visualization tools, like images and 3D models, are also chosen to present the indoor scenes. Some applications make use of other navigation tools, such as images, arrows, textual and audio instructions for showing the routes. To get an overview of some selected indoor wayfinding applications, Table 2.3.1 compares them with respect to their components.

Usually, maps are regarded as an efficient way(Puikkonen, et al., 2009) to confirm the location, orient the direction and plan the route in outdoor navigation. However, it is not clear whether maps are useful in indoor environments as other visualization and navigation tools are proved to be helpful as well in previous studies and indoor navigation applications. Therefore, the goal of this research is to explore the role of maps in indoor wayfinding in combination with other means of navigation support by figuring out whether, and if so, when, how and where users want to make use of indoor map displays. For this purpose, I will conduct user researches to answer these research questions as user research is a fit way to understand user behaviors, needs, and motivations.

Table 2.3.1 Overview of selected indoor wayfinding applications and their components

Component	Schiphol Airport App	MazeMap	Eyedog Photo Landmark	Google Maps	Guide 3D
Navigation interface	Floor-plan maps	Floor-plan maps	Photo overlaid with arrows	Floor-plan maps	3D model
Planning route display	Red dash line	Blue line	-	Blue line	Animation
Arrow for direction	YES	NO	YES	NO	YES
Turn by turn navigation	YES	NO	YES	NO	NO
Textual or audio instructions	YES	NO	YES	NO	NO
Internet connection required during navigation	YES	YES	NO	YES	NO
Dynamic routing	YES	YES	YES	YES	NO
Operating system	iOS and Android	iOS and Android	iOS and Android	iOS and Android	Windows
Positioning					
During navigation, external positioning hardware / software is required	YES	YES	NO	YES	NO
Actively warn users when taking wrong directions	NO	NO	NO	NO	NO
Manually selecting starting point	NO	NO	YES	NO	YES
Automatic Positioning	At 100% of the walking area	At 100% of the walking area	At key spots only	At 100% of the walking area	At key spots only
Position is detected by	Beacons and Bluetooth	WIFI	QR codes	WIFI	-

2.4. Indoor wayfinding user research

It is important to know what is the usability of indoor wayfinding applications and their components like map interfaces. User research with respect to indoor wayfinding already has a long tradition, Goodman, Kuniavsky, & Moed (2013) called user research "the process of understanding the impact of design on an audience". User research has been employed in many fields, like psychology and geography. It includes different methods and techniques, like questionnaires, interviews, observation, thinking aloud, eye-tracking, etc. A broad range of methods have been applied in the past with their specific advantages.

In the research of signs and maps produced by Hölscher et al. (1997), participants had to find six locations in the test building subsequently and one task's destination was the next task's starting location so that all the tasks were linked. The difficulty of all tasks was designed in a realistic range with the consideration of floor changes. The comparative analysis of task results indicated that participants paid more attention on maps than on signs. The design of wayfinding tasks are remarkable, however, I think the weakness of the research of Hölscher et al. (1997) was the ignorance of the influence of the different spatial abilities of participants. As shown in section 2.2.2, many factors may influence the wayfinding behaviors. So, it is better to investigate individual wayfinding abilities and personal attributes before asking participants to execute wayfinding tasks. Some researchers have considered that in their researches. For instance, Lorenz et al. (2017) employed a prior survey to obtain information about past user experiences and wayfinding abilities before letting them execute wayfinding tasks, and a posteriori survey to solicit individual experiences after the wayfinding tasks in researching user satisfaction with indoor navigation maps. The authors concluded that personal social factors could be significant as wayfinding is an interactive social process. Additionally, a survey after the execution of wayfinding tasks may possibly help to interpret the test results in the analysis.

To observe and record the wayfinding performance of participants during task execution, researchers made use of different technologies. Hölscher et al. (1997) utilized thinking aloud and videotaping as the main techniques for recording the thoughts and considerations of participants and their behaviors in the process of finding their way. Viaene er al. (2015) investigated when and where people need landmarks as navigational aid during an indoor wayfinding task though analysing and comparing the verbal description of test persons' thinking aloud. Thinking aloud is a common technology in many user researches as it can supply qualitative and complete information regarding cognitive processes (van Elzakker, 2004). Apart from thinking aloud, eye-tracking systems became increasingly popular in the field of human interaction with the development of more accurate and performant mobile eye trackers. Lee, Kim, & Platosh (2015) evaluated the use of an interactive map in library wayfinding through an eye-tracking system. In the research of this interactive map, eye movement data were studied quantitatively and qualitatively. Qualitative analysis was for examining the interactive map use and hesitation point errors in wayfinding while quantitative data included the route planning time, task completion time, number of errors, number of hesitations and hesitation time for each participant for all tasks. .

2.5. Summary

First, indoor wayfinding is more challenging than outdoor wayfinding as more factors have an influence on frustrating people in finding the right way inside a building, like the complex structure and low visual access to indoor environments. The impact made by these factors should be taken into consideration when analyzing people's wayfinding behaviors. Second, there are eight types of possible indoor wayfinding strategies, and the shortest-time and shortest-distance paths are the commonly planned paths, similar to outdoor wayfinding. To get knowledge about the possible indoor routes it is helpful to interpret human indoor wayfinding behavior because people have different preferences and habitats in indoor wayfinding. To help people to find their way inside buildings, lots of approaches are available. Indoor maps are the most common visualization of indoor space that most of the existing indoor wayfinding application make use of as the primary component, like Schiphol Airport App, MazeMap and Google Maps. But many people have difficulties in reading maps; they may not like to (only) use indoor maps for indoor wayfinding. So, there are other aids for helping people in indoor navigation. Textual instructions, audio instructions, images, and signs have been evidenced by Radoczky (2007) to improve the indoor wayfinding performance. For example, the Eyedog Photo Navigation utilizes images, arrows and textual instructions to show the route to destinations. On the last, to reach the objective of this research, user research will be employed to explore the role of maps in indoor wayfinding in combination with other navigation aids.

3. A CONCEPTUAL MODEL OF INDOOR WAYFINDING

3.1. Introduction

To understand the process of indoor wayfinding scientifically and systematically, a conceptual logic model is a feasible choice. In this research, the indoor wayfinding behavior is explained and analyzed through a model of user tasks which are involved in the wayfinding. The tasks are designed on the basis of wayfinding questions which are related to the destinations, confirmation of location and orientation inside buildings. In the conceptual model, the user tasks are linked to navigation aids like maps, signs, images and instructions.

3.2. Indoor wayfinding task analysis

Throughout the past relevant researches, wayfinding was characterized as the generalized behavior of humans navigating through space (Tenney, 2013). It is not only a simple geographical issue, from one point to another point, but also a psychological process in which human beings interact with space, called spatial cognition. Like most human behavior, wayfinding is a process which involves a set of complicated and associated sub-tasks, each with corresponding mechanisms no matter in outdoor or indoor environments. When human beings enter an unfamiliar environment, usually the first question that jumps into mind is "Where am I? How do I know my position?" Instead of starting to move immediately, without any information, people usually find their way by considering a set of related spatial questions and executing involved wayfinding tasks one by one. Delikostidis (2011) modelled the outdoor wayfinding behaviors through a task-based user experiment. In his conceptual design, the process of orientation and navigation in outdoor environments was transformed into four main user tasks and each of the tasks is related to specific user questions. The user tasks and relevant user questions are presented in Figure 3.2.1.

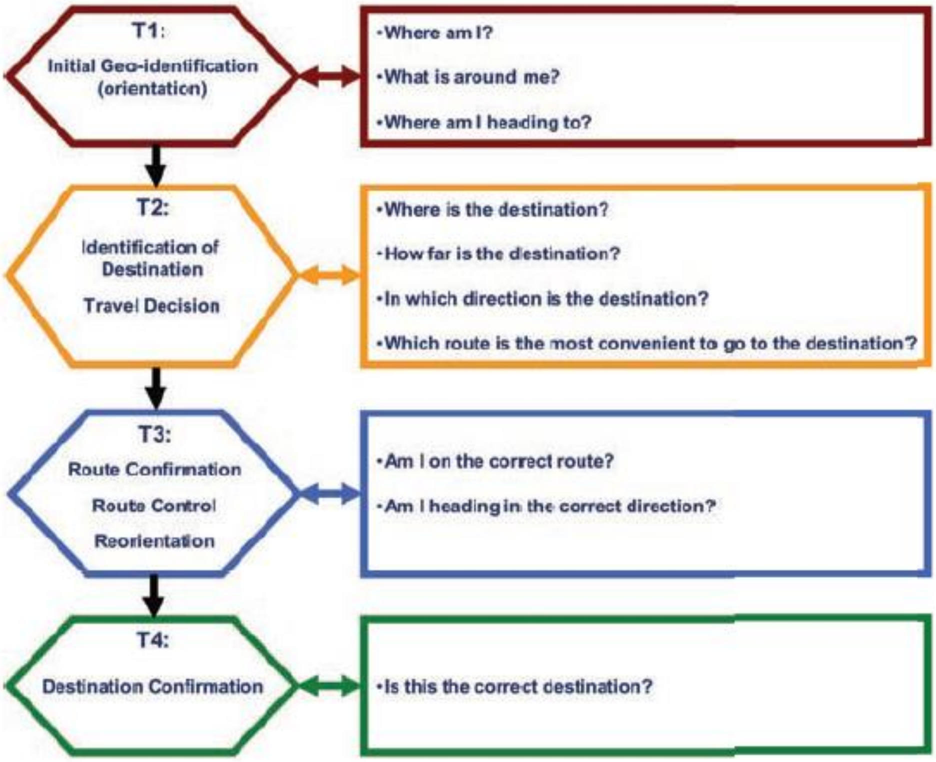


Figure 3.2.1 Orientation and navigation tasks and user questions (Delikostidis, 2011).

Based on the idea of Delikostidis (2011) for outdoor wayfinding and empirical researches, I propose a concise conceptual model of indoor wayfinding behavior by specifying 5 particular tasks and related user questions:

1. Initial Geo-identification
2. Identification of destination
3. Route planning
4. Route navigation
5. Destination confirmation

Every task is illustrated below by related user questions and a detailed description.

Task 1: Initial Geo-identification
Identifying the origin (current location) is the first step in finding the way to the destination. The goal of this first user task is to orient himself/herself and to determine where he/she is. A positioning system can read the location by coordinates, while for human beings, to define a position inside a building is a cognitive process which requires global knowledge of the environment, i.e. defining one's position by looking around and linking the surroundings . In addition, it is necessary to be aware of the floor information, next to the planar information for indoor navigation as most of the buildings have multiple floors.

The main questions that users may want to figure out during this task are:

- Where am I?

- How many floors has the building?
- Which floor am I?
- What is around me?

Task 2: Identification of destination
After acquiring the knowledge of the origin, the next task is to establish the location of the destination. The goal of this task is to get the target knowledge and to prepare for planning the preferred route. It is impossible to start planning the route without the information of the destination. Furthermore, users can read some useful information from the given destination. For example, if the destination is 7-119, users may realize that they should move to floor 7 first. The major questions that users may have are:

- What/where is the destination?
- Which floor is the destination?
- Which direction is the destination?
- How far is the destination?

Task 3: Route planning
After identifying the locations of origin and destination, users start designing the route for connecting them. The goal of this task is to select the ideal way to reach the destination. Usually, there is more than one possible route to the destinations and the user chooses the best route considering his / her own preferences and reality. It could be easiest/fastest/shortest way (Zlatanova, et al., 2014). The major questions that users may want to figure out are:

- How many possible routes go to the destination?
- Where and how I can move from one floor to the other?
- Which navigation strategy am I going to follow?

Task 4: Route navigation
Once users have planned the route or decide how they want to reach the destination, they start to execute their route planning decision through following the planned route, i.e. navigating. The goal of this task is to confirm whether they are locating the right floor, whether they are heading into the correct direction, and avoid missing turns and mistakes. If users get lost, they have to reorient themselves. If they are always in the right track, they keep moving until they are arriving at the destination. The major questions that users may want to figure out during this task are:

- Where am I? /Am I on the correct route? Where am I? / Am I on the correct floor?
- Am I heading in the correct direction?

Task 5: Destination confirmation
When users believe that they have arrived at the destination, the last task of their indoor wayfinding is to verify that the current location is the correct target. The question that users want to figure out during this task is:

- Is this the right destination?

3.3. Test hypothesis

In chapter 2, several existing navigation aids have been introduced, such as maps, signs, images and textual/audio instructions. To reach the objective of this research, which is to explore the role of maps in indoor wayfinding in combination with other navigation aids, such external tools should be embedded into this model. In the embedded model, possibly used external aids for every wayfinding sub-task are listed (see Figure 3.3.1). Maps could be floor-plans hanging on the wall, handheld indoor maps print on paper, digital maps, 3D maps and digital maps with a positioning system. "Images" refer to photo navigation with arrows. Signs include the number plates identifying rooms and offices as well. Below, the model also can be called hypothetical user scenario, is described in somewhat more detail is described in somewhat more detail.

Task 1: Initial Geo-identification

When people are at a certain place inside a building they have never been to before, they try to identify their position at first. They start to look around to find some clues about where they are. They notice the things around, what is in their left hand, what things are on the right and estimate how many floors the building has. They may recognize which floor they are in through observing signs. Furthermore, they would like to check where the stairs and elevators are so that they can move to other floors.

If there are indoor maps available, they tend to use the maps to identify where they are through observing what things or objects are around, searching for easily recognizable features in reality and then matching this information to the map to determine where they are. Because indoor maps indicate the number of floors, people may get to know the number of floors easily and choose the map which is for the floor that they are on at first. Many buildings provide visitors with public maps, like floor plans hanging on the wall on every floor and "You are here" maps. People may also make use of them to identify their location. But if there is an indoor navigation app with a positioning system, people may open their smartphone and the app to locate themselves, by the location that will be shown on the map displayed on screen. They will look around to check whether this the right location.

Task 2: Identification of destination

When people have identified their position, the next step is to find out where the destination is. They are supposed to know the room number or name or function of the room. From the given room number, they can recognize which floor the destination is on. Then, people can estimate the approximate location of the destination through observing the signs around them and/or the room numbers.

They may look at the map which presents the floor on which the destination is located as well and find/search the room number or room name on the map.

Some indoor wayfinding applications have textual instructions and images and people also can browse the whole textual instructions and to determine the position of the destination through drawing a mental map.

Task 3: Route planning

Once people know where their position and destination are, they will start thinking about how to move to the destination from the origin. If the destination is on the same floor as the origin, people would like to determine in which direction they should head firstly. If the destination is on a different floor, they tend to first plan the route to elevators or stairs. They can also look for signs to plan the route. For example, they may try to search for the signs of stairs or elevators if they need to change floor.

Maps are another possible tool for planning the route. As people already know their location and destination, they can connect the two points on maps. If the two points are on different floors, people may try to find the route to stairs or elevators, then connect the stairs and the destination on another map. More than one solution can be found and people may want to choose the path according to their preferred strategy. Some like the shortest way and others prefer the easiest way.

The alternative for planning a route can be photo navigation and textual instructions. Some indoor navigation apps only provides images with arrows and instructions to show the way to the destination. Individuals can rely on these tools for following the route and, basically, their plan is just to do that, instead of them actually planning the route themselves.

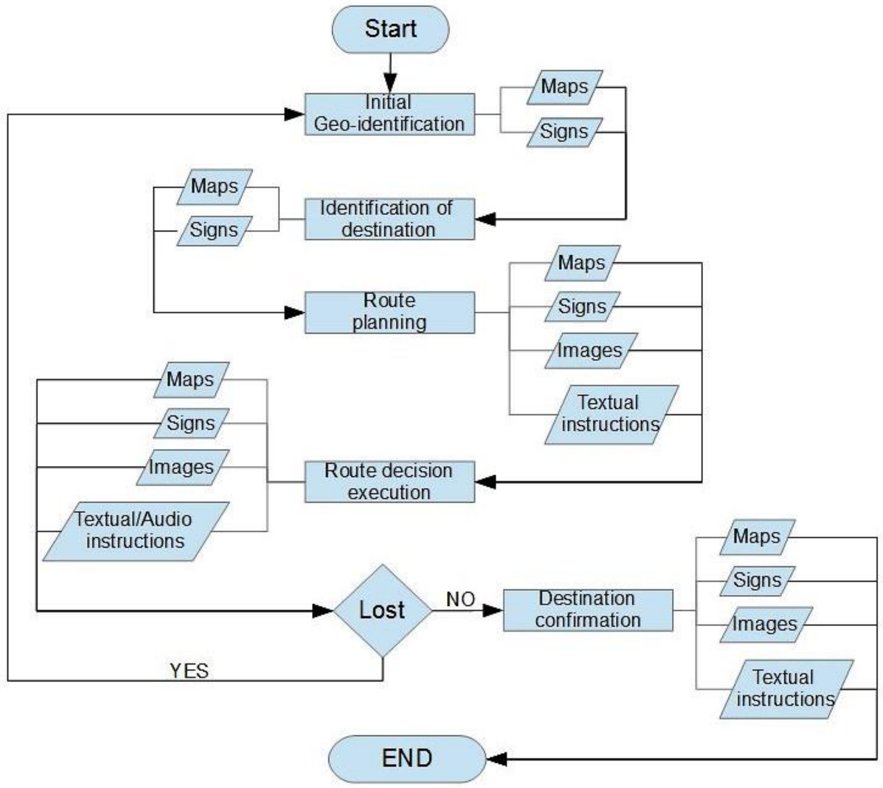


Figure 3.3.1 Conceptual model of indoor wayfinding

Task 4: Route navigation

To execute the wayfinding decision, people may follow the signs until they reach the destination. When they are located in places without signs, they could try to check the number plates nearby, find some disciplines and estimate the direction of the destination. They may return to the last place with signs and plan the route again when they get lost.

If maps are used to make the decision, then they start following the planned route on the map from the origin. During the wayfinding, they can check whether they are in the right direction and on the right route by matching the surroundings with the map. After they arrived on the floor of the destination, they will ensure that the floor is the one on which the destination is located. Then the map of destination floor will be utilized to guide the way. If they find they are lost, they will reorient and plan a route again.

When images are chosen to be the navigation aid, people would like to compare the photo with what they see and follow the instructions. For textual instructions, people also follow the instructions step by step. But when mistakes are made during wayfinding, they may want to change the navigation tools to maps or signs and reorient.

Task 5: Destination confirmation

When they think the destination is almost there, they might confirm the destination through a number plate or room name. If there is no obvious clue that shows that this is the right destination, they may try to observe the surroundings and relate them to the map or the description of the destination on images and in textual instructions.

3.4. Summary

This chapter built a conceptual model of indoor wayfinding based on the idea of the PhD thesis of Delikostidis (2011). The conceptual model is constituted of 5 user tasks and each task is described in a detailed way, focussing on several user questions. This model should make it easier to study the indoor wayfinding behaviour systematically in the later works of this research. To reach the objective of this research, possible navigation tools are linked with the conceptual model. A hypothetical use scenario was raised to this end as well. To validate the model, user research is the way applied in this research.

4. RESEARCH METHODOLOGY

4.1. Introduction

To get the answers to the research questions formulated in Chapter 1, a suitable methodology has to be selected. This chapter briefly describes several quantitative and qualitative methods that have been applied in previous map use research at first. For the goal of this research, with the emphasis on finding out whether, and, if so when, where and how participants make use of indoor maps, a combination of quantitative and qualitative methods appears to be more appropriate. The following sub-sections present the methods selected: online survey, eye-tracking, think aloud method and interview. This chapter ends with an illustration of the combined method with multiple research techniques.

4.2. Methods of user research

User research is regarded as a feasible and suitable approach for understanding user behaviors, motivations, and demands through observing user experience, task analysis and other feedback methods. From previous user studies (Puikkonen et al., 2009; Rehrl et al., 2014; Vanclooster et al., 2014), the methods applied can be categorized into two types: quantitative and qualitative techniques. The quantitative research proposes to measure, quantify and count study issues identified during user research. Such research results can give scientific evidence for explaining research questions. Qualitative research is more suitable for interpreting cognitive processes in problem-solving (van Elzakker, 2004). With the technical developments, a number of techniques can be utilized for quantitative and qualitative research. Such as focus group, questionnaire, interview, video-recording, think aloud, online survey, and eye-tracking. Through these techniques, diverse types of data can be collected from user experiences. As the objective o is to figure out the role of map displays in indoor wayfinding in combination with other navigation aids, this research is exploratory and inductive in essence. So, a mixed methods approach centered round the mobile eye-tracking system will be employed. Other research techniques applied are the thinking aloud method, individual interviews, and an online survey. I choose the ITC building as the place for user testing. A limited number of participants will execute wayfinding tasks from a specified origin to successive destinations inside the building with various navigation aids, including indoor maps, images, and textual instructions. In the following sections, the applied methods for this research are discussed separately to justify their selection.

4.3. Online survey for pre-selecting participants

An online survey is a structured questionnaire that users can complete over the internet generally through filling out a form. Nowadays, plenty of websites and tools are available to do the survey at little cost but can reach a large number of audience. An invitation to participate to the target audience can be sent out through email, a web-link and social media.

In this research, the online survey focuses on collecting background information of volunteers beforehand so that eligible participants can be pre-selected based on the outcomes of the online survey. An important reason for choosing the online survey for selecting participants is its convenience for analyzing the results. Compared to the traditional questionnaire on paper, the data of an online survey are stored in a database and the survey tool generally provides some level of analysis of the data in addition to the review by the researcher. It is easier to collate the answers of the questions and get a quantitative analysis automatically.
I used Survey Monkey to do the online survey. The survey questions were created based on the discoveries from the literature review and related to the sub-questions about user tasks. The questions are about personal attributes of volunteers, prior experience with indoor wayfinding, sense of direction and

spatial abilities. This information should give clues for selecting participants and dividing them in test groups of a similar composition.

4.4. Eye tracking

With the development of more accurate and performant eye trackers, these systems became increasingly popular in the field of human interaction (Lee et al., 2015). The eye-tracking system is used for recording eye movement data of participants. The psychologist Ellard (2009) said that "your eye movements contribute to your perception of the world" and he stated that what would our eye movements reflect was the purpose of our looking, the strategies that we were using to search for answers, rather than the biggest, brightest, or flashiest in a visual scene. In the analysis of eye-tracking systems, eye movement data are described by fixation count, fixation duration, and fixation pattern. The focus of eye fixation and its duration can address what, where, how often and how long people look (Çöltekin, Heil, Garlandini, & Fabrikant, 2009). The eye-mind hypothesis also indicates that cognitive processes can be analyzed by the aspects of the gaze during the task (Bergstrom, Olmsted-Hawala, & Jans, 2013). Razeghi (2010) investigated the usability of eye tracking as a user research technique in geo-information processing and the results indicated that eye tracking indeed can provide information about 'human cognitive aspects' in selecting salient objects. In addition, P. Viaene, Ooms, Vansteenkiste, Lenoir, & De Maeyer (2014) also gave evidence that eye tracking can provide qualitative and quantitative data which can be used to identify indoor landmarks through conducting a user study.

As discussed in chapter 2 and chapter 3, indoor wayfinding is a spatial cognitive process and scan paths address where, what, how often and how long people look at navigation aids. So it is suitable to apply an eye tracking system to observe the indoor wayfinding behavior. Lee et al. (2015) used eye tracking to explore the use of the interactive map for the library building as well.

There are two main eye tracking systems: mobile and stationed. Stationed eye-trackers have been in use for a long time already but mobile eye tracking systems only since recently. Originally, the mobile eye-tracking systems suffered from calibration problems (Delikostidis, 2011) but, because of technological developments, the current generation of mobile systems became very suitable for user research in the geospatial domain. In this research, a mobile eye tracker is used for recording the eye movement data of participants during an indoor wayfinding experiment. The recorded eye gaze videos from the mobile eye tracker are transferred into both quantitative and qualitative data, such as the task completion time, the number of hesitations, the number of errors, and the pattern of eye fixations. These results can reveal that how people navigate and orient themselves how they use the indoor maps or other navigation tools and what are their path strategies and indoor wayfinding patterns.

4.5. Thinking aloud

In order to capture a more detailed wayfinding performance of the participants, thinking aloud is an important technique for collecting their thoughts and considerations while executing wayfinding tasks. Participants are required to speak aloud their thoughts, whatever jumps into their minds. Their voice is recorded with the eye gaze video and these recordings are used to interpret the user behaviour. With the help of the think aloud recordings a researcher may find out, for instance, why a participant looks at a navigation aid for a longer time: is that because he / she is deriving information from the navigation aid or is it because the navigation aid confuses him / her?

Among the methods of user research, thinking aloud now is one of the most popular techniques. A number of articles reports on the employment of thinking aloud in user research(Kato & Takeuchi, 2003; Viaene et al., 2015; Wenig, Schöning, Hecht, & Malaka, 2015). The verbalization is helpful to understand the cognitive behavior and exposes the information stored in the working memory of participants at critical moments. (Lundgrén-Laine & Salanterä, 2010). Besides, thinking aloud is the method easy to execute as no extra equipment is needed except a microphone and participants do not need to memorize their thoughts as they speak out immediately whenever they have an idea (van Elzakker, 2004). However, of course, thinking aloud has several drawbacks as well. Van Elzakker (2004) presented the major disadvantages of the think aloud method: time-consuming on collecting data and analyzing the verbal protocols; incomplete protocols as participants do not voice all their thoughts; it may be challenging for participants to translate all the thoughts into words. To avoid these problems, the verbal protocols are analyzed with eye gaze videos together.

4.6. Posterior - survey: Individual Interview

After their execution of the wayfinding tasks, the researcher interviews the participants about their wayfinding experience, with emphasis on the use of indoor maps or other navigation aids. The interview is structured with questions which are related to the research questions.

The conversations are recorded in audio files by voice recorder and they can be used to supplement the eye gaze videos. Interviewing participants after the wayfinding test allows the researcher to probe for details and reasons behind the wayfinding decisions and strategies.

4.7. Summary

In this research, a combination of methods and techniques of user research is applied, centered around the eye tracking and think aloud methods. To acquire the background information, participants are asked to complete an online survey in Survey Monkey. During the wayfinding experiment, test persons are required to wear the eye tracker and think aloud for recording their behavior. After the task execution, the researcher interviews the participants face to face about their experiences with the wayfinding tasks, the use of navigation aids and their opinion on indoor wayfinding maps or applications. The next chapter will report on the execution of the experiment.

5. EXPERIMENT: INDOOR WAYFINDING IN THE ITC BUILDING

5.1. Introduction

The goal of this experiment is to identify the use of maps in indoor wayfinding in combination with other navigational support like signs, numbering systems, image and textual navigation instructions, by figuring out whether, and if so, when, how and where users want to make use of indoor map displays. In this experiment, participants are requested to plan the routes and navigate themselves from predefined origins to destinations in the ITC building which should be unfamiliar to them. This chapter introduces the set-up of the experiment regarding to the test persons, test environment, test materials, test techniques and test execution.

5.2. Test participants and their division into three test groups

Individuals were eligible to participate in the indoor wayfinding experiment if they are unfamiliar with the ITC building and speak English fluently. Test persons were invited through Email and Social media. The invitation is in Appendix 1. They were asked to complete an online survey if they were willing to participate (see Appendix 2). Eighteen test participants (TP's) were selected from 25 volunteers based on their schedule and the outcome of the online survey. The participants' ages range from 18 to 44 years old. The majority of participants were of the age of 25 to 34. TPs had various backgrounds and different levels of education and sense of direction. Seven women and eleven men took part in this experiment. They were from different countries. The user profiles are presented in Table 5.2.1 and directly related "spatial" characteristics of TPs are shown in Table 5.2.2. Most of them had already visited ITC before (once or twice) but none of them was really familiar with the structure of the ITC building.

Part of the participants was kind of confident or very confident to find their way inside buildings on their own, while the rest of them was neither confident nor not confident. Almost all of them get lost in unfamiliar indoor environments sometimes, excluding TP3 and TP 12 who never get lost inside an unknown building. All TPs have experiences with maps or map apps on smart devices with different frequency. When traveling to unfamiliar buildings, almost everybody prefers using signs as the navigation tool. Public indoor maps and number plates are utilized by a small number of participants to help them in indoor wayfinding. Few of them try to use indoor wayfinding applications Only TP 10 use Google Maps for indoor navigation. In addition, 3 participants would like to ask people to find their way. Figure 5.2 1 shows the percentage of possible external aids used by TPs.

Table 5.2.1 General profiles of TPs

Nr.	Group	Age group	Gender	Origin	Education Level	Profession
TP1	1	25-34	Male	Brazil	Bachelor	Solider
TP2	1	25-34	Female	China	MA	Agrometeorology
TP3	1	25-34	Male	China	MSc	Meteorology
TP4	1	18-24	Male	Nepal	High School	Computer science
TP5	1	35-44	Male	Netherlands	Bachelor	Applied Physics
TP6	1	14-18	Male	Netherlands	VMBO	Sports and Security
TP7	2	35-44	Male	China	Bachelor	Meteorology
TP8	2	25-34	Male	Oman	Bachelor	Geography
TP9	2	18-24	Female	China	Bachelor	International business
TP10	2	25-34	Female	Netherlands	MSc	Communication Studies
TP11	2	25-34	Male	Slovenia	Bachelor	Mechanical engineering
TP12	2	25-34	Female	Brazil	Bachelor	Electrical Engineering
TP13	3	18-24	Male	Nepal	Bachelor	Sustainable Energy Technology
TP14	3	25-34	Male	Netherlands	MSc	Industrial Design Engineering
TP15	3	25-34	Female	Mexico	Bachelor	Engineering
TP16	3	25-34	Female	Indonesia	Bachelor	Pharmacy
TP17	3	18-24	Female	India	Bachelor	Engineering
TP18	3	18-24	Male	China	Bachelor	Graphic design

Participants were also requested to answer the questions of Santa Barbara Sense of Direction Scale (see Appendix 2). The researcher summarized the answers and ranked the sense of direction of TPs from 1 to 6 taking into account every question. The bigger number, the better the sense of direction. The participants with a good sense of direction tend to be more confident in avoiding to get lost inside buildings. Furthermore, most of TPs have good spatial abilities except TP 4 who has a poor spatial ability. To find out that how participants behave with different test materials and to achieve comparative task analysis, 18 participants were divided into 3 groups with a composition which is as similar as possible. The criteria to assign test persons to each group includes the general profiles (see Table 5.2.1) and spatial characteristics (see Table 5.2.2). Every participant was assigned a group number like 1, 2 and 3 in Table 5.2.1 and a test number like AX, BX and CX in Table 5.2.2 to identify which group they belong to easier.

Table 5.2.2 “Spatial” characteristics of TPs

Nr.	Test Number	Sense of direction	Confidence of finding the right way	Frequency of using maps
TP1	A1	4	Very confident	Daily
TP2	A2	2	Neither confident nor not confident	5-10 times per year
TP3	A3	5	Very confident	Never
TP4	A4	3	Neither confident nor not confident	5-10 times per year
TP5	A5	5	Somewhat confident	Weekly
TP6	A6	5	Somewhat confident	5-10 times per year
TP7	B1	2	Somewhat confident	Weekly
TP8	B2	6	Somewhat confident	Weekly
TP9	B3	2	Neither confident nor not confident	Weekly
TP10	B4	3	Somewhat confident	Weekly
TP11	B5	6	Neither confident nor not confident	Daily
TP12	B6	4	Slightly confident	Weekly
TP13	C1	3	Neither confident nor not confident	Weekly
TP14	C2	6	Very confident	Daily
TP15	C3	5	Very confident	Weekly
TP16	C4	6	Very confident	Monthly
TP17	C5	4	Somewhat confident	5-10 times per year
TP18	C6	3	Somewhat confident	Daily

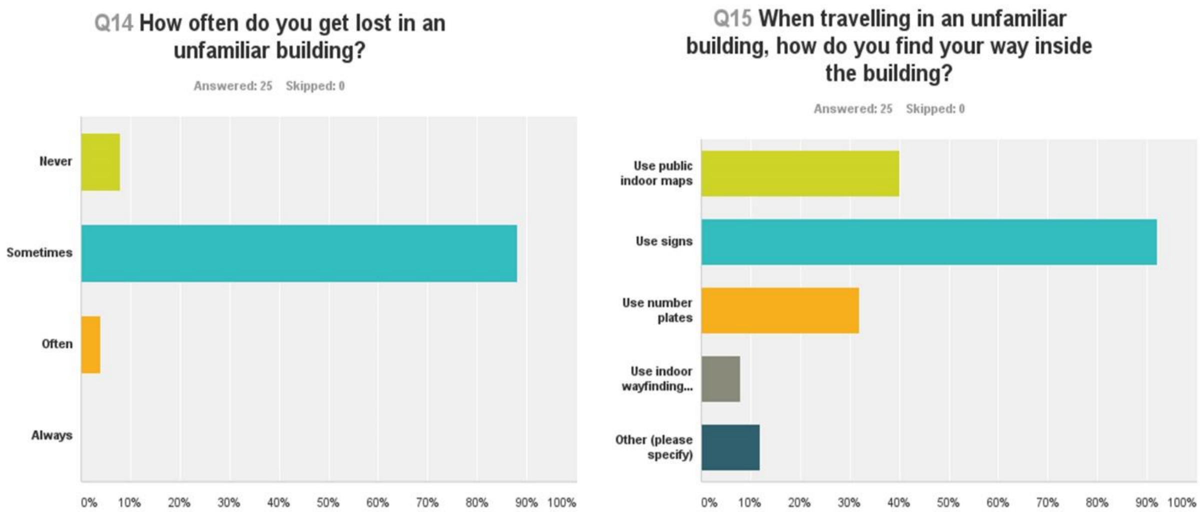


Figure 5.2.1 the responses from participants about their previous indoor wayfinding experience

5.3. Test environment

The ITC building was the place where test persons executed their wayfinding tasks. It has 6 floors and the structures of each floor are a little bit different. In this building, there are offices, classrooms, meeting rooms, study rooms and special purpose rooms like a restaurant, library etc. All rooms have a number with the format x-0yy or x-1yy. "x" refers to the floor number (0 = ground floor, 1 = first floor, 2 = second floor, etc.). When participants enter the building or move up the stairs, they should go to the left for all rooms with a number starting with "1" and go to the right for all rooms with a number starting with "0". E.g. when people move up the stairs to the first floor, they must go to the right to reach room 1-062. Next to the entrance of each room, a number plate is showing the number of the room and an indication of the nature of the room or the name of the person(s) in the office (if the room is an office). In addition, brown colored signs hanging everywhere on the ceilings or walls with arrows point at room numbers or special purpose rooms. Finally, in the lobbies of every floor (with the entrances to the elevators and the stairs) fire floor plans are displayed on the walls.

5.4. Test materials

As the objective of this research is to explore the role of maps in indoor wayfinding in combination with other means of navigation support, it is not sufficient to do the test only with maps. Participants should be given more alternatives than maps and the common external indoor wayfinding aids mentioned in Section 5.3 above. From previous studies and existing indoor wayfinding applications, indoor maps, turn by turn textual navigational instructions and photo navigation were selected as the test materials in this study. Besides, participants were free to look at the signs and number plates in the building.

5.4.1. Indoor maps

As mentioned in chapter 2, several different representation forms of indoor environments are existing, such as the most common floor plan, Indoor Tubes, Vertical Color Maps and 3D models. Many studies have evaluated different forms of indoor maps and results showed that, so far, floor plans are the most effective (Radoczky, 2007) to represent complex indoor structures as they can decrease the influence of unfamiliarity (Garling et al., 1983) with the environment and improve the users' wayfinding performance most. In addition, most of the existing indoor wayfinding applications make use of floor plan maps as their visualization of indoor environments, like the Schiphol Airport App, Maze Map and Indoor Atlas. Therefore, the indoor maps used in this research are based on existing floor plans. The original digital format of the source data is DWG CAD files. The spatial structure and room numbers of the ITC building are demonstrated clearly on these floor plans. However, they present too many details like the lengths of the walls, the shapes of the windows, closestools and doors. These details are beneficial for architecture, construction workers and other professionals rather than normal people who only are eager to find out their way. In order to build meaningful maps with objects and annotations that users would be able to understand, the original files were edited and generalized for the final representation scale in ArcMap, which includes the selection of relevant architectural structures, geometric simplification, exaggeration of important details, and amalgamation of building parts according to their function. In general, the constructed indoor maps of the ITC building present:

- the spatial structure of environments
- the rooms and their numbers
- the landmarks(e.g. printer, automatic door, and locker)
- the connections to other floors (elevators and stairs)
- accessible and inaccessible areas

The design criteria for creating the simple indoor maps were based on the design of the Schiphol Airport maps (Smolders, 2016) in particular its generalization and symbology. The Schiphol Airport maps are part of the Schiphol Airport App (see Section 2.3.3) In the Schiphol Airport maps, detailed asset objects are transformed into cartographic objects; the asset elements are merged, boundaries are generalized and gaps are filled. Particular areas were transformed into cartographic symbols as well. For instance, a toilet consists of many components, such as stool, sinks, internal doors and internal walls, but none of them provides navigational information to the users. Hence, these areas are presented by appropriate symbols and different colors with other areas. Comparing to the map design of MazeMap and Google indoor maps which just converted the floor-plans into digital version, the design of Schiphol Airport maps tend to be more suitable for ITC indoor maps.

For the ITC indoor maps, all the rooms were generalized into independent polygons and categorized into specified classes based on their functions. Doors and windows were removed. Areas with different functions differentiate in color. A blue color expresses offices, pink serves toilets and elevators are represented in yellow etc. Symbolic icons are utilized to describe landmarks and functional areas like lockers, coffee machines, male/female toilets, printers, and elevators. As this information may help users to locate and navigate themselves, the map should be precise. Figure 5.4.1 shows a sample map of floor 1 of the ITC building and all the maps are shown in Appendix 6. In this way, hard copies of maps of every floor were produced and combined in a booklet at A4.

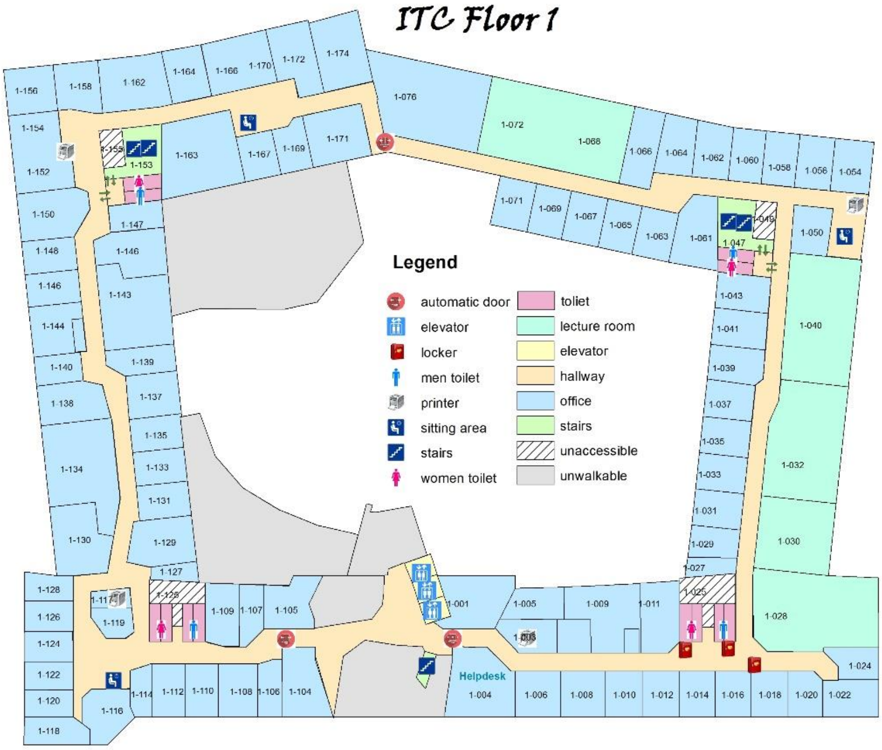


Figure 5.4.1 ITC floor 1 map

5.4.2. Digital maps and simulation of a positioning system

As interactive maps become increasingly popular with the development of positioning systems, it is necessary to test the use of indoor maps with a positioning system as well. In this research, the digital maps are created on the basis of the same data source of paper maps. An artificial positioning system was simulated with the digital maps for exploring the role of indoor maps with a positioning system. This had to be done because the ITC building is not equipped with a real-time indoor positioning technology. The positioning system is composed of two web pages, the controller (http://kartoweb.itc.nl:8080/control.html), and the viewer (http://kartoweb.itc.nl:8080/view.html). Both of them present the indoor maps. The location of the participant and the floor number are shown on the viewer page in the meantime when the researcher assistant clicks the location on controller page. Participants are given a smart phone which displays the indoor maps through visiting the viewer page while the researcher assistant click the location on controller page on the tablet. The real-time location of participants is shown on the digital map by a red dot. Users can zoom in or zoom out to change the scale of the indoor maps.

5.4.3. Textual instructions

Previous studies have given evidence that textual guidance is a simple presentation form for navigation systems because they are easy to create and implement (Gartner & Radoczky, 2005; Wenig et al., 2015). Users can obtain additional helpful navigation information from them. So, in this study, textual instructions were prepared to support the wayfinding tasks. The instructions describe all the steps from the start point to the destination turn by turn. Landmarks are also mentioned to help users to locate themselves. For example, the textual instructions for origin to destination 1 are listed as following:

- Take the door on your left next to the reception
- Turn right and move across the restaurant
- Keep walking to the next door
- Continue walking 20 meters, auditorium is on your right.

5.4.4. Photo Navigation

The photo navigation was designed based on the style of the Eyedog photo navigation system which was mentioned in chapter 2. It shows the direction by pictures with an arrow at every junction, like in Figure 5.4.2.

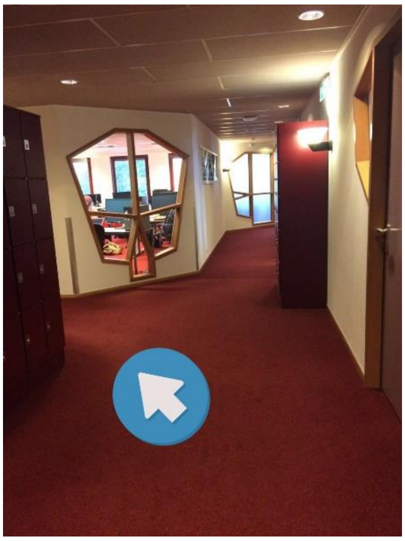


Figure 5.4.2 a picture with an arrow at a junction

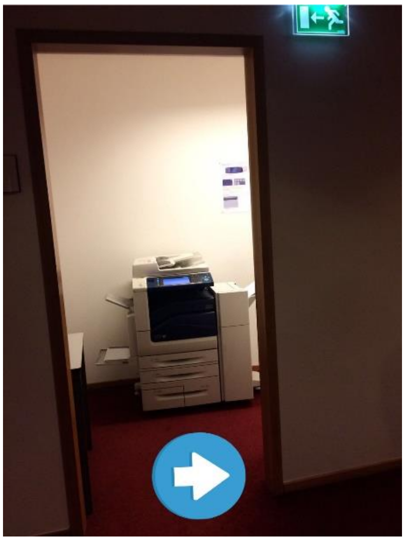


Figure 5.4.3 a picture of a printer with an arrow

Some studies (Viaene et al., 2014) regarded landmarks as powerful wayfinding tools and considered them as the key elements of our mental representation of space, which is central in our ability to navigate (Viaene, Vansteenkiste, Lenoir, De Wulf, & De Maeyer, 2016). Hence, the images of landmarks like coffee machines, doors, stairs and printers (Figure 5.4.3) were provided to participants (in a paper booklet).

5.5. Test techniques

Survey Monkey was used to do the online survey in this research. It is a free online survey tool and provides customizable survey and data analysis functions.

Tobii Pro Glasses 2 is the electronic equipment used for recording the users' eye movements and verbalization during the test execution. For the Tobii Pro Glasses 2, it is the world's smallest, most natural, and easy-to-use wearable eye tracker which is designed for use in the real world ("Tobii Pro Glasses 2 wearable eye tracker," 2015). There are two cameras per eye to identify the reflection of the light source on the cornea (glint) and in the pupils. What is measured eventually are fixations and saccades in milliseconds. Combined with the measurement of the fixations and saccades, the glasses also record a video feed of what the participant is looking at, with a camera in the front of the glasses. It is also possible to use think aloud protocols with the glasses thanks to the integrated microphone. For the glasses to work, a tablet is needed to run the Tobii Pro Glasses 2 Controller software. As the tablet can wirelessly connect with the Glasses at a limited distance (approximately 20 meters), the researcher always carried the tablet and followed the participants during the experiments. In addition, Tobii Pro Lab is the software for analyzing the gaze videos. It provides quantitative and qualitative analysis.

I used a voice recorder to record the interviews. Furthermore, as mentioned at Section 5.4.2., an android smartphone was needed to present the digital maps with real-location and an additional tablet was required for the simulation of the positioning system.

5.6. Execution of the experiments

The experiment consists of three groups:

1. One group with written turn-by-turn directions and photo navigation;
2. One with textual instructions, photo navigation, and a booklet with paper indoor maps;
3. One with textual instructions, photo navigation and indoor maps displayed on a smartphone with a simulated positioning system.

Through comparing the results of the group without maps and groups with maps, it is possible to see whether, where, when and how people use maps, or want to use maps at all, and whether the maps really help people in indoor wayfinding. The textual instructions and photo navigation are presented in Appendix 7, 8 respectively.

In order to investigate the role of maps in indoor wayfinding, the set-up of the experiment had to be designed to be useful to compare participants' wayfinding performance and to respond to the main research questions. The set-up had to reflect as much as possible the real indoor navigation requirements. A pre-defined set of test instructions was organized for participants of each group (see Appendix 4 which is for group 1). For the different groups, participants were given different test materials but the data collection methods were same, eye tracking and thinking aloud, followed by an interview. So the test instructions for 3 groups are same except the description of test materials. During the test, the researcher held the controller tablet and followed the participants at a suitable distance, so as to ensure that the tablet can be connected with the eye tracker and the wayfinding behavior of participants can be recorded. In this set-up, the researcher is also available to help in case of participants encountering unexpected problems. The researcher would not allow to help participants to navigate or use particular navigation aids, but could provide help when the problems with the simulated positioning system of group 3 occur as it might be a technical issue.

During the wayfinding tasks, participants were requested to wear the eye tracker and speak their thoughts loudly. The script for researcher is attached in Appendix 5 and the experiments were executed as follows and:

Following the determined schedule for each participant, the researcher and the participant met at the ITC building at a specified time. The researcher briefly introduced herself to the participant and gave the participants the corresponding text instructions based on the group number. After reading the test instructions, the participants could prepare to start with the wayfinding task. They were given the test materials for the test group they belonged to. Each of them got some time to get familiar with the eye tracker and to get used to speaking their thoughts out loud through the instructions given by researcher and basic practices. Then, the participants were guided to the start point of the wayfinding tasks. After the calibration of the Tobii Glasses, participants began to execute the wayfinding tasks by saying "Ready go!" and the researcher pressed the record button. At first, participants were supposed to orient themselves and to find out about their location. Then, they started to find out where the destination might be. There were 6 successive destinations that participants had to find one by one, meaning that the last task destination became the next task start point in the relay. The wayfinding tasks were designed to cover a realistic range of difficulties like floor changes. There was no time limit for completing the tasks but participants were supposed to be in a hurry. Participants were free to use any of the materials they received or not. Once they recognized the destinations, they had to express that they had reached their goal by stating "Number x, got it!" And then they started to find the next destination, plan the route to it and navigate. When participants finished all tasks, they had to say "Game Over!" and, then, the researcher stopped recording.

After the execution of the wayfinding task, the participants were interviewed about their experiences of finding the way in the building with the help of maps or other navigation tools such as signs and landmarks. The participants were interviewed based on a set of pre-defined questions (see Appendix 3).
To ensure that the experiment could be executed successfully with the test instructions, test materials and the equipment, pilot tests were required to be done before the actual testing. Two pilot tests were carried out with my first supervisor and second supervisor. The first pilot test was for testing the set-up of the experiment for group 2 and the second one was for group 3. The pilot tests took almost 1 hour to complete. So for the actual tests, the interval between two test appointments was set at least 1.5 hours. Through the pilot test, it was also found that the position of the user on the digital maps of the simulated positioning system could not be updated automatically when the user changed floors because the phone lost the Wi-Fi connection. It was discovered that, to avoid this problem, participants were required to reload the website after their arrival at another floor and they were instructed to do so once they wanted to consult the map on the smartphone. They were not instructed to do so when they did not use the smartphone.

The tests were carried out from 24th to 31st of January 2017. All the participants finished the wayfinding tasks successfully. However, most of them sometimes did not express completely their thoughts wayfinding strategies. They just said some key words of their behavior, like "I turned left" and "I take stairs", even though they were instructed to try to describe the process of their indoor route planning and navigation decision making. Moreover, the participants who used the digital maps had difficulty in zooming and moving the maps on screen and reloaded the page several times.

The test outcomes include the recorded videos with eye movement data and think aloud protocols and the recordings of the interviews. The recorded videos can only be replayed with the TobiiPro Glasses Analyser software. The interviews were recorded in audio files. Most of the videos were complete with good quality. However, the recording of participant C4 was incomplete because of one unexpected problem. The gaze sample of A5 and C2 were a little bit low as they move eyes too quickly during the test.

5.7. Summary

This chapter introduced the set-up of the experiment in detail. The indoor wayfinding experiment consisted of three groups which received different navigation tools. Each group had 6 participants who were not familiar with the ITC building. Group 1 did the test without the provision of indoor maps. Printed maps were available for group 2 and group 3 could see their location digital maps displayed on the screen of a smartphone. During the wayfinding, participants were required to wear the eye tracker for recording their eye movement data and verbalizations. The researcher interviewed all participants after the test. The analysis of test results is discussed in the next chapter.

6. ANALYSIS OF RESULTS

6.1. Introduction

Chapter 5 has demonstrated the set-up of the indoor wayfinding experiment. This chapter processes the outcome of the recorded data of the user tests and the interviews. These data are analyzed qualitatively and quantitatively related to the research objectives and research questions. The wayfinding performance and the aid usage especially the map usage are explained in the subsections. Furthermore, a verification of the conceptual model as presented in chapter 3 is done based on the analysis. The last subsection collates the outcome of the interviews with all participants question by question.

6.2. Resulting test data

The data recorded in the mobile recording unit was transferred to the Tobii Pro Lab software for analyzing the eye movement data. This software can replay the recordings and allows different quantitative and qualitative analysis (see Figure 6.2.1).

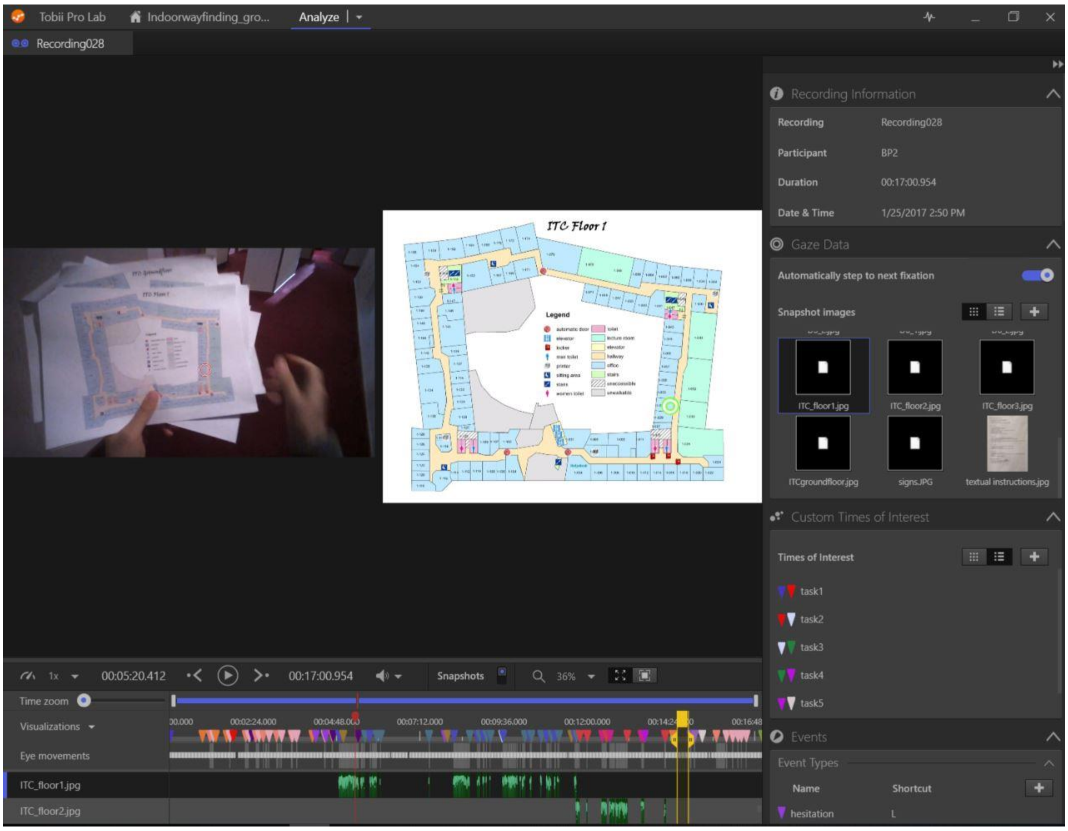


Figure 6.2.1 Tobii Pro Lab eye tracking data analysis software screenshot

The task completion time, counts of mistakes, numbers of hesitations and aid usage were measured for every test person for all tasks. These statistics are computed as custom events through classifying the behavior of participants in the analysis software. When a participant said something like "No x, done.", it meant the completion of task x. When a participant made a wrong turn or executed a different route decision compared to his / her original planning, it was regarded as a mistake. When he/she stopped walking and thought about which path to go or when he / she planned his / her route again through navigation aids, it was considered a hesitation. The aids usage was calculated from the eye gaze data, which were mapped onto the snapshots automatically with the real-world mapping function. These snapshots are the pictures of navigation aids, which include the indoor maps, photo navigation, textual instructions, and signs. When participants focused on these navigation tools, their eye fixations and attentions were mapped onto the snapshot. The counts and duration of aids usage were calculated from the fixations and attentions on snapshots. Also, the snapshots could be used for generating visualizations of eye gaze data, like heatmaps and gaze plots. The locus and modality of eye movement data can be analyzed from the heatmaps and gaze plots. In this research, heatmaps and gaze plots of map usage were created for analyzing the pattern of eye movement about the participants' map usage.

Through a qualitative analysis, the video recordings with the eye gaze data and oral thinking aloud were interpreted to answer the research questions and to validate the conceptual model presented in Chapter 3, while studying how participants behaved in every wayfinding task. Furthermore, possible reasons for the choice of particular navigation aids, mistakes and hesitations were investigated.

6.3. The wayfinding performance

All the participants were required to reach the same six destinations one by one during the wayfinding experiment. They all completed the wayfinding tasks in distinct performance. The outcome of analysis was organized according to the task, participant number and group number as the participants were divided into three groups with diverse test materials. The test persons of group 1 did the test with photo navigation and textual instructions only. Besides the test materials of group 1, group 2 participants had the support of paper indoor maps as well and group 3, instead of the paper maps, had a smartphone displaying digital indoor maps with a simulated positioning system.

Table 6.3.1 Wayfinding per groups

	Average of duration (s)	Minimum of duration (s)	Maximum of duration (s)	Hesitation(n)	Mistake(n)
Group1	741.9098	570.6	1036.341	23	10
Group2	898.3665	600.292	1146.561	21	7
Group3	897.3722	607.385	1315.259	21	9

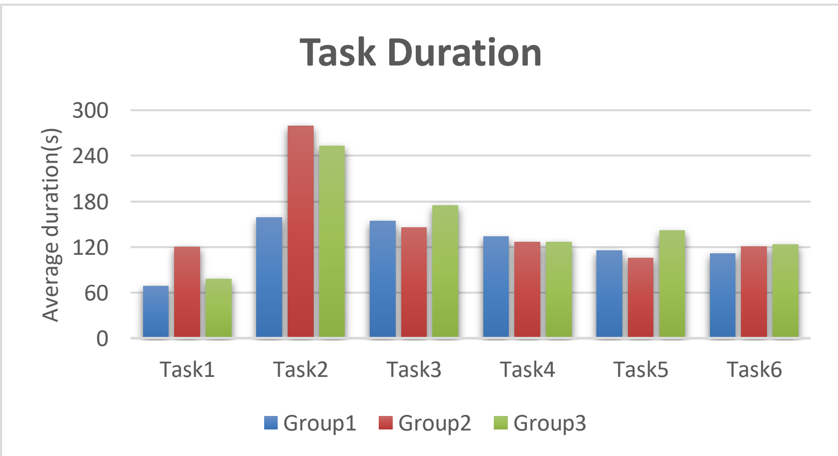


Figure 6.3.1 Average duration per task

At first, to compare the performance of each group, Table 6.3.1 presents the average, minimum, and maximum duration of the complete task execution, the number of hesitations, and the number of mistakes for the three groups. Group 1, which did not use maps, used less time to complete the tasks than group 2 and group 3. The result may be concluded that the people in group 2 and group 3 took more time on reading maps. However, noticeable difference did not appear with respect of the number of hesitations and mistakes for each group.

When it comes to the completion time of each task, figure 6.3.1 shows the average duration per group per task in seconds. From the chart, it can be found that task 2 was the most time consuming task for all three groups because the destination of task 2 was in a secluded place and participants had to change floors for the first time. Some test persons got lost on the way to the stairs. The participants of group 2 and group 3 spent more time on task 2 than group 1, some of them lost the time on wrong turn while others cost more time on consulting maps. Task 1 was the easiest one for all participants, but group 2 used almost twice the amount of time than the other groups to complete it. For the rest of the tasks, there was no remarkable time gap between the three groups. The difference were greater for the first two tasks, which may be concluded that people took diverse time on understanding the navigation tools or the structure of the buildings in the beginning. Once they became familiar with building, it was easier out with the later tasks. In general, group 1 had a faster performance on the completion of tasks. When comparing the results of each task, the three groups performed at the same level with the exception of task 2. Considering the results above all, it seems that maps did not show an apparent influence on improving the wayfinding performance even though they did provide help in some extent in this experiment.

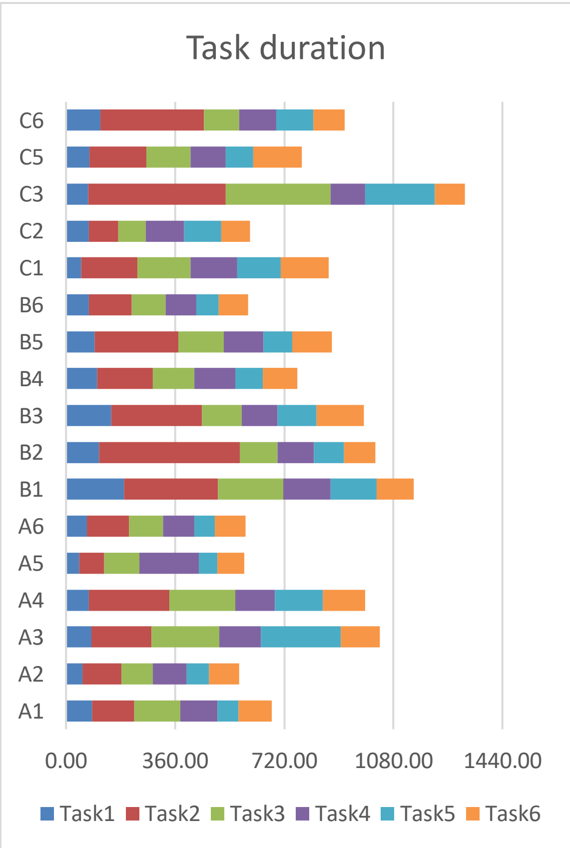


Figure 6.3.2 Duration of every task for all participants

To study the performance of each test person in each task, the aid usage and task completion time were measured for all participants. Figure 6.3.2 shows the duration of the execution of each task for every participant, and the aid usage of all test persons is demonstrated through Table 6.4.1. Because the recording of participant C4 was incomplete, so the data cannot be interpreted. From Figure 6.3.2, it also can be seen that task 2 was the most difficult task for most of the participants. Also, most of the mistakes were made during the completion of task 2. Task 1 was the easiest task for every participant. Participant B1 used more time on task 1 than others as he took more time with talking out loud his thoughts. Most participants finished task 4, 5 and 6 very quickly and did not make any mistake. Especially for task 6, all participants performed very well as they said the last destination is the start point again and they remembered the route back. Most of them did not utilize any navigation tools for task 6. Through observing the video, the possible reason is that they already got familiar with the structure of the building.

6.4. The aid usage

Overall, photo navigation appeared to be the most popular navigation aid that participants would like to use, as 13 participants had checked the images and 5 of them spent more than half of the completion time on photos during the experiment. Most of the people who mainly relied on photo navigation had performed very well because their task completion times were all below the average duration. 7 Test persons followed the textual instructions, but they needed more time for reading the text and, therefore, had longer test completion times than the individuals who used pictures. For group 2 and group 3, the participants had the chance to use indoor maps. However, out of 12 test persons, only 6 made use of them. Their completion time went over the average time except for B6. Among the other six people, B5 glanced at map once and the other 5 did not look at map once. For group 3, only C3 relied on the maps to find the way, and she took the most time to complete the tasks among all participants. The majority of participants looked at signs for a short time for confirming they were heading in the right direction.

For group 1, all participants made use of photo navigation, participants A1, A2, A5, and A6 took photo navigation as the main navigation tools, and they had a better performance (less completion time for all tasks) than others. Moreover, none of them did not look at the floor plans hanging on the wall and they did not express that it could be better to have a map in their thinking aloud during the test. Participant A2 was the fastest one to finish the tasks. Participant A3 was the person who took the longest time to complete all the tasks in group 1 and needed much more time with the textual instructions because he looked at the photo navigation and the textual instructions at the same time during the experiment. He planned the route going through the complete textual instructions for specific task before he started moving, and he checked the photo navigation to ensure the path was right during the route navigation. He took the most time to reach the fifth destination among all the participants due to a wrong turn on the third floor. He realized that when he could not find the things mentioned in the textual instructions (the locker and printer). Then he checked the photo navigation again through scanning the steps he had walked and found he had to go to the right side. Participant A3 used the textual instructions to plan the route but looked at the photo navigation during the execution. So he checked whether he was in the right way through the textual instructions at first and photo navigation secondly, and that wasted time. What is interesting is that he made a wrong turn with the textual instructions and followed the opposite direction with the planned route for task 3, but he still reached the destination as he read that a printer was near the destination from the textual instructions and he just tried to find the printer. Participant A5 was the one who completed the tasks very quick and spent less time on test materials. He only used pictures to plan the route through scanning all the steps and execute the route decision without the favor of any aids.

Hardcopy indoor maps were available for the participants of group 2. Half of them made use of these indoor maps (B2, B3, and B6). They completed the tasks in different times. B2 paid most time among the three participants because he made three mistakes on task 2. Before moving to the second destination, he found the nearest stairs on the map and tried to reach it. But he did not notice that the access to the stairs was the door on his right side and kept going. Through matching the surrounding room numbers on the map, he was sure that the stairs were around there. Then he went back and found the door to the stairs through the signs. When he arrived at the first floor, he mixed the number of destination 1-119 with 1-019. So he found 1-019 on the map and planned the route. But he did not see the room with number 1-019 when he reached the place, and he finally checked that the destination was 1-119. So he searched 1-119 on the map, located it quickly and got to this destination. Maps provided much help to him for planning the route to the destinations, but his carelessness caused the results. Participant B3 and B6 both used maps for navigating and made the same strategy to destinations. If the destination was on a different floor, they went to the right floor at first and then located the destination on the corresponding floor plan map. They both planned the easiest path to destination 2: they chose the stairs in the lobby which they memorized from the start point rather than looking for the nearest stairs. However, participant B3 paid more time on reading maps to recognize the location of destinations and to plan the route. Participant B6 only relied on the indoor maps for completing the tasks, and she accomplished very well. She could make a choice very quickly whenever she hesitated at a decision point. What is important is that she had never been to ITC before. Her performance evidenced that she has excellent map reading skills and sense of direction as her background.

Table 6.4.1 Aids usage for all participants: the percentages means the proportion of the total task time that participants actually looked at the navigation aids

Participant	Aid usage						Hesitation	Mistake
	Photo navigation	Textual instruction	signs	Maps	Maps with positioning system	Test duration		
A1	61.80%	--	0.70%	--	--	677.8	6	5
A2	62.60%	--	1.00%	--	--	570.6	1	
A3	12.40%	42.20%	--	--	--	1036.34	3	1
A4	8.50%	8.90%	0.60%	--	--	986.3	6	4
A5	11.00%	--	0.50%	--	--	587.14	5	
A6	67.40%	--	--	--	--	593.28	2	
Average(Group1)	37.30%	25.60%	0.70%			741.91	3.8	3.3
B1	29.60%	--	6.90%	--	--	1146.56	4	2
B2	--	--	2.30%	25.80%	--	1020.95	3	3
B3	3.90%	--	0.60%	13.80%	--	982.74	5	
B4	30.70%	20.80%	1.60%	--	--	762.8	3	
B5	22.30%	13.80%	--	1.10%	--	876.86	4	2
B6	--	--	--	30.90%	--	600.29	2	
Average(Group2)	21.60%	17.30%	2.90%	17.90%		898.37	3.5	2.3
C1	20.90%	23.20%	0.20%	--	--	866.85	1	
C2	--	--	--	--	4.80%	607.39	3	
C3	--	7.50%	0.60%	--	47.40%	1315.26	10	5
C5	67.10%	--	0.10%	--	--	777.66	2	1
C6	72.40%	5.80%	0.20%	--	5.50%	919.71	5	5
Average(Group3)	53.50%	12.20%	0.30%		19.20%	897.374	4.2	3.67

To observe how participants use the maps in indoor wayfinding, the eye gaze data of participants who used maps were visualized using heat maps and gaze plots. They were created on top of the maps. In the heat maps (see Figure 6.4.1), different colors illustrate the duration of fixations that participants made within certain areas of the maps. Red indicates the longest time, and green the least, with varying levels in between. Gaze plots (see Figure 6.4.2) were utilized to demonstrate the gaze pattern of the participants who used maps throughout the entire eye tracking session by showing the sequence and position of fixations (dots) on maps. Green dots represent the fixation of B2; red is B3 and B6 is yellow. From the heat maps and gaze plots, it can be seen that participants paid more attention to the destinations and decision points. For example, in the heat map the red fields on the map of the ITC ground floor were mostly within the range from the origin to destination 1. Participants matched the things described on the map with reality, like the doors and dining room. The top left corner of the ground floor map had more fixations because participant B2 got lost at the corner which is near the stairs to the other floors, as mentioned before.

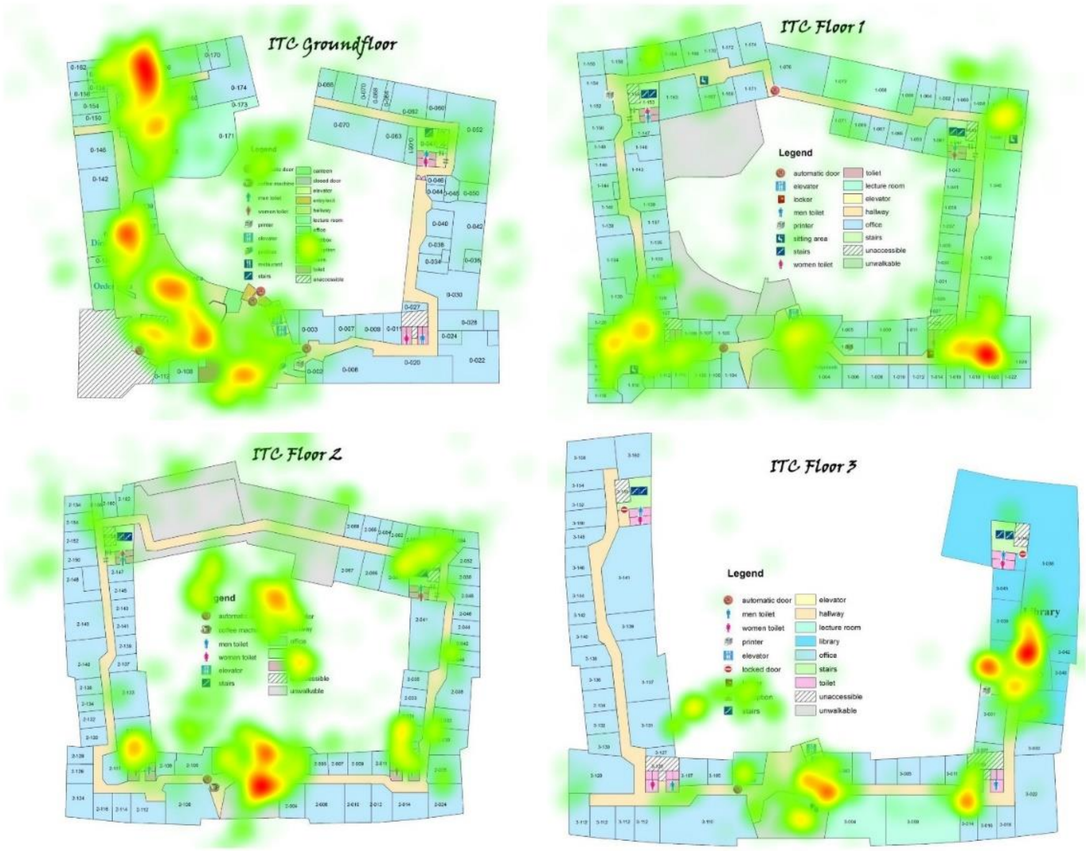


Figure 6.4.1 Heat maps of ITC indoor maps

Participants B3 and B6 used the map when they moved upstairs and arrived on the right floor. At first, they located themselves on the map and looked for the destinations. During the route execution, they looked at the map often at the branches of corridors, which can also be noticed from the heat maps. They made their turns through comparing landmarks, such as the locker or special rooms like the toilet, to ensure that they were in the right direction. From the gaze plots, the mistakes that participant B2 made are visualized again through the locus of his eye movement data (the green dots in the top left hand corner). Besides, the participants who performed better, like B6, focused more on the destinations rather than on other irrelevant points. In contrast, the fixations of B2 are more disperse. It is obvious that the maps of the ground floor and first floor have much more fixations than those of the second and third floor heat maps and gaze plots. The reason could be that the participants became more familiar with the maps and the building.

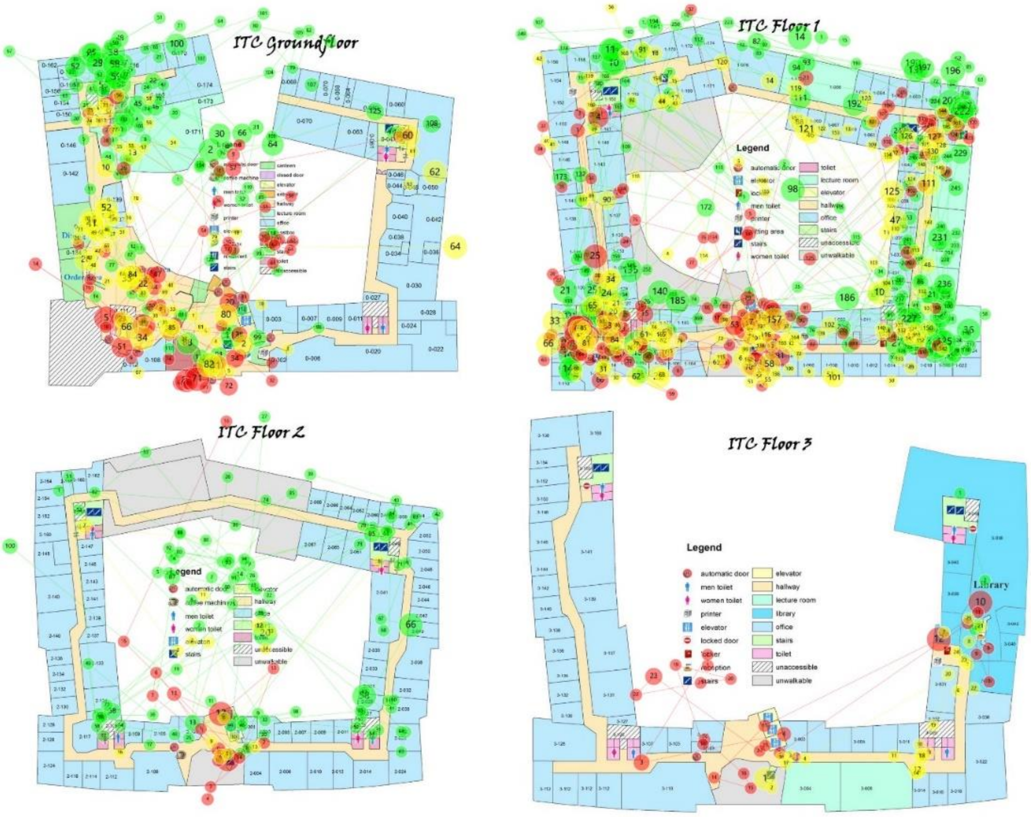


Figure 6.4.2 Gaze plots of ITC indoor maps

In group 3, three participants tried to use the maps with the simulated positioning system, but only participant C3 took the smartphone as the primary navigation tool. Participant C2 did not use any test materials except looked at the smartphone in short time during the experiment. He estimated the location of destinations through room numbers because he understood the format of these numbers (the first number refers to the floor number and the second number indicates at which side of the building the room is located). Once he recognized the approximate location of the destination, he just moved directly and checked the number plates when he thought the destination was near. For task 2, he went to the first floor through the stairs near the start point because he said that he remembered them. He was a little bit confused at the third destination as this room has two numbers (1-050/052). So he confirmed his location on the digital map and noticed the nearest stairs to the second floor. Then he took these stairs rather the recommended one to the next destination, while other participants went to the second floor through the central stairs next to the elevators. Participant C3 planned the route through seeing the complete textual instructions but used the smartphone many times, and she spent much time on finding the locations on the map and checking which way she should head at the decision points like corridors. This caused that she was the one who needed most time for completing the tasks. She made two mistakes for reaching destination 2. First, she could not find the access to the stairs near the Auditorium, but she believed it was around after looking at the digital map. She hovered several seconds around that corner and finally found the sign for the stairs. Another mistake was that she found the destination on the map when arriving on the first floor, but was confused about which direction to go. So she tried to walk several steps to check whether her location was approaching the destination. She also took much time on recognizing the location of destination 3 because of the usability problem as mentioned in Section 5.6. Anyway, she got help from the digital map. For sure, she could have saved more time on operating the application if the functions were better. Participant C6 also tried to use the map application, but he gave up as he could not recognize where he was on the map even though the red dot showed his location. He was confused about photo navigation at first, but became familiar with it after the first task and performed the rest of tasks very well.

6.5. Verification of the conceptual model of indoor wayfinding

In Chapter 3, a conceptual model was built for understanding indoor wayfinding behavior. Navigation tools were part of the conceptual model and raised the hypothetical use scenario. Before every test, participants were asked to execute the sub-tasks, like to orient themselves, to determine where the destination is and to plan the route. Therefore, to validate the conceptual model of indoor wayfinding, the gaze videos were analyzed qualitatively.

Initial identification

Most of the participants who relied on photo navigation and textual instructions did not try to orient themselves before moving, and they just walked following the steps of the test materials once they started the tasks. But there were still several participants who tried to identify their locations before moving. Participant A1 looked around to check whether he was at the origins shown in the pictures through comparing them with the surroundings for task 2 and task 3. B1 only located himself through observing the surroundings at the start point of the first task. He said, "I am on the ground floor and next to the reception." But for the rest of the tasks, he just started walking after identifying the destination. The map users, B3 and B6, located themselves on the map through matching the room number and surroundings for all tasks before moving. Participant C3 also identified her location for task 2 and 3 through the digital maps with the positioning system and checked whether the location that was shown on the screen was the same as her real position. However, they did not check where the stairs or elevators were for identifying their locations.

Identification of destination

Many participants estimated the location of the targets by the room numbers, but they just determined on which floor the destination was instead of its exact location. Participant C2 could determine the approximate location through the format of the room number, like in 1-119, the first 1 refers to the first floor and the second "1" means the left side of the building. A1 and B1 tried to locate the destination by searching for signs to the first destination "Auditorium." Participants B2, B3, and B6 confirmed the locations of destinations by looking for the room number or the special symbol on the maps. For example, the third and fourth destinations are the elevator and the reception of the library respectively. So, they found the targets through diagnosing the symbol of the elevator and the unique color for the library. Participant C3 also tried to determine the location of destinations on the map through room numbers when she arrived at the corresponding floor.

Route planning

A large number of participants planned the routes by photo navigation, see Table 6.2.1. They did that by scanning all pictures which cover all steps to the destination. 6 Participants used textual instructions for planning the route. Similar to the users of photo navigation, they first read the description of all steps to the destinations. Several participants used two aids or more to plan their paths. Participant A4 used both the textual instructions and pictures for planning the route. He read the text first and then checked the pictures again. Participant A1 and B1 planned the route to destination 1 through searching signs and pictures. For the participants who used the textual instructions and pictures, the pre-defined paths provided by the test materials were the easiest for them and the fastest way to go.

Participants B3 and B6 planned the routes using the maps only. At first, they planned the route to the specified floor through connecting their current locations to the stairs along the hallway, then turned to the corresponding floor plan map and linked the stairs to destinations along the corridor. Participant B2 mostly used signs and the numbering system for planning the route, but also looked at maps for task 3 and task 4.

Participants B2, B3, B6 and C6 designed the easiest path to destination 2 rather than fastest one as they remembered the stairs near the entrance of ITC (the starting point). They could go there very quickly and did not spend time on finding the nearest stairs. C2 made a different route decision towards destination 4 with others. He took the nearest stairs, which he noticed on the digital maps, to the second floor rather than going back to the central stairs. He believed that way was the fastest way to the destination.

The majority of participants did not realize which way was the fastest or shortest, they just figured out a way to a destination as quickly as possible and which was the easiest for them.

Route navigation

When participants executed the route navigation, they wanted to check whether they were in the right direction/ on the right floor with different navigation aids. Test persons who made use of photo navigation for planning the route tended to check whether they were heading to the correct direction through comparing the pictures with reality. In detail, they tried to match the recognizable objects shown on the pictures with the real things that they saw, like a printer and locker. For example, participants sought to find the signs and the printer shown and covered by red polygons in figure 6.5.1 in reality, so as to help them to confirm that they are in the right place. Participants who used textual instructions checked directions through matching the objects mentioned in the instructions with what they saw in reality. For instance, A3 searched for the printer and the locker near the library to ensure that he was at the right point.

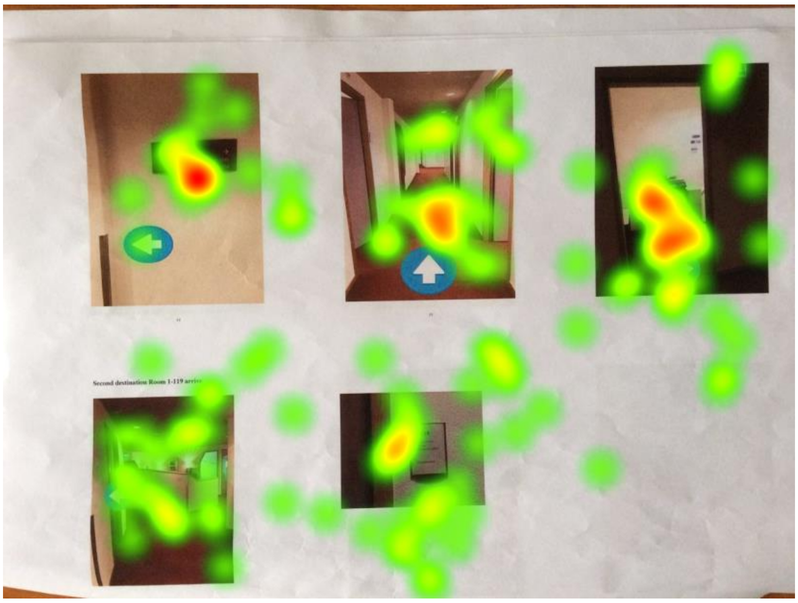


Figure 6.5.1 Heat map of photo navigation: red areas represent more fixations

The interesting thing is that some participants planned the route by textual instructions and executed the route navigation with pictures such as A4, B4, and B5. They explained that the pictures were easier for visually comparing.

The map users confirmed their directions through comparing the room numbers they passed by and the landmarks. They usually focused on the maps when they hesitated at decision points and observed surrounding objects to choose the right corridor to reach the destination. Participant C3 checked her location with the positioning system when she was approaching the destination to ensure that she was heading into the correct way.

Many participants got lost on the way to destination 2. One of the most common mistakes happened on the ground floor where the door near the auditorium leads to the stairs. B1, B2, C3 and C5 thought they should turn right at the end of the corridor. Then they did not find the access to the stairs. Participants B2 and C3 noticed that the stairs should be close to them, so they stepped back and found the door to the stairs in the end. C5 found he made a wrong turn through checking the pictures again and he went back to the door displayed on the picture. B1 did not recognize where the stairs were, but he remembered the stairs in the lobby and went back.
When they got lost, participants used the photo navigation or textual instructions by preference to reorient themselves through stepping back to the last point where they were in the right direction, or they started to ignore the instructions and observed the number plates.

Destination confirmation

If the destinations had number plates, all participants preferred to confirm it by these number plates. Participants who used pictures wanted to double check the destinations by comparing reality with the pictures. If the destinations did not have number plates, the test persons confirmed the destinations by the signs.

In general, the majority of test persons did not do a lot of initial geo-identification and identification of the destination. They usually just followed the provided instructions. However, the participants who used maps were more fitting to the model, and their execution was more similar to the hypothetical use scenario.

6.6. The outcomes of the interviews

To fully understand the indoor wayfinding behaviors of participants with the navigation aids, they were asked to take part in an interview after executing the tasks. Through these structured interviews, participants expressed their experiences, satisfaction about the provided navigation aids and opinions on the indoor maps and indoor wayfinding applications. Moreover, their suggestions for the improvement of indoor wayfinding applications were collected. As mentioned in chapter 2, audio instructions are also regarded as an indoor navigation aid. However, in this experiment, it was impossible to provide spoken instructions to test persons due to the technical problem of not having available a real indoor positioning system. Therefore, the test persons were asked about the usefulness of audio instructions as a component of indoor wayfinding applications as well. In this section, the answers from all participants can be summarized as follows:

1. How was the indoor wayfinding tasks completion? Were the tasks difficult to complete?

Overall, participants agreed that the tasks were not hard to finish except participant B2. He stated that the tasks were a little bit difficult as he got lost twice on the way to destination 2. B1, B4, B6 and C3 indicated that they were somewhat confused about task 2 but the rest tasks were considered to be easy. C3 commented that it was challenging in the beginning because she had never been in the ITC building and was not familiar with the navigation tools. After reaching the first three destinations, she felt more confident to complete the tasks as she became slightly familiar with the structure of the building and understood the navigation tools.

2. ***Did the navigational tools and materials you received from me help you a lot? Do you think they presented the information you need?***

All test persons believed that they got much help from the provided test materials. A3 said that he could not find the library quickly without the help of the textual instructions. Most of the participants thought the navigation tools presented the whole information needed for them. Besides the test materials, signs and number plates provided useful information to B3, C1, and C4. C4 realized that she could find the destination only relying on signs. On the other hand, A5, B6, and C2 indicated that the numbering system was helpful as well.

3. ***Which aid was the most helpful one? Explain why.***

Photo navigation was the most helpful tool for 8 test persons because the images provided visual information, so as to match those things with reality and the arrows showed the direction pretty clear. They could understand the pictures quickly. A3, A4, B4 regarded the textual instructions as the most useful tool. B4 fed back that the written turn-by-turn instructions were precise and that they described the direction linked with nearby landmarks, which helped him to confirm the location. B2, B3, B6 and C4 expressed that the map was the most helpful aid. For B2 and B6, the reason was that the maps presented room numbers, the landmarks in different symbols and functional rooms in a specific color. They could quickly recognize where they were and where destinations are. C4 liked the map because she could see her precise location on the digital map. The signage was most helpful for C2 because he said the signs were pretty clear for him.

4. ***For Group 1 only: did you miss any indoor maps? If they would have been made available, would you use them?***

The participants of group 1 were very sure that they would like to use the map to find the way in indoor environments if maps would be available as they answered the question without hesitation.

For Group 2 & 3 only: Did the indoor maps provide help? How do they help?

For group 2&3, only six out of 12 persons (B2, B3, B6, C2, C3 and C4) made use of the map. B2, B3, and B6 believed that the indoor maps provided help to them during indoor wayfinding through presenting the spatial structure of the building and visual information like room numbers, landmarks and functionality of the rooms. They could determine the locations of their position and destinations and could plan the route on the map. Once the route was planned, they followed the route and could confirm whether they were in the right direction through comparing the surroundings with the maps. C2 used the map once to confirm the fourth destination because he did not see any signs for the library reception and he found that the symbol of the reception was near the entrance of the library on the map. For C3 and C4, the maps helped them to confirm their location, so that they could check whether they were heading towards the right direction.

5. ***When and where did you realize that you (may) need the help of maps?***

Most of the participants indicated that they might use the map to check the location when they get lost or when they are in decision points like corners and junctions. B4, C1, and C2 said that they would like to use the map when they do not have any other supports, such as signs and pictures. When the map was available, B6 realized that she should use the map in her subconscious mind.

6. ***What drawbacks do the indoor maps you received have in your opinion?***
For group 2, the participants did not give any feedback about the drawbacks of the maps, and only B3 mentioned that it could be better to show the route that leads to the destination on the map.

For group 3, C1 complained that the screen was locked several times and he lost time with unlocking the screen. C3 felt that the web map was not functional because it was impossible to mark the destination on the map. The scale of the digital indoor maps was the problem that concerned C4. The screen size was too limited to present all information at the same time. If the maps present the complete information after zooming out, some things were hard to recognize.

7. ***Do you think a positioning system is important for indoor wayfinding? If an indoor positioning system would be available, would you like to have the opportunity to constantly be able to see where you are in the building on a map, or would it be sufficient for you to use the positioning system only to give you navigation instructions at the right place and moment?***

Most of the participants considered the positioning system as an important component of indoor wayfinding applications for large and complex buildings. They also would like to see their location on the map. A2, A3, and B6 addressed that the accuracy was the problem of the indoor positioning system. If it were accurate, they would like to utilize an application with a positioning system.

8. ***Do you have any suggestions for improving the indoor maps or indoor wayfinding applications?***

For indoor maps, B4 suggested updating the content of the maps in time. When it comes to the improvement of indoor wayfinding applications, participants gave some interesting advice. A2 and B1 proposed to combine photo navigation with indoor maps, whereby the pictures can be shown on the map at decision points. Audio instructions are suggested as a function of the application by A3 and B3. Moreover, B6, C2, and C4 proposed to improve the functionality and precision of the positioning system.

9. ***What is your opinion about audio instructions?***

Out of 18 participants, 11 agreed that audio instructions could be a useful component of indoor wayfinding applications, especially for blind people. However, some participants (A2, B4, B6, C2 and C4) had an adverse attitude on this. A2 was worried about the accuracy of the positioning system that may cause inaccurate instructions. B4 and B6 felt that they would be confused with the spoken instructions because the sound would continue when they stop. C2 said that he would feel awkward to follow the machine's order, especially in indoor environments. B5 claimed that it could be better to use headphones. Otherwise, the audio may disturb others in quiet places, like a museum and library.

6.7. Summary

This chapter presented the analysis of the results. The wayfinding performance of each group, for each task, and each participant are demonstrated through quantitative data, such as task completion time, mistake counts and error counts. It can be concluded that group 1 has a better performance than other groups and task 2 is the most difficult one. To compare the performance of participants with different navigation aids, the aids usage was measured to investigate whether the use of maps can improve the wayfinding performance. The results indicate that photo navigation is the most popular navigation aid, whereas part of the participants prefer indoor maps and few of them like the digital maps with the positioning system. For the floor plan maps, none of them used them even look at them once. Possible reasons for hesitations and mistakes were interpreted as well. Hesitations occurred at major decision points, like stairs and the junction of aisles. The mistakes happened most often at the stairs near the Auditorium. Some participants took a different route than the recommended route, which means that they pursued the easiest way rather than the shortest one. Also, it can be found that participants with a good sense of direction performed better. Therefore, it is necessary to consider the influence of the participants' backgrounds. About the verification of conceptual model, only participants who used maps fit for the model. The outcome of the interviews was summarized as well. It is interesting that when the participants of group 1 were asked whether they want to use the map in indoor wayfinding, most of them chose YES. However, out of 12 participants who had the chance to use the indoor maps, only 5 of them utilized the maps, either the paper maps or the digital map with the positioning system. Furthermore, from the feedback from participants about the indoor maps, they were satisfied the design. It can be concluded that the design of indoor maps is advisable for other indoor maps. According to this analysis, the next chapter discusses the conclusions and presents recommendations for developing new indoor wayfinding applications.

7. CONCLUSIONS AND RECOMMENDATIONS

7.1. Conclusions

The overall objective of this research was to investigate the role of map displays in indoor wayfinding in combination with other means of navigation support by figuring out whether, and if so, when, how and where users want to make use of indoor map displays. The objective was split into three main research questions, and each research question was followed by several sub-questions. This section concludes the results of the research by answering the research questions.

1. **How do people find their way in indoor environments?**

Sub-questions:

- Which indoor wayfinding applications are currently available? What are the components of current wayfinding applications?

  Nowadays, with the development of technology, various types of indoor wayfinding applications are available. It is impossible to list all existing applications. So, in this research, several typical indoor wayfinding applications were introduced in Section 2.3.3: the Schiphol Airport App, Eyedog photo navigation, MazeMap, Google Maps and Guide3D. Each of them is different with respect to their basic components and functions. Table 2.3.1 showed the elements of each indoor wayfinding application which were involved in this research. In general, floor plan maps, textual or audio instructions, images, and positioning systems are the most common components of existing indoor wayfinding applications.

- Which are the user tasks involved in indoor wayfinding?

  Possible involved user tasks in indoor wayfinding were formulated as a conceptual model in Chapter 3. Based on previous researches and empirical works, the conceptual model contains five user tasks, they are

  6. Initial Geo-identification
  7. Identification of destination
  8. Route planning
  9. Route decision execution
  10. Destination confirmation

  Each task is explained with related user questions, I also linked the navigation aids to every task in this conceptual model (See Section 3.3).

- Which components are meant to support which user tasks?

  Maps are intended to support all the tasks and, according to the analysis of the user test results, test persons who utilized map in the test indeed completed these tasks with the help of maps. Images and textual instructions are more helpful in executing route navigation. When participants are provided with a recommended route, they do not care where they are and where the destination is, but move by following the provided instructions. With a positioning system, people can check their real-time location on the map. In this way, it provides more help in the initial identification, route navigation and destination confirmation.

- What are the forms of visualization of indoor space among existing indoor wayfinding applications?

  Through the review of existing indoor wayfinding applications in Chapter 2, it can be seen that the floor plan map is the most common visualization of indoor space for most of the indoor navigation applications such as Google maps, MazeMap and the Schiphol Airport App. On the other hand, there are other forms as well. For example, the Eyedog application presents the indoor environments through pictures (photographs). Guide3D uses a 3D model to visualize the indoor area of the Alice hospital in Germany. Furthermore, some advanced technologies like AR are considered as visual representation of indoor space by developers.

- How are the map displays in current wayfinding applications designed (e.g. how are multiple floors represented)?

  Usually, each floor is represented in one map for floor plan maps. In the indoor wayfinding applications that utilize floor plan maps, users can switch the floor through clicking a floor number button. There are other map displays mentioned in Section 2.3.1 like IndoorTube. The concept of IndoorTube map of Nossum (2011) that does show several floors at the same time.

2. **What are the uses of maps in indoor wayfinding?**

Sub-questions:

- Do users want to use indoor map displays for wayfinding?

  Through the analysis of the results of the user tests in Chapter 6, it became clear that half of the participants of group 2 (the only group that received a booklet with printed floor plan maps) preferred to use the indoor maps. The rest of them indicated that they want to use indoor maps when other navigation aids are not available. Very few of the test persons of group 3 were happy with the digital maps with the simulated positioning system. This was not only a matter of personal preference but it was probably partly due to the not smooth simulation of the positioning system and the sub-optimal design of the digital indoor maps and their interactive functionality.
  According to the interview in Section 6.6, the participants of group 1 were very sure that they would like to use the map to find the way in indoor environments if maps would be available.

- When do the users want to employ a map (i.e. for executing which tasks)?

  From the recorded eye gaze videos of those participants who used the indoor maps during the test, it became clear that they employed a map to identify the locations of their position and destinations, and to plan the route to the destination before they start moving. During the way to the target, they also would like to check the map to ensure that they are heading in the correct direction when they are at a decision point. If there was a floor change, they tended to use the map when arriving at a new floor. For the participants who did not look at the map, the outcome of the interviews implied that they would use maps to orient themselves when they get lost and do not have other supports.

- Where do the users tend to make use of the map?

  In Chapter 6, the analysis of the videos demonstrated that the users focused on maps at connections of different floors and at points with multiple branches or more than one choice to go, especially when they were uncertain about the way to choose. Besides, when they noticed an object/landmark which was presented on the map by a particular symbol, the users want to search it on the map. In the interviews, participants mentioned that they want to use the indoor maps in the compound and big buildings and at decision points inside the building.

- How do the users use map displays during the wayfinding process?

  The heat maps and gaze plots of indoor maps, as presented in Section 6.4, showed that the connections of floors, the destinations, and the corners had more fixations and attentions from users. Based on the analysis of the eye gaze videos, it can be concluded that the users identify the destinations through searching for the room number or the symbol of the destinations on the map and orient themselves by matching the surroundings such as the room numbers, landmarks and functional rooms with the map.

- Does the indoor map help users to find the right way?

  Of course, maps can provide help to users for reaching their destinations. This is demonstrated by the fact that the participants who only made use of maps could all complete their wayfinding tasks. However, in terms of efficiency, the comparison of the test results from different groups did not show that maps have a positive influence on improving the wayfinding performance as the users of maps spent more time on executing their tasks by reading the maps.

- Which visualization of indoor space do users prefer to execute which tasks?

  In this research, 3 test materials were provided to test persons. The majority preferred the images (photos) to visualize the indoor environment and execute the wayfinding tasks. It can also be found that most people stay with their initial choice once they decided which navigation aid they wanted to use first. They seldom switch tools unless the last one is not functional.

- Which navigation aids do people prefer to find their way inside buildings?

  As mentioned in the last question, photo navigation was the most popular navigation aid among all participants.

- What difficulties do people have when they are using maps for indoor navigation?

  For the users of the maps, finding their locations and destinations on the map took most of the time. Participants had difficulties with the digital maps and the simulated positioning system. Also, users paid more attention to diagnosing the direction at corners or junctions. Besides, the design of the indoor maps did not seem to cause problems.

3. What are the suggestions for improving the design of indoor wayfinding applications (with emphasis on the incorporation of map displays)?

Sub-questions:

- What recommendations can be made for the design of new indoor wayfinding applications?

  From the outcomes of the user tests and feedback from participants, photo navigation appears to be effective and efficient for route navigation through new indoor wayfinding applications. For route navigation, it can be considered as an alternative to indoor maps. Indoor maps could be more practical for some users if the positioning system was more accurate. Indoor maps could also be used for route planning and may serve to understand the structure of a building. Furthermore, some people like audio instructions, but others may be bothered by the sound, especially in noisy environments.

- What recommendations can be made regarding the cartographic design of indoor map displays?

  In general, the users of the maps were satisfied with the design of the indoor maps which presented all room numbers, functional rooms in different colours and landmarks in specific symbols. To create a meaningful indoor map, it is recommended to include recognisable cartographical objects through generalising asset objects like lecture rooms, computer clusters, and restaurants. The second suggestion is to use particular icons to represent landmarks and particular areas like toilets, so as to assist in indoor route navigation.

- How may indoor map displays be integrated with the other components of indoor navigation systems?

  As discussed in Section 6.6, it is proposed to integrate map displays with photo navigation, may be by showing the pictures with arrows on the map at decision points.

7.2. Recommendations for future research.

Overall, the objective of this research has been reached. The mobile eye tracking and thinking aloud methods played a significant role in observing the wayfinding behaviour of participants and provided evidence to support the results. For further research, several recommendations can be made based on this research.

- To learn more about the use of maps in indoor navigation this user research should be repeated with fully operational indoor wayfinding applications rather than providing participants with several navigation tools separately.
- Such user research should be done in more than one building, so as to be able to decrease the impact caused by the building itself, as the structure of the buildings may bias the results.
- It can be seen that the participants with good sense of direction performed wayfinding tasks better than others. Thus, user tests with a bigger sample size would be helpful to retrieve more reliable results
- As most of the participants have difficulties with thinking aloud, it is suggested to train the test persons beforehand that make them more familiar with speaking out their thoughts.
- Through the user test, it was found that the conceptual model did not always fit the indoor wayfinding behaviour because some participants did not determine where they are and where the destination is. Perhaps the conceptual model should be upgraded to better reflect the actual (instead of the optimal) behaviour of people in indoor navigation.

In this research, participants only received three navigation aids. However, more and more advanced technologies may now be applied in developing indoor navigation systems, such as Augmented Reality (Kolbe, 2004; Mulloni et al., 2011), and 3D models (van Schaik et al., 2015). So, I recommend to provide test participants more possible choices.

LIST OF REFERENCES

Alice-Hospital. (2013). Retrieved from http://guide3d.alice-hospital.de/kiosk/?web&

Arthur, P., & Passini, R. (1992). *Wayfinding: people, signs, and architecture*. McGraw-Hill Book Co. Retrieved from http://worldcat.org/isbn/0075510162

Butler, D. L., Acquino, A. L., Hissong, A. A., & Scott, P. A. (1993). Wayfinding by Newcomers in a Complex Building. *Human Factors: The Journal of the Human Factors and Ergonomics Society*, *35*(1), 159–173. http://doi.org/10.1177/001872089303500109

Car, A. (1997). Hierarchical Spatial Reasoning : Theoretical Consideration and its Application to Modeling Wayfinding. *Ph. D. Thesis, Dept. of Geoinformation, Technical University Vienna*. Retrieved from http://ci.nii.ac.jp/naid/10018342315/en/

Carlson, L. A., Hölscher, C., Shipley, T. F., & Dalton, R. C. (2010). Getting Lost in Buildings. *Current Directions in Psychological Science*, *19*(5), 284–289. http://doi.org/10.1177/0963721410383243

Çöltekin, A., Heil, B., Garlandini, S., & Fabrikant, S. I. (2009). Evaluating the Effectiveness of Interactive Map Interface Designs: A Case Study Integrating Usability Metrics with Eye-Movement Analysis. *Cartography and Geographic Information Science*, *36*(1), 5–17. http://doi.org/10.1559/152304009787340197

Deakin, A. K. (1996). Landmarks as Navigational Aids on Street Maps. *Cartography and Geographic Information Systems*, *23*(1), 21–36. http://doi.org/10.1559/152304096782512159

Delikostidis, I. (2011). IMPROVING THE USABILITY OF PEDESTRIAN NAVIGATION SYSTEMS. Retrieved from https://www.itc.nl/library/papers_2011/phd/delikostidis.pdf

Ellard, C. (2009). *You are here: Why we can find our way to the moon, but get lost in the mall*. Anchor.

Gaisbauer, C., & Frank, A. U. (2008). Wayfinding model for pedestrian navigation. *11th AGILE International Conference on Geographique Information Science*, 1–9. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.522.9745&rep=rep1&type=pdf

Garland, K. (1994). Mr Beck's underground map. Capital Transport.

Garling, T., Lindberg, E., & Mantyla, T. (1983). Orientation in buildings: Effects of familiarity, visual access, and orientation aids. *Journal of Applied Psychology*, *68*(1), 177–186. http://doi.org/10.1037/0021-9010.68.1.177

Gartner, G., & Radoczky, V. (2005). Schematic vs. Topographic Maps in Pedestrian Navigation: How Much Map Detail is Necessary to Support Wayfinding. *AAAI Spring Symposium: Reasoning with Mental and External Diagrams: Computational Modeling and Spatial Assistance*, 41–47. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/citations;jsessionid=764D929342346F7EF2B759FB05BE8760?doi=10.1.1.564.236

Giudice, N. A. (2013). Vertical Color Maps : A Data Independent Alternative to Floor Plan Maps. http://doi.org/10.1353/car.2013.0028

Goodman, E., Kuniavsky, M., & Moed, A. (2013, September). Observing the User Experience: A Practitioner's Guide to User Research (Second Edition). *IEEE Transactions on Professional Communication*, pp. 260–261. http://doi.org/10.1109/TPC.2013.2274110

Hölscher, C., Büchner, S. J., Brösamle, M., Meilinger, T., & Strube, G. (2007). Signs and maps – cognitive economy in the use of external aids for indoor navigation introduction. *Proceedings of the 29th Annual Cognitive Science Society*, 377–382. Retrieved from http://citeseerx.ist.psu.edu/viewdoc/download?doi=10.1.1.114.6558&rep=rep1&type=pdf

Hölscher, C., Büchner, S. J., & Meilinger, T. (2007). Map use and wayfinding strategies in a multi-building ensemble. *Spatial Cognition V: Reasoning, Action, Interaction*, 365–380. http://doi.org/10.1007/978-3-540-75666-8_21

Indoor Maps – About – Google Maps. (2011). Retrieved August 17, 2016, from https://www.google.com/maps/about/partners/indoormaps/

Karimi, H. A. (2015). *Indoor Wayfinding and Navigation*. CRC Press. Retrieved from http://ezproxy.utwente.nl:2200/patron/FullRecord.aspx?p=1834005

Kato, Y., & Takeuchi, Y. (2003). Individual differences in wayfinding strategies. *Journal of Environmental Psychology*, *23*(2), 171–188. http://doi.org/10.1016/S0272-4944(03)00011-2

Klippel, A., Freksa, C., & Winter, S. (2006). You-are-here maps in emergencies–the danger of getting lost. *Journal of Spatial Science*, *51*(1), 117–131.

Kolbe, T. H. (2004). Augmented Videos and Panoramas for Pedestrian Navigation, (Azuma 1997), 28–29.

Lee, Kim, E. Y., & Platosh, P. (2015). Indoor Wayfinding Using Interactive Map - Volume 7 Number 1 (Feb. 2015) - IJET. *International Journal of Engineering and Technology*, *7*(1), 75–80. http://doi.org/10.7763/IJET.2015.V7.770

Li, H., Chan, G., Wong, J. K. W., & Skitmore, M. (2016a). Real-time locating systems applications in construction. *Automation in Construction*, *63*, 37–47. http://doi.org/10.1016/j.autcon.2015.12.001

Li, H., Chan, G., Wong, J. K. W., & Skitmore, M. (2016b). Real-time locating systems applications in construction. *Automation in Construction*, *63*, 37–47. http://doi.org/10.1016/j.autcon.2015.12.001

Lorenz, A., Thierbach, C., Baur, N., & Kolbe, T. H. (2013). Map design aspects, route complexity, or social background? Factors influencing user satisfaction with indoor navigation maps. *Cartography and Geographic Information Science*, *40*(3), 201–209. http://doi.org/10.1080/15230406.2013.807029

Lorenz, A., Thierbach, C., Baur, N., Kolbe, T. H., Lorenz, A., Thierbach, C., … Kolbe, T. H. (2017). Map design aspects , route complexity , or social background ? Factors influencing user satisfaction with indoor navigation maps, *406*(January). http://doi.org/10.1080/15230406.2013.807029

Lovelace, K. L., Hegarty, M., & Montello, D. R. (1999). Elements of good route directions in familiar and unfamiliar environments. *Lecture Notes in Computer Science (Including Subseries Lecture Notes in Artificial Intelligence and Lecture Notes in Bioinformatics)*, *1661*, 65–82. http://doi.org/10.1007/3-540-48384-5_5

Lundgrén-Laine, H., & Salanterä, S. (2010). Think-aloud technique and protocol analysis in clinical decision-making research. *Qualitative Health Research*, *20*(4), 565–75. http://doi.org/10.1177/1049732309354278

Lynch, K. (1960). The image of the city (Vol. 11). MIT press.

M2mobi - Schiphol App. (2016). Retrieved January 1, 2016, from https://www.m2mobi.com/projects/Schiphol-MTS

Mast, V., Jian, C., & Zhekova, D. (2012). Elaborate Descriptive Information in Indoor Route Instructions. *Proceedings of the 34th Annual Meeting of the Cognitive Science Society*, 1972–1977. Retrieved from https://mindmodeling.org/cogsci2012/papers/0345/paper0345.pdf

MazeMap Indoor Maps and Navigation. (2015). Retrieved from https://www.mazemap.com/

Michon, P.-E., & Denis, M. (2001). When and why are visual landmarks used in giving directions? *Spatial Information Theory*, *2205*, 292–305. http://doi.org/10.1007/3-540-45424-1_20

Mulloni, A., Seichter, H., & Schmalstieg, D. (2011). Handheld augmented reality indoor navigation with activity-based instructions. In *Proceedings of the 13th International Conference on Human Computer Interaction with Mobile Devices and Services - MobileHCI '11* (p. 211). New York, New York, USA: ACM Press. http://doi.org/10.1145/2037373.2037406

Nossum, A., & Nguyen, A. (2012). Comparing Two Different Map Types for Patient Navigation Inside a Hospital. *Giscience.Org*, (Garland 1994). Retrieved from http://giscience.org/proceedings/abstracts/giscience2012_paper_75.pdf

Nossum, A. S. (2011). IndoorTubes A Novel Design for Indoor Maps. *Cartography and Geographic Information Science*, *38*(2), 192–200. http://doi.org/10.1559/15230406382192

O'Neill, M. J. (1991). Effects of Signage and Floor Plan Configuration on Wayfinding Accuracy. *Environment and Behavior*, *23*(5), 553–574. http://doi.org/10.1177/0013916591235002

Ohm, C., Müller, M., & Ludwig, B. (2015). Displaying landmarks and the user ' s surroundings in indoor pedestrian navigation systems, *7*, 635–657. http://doi.org/10.3233/AIS-150335

Passini, R. (1981). Wayfinding: A conceptual framework. *Urban Ecology*, *5*(1), 17–31. http://doi.org/10.1016/0304-4009(81)90018-8

Photo Landmark Navigation — Eyedog Indoor Navigation - Mobile Wayfinding. (2016). Retrieved January 1, 2016, from http://www.eyedog.mobi/indoor-navigation-application

Puikkonen, A., Sarjanoja, A., Haveri, M., Huhtala, J., & Häkkilä, J. (2009). Towards designing better maps for indoor navigation. *Proceedings of the 8th International Conference on Mobile and Ubiquitous Multimedia - MUM '09*, 1–4. http://doi.org/10.1145/1658550.1658566

Radoczky, V. (2007). How to design a pedestrian navigation system for indoor and outdoor environments. In *Location Based Services and TeleCartography* (pp. 301–316). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-540-36728-4_23

Raubal, M., & Winter, S. (2002). Enriching Wayfinding Instructions with Local Landmarks (pp. 243–259). Springer, Berlin, Heidelberg. http://doi.org/10.1007/3-540-45799-2_17

Razeghi, R. (2010). Usability of Eye Tracking as a User Research Technique in Geo-information Processing and Dissemination. *Geo-Information Science*, (March). Retrieved from http://www.itc.nl/library/papers_2010/msc/gfm/razeghi.pdf

Rehrl, K., Häusler, E., Leitinger, S., Bell, D., Rehrl, K., Häusler, E., … Pedestrian, D. B. (2014). Pedestrian

navigation with augmented reality , voice and digital map : final results from an in situ field study assessing performance and user experience, *9725*(September 2016). http://doi.org/10.1080/17489725.2014.946975
Romano Bergstrom, J. C., Olmsted-Hawala, E. L., & Jans, M. E. (2013). Age-Related Differences in Eye Tracking and Usability Performance: Web Site Usability for Older Adults. *International Journal of Human-Computer Interaction*, *29*(8), 541–548. http://doi.org/10.1080/10447318.2012.728493
Ryder, K. J. (2015). Designing and Publishing Indoor Maps for Patients and Visitors in an Academic Teaching Hospital. Retrieved from http://epubs.rcsi.ie/cgi/viewcontent.cgi?article=1076&context=mscttheses
Scientific, E., Company, P., & Passini, R. (1981). The term wayfinding , although it has appeared in the literature on environ- mental psychology , psychology , geography and even anthropology , does not encompass a field of study in its own right . Studies most closely related to wayfinding appear under , *5*, 17–31.
Smolders, M., & Görtz, H. (2016). Indoor wayfinding at Amsterdam airport. *GIM International*, *30*(3), 16–19. Retrieved from https://www.gim-international.com
Sorrows, M. E., & Hirtle, S. C. (1999). The Nature of Landmarks for Real and Electronic Spaces (pp. 37–50). Springer, Berlin, Heidelberg. http://doi.org/10.1007/3-540-48384-5_3
Tenney, M. (2013). *A conceptual model of exploration wayfinding: An integrated theoretical framework and computational methodology*. *Theses and Dissertations*. Retrieved from http://scholarworks.uark.edu/etd/724
Tobii Pro Glasses 2 wearable eye tracker. (2015). Retrieved from http://www.tobiipro.com/product-listing/tobii-pro-glasses-2/
U.S. EPA/Office of Air and Radiation, O. of R. and I. A. (2012). The inside story: A guide to Indoor Air Quality, (April). Retrieved from http://www.epa.gov/iaq/pubs/insidestory.html#Intro1
van Elzakker, C. P. J. M. (2004). The use of maps in the exploration of geographic data. Retrieved from https://www.itc.nl/library/Papers_2004/phd/vanelzakker.pdf
van Schaik, P., Mayouf, M., & Aranyi, G. (2015). 3-D route-planning support for navigation in a complex indoor environment. *Behaviour & Information Technology*, *34*(7), 713–724. http://doi.org/10.1080/0144929X.2015.1004649
Vanclooster, A., Ooms, K., Viaene, P., Fack, V., Van de Weghe, N., & De Maeyer, P. (2014). Evaluating suitability of the least risk path algorithm to support cognitive wayfinding in indoor spaces: An empirical study. *Applied Geography*, *53*, 128–140. http://doi.org/10.1016/j.apgeog.2014.06.009
Viaene, P., Ooms, K., Vansteenkiste, P., Lenoir, M., & De Maeyer, P. (2014). The use of eye tracking in search of indoor landmarks. *CEUR Workshop Proceedings*, *1241*, 52–56. Retrieved from https://www.semanticscholar.org
Viaene, P., Vanclooster, A., Ooms, K., & De Maeyer, P. (2015). Thinking aloud in search of landmark characteristics in an indoor environment. *2014 Ubiquitous Positioning Indoor Navigation and Location Based Service, UPINLBS 2014 - Conference Proceedings*, 103–110. http://doi.org/10.1109/UPINLBS.2014.7033716
Viaene, P., Vansteenkiste, P., Lenoir, M., De Wulf, A., & De Maeyer, P. (2016). Examining the validity of the total dwell time of eye fixations to identify landmarks in a building. *Journal Of Eye Movement Research*, *9*(3), 1–11. http://doi.org/10.16910/jemr.9.3.4
Wenig, D., Schöning, J., Hecht, B., & Malaka, R. (2015). StripeMaps: Improving Map-based Pedestrian Navigation for Smartwatches. In *Proceedings of the 17th International Conference on Human-Computer Interaction with Mobile Devices and Services - MobileHCI '15* (pp. 52–62). http://doi.org/10.1145/2785830.2785862
Werner, S., Krieg-Brückner, B., Mallot, H. A., Schweizer, K., & Freksa, C. (1997). Spatial Cognition: The Role of Landmark, Route, and Survey Knowledge in Human and Robot Navigation1 BT - Informatik '97 Informatik als Innovationsmotor: 27. Jahrestagung der Gesellschaft für Informatik Aachen, 24.–26. September 1997. In M. Jarke, K. Pasedach, & K. Pohl (Eds.), (pp. 41–50). Berlin, Heidelberg: Springer Berlin Heidelberg. http://doi.org/10.1007/978-3-642-60831-5_8
Zlatanova, S., Liu, L., Sithole, G., Zhao, J., & Mortari, F. (2014). Space subdivision for indoor applications. GISt Report No. 66. Delft University of Technology, OTB Research Institute for the Built Environment. Retrieved from http://resolver.tudelft.nl/uuid:c3ef4c87-9c35-4d05-8877-a074c3f7fdbf

APPENDIX 1

Participant invitation letter

Dear sir /madam,

My name is Qiujun Li and I am an MSc student Geoinformatics at the Faculty ITC of the University of Twente. I am now doing my thesis research under the supervision of Corné van Elzakker and Barend Köbben. Hopefully, some of my results can be used for the further development of the UT Campus App.

I am now looking for volunteers to participate in an indoor wayfinding experiment. The experiment itself will take place in the ITC building (Hengelosestraat 99, Enschede) and will last around 30 minutes. I will ask you to wear a mobile eye-tracker and to think aloud when completing some indoor wayfinding tasks.

You are eligible to participate if you are not very unfamiliar with the ITC building and I also hope you will be willing to think aloud in English.

Of course, your participation in the experiment is totally voluntary. By participating you will help us, but you will also have the chance to learn to know the ITC and experience user testing with a mobile eye-tracking system.

The tests will take place next week (i.e. the week starting Monday 23 January) at a day and time that suits you. I will contact you to make an appointment.

If you are willing to participate, I would first like to ask you to complete an online survey. Please go to this link https://www.surveymonkey.com/r/MKSN2NW and fill in the questionnaire. In case of questions, you may contact me directly by Email or call me: +31646669956.

Thanks for reading.

Look forward to your response.

Best regards,

Qiujun Li

GFM, ITC

APPENDIX 2

Online survey

Prior-survey for user research

Welcome to My Survey

Dear participant:

This survey is one part of my thesis, which aims to investigate how people find their way inside buildings. Therefore I am looking for people with varying levels of spatial abilities.

In this questionnaire, you will be presented with three documents you are supposed to complete. It will take you approximately 20 minutes to complete the documents. First, we ask you to provide some background information. When we ask you to provide your name and contact details, this is only so that you may be contacted for making an appointment for doing the actual experiment in the ITC building. Only the researcher will have access to this information. Should you be invited, and agree to participate in further studies, you will be assigned a participant ID number so that you will remain anonymous in further testing.

The second document you will complete is the Santa Barbara Sense of Direction Scale. It is a questionnaire that asks you questions relating to map-reading and map-use. You will agree or disagree with the statements along a scale from 1 to 7, where 1 is strongly agree and 7 is strongly disagree.

The third and final document is an investigation of spatial ability. In this document, you are provided with a diagram of a bottle which has been partially filled with water. The bottle is then rotated at various angles, and you are required to draw the water line in each of the rotated bottles.

These documents will be used to further determine your suitability to the study. If selected, you will be required to attend another session in the ITC building (Hengelosestraat 99, Enschede) with an approximate duration of 20-30 minutes. In this session, you will be asked find pre-defined destinations from an origin inside the ITC building. This session will involve the use of mobile eye-tracking glasses. You will be required to speak your thoughts aloud while completing the tasks. Should you be selected for the second session, you are not obliged to complete it. You may exit from the study at any time, you are not required to engage in this study if you do not wish to.

I would like to stress that all information collected will be kept strictly confidential and that individual details will not be disclosed or identifiable from this survey.

For any further information, please contact Ms. Qiujun Li at q.li-1@student.utwente.nl.

Thank you for participating in this survey.

1

Prior-survey for user research

Preliminary Information

Please note: all questions with an asterisk (*) must be answered before you can continue.

* 1. Name:

* 2. Email Address

* 3. Age:

- 18-24
- 35-44
- 55-64
- 25-34
- 45-54
- 65 and above
- Other (please specify)

* 4. Gender:

- Male
- Female

* 5. Country of Origin:

* 6. Occupation:

2

* 7. Highest Completed Education Level:

- ◯ Primary
- ◯ Preparatory Vocational Secondary (VMBO)
- ◯ Senior General Secondary (HAVO)
- ◯ Pre-university (VWO)
- ◯ Bachelor
- ◯ MSc
- ◯ MA
- ◯ PhD
- ◯ Other (please specify)

* 8. What is or was your main field of study?

Prior-survey for user research

Preliminary Information

* 9. Do you have normal or corrected to normal vision?

◯ Normal ◯ Corrected to normal

10. If you have corrected to normal vision, do you wear glasses/spectacles?

◯ Yes ◯ No

11. If you have corrected to normal vision, do you wear contact lenses?

◯ Yes ◯ No

* 12. Do you have any physical disabilities that would affect your ability to use a smartphone or move about indoors?

◯ Yes ◯ No

3

Prior-survey for user research

Preliminary Information

* 13. When you travel in an unfamiliar building, how confident are you to find your way inside the building on your own?

- ◯ Very confident
- ◯ Somewhat confident
- ◯ Neither confident nor not confident
- ◯ Slightly confident
- ◯ Not at all confident

* 14. How often do you get lost in an unfamiliar building?

- ◯ Never
- ◯ Sometimes
- ◯ Often
- ◯ Always

* 15. When travelling in an unfamiliar building, how do you find your way inside the building?

- ☐ Use public indoor maps
- ☐ Use signs
- ☐ Use number plates
- ☐ Use indoor wayfinding applications on smartphone
- ☐ Other (please specify)

* 16. How often do you use maps?

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ 5-10 times per year
- ◯ 2-4 times per year
- ◯ Less than once per year
- ◯ Never

* 17. How often do you use a map app on a smartphone or tablet?

- ◯ Daily
- ◯ Weekly
- ◯ Monthly
- ◯ 5-10 times per year
- ◯ 2-4 times per year
- ◯ Less than once per year
- ◯ Never

* 18. Do you have any experience with indoor wayfinding applications?

- ◯ YES
- ◯ NO

4

19. If the last question is YES, please indicate the name of the application you have used:

* 20. Have you ever been ITC building?

- YES
- NO

21. If the last question is YES, how often have you been to the ITC building?

- only once
- only twice
- 3-5 times
- more than 5 times

Prior-survey for user research

Santa Barbara Sense of Direction Scale

* 22. I am very good at giving directions

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 23. I have a poor memory for where I left things.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 24. I don't have a very good "mental map" of my environment.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

Prior-survey for user research

Santa Barbara Sense of Direction Scale

* 25. My "sense of direction" is very good.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 26. I tend to think of my environment in terms of cardinal directions (N, S, E, W).

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 27. I very easily get lost in a new city.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

Prior-survey for user research

Santa Barbara Sense of Direction Scale

* 28. I enjoy reading maps.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 29. I have trouble understanding directions.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 30. I am very good at reading maps.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

Prior-survey for user research

Santa Barbara Sense of Direction Scale

* 31. I don't remember routes very well while riding as a passenger in a car.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 32. I can usually remember a new route after I have travelled it only once.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 33. I don't enjoy giving directions.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

Prior-survey for user research

Santa Barbara Sense of Direction Scale

* 34. I usually let someone else do the navigational planning for long trips.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

* 35. It's not important to me to know where I am.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

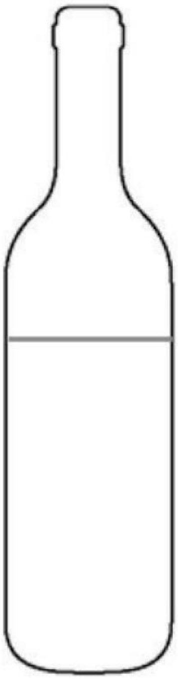
* 36. I am very good at judging distances.

Strongly Agree	2	3	4	5	6	Strongly Disagree
○	○	○	○	○	○	○

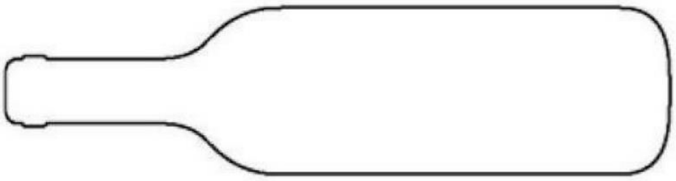
Prior-survey for user research

Spatial Ability Evaluation

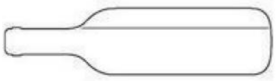
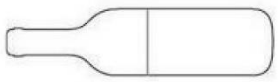
Below is an image of a bottle. The level of the water in the bottle is indicated by the blue line. Underneath this bottle are five other bottles rotated at different angles. For each rotated bottle, you must select the correct water level angle.

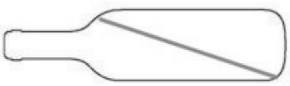


*



37.

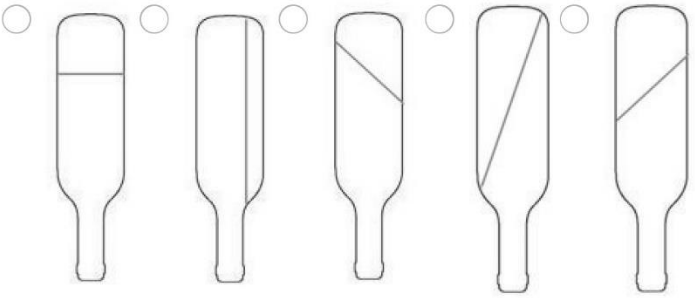
○  ○  ○ 

○  ○ 

8

*

38.



9

APPENDIX 3

Post-test interview questions:

1. How was the indoor wayfinding tasks completion? Were the tasks difficult to complete?
2. Did the navigational tools and materials you received from me help you a lot? Do you think they presented the information you need?
3. Which aid was the most helpful one? Explain why?
4. For Group 1 only: did you miss any indoor maps? If they would have been made available, would you use them?

   For Group 2 & 3 only: Did the indoor maps provide help? How they help?
5. When and where did you realize that you (may) need the help of maps?
7. What drawbacks do the indoor maps you received have in your opinion?
8. Do you think a positioning system is important for indoor wayfinding? If an indoor positioning system would be available, would you like to have the opportunity to constantly be able to see where you are in the building on a map, or would it be sufficient for you to use the positioning system only to give you navigation instructions at the right place and moment?
9. Do you have any suggestions for improving the indoor maps or indoor wayfinding applications?

APPENDIX 4

Instructions to the test participants of group 1

Dear participant:

This experiment is part of my MSc thesis which is about indoor wayfinding. As you probably know, it can be challenging and frustrating to find the way inside a complex and unfamiliar building. With the development of technology and society, many solutions have been developed for this problem, like floor-plans, you are here maps and indoor wayfinding Apps. Together with other navigation aids, such as spoken or written navigation instructions (e.g. "walk upstairs"), landmarks (e.g. an escalator), signs and room number plates, these tools may help users to recognize the way in unfamiliar buildings.
The ITC building is the place where you will execute your wayfinding tasks. It has 6 floors and the structures of each floor are a little bit different. In this building there are offices, classrooms, meeting rooms, study rooms and special purpose rooms like a restaurant, library etc. All rooms have a number with the format x-0yy or x-1yy. "x" refers to the floor number (0 = ground floor, 1 = first floor, 2 = second floor, etc.). When you enter the building or move up the stairs, go to the left for all rooms with a number starting with "1" and go to the right for all rooms with a number starting with "0". E.g. when you move up the stairs to the first floor, go to the right to reach room 1-062. Next to the entrance of each room you will find a number plate showing the number of the room and an indication of the nature of the room or the name of the person(s) in the office (if the room is an office). In addition, brown/aborigine colored signs hanging everywhere on the ceilings or walls with arrows point at room numbers or special purpose rooms.

Tobii Glasses 2 is the electronic equipment used for recording your eye movement and verbalization during the test execution. You are required to wear the glasses and speak out whatever comes into your mind when you execute the wayfinding tasks. For the glasses to work, the tablets needs to be running the TobiiPro Glasses Controller software. As the tablets can connect with glasses in limited distance, that approximately 20 meters, researcher will always carry the tablet and follow the participants in around 10 meters when experimenting. You have several minutes to get familiar with the glasses and practice thinking aloud before going into the field for data collection. The researcher will help you wear the glasses and calibrate it.

Then, you will start the test. You will be lead to the starting point and you will be given a set of materials / tools that you may use for route planning and navigation to a series of destinations.

- Start point: the entry of ITC
- Destination 1: 0-143 Auditorium
- Destination 2: 1-119
- Destination 3: 1-050
- Destination 4: floor 2 elevator
- Destination 5: library reception 3-040
- Final destination: group floor reception

In your case (Group 1) you will receive a booklet providing written turn-by-turn directions, supported by pictures of landmarks you are passing by, as well as pictures of the destinations. You are completely free to use this booklet or not. You may also rely on signs, number plates and floor-plans hang on the wall in the building, but you may not ask directions.

While executing these tasks, please always try to think aloud and express any thoughts, feelings, ideas about the orientation, navigation process, external aids and any difficulties/solutions that you meet. If you forget to think aloud for some time, the researcher will remind you to express your inner thoughts.

This is what I would like you to do now:

1. I will take you to the start position near the entrance of the ITC building.
2. Once you are ready to execute the wayfinding tasks, you can ask the researcher to start. When the researcher informs you that you can begin, you start and say "start!
3. First, orient yourself and determine where you are by looking around and at the materials you have received from me.
4. Your first destination will be:

The Auditorium (room 0-143)

5. From where you are standing now, first determine how you can reach this destination (i.e. plan your route). For this, you can again make use of the materials you received are you may want to look for signs or other clues in the building itself. The idea is that you should try to reach your destination as quickly as possible (you are in a hurry).
6. Once you have planned your route or decided how you want to reach the destination, you can start moving to find the way to the first destination.

While executing these tasks, please always try to think aloud and express any thoughts, feelings, ideas about the orientation, navigation process, external aids and any difficulties/solutions that you meet. If you forget to think aloud for some time, the researcher will remind you to express your inner thoughts.

7. Whilst navigating to your destination, you may stop whenever/wherever you meet a decision point, i.e. a point at which you have more than one possible way to go to or where you are confused about which direction to go. At those decision points, please describe your thoughts and reasoning process, and choose one option.
8. When you reach the first destination, please imply that, like "No.1, done!"

9. Now repeat the whole process, as described in steps 3 to 8 above to reach your next destination from here:
10. Your next destination is: Room 1-119
    Your third destination is: Room 1-050
    Your fourth destination is: Floor 2 elevator
    Your fifth destination is: Library reception 3-040
    Your final destination is: Ground floor reception
11. When you have reached your last destination, please speak "Finish!" and the researcher will stop recording.

During your task execution, I will be following you at a distance of around 10 meters. You should not look for me and try to talk to me face to face unless you have a very critical problem.

After the test, I will interview you about the experience of executing the wayfinding tasks with the help of the navigation tools provided.

Thanks for taking part in the experiment.

APPENDIX 5

Researcher to-do list

1. Before the test:

- Before data collection day, make a test recording before going into the field for data collection.
- Check the status of eye tracker and tablet, charging the batteries and preparing memory cards.
- Before an hour early of participant arrive at the meeting room, turn on the smart phone, and check the eye tracker and tablet (batteries, memory card, and connection).
- Put the specified hardcopy of instructions for different groups on the table.
- Put the hardcopies of textual instructions on the table.
- (for group 2&3)Open the smart phone which shows the indoor maps of ITC building.
- (for group 3) Open the tablet which control the positioning system

2. Participant welcome and introduction：

- Thanks for the test person for coming and welcome.
- First, I will introduce myself and basic information of this study.
  (Hi! Nice to meet you! I am Qiujun Li. I am MSc student who major in Geoinformatics in ITC. Thanks for taking part in this experiment. This is an indoor wayfinding experiment in ITC building. You can know the details of the experiment from the test instructions.)
- Second, I will give the specified instructions about the test procedure to test person and wait the questions.
- Then, I will introduce TobiiPro Glasses 2. If the participant wear glasses, I will fit the appropriate prescription lenses into the glasses after the introduction. Before the wayfinding task, I will give test materials to participant and he/she will wear the eye tracker and have 10 minutes to get familiar with the glasses, think aloud and test materials.
- If participant has not any questions, we will move to the start point of the wayfinding tasks.

3. During the test:

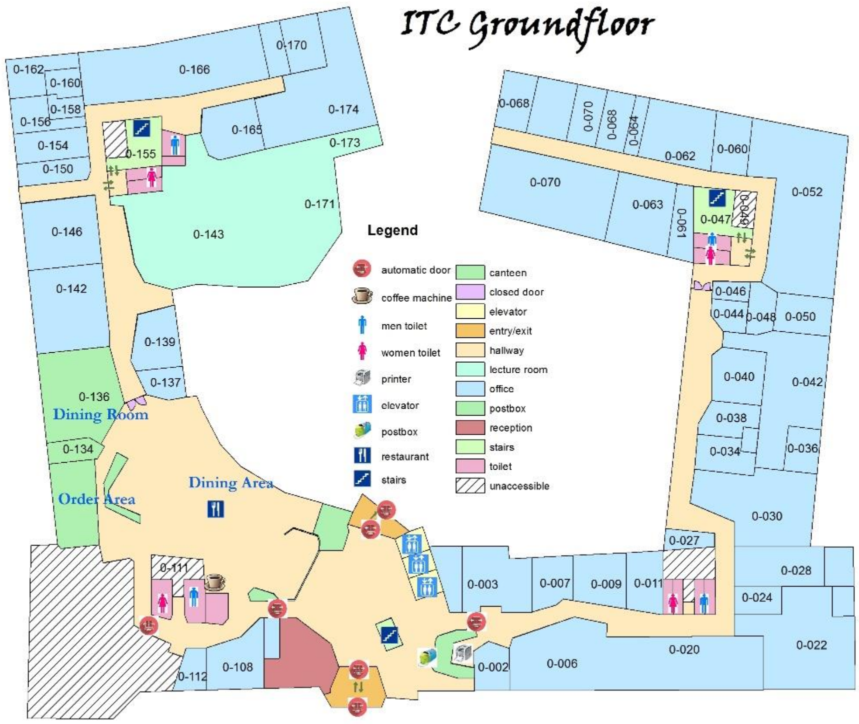
- Open the tablet and create a new recording named by participant number.
- Ask whether the participant is ready to start, if not, wait, if yes, start calibration.
- After the calibration, press the recording button to start recording.
- Then, participant begins to execute the wayfinding tasks with specified test materials, I will follow him/her at a distance of around 10 meters.
- For group 3 which test with the positioning system, a researcher assistant will click the real-location of participant on another laptop and participant can see the real-time location on the tablet.
- If participant forgets to think aloud, I will remind him / her to do so.
- After finishing all wayfinding tasks, press "end" button.

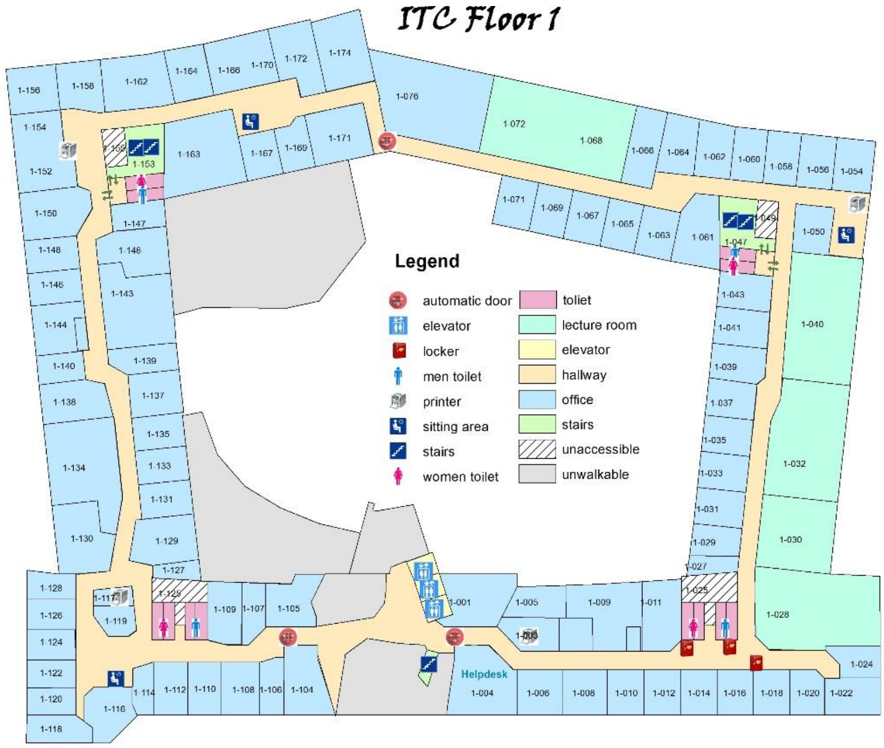
4. After the test:

- I will interview the participant based on the pre-defined questions about the wayfinding experience with the navigation aids especially maps.
- After the interview, thanks participant cooperation again and the whole test finishes.

APPENDIX 6

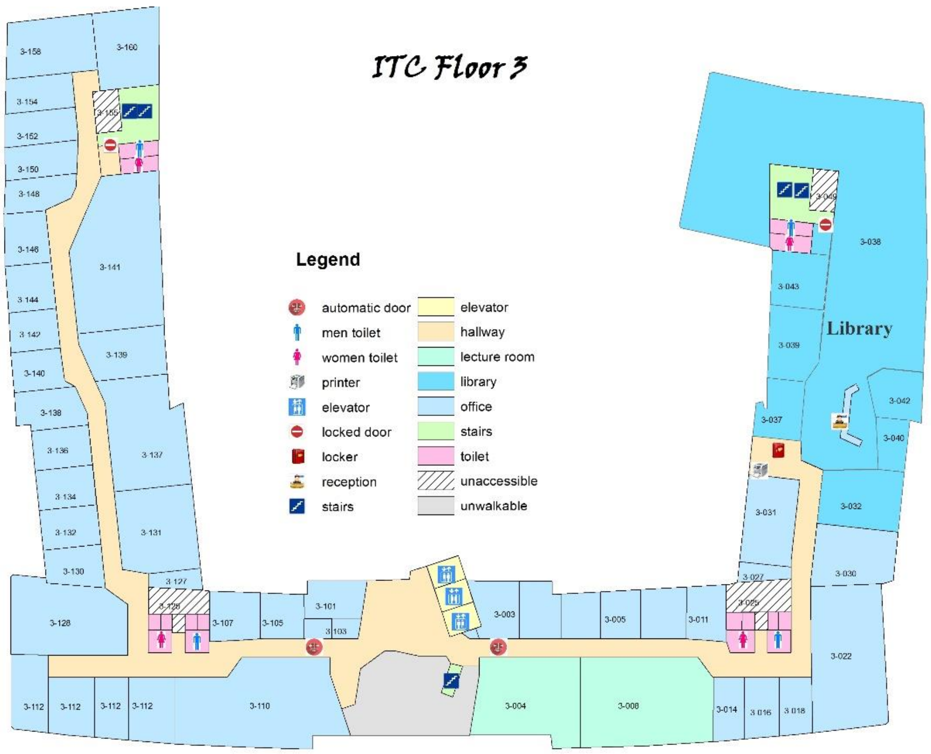
Indoor maps





ITC Floor 2


Legend
automatic door
coffee machine
men toilet
women toilet
elevator
stairs
elevator
hallway
office
stairs
toilet
unaccessible
unwalkable
2-154
2-154
2-152
2-150
2-148
2-140
2-140
2-136
2-134
2-132
2-130
2-128
2-126
2-124
2-158
2-160
2-162
2-156
2-147
2-145
2-143
2-141
2-139
2-137
2-133
2-131
2-127
2-125
2-117
2-116
2-114
2-112
2-109
2-105
2-103
2-108
2-001
2-003
2-005
2-007
2-009
2-011
2-004
2-006
2-010
2-012
2-014
2-024
2-025
2-027
2-026
2-029
2-031
2-033
2-035
2-041
2-030
2-032
2-038
2-040
2-042
2-044
2-046
2-048
2-050
2-052
2-049
2-054
2-056
2-058
2-060
2-062
2-064
2-066
2-068
2-067
2-065
2-061


ITC Floor 3
Legend
automatic door
men toilet
women toilet
printer
elevator
locked door
locker
reception
stairs
elevator
hallway
lecture room
library
office
stairs
toilet
unaccessible
unwalkable
Library
3-158
3-160
3-154
3-152
3-150
3-148
3-146
3-144
3-142
3-140
3-138
3-136
3-134
3-132
3-130
3-128
3-155
3-141
3-139
3-137
3-131
3-127
3-126
3-107
3-105
3-101
3-103
3-112
3-112
3-112
3-112
3-110
3-003
3-005
3-011
3-004
3-008
3-014
3-016
3-018
3-022
3-025
3-027
3-030
3-031
3-032
3-037
3-039
3-040
3-042
3-043
3-038
3-049

APPENDIX 7

List of destinations:

Start point: the entry of ITC
Destination 1: 0-143 Auditorium
Destination 2: 1-119
Destination 3: 1-050
Destination 4: floor 2 elevator
Destination 5: library reception 3-040
Final destination: ground floor reception

Turn by turn textual instructions

Origin to point 1 (auditorium 0-143):

- Take the door on your left next to the reception
- Turn right and move across the restaurant
- Keep walking to the next door
- Continue walking 20 meters, auditorium is on your right.

Point 1 to point 2:

- Follow the path 20 meters
- A door on your right leads to toilet/stairs
- Take the door to the stairs
- Climb the stairs and walk back into the main corridor on the first floor
- Turn left and follow the hallway
- When the path splits, take right
- 1-119 on your right. (opposite the awards case)

Point 2 to point 3:

- With 1-119 on your left, continue walking along the corridor
- Continue walking until the corridor splits where three lockers stand, take left
- Keep walking and take right
- Keep walking along the corridor and take the last right. You will find a printer is in front of you and the room 1-050 on your right

Point 3 to point 4:

- Follow the path and go back to common hallway of the first floor
- Climb stairs till the second floor
- You will find the elevators on your right in the common hallway

Point 4 to point 5:

- Climb upstairs to get to the third floor
- Take right and follow the path until you reach the library's entrance. A printer and locker is on your left corner
- The library's reception is on your right

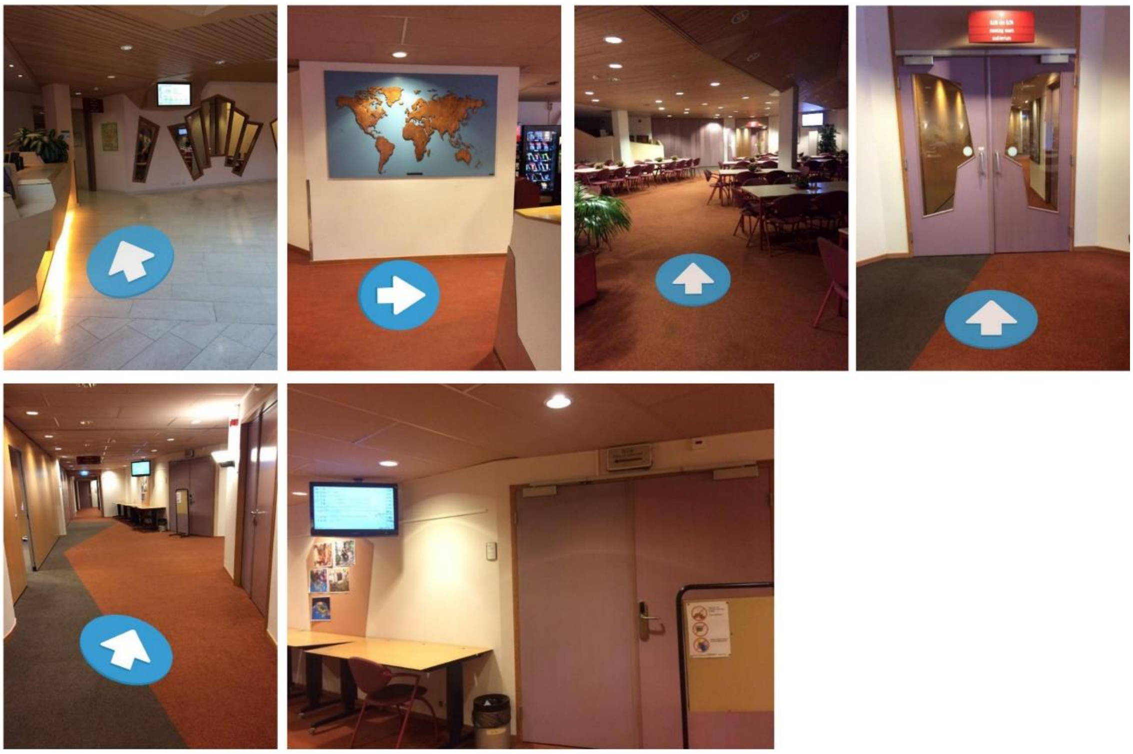
Point 5 to final destination:

- Go back to the common hallway of the third floor
- Take the elevator or walk stairs to ground floor
- The reception is on your left.

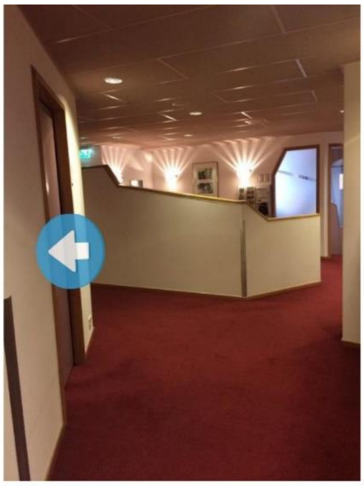
APPENDIX 8

Photo navigation

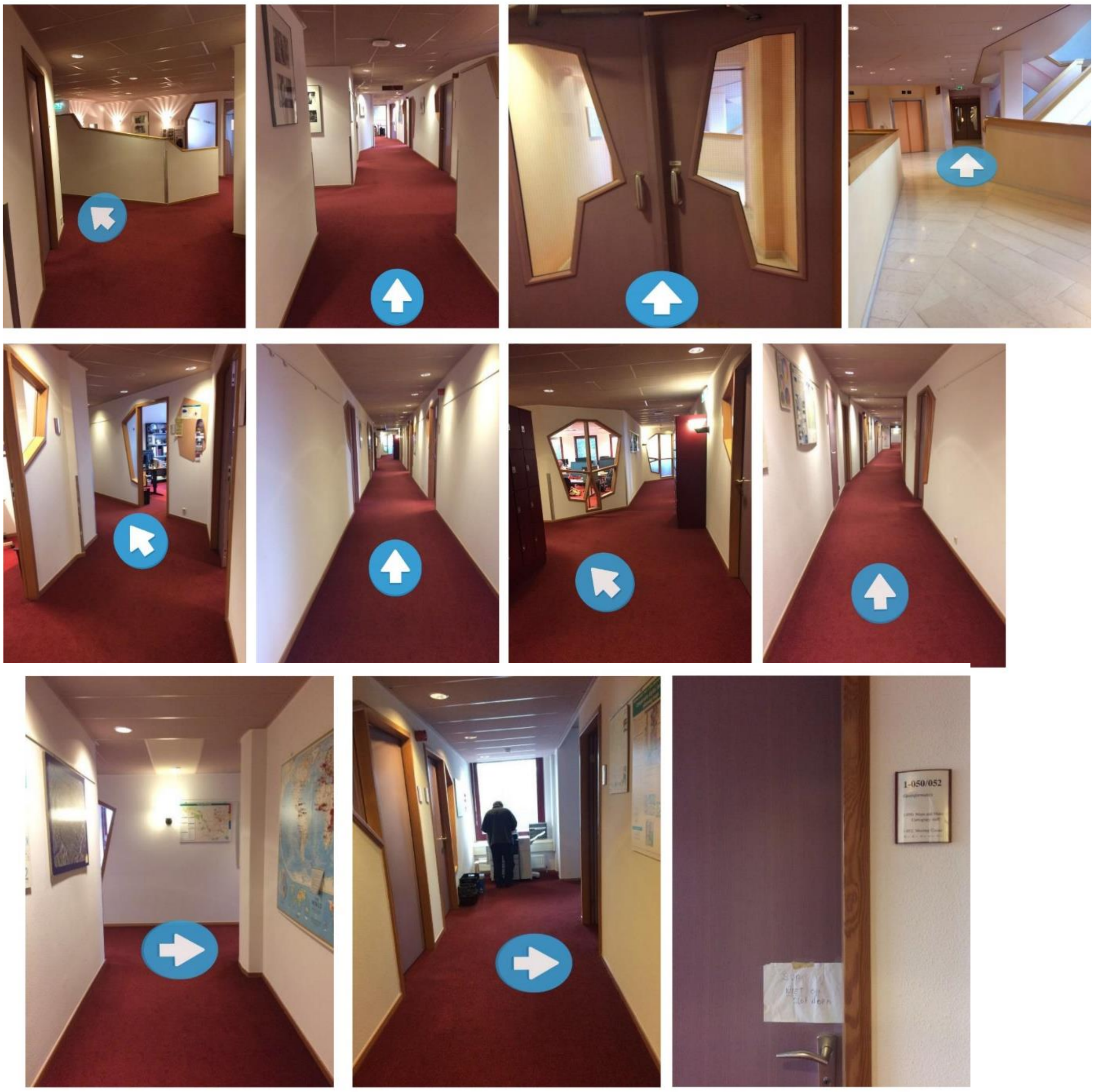
Origin to First destination Auditorium 0-143



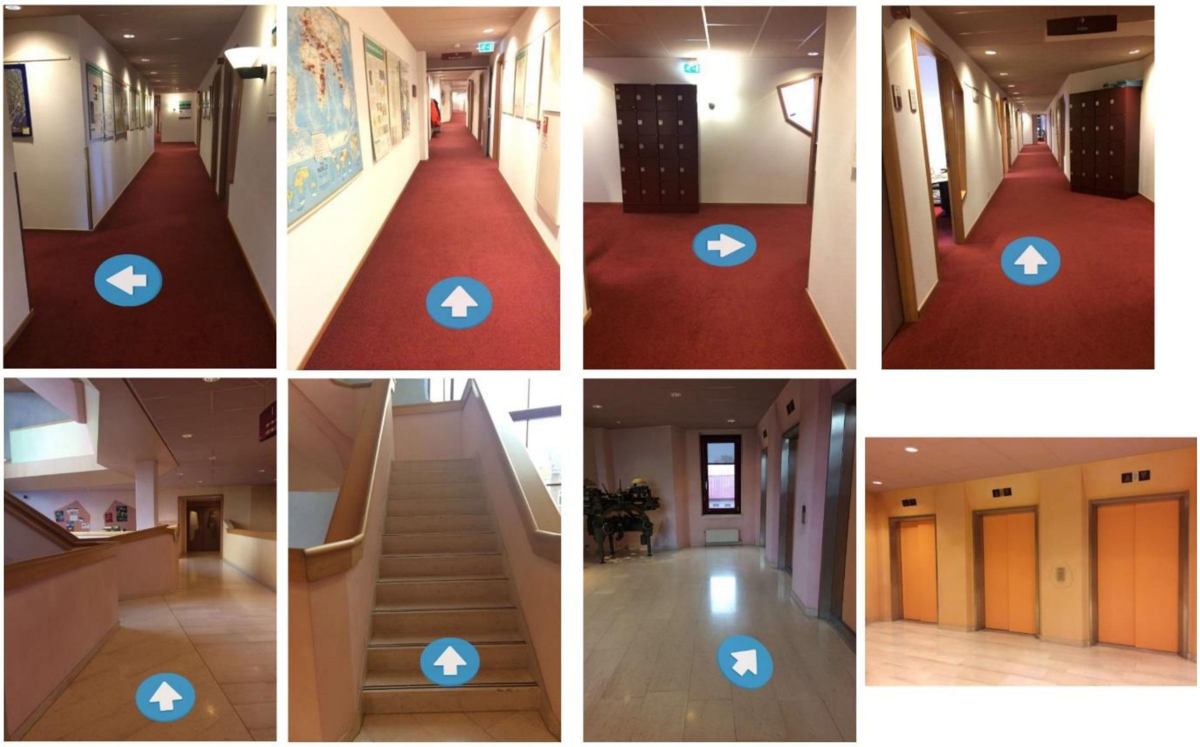
Auditorium 0-143 to second destination Room 1-119



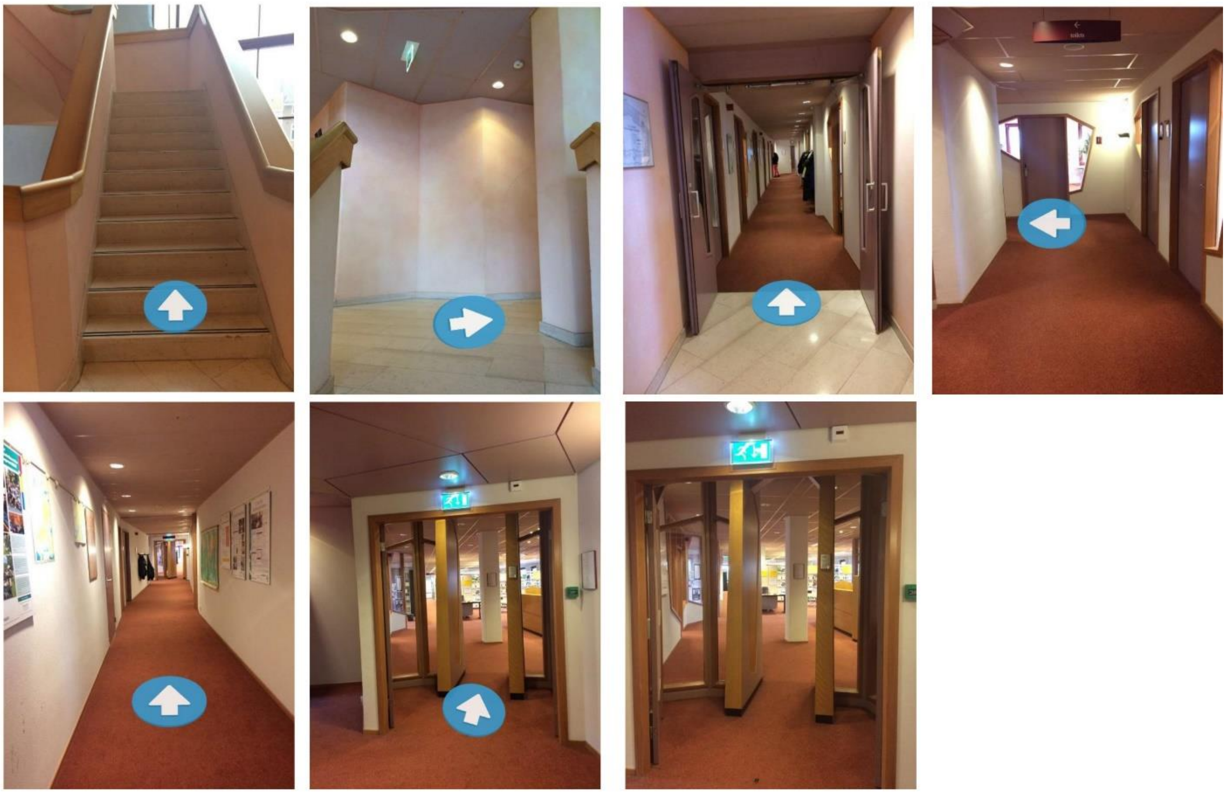
Room 1-119 to third destina tion 1-050



Room 1-050 to forth destination 2nd floor elevator



2nd floor elevator to fifth destination Library reception 3-042



Library reception to Final destination ground floor reception