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Impact of Navigation Aid and Spatial Ability Skills on Wayfinding Performance and Workload in Indoor-Outdoor Campus Navigation: Challenges and Design

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Abstract: Wayfinding is important for everyone on a university campus to understand where they are and get to where they want to go to attend a meeting or a class. This study explores the dynamics of mobile navigation apps and the spatial ability skills of individuals on a wayfinding performance and perceived workload on a university campus wayfinding, including indoor-outdoor navigation, by focusing on three research objectives. (1) Compare the effectiveness of Google Maps (outdoor navigation app) and MazeMap (indoor-outdoor navigation app) on wayfinding performance and perceived workload in university campus wayfinding. (2) Investigate the impact of participants' spatial ability skills on their wayfinding performance and perceived workload regardless of the used navigation app. (3) Highlight the challenges in indoor-outdoor university campus wayfinding using mobile navigation apps. To achieve this, a controlled experiment was conducted with 22 participants divided into a control (using Google Maps) and an experiment group (using MazeMap). Participants were required to complete a time-bound wayfinding task of navigating to meeting rooms in different buildings within the Gløshaugen campus of the Norwegian University of Science and Technology in Trondheim, Norway. Participants were assessed on spatial ability tests, mental workload, and wayfinding performance using a questionnaire, observation notes and a short follow-up interview about the challenges they faced in the task. The findings reveal a negative correlation between overall spatial ability score (spatial reasoning, spatial orientation, and sense of direction) and perceived workload (NASA TLX score and Subjective Workload Rating) and a negative correlation between sense of direction score and total hesitation during wayfinding task. However, no significant difference was found between the Google Maps and the MazeMap group for wayfinding performance and perceived workload. The qualitative analysis resulted in five key challenge categories in university campus wayfinding, providing implications for designing navigation systems that better facilitate indoor-outdoor campus navigation.

Keywords: indoor-outdoor navigation; wayfinding; campus navigation; mobile navigation app; spatial ability skills

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1. Introduction

Wayfinding and navigation are essentials for everyday experiences, whether we need to find our way to university, the grocery store, hiking up a mountain, or going to a new location [1,2]. Wayfinding is the ability to navigate through the environment by identifying one's location and arriving at destinations both cognitively and behaviorally [1]. The wayfinding task can be aided by providing environmental information cues that are helpful in building up important knowledge for the required wayfinding task. Such knowledge is classified into two categories: knowledge in the head and knowledge in the world, and wayfinding aids are useful to acquire information for transforming the knowledge in the world into knowledge in the head [3]. Several theories (such as route-based strategies and landmark-based strategies) and mechanisms (such as images or dual coding) have been studied to understand how knowledge is learned, structured and stored [4].

In general, all research focusing on navigation in the physical environment can be mainly divided into (1) outdoor navigation, (2) indoor navigation, and (3) a combination of both [4,5]. Outdoor navigation systems are already present everywhere and are widely used [6,7]. However, large campus buildings with connected facilities require indoor navigation aids. Therefore, in recent years, indoor navigation has become equally important and is a central challenge as it is a less developed area [6–9]. One of the most popular projects for navigation is Google Maps, but this is limited to outdoor services. This is because digital navigation solutions such as Google Maps are based on GPS signals, aerial photography, and satellite imagery that do not cover the inside of buildings, meaning a different service (indoor positioning system (IPS)) is needed to facilitate indoor navigation. Indoor navigation intends to help users find their way, avoid obstacles, recognize people, and find objects and resources, among others [5]. Several technologies such as Bluetooth, radio-frequency identification, Wi-Fi, magnetic and even LED light-based are used to solve the indoor navigation problem [10]. Some specialized solutions are available for indoor navigation, but the services are only for limited buildings [7]. With the advent of technology, working environments such as organizations or universities are becoming complex and consist of multiple buildings [3]. Therefore, finding one's way around becomes an additional challenge on top of work and study and requires integration of indoor and outdoor navigation [10–13] to provide seamless navigation from the start point to the point of interest within a building, saving time and energy. Although navigation tools have become more prevalent over the last decade as a resource for reliable wayfinding and route planning, finding systems that integrate indoor to outdoor navigation is a challenge in navigational research [14]. MazeMap is one such digital wayfinding solution that seamlessly integrates indoor and outdoor navigation, allowing users to move between buildings, e.g., on a university campus, with ease. Previous research has also focused on the comparison between different navigation aids to examine their effectiveness. For example, a comparison between mobile navigation systems and paper maps [15], a comparison between Electronic Map Interfaces (Google Maps and Yahoo! Map interfaces) [16], Novel map displays such as Mirror-In-The-Sky Map (MitS) and track-up maps [17]. However, among several research studies conducted on navigational aids, only a few are devoted to outdoor vs. indoor-outdoor navigation systems. Although there are several studies on outdoor navigation systems, only a few studies have focused on the human factors of indoor navigation systems, and there is a strong need to evaluate them [6].

Many factors contribute to the wayfinding ability and performance, including both internal (such as age, gender, types of strategies, sense of direction, comprehension, spatial abilities, etc.) and external (density of buildings, availability of meaningful landmarks, etc.) [1,18–20]. However, there is little consensus in the literature regarding the most important factors for predicting wayfinding ability and how to measure it [1]. Many researchers have investigated factors focusing on components of spatial ability, such as mental rotation skill tests, spatial visualization and spatial relations tasks [21]. Spatial ability is the ability to precisely visualize and recognize the visual-spatial world and the cognitive processes involved to achieve transformations (such as locating a target in space, directional relationships, perceiving distance, and mentally transforming objects based on orientation in space) on those perceptions. Spatial abilities are applied in everyday activities while finding a way [22]. According to research, individuals differ in their ability to process and visualize spatial information [23]. Some studies reported that people who have a good sense of direction (SOD) are faster wayfinders, show better performance, make fewer errors and make flexible use of strategies compared to people who have bad SOD [20,24]. Moreover, research has found that self-reported SOD measures quite highly predict the objective measures of these abilities [25]. However, only a few research studies have explored the relationship between spatial ability and wayfinding in the real world, and these studies have shown mixed results [21,26]. Overall, these studies can be grouped into self-assessment (in which researchers ask participants about their ability) studies and behavioral studies (in which researchers ask participants to solve tasks), with very few studies that have examined wayfinding tasks in the real environment [2]. More detailed research is required to investigate different variables in spatial ability skills and wayfinding and understand their influence on wayfinding performance to design more legible wayfinding systems [22].

Due to technological advancements, there is an increased reliance on navigation systems for wayfinding, but research focusing on the use, effects and evaluation of these approaches is still limited [22]. Therefore, in this study, we aim to examine Google Maps (an outdoor navigation app) in comparison with MazeMap (an indoor-door navigation app) for wayfinding on a university campus. The study focuses on understanding the role of navigation aids and spatial ability skills on perceived workload and wayfinding performance in indoor-outdoor campus navigation tasks. Moreover, the study also aims to identify the challenges in the use of current navigation systems for wayfinding in complex environments such as large university campuses requiring indoor-outdoor navigation. These results could provide empirical evidence and insights supporting the future design of integrated indoor-outdoor navigation systems. To achieve this, the study aims at answering the following research questions.

RQ1. Does indoor-outdoor navigation aid improve university campus wayfinding performance and reduce workload in comparison with outdoor-only navigation systems?
RQ2. Do spatial ability skills of wayfinders affect workload and wayfinding performance in university campus navigation?
RQ3. What are the main challenges in indoor-outdoor university campus navigation using mobile navigation aids?

The rest of this paper is structured as follows: Section 2 presents the related work. Section 3 describes the method used for this study. Section 4 presents the results from the wayfinding experiment concerning the three research questions. Section 5 discusses the results, presents design implications, and highlights the limitations of the study. Lastly, Section 6 concludes the paper and gives directions for future research.

2. Related Work

In this section, we provide an overview of relevant studies on wayfinding systems, indoor-outdoor navigation and the role of spatial ability and workload in wayfinding tasks that ground and guide our research. As far as we know, there are no other studies published that look at the relation between spatial ability, workload, and performance in wayfinding tasks for indoor-outdoor navigation. Moreover, there are only a few studies that compare the performance of outdoor-only navigation systems with indoor-outdoor navigation systems for wayfinding in urban environments, such as university campuses combining indoor and outdoor spaces.

2.1. Wayfinding and Navigation Systems

Wayfinding and navigation systems are important for improving people's quality of life. A number of applications are used by people on a daily basis to help them in moving across the urban environment and within buildings by providing them with useful information and detecting their position [27]. Outdoor navigation systems use global positioning systems (GPS) to track the location of the user, which are not effective in an indoor environment; therefore, other technologies (such as WiFi, Bluetooth, Beacons or RFID, etc.) are needed to track the location of the user in indoor areas [11,28].

A large body of research has been conducted to study navigation in outdoor environments. While outdoor navigation systems have been used extensively and are already represented everywhere, navigation is much less developed in the enclosed space and therefore, indoor navigation systems are still in the early stages of development [6,7,29]. Huang and Gartner [29] proposed an evaluation framework combining the key aspects of indoor navigation to investigate mobile indoor navigation systems. The study also presents a comparison of current mobile indoor navigation systems based on the proposed framework and concludes that "indoor navigation systems are still in an early development stage". Rehman and Cao [6] presented an augmented-reality application to assist people with indoor navigation. This research study particularly examined a wearable head-mounted device (Google glass) compared to handheld navigation aid such as a paper map and smartphone, focusing on technical assessment (including reliability and feasibility of the system) and human factors (including navigation time, route memory retention, perceived accuracy, subjective workload, and subjective comfort). The results indicated that the digital navigation aids (both wearable devices and smartphones) were better than the paper map with regard to lower workload and shorter navigation time. However, they were worse in terms of route retention. Moreover, the wearable device was not significantly different from the smartphone based on performance and workload but was perceived to be more accurate.

2.2. Wayfinding Focusing Indoor-Outdoor Navigation

Complex working environments, such as organizations with large campuses and multiple buildings, require the integration of indoor and outdoor navigation [10–12]. Although several studies have been conducted on navigation and wayfinding, more research focusing on combined indoor-outdoor navigation is required to meet the needs of wayfinding in complex urban environments [29].

Only recently, researchers have started to focus on combined indoor-outdoor navigation. For instance, Giudice et al. [9] reported on the development of a research plan for integrating outdoor and indoor spaces and discussed potential application domains and a variety of models (from formal models to functional models) related to the usability of indoor and indoor-outdoor information systems. Prandi et al. [27] presented a systematic mapping study focusing on software applications and devices intended to foster accessible wayfinding and navigation in outdoor and indoor environments [27]. Ren et al. [30] proposed an integrated navigation method (using differential GNSS and Lidar SLAM) to meet the needs of indoor and outdoor navigation. Similarly, Jiang et al. [31] described an integrated navigation system to support seamless indoor-outdoor navigation based on Global Navigation Satellite Systems (GNSS), Inertial Navigation Systems (INS), and Terrestrial Ranging Techniques. The proposed system was evaluated by conducting an indoor-outdoor test, and results showed that it could provide reliable and continuous position and attitude solutions. Moreover, Vanclooster and Maeyer [14] studied the impact of combining indoor and outdoor navigation on route planners by reviewing several case studies in multiple route planners. The study revealed different aspects and requirements, such as data constraints (preventing optimal use of navigation routes) and addressed matching methodologies (the exit influencing the exit choice of the building) for integration of indoor with outdoor connection in wayfinding. Furthermore, Pfaff et al. [32] proposed an approach based on multi-level surface maps for navigation in combined outdoor and indoor environments. The approach does not rely on GPS information, and the presented technique allows the robot to actively explore the environment [32]. Nikander et al. [11] presented a prototype for an indoor and outdoor mobile navigation system using floor plans together with street maps for route finding and displaying a hybrid map for a university campus. The prototype is implemented on iPad, but the work is still under process; GPS is used for outdoor positioning, and QR codes are used for indoor positioning.

2.3. University Campus Navigation

The route planning functions in current navigation systems in the market do not efficiently process the outdoor and indoor localization information simultaneously. Moreover, these systems also have limitations by the service platforms which compromises the user interface (UI) experiences [12]. Torres-Sospedra et al. [10] focused on mobility in smart campuses and developed a novel combined indoor and outdoor positioning system to support wayfinding with seamless indoor-outdoor navigation for the Universitat Jaume I

(Spain). They further developed and evaluated two mobile applications (SmartUJI APP and SmartUJI AR) that allow users to get map-based information about different campus facilities and provide an augmented reality interface to interact with the campus. The applications were tested by university staff, students and visitors, and they found it useful for locating university facilities and improving spatial orientation. Similarly, Zhou et al. [12] presented an augmented reality-based campus navigation system and conducted indoor and outdoor navigation experiments at the campus of Shanghai University of Electric Power to compare the proposed system with traditional systems, such as Internet media or Gaode map. The results showed an increased precise outdoor localization and improved the user's interactive experience facilitating the usability and effectiveness of learning on campus. The Norwegian University of Science and Technology (NTNU) partnered with Wireless Trondheim to develop MazeMap (earlier known as CampusGuide [33]) to provide seamless indoor-outdoor navigation initially for its main Gløshaugen campus [8], which is now used on a large number of campuses and universities [34]. Biczok et al. [8] conducted a campus case study presenting insights from MazeMap reflecting on the spatial and temporal distribution of MazeMap user requests (geo-location and wayfinding), mapping user mobility patterns of the campus, and spatial-logical connection between different locations in different buildings. The results from their study highlighted the potential of such systems for usage on campus and for other venues such as hospitals, shopping malls, and emergency preparedness.

Several researchers have focused on the use of different navigation aids for wayfinding across campus environments. Schnitzler and Hölscher [18] compared user experience and wayfinding strategy choices for navigation through a complex building using three different types of wayfinding aid (without any map, with a printed map, and with a digital map). According to the results, there was a significant difference between the two map groups and the no map group with respect to search time. However, there were no significant differences between the two map groups in how efficiently they found destinations. Moreover, wayfinding strategy choices did not differ between the groups, but the choices were shaped by the participants' individual preferences and the building with its signage. Cheung [35] investigated the use of different representational options for providing visitors with navigational cues to the site (Auckland University Campus). Wayfinding performance data was obtained from participants for prototyped navigation systems of different representations. The advantages and disadvantages of different systems were identified to find appropriate approaches for designing an interactive system. Kim et al. [36] explored the use of digital signage for improved wayfinding performance. The study evaluated the campus information digital signage, which can be useful for campus visitors as a wayfinding tool. The results showed that digital signage is better than traditional or paper signage and indicated that the integration of these methods could highlight effective content and design features to help design user-centered wayfinding digital signage. Asif and Krogstie [37] investigated and evaluated the use of a mobile student information system (MSIS) to provide relevant information to students to enhance their campus life. The results showed a high intention to use such services, especially providing information based on students' schedules, interests, and localization. Gao et al. [38] explored the adoption of indoor location-based services in Norway using Technology Acceptance Model (TAM). The results of the survey showed a strong influence of perceived usefulness on the intention to use, whereas no positive effect of trust was found on intention to use.

2.4. Spatial Ability and Workload in Wayfinding Task

Different researchers have investigated the relationship between spatial ability and wayfinding, focusing on either outdoor or indoor navigation. Malinowski [21] investigated the relationship between mental rotation skills (using the Vandenburg Kuse Mental Rotations test) and college students' wayfinding performance in an outdoor navigation task. The results showed a significant correlation between mental rotation skills and wayfinding performance on a 6-km orienteering task. The study also highlighted sex differences in spatial ability. Similarly, Nori et al. [26] examined the impact of visuo-spatial ability (V-SA) on wayfinding performance. The wayfinding task focused on a route (approximately 360 m long) in the botanical garden of the university. According to the results of their study, participants with high V-SA had better wayfinding performance and different wayfinding behavior than participants with low V-SA. Participants with low V-SA hesitated more during traveling even if traveling time was the same. Moreover, participants with low V-SA adopted a landmark strategy to navigate, whereas people with high V-SA adopted a route or survey strategy. Verghote et al. [23] conducted an experiment to analyze the influence of spatial cognition and different information formats (two-dimensional (2D) drawings or a three-dimensional (3D) model) on individual wayfinding in an unfamiliar environment. The wayfinding task focused on indoor navigation from the starting point to checkpoint A and then to checkpoint B within the building. The results showed that 3D models have a positive impact on individual wayfinding. Moreover, participants with a low spatial cognition had a significantly improved success rate when using a 3D model but the success rate of participants with a high spatial cognition was not affected by the information format. However, more research is needed to confirm whether information format such as 3D effectively reduces cognitive demand [23]. Although there are many studies that examine the relationship between spatial ability and wayfinding performance, only a few focus on complex environments with combined indoor-outdoor navigation [39].

Mental workload is another important measurement and subject of interest for wayfinding and navigation tasks. Researchers have investigated the effects on users' mental workload and task performance when navigating through indoor or outdoor environments using different technologies or evaluating the usability of technologies in many application areas [17,40]. Vasquez et al. [17] investigated the effect of practice with Mirror-in-the-Sky (MitS) and track-up maps on navigation performance and mental workload (MWL) in a simple navigation task in a virtual environment. According to the results of a three-session experiment, secondary task performance improved, and task completion times, collisions and subjective MWL decreased with practice. The decrease in MWL was larger with MitS as compared with the track-up map. However, the differences between the track-up map and MitS decreased and were negligible as sessions progressed. Lin and Wang [16] studied the impact of four designing factors (map type, map size, zoom function and direction key) as well as gender differences and sense of direction (SOD) ability on the visual wayfinding performance for a simulated electronic map interface for three wayfinding tasks. The research showed that participants with higher SOD scores had faster response times and lower overall workload for the target task. As the response time of participants increases, they experience a higher workload. Moreover, for target and direction tasks, the interaction effect of map type and SOD affect the mean response time. The male participants with good SOD, using a mixed map, and good SOD using E-map had faster mean response times. Whereas females using E-map had faster mean response time. Bradley and Dunlop [4] investigated the difference in mental and physical demands between a group of sighted and visually impaired participants when provided with two different verbal instruction sets guiding them to four different landmarks. The two verbal instructions were a set of route descriptions: the first derived from sighted people, and the second set derived from visually impaired people. The study focused on navigation time, number of deviations and workload. The results showed that instructions derived from visually impaired people resulted in quicker time, fewer deviations and lower workload scores for visually impaired participants but caused higher workload scores for the sighted participants. It is important to understand if some navigation aids are more intuitive than others, but it is also crucial to investigate if the effects on task performance are resultant of the effect on mental workload, and this area is less explored [17,40].

3. Materials and Methods

This section presents the participants of this study, the experimental design describing research context and procedures, the digital navigation platforms used for the experiment, the data sources, and the methods used for data analysis in this wayfinding study.

Wayfinding is important for students, faculty, staff, visitors, and anyone else on a university campus to understand where they are and where they want to go to attend a meeting or a class. Navigation systems are ubiquitous tools to assist wayfinders with various navigational tasks, thus reducing human effort for navigating. In this study, we conducted a field experiment using control and experiment groups to evaluate users' wayfinding performance and workload in an indoor-outdoor campus navigation when using Google Maps (an outdoor-only navigation app) in comparison with MazeMap (an indoor-outdoor navigation app) for wayfinding on a university campus. In addition to understanding the role of navigation aids, this study also explores the effects of spatial ability skills on perceived workload and wayfinding performance in campus wayfinding tasks and identifies challenges for designing efficient indoor-outdoor navigation systems for wayfinding in complex environments such as large university campuses. This study uses both quantitative and qualitative methods to address the three research questions presented in the introduction. The following hypotheses were formulated for the first two research questions:

Hypothesis (H1). *Indoor-outdoor navigation app group will show better wayfinding performance as compared to the outdoor-only navigation app group in the university campus wayfinding task.*

Hypothesis (H2). *Indoor-outdoor navigation app group will experience less workload as compared to the outdoor-only navigation app group in the university campus wayfinding task.*

Hypothesis (H3). *Participants who have better spatial ability skills will experience less workload in the university campus wayfinding task.*

Hypothesis (H4). *Participants who have better spatial ability skills will have better wayfinding performance in the university campus wayfinding task.*

3.1. Participants

For this experiment, twenty-two participants were recruited during March and April 2022. Out of the 22 subjects, 5 were males (23%) and 17 females (77%) who ranged in age from 24 to 43 (mean = 30.8 years, SD = 5.9). This research focused on wayfinding tasks, including indoor-outdoor navigation at the Gløshaugen campus of the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway. The Gløshaugen campus is the largest campus of NTNU and covers 350,000 sqm with more than 60 buildings and 13,000 rooms [8]. The participants for this experiment were students, permanent and temporary staff, visitors, and others on the university campus, as wayfinding is important for them to understand where they are and how to get to where they want to go, such as attending a meeting or a class. The participants included 14 temporary staff (63.6%), 5 students (22.7%), and one of each: permanent staff, visitor and other (4.5% each). The participants had different academic backgrounds; 13 had a master's degree (59.1%), 5 had a bachelor's degree (22.7%), and 4 had a PhD (18.2%). All participants had experience using outdoor navigation apps, e.g., Google Maps, and most of them (95.5%) reported frequent use. On the contrary, all except one participant had experience using indoor-outdoor navigation apps, e.g., MazeMap, but most of them (77.3%) reported that they rarely use them, and only 4 participants (18.2%) reported frequent use. None of the participants had already seen the rooms mentioned in the wayfinding task in the experiment.

The participants were contacted through the university mailing list and intranet channel. This study was organized in multiple sessions conducted over two weeks, from 24 March 2022 to 7 April 2022. The researcher explained the study and obtained consent from participants for data collection. They were told that their participation was voluntary, that they could withdraw their consent at any time without giving a reason, and that all information about them would then be made anonymous. The participants were compensated with a gift card as a token of appreciation for their time and effort. The experiment was conducted on the Gløshaugen campus at the Norwegian University of Science and Technology (NTNU) Trondheim, Norway. No prior knowledge or preparation was required; participants just came with their smartphones or were provided with one.

3.2. Experiment Design

The wayfinding experiment design is illustrated in Figure 1. The experiment took approximately one hour and had three phases (as shown in Figure 1):

1. Pre-Wayfinding Task Phase (15–20 min): Before the task, all participants read and signed a consent form and filled out a demographic questionnaire. The participants were also required to complete the Santa Barbara Sense of Direction Scale (SBSOD) [25] and two spatial ability tests to evaluate the sense of direction, spatial orientation and spatial reasoning (see Appendix A) of each individual.
2. Wayfinding Task (30–35 min): This phase focuses on performing the actual wayfinding task. The study used an independent group design, and participants were divided into two groups (control and experiment) of eleven participants each. Participants were randomly assigned to either the control or the experiment group and were required to complete a wayfinding task using either an outdoor or indoor-outdoor navigation app, depending on the assigned group. Both groups were provided with a clear set of instructions concerning the experiment and performed the same wayfinding task. The only difference was that the control group used an outdoor navigation app (Google Maps), and the experiment group used an indoor/outdoor navigation app (MazeMap) to complete the same wayfinding task. Each participant was tested individually.

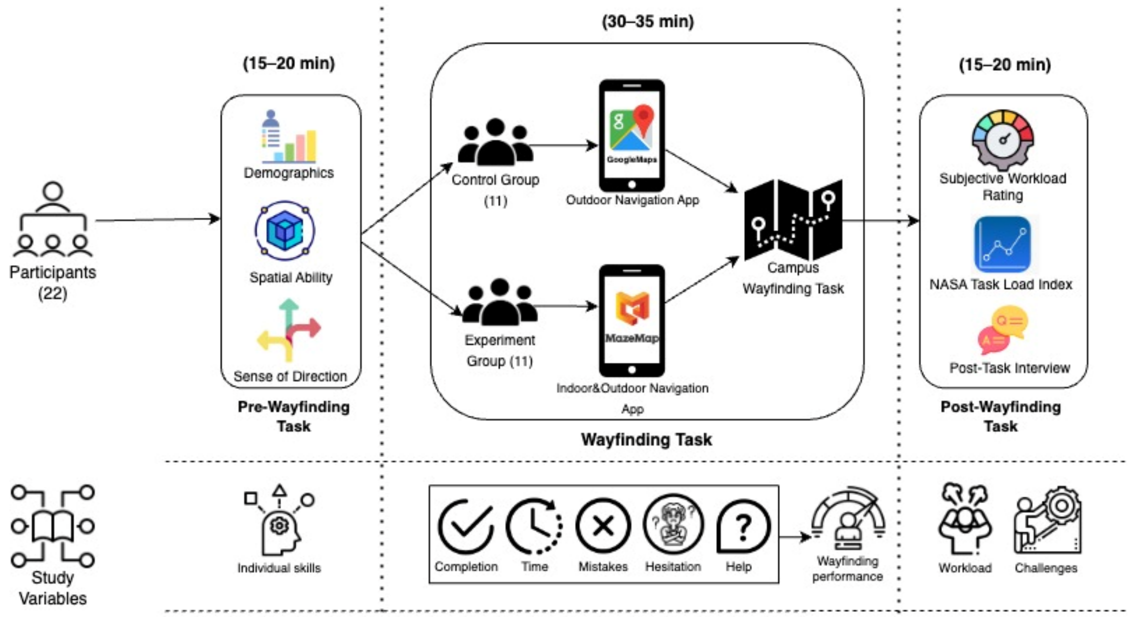

Figure 1. Wayfinding experiment design.

The wayfinding task selected for the experiment included navigating to two different meeting rooms in a specified order within the campus (see Appendix B for details of the task). The wayfinding task routes were all located on the Gløshaugen campus of the Norwegian University of Science and Technology (NTNU) in Trondheim, Norway (shown in Appendix B). The starting points and destinations were pre-defined. The participants were instructed to find their way to the destinations from the starting point by referring to the mobile navigation app (Google Maps or MazeMap), depending on their designated group.

The task finished when the participant reached the second venue. Each participant individually performed this task where an observer followed them silently (without intervening) to take field notes (recording wayfinding performance parameters, i.e., task completion, time, mistakes, hesitation, and help) and observations. The participants had 30 min to complete this task. The task scenario and route maps are presented in Appendix B.

3. Post-Wayfinding Task Phase (15–20 min): After completing the wayfinding task, participants were asked to complete mental workload questionnaires (NASA-TLX rating and subjective workload questionnaire) and a short follow-up interview.

3.3. Digital Mobile Navigation Apps Used

Two digital navigational aids were used for the experiment: Google Maps was adopted as an outdoor-only navigation aid, and MazeMap was used as an indoor-outdoor navigation aid. Participants used a smartphone to run the application for navigation during the wayfinding task.

Google Maps is one of the most popular navigation aids and enables people to navigate to their desired destination by providing the shortest and most convenient route. However, Google Maps is only limited to outdoor navigation. It has many helpful features, such as street view and the location of nearby cafes, hospitals and police-stations [41]. MazeMap is an indoor-outdoor positioning and navigation system. It can locate the position of the user on campus and provides room-level wayfinding and object search capabilities. Moreover, when the user is outdoors, MazeMap is also able to use standard GPS positioning, and the system is also able to combine WiFi and GPS signals if available. The system uses construction drawings on the user interface side to present the users with readable maps and interprets them to recognize different objects. The user can choose what to hide or show so the maps are not overloaded with unnecessary technical data [8].

3.4. Data Sources

The data sources used in this study included the following:

- Demographic questionnaire: This included questions related to bio-demographics (such as age, gender, education, and role) and experience using outdoor and indoor-outdoor navigation tools.
- Spatial ability test: The measurement of spatial ability skills depends on multiple factors focusing on multiple spatially relevant abilities. While different researchers have focused on different factors, the two that are most often cited include spatial orientation (also referred to as spatial relations) and spatial visualization (Spatial reasoning) [42]. Therefore, we included two tests, a "spatial reasoning test" and a "spatial orientation test", to assess participants' visuo-spatial ability. A spatial reasoning test (shown in Appendix A) was used to determine the participant's ability to manipulate 2D and 3D objects, visualize movements and changes between shapes, and spot patterns between those shapes. This test consisted of 9 questions, each consisting of abstract shapes, which participants had to mentally manipulate and choose the correct option out of the four choices. There is a limit of 40 s for each question. The spatial orientation test was used to test participants' ability to imagine different perspectives or orientations in space. The test used for this study was adopted from the version used by [43]. There were 12 items in this test, one on each page. Each question contained a picture of an array of objects and an "arrow circle" with a question about the direction between some of the objects. The task was to draw an arrow from the center object showing the direction to a third object from the facing orientation. Participants had 5 min to complete this test.
- Santa Barbara Sense of Direction scale (SBSOD): According to [44], three substantially correlated factors emerged after examining the structure of spatial ability, and this included navigation in addition to object manipulation and visualization. Therefore, we used the Santa Barbara Sense of Direction Scale (SBSOD) scale [25] to access navigation. This is a self-report scale of environmental spatial ability and is a useful instrument for

measuring the construct of Sense of Direction (SOD). It contained 15 statements asking about participants' spatial and navigational abilities, experiences, and preferences. The participants had to rate each statement that describes the participant's sense of direction on a 7-point Likert scale from "1" (strongly agree) to "7" (strongly disagree).

- NASA Task Load Index (TLX) rating: NASA-TLX [45,46] is a multi-dimensional scale that provides an overall workload score using six workload-related factors consisting of mental demand, physical demand, temporal demand, performance, effort and frustration). This study aimed to use NASA-TLX as an objective measure of the workload of the wayfinding task [47].
- Subjective workload rating (SWR): In addition to the NASA-TLX, a second instrument was used as a subjective measure of workload. A Subjective Workload Rating (SWR) questionnaire developed by [42] was administered to all participants to evaluate how they felt about the wayfinding task on a scale of 1 to 10. This instrument consists of the following sub-scales: Easy/difficult, relaxing/stressful, required minimal effort/labor intensive, pleasant/annoying, calming/frustrating and simple/complex.
- Field Notes: This was used to record the parameters of wayfinding performance [48] and observation notes. The following parameters were recorded for the wayfinding task: start time, end time, number of times asked for help/assistance, took a wrong direction (e.g., turned back after taking a direction), frequency of hesitations (i.e., every time participant stopped to think about the way to take), task completion and observation notes regarding campus navigation during the task.
- Post-Task Interview: The interview consisted of three questions related to their experience, challenges they faced, and suggestions to mitigate such challenges and improve wayfinding applications. The questions were:
    1. How was your experience with this wayfinding task? (e.g., were you stressed/relaxed, was it easy/difficult, asked for help for navigating to the meeting rooms, etc.)
    2. Describe the challenges you faced during the wayfinding task?
    3. What would have helped you in completing this wayfinding task more efficiently? Give suggestions for improving the navigation tool.

3.5. Data Analysis

The IBM SPSS Statistics v28 software was used for the quantitative data analysis (RQ1–2) and NVivo software was used for the qualitative data analysis (RQ3). We conducted a *t*-test to examine any potential difference in the Wayfinding performance (Task time, task completion, mistakes, hesitation, help) and workload of participants in the control and experiment groups. Spearman correlation was used to identify any potential correlation between spatial ability skills, workload, and wayfinding performance. The qualitative data collected through interviews and observation notes was analyzed and interpreted through grounded theory approach proposed by Gioia et al. [49]. This resulted in a data structure for challenges and identified key issues that hindered the successful and satisfactory usage of navigational apps for indoor-outdoor navigation in large university campuses. Finally, based on the findings, some design recommendations were proposed for designing efficient navigation tools for campus wayfinding.

4. Results

This section presents the results from the wayfinding experiment to answer the three research questions presented in the introduction section. The first two questions are addressed with quantitative data analysis using statistical tests. We reported the differences in the wayfinding performance and workload between the control and experiment groups. Secondly, we looked at the effect of spatial ability skills on the workload and wayfinding performance of participants regardless of their group in indoor-outdoor navigation tasks. We will explore four hypotheses (H1–H4 presented in Section 3) in this study. The first two are linked to research question one, and the next two are related to research question two.

The third question is addressed with qualitative data analysis and identifies the challenges and issues faced by participants when performing the indoor-outdoor university campus wayfinding task using mobile navigation apps.

4.1. RQ1: Indoor-Outdoor vs. Outdoor Only Mobile Navigation Aid in Campus Wayfinding (Performance and Perceived Workload)

This research question investigated how the participants' wayfinding performance and perceived workload in campus navigation tasks using the provided navigation aid (outdoor navigation app vs. indoor-outdoor navigation app) differs between the control (using Google Maps) and the experiment group (using MazeMap). This research question focused on hypotheses H1 and H2.

The null hypothesis for H1 was that there was no difference between the wayfinding performance of participants in the control (outdoor navigation app: Google Maps) and experiment (indoor-outdoor navigation app: MazeMap) groups.

The wayfinding performance is measured in terms of total task duration, total help, total wrong directions, total hesitation, and total task completion. An independent *t*-test was conducted to compare the wayfinding performance between the control and experiment groups. The independent variable was the groups with different navigation aid: outdoor navigation app vs. indoor-outdoor navigation app, and the dependent variables were wayfinding performance parameters: total task duration, total help, total hesitation, total wrong directions, and total task completion. The *t*-test is appropriate for our experiment as it is used to study if there is a statistical difference between two independent groups. The results from the *t*-test are shown in Table 1.

Table 1. Independent *t*-test to compare wayfinding performance between the control and experiment groups.

				Levene's Test for Equality of Variances		*t*-Test for Equality of Means						
		Mean	SD	F	*p*-Value	t	df	*p*-Value	Mean Diff.	Std. Error Diff.	95% Confidence Interval of Difference	
											Lower	Upper
Total task duration	CG EG	24.82 22.00	7.561 8.390	0.015	0.902	0.828	20	0.418	2.818	3.405	−4.285	9.922
Total help	CG EG	1.18 0.55	1.168 0.934	1.107	0.305	1.411	20	0.174	0.636	0.451	−0.304	1.577
Total wrong directions	CG EG	2.00 2.19	1.414 1.514	0.107	0.747	−0.146	20	0.886	−0.091	0.625	−1.394	1.212
Total hesitation	CG EG	2.27 1.64	1.555 1.120	3.805	0.065	1.101	20	0.284	0.636	0.578	−0.569	1.842
Total task completion	CG EG	1.64 1.73	0.674 0.647	0.217	0.646	−0.323	20	0.750	−0.091	0.282	−0.678	0.497

Significance level, $p < 0.05$. Mean for total task duration is in minutes and number of times for others. For task completion, a score of 0 was given if no meeting room was found, 1 if one meeting room was found and 2 if both meeting rooms were found.

According to the results, no significant difference was found in wayfinding performance between the control and experiment groups. There were no significant differences in total task duration (t (20) = 0.828, p = 0.418); total help (t (20) = 1.411, p = 0.174); total wrong directions (t (20) = −0.146, p = 0.886); total hesitation (t (20) = 1.101, p = 0.284); and total task completion (t (20) = −0.323, p = 0.750) between the two groups ($p \geq 0.05$), failing to reject the null hypothesis. Despite this, the mean task duration (M = 24.82, SD = 7.561) for the control group (CG) was higher than the experiment group (EG) (M = 22.00, SD = 8.390). Similarly, the mean help (M = 1.18, SD = 1.168) and hesitation (M = 2.27, SD = 1.555) for the control group (CG) was higher than the mean help (M = 0.55, SD = 0.934) and hesitation (M = 1.64, SD = 1.120) for the experiment group (EG). However, the magnitude of the difference in the means for total task duration (mean difference = 2.818, 95% CI: [−4.285, 9.922]), total help (mean difference = 0.636, 95% CI: [−0.304, 1.577]), and total hesitation (mean difference = 0.636, 95% CI: [−0.569, 1.842]) was not significant. Hence, H1 was not supported.

The null hypothesis for H2 was that there was no difference between the perceived workload of participants in the control (Google Maps) and experiment (MazeMap) groups.

The perceived workload is measured using the NASA TLX score and subjective workload rating (SWR) score. Again, an independent *t*-test was conducted to compare the perceived workload between the control and experiment groups as it is used to study if there is a statistical difference between the two independent groups. The independent variable was the groups with different navigation aid (outdoor navigation app vs. indoor-outdoor navigation app). The dependent variables were the NASA TLX score and SWR score. The results from the *t*-test for H2 are shown in Table 2. According to the results, there was no significant difference in NASA TLX score (t (20) = −0.429, p = 0.673) and SWR score (t (20) = 0.706, p = 0.488) between the two groups ($p \geq 0.05$), failing to reject the null hypothesis. Hence, H2 was also not supported.

Table 2. Independent *t*-test to compare perceived workload between control and experiment group.

				Levene's Test for Equality of Variances		*t*-Test for Equality of Means						
		Mean	**SD**	**F**	***p*-Value**	**t**	**df**	***p*-Value**	**Mean Diff.**	**Std. Error Diff.**	**95% Confidence Interval of Difference**	
											Lower	**Upper**
NASA TLX score	CG EG	40.23 43.71	22.064 15.498	0.616	0.442	−0.429	20	0.673	−3.485	8.130	−20.443	13.473
SWR score	CG EG	5.02 4.45	1.849 1.874	0.007	0.932	0.706	20	0.488	0.561	0.794	−1.095	2.216

Significance level, $p < 0.05$.

4.2. RQ2: Effect of Spatial Ability Skills on Campus Wayfinding (Performance and Perceived Workload)

This research question investigated the effect of spatial ability skills on the perceived workload and wayfinding performance of all participants in indoor-outdoor campus navigation tasks regardless of their group (i.e., used navigation aid). The spatial ability skills of all participants were assessed before conducting the navigation task using mobile navigation aid. After the first phase (pre-task phase, see Figure 1), participants were randomly assigned to the control and experiment groups. The descriptive statistics presented in Table 3 show that the spatial ability skill parameters of participants in both groups are fairly equal, which shows that results in the previous section were not affected by the spatial ability skills of participants. The spatial ability skills were measured on three parameters spatial reasoning test, spatial orientation test and navigation (using the Santa Barbara Sense of Direction (SBSOD) scale). The scores of these three factors were added to get an overall score for spatial ability skills.

Table 3. Descriptive statistics for control and experiment groups.

Descriptive Statistics	Control Group	Experiment Group
Age	29.54	31.64
Male	2	3
Female	9	8
Spatial reasoning	6.45	6.73
Spatial orientation	7.27	8.09
SBSOD	3.96	4.16

A series of Pearson's correlations were conducted to identify any potential correlation between the participant's spatial ability skills parameters (spatial reasoning score, spatial orientation score and SBSOD score), their perceived workload (NASA TLX score and SWR score), and wayfinding performance parameters (task duration, task completion, total help, total hesitation, and total wrong directions). Pearson's correlation measures the strength and direction of the linear relationship between two variables. Pearson's correlation was used to determine whether the variables of interest are correlated or related to each other, and the data met all the assumptions required for using Pearson's correlation. All results for Pearson's correlation are presented in Tables 4 and 5. This research question focused on hypotheses H3 and H4.

Table 4. Pearson's correlation between spatial ability skills and perceived workload.

		NASA TLX Score	SWR Score
Overall Spatial Ability Skill	Pearson Correlation	−0.559 **	−0.466 *
	p-Value	0.007	0.029
	N	22	22
Spatial reasoning	Pearson Correlation	−0.404	−0.287
	p-value	0.062	0.195
	N	22	22
Spatial orientation	Pearson Correlation	−0.500 *	−0.348
	p-value	0.018	0.113
	N	22	22
SBSOD	Pearson Correlation	−0.104	−0.351
	p-value	0.644	0.109
	N	22	22

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

Table 5. Pearson's correlation between spatial ability skills and wayfinding performance.

		Total Task Duration	Total Help	Total Wrong Directions	Total Hesitation	Total Task Completion
Overall Spatial ability skill	Pearson Correlation	−0.342	−0.079	−0.195	−0.266	0.365
	p-value	0.119	0.726	0.385	0.231	0.095
	N	22	22	22	22	22
Spatial reasoning	Pearson Correlation	−0.040	−0.133	−0.062	−0.035	0.112
	p-value	0.860	0.556	0.786	0.877	0.619
	N	22	22	22	22	22
Spatial orientation	Pearson Correlation	−0.330	−0.161	−0.157	−0.151	0.308
	p-value	0.134	0.474	0.485	0.501	0.164
	N	22	22	22	22	22
SBSOD	Pearson Correlation	−0.239	0.346	−0.183	−0.498 *	0.306
	p-value	0.285	0.115	0.415	0.018	0.166
	N	22	22	22	22	22

* Correlation is significant at the 0.05 level.

The third hypothesis focuses on the relationship between spatial ability skills and workload in campus wayfinding. The null hypothesis for H3 was that the spatial ability skills of participants will not impact the workload they experience in the university campus wayfinding task.

Pearson's test (see Table 4) revealed a significant negative relationship between the overall score for spatial ability skill and perceived workload parameters: NASA TLX and SWR. It means that the spatial ability skills of participants affect the workload they experience in indoor-outdoor campus wayfinding tasks using mobile navigation apps. It shows that participants who had higher spatial ability skills experienced less workload during campus navigation using mobile apps. However, if we look further in detail at the three parameters of spatial ability skill, only spatial orientation has a significant relationship with the NASA TLX score. There was no significant relationship between any of the other two spatial ability skill parameters (Spatial reasoning and *SBSOD*) and perceived workload (NASA TLX score and SWR score).

Pearson's correlation of overall spatial ability skill and NASA TLX score was found to be a strong correlation and statistically significant ($r = -0.559$, $p < 0.01$), rejecting the null hypothesis. Similarly, the correlation between the spatial orientation and NASA TLX score was also found to be a strong correlation and statistically significant ($r = -0.500$, $p < 0.05$). At the same time, a medium correlation ($r = -0.466$, $p < 0.05$) was found between the overall spatial ability skill and SWR score. Hence, H3 was supported. This show that participants with higher spatial ability skills would experience less workload in the indoor-outdoor campus wayfinding task.

The fourth hypothesis focuses on the relationship between spatial ability skills and wayfinding performance in campus wayfinding. The null hypothesis for H4 was that the spatial ability skills of participants will not impact their wayfinding performance in the university campus wayfinding task.

Pearson's test (see Table 5) revealed a significant negative relationship only between one of the three parameters of spatial ability skills, i.e., navigation (SBSOD score) and total hesitation. It means that participants' sense of direction affects one of the five parameters of wayfinding performance, i.e., total hesitation. It shows that participants with a better sense of direction experienced less hesitation during wayfinding in indoor-outdoor campus navigation using the mobile app. However, none of the other two parameters of spatial ability nor the overall spatial ability skill had a significant relationship with any of the five wayfinding performance parameters (total task duration, total help, total hesitation, total wrong directions, and total task completion). Pearson's correlation of SBSOD and total hesitation was found to be a medium correlation and statistically significant ($r = -0.498$, $p < 0.05$), rejecting the null hypothesis. Hence, H4 was partially supported.

4.3. RQ3: Challenges in University Campus Wayfinding Using Mobile Navigation Apps

The last research question investigated the challenges faced by participants during indoor-outdoor university campus wayfinding task using mobile navigation apps. As the participants were divided into control and experiment groups, two navigation apps were used. The control group used Google Maps (an outdoor-only navigation app), and the experiment group used MazeMap (an indoor-outdoor navigation app). The qualitative data was collected through observation notes from the wayfinding task and short post-task interview responses from participants of both groups regarding their experience and challenges in university campus wayfinding. According to [50], qualitative data analysis is important to deepen the understanding of research participants. Therefore, the procedure described by Gioia et al. [49] was followed for analyzing, interpreting, and presenting data. The results highlight the issues in indoor-outdoor campus wayfinding using the two navigation apps: Google Maps and MazeMap. It also provides insight into challenges related to the specific technology that they used and how these navigation applications can be further improved to facilitate university campus wayfinding that combine indoor and outdoor navigation.

The analysis followed the grounded theory approach described by [51,52] and resulted in a data structure with three levels, as shown in Figure 2:

(1) First column—the first level highlighted the challenges from participant's feedback, i.e., raw data.
(2) Second column—the second level identified the themes for these challenges.
(3) Third column—the third level aggregated the created themes into categories.

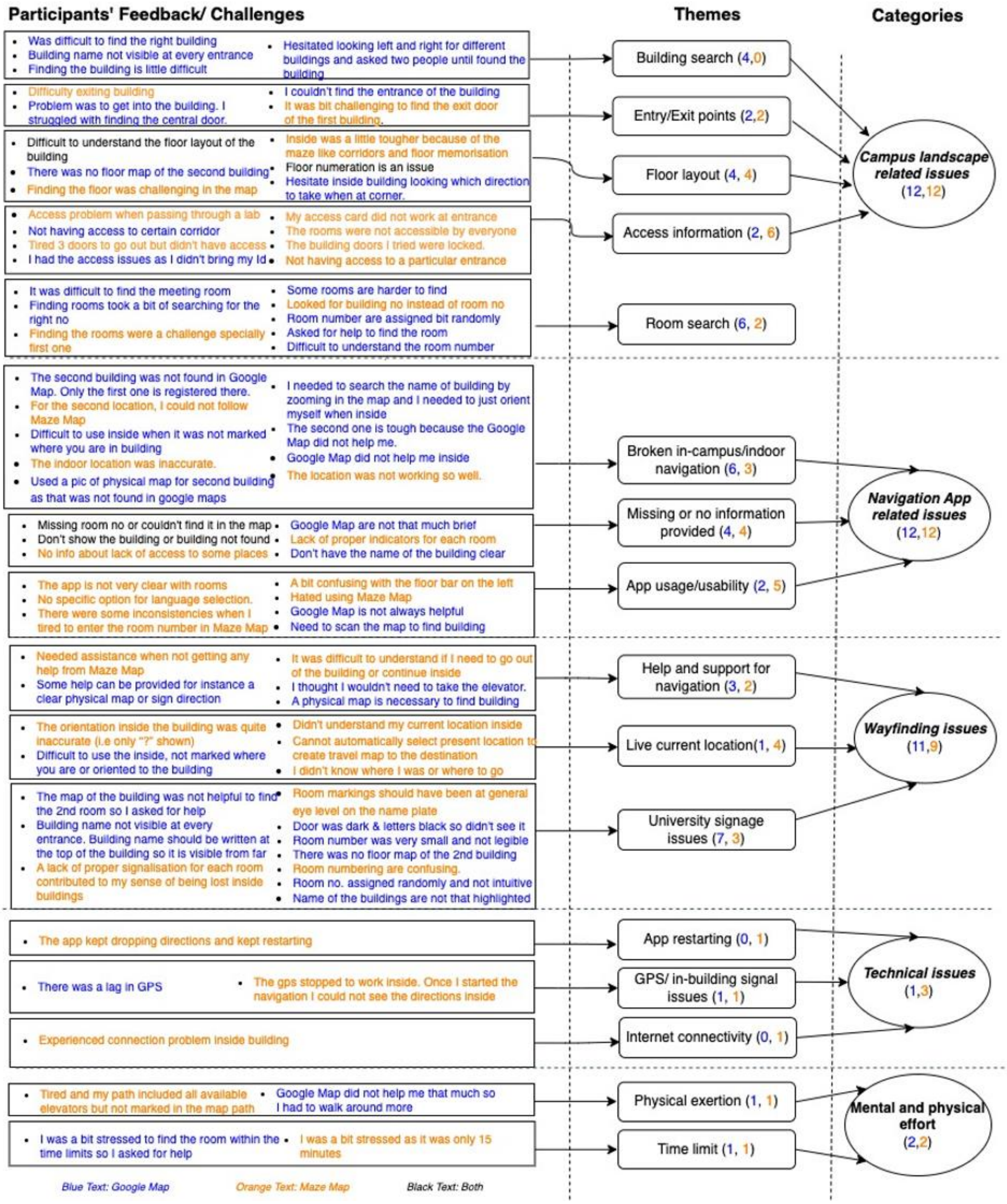

Figure 2. Challenges in indoor-outdoor campus wayfinding using mobile navigation apps (Google Maps and Maze Map).

For simplicity of representation, in the first column in Figure 2, the participants' feedback is encoded using the colors orange, blue, and black. The "blue" color represents the feedback from participants using Google Maps, the "orange" color for feedback from participants using MazeMap, and the "black" color infers that the same feedback is from both groups. Moreover, the frequency of occurrence of challenges for each theme is reflected in the second column with numbers in round brackets using blue color for Google Maps and orange for Maze Map, and cumulatively the parameters of all themes are presented in the categories respectively in column three of Figure 2.

Our analysis resulted in five categories that characterize challenges in indoor-outdoor university campus wayfinding using mobile navigation apps. The categories include campus landscape-related issues, navigation app-related issues, wayfinding issues, technical issues, and mental and physical effort. According to the qualitative analysis (presented in Figure 2), the category "campus landscape related issues" was based on five themes related to challenges linked to the university campus landscape. The themes include building search, entry/exit points, floor layout, assess information and room search. It was difficult for some participants to find the right building. Moreover, participants found it challenging to find the entry and exit points to get into or out of the building. Similarly, finding room numbers and understanding the floor map by navigating corridors was troublesome for some participants. Lastly, lack of access to some places made it difficult to navigate to the desired location as certain corridors and rooms were not accessible by everyone and required card access to open doors. As shown in Figure 2, participants in both groups (Google Maps and MazeMap) reported equal challenges in this category. However, participants using Google Maps faced more difficulty in building and room searches as compared to participants using MazeMap. This is evident from the fact that in addition to outdoor navigation MazeMap also provides indoor navigation, which is lacking in Google Maps. Moreover, the experiment group (participants using MazeMap) reported more access problems. This is because they were following the route provided by the app but had access issues to certain places within that route, which was more frustrating as they were following the directed path. Whereas for the control group (participants using Google Maps), the reported access issues were comparatively less as participants were not using Google Maps inside and orienting themselves, so they considered it as the wrong route instead of an access issue.

The category "navigation app related issues" was based on three themes that included challenges linked to the used technology (Google Maps and MazeMap). The themes include broken in-campus/indoor navigation, missing or no information provided and app usage/usability. For "broken in-campus/indoor navigation", participants using Google Maps experienced more challenges compared to the MazeMap group as it did not provide indoor navigation. Most participants reported that they did not use Google Maps for indoor navigation as it was not helpful and pointless to use inside when it is not marked where you are in the building. In addition to this, some of the campus buildings were not registered in Google Maps, and participants needed to 'zoom in' the map to search for the building. On the contrary, participants using MazeMap did not have complaints about finding the building on the map. However, the issues they experienced were either the indoor location given in the app was not very accurate, or it was difficult to follow the map when the indoor positioning was not working so well. For "missing or no information provided", most participants using Google Maps complained that the app is not complete and detailed for campus wayfinding as no information was provided for indoor navigation, such as rooms and buildings are either not found in the map or the name is not clear. On the contrary, the issues faced by the MazeMap group were more related to missing information, such as missing room numbers, lack of proper indicators for each room or missing information related to lack of access to some places. Lastly, for "App usage/usability", the group using MazeMap reported more issues as compared to the group using Google Maps. The usability issues related to MazeMap included inconsistencies with room search, confusing floor bar on the left, did not find any option for language selection, or participants did not like the overall experience of using MazeMap. Whereas participants using Google Maps only had an issue that they needed to scan the map to find the building, and they were not satisfied with the app for campus navigation as it was not helpful for indoor navigation.

The "wayfinding issues" category was related to the following themes: help and support for navigation, live current location, and university signage issues. Overall, the Google Maps group experienced more wayfinding issues as compared to the MazeMap group. For "help and support for navigation", most participants using Google Maps relied more on receiving as much help as possible from physical maps and directions within the university campus. This is because indoor navigation was not provided, and even for outdoor navigation, some building names were not clear or helpful. On the contrary, based on the qualitative analysis, the participants using MazeMap only asked for assistance when they got stuck or when certain information was not provided in the app. For example, when it was difficult to understand whether to go out of the building or continue inside while following the route in the app because either the signal dropped or the door was not accessible, or the current location was not clear. For "live current location", most issues were reported by the MazeMap group. Overall, the majority of participants were satisfied with the live location feature provided by Google Maps, except that it was not available for indoor navigation. The MazeMap group also referred to it when giving feedback "MazeMap should also provide live location like Google Maps". Although MazeMap provides the current location, most participants faced issues with accuracy. Most of the time, only "?" was shown instead of the exact current location when inside the building, which made orientation difficult as the participants could not understand where they were and where to go. Moreover, participants also complained that MazeMap does not automatically select the current location to create the route map to the destination; instead, you must enter the current location yourself, which is sometimes difficult when you do not know your exact location. Lastly, for "university signage issues", most challenges were reported by participants using Google Maps. This is because participants in this group relied more on university signage and physical maps on campus, which is also in line with the theme "help and support for navigation" and "broken in-campus/indoor navigation". The university signage issues included problems such as building names not being visible at the entrance or not highlighted, room numbers being randomly assigned and not intuitive, font size and color contract issues with the displayed room labels, no floor maps in some buildings, the physical maps inside the building not helpful to find the meeting rooms and lack of proper directions for each room. These problems are in the real world and not inside the map of navigation apps.

The category "technical issues" were related to app restarting, GPS/in-building signal issues and internet connectivity. The participants using MazeMap reported more technical issues. There were problems with the app restarting and dropping directions, the GPS stopped working inside, and the indoor positioning system had some issues as participants experienced connection problems inside buildings. On the other hand, participants using Google Maps only had a few technical issues related to lag in GPS.

Lastly, the "mental and physical effort" category included challenges related to physical exertion and time limit. Both groups (Google Maps and MazeMap) experienced similar challenges related to these themes. Participants were tired as they had to walk more when the app was not helping them or giving them information for quicker or easier paths (such as the availability of elevators instead of taking stairs). Similarly, most participants were stressed due to the time limit for finding a location which is similar to when you are running late for a meeting.

Overall, from the qualitative analysis presented in Figure 2, analyzing the parameters in the category column (third column) shows that both the Google Maps and MazeMap groups had equal challenges for "campus landscape related issues", "navigation app related issues" and "mental and physical effort". However, the analysis highlights that participants using Google Maps experienced more "Wayfinding issues" and participants using MazeMap experienced more "technical issues".

5. Discussion

This section will first discuss some more general conclusions based on results (presented in the previous section) from the university campus wayfinding experiment. The study examined the impact of navigation aid and spatial ability skills on workload and performance in university campus wayfinding contexts using quantitative and qualitative data. Subsequently, some of the implications and design recommendations will be presented for indoor-outdoor campus navigation technology, and some limitations of this study will be discussed.

5.1. Impact of Workload on University Campus Wayfinding Performance

We found significant negative correlations between participants' spatial ability skills and their workload and wayfinding performance. The participants who had higher overall spatial ability skills had lower perceived workload and less frequency of hesitation in the wayfinding task. In this study, the participants in the experiment group had a slightly lower mean SWR score (4.45) than participants in the control group (5.02). Similarly, the mean total task duration (22.00), mean total help (0.55), and mean total hesitation (1.64) for the experiment group were also slightly lower than the mean total task duration (24.82), mean total help (1.18), and mean total hesitation (2.27) for the control group. Therefore, we again used Pearson's correlations to identify any potential relation between the participant's perceived workload and wayfinding performance parameters (See Table 6). It is interesting to investigate if the effects on task performance are resultant of the effect on mental workload [17,40]. Pearson's test verified a statistically significant strong positive relationship between the SWR score and the two parameters of wayfinding performance (total task duration and total wrong directions) and a statistically significant strong negative relationship between the SWR score and total task completion. Similarly, participants' NASA TLX score was positively related to total task duration and negatively related to total task completion. On the other hand, no significant relation was found between any of the two workload parameters (SWR score, NASA TLX score) and total help and total hesitation.

Table 6. Pearson's correlation between workload and wayfinding performance.

		Total Task Duration	Total Help	Total Wrong Directions	Total Hesitation	Total Task Completion
SWR score	Pearson Correlation	0.593 **	0.109	0.518 *	0.299	−0.742 **
	p-value	0.004	0.631	0.014	0.176	<0.001
	N	22	22	22	22	22
NASA TLX score	Pearson Correlation	0.491 *	0.334	0.411	0.211	−0.764 **
	p-value	0.020	0.129	0.058	0.346	<0.001
	N	22	22	22	22	22

* Correlation is significant at the 0.05 level. ** Correlation is significant at the 0.01 level.

It means that participants who experienced a higher workload took more time to complete the task and took more wrong directions. Overall, the results showed that the task completion rate was higher for participants who experienced less workload. The qualitative data from observation showed that participants were mostly stressed and exhausted because of time and more physical exertion. Some participants complained that app did not provide additional information about the availability of escalators and no access to certain doors, due to which they had to walk more. Others also suggested that the navigation app should provide options for different routes (shortest, accessible, etc.) so they can decide which path to take based on their time and accessibility; this could reduce stress. Moreover, participants who experienced more workload also recommended that the navigation aid should provide notifications for route directions. For instance, if we take the wrong direction, the app should immediately notify us and accurately guide us. To conclude, it appears that the workload experienced by the wayfinders affects their wayfinding performance in university campus navigation. This is in line with previous research [53] that conflicting cognitive demand in the navigational task affects navigation performance. Therefore, it is important to consider cognitive load when designing navigation technologies and systems, as navigation applications with low cognitive load will ensure better performance and safety [53]. Although no significant difference was found in workload and wayfinding performance between the two groups using different navigation apps in this study. However, it is important to design options in the navigation aids that reduce the cognitive load of wayfinders.

5.2. Impact of Navigation Aid: Cognitive Load and Wayfinding Strategy

Outdoor navigation apps and indoor-outdoor navigation apps are two common mobile-based navigation aids, and one of the objectives of this research study was to explore the benefits of using these two aids in university campus wayfinding that includes both indoor and outdoor navigation.

5.2.1. No Effect on Performance and Workload

It was assumed that MazeMap should have provided better results as it provides seamless outdoor to indoor navigation, which is required in university campus wayfinding. Surprisingly this was not the case. According to the results from the conducted experiment, no significant differences were found between the two aids in workload and wayfinding performance. There were no differences in NASA TLX score, SWR score, frequency of wrong directions and total task completion. Although the findings showed differences in mean task duration, frequency of help, and hesitation, which was higher for outdoor navigation app. However, these differences were also not significant. Many researchers have focused on the use of different navigation aids for wayfinding and have found similar results. Dong et al. [48] found no radical difference in the effectiveness and efficiency of wayfinding time, errors, and interaction with tools between AR users and 2D electronic map users. Similarly, Xu et al. [54] compared voice-assisted digital maps with paper maps and found that regardless of the navigation aid used, the cognitive workload and search efficiency of environmental information are quite similar, and no significant difference was found in landmark knowledge acquisition and distance and time estimation. Rehman and Cao [6] also found that digital navigation aids (wearable devices and smartphones) were not significantly different in performance and workload. However, the wearable device was perceived to be more accurate. According to the results of Schnitzler and Hölscher [18], there were no significant differences between the two wayfinding aids (printed map, and digital map) in how efficiently they found destinations. However, these non-significant results may have several causes. First the small sample size (N = 22) could be one of the reasons as statistically significant findings are harder to detect with small sample sizes. The other possible reasons are presented in the next section.

5.2.2. Previous Experience, Usability, and Technical Issues: Cognitive Load and Multimodal Navigation

The quantitative data from the demographic questionnaire showed that all the participants had frequently used Google Maps, whereas most of the participants had rarely used MazeMap before. This difference in *previous experience* led to a difference in familiarity with apps between the groups, which could have affected the cognitive load and, thus, wayfinding performance. According to Ishikawa et al. [15], novelty could be one reason for the ineffectiveness of GPS-based navigation systems. Therefore, it is interesting to see if the wayfinding performance improves after multiple uses. Another research by Ishikawa [55] reported that the accumulated experience of navigation tool use affects wayfinding and spatial orientation. The participants using MazeMap also faced more *usage/usability issues* (floor understanding, room search, and overall experience as highlighted by the qualitative data) which added to the cognitive load and, in turn, increased the workload for this group. As highlighted by Albers [56], usability issues increase the user's cognitive load, thus increasing the cognitive resources required for the primary task. According to Georgsson [57], NASA TLX determines the cognitive load of the user in performing a task. Therefore, the results could be different if participants had more experience and fewer usability issues. However, Google Maps does not provide indoor navigation, so participants in this group were on their own when inside the building; this could offset the ease of using Google Maps compared with the ease of using MazeMap. Third, the qualitative analysis from the interview revealed that participants using MazeMap faced more *technical issues* related to internet and GPS/IPS connectivity which also affected live or current location inside the building and could have affected the workload. Regardless the experiment group performed better although not significant.

According to [58,59], multimodality can enhance the usability of applications and provide better results in complicated tasks compared to unimodal interaction. Liljedahl et al. [60] reported that careful design of multimodal interfaces can provide good user experiences. Multimodal technology can also improve accessibility in user environments such as navigation systems and mobile devices [61]. Therefore, multimodal navigation has the potential to produce good user experiences for various user groups by integrating several modalities and facilitating learning of the application [60].

5.2.3. Navigation Aid and Wayfinding Strategy: Importance of Landmarks

The qualitative data from the interview and observation notes showed that most participants in the control group (using Google Maps) focused more on landmarks. Google Maps did not provide indoor navigation at all, and the outdoor navigation within the campus was not great as most building names were not provided on the map, so they relied on direct experience. Whereas participants using MazeMap did not focus on landmarks around them and relied on the app. According to qualitative data, participants who did not focus on landmarks thought they were lost and made more wrong turns. This difference in focus on landmarks is also highlighted in research by Dong et al. [48]. They found that participants using smartphone-based AR aids paid less attention to environmental objects such as buildings compared to participants using 2D maps. Total wrong directions are the only parameter where the control group performed slightly better than the experiment group (see Table 1). Although it is a very minor difference, a large sample size might have produced different results. This finding is consistent with [15,62,63], who found that participants using GPS-based mobile navigation systems made more mistakes/direction errors and provided fewer details of landmarks than participants who used local signs or direct experience for wayfinding. Moreover, Ishikawa et al. [15] found that participants using mobile navigation apps rated wayfinding tasks as more difficult compared to direct-experience participants. The finding from our experiment also showed that the workload parameter (NASA TLX scores) for the experiment group (mean = 43.71) was slightly higher as compared to the control group (mean = 40.23). However, based on results from our experiment there was not much difference in total wrong directions taken by the control (mean = 2.00) and experiment groups (mean = 2.19). Moreover, results from our experiment also showed a strong and statistically significant correlation between total wrong direction and SWR score ($r = 0.518$, $p < 0.05$). Based on previous research and our findings, wayfinding strategy affects the workload and wayfinding performance. Although, more quantitative research is required to prove it. However, it is important to explore and improve wayfinding strategies as participants who focus on landmarks perform better.

To conclude, in this study, the mobile-based outdoor and indoor-outdoor navigation aids did not affect the perceived workload and wayfinding performance of participants in the university campus wayfinding task, but it impacted their cognitive load and wayfinding strategy (RQ1). To summarize the above discussion, the navigation aid for university campus wayfinding can be improved by improving usability and technical issues in the app and following design guidelines to reduce the cognitive load of users. We know from Section 5.1 that workload is related to wayfinding performance; thus, higher performance can be achieved by designing navigation aids that reduce the cognitive load of participants. The integration of appropriate landmarks in university campus navigation apps can decrease the cognitive load on the wayfinders [64,65] and help users increase their environmental awareness and spatial recognition ability [65,66]. Landmark-based campus wayfinding solutions can increase the efficiency and reliability of such applications [65].

5.3. Impact of Spatial Ability Skills: Technology and Design for Spatial Knowledge Acquisition

The findings from this research study showed a negative correlation between participants' overall spatial ability skills and their workload, consistent with the previous research in this area. According to Nori et al. [26], basic spatial abilities are related to navigation in a real-world environment. Lin and Wang [16] found in their study that participants with a better sense of direction (SOD) had a lower overall workload for the target task. However, in our study, only spatial orientation out of the three individual parameters of overall spatial ability had a significant relationship with the NASA TLX score (see Table 4). With respect to wayfinding performance, this study outlined that the spatial ability skill parameter (sense of direction) is negatively related to the frequency of hesitation. However, total task duration, total help, total wrong directions, and task completion are not associated with spatial ability skills. Other researchers have also found an association between sense of direction and wayfinding performance. A study by Brunyé et al. [67] found that a higher spatial sense of direction was related to higher path efficiency. Lin and Wang [16] indicated that participants with a better SOD had faster response time.

To conclude, the spatial ability skills of wayfinders can be associated with their perceived workload and wayfinding performance (RQ2). The wayfinders with higher spatial ability skills experience less workload and are more confident navigating indoor-outdoor campus wayfinding. According to the research investigating navigation assistance and wayfinding, navigation aid can play a role in shaping human spatial ability as it influences human wayfinding and navigation [54]. Therefore, it is important to design navigation aids that improve spatial ability as it affects the workload.

Navigation assistance systems should be improved in regard to the acquisition of spatial knowledge. Navigation applications should include features to improve users' skills and knowledge instead of taking on all cognitive functioning. In this way, users will make informed choices when using the navigation aid, which provides optimal support for the acquisition of spatial knowledge [68]. Modern digital technology can provide novel options for enhancing spatial learning with promising transformative impacts [69]. Researchers have explored different aspects of navigation aids that can influence spatial knowledge acquisition. Xu et al. [54] found that the use of voice-assisted digital maps may result in time efficiency, but it can reduce the spatial knowledge acquisition of pedestrians. According to Münzer et al. [68], appropriate visualization can support the acquisition of self-to-object spatial knowledge. The findings by Verghote et al. [23] showed significant improvement in the success rate of the participants with low spatial cognition when using 3D models instead of 2D drawings. However, the format of information did not affect the participants with high spatial cognition. Similarly, Qiu et al. [70] found that AR maps are better than 2D maps in assisting individuals in acquiring spatial knowledge. AR displays provide comprehensive information about the environment highlighting the landmark locations and providing exocentric spatial information, thus helping in acquiring landmark and route knowledge. Moreover, landmarks are important for wayfinding and navigation [66]; they can assist in spatial knowledge acquisition during navigation [71] and can support correct decision-making [72]. According to Zheng and Hsu [66], highlighting buildings at intersections can aid wayfinders in increasing their intuitive spatial ability by helping them to use intersections as references.

5.4. Implications for Indoor-Outdoor Campus Navigation App Design

In this section, design implications are presented based on both the qualitative analysis of interview data and observation notes that identified the main challenges in indoor-outdoor campus wayfinding using a mobile navigation app (RQ3) and the lessons learned from the main findings of the quantitative data (RQ1–2). The design recommendations are summarized as follows.

5.4.1. Landmarks and Additional Route and Location Information

Landmarks play an essential role in wayfinding and navigation tasks [66] and can aid in the acquisition of spatial knowledge without much workload [71]. Landmarks can be used by wayfinders as a point of reference for the identification of directions and for making route decisions which can reduce confusion and hesitation [66]. Therefore, navigation systems should use physical landmarks as a directional aid in wayfinding directions because they help with orientation [73,74]. Previous research has provided different landmark suggestions. According to Ishikawa et al. [15], a global landmark in the area does not help navigation if they are not shown on the map as a navigation clue. According to Qiu et al. [70], AR displays are useful for supporting individuals in acquiring landmark and route knowledge. In the present study, participants who focused on landmarks and the surrounding environment were more confident navigating in the wayfinding task.

It was also found from qualitative data that most participants faced challenges related to route and location. Participants in both groups (Google Maps and MazeMap) reported issues related to missing or no information provided (see Figure 2). Some of the participants' suggestions to improve the navigation app included: "Provide information about access to rooms", "Maybe show which doors I have access or not", "Clearly marked elevators", "Building/door opening hours", "Info telling me where public access doors are", "Clearly marked entrances, including which are for common use and which require special access", "Providing options of accessible entrance (updates)". Previous research also shows that route and location information is important and can improve navigation aid for users [59]. Mallik et al. [75] found that floor identification is important where a user can travel between floors, and it is crucial to provide floor numbers in multi-floor structures.

According to Sato et al. [76], the surrounding information, such as elevator locations, access information, and floor changes, is useful to aid in the orientation and mobility of users and increase confidence during navigation by confirming their location. Vainio [59] concluded that navigation aids could be improved for users by designing predictive clues and rhythm in mobile-based navigation applications. Mallik et al. [75] suggested that sensor-based 3D localization strategies should be used for localizing a person traveling through elevators, stairs, or escalators. Huang et al. [77] suggested adding landmark objects into real-world environments in order to enhance the user experience of indoor navigation systems.

5.4.2. Real-Time Location

There is a high demand to provide real-time indoor navigation solutions as most location-based service users spend the majority of their time (70–90%) indoors, increasing public attention to these potential applications [78]. In the present study, most participants faced wayfinding issues related to live current location, especially during indoor navigation with MazeMap (see Figure 2). Based on interview results, some of the suggestions for improvement included: "Indicate my current position", "Location dot moving in real time", "It would be helpful if the navigation feature in the map was real time showing the path you are following", "Updating real time location of the person", "It could be helpful to highlight both the start and target floor in the bar so that one knows where to navigate and from where". Zheng and Chen [79] suggested that floor indication design in mobile-based indoor navigation interfaces should mark the current floor and be arranged according to the sequence of floors from the bottom up. MazeMap provides such floor indication; however, according to qualitative analysis in the present study, some participants felt that the floor bar in the app was confusing and should be improved in design with respect to marking the current floor.

A lot of research is focusing on indoor location determination technologies for making indoor positioning systems reliable and highly accurate [80]. An ideal navigation application should present real-time location and direction [81]. According to Harper et al. [73], it is important that navigation apps are designed with knowledge of the user's current location to help them identify their location in the environment, as they have expectations that maps should operate from their viewpoint.

5.4.3. Improved Location Search

Navigation systems should provide different options for improved location search. Some of the options for improved location search suggested by participants in this study include: "Option to automatically put current location as starting point instead of a manually entering the location", "Floor maps within the building and option to find the building by name", "If there was room search option in Google Maps it would have saved some time".

Wayfinding focuses on searching the route from the user's current position to the target destination. Therefore, it is not only important to detect the user's position, but providing different options related to route guidance and search is also important [82]. Zheng and Chen [79] suggested providing a self-locating icon and using a dialogue box with text showing "your current location" in the beginning to prompt users to use the self-locating icon. According to Ng and Lim [82], AR technology can be used in the mobile-based indoor navigation system to detect the user's position and display AR navigation directions on top of real-world camera view to provide an immersive navigation experience and guide the user to the destination. Guo et al. [83] focused on providing a personalized, customized navigation menu bar, one click to open and search on demand functions for 3D visualization indoor navigation system. Harper et al. [73] proposed including a universal search function in wayfinding systems to enable users to search for things specifically instead of by category, which may be difficult to use and frustrating.

Zheng and Chen [79] indicated that smartphone-based indoor navigation interfaces must also provide options such as multiple choices of route planning and reminders. Moreover, in the present study, participants suggested that the navigation app should provide alternate route options. Some of the comments include: "Show alternate routes", "Quickest path illustrating on MazeMap", "It should have alternative options as well. I could not find the second building, so I think it should be more specified towards the building name".

5.4.4. Improved Location Visualization

Appropriate visualization can support the acquisition of spatial knowledge [68]. Previous research has highlighted the benefits of using 2D, 3D and augmented reality (AR) technology for visualization in indoor and outdoor navigation apps. The results from the research by Torres-Sospedra et al. [10] indicated the usefulness of visualizations (AR viewer and intuitive map-based view) in locating university facilities and improving spatial orientation. They developed and evaluated two mobile-based indoor-outdoor navigation applications: SmartUJI APP, which uses an intuitive map-based view to visualize information, and SmartUJI AR, which uses an AR interface with interactive icons placed over campus facilities allowing users to interact with the campus and visualize the location of the nearby facilities and points of interest with an AR viewer through the mobile device camera. Sandoval et al. [84] used 3D-Enhanced Facility Management System to assist visually impaired users in indoor navigation and achieved satisfactory preliminary results regarding user experience.

In the present study, participants also suggested improving the visualization for indoor-outdoor campus navigation systems. Some of the comments from participants interviews include: "Visualising buildings by their photos", "Street view/corridor view inside the building", "Show picture of target room (sometimes no room number is given at the door, or it is hard to find)", "Different angles to see where I am waiting", "It should be more visualised with the 3D view and updated always".

5.4.5. Notifications and Alerts

Navigation systems should provide notifications and alerts to guide users in finding their destination [85–87]. Previous research has shown that a lack of visual or audio notification upon arrival at a destination can lead to failure in recognizing the target location by participants [88]. Therefore, one useful feature of wayfinding technology is providing notification when the user is approaching the destination [87,88]. Moreover, notification of obstacles or road closures in the path can lead to further improvement in wayfinding aid [89].

However, sudden notifications can disturb users in uncertain situations [90]. According to Huang et al. [77], the responsiveness of the notification system is important to create a better user experience. It is useless to notify the user when they are not in the area or notify when they have already passed the area. Alnabhan and Tomaszewski [86] highlighted the importance of the accuracy of displayed notifications. They developed an AR-based indoor navigation system, "INSAR", that issues a 2 s notification vibration when it finds the destination and displays a message telling the user that they have arrived at their destination [86]. Hall [91] used a map feature to support users in campus navigation which is enabled by sending notifications when they are within 60 m of the target destination.

The qualitative data also highlighted the importance of notifications and alerts. Many participants suggested that the navigation app must provide relevant notifications about destinations and warnings for wrong directions for further improvement as a campus wayfinding aid. Some comments include: "More obvious notification when a room is inside another room, is behind a locked/special access door, etc.", "Pop-up notification when you are taking the wrong direction", "Warning if you are turning towards wrong directions", "I think a beep or a sound to inform me when I need to go upstairs or downstairs of the building", "A ring when the location is closer."

5.4.6. Assistance or Help: Voice, Text, Symbolic Notations

It is important to design adequate help and assistance in campus navigation applications to support users in wayfinding. However, not much navigation assistance is currently available for indoor navigation [92]. In the present study, many participants faced challenges related to help and support for navigation and suggested that campus wayfinding apps can be improved by providing path directions with arrows, symbolic notations, text for description of route, turn-by-turn instructions and voice or audio instructions to make the navigation easier. Some of the participants' comments include: "Show path directions maybe with arrows", "Symbolic notations to make the navigation easier for all in any condition", "Some text may help the navigation. For example, buildings like Realfagbygget, some suggestions about which entrance to take which block, etc. can be helpful", "Offer caption to get description of route (similar to Google Maps) so that one knows i.e., to which floor to navigate. Especially helpful if connection is lost", "Turn by turn written instructions (e.g., turn left, go 100 m, turn right)", "Audio of the written instructions", "Voice commentary should be there", "Would be cool to have a tool that guide in a smart way with voice hints", "Voice instruction".

Previous research has also explored different ways to provide assistance and help in navigation applications to aid users in wayfinding and should be used in designing better campus navigation applications. Xu et al. [54] found that voice-assisted digital maps can increase participants' comfort levels and help them reach their destination more quickly compared to the other types of maps. Vainio [59] demonstrated the potential of multidisciplinary approaches and multimodal navigation aids to support the navigation and wayfinding of mobile users [59]. Liu and Meng [93] suggested, based on their study focusing on augmented reality-based indoor navigation applications, that adding more semantic icons with text to an AR real-time scene interface can serve as virtual landmarks and enhance users' spatial learning [48]. Harper et al. [73] suggested using relatable and simple instructions for users; for example, instead of telling how many steps or feet to walk, using time such as 15 min walk is more beneficial as it is not easy for users to estimate distance by steps. Sato et al. [76] suggested augmenting navigation aids and providing more instructions when the user is standing and only offering little and essential guidance when walking so as not to hinder awareness of their surroundings.

Harper et al. [73] recommended that a wayfinding system should provide users an option to request assistance through human-human contact if they are unable to find the location. This is because sometimes users just want to speak to a person instead of interacting with a system. Helmi et al. [94] suggested improving indoor campus navigation applications by adding features such as arrow-based direction for giving indoor direction pathways or adding a Live chat page so users can contact the admin if needed.

5.4.7. Consistency

The consistency between the user interface (UI) and the real world is crucial and should be addressed when designing maps and UI for navigation systems [95]. High interface consistency is expected to result in higher user satisfaction, fewer errors, and faster task completion [96]. To ensure consistency, it is important to match the elements of the application to those in the environment by understanding the naming conventions, landmarks, labeling, zones, icons, color codes, images and signage of buildings and places [73]. According to [95,97], more attention should be paid to designing consistency between the real world and digital presentation when designing indoor maps because the shapes, colors, and materials of the environment vary from building to building.

However, consistency in navigational signage used in the real world is also important to aid wayfinding in complex environments with multiple buildings. Apelt et al. [98] also recommended using consistent naming protocols for places with multiple buildings, such as educational institutions, although it is suggested to avoid alphanumeric coding as it is less memorable as compared to place names. However, it is also important to provide consistency within the alpha-numeric coding system (such as Room B3.7) when using it as a naming protocol. Moreover, ensuring consistency in sign types is also important to identify and recognize signage, for example, consistent colors, logos, and typeface; consistent graphic layouts; consistent materials and construction; and consistent overall appearance [98]. In the present study, participants reported some challenges related to university signage issues highlighting inconsistency in naming, numbering, and labeling for rooms, floors, and buildings. The suggestions for improvement focused on the need to ensure consistency, some of the comments included: "There should be consistent numbering of floors", "Same buildings names in different platforms/navigation tools", "It is possible to mark every building by their name and number both".

5.4.8. Easy to Understand

It is important that the campus navigation system is easy to use for a truly seamless behavior. However, the ease of use and user experience of such applications depends not only on user-friendly interface design but many other factors, such as intermittent internet connectivity or storage limitation of mobile phones for location prediction and delivering a quality experience [75]. According to Harper et al. [73], it is important to reduce unnecessary on-screen information so users can focus on important pieces of information. This can be done by avoiding clutter and adhering to platform standards instead of making users learn new methods of interaction [73]. Similarly, designing less detailed maps in navigation apps can make orientation easier [95,97]. Information and wording should be classified according to user expectations, and it is important to consider accessibility in on-screen interactions and hand positioning for touchscreen systems [73].

In the present study, participants reported some issues related to app usage and usability that negatively impacted their experience of using the navigation app for campus wayfinding. Some participants using MazeMap were frustrated as they thought it was a bit confusing and not easy to use. From the qualitative analysis, one of the suggestions for improvement was that the campus navigation app should provide a "simple layout".

5.4.9. Update Location Changes

It is crucial for the navigation app to provide updated location information and maps. Participants are interested and want to be aware of landmarks and points of interest, such as cafes, escalators or stairs, that can help them in confirming their location or aid in navigating the environment [76]. However, as the layout and appearance of the facilities change greatly, and the navigation system must be able to rescan and post-process the new data in a short time in order to minimize the drop in user experience due to layout change [83].

In the present study, one of the participants pointed out that location changes were not updated in MazeMap, which caused confusion in indoor navigation. However, this could be due to delays in updates by the organization rather than the application and taps into the issue of how often universities (in this case, NTNU) update MazeMap. The participants further suggested that the navigation app needs to be regularly updated to improve campus wayfinding. The comment made was as follows: "MazeMap scenery description needs to be regularly updated as it conveyed wrong surroundings. The cafe area with seating arrangement now in realfag building is not the same as shown in MazeMap. It is on the opposite side and not as many tables as shown in MazeMap".

5.5. Limitations of the Study

This work entails several limitations. One such limitation is that the gender distribution was not equal. Overall, the study included more female participants (77%) than male participants (23%). It is possible that results could have been different if there were more male participants. Some of the previous research has shown gender differences in spatial ability skills [99], where males significantly outperformed females in overall spatial ability. However, the gender distribution within both groups was fairly equal and thus reducing gender bias. The control group had two male and nine female participants, whereas the experiment group had three male and eight female participants. Therefore, the analysis was not affected due to overall unequal gender distribution. Moreover, there were no differences in the navigation task and how the two mobile navigation apps were used. Moreover, the spatial ability skills of the two groups were relatively similar.

Another limitation of this study was its size. The small sample size makes it harder to detect statistically significant findings and even difficult to generalize the resulting findings. No statistically significant difference was found in wayfinding performance and workload of the control and experiment groups which could be potentially due to the small sample size. One of the concerns with a small sample size is more chances of producing type II errors (beta errors) and failing to reject the null hypothesis (H0) when the null is false. Therefore, these initial findings and the outlined effects need to be replicated with additional testing using a larger and more diverse sample of participants and with different navigation apps. However, we also collected qualitative data from participants to triangulate the findings, thus increasing the validity.

The results reported in this paper should apply to other mobile navigation apps and different venues and scenarios requiring combined indoor and outdoor navigation. However, we acknowledge that the results might not be transferable to any navigation app, especially for different platforms and other indoor-outdoor wayfinding scenarios, such as hospitals or large organizations with multiple buildings. The results presented in this study may be only relevant in the context of the use of university campus wayfinding and navigation systems that provide navigation features like Google Maps and MazeMap. The average age of participants in this study is 30.8, and it is possible that similar analyses with other user groups (elderly or children) might produce different results due to age differences.

6. Conclusions and Future Work

This study explored the effects of two different navigation aids (outdoor vs. indoor-outdoor navigation app) and spatial ability skills on university campus wayfinding performance and perceived workload. This paper also identified the challenges in indoor-outdoor campus wayfinding using mobile navigation aids. An experiment was conducted with twenty-two participants divided into control and experiment groups using Google Maps and MazeMap, respectively, to complete a time-bound university campus wayfinding task.

Both quantitative and qualitative data was collected using multiple methods, including spatial ability test, questionnaires, interview, and observation/field notes. Based on the findings, the following conclusions and design implications are presented for facilitating university campus wayfinding by improving navigation systems:

- Seamless indoor-outdoor navigation is crucial for university campus wayfinding, and navigation apps must provide support for indoor navigation.
- The spatial ability skills of participants affect their perceived workload and wayfinding performance. Moreover, the mental workload experienced by the wayfinders also impacts their wayfinding performance in university campus navigation. Therefore, it is important to consider cognitive load and spatial knowledge acquisition when designing campus navigation systems.
- The employed navigation aids do not affect the workload and wayfinding performance, but they can impact the cognitive load and wayfinding strategy of participants in university campus wayfinding. Therefore, navigation aid can play a role in reducing cognitive load and shaping human spatial ability to improve wayfinding and navigation.
- The app usage experience, usability and technical issues in the navigation app can affect the cognitive load of users. Thus, the design of indoor-outdoor campus navigation applications should focus on reducing the cognitive load of wayfinders by improving usability and technical issues in the app and catering to users with different prior experiences (novice and experienced). The effective use of multimodal technology integrating multiple modalities can enhance the usability and user experience of navigation systems and facilitate learning the application.
- The campus navigation apps should help wayfinders in spatial knowledge acquisition. The wayfinders with higher spatial ability skills experience less workload and are more confident navigating indoor-outdoor campus wayfinding. Modern digital technology, such as 3D models, AR maps and appropriate visualization, can assist individuals in acquiring spatial knowledge.
- Landmarks can decrease the cognitive load on the wayfinders and assist them in spatial knowledge acquisition. Therefore, the integration of appropriate landmarks is important in designing university campus navigation systems.
- Some other design recommendations for indoor-outdoor campus navigation applications include additional route and location information, real-time location, improved location search, improved location visualization, notifications and alerts, assistance or help, consistency, easy to understand and updated location changes.

Some of the directions for future work include focusing on conducting experiments on a larger scale to compare the differences between navigation aids with different user groups and on multiple campuses, exploring the impact of different wayfinding strategies on the workload and wayfinding performance with navigational aids, and exploring the impact of gender and age difference on wayfinding performance. Future studies could also investigate topics such as how user's spatial knowledge can be improved through navigation aids, how to adapt navigation aids for different types of wayfinders and their strategies and investigate the effectiveness of multimodal instructions on wayfinding performance in navigation tasks with different cognitive loads.

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Appendix A Spatial Reasoning Test

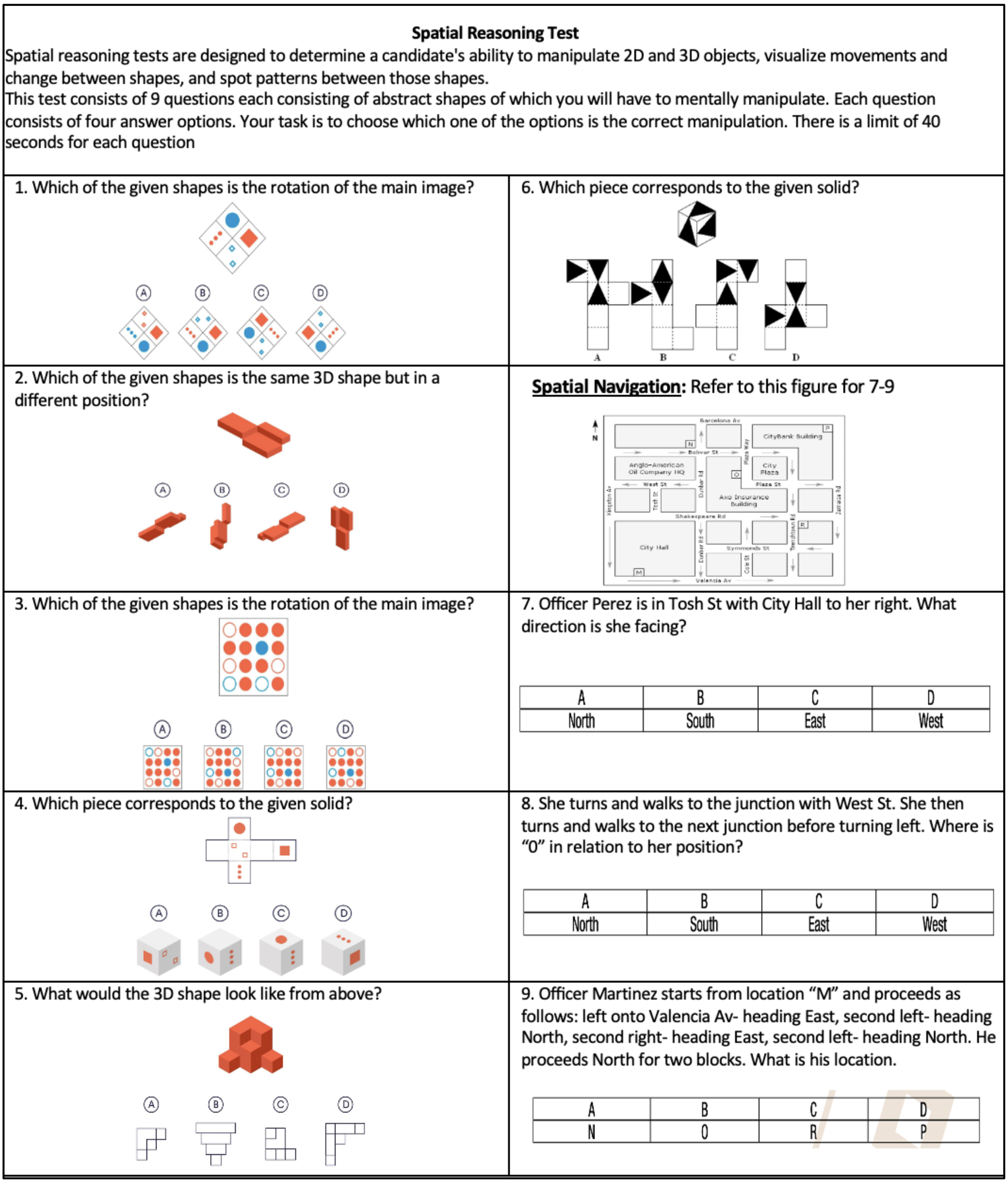

Figure A1. Spatial reasoning test.

Appendix B Navigation Task and Route Maps Generated from MazeMap and Google Map

You are in Gløshaugen campus on a normal workday. This is your office room (Gløshaugen IT-bygget (317): Room number 122, floor 1) and you have two upcoming consecutive meetings. You have already booked two different meeting rooms (see venue below) for these meetings.

Venue 1: The room booked for the first meeting is: **Building name & code**: Gløshaugen Byggteknisk (337): **Room number**: 1-001, **Floor** 1
Venue 2: The room booked for the second meeting is **Building name & code**: *Gløshaugen Hovedbygningen (301)*: **Room number:** *228*, **Floor** *2*

Your task is to navigate from your office room (IT-bygget:122, floor 1) to the venue 1 (Byggteknisk: Room number 1-001, Floor 1 to attend the first meeting and then from this place navigate to the venue 2 (Hovedbygningen: Room number 228, Floor 2) to attend the second meeting. You do not need to stop at venue 1, as soon as you reach the room continue to navigate to the venue 2. Your task finishes when you reach venue 2. You have 30 minutes to complete this task.

Control Group: You will only use **Google maps** to complete this navigation task. *Please do not use any other tool.*
Experiment Group: You will only use **Mazemap** to complete this navigation task. *Please do not use any other tool.*

Figure A2. Navigation task.

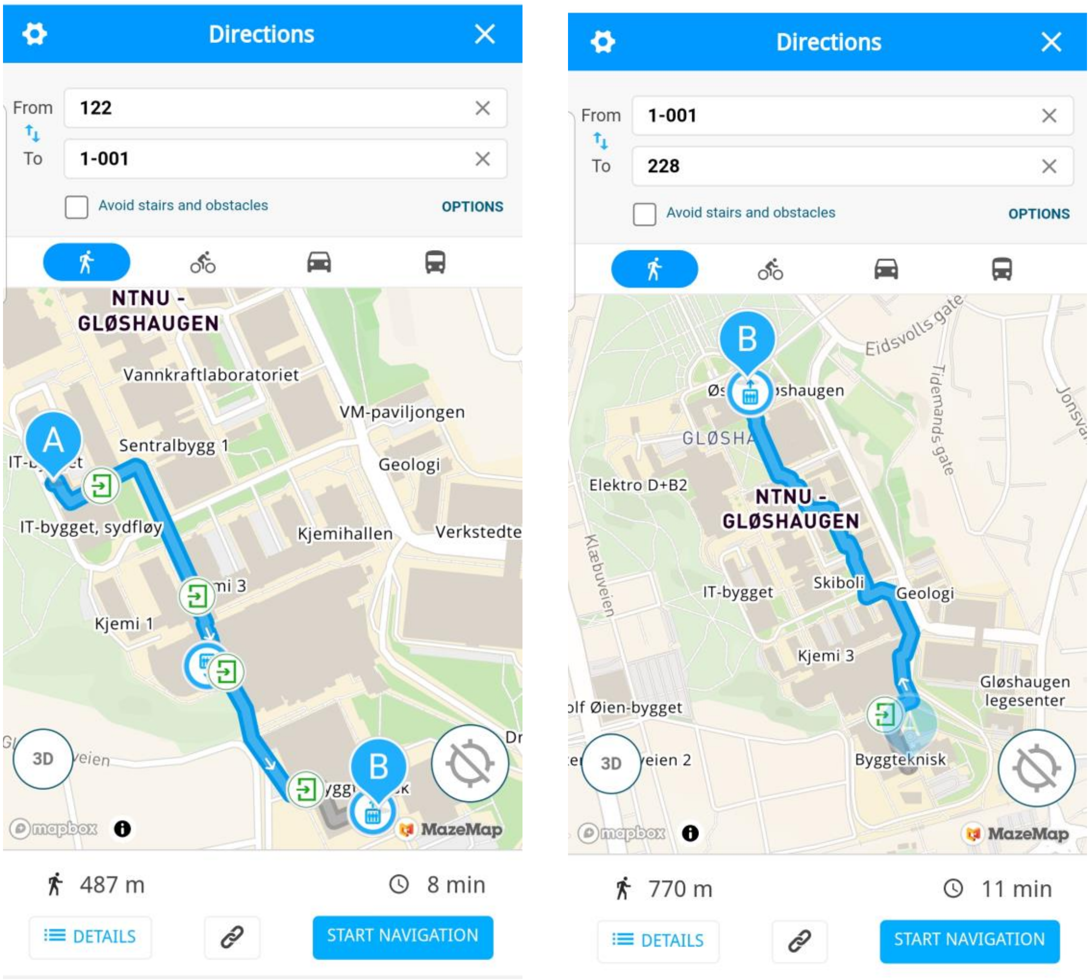

Figure A3. MazeMap: Start point to 1st meeting room (**left image**); 1st meeting room to 2nd meeting room i.e., end point (**right image**).

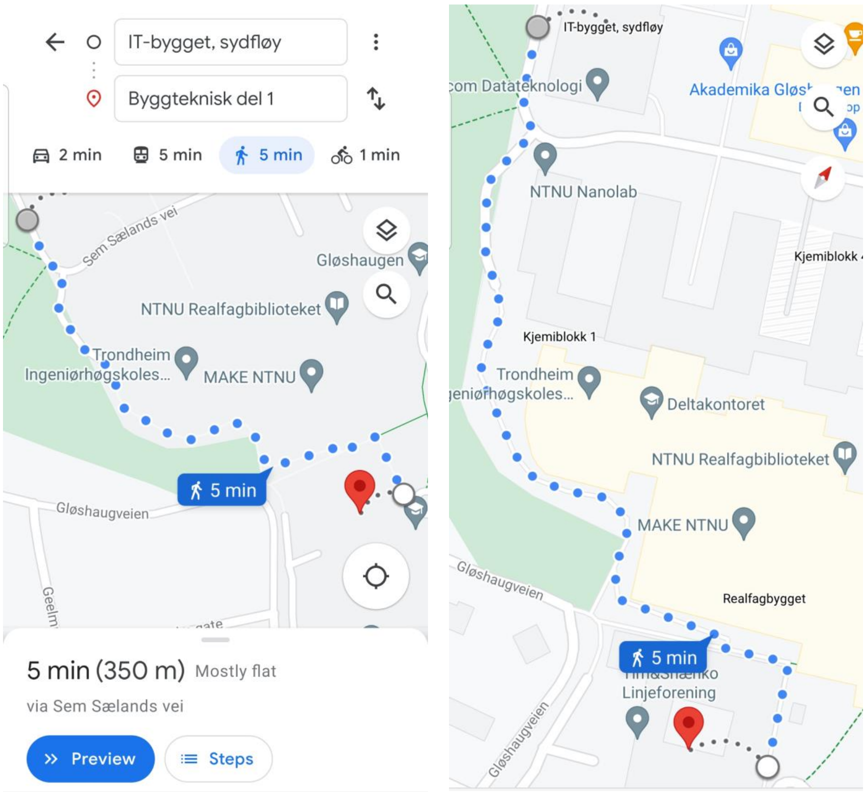

Figure A4. Google Map: Start point to 1st meeting room (right image is enlarged view).

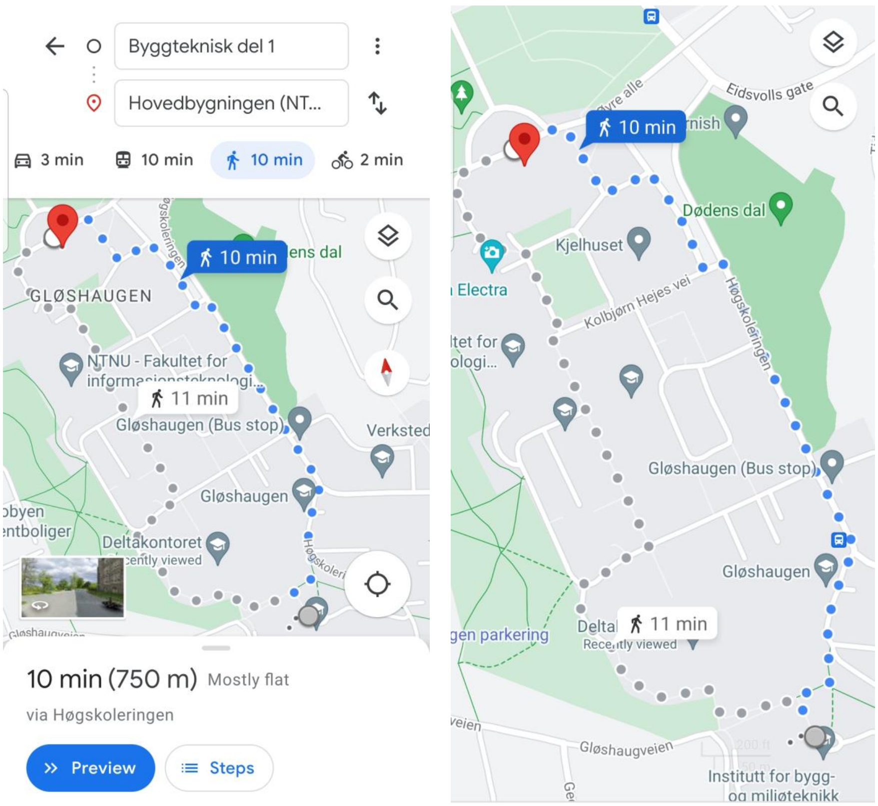

Figure A5. Google Map: 1st meeting room to 2nd meeting room i.e., end point (right image is enlarged view).

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